Chapter 1. Introduction

1.1. Importance of Power System Restoration

Power system blackouts are rare events [1,2]. However, when they occur, the effects on commerce, industry and everyday life of the general population can be quit severe. In the aftermath of a blackout, a subject of critical importance is the rapidity with which electric service is restored [3,4].

In order to diminish the economic and social costs of a blackout, majority of electric utility companies have pre-established guidelines and operating procedures to reestablish the system [5,6,7,8,9,10,11]. These guidelines and operating procedures contain sequential restoration steps that an operator should take in order to restore the system. However the highly stressful conditions encountered in the aftermath of a blackout together with the fact that these guidelines are based on assumed system conditions which may not be presented, diminishes the success rate of the technique [12]. The main reason for unsuccessful restoration is that the prevailing conditions of the power system differ significantly from the assumed conditions when the restoration plan was developed [15] which obligates the system operator to create a new restoration procedure at the exact time following a blackout.

In recent years there have been a number of approaches [13,15,16,17,18,19] that propose new restoration techniques as alternatives to these commonly used restoration procedures. Next these proposed techniques are presented.

1.2. Power System Restoration Methodologies

There are three main Power System Restoration (PSR) techniques recently proposed to substitute the pre-established guidelines used by the majority of the utilities. The three PSR techniques are known as: Mathematical programming technique; Knowledge based systems technique; and Petri-nets technique. Details of these techniques will be presented in the following sections, however it can be stated that these techniques have different approaches to the PSR problem. While these techniques may vary in implementation detail it can be said that there are three main organization principles for power system restoration (PSR) [20]:

(a) Automated Restoration: In this restoration technique computer programs are responsible for the PSR plan development and implementation. The PSR techniques based on this principle acquire system data from the Supervisory Control and Data Acquisition System (SCADA) and the Energy Management System (EMS). When the electric power system is undergoing a wide area disturbance, a PSR program installed in the EMS system will use the acquired system data to develop a restoration plan for the transmission system. After developing the restoration plan, a switching sequence program which is also a part of the EMS will be responsible for the transmission of control signals through SCADA to circuit breakers and switches to implement the plan. In this technique the system operator plays the role of a supervisor.

(b) Computer Aided Restoration: In this technique the PSR plan development and implementation is performed by the system operator. The PSR techniques that use this principle also acquire system data from the local SCADA/EMS. Following a wide area disturbance, the system operator uses electric system data provided by the SCADA/EMS to develop a PSR plan. The system operator can use the PSR procedures and power system analysis programs as aids to develop the restoration plan. The system operator will also use the local SCADA/EMS to transmit to circuit breakers and switches control commands in order to implement the chosen PSR plan. Figure 1-1 illustrates this technique.

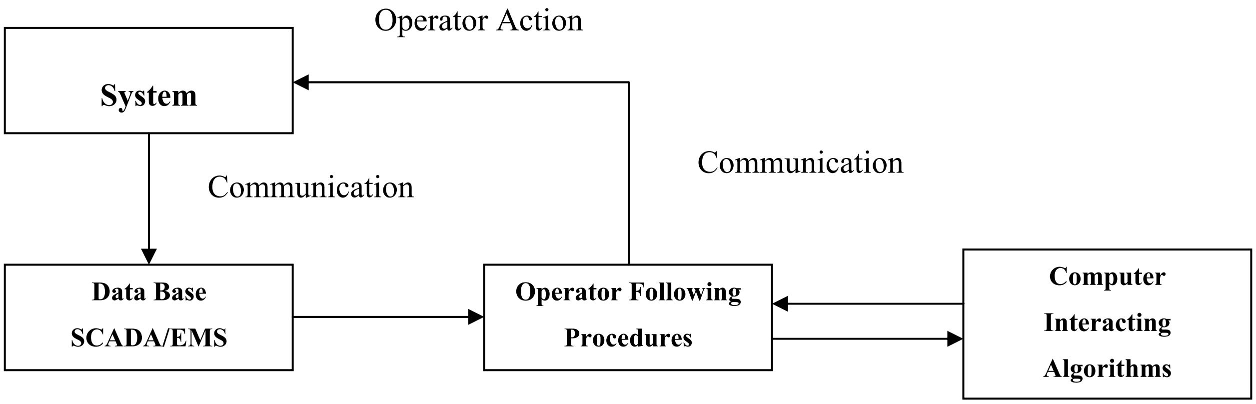


Figure 1-1 Computer Aided Restoration

(c) Cooperative Restoration: In this technique a PSR program installed at the EMS develops the restoration plan. The system operator is responsible for the implementation of the PSR plan. The PSR techniques that apply this principle also use electric system data obtained from SCADA/EMS. When the power system is undergoing a wide area disturbance, the PSR program installed in the EMS will use the acquired system data to develop a restoration plan. With the restoration plan developed, the system operator can send controlling signals through local SCADA/EMS to circuit breakers and switches to implement the plan. Figure 1-2 illustrates this technique.

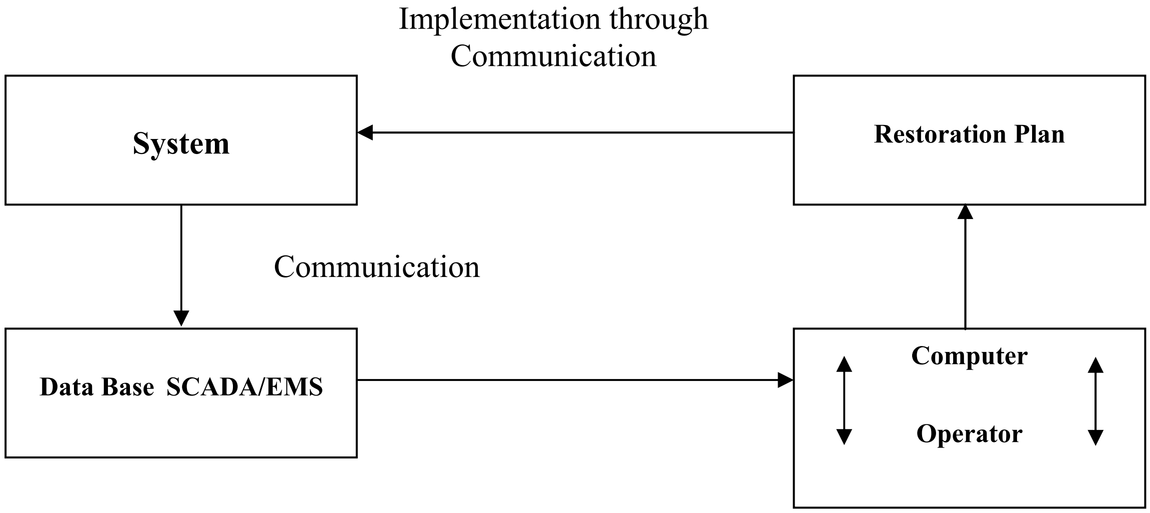


Figure 1-2 Cooperative Restoration

Recent publications indicate that the majority of power utilities apply the Cooperative Restoration Principle whereby the computer is responsible for the restoration plan development and the system operator is responsible for its implementation. The three main PSR techniques recently proposed to solve the limitations of the pre-established guidelines were implemented based on the Cooperative Restoration Principle. In the following, details of these three PSR techniques, their problems and limitations are presented.

1.2.1. Mathematical Programming Techniques for Power System Restoration

The mathematical programming technique is better known by its applications in distribution systems, where it obtained good results. The technique, first introduced by Komai et al. [21], considers the system to be in a state space where a search must be conducted in order to find the final configuration of the restored system. In order to find the final configuration the technique represents the system configuration by a vector containing the breakers status. Several search algorithms can be implemented to find this final system configuration. Breadth-first and depth-first search algorithms have been implemented, heuristic search algorithms have been proposed [22,23]. After finding a possible configuration of the system, a load flow program is used to check the operating feasibility of the chosen restoration configuration.

1.2.2. Knowledge based Techniques for Power System Restoration

A knowledge-based technique for PSR was first published by Sakaguchi et al. [24]. The technique was tested using data from a small transmission system in Japan obtaining good results. This technique, along with the vast majority of the techniques for PSR based on expert systems [25,26,27,28,29,30,31,32] basically comprehend a series of production rules gathered from operator's experience. A production rule can be seen as a decision tree that will generate one action if the input is true and another action if the input is false. In order to find the final configuration of the restored system the technique uses a set of these production rules that represent sequential checks and actions that should be taken in order to restore the system. A load flow program is also used to verify the operating feasibility of the chosen restoration configuration.

1.2.3. Petri Nets in Power System Restoration

The petri-net (PN) algorithm was first proposed for PSR by Wu et al. [33]. The PN model incorporates some conditions that have to be met before an action can be taken. The technique models the states of the power system components with 'place' nodes and the restoration tasks by 'transition' nodes. Once the PN model is established, a search algorithm can generate a sequence of actions that will enable the operator to restore the system. In the majority of publications of PN in PSR the breadth-first search algorithm is used [34,35,36] to determine this sequence of restorative actions. A load flow program is also used to verify the operating feasibility of the chosen restoration configuration.

1.2.4. Limitations of the Proposed Power System Restoration Techniques

As it is known the necessary time and the capability of finding restoration plans under unseen restoration scenarios plays a critical role in PSR estimation [37]. Using these characteristics as evaluation parameters it can be said that the three previous techniques have limitations. The main problem with these techniques is the time required to find the restoration plan [13,14,18,22,]. The rule-based technique usually takes several minutes to find the plan, mainly because the number of rules is proportional to the size of the system. In this way, in bigger transmission systems where all restoration possibilities must be covered, the number of production rules increases significantly, which diminishes the technique’s speed considerably. The mathematical programming and the petri net approach have similar performance characteristics. In both cases a certain search algorithm has to be applied in order to determine the restoration plan. The fastest search algorithm, the depth-first search, doesn’t guarantee an optimum solution and its performance depends upon the size of the state space. In large transmission systems, where the size of the state space increases, the search process will take a longer processing time, time that could increase even more if a load flow is needed after each state is obtained to check the state’s feasibility.

Due to these limitations it is proposed the use of Artificial Neural Networks (ANN) in PSR. The proposed use of ANN in restoration has already been a subject of research in small distribution systems [38] and small transmission systems [39]. It has proven to be a fast and reliable technique in these systems and, as it will be shown it can also be useful in larger and more complex transmission systems.

1.3. Scope of the Dissertation

1.3.1. Area of Interest

This dissertation addresses application of artificial neural networks in Power System Restoration. The use of ANN in PSR is proposed due to generalization capability of the technique, parallel processing characteristic and relatively short processing time.

1.3.2. Arrangement of the Dissertation

This dissertation has seven chapters. Chapter 1 (this chapter) is an introduction to the problem, discussing the standard PSR techniques and their limitations. Chapter 2 will review the main PSR issues. Chapter 3 will concentrate on the constraints that should be taken into account by the proposed PSR technique and their influence in the development of a restoration plan. Chapter 4 will study artificial neural networks (ANN) extensively, including neural network selection, input vector and topology optimization. Chapter 5 will introduce the principle and implementation of a PSR scheme based on ANN, the study system and the switching sequence algorithms. Chapter 6 will present and discuss the results obtained on the study system. As a conclusion, Chapter 7 will summarize the work and present what are the major achievements of this dissertation. It will also suggest ideas for additional research in this field.

Chapter 2. Restoration of Bulk Power Systems

In this chapter the main power system restoration issues will be summarized [40,41,42]. First, studies on real and reactive power balance will be reviewed emphasizing the importance of voltage control. Then the significance of fault location in PSR will be discussed. Next, intentional islanding and phase angle reduction will be discussed. At the end of this chapter will be presented the subject of interconnection assistance and cold load pickup, which are the other important issues in PSR.

2.1. Reactive Power Balance

Reactive power balance is a very important subject in PSR [41]. Reactive power balance is necessary to keep system voltages within allowable limits. This balance is extremely important mainly during the early stages of the restoration where high voltages can be generated due to the energization of unloaded transmission lines [44,45,46,47]. Sustained overvoltages can be controlled if the system is able to absorb the charging reactive power of the lightly loaded transmission lines. This can be accomplished by:

- Generators having sufficient under-excitation capability.
- Connecting reactive loads to the system including shunt reactors.
- Remove sources of reactive power and switching off shunt capacitors.
- Run generators at maximum possible reactive power output to allow margin to adjust for charging reactive power when lines are switched on.
- Energize only transmission lines that carry a significant amount of load avoiding the energization of extra lines that will generate unwanted reactive power.

The inability to perform these tasks can cause reactive power imbalance resulting in, for example, runaway voltages rise. Any restoration scheme that expects to be successful has to incorporate these heuristic considerations to avoid reactive power unbalance.

2.2. Load and Generation Balance

During the restoration process it is extremely important to maintain system frequency within allowable limits. This is required in order to maintain system stability and to avoid operation of frequency sensitive protection devices. The system frequency is maintained within these limits by a load and generation balance during the restoration process [48,49, 50,51]. This means that during the restoration process real load needs to be balanced with generator capabilities. This is generally accomplished by picking up loads in increments that can be accommodated by the inertial response of the restored and synchronized system. Restoring excessively large load blocks can result in unacceptable frequency or voltage excursions (particularly in an islanded power system which is more vulnerable than a large interconnected system). On the other hand, load pick-up in small increments tends to prolong the restoration duration. The size of load pick-up depends on the rate of response of prime movers, which at the early stages of the restoration are more likely to be under manual control. Thus each system will have its own size of load pick-up that will maintain system frequency and voltage levels within allowable limits. A successful restoration scheme must take this aspect into account.

2.3. Fault Location

Faults or equipment failures are the main causes of major disturbances in bulk power systems [40]. Most of these faults originate in the transmission system and can lead to a wide area outage due to cascading events. A very large number of these faults are tempory which are cleared immediately, leaving the system in an unfaulted condition. In this case identification and localization of the cause of the power failure is not considered to be a priority in the PSR problem. However, in the case when the fault is permanent, it is recognized that attempting to restore a faulted line or equipment can cause a larger disturbance or even increase the restoration time. The knowledge of the transmission lines and viable paths that are available for use in the restoration are then extremely important and can alter the restoration plan.

Several techniques have been recently proposed to identify the fault location in a power system [52,53,54]. The results obtained have been satisfactory and all restoration schemes must take into account this information.

2.4. Phase Angles

One of the concerns in closing a transmission line between to adjacent buses is the prevailing phase angle difference between the two bus voltages that may exist [55,56,57,58]. Closing a transmission line with a large phase angle difference could cause power swings and lead to a recurrence of the outage. There are several techniques proposed to reduce this angle. The technique commonly used proposes the alteration of the generation pattern on both sides of the closing circuit breaker. In order to avoid inadvertent closing on large phase angle differences, circuit breakers are equipped with synchrocheck relays which prevent their closure on angles greater that a preset value. The range of standing phase angle differences that a system can withstand depends upon the operating voltage levels and can be determined by dynamic and steady state simulations. The synchronous relay settings commonly used are 60 degrees for 500kV, 40 degrees for 230 kV and 20 degrees for 115 kV systems. Phase angle difference has to be taken into account by the restoration strategy to avoid further delay in the restoration process and resulting damage to the equipment.

2.5. Intentional Islanding

During the occurrence of a system outage, when several groups of generators can go out-of-step with each other, it is desirable to have selected system islands where there is a minimal mismatch between load and generation. Switching operations carried out to split the system into such self-sufficient regions is called intentional islanding [1,13,17,59]. In order to ensure satisfactory system separation, it may be necessary that some relays are blocked from tripping where a certain splitting is not desired and trip the relays where this splitting is desired.

In case that there is a wide area outage (blackout) there are two general strategies that can be implemented to generate the desired islands, the “all open” or “controlled operation” strategy [37]. The “all open” strategy islands the system by opening all circuit breakers. This strategy can be implemented by supervisory signals sent to all the circuit breakers in the system by the system operators through the Supervisory Control and Data Acquisition System and the Energy Management System. The “controlled operation” strategy islands the transmission system by opening selected circuit breakers. This strategy is implemented by control signals sent by system operators through the SCADA/EMS to only certain selected circuit breakers. The advantage of the “all open” strategy is that it generates a well defined system state for the system operator. In this strategy the system operator has to be concerned only with which circuit breakers should be closed and not be concerned with opening breakers that are left closed.

Intentional islanding is extremely important to reduce the restoration time in large transmission systems. In these systems the parallel restoration method, by which restoration of each island is executed in parallel, requires a significantly smaller time to restore the system than the sequential restoration. In the sequential restoration method the strategy is to restore the system as a whole, reenergizing transmission line one after another in a sequential mode. In small transmission systems, where usually there is a centralized blackstart capability this technique is applied. However in larger transmission systems where the blackstart capability is spread throughout the system, the parallel restoration method is commonly used.

Thus any restoration technique that will be used in a large transmission system should apply intentional islanding and the parallel restoration method in order to reduce the restoration implementation time.

2.6. Interconnection Assistance

The use of tie lines in the PSR has been a subject of recent studies [60,61] in PSR. In these studies there has been a great emphasis on interconnections with neighboring utilities and the possibilities of an inter-system assistance. The term “tie lines” refers to transmission lines connecting different systems or islands of one system. In the case of recent studies mentioned earlier the term is applicable for transmission lines connecting two different systems.

The use of tie lines for cranking non-blackstart units, serve customer loads and respond to the request from neighboring utilities would help systems with limited generation capability or with insufficient blackstart units to restore their systems and decrease their restoration time. In these cases the PSR scheme would take into account the tie lines of the system and the remote generation from neighboring systems to form its restoration plan. However there are several concerns with the use of tie lines in PSR among a great majority of the system operators that impede the use of tie lines in the restoration process [62]. The major concerns of system operators with the use of tie lines in PSR are:

- Propagation of the system disturbance to the neighboring utility.
- Transient and dynamic stability of both utilities.
- Coordination between the utilities.
- Impact of overvoltages produced by the connection.

Due to these reliability and security concerns the role of tie lines in PSR has been significantly small. In the great majority of the PSR schemes the tie lines are open during the restoration implementation and only closed when all systems (or islands) are in stable condition. In this way PSR schemes must not use tie lines for the formulation of the restoration plan.

2.7. Cold Load Pickup

During early stages of restoration it is very important to determine the amount of power demand following the system outage [63,64]. This amount of power usually called "cold load" will give the PSR scheme an idea of what quantity of load will be in demand by the system as it is restored. The knowledge of this amount of load is extremely important because of its direct relation with the PSR plan creation [40].

The main problem with cold load pickup (CLPU) is that the demand of load depends on many factors such as the duration of the outage, local weather conditions, and habits of the customers. However, generally it can be said that if the reconnection is made less than 10 minutes after a blackout the connected load will draw an almost normal current from the utility [43,65,66,67]. Since the connection of the loads could take less than 10 minutes if the PSR scheme is fast and reliable, the consideration of a CLPU equal to the pre-system outage load is an acceptable approximation.

2.8. Common Concerns of Power System Restoration Schemes

A review of the main PSR schemes reveals some common concerns. Among them are these:

- Identification of faulted components.
- Energization of large sections of transmission lines under acceptable voltage limits.
- Pickup load in large increments without frequency decline.
- Deactivation of automatic load shedding schemes and switching off capacitor banks during early stages of restoration.
- Maintenance of stability as the system is being restored.

Restoring a power system in a minimum time is a complex problem. Many issues have to be taken into account in order to achieve a fast and reliable PSR plan. Several schemes solve simpler problems or sub-problems in a reasonable manner for a limited number of possible initial conditions. As will be presented later, the proposed PSR scheme tries to solve the problem of large systems by taking into consideration several different initial conditions.

Chapter 3. Constraints in Power System Restoration

In order to generate feasible restoration plans the PSR schemes must take into account several operational constraints. This chapter will summarize the major constraints in PSR. First the subject of transmission lines operational limits will be presented. Following this will be discussed power system stability in restoration. At the end of this chapter important PSR implementation constraints will be discussed, such as the number of used transmission lines and locked out circuit breakers.

3.1. Operational Limits of Transmission Lines

The energization of high voltage transmission lines is extremely important for the success of the restoration plan implementation. During energization of transmission lines the main concerns of system operators are: the length of line to be energized, the size of the underlying load and the thermal limits of the transmission line [14].

Generally it is desirable to energize as large sections of lines as the steady state and transient voltages will allow. Energizing small sections will prolong the restoration time and energizing a large section can lead to overvoltages that could damage equipment insulation [45].

The loads at the end of the transmission lines are also an important issue to be treated during the restoration implementation. Loads tend to reduce the steady state and transient voltages during the energization of transmission lines. However a large amount of loads could generate undervoltages [68].

While energizing the transmission line one of the objectives of the system operator is to pickup as much load as possible. In order to do so the energized transmission line will have to support a certain amount of transmitted power. As is well known, if the bus voltages are considered to be kept constant, the only way to increase the magnitude of transmitted power is by changing the phase angle difference between the respective buses [69]. The following figure shows the relationship between transmitted power and the angle difference.

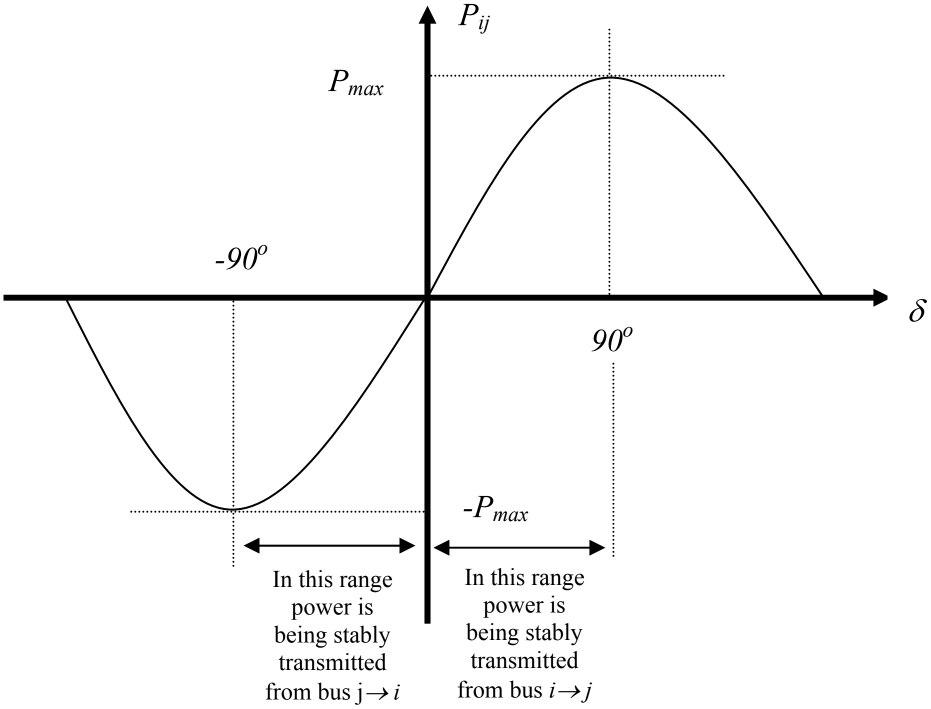


Figure 3-1 Line Power versus Power Angle

In the next equation, considering a loss-less transmission line, the transmitted real power between buses *i* and *j* is given by,

$$P_{ij} = -P_{ji} = \frac{|V_i||V_j|}{X}\sin\delta \tag{3-1}$$

If the bus voltages are kept constant the above equation can be written as

$$P_{ij} = P_{\max}\sin\delta \tag{3-2}$$

Where:

- $P_{\max} = \frac{|V_i||V_j|}{X} = \text{Constant.}$
- V_i is the voltage of bus *i*.
- V_j is the voltage of bus *j*.
- X is the reactance of the transmission line between buses *i* and *j*.

- δ is the angle difference between the voltages of buses i and j.

When the transmission line is forced to transmit P_{max}, the power angle has the value of 90^0, and any added increment in the load will not result in a corresponding increase in transmitted power. Actually the power transmitted will begin to decrease, because the added load forces δ beyond 90^0. This point is referred as the *static stability limit*, and power transfer of this magnitude would lead to a loss of synchronism between the buses i and j.

Besides the transmission capacity constraint, transmission lines also have thermal limits that should be considered while reconnecting loads [70]. Thermal limits of transmission lines will usually limit the amount of power that can be transferred to values smaller than the maximum transmission capacity. In Table 3-1 typical thermal ratings of Extra-High Voltage (EHV) transmission lines are presented.

Table 3-1 Thermal Rating of EHV Transmission Lines of 200 miles

Voltage (kV)	*Thermal Rating (MW)*
230	400
345	1200
500	2600
765	5400
1100	24000

The thermal rating of normally designed transmission lines depends mainly on the voltage level at witch they operate, the line length and reactance. If the transmission line has not been loaded to its thermal limit the power transfer capability can be increased by the use of power electronics. The most acceptable technique uses a Static Var Compensator (SVC). This device, which consists of switchable capacitors and thyristor controlled reactors can supply reactive power, raising the voltage of the transmission line, or absorb reactive power, lowering the voltage of the transmission line. Also series compensation is used to increase the capability of power transfer by reducing the inductance of the line. Adding capacitors in series with the line have been mostly used in the western US systems due to their long transmission lines.

All the operational constraints of transmission lines mentioned above have been the topic of recent studies [44,68,71]. From these some general conclusions can be drawn:

- If steady state voltages are less than 1.2 per unit values, typical arresters can accommodate the switching transients generated by the re-energization of transmission lines.
- Switching transients are usually not a limiting factor in re-energizing a transmission line.
- The percentage of voltage rise due to the Ferranti effect between sending-end and receiving-end is independent of voltage level, being only proportional to the square of the line length.
- Underlying loads will considerably reduce the voltage rise at the receiving-end, depending upon the amount of load, the operating voltages and the line length.
- Transmission lines should not be overloaded in the process of re-energization.
- Each system will have its own operating constraint which should be taken into account during the re-energization of the transmission lines.

In order to energize transmission lines in a feasible manner a PSR scheme should take these general guidelines as a part of the restoration plan.

3.2. Power System Stability

Power system stability is a subject of major concern in PSR [72]. The restored system generated by the PSR scheme has to be able to allow for sufficiently large load and generation variations without encountering undesirable and uncontrollable behavior that could lead to instability and a recurrence of the system blackout.

In order to check the stability of the restored power system transient stability studies much be conducted. The dynamics of a multi-machine system is described by a set of second order differential equations. The number of differential equations of this set is equal to the number of machines in the system and the number of their state variables. The following equation is provided as an example, and is known as the *swing equation* of a simple machine in a one-machine-infinite bus representation of the power system.

$$M\ddot{\delta} + D\dot{\delta} = P_m - P_e \tag{3 - 3}$$

$$\frac{d}{dt}\delta = \omega - \omega_R \tag{3 - 4}$$

Where:

- M is the inertial constant of the machine.
- D is the damping constant of the machine.
- P_m is the constant mechanical power input of the machine.
- P_e is the electric power output of the machine.
- δ is the angle of the internal complex voltage of the machine.
- ω is the rotor angular velocity of machine.
- ω_R is the reference angular velocity.

One of the more accepted forms to check if the system is going to remain stable after a change in its load or generation pattern is by checking the solutions of the dynamic equations for all conceivable load/generation variations. However this methodology is extremely time consuming and clearly unrealistic for real-time use. Due to this limitation, in recent years there has been the proposal of other methods [73,74,75] to define the regions of stability of a multi-machine system due to load/generation changes. One form to obtain quite reliable stability margins is to consider the distribution of machine rotor angles in the load/flow equations.

One such method [76,77] uses steady state generator angle limits to define regions of transient stability. As is known from equation (3-1), under static conditions and considering that the bus voltages are kept constants, real power can be transmitted stably for,

$$-\frac{\pi}{2} < \theta_{ij} < \frac{\pi}{2} \tag{3 - 5}$$

Where

- θ_{ij} is the angle difference between the rotors at buses *i* and *j*

In this method, the margin for angle difference used to insure static stability is also used to guard against transient instability of the system by using a lower limit which is based upon previously performed transient stability simulations. In order to have a better safety margin to predict the transient stability of the system, it is common to reduce the margin of allowable angle difference between the buses. For example for a 345 kV systems one may have an angular separation between bus voltage angles across the line *ij* given by,

$$-\frac{\pi}{6} < \theta_{ij} < \frac{\pi}{6} \tag{3-6}$$

In this way, in order to ensure that the 345 kV-restored systems will be dynamically stable, the angle differences between connected buses must remain within the range of equation (3-6) in their load flow solution.

3.3. Number of Transmission Lines Used in the Power System Restoration Plan

The number of transmission lines used in the PSR plan is very important. Transmission lines play a critical role in the reactive power balance and overvoltage control during the restoration implementation. As generators of reactive power due to their shunt capacitances, if not correctly energized in a proper sequence transmission lines can create sustained and transient overvoltages reactive power unbalance and consequently cause damage to transformers, create harmonic distortions and in general delay the PSR [37,44]. In order to maintain a normal voltage profile and avoid the generation of excessive reactive power it is advisable to energize the smallest possible number of transmission lines during the restoration process.

Along with the problems mentioned previously, one important constraint that also leads to the use of a minimum number of transmission lines in the PSR plan are the extra amount of switching actions necessary if more lines are to de used. Obviously, the number of switching operations executed by circuit breakers affects their maintenance requirements [68]. Additionally, switching operations can some times involve field operators and can be time consuming. For these reasons it is advisable that the PSR plan use a minimum number of transmission lines during the energization process.

3.4. Lockout of Circuit Breakers

Circuit breakers are control devices which are responsible for switching of transmission lines transformers and loads. Circuit breakers are primarily responsible for isolating faults from the rest of the power system. They may also be used to switch load currents. Circuit breakers normally remain closed, and are called upon to operate (open) relatively infrequently. Thus they are required to be reliable under normal conditions for a long period of time and be effective instantaneously when called upon to operate [78].

There are several types of circuit breakers oil circuit breakers, air-break circuit breakers, air-blast circuit breakers, SF_6 circuit breakers and vacuum circuit breakers are the most commons types. The main difference between these circuit breakers is the interruption medium for the arc extinction: oil, air, compressed air, SF_6 and vacuum respectively.

The power system restoration process is basically composed of several re-energization actions in the network. Since these actions are accomplished with the use of circuit breakers, the importance of these devices to PSR is obvious.

In order to achieve a feasible plan to re-energize the system, the PSR scheme must have knowledge of the system status. The knowledge of all possible configurations will allow the scheme to decide the best restoration plan. It is imperative for the PSR scheme to know the available and unavailable transmission paths in the power system network after the wide area disturbance. Circuit breakers, as mentioned earlier, are responsible for the connection or electrical isolation of these possible transmission paths in the network. Figure 3-2 shows two circuit breakers responsible for the connection/isolation of a transmission line in the network. Depending upon the bus configuration, a breaker shown in the figure may actually be one of a pair at each end.

Figure 3-2 Transmission Line and Circuit Breakers

In Figure 3-2 it can be seen that the transmission line between buses **A** and **B** will be connected to the rest of the network if breakers **1** and **2** are in closed position. If for any reason one of these two breakers is unable to switch from the open position (position that all breakers begin in an "all open" switching restoration strategy) to a closed position, this will mean that this transmission line cannot be used in the restoration plan. This unavailability condition is similar to the unavailability of a faulty transmission line, which due to its condition also cannot be used in the restoration plan.

Circuit breakers have the capability to go through a certain number of open-close sequences when automatic reclosing is enabled. Once the available number of open-close sequences is exhausted the circuit breaker goes into a lock-out state. A locked out circuit breaker will normally require manual resetting before it can be made available for normal operation. Clearly, the lock-out circuit breakers can not be used for remote controlled automatic restoration.

In addition to being in a locked out state as described above, a circuit breaker may itself be subject to faults.

Circuit breakers are highly reliable devices. They have a design life of 30 or more years, and are rarely switched form one position to another. However, circuit breakers are also subject to failure. In Table 3-2 [79] several types of air-blast circuit breaker failures are shown together with their percentage of occurrence over a certain time period. The definition of failures for the creation of this table was 'unable to execute a switching action when requested'.

Table 3-2 Circuit Breaker Failures

Type of Failure	*Percentage of all Failures*
Electrical	10
Air leaks and Air Conditioning	20
Pipes and Joints	3
Control Circuits	10
Air Valves	15
Auxiliary Switches and Interlocks	12
Mechanical	25
Unknown	5

Although these failure rates apply to outdoor circuit breakers of the air-blast type and that other types of circuit breakers have different type of construction, the evidence suggests that the statistical behavior shown in Table 3-2 applies to all types of circuit breakers. Analyzing table 3-2 it can be concluded that the major failures in circuit breakers are due to mechanical reasons. The explanation for this is the fact that circuit breakers are used in the power system network for many years. Under these situations, electrolytic corrosion and chemical degradation become important factors that can lead to mechanical failures of the circuit breakers.

In a recent study [80] an effort was made to identify major problems encountered in the PSR implementation. Table 3-3 presents the results encountered based on 48 major disturbance reports.

Table 3-3 Restoration Problems by Frequency of Occurrence

Description	*Number*
Switching Operation	8
Procedure Out-of-Date	7
SCADA Inadequate	7
Dispatch Offices Coordination	7
System Status Determination	6
Sustained Overvoltage	5
Synchronization Location & Facilities	5
No Restoration Plan	4
Sustained Undervoltage	3
Response to sudden Increase in Load	3
Standing Angles	3
Energy Storage	3

Steam Unit Restart	2
Line Over Load During Restoration	2
Restoration Procedure not Followed	2
Operator Training	2
Switched Capacitors/Reactors	1
Interlocking Schemes	1
Inadequate Communication	1
Inadequate Displays	1

From Table 3-3 it can be seen that switching operation failures are among the most frequent problems seen in PSR implementation. As mentioned earlier these failures can prevent the use of the affected power system equipment in the restoration implementation, reducing the number of possible reconnection/re-energization paths. The inability of correctly informing the status of all circuit breakers to the PSR scheme can lead to a wrongful assumption of possibility of use of certain equipments that will endanger the success of the restoration implementation.

Circuit breakers are reliable power system equipment. They are responsible for the connection/isolation of other equipment to the network via switching operations. However they are subject to failures that should be accounted for. The failure of switching operations of circuit breakers can lead to a delay in the system restoration, or in extreme cases lead to the recurrence of the system outage. In order to avoid these outcomes, circuit breaker status should be correctly known to the PSR scheme.

Chapter 4. Artificial Neural Networks

Artificial neural networks (ANN) have been a successfully tool used in many recent applications [81,82,83,84,85,86,87] in electric power systems. ANN is a mathematical methodology inspired by the way in which human brains performs particular tasks. An ANN can be viewed as a parallel processor composed of interconnected processing units/neurons that are able to store experiential-based knowledge and make them available for future use [88]. The ANN can be implemented by electronic circuits or simulated in a digital computer. The main characteristics from the human brain which this artificial system emulates are [89]:

- Robust and tolerant to faults.
- Flexible and adjustable to other environments through learning process.
- Ability to deal with noisy, inconsistent and nebular information.
- Parallel processing.
- Small, compact and consuming small amounts of energy.

It is clear that there is still a long way to go before a computer architecture that mimics the human brain can be built. However the use of ANN can offer several useful capabilities and properties. Among the useful capabilities and properties that ANN can provide are:

- Nonlinearity: A processing unit of the network can be linear or nonlinear. An ANN made of nonlinear processing units is itself nonlinear. This characteristic is very important when the ANN should map/classify nonlinear functions.
- Input-Output Mapping: An ANN is capable to learn from a set of input/output patterns called training samples. In this learning process, also known as supervised learning, the desired outputs are known and the network will try to produce a value when a certain input is applied. In order to correctly learn how to generate the desired output when an input is applied, the network will modify the value of its connection coefficients between processing units, also known as synaptic weights, to minimize possible errors. The modification of the synaptic weights is continued until the

network is able to generate the desired outputs when the training input patterns are applied.

- Adaptability: An ANN has the ability to adapt its synaptic weights to minor changes in the environment. The network can easily be retrained to deal with these minor changes in the operating environment and when operating in a non-stationary environment the network can be designed to change its synaptic weights in real time.
- Evidential Response: The ANN can be trained to provide a value that reflects it confidence corresponding to its decision. This tool is very useful when the network performs activities such as pattern classification.
- Fault Tolerance: An ANN has the potential of being fault tolerant in the sense that its performance doesn't degrade significantly when adverse operating conditions are presented. An example is when a processing unit or a connecting link is damaged or lost due to a fault. Due to the distributed nature of knowledge stored in the network the fault has to be extensive before the overall performance of the network is affected.
- Neurobiological Analogy: ANN methodology is inspired by the human brain. The human brain is a massive fault tolerant parallel processor which is extremely fast and reliable. While neurobiologists look to ANN as a research tool for the study of the neurobiological phenomena, engineers look to this tool as a way to solve complex problems that conventional techniques have difficulty to deal with.

In the next sections the basic characteristics of ANNs will be presented. First the biological neuron and its mathematical model will be introduced. Following this the Multilayer feedforward network architecture and the back-propagation learning algorithm will be discussed. This chapter will end with the presentation of basic heuristics that can help the back-propagation learning algorithm to perform better.

4.1. Biological Neuron

It is estimated that the human brain possesses approximately 10 billion neurons of diverse types and forms. The human brain can be seen as a network of interconnected neurons that receive information, perceive it, and make appropriate decisions. Figure 4-1 illustrates a representation of typical neurons.

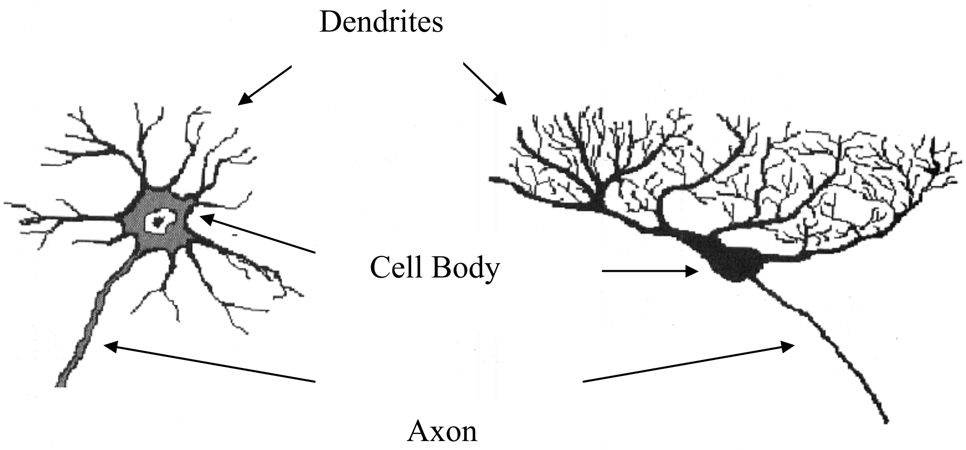


Figure 4-1 Typical Biological Neuron

A neuron is composed of four basic entities. The first one are called dendrites. Dendrites are a network of cell filaments that form the receptive zones. It is through the dendrites that the neuron receives its inputs. The dendrites are connected to the cell body and are responsible for the transmission of the input created by a stimulus to the latter entity. The cell body is where the nucleus is located and where all the information received by the neuron is processed. The cell body is connected to the axon, a long smooth surface cell filament. This cell filament has fewer branches than the dendrites and is responsible for the transmission of the processed information to other neurons since the axon is connected to the dendrites of other neurons. A functional unit called synapses does the interaction between neurons, transmitting electric signals from one neuron to the other. The synapses are connections that can impose excitation or inhibition and are encountered at the junction of neurons.

The inputs of a neuron are derived from the synaptic junctions between axons and its dendrites. The signals that arrive via dendrites are neurotransmissions that the cell body will process and generate an output in the form of an electric impulse that will be sent to the neuron's axon. The signal transmission from one cell to another occurs via a synapse. An emission side and a reception side compose the synapse. A chemical and electrical process in the synapse performs this signal transmission function. The process that transmits the signal begins with the emission of transmitter substances across the synaptic junction. The synapse converts a presynaptic electrical signal into a chemical signal and then to a postsynaptic electrical signal. This signal is then transmitted to the cell body where it is processed.

After years of study, researches concluded that a neuron could be considered as a logical processing unit. In this analogy the neuron would receive several inputs and generate an output [90]. To generate an active output the neuron would have to receive a sufficient number of active inputs. If sufficient active inputs were not received, the neuron would become inactive and not generate an output.

From this general idea several models of artificial neurons were proposed which form the basis of neural networks. Next, one of the more used models in ANN will be presented.

4.2. Mathematical Model of a Biological Neuron

Several processing units modeled in the biological neuron compose an ANN. These units, called artificial neurons, have their block diagram shown in Figure 4-2.

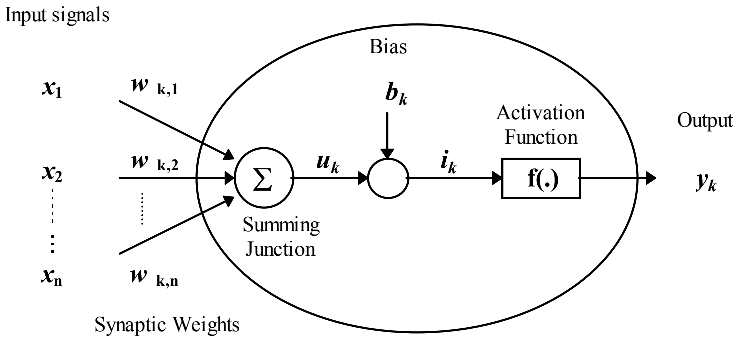


Figure 4-2 Nonlinear Mathematical Model of a Neuron

In this model three basic elements are identified:

- Synaptic weights: These are connection links, each with their own strength or weight, which connects the inputs to the neuron.
- Summing junction: This element sums the weighted inputs in a linear form.
- Activation function: This function is applied to the sum of the output of the junction and the bias. This function limits the amplitude of the output of the neuron.

The operation of the processing unit starts by the gathering of the total input. The total input u_k is obtained by the sum of the weighted inputs as defined by equation (4-1).

$$u_k = \sum_{j=1}^{n} w_{kj} . x_j \tag{4-1}$$

Where:

- u_k is the total input.
- w_{kj} is the weighted input j of neuron k.
- x_j is the input j.

After the total input is obtained a bias can be added to this value.

$$i_k = u_k + b_k \tag{4-2}$$

Where:

- i_k is the induced local field.
- b_k is the bias.

The addition of the bias has the effect of applying a transformation to the total input. In Figure 4-3 an example of this transformation can be seen.

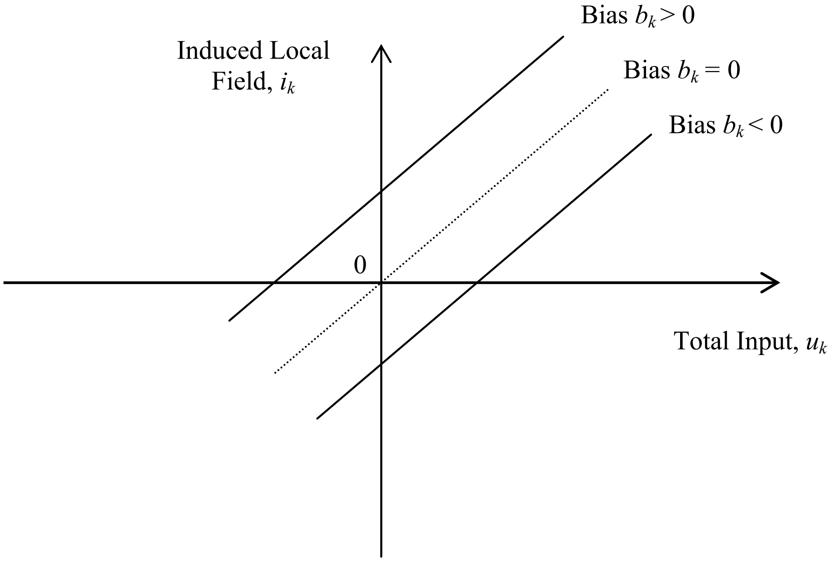


Figure 4-3 Transformation produced by the addition of the Bias

After obtaining the induced local field, the output of the neuron is obtained by applying an activation function to the induced local field. The activation function used in the neuron can be of several types, among them are: threshold function, piecewise-linear function and the sigmoid function.

The most used activation function in the construction of ANN is the sigmoid function. One common example of a sigmoid function is the logistic function. This function, defined by,

$$f(i) = \frac{1}{1 + e^{(-ai)}} \tag{4-3}$$

where a is the slope parameter of the function. This function is differentiable, assuming a continuous range of values through 0 and 1. By varying the value of a it is possible to obtain sigmoid functions with different slopes. In the Figure 4-4 a logistic function with different slopes is presented.

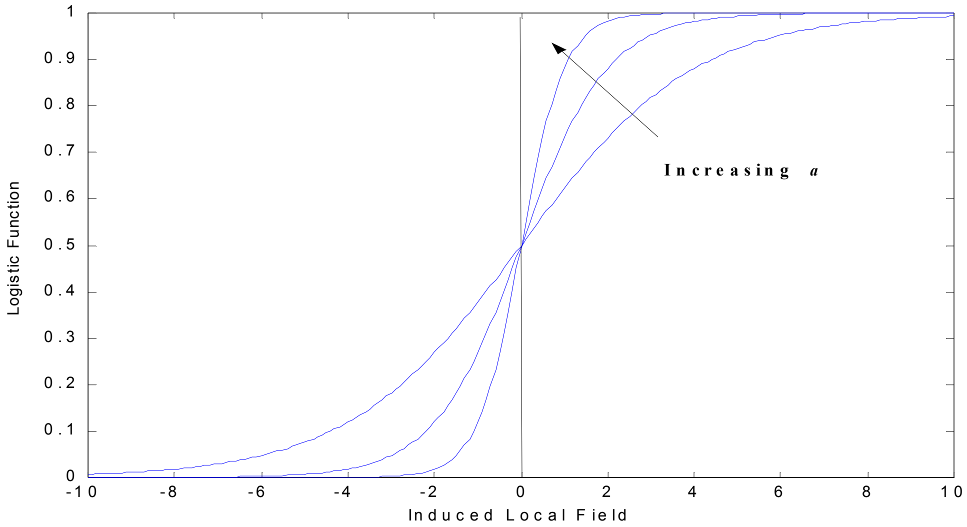


Figure 4-4 Logistic Function for different *a*

It is sometimes desirable to have an activation function with a range of –1 to 1. In this case the most used function is the hyperbolic tangent function, defined by,

$$f(i) = \tanh(i) \tag{4-4}$$

This function is shown in Figure 4-5.

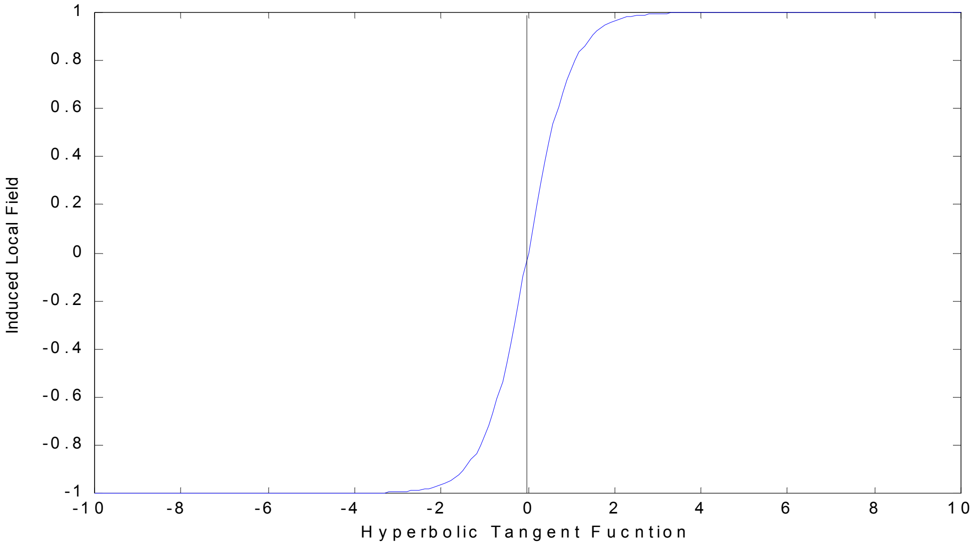


Figure 4-5 Hyperbolic Tangent Function

The mathematical model of a biological neuron is the fundamental basis of ANNs. It will be seen that a neural network is basically an interconnection of these processing units organized in a structure linked with the learning algorithm.

4.3. Feedforward Networks

The network architecture that is used in this research is the multilayer feedforward network (MFN). In this type of network there is a layered organization, which means that artificial neurons form layers and are interconnected by the synaptic weights. One input layer, one or more hidden layers and one output layer compose this type of network. In figure 4-6 a diagram of a fully connected MFN is shown.

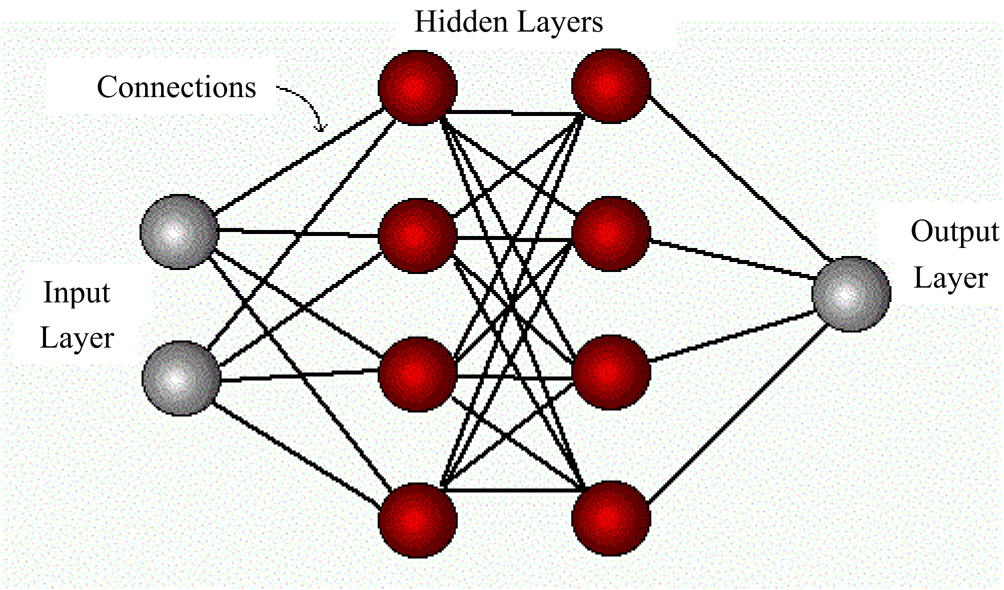


Figure 4-6 Multilayer Feedforward Network

In this class of network architecture, the propagation of the information occurs from the input layer in the direction of the output layer without feedback loops. Also, the connections or synaptic weights exist only between processing units of different layers. The structural formation of this type of network imposes a certain operational form on all MFNs. The operation of a MFN begins with the presentation of the input pattern to the input layer. In some cases the input layer is composed of source nodes only and no processing units. In this case the input layer will only redistribute the weighted input vector to the first hidden layer. If the network is fully connected, every node in each layer is connected to every node in the adjacent forward layer. With the arrival of the weighted vector, each processing unit of the hidden layer calculates a total input. To this value an activation function is applied and an output vector is obtained. This output vector will be again weighted and then redistributed to the adjacent forward layer, which could be an output layer. In each processing unit the process of calculation of the total input and the application of the activation function to this value is then repeated. After this calculation the output vector is obtained which completes the operation of the MFN.

In the case that the MFN is not yet trained, the obtained output vector could be compared with a desired output vector in order to change the values of the weights using an appropriate learning algorithm.

4.4. Learning Paradigms

In order to perform a task efficiently, an ANN will need to pass through a training/learning process in which the weighted connection values between the processing units will be changed. In these learning processes the change in the weights of the connections can lead to the appearance of new connections, the loss of existing connections, or to a simple value modification of old connections. There are several different types of learning algorithms that can be implemented to change the value of the weight connections. One of the big differences between these algorithms is the learning paradigms on which they are based. There are two basic learning paradigms in ANNs; the first one is called *supervised learning* and the second one *learning without a teacher*.

- Supervised learning: The main characteristic of the learning algorithms inspired by this paradigm is that they use the knowledge of the environment, also known as a *teacher*, to guide the process. This knowledge of the environment is represented by a set of input-output examples that will provide the ANN with the desired response for a specific training vector. The desired response will be used to generate an error signal. The difference between the desired and the obtained output vector, together with the training input vector will influence the adjustment of the network parameters. This adjustment is continued until the obtained error for all the examples is under an acceptable pre-established threshold. After this process is finished the ANN is allowed to deal with the environment by itself. In Figure 4-7 a block diagram of the supervised learning paradigm is presented.

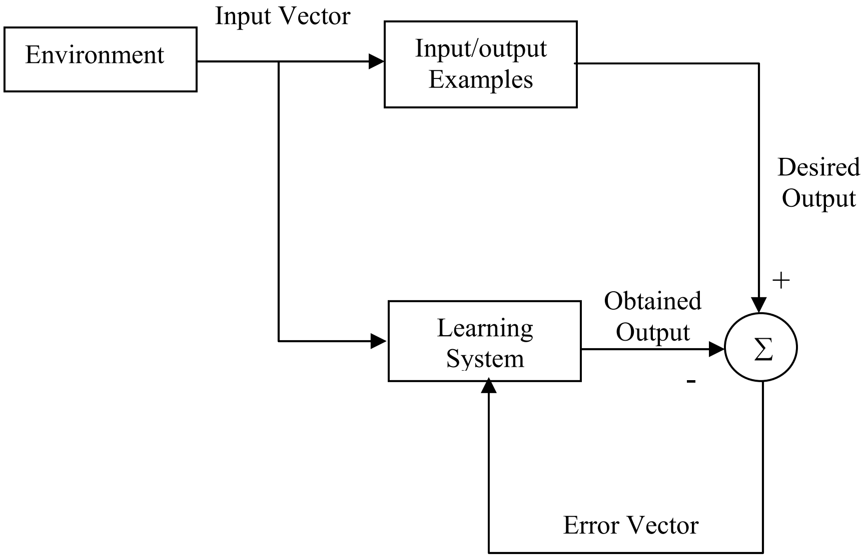


Figure 4-7 Block Diagram of the Supervised Learning Paradigm

- Learning without a teacher: In this type of learning process there is no teacher to oversee the learning process. In this case there are no input-output examples to guide the learning process. There are two subclasses under this paradigm, the reinforcement learning and the unsupervised learning. In the first subclass (the reinforcement learning) the learning process is performed through continuous interaction with the environment. In one possible form this system can be built with a *critic* that receives a primary reinforcement signal from the environment and then generates a heuristic reinforcement signal that will be sent to the learning system. Both signals are scalar inputs and will help the learning system minimize a cumulative cost of *actions*. The system is designed to interact with the environment and develop the ability to learn a certain task on the basis of the outcomes of its experience resulting from the interaction. The second subdivision of this type of paradigm is the unsupervised learning. In this type of learning system there is no teacher and also no critic to guide the process. The network parameters will be modified to optimize a *task-independent measure* of the quality of representation that the network should learn. Once the network is able to correlate some similarity criteria between the input patterns it will be able to create new classes automatically.

One of the most commonly used learning algorithms for training MFN is the back-propagation algorithm. This algorithm [91] is based on the supervised learning paradigm and will be discussed in details in the following section.

4.4.1. Back-Propagation Algorithm

The back-propagation learning algorithm is the most commonly used algorithm in ANN applications in power systems. This type of algorithm can be applied in MFN and is divided into two distinct operations. In the first operation the input signal is applied to the network and propagates in a forward direction through the network emerging at the output terminal. This output signal propagates through the network is also know as a function signal. In the second operation an error signal is generated at the output layer of the network and is propagated in a backward direction through the network, layer by layer. It is in this part of the operation of the algorithm that the weights of the connections are modified to minimize the error between obtained and desired output vectors. In Figure 4-8 it will be illustrated the two directions of signal flows in the back-propagation algorithm are illustrated.

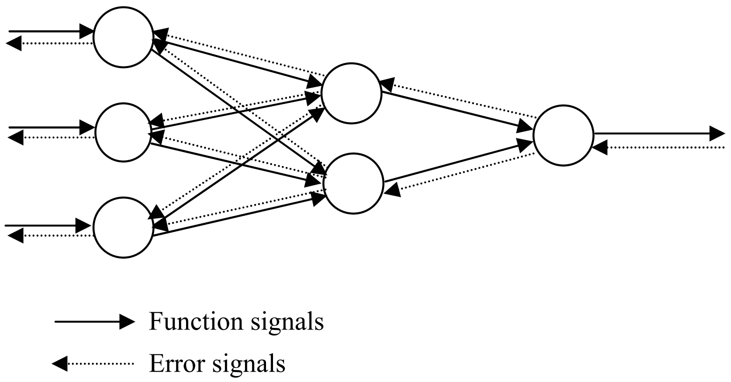


Figure 4-8 Two Basic Direction Flows in the Back-Propagation Algorithm

As mentioned before, the first operation of the back-propagation algorithm consists of the propagation of the function signal through the network. After the signal arrives at the output layer an output vector can be obtained and compared with the desired output. With these two values an error can be obtained as given in equation (4-5) for output neuron j.

$$e_j(n) = d_j(n) - y_j(n) \tag{4-5}$$

Where:

- $e_j(n)$ is the error of output of neuron j at iteration n.
- $d_j(n)$ is the desired output of neuron j at iteration n.
- $y_j(n)$ is the output of neuron j at iteration n.

With the obtained output the algorithm also calculates the error per pattern as shown in equation (4-6):

$$\xi(n) = \frac{1}{2}\sum_{j \in D} e_j^2(n) \tag{4-6}$$

Where:

- D includes all processing units of the output layer.

With the error per pattern obtained, the algorithm calculates the average squared error energy that is given in equation (4-7):

$$\xi_{av} = \frac{1}{N}\sum_{n=1}^{N} \xi(n) \tag{4-7}$$

Where:

- N is the total number of patterns in the training set.

The average squared error energy error per pattern is a function of the synaptic weights and the bias level of the network. For a given set of training patterns the average error energy can be seen as a cost function that the back-propagation learning algorithm has to minimize by adjusting the values of the weights of the network. The more common adjustments of the weights are done pattern-by-pattern until the entire training set has been used. The adjustment of the weights is based on the error calculated for each pattern.

The back-propagation learning algorithm uses the error per pattern to guide the adjustment of the weights in order to minimize the cost function defined as the average squared error energy. First consider the induced local field produced at the input of a certain processing unit j.

$$v_j(n) = \sum_{i=0}^{m} w_{ji}(n) y_i(n) \tag{4-8}$$

Where:

- $v_j(n)$ is the induced local field of neuron j at iteration n.
- $w_{ji}(n)$ is the weight of connection between input i and neuron j.
- $y_i(n)$ is the i^{th} input of neuron j at iteration n.
- m is the total number of inputs.

In equation (4-8) the bias is a weight w_{j0} with a fixed input y_0 equal to 1. With the induced local field the output of the neuron can be calculated by,

$$y_j(n) = \varphi_j(v_j(n)) \tag{4-9}$$

Where:

- φ_j is the activation function of neuron j.
- $y_j(n)$ is the output of neuron j at iteration n.

In order to minimize the cost function the back-propagation learning algorithm applies the delta rule to correct the weights of the connections. The delta rule applied to the weight correction is shown in equation (4-10):

$$\Delta w_{ji} = -\eta \frac{\partial \xi(n)}{\partial w_{ji}(n)} \tag{4-10}$$

Where:

- Δw_{ji} is the weight connection correction.
- η is the learning-rate parameter.

The minus signal is used in the gradient descent in the weight space. The minus sign accounts for seeking of a direction in which the change of the weight will decrease the value of the error per pattern. Using the chain rule of calculus the above gradient can be written as shown in the equation (4-11):

$$\frac{\partial \xi(n)}{\partial w_{ji}(n)} = \frac{\partial \xi(n)}{\partial e_j(n)} \frac{\partial e_j(n)}{\partial y_j(n)} \frac{\partial y_j(n)}{\partial v_j(n)} \frac{\partial v_j(n)}{\partial w_{ji}(n)} \tag{4-11}$$

In order to find an easier form for the weight correction expressed in equation (4-10) some mathematical operations with the equation (4-11) will be performed. First both sides of equation (4-6) will be differentiated with respect to $e_j(n)$.

$$\frac{\partial \xi(n)}{\partial e_j(n)} = e_j(n) \tag{4-12}$$

Now, differentiating equation (4-5) with respect to $y_j(n)$:

$$\frac{\partial e_j(n)}{\partial y_j(n)} = -1 \tag{4-13}$$

Next, equation (4-14) can be obtained by differentiating equation (4-9) with respect to $v_j(n)$.

$$\frac{\partial y_j(n)}{\partial v_j(n)} = \varphi_j'(v_j(n)) \tag{4-14}$$

Now, if equation (4-8) is differentiated with respect to $w_{ji}(n)$:

$$\frac{\partial v_j(n)}{\partial w_{ji}(n)} = y_i(n) \tag{4-15}$$

Substituting equations (4-12) through (4-15) in (4-11) yields

$$\frac{\partial \xi(n)}{\partial w_{ji}(n)} = -e_j(n)\varphi_j'(v_j(n))y_i(n) \tag{4-16}$$

Local gradient is defined as,

$$\delta_j(n) = -\frac{\partial \xi(n)}{\partial v_j(n)} = \frac{\partial \xi(n)}{\partial e_j(n)}\frac{\partial e_j(n)}{\partial y_j(n)}\frac{\partial y_j(n)}{\partial v_j(n)} = e_j(n)\varphi_j'(v_j(n)) \tag{4-17}$$

The correction to the synaptic weight w_{ji} used by the back-propagation algorithm can be found from equation (4-17). The correction factor is given in equation (4-18).

$$\Delta w_{ji}(n) = \eta\delta_j(n)y_i(n) \tag{4-18}$$

As it can be seen from equations (4-17) and (4-18) a main factor in calculating the weight adjustment is the error signal $e_j(n)$ of the processing unit j. However, depending on where the processing unit is located in the network, two distinct calculations to obtain the error signal can be identified. As a first case it can be considered that the processing unit j is located at the output layer of the network. In this case when supplied with the error signal $e_j(n)$ the desired output can be easily calculated by the equation (4-5). With this value determined it is a straightforward operation to calculate the local gradient by equation (4-17) and then obtain the weight adjustment from equation (4-18). When the processing unit j is located at a hidden layer, the calculation of the local gradient is not so direct.

In order to find the equation for this case first redefine the local gradient as,

$$\delta_j(n) = -\frac{\partial \xi(n)}{\partial y_j(n)} \frac{\partial y_j(n)}{\partial v_j(n)} = -\frac{\partial \xi(n)}{\partial y_j(n)} \varphi_j'(v_j(n)) \tag{4-19}$$

Referring to Figure 4-9, and differentiating equation (4-6) for a neuron *k* with respect to $y_j(n)$:

$$\frac{\partial \xi(n)}{\partial y_j(n)} = \sum_k e_k \frac{\partial e_k(n)}{\partial y_j(n)} \tag{4-20}$$

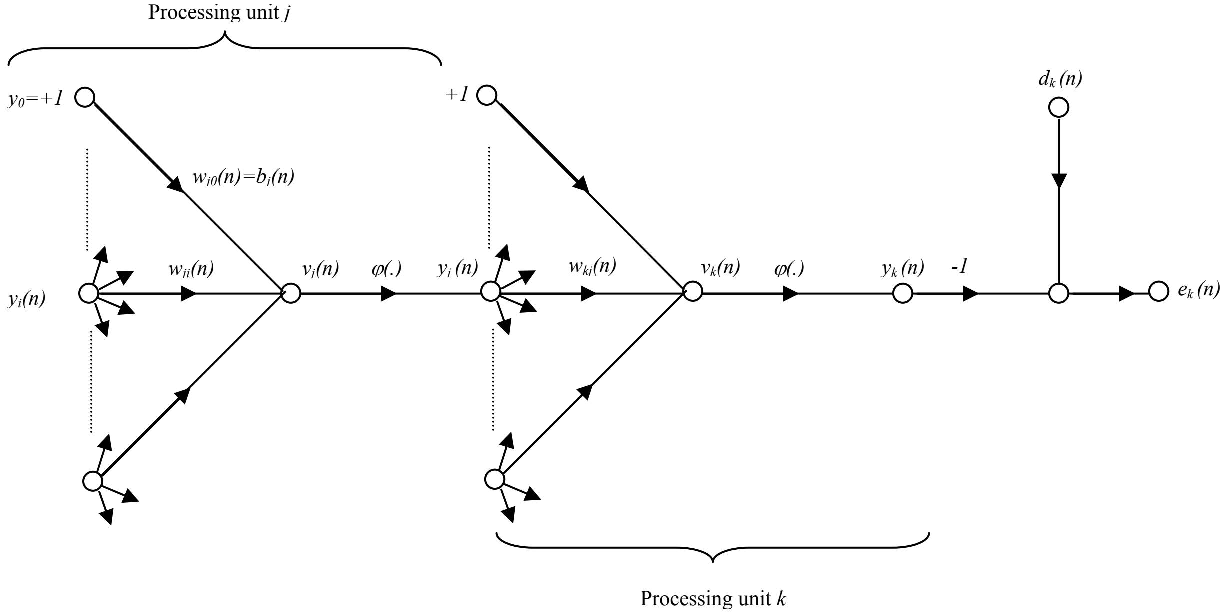


Figure 4-9 Signal Flow

Using the chain rule of calculus equation (4-20) can be reformulated as,

$$\frac{\partial \xi(n)}{\partial y_j(n)} = \sum_k e_k \frac{\partial e_k(n)}{\partial v_k(n)} \frac{\partial v_k(n)}{\partial y_j(n)} \tag{4-21}$$

From equation (4-5)

$$e_k(n) = d_k(n) - \varphi_k(v_k(n)) \tag{4-22}$$

Differentiating both sides with respect to $v_k(n)$,

$$\frac{\partial e_k(n)}{\partial v_k(n)} = -\varphi'_k(v_k(n)) \tag{4-23}$$

If equation (4-8) is differentiated for a neuron *k*, with respect to $y_j(n)$

$$\frac{\partial v_k(n)}{\partial y_j(n)} = w_{kj}(n) \tag{4-24}$$

Substituting equations (4-23) and (4-24) in equation (4-21):

$$\frac{\partial \xi(n)}{\partial y_j(n)} = -\sum_k e_k(n)\varphi'_k(v_k(n))w_{kj}(n) = -\sum_k \partial_k(n)w_{kj}(n) \tag{4-25}$$

Finally with equations (4-25) and (4-19) the back-propagation formula for the local gradient $\delta_j(n)$ for the case of the processing j unit being located at a hidden layer can be obtained.

$$\delta_j(n) = \varphi'_j(v_j(n))\sum_k \delta_k(n)w_{kj}(n) \tag{4-26}$$

Summarizing the relations derived above it can be said that the weight adjustment of a certain processing unit *j* in the backward pass of the back-propagation algorithm is given by the delta rule and is given by

$$\Delta w_{ji}(n) = \eta\delta_j(n)y_i(n) \tag{4-27}$$

Where:

- η is the learning parameter.
- $\delta_j(n)$ is the local gradient at iteration n.
- $y_i(n)$ is the input signal of neuron j at iteration n.

And the local gradient $\delta_j(n)$ will depend on the location of the processing unit j in the network.

- If the processing unit j is a neuron of the output layer, the local gradient will be given by the product of the derivative of the activation function of the neuron $\varphi'_j(v_j(n))$ and its error signal $e_j(n)$. It should be mentioned that both terms of the product depend only on the processing unit j.
- If the processing unit j is a neuron of a hidden layer, the local gradient will be given by the product of the derivative of the activation function of the neuron $\varphi'_j(v_j(n))$ and the weighted sum of the local gradients of the neuron connected to the unit j that are in the next hidden or output layer.

As the adjustment of the weights in the backward pass of the back-propagation algorithm ends, the forward pass is initiated. The forward pass will end, as mentioned previously, with the calculation of the output vector. This process should be repeated until certain pre-established convergence criterion is met. For example the back-propagation algorithm would stop when the average squared error energy ξ_{av} at certain iteration is under a pre-established threshold.

One important component in the adjustment of the weights in the backward pass is the knowledge of the derivative of the activation function of the processing units. For this derivative to exist, the activation function $\varphi(.)$ used has to be continuous. One of the more commonly used functions, as mentioned earlier, is the sigmoid function. There are two forms of this function which are commonly used, the logistic function and the hyperbolic tangent function. In the following a formula for the local gradient having a logistic activation function, is derived.

- Logistic function: The general form of the logistic function for a neuron j is given by equation (4-28):

$$\varphi_j(v_j(n)) = \frac{1}{1+e^{(-av_j(n))}} \tag{4-28}$$

Where:

- *$v_j(n)$* is the induced local field of neuron *j* at iteration *n*.
- *a* is a constant greater than zero.

Differentiating equation (4-28) with respect to *$v_j(n)$*:

$$\varphi'_j(v_j(n)) = \frac{ae^{(-av_j(n))}}{\left(1+e^{(-av_j(n))}\right)^2} \tag{4-29}$$

By using equation (4-9) another expression for the derivative of the logistic function can be derived as shown in equation (4-30).

$$\varphi'_j(v_j(n)) = \frac{a}{1+e^{(-av_j(n))}}.\frac{e^{(-av_j(n))}}{1+e^{(-av_j(n))}} = ay_j(n).\frac{e^{(-av_j(n))}}{1+e^{(-av_j(n))}} = ay_j(n)(1-y_j(n)) \tag{4-30}$$

For a neuron located at the output layer, where *$y_j(n) = o_j(n)$* the local gradient can be expressed as:

$$\delta_j(n) = a.o_j(n)\left(d_j(n)-o_j(n)\right)\left(1-o_j(n)\right) \tag{4-31}$$

Where:

- *$o_j(n)$* is the obtained output in iteration *n*.
- *$d_j(n)$* is the desired output in iteration *n*.

For a neuron *j* located at a hidden layer, the local gradient will be expressed as,

$$\partial_j(n) = a.y_j(n)\left(1-y_j(n)\right)\sum_k \partial_k(n)w_{kj}(n) \tag{4-32}$$

4.4.2. Heuristics for the Back-Propagation Algorithm

The design of an ANN using the back-propagation algorithm has numerous factors defined by the personal experience of the designer [88]. However there are some methodologies that can help the learning algorithm to perform better. Some of these methods are presented in the following.

- Design of hidden layers:

The design of the hidden layers of a MFN plays a critical role in the success of the back-propagation learning algorithm because they act as feature detectors of the input data. ANN can be designed with a different number of hidden neurons and a different number of hidden layers.

The best design of the hidden layer is usually determined by cross-validation. In this method, the available data set is randomly partitioned into a training set and a test set. The training set is further partitioned into two disjoint subsets:

- Estimation subset: used to select the model.
- Validation subset: used to test or validate the model.

In the learning stage a set of candidate model structures with different numbers of hidden layers and neurons can have their performance checked with the two data subsets mentioned above. During this learning process, the *estimation subset* is used to train the ANN and the *validation subset* to check the network's generalization capability. The chosen network architecture would be the one that achieves the best results according to a certain criterion, for example the ANN that has the smallest average squared error on the estimation subset when the validation learning curve achieves a minimum. Figure 4-10 illustrates the stopping criterion in which the results of each ANN structure should be compared and the best design of the hidden layers determined.

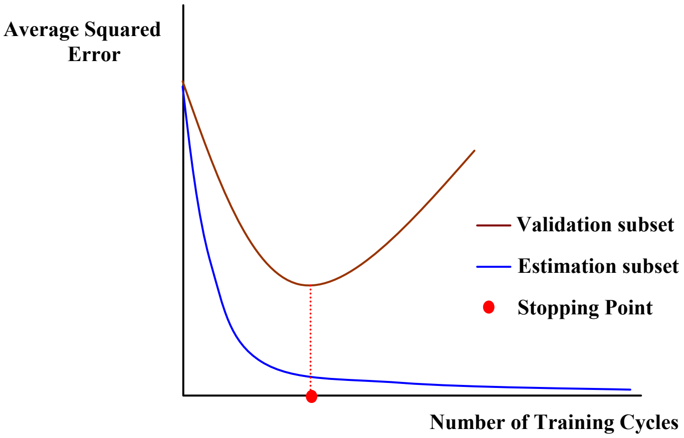


Figure 4-10 Stopping Rule Based on Cross-Validation

Besides determining the best design of the hidden layers, the cross-validation method can also be used to avoid overtraining. Overtraining is a phenomenon where the ANN learns too many input-output examples ending up memorizing the training data. When this phenomenon occurs, the ANN loses its capability to generalize by finding a feature that is present in the training data but not true to the function that is being modeled. In order to avoid the overtraining of the ANN a stopping criterion as the minimum point on the validation learning curve can be used.

There are some practical considerations that also can be used to build the initial set of ANN architecture models to be tested. For example, usually two hidden layers are preferred to one when the classification objective is complex. In the two hidden layer design the *local features* are extract in the first hidden layer, and the *global features* in the second hidden layer.

- Maximizing the information content:

In order to maximize the search through the weight space during the learning process, the training examples should have the largest possible information content. In order to achieve this aim two strategies should be implemented:

- Use of training patterns different from all the previous ones of the set.

- Use of training patterns that generate large training errors.

Another strategy commonly used to increase the search through the weight space is the randomization of the training patterns order of presentation to the ANN in the back-propagation algorithm from one cycle/epoch to another. This technique is used together with the sequential update of the connection weights (pattern by pattern updating) that also improves the performance of the back-propagation learning algorithm.

• Target Values:

In the case of using a sigmoid function as an activation function it is important that the desired output be within the range of this function. Specifically, the desired output should be bounded by a value smaller that the limiting values of the activation function. This strategy will avoid the possibility that the back-propagation learning algorithm takes the processing units of the hidden layers into saturation by driving the free parameters of the network to extremely high values. Figure 4-11 illustrates this method by setting the limiting value of the activation function to $\pm a$, and the desired output to,

$$d_j = a - \varepsilon \tag{4-33}$$

For the limiting value of + a, and

$$d_j = -a + \varepsilon \tag{4-34}$$

for a limiting value of – a.

Where ε is a positive constant and represents a safety margin. In Figure 4-11 the hyperbolic activation function is chosen as an illustration. This function is defined by,

$$\varphi(v) = a \tan\text{h}(bv) \tag{4-35}$$

Where:

- a is a positive constant.
- b is a positive constant.

In this illustration a value for *a* of 1.5 is chosen and a value for *b* equal to 2/3. With the activation function limits established for example, a safety margin ε equal to 0.5 could be chosen, in which case the desired outputs d_j can be set to be equal to ± 1. This choice of activation limits and desired outputs would avoid the slowing down of the back-propagation algorithm and improve its performance.

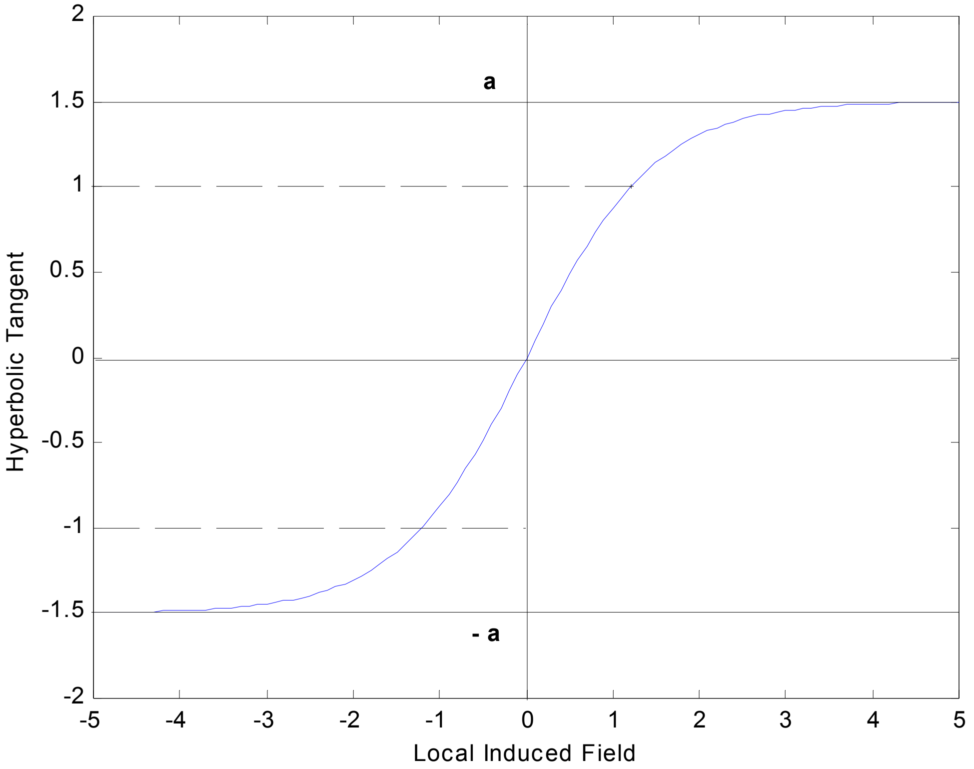


Figure 4-11 Hyperbolic Tangent Function and its Limits

• Training set size for a valid generalization:

An ANN that is able to generalize is a network that is able to correctly classify, unseen testing patterns. One of the major factors that can influence the ANN acquisition of this generalization capability is the size of the training set used in the back-propagation learning algorithm. If the amount of training data is not enough, the ANN will be unable to correctly learn, and when tested with unseen patterns can misclassify. On the other hand, if the ANN learns too many input-output examples, the network may end up memorizing the training data and losing its capability to generalize.

The use of correct amount of training data is very important for the performance of the back-propagation learning algorithm. In practice it seems that for a good generalization the size of the training set should satisfy the condition:

$$\mathrm{N} = O\left(\frac{W}{\in}\right) \tag{4-36}$$

Where:

- W is the total number of free parameters (i.e. synaptic weights and biases) in the network.
- $\in$ denotes the fraction of classification errors permitted on the test data.
- O (.) denotes the order of quantity enclosed within.

For example if a maximum error of 10 percent in the test patterns is permitted the back-propagation algorithm would need a number of training examples about 10 times the number of free parameters in the chosen network.

- Learning rate variations:

Back-propagation can be seen as a hill climbing technique that basically runs through the error surface along the weight dimension looking for a global minimum and being guided by the negative gradient vector. In this technique, as was seen in equation (4-18), the step size of each change in the synaptic weights and the step size of each movement in the error surface is selected among other possibilities by the value of the learning rate parameter. Due to this characteristic, the learning rate is one of the parameters that control the convergence speed of the back-propagation algorithm. In order to increase the convergence speed of the back-propagation algorithm by a learning rate adaptation there are some heuristics that provide useful guidelines. Some of these heuristics are:

- In order to avoid the risk of being trapped in a local minimum of the error surface, the learning rate parameter should be allowed to vary from one iteration to the other. A common practice is to use larger learning rates at the initial stage of the back-propagation algorithm and decrease this parameter to smaller values as the training process progresses.
- An equal learning parameter for the adjustment of all the synaptic weights in a network can slow down the back-propagation convergence. The explanation for this is that while a certain learning rate parameter can be appropriate for the adjustment of one synaptic weight, it may not be appropriate for the adjustment of other synaptic weights of the network. In order to avoid the slowing down of the convergence of the back-propagation algorithm different learning rates should be used for each adjustable synaptic weight.
- The learning rate parameter of a synaptic weight should be decreased if during several consecutive iterations its cost function derivative alternates its sign. This heuristic is applied to a back-propagation algorithm whose error surface exhibits peaks and valleys along the weight of interest. In this case, in order to prevent the learning rate parameter from oscillating and slowing down the convergence of the back-propagation algorithm, an appropriate reduction in its value should be performed.
- The learning rate parameter of a synaptic weight should be increased if during several consecutive iterations its cost function derivative maintains a constant sign. This heuristic is applied to a back-propagation algorithm whose error surface is flat along the weight of interest. In this case, the heuristic will decrease the number of iterations necessary to move across the flat portion of the error surface with an appropriate adjustment in the learning rate parameter.

The above methods can provide significant improvement in the back-propagation learning algorithm performance. These methods provide guidance for the design of ANN when the back-propagation algorithm is to be used. It should be said that personal experience of the user is also important and should be applied to improve the algorithm’s performance.

Chapter 5. Power System Restoration Scheme using Artificial Neural Networks

In chapter 1 were presented the three main organizational principles in PSR. In the same chapter some of the new state of the art PSR techniques proposed to eliminate the existing limitations of the actual restoration procedures and guidelines still in use by the majority of the utilities were discussed. It was also mentioned that these new PSR techniques have obtained good results, however it was seen that there is stillroom for improvements.

In this chapter the characteristics of a PSR scheme based in ANN will be presented. This proposed scheme utilizes the organizational principle *Cooperative Restoration* and ANN techniques to achieve the PSR plan. Following this the load flow program used to check the feasibility of the restoration procedures, the schemes input-output patterns, and an algorithm that determines the switching sequence of the circuit breakers will be discussed. Next will be presented a breadth-first search algorithm used to generate these patterns and to have the results compared to the proposed PSR scheme and the transmission system in which the proposed technique will be tested. This chapter will end with the presentation of the training processes of the ANNs that make up the PSR scheme.

5.1. Description of the Proposed Power System Restoration Scheme

In order to find the restoration plan of a transmission system under a blackout a PSR scheme based on ANN techniques is proposed. The PSR scheme that is proposed is formed by multiple ANNs divided into pairs. Each pair of ANN is built together with a switching sequence program and is responsible for the restoration of an island of the electric power system. Thus each island of the electric power system in the PSR scheme will have a pair of ANNs together with the switching sequence program called *Island Restoration Scheme* (IRS). As mentioned earlier the IRS is responsible for the restoration plan development of its respective island. The restoration of the electric power system will be done in each island in parallel, with the re-connection of the tie lines being made only after all islands are restored. Each IRS of the PSR scheme will receive only local data (data from its respective island) and will only develop local restoration plans. An illustration of an IRS is shown in Figure 5-1.

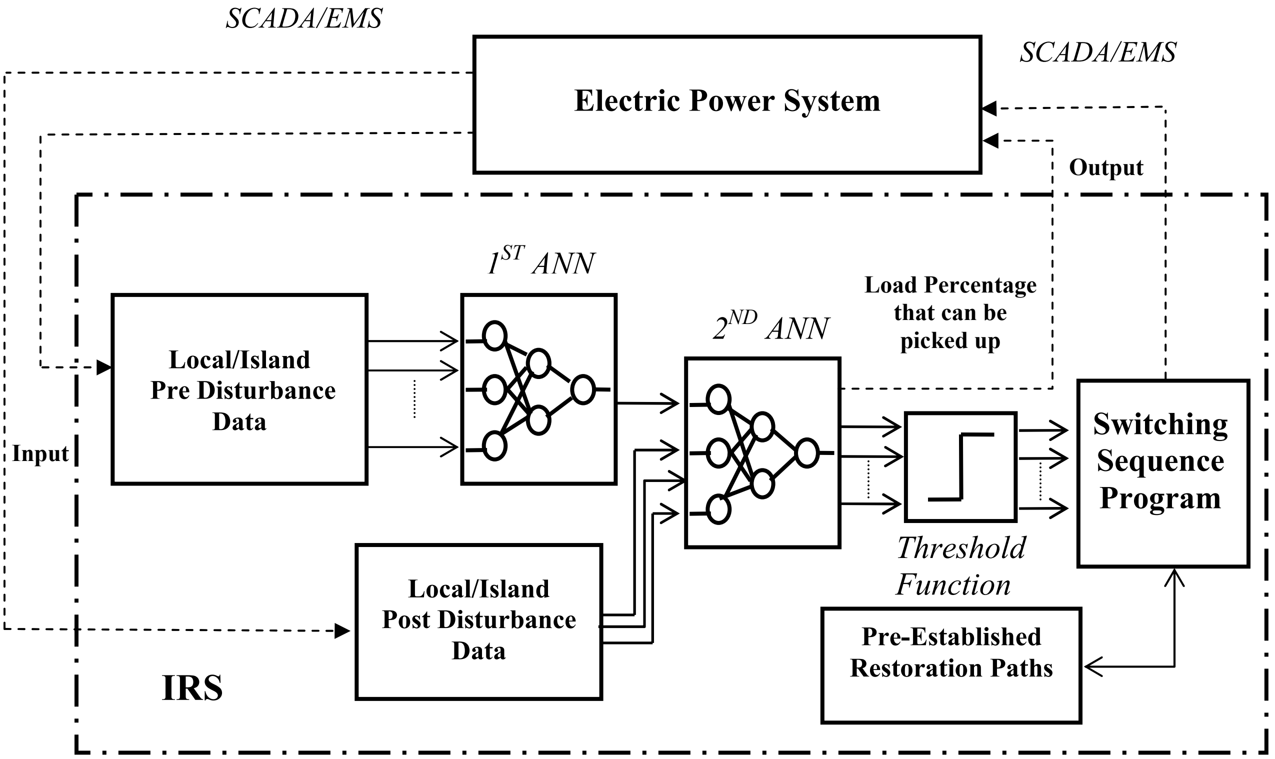


Figure 5.1 Island Restoration Diagram Block Scheme

From Figure 5-1 it can be seen that the input data of the IRS is composed of local post and pre disturbance data. The output data of the IRS is composed by a switching sequence vector and the percentage of load that can be picked up with that configuration. This input/output composition will be addressed in more detail in latter sections, however it can be stated that each IRS will develop a local restoration plan based only on pre and post disturbance information for the area. The restoration plan of each island is developed by its respective IRS, and consists of a switching sequence of its circuit breakers and the percentage of the forecasted restoration load that can be picked up in the final configuration generating a feasible island state. In this research it is assumed that the transmission system in which the PSR technique is going to be applied was affected by a wide area disturbance (blackout), and has used the *all open* switching strategy in which all circuit breakers of the system are open. Under this condition this electric power system can be considered to be as a union of multiple electric islands. These electrical islands would be formed under the reactive and real power balance constraints mentioned in chapter 2. Also due to the needs of interconnection assistance provided by the of tie lines discussed in chapter 2 it will assumed that the tie lines of each island will remain open during the parallel restoration process. In Figure 5-2 the New England 39-bus system divided into two electrical islands after the occurrence of a wide area disturbance is shown. Also it is assumed that due to a permanent fault, the line between buses 4 and 3 is considered unavailable for the restoration plan development.

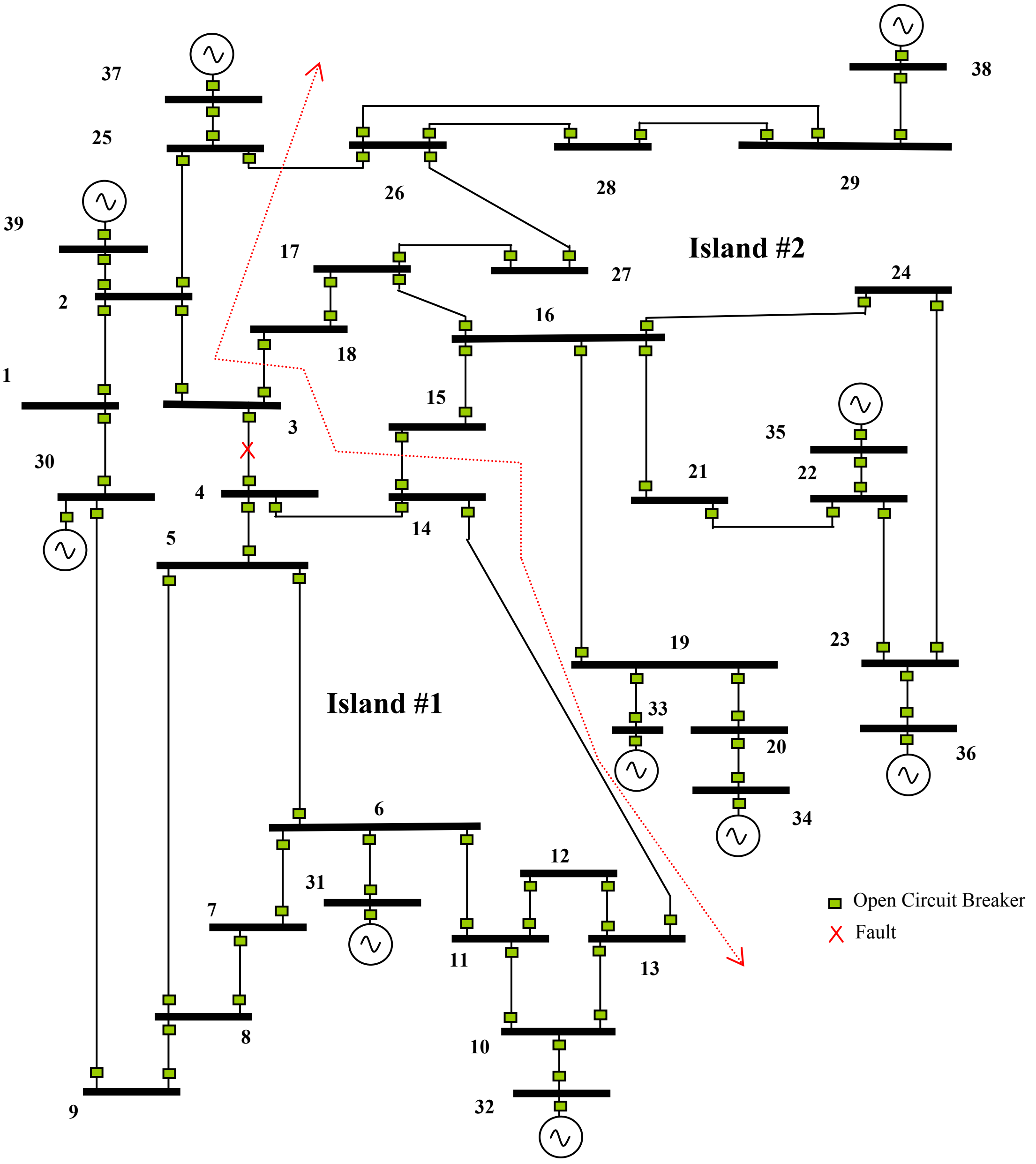


Figure 5.2 New England 39-Bus Transmission System

It can be seen from the Figure 5-2 that all of the circuit breakers of the 39-bus system are open after the occurrence of the blackout. The two electric islands of the system are pre-defined and generated according to real/reactive load/generation balance. For the 39-bus system shown in the Figure 5-2, the proposed PSR scheme would be composed of two IRSs. Each ISR would be responsible for the restoration plan development of its respective island. The tie lines between buses 18-3, 26-25 and 15-14 will not be considered as available lines for the development of the restoration plan by the IRSs because of possible problems discussed in chapter 2. These lines, as mentioned before, will only be closed after the two electric islands are restored. The faulty line between buses 4-3 will also not be considered as an available transmission line by the IRS schemes because the line is supposedly under a permanent fault condition. After each IRS develops a restoration plan for its respective island, the implementation of each plan would then occur in parallel.

Two ANNs and one switching sequence program make up each IRS. The IRS begins to develop the restoration plan of its respective island by first receiving data form the electric power system through the Supervisory Control and Data Acquisition System and the Energy Management System.

The EMS is a computer system that collects measurements from the electric power system performs state estimation, displays the system state for the system operator(s) and processes this data with the use of other real-time control. The SCADA system is the simplest form of an EMS that only collects data from the electric power system and presents it to the system operator(s). The SCADA system allows the system operator(s) to change the operational condition and the system configuration of the electric power system by entering commands manually or automatically as appropriate. The role of the SCADA system is illustrated in Figure 5-3.

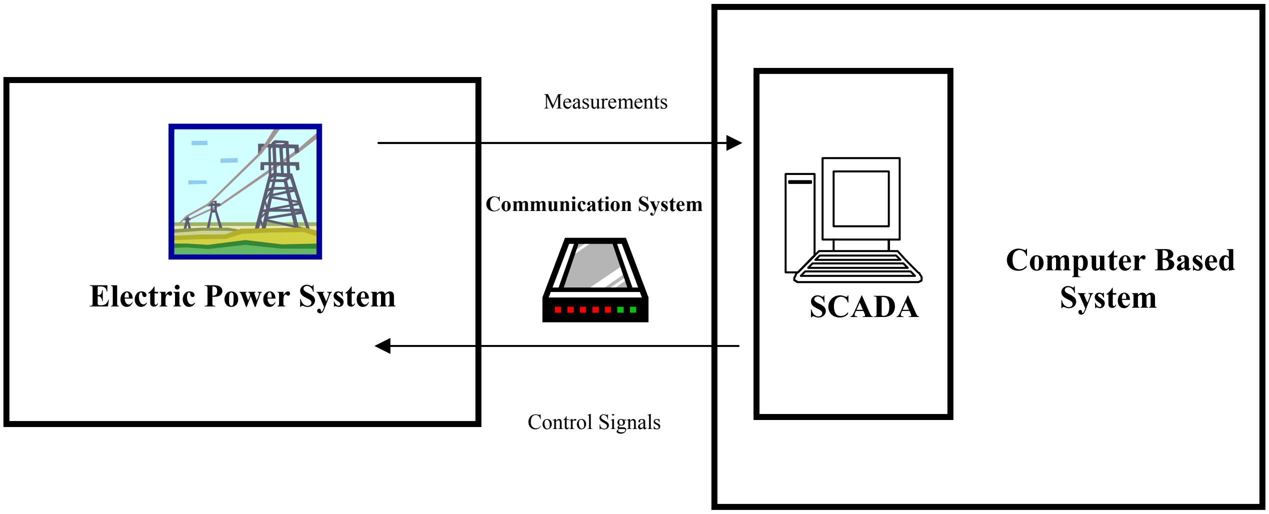


Figure 5.3 The SCADA System for the Electric Power System

From Figure 5-3 it can be seen that the control actions (opening and closing of circuit breakers; adjusting power generation, etc…) are initiated by the system operator to change the state of the power system and are implemented through the SCADA which sends corresponding control signals via communication systems to the controllers in the power system.

The EMS is an advanced system which performs several key control center functions. The EMS possesses the transmission data capability and algorithms that can process the huge amount of data obtained from the electric power system and perform system analysis tasks. Due to these characteristics the EMS can be viewed as a system utilizing data from SCADA that performs applications with this data and presents the output of the application to the EMS operator. Figure 5-4 illustrates the philosophy behind the EMS.

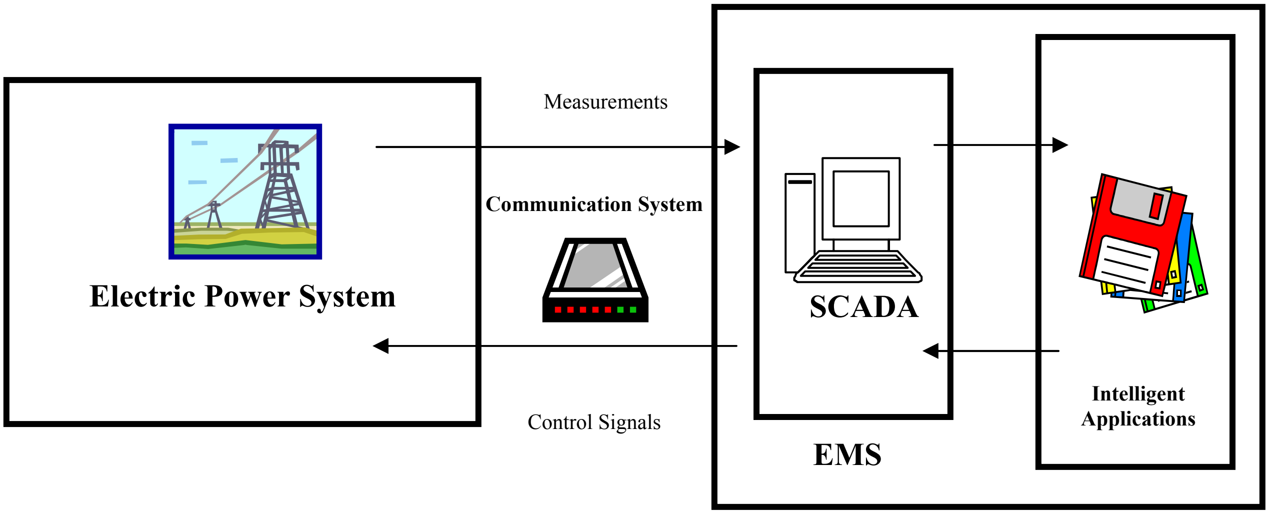


Figure 5-4 The EMS for the Electric Power System

The EMS can include several different types of applications. These applications will process the data obtained by the SCADA system in different ways and generate different enhanced system outputs for the EMS operator. Typical applications include the following:

- Computation of the electric power system state as complex voltage vector representing the amplitude and relative angle differences between various bus voltages and active and reactive power flow in the transmission lines.

- Estimate of the quality of the measurements obtained from the SCADA system.

- Complete power flow information of the electric power system at the time when measurements were obtained.

- Advanced graphical presentation of the electrical power system state and near-term predicted state.

- Computation of possible changes in generation and voltage levels of the electric power system that would reduce the total network losses and generation costs of the system.

The EMS is designed to guide and help the operator to manage the electric power system under the constraints that the electric utilities have to satisfy. During normal operation of the electric power system the objective of the advanced functions of EMS are to help the system operator to manage the system in an optimum way by implementing necessary changes.

The EMS can also be designed to help the system operator to restore the electric power system to a feasible operating condition following the occurrence of a wide area disturbance. During an emergency condition such as the occurrence of a blackout, the EMS can present to the system operator a power system restoration plan. In order to provide the system operator with a feasible restoration plan it is proposed that the PSR scheme developed in this dissertation be a part of the EMS of the electric power system serving as one more advanced EMS application.

As mentioned earlier, after receiving the data from the electric power system, some of the applications of the EMS will process this data and make available to the system operator enhanced information. Besides providing the system operator with system information in a graphical display, the enhanced information will also be used by each IRS of the proposed PSR scheme in case a wide area disturbance is experienced. In this case, the ANNs of each IRS will use part of the enhanced information generated by the applications functions of the EMS to develop a local PSR plan.

After the computation of the enhanced information from the applications of the EMS the PSR scheme can be launched if a wide area disturbance occurs.

Two ANNs and a switching sequence program constitute each IRS. The 1st MFN of each IRS is responsible for a local restoration load forecast (LRLF). During early stages of power system restoration it is very important to determine the amount of load power demand (cold load pickup) following the system outage, as discussed in chapter 2. As mentioned earlier, the knowledge of this amount of load is extremely important because of its direct relationship to the PSR plan creation. It should be remembered that if the reconnection is made in less than 10 minutes following a blackout the connected load will draw almost normal current from the electric power utility. In this research it is assumed that the local CLPU equals the load before the outage. This approximation is an acceptable approximation as discussed in chapter 2.

The 1st MLN of each IRS will be responsible for the LRLF of its respective island. This MLN will use as an input the pre disturbance load pattern to develop the LRLF. The output of the 1st MLP of each IRS, representing the LRLF, will be a scalar value associated with possible local load patterns. The detailed characteristics of the input/output patterns of each ANN of each IRS will be discussed in later sections. In the Figure 5-5 an ANN representing the 1st MLN of each IRS is illustrated.

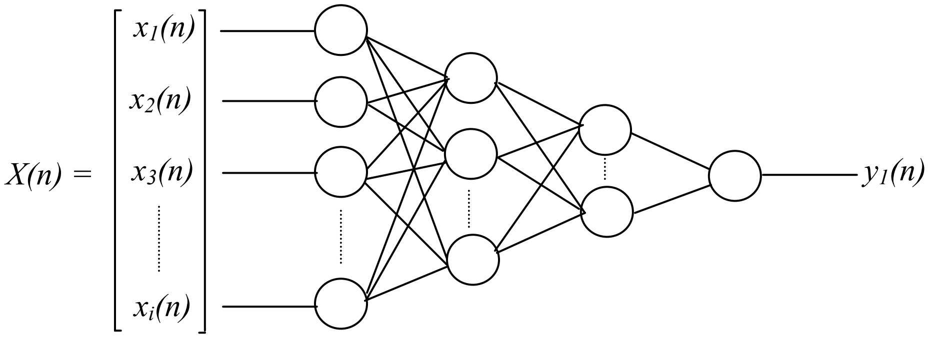


Figure 5-5 ANN responsible for the Local Restoration Load Forecast

In Figure 5-5, the vector *X(n)* represents the normalized pre disturbance local load pattern number *n*. This input vector *X(n)* will have a number of elements equal to the total number of loads of the respective island. In the case of the illustration in Figure 5-5 this number would be equal to *i*. The output of the ANN shown in Figure 5-5 is a scalar value represented by $y_1(n)$. This value, as mentioned before, is associated with the pre disturbance system operating condition and represents a forecast of the expected restoration local load pattern.

The second major component of each IRS is another ANN. With reference to Figure 5-1, the 2nd ANN of the illustration is responsible for the assignment of the respective paths (transmission lines, transformers, etc…) that should be energized, considering the power system restoration constraints discussed in chapter 3, and generating a local system restoration configuration. Also, this 2nd ANN will be responsible for a maximum local load pickup percentage that will generate a feasible operating condition for the restoration configuration of the chosen island. The local load pickup value assigned by the 2nd ANN of the IRS represents a percentage of the pre disturbance local load that can be picked up generating a feasible system operating condition for the chosen local system restoration configuration. The number of output elements in the output vector of this ANN will be equal to the number of transmission paths of the respective island plus one. As can be seen in Figure 5-1, a vector with four elements composes the input of this ANN. The first element of the input vector of the 2nd ANN of the IRS is equal to the output of the 1st ANN of the same IRS. This scalar value, as mentioned earlier, represents a forecast of the expected load. The second, third and fourth elements of the input vector of the 2nd ANN are normalized values that are provided from the EMS application algorithms. These values, as indicated in Figure 5-1 are post disturbance data and will indicate the local transmission paths that are unavailable and should not be considered for use in the final system restoration configuration. The transmission paths that cannot be available for use in the power system restoration plan when the system is undergoing a wide-area disturbance are unavailable mostly due to the occurrence of permanent faults. In the following table is presented the result of a ten-year study of permanent faults in a 500 kV transmission system [92].

Table 5-1 Permanent Faults in a 10-year span in a 500kV Transmission System

FAULTY EQUIPMENTS	*NUMBER OF FAULTS*
Transmission Lines	82
Voltage and Current Transformers	6
Circuit Breakers	4
Buses	1
Generators	1

From Table 5-1 it can be observed that permanent faults in transmission lines are the most common types of permanent faults in electric power equipment. Of course the explanation for this is the physical spread of transmission lines [93].

The 2nd ANN of each IRS will use the location of the possible unavailable transmission paths as input information in order to avoid their use in the final system restoration configuration. In Figure 5-6 an illustration of the 2nd ANN and a fully connected MFN used by each IRS is presented.

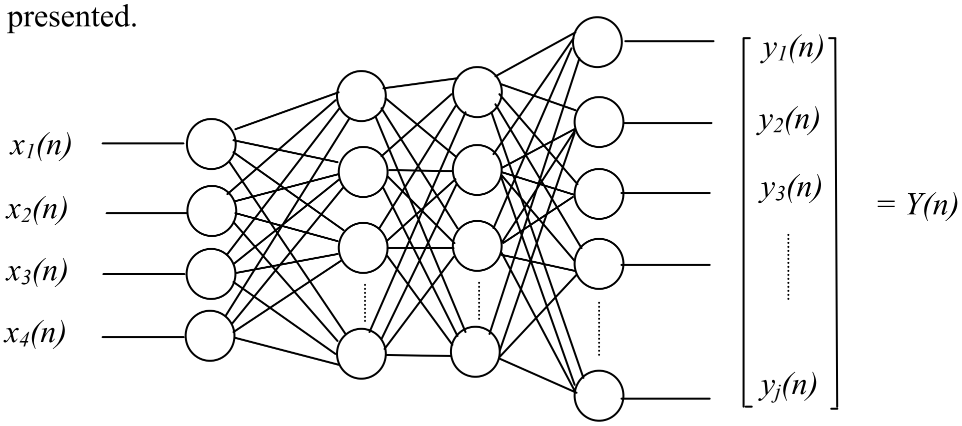


Figure 5-6 ANN responsible for the Final System Restoration Configuration

The number of elements in the output vector of the 2nd ANN of the IRS will depend on the size of the respective island, while the input pattern of the network will always be composed of four elements. As mentioned before, the first element of the input vector will correspond to the forecast of the local restoration load pattern. The three other elements of the input vector will correspond to the normalized buses between which an unavailable transmission path exists and the respective normalized unavailable transmission path number.

As seen in Table 5-1, the majority of permanent faults that occur in an electric power system are on the system transmission lines. A fault locator algorithm installed at the EMS will generate the information concerning the unavailable transmission paths. A commonly used technique for fault location at transmission level is known as the Takagi technique [94].

The Takagi fault location technique uses complex phasors from one terminal to calculate the fault location on the transmission line. In Figure 5-7 an illustration of a transmission system under a permanent symmetric fault is presented.

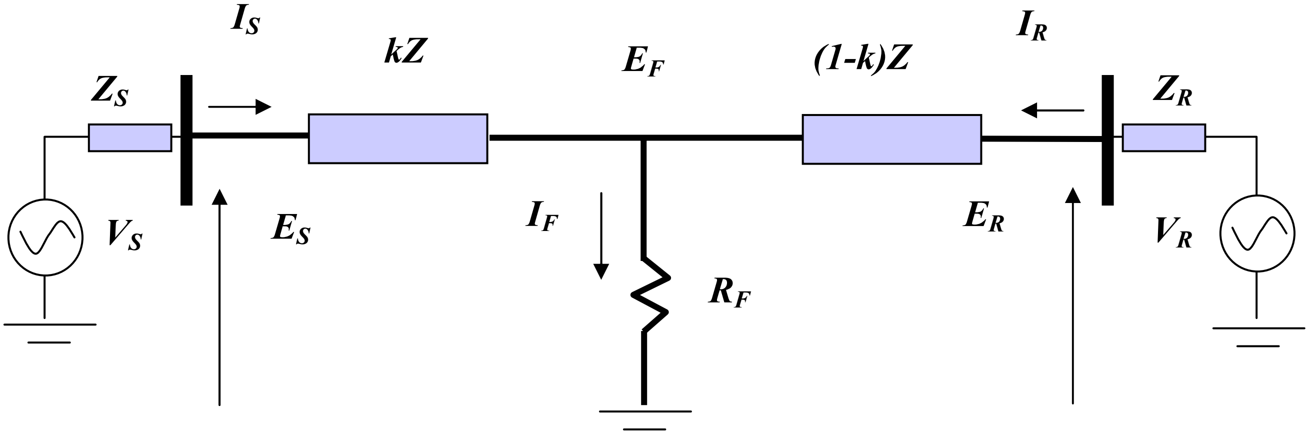


Figure 5-7 Transmission System under a Permanent Symmetric Fault

In Figure 5-7, the quantities I_S, I_R and I_F represent the phasor currents at the sending end, the receiving end and at the fault respectively. In the same illustration, the quantities E_F, E_S, E_R, Zs, Z_R, V_R and V_S represent the voltage phasor at the fault, the voltage phasor at the sending end bus, the voltage phasor at the receiving end bus, the complex impedance of the equivalent system behind the sending end bus, the complex impedance of the equivalent system behind the receiving end bus, the Thevenín voltage of the system behind the receiving end bus and the Thevenín voltage of the system behind the sending end bus respectively. The objective of the technique is to calculate the fault distance from the sending end bus represented by the parameter *k*. This fault distance is seen as a fraction of the total transmission line impedance *Z*. By using a loop equation:

$$E_s = E_F + I_F kZ = I_S kZ + I_F R_F \tag{5-1}$$

Assuming that the fault current I_F is proportional to the change in the sending end terminal current (ΔI_S) by a factor *d*,

$$I_F = d\Delta I_S \tag{5-2}$$

This leads to,

$$E_s = I_S kZ + d\Delta I_S R_F \tag{5 - 3}$$

Using the assumption made in equation (5-2) another representation of the transmission system under a permanent fault can be derived, and is shown in Figure 5-8.

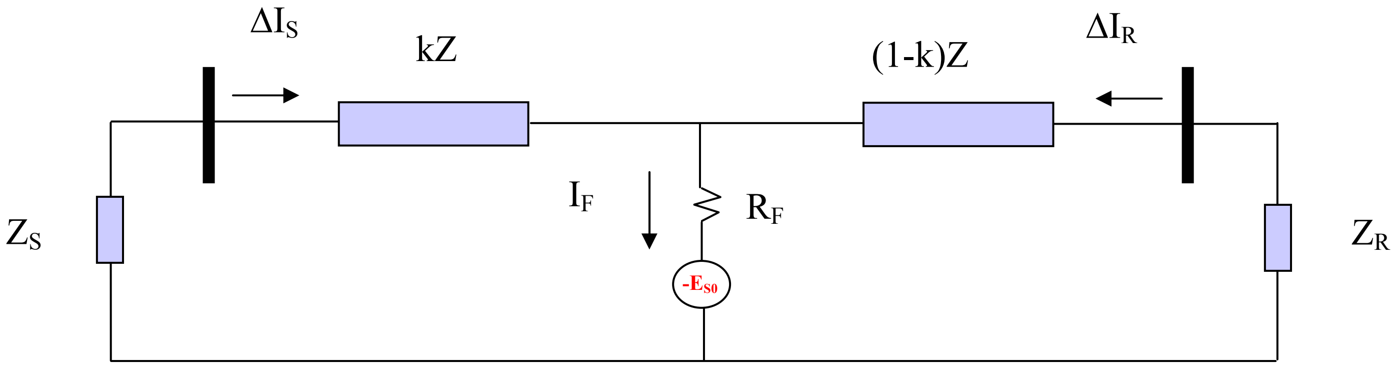


Figure 5-8 Transmission System Under a Permanent Fault with Proportionality Assumption

Now, using a current division formula for the circuit represented by Figure 5-8 it can be seen that,

$$\Delta I_s = I_F \frac{Z_R + (1-k)Z}{Z_R + Z_S + Z} \tag{5 - 4}$$

$$d = \frac{Z_R + Z_S + Z}{Z_R + (1-k)Z} \tag{5 - 5}$$

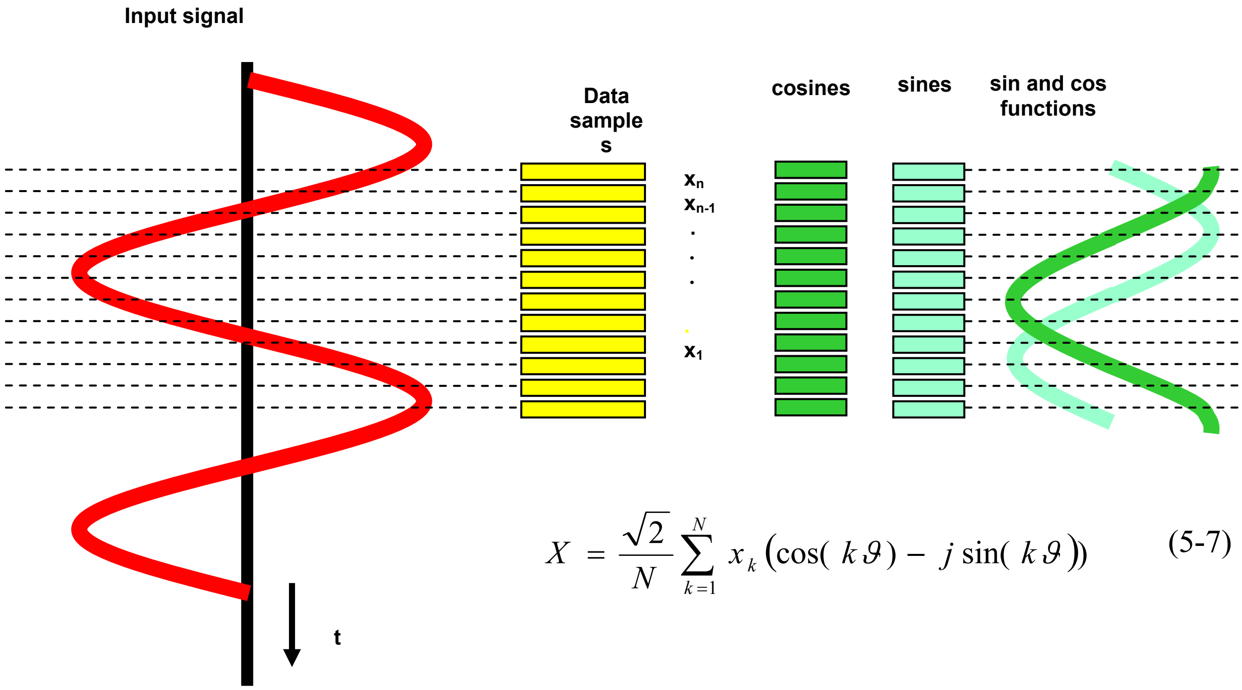
Assuming that the proportionality factor *d* is real an equation for the fault distance *k* it can be derived,

$$k = \frac{E_{Sr}\Delta I_{Si} - E_{Si}\Delta I_{Sr}}{\left(RI_{Sr} - XI_{Si}\right)\Delta I_{Si} - \left(XI_{Sr} + RI_{Si}\right)\Delta I_{Sr}} \qquad (5\text{-}6)$$

Where:

- E_{Si} and E_{Sr} are the sending end imaginary and real post-fault voltage phasors.
- I_{Si} and I_{Sr} are the sending end imaginary and real post-fault current phasors.
- X and R are the imaginary and real part of the total transmission line impedance.
- ΔI_{Si} and ΔI_{Sr} are the changes in the sending end current imaginary and real parts.

As can be seen from equation (5-6), in order to find the fault distance it is only necessary to calculate certain pre and post fault phasor quantities. The more common technique to calculate phasors is the Discrete Fourier Transform (DFT) [95]. An illustration of this technique is shown in the following figure.



$$X = \frac{\sqrt{2}}{N}\sum_{k=1}^{N} x_k\left(\cos(k\vartheta) - j\sin(k\vartheta)\right) \qquad (5\text{-}7)$$

Figure 5-9 One Cycle Discrete Fourier Transform

From Figure 5-9, it can be observed that the fundamental frequency phasor X is calculated by a sum of N cosine and sine terms. The sample data x_n is separated by ϑ radians. A common value for this angle is 30 degrees, or a sampling frequency of 720 Hz for a 60Hz system. This angle is called the sampling angle and considering a period T of the sampled signal with N samples per cycle, is equal to,

$$\vartheta = \frac{2\pi}{N} \tag{5-8}$$

The use of a smaller number of samples in order to decrease the processing time of the phasor calculations is an option considered by many algorithms. However, the decrease in the processing time for phasor calculations that the use of a smaller number of samples provides comes together with a reduced precision in the phasor calculation. In the next figure this relationship is illustrated.

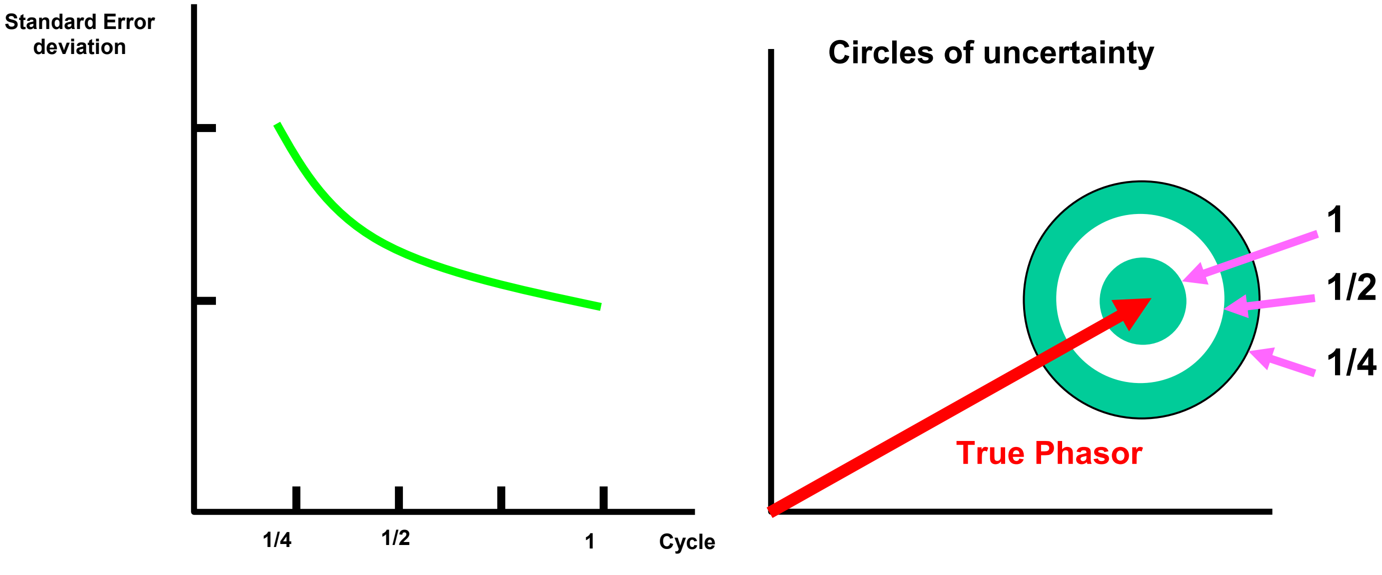


Figure 5-10 Number of Samples and Phasor Representation Relationship

The One Cycle DFT uses double the number of samples than the Half-Cycle DFT. As can be seen from Figure 5-10, as the number of samples used in the phasor calculation decreases, the precision of the phasor calculation also decreases. Thus the selection of the number of samples to be used in the phasor calculation by the DFT used by the Takagi fault location algorithm should be based upon a choice between desired processing speed and desired calculation precision.

Having chosen the DFT type, the calculation of the fault distance can be realized using the Takagi technique. The algorithm of this technique, as mentioned before, will be a part of the EMS of the system of study, and together with other application functions would identify the unavailable transmission paths, information that will be used by the 2nd ANN of each IRS.

The third and the last component of each IRS is the switching sequence program. This program will provide to the system operator the switching sequence of circuit breakers in order to achieve the local restoration configuration chosen by the 2nd ANN of the IRS. The input of this program, as shown in Figure 5-1, is composed of part of the output of the 2nd ANN of the respective IRS.

Details of the switching sequence program (SSP) will be given in later sections. However it can be stated that this third component of the IRS will generate the switching sequence of the circuit breakers based on the restoration configuration chosen by the 2nd ANN and a database containing pre-established restoration paths.

Restoration paths of the respective island will make up the database used by the SSP of each IRS. The restoration paths of the database are pre-established feasible transmission path sequences. Each of these restoration paths of the database connects one island generator to one island load using a minimum number of transmission segments (transmission lines and transformers). The database of the SSP will be generated off line. In order to check the feasibility of the paths, a load flow program will be run for each path, and the achieved operating conditions checked. In Figure 5-11 an illustration of an SSP is presented.

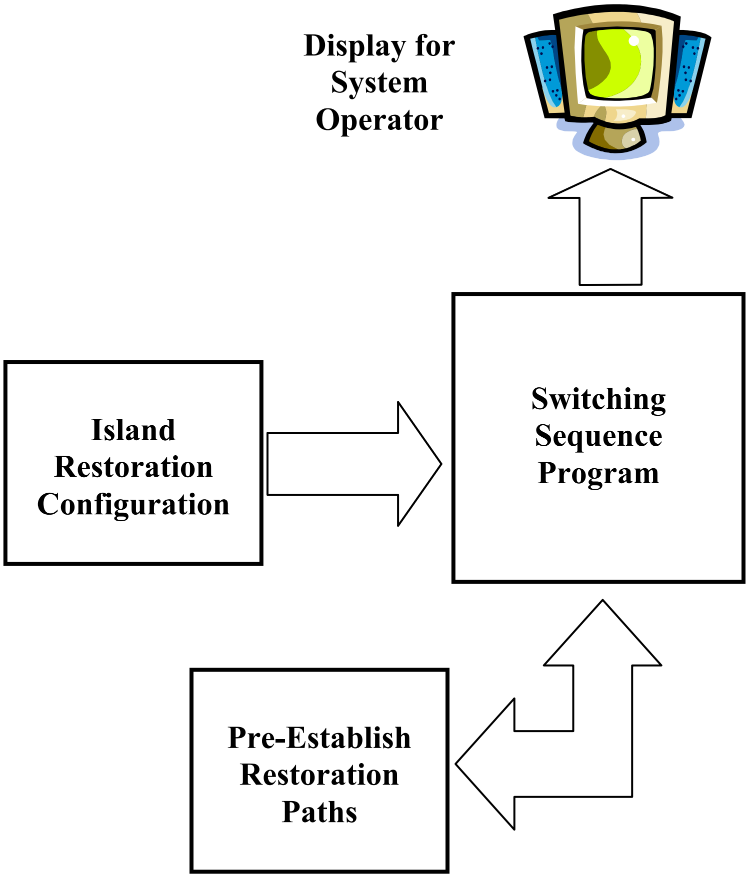


Figure 5-11 Switching Sequence Program Diagram Block

The viability of an operating state of a power system configuration is an important part of the database building of the SSP and the generation of training and validation patterns of the ANNs. The feasibility of an operating condition can be determined with the help of a load flow program. Given a certain system with a tentative initial operating condition, a load flow program will try to determine the load flow solution (complex bus voltages, real and reactive power flow) of the system. The load flow solution of a system contains an operating state that satisfies the non-linear equations and voltage/power constraints that mathematically model the network. In the next section the load flow problem and the load flow program used will be discussed.

5.2. Load Flow Analysis

Load Flow Solution is a power system jargon used for the steady state solution of an electric power network. An electric power network can be mathematically modeled by a set of non-linear equations. The solution of this set of equations does not differ essentially from the solution of any set of non-linear equations, the only exception is that certain constraints are peculiar to electric power systems [96].

The load flow analysis for a certain electric power system under a desired operating condition is a simulation of this system, through mathematical equations, that will provide the real and reactive power flow through the system and the voltage and angles of all its buses. This information will determine if any equipment of the power system is operating under unacceptable conditions or violating any constraints. If this is the case it will be said that the desired operating condition of this electric power system is unfeasible. In the case that no such violation occurs, it will be said that the desired operating condition for the electric power system is feasible [97].

The two methods which are commonly used for the load flow analysis are the Gauss-Seidel and the Newton-Raphson method.

With the entire load flows calculated and the voltages determined it is then possible to check for operating constraint violations as overloaded equipment, bus undervoltages or overvoltages and maximum angle differences allowed. If none of these values are violated, the operating condition is considered feasible.

In this research a load flow software called *ANAREDE* [98] was used. This load flow program uses the *Newton-Raphson Method* to solve the non-linear equations. This program was used in the database building of each SSP and the training and validation pattern generation for the ANNs of each IRS. The program was also used in testing of results generated by the IRS.

5.3. Input/Output Data

It was mentioned earlier that several IRSs will make up the proposed PSR scheme and that this scheme would be installed at the EMS of the system center control under study. It was also discussed earlier that each IRS would be responsible for the restoration plan development of a specific pre-defined island of the power system. In earlier sections two ANNs and a switching sequence program for each IRS were described. In this section will be described with details the input/output patterns of each of the components of the IRS.

5.3.1. Artificial Neural Network for Restoration Load Forecast

The first ANN of each IRS is responsible for a restoration load forecast. As shown in Figure 5-1 the input data of this ANN will be composed of a local island pre disturbance data. The input data of the first ANN of each IRS will be obtained by the SCADA system and will be made up of the normalized pre disturbance real power demanded from all load buses. The normalizing factor used to limit the input data between the range of [0-1] was the maximum island real power demand among all the data sets (several pre distribution operating conditions). The normalization factor is pre-determined by offline studies. This preprocessing of each input variable was done in order to increase the back-propagation learning algorithm performance by allowing a quicker convergence.

Also as shown in Figure 5-1, the output pattern generated by the first ANN of the IRS will be a scalar. This output value will quantify a load configuration pattern expected during the power system restoration implementation. As mentioned in earlier sections, it will be assumed that the expected restoration load pattern will be equal to the pre disturbance load pattern. Thus the scalar output of the first ANN of the IRS will contain information about the load restoration location and also about their respective MW values.

5.3.2. Artificial Neural Network Restoration Plan Builder

The second ANN of each IRS will be responsible for the island restoration plan builder. The restoration plan is specified by a final island restoration configuration and by a load pickup restoration percentage value. The input of this ANN will be a vector with four elements. The first element of the input vector is the restoration load forecast value generated by the first ANN as shown in Figure 5-1. The other three input elements will be normalized values representing possible transmission paths unavailable for use in the power system restoration plan. In case that there is an unavailable transmission path in the island, the three values are obtained by normalizing the pre-determined bus numbers between which the unavailable transmission path is encountered and by normalizing the pre-determined transmission path number. The buses and transmission paths numbers are encountered and defined in the system data file. The buses of the electric power system of study and the transmission paths are assigned numbers corresponding to their physical position in the network. The normalizing values are determined by off-line studies. The normalizing values are selected as the highest bus number value and highest transmission path number of the island. This normalizing process will limit the three elements between the range [0-1]. This preprocessing of each input variable was again done in order to increase the back-propagation learning algorithm performance by allowing a quicker convergence.

The output of the second ANN of the each IRS is a vector. The components of this vector, besides the last component, represent the transmission path status during the final system restoration configuration. If the transmission path (transmission line or transformer) is to be energized in the restoration plan implementation, the output associated with this path will be assigned a value of 1. If the transmission path is not to be used the associated output value will be assigned a zero value. The last element of the output vector of the ANN represents the forecasted restoration load percentage that the chosen system configuration can pick-up generating a feasible operating condition. This restorable load percentage generated by the second ANN provides a value that will determine the amount of load in each bus that can be restored. In order to find the load that each island load bus can pick-up, the percentage value should be multiplied by the forecasted restoration load of the bus generated by the first ANN of the IRS.

5.3.3. Switching Sequence Program

The third component of the IRS is a program that determines the sequence of transmission path energization. As shown in Figure 5-11, this program will use as input the chosen final restoration system configuration generated by the second ANN of the IRS and a database with all pre-established island restoration paths.

As mentioned earlier, each restoration path of the database contains a feasible pre-established energization sequence of transmission paths connecting a certain generator to a certain load. The sequence of energizing transmission paths is tested off line for operational feasibility with the use of a load flow program and is generated using a breadth-first search algorithm.

The energization sequences connecting buses with generation to the highest priority loads are selected to be the first sequences of the database. This position of the energization sequences of transmission paths connecting generator buses to the highest priority loads in the database is due to the switching sequence program search strategy. The programs search strategy is a top-down one. With this strategy, the program searches in the database for energizing sequences that only contain transmission paths used in the final restoration tree (system configuration) generated by the 2nd ANN. Due to the search strategy of the program, the first sequences used to generate the final energizing sequence of transmission paths will be the ones connecting the generating units to the highest priority loads. In this way, the loads that will be first restored will be the ones defined as having highest priority. More details of the switching sequence program will be given in later sections.

The output of the switching sequence program will be a vector representing an energizing sequence of transmission paths that will lead to the final restoration tree generated by the 2nd ANN. This information, together with the forecast restoration load will be presented to the system operator in the EMS environment.

5.4. Switching Sequence Algorithm

The number of switching sequence programs in the proposed PSR scheme will depend on the number of IRS making up the scheme. As mentioned before each IRS will have a SSP to generate an energizing sequence of transmission paths in order to restore the system. The SSP of every IRS will have the same strategy to build a switching sequence of transmission elements. In Figure 5-12 the block diagram of the switching sequence algorithm is presented.

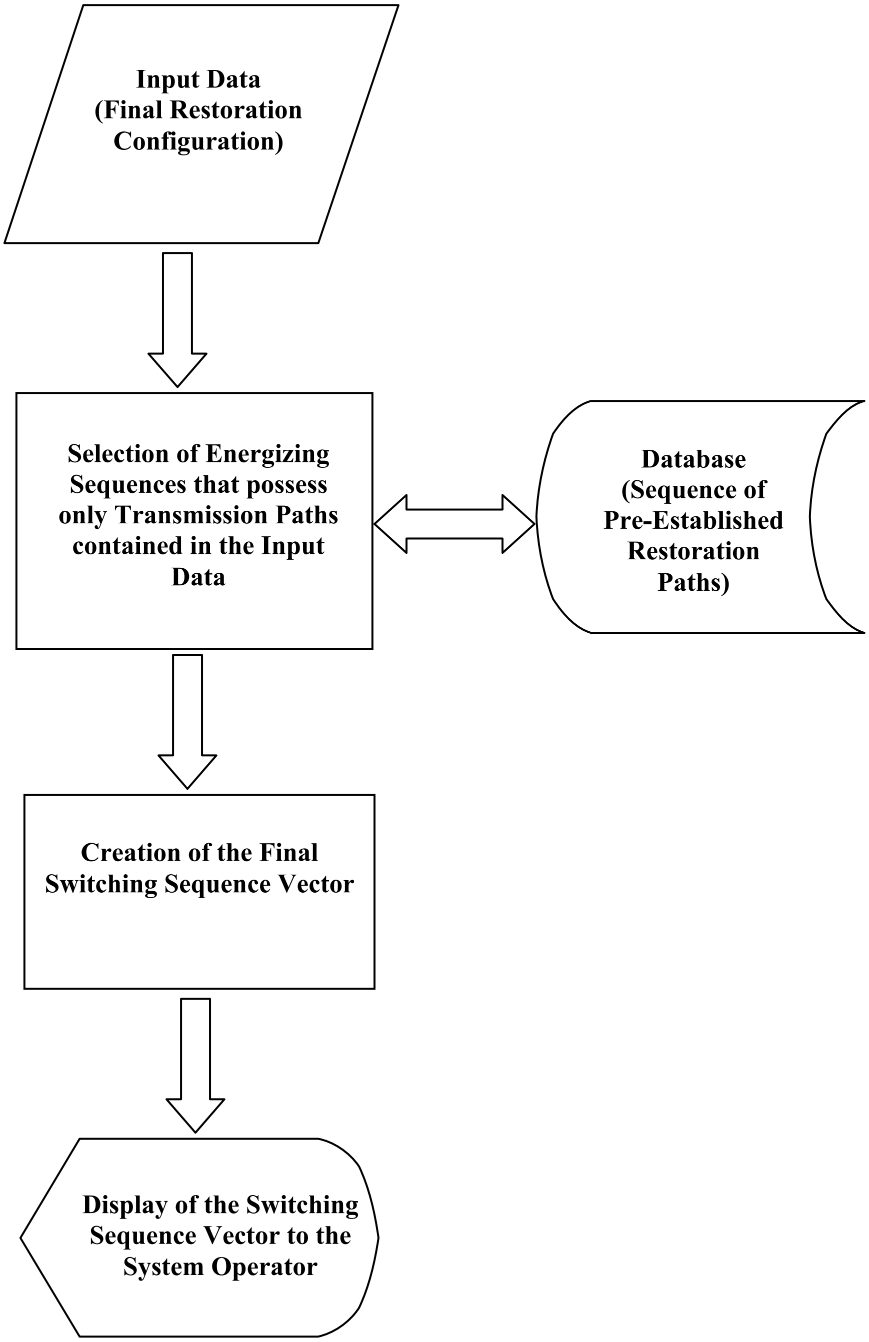


Figure 5-12 Block Diagram of the Switching Sequence Program

With the input vector (final restoration system configuration) furnished by the 2nd ANN of the IRS the SSP can be initialized. The first process that the program performs is to identify the sequences of the database that only possess transmission paths present in the final system restoration configuration represented by the input vector. After identifying these sequences and storing them into a matrix, the program then starts to create the final switching sequence by including the first identified energization sequence of the matrix (energizing sequence for the highest priority load) into a vector that will represent the restoration switching sequence. All the transmission paths from the sequence included in the switching sequence vector are identified in order to the avoid transmission path repetitions. The next step taken by the program is to restore another load by checking if all the transmission paths of the following sequence have been already included in the switching sequence vector. In case that the sequence possesses paths not previously included, these transmission paths will be included in the restoration switching sequence vector avoiding a repetition of paths. This process will be repeated until all paths of the input vector are included in the restoration switching sequence vector, i.e., the system restoration configuration is obtained by a set of switching sequences represented in the generated vector.

The final vector obtained by the program contains an energization sequence of transmission paths that will lead to the final system restoration configuration generated by the 2nd ANN of the respective IRS. The elements of the output vector furnished by the SSP are scalar numbers associated with transmission paths of the respective island. The association of scalar numbers to the transmission paths and buses of the transmission system of study is done off-line and before the PSR scheme is implemented. After the SSP obtains the restoration switching sequence vector, the result is presented to the system operator together with the load percentage pick-up through the EMS.

5.5. Study System

In order to test the PSR scheme's capability the 162 bus Iowa reduced transmission system was used as a sample test system [99,100]. The transmission test system possesses 21 generators, 103 loads and 284 transmission elements (transmission lines and transformers). The transmission system data is shown in appendix A. Due to its size, the transmission system of study will be considered as the union of 10 electric islands, which means that 10 IRS (one for each electric island) will make up the proposed PSR scheme. These islands will be interconnected via normally closed tie lines, and were pre-defined in accordance with the generation/load power balance. With the occurrence of a wide area disturbance, these tie lines will remain open until the parallel restoration of all the electric islands is completed. The first electric island that makes up the test transmission system is called *Island #1*. This Island is illustrated without its tie lines in Figure 5-13.

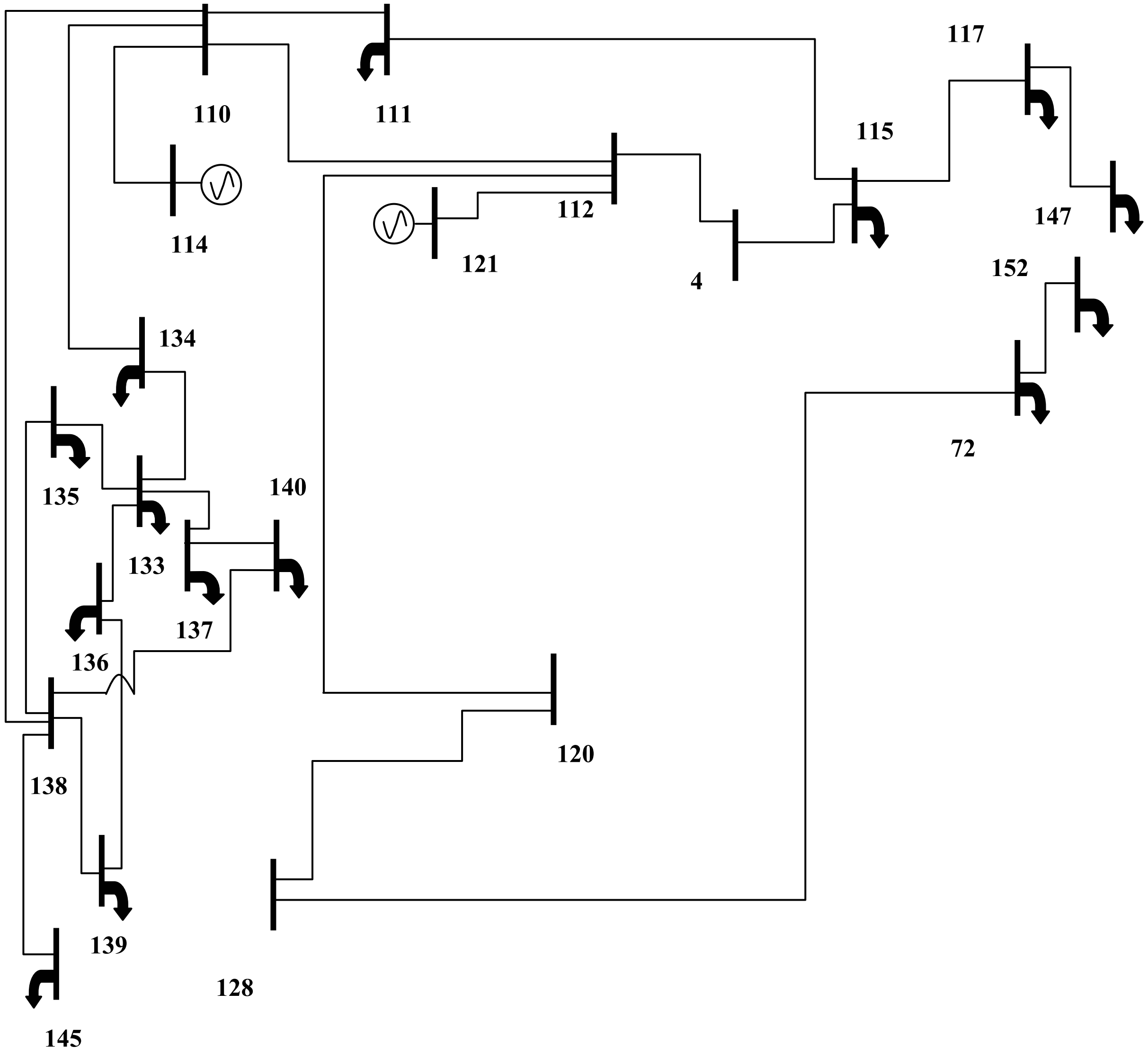


Figure 5-13 One Line Diagram of Electric Island #1

As can be seen in Figure 5-13, Island #1 has 14 loads, 2 generators and 25 transmission paths. In table 5-2 the transmission paths numbers that will be used in the islands IRS are presented.

Table 5-2 Transmission Paths of Electric Island #1

Bus	*Bus*	*Transmission Path Number*
110	111	221
111	115	226
110	112	222
110	138	254
112	120	227
120	128	237
110	134	224
72	128	245
133	134	247
4	112	14
133	135	248
135	138	251
133	136	249
138	139	255
138	140	256
136	139	252
4	115	15
133	137	250
137	140	253
115	117	231
138	145	257
72	152	174
117	147	235
112	121	228
110	114	223

The second electric island that makes up the transmission test system is called *Island #2*, and is illustrated without its tie lines in Figure 5-14. Three generators, 7 loads and 26 transmission paths constitute this electric island.

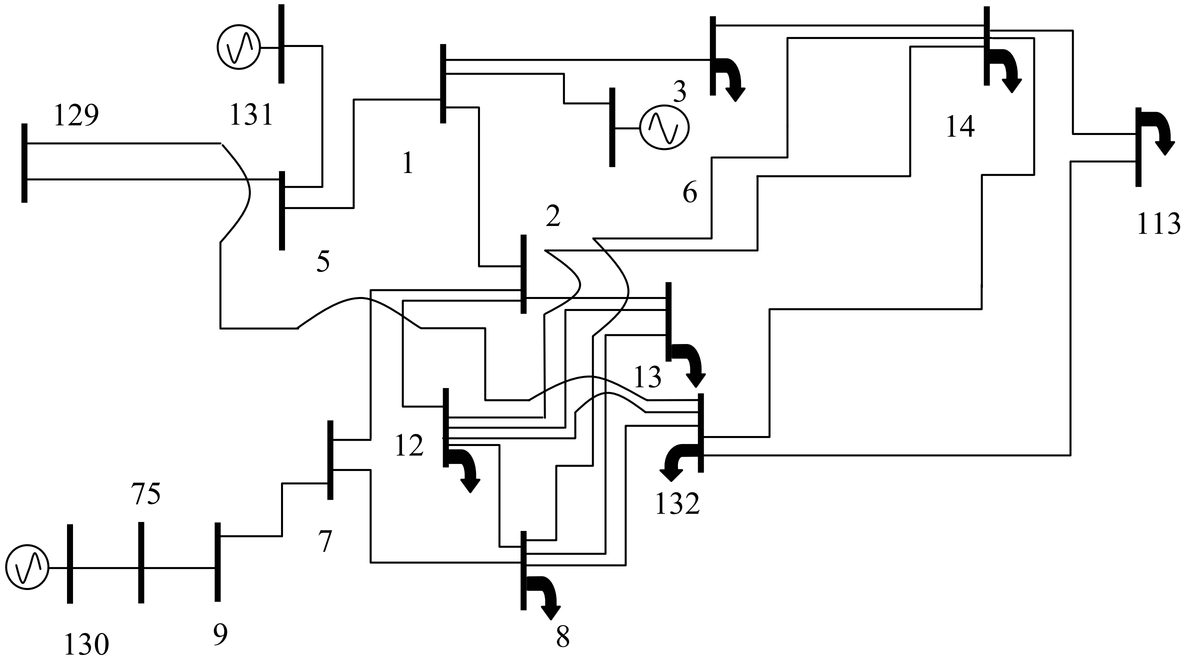


Figure 5-14 One Line Diagram of Electric Island #2

Table 5-3 presents the transmission path numbers that will be used in the island's IRS.

Table 5-3 Transmission Paths of Electric Island #2

Bus	*Bus*	*Transmission Path Number*
1	3	2
1	5	4
5	129	18
129	132	246
2	7	6
8	12	23
2	12	37
8	14	25
12	132	40
12	13	38
1	2	1
12	14	39
7	8	20
8	13	24
8	132	27
3	14	8

2	13	7
4	113	44
113	132	229
14	132	45
7	9	21
9	75	28
75	130	177
9	75	28
1	6	5
5	131	19

The third electric island that makes up the transmission test system is called *Island #3* This Islands is illustrated without its tie lines in Figure 5-15. Two generators, 4 loads and 16 transmission paths make up this electric island.

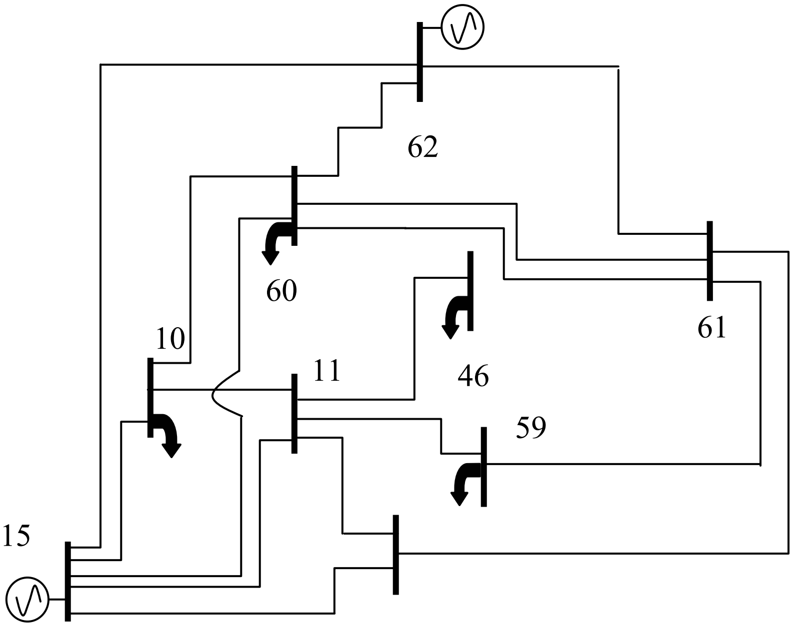


Figure 5-15 One Line Diagram of Electric Island #3

Table 5-4 presents Island #3 transmission path numbers that will be used by its respective IRS.

Table 5-4 Transmission Paths of Electric Island #3

Bus	*Bus*	*Transmission Path Number*
10	60	32
10	11	29
10	15	31
15	62	48
11	46	34
15	58	46
11	58	35
11	59	36
15	60	47
11	15	33
60	62	149
58	61	145
61	62	152
59	61	146
60	61	147
60	61	148

The fourth electric island that composes the transmission test system is called *Island #4*. This Island is illustrated without its tie lines in Figure 5-16. Two generators, 8 loads and 18 transmission paths make up this electric island.

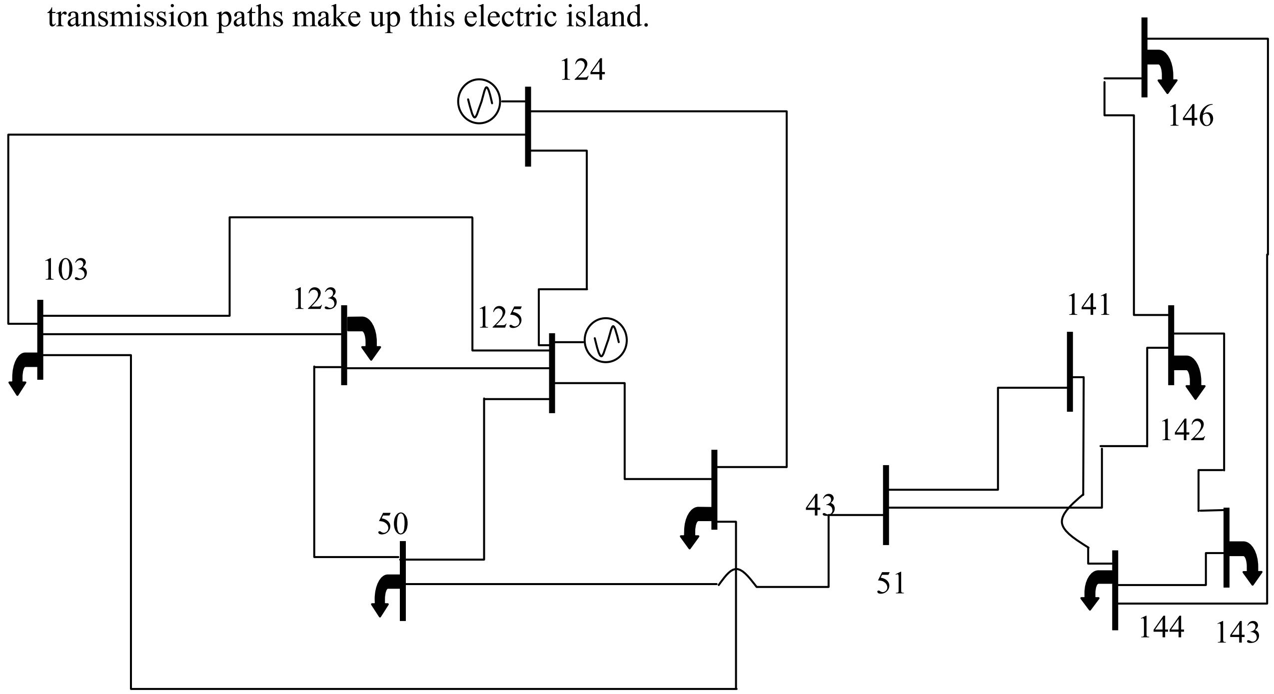


Figure 5-16 One Line Diagram of Electric Island #4

Table 5-5 presents Island #4 transmission path numbers. Its respective IRS will use these associated numbers.

Table 5-5 Transmission Paths of Electric Island #4

Bus	*Bus*	*Transmission Path Number*
103	124	212
103	125	213
123	125	240
124	125	241
50	125	128
103	123	211
43	103	113
43	124	114
43	125	115
50	123	127
50	51	126
51	141	129
144	146	264
142	146	260
142	143	259
51	142	258
143	144	261
141	144	262

The fifth electric island that makes up the transmission test system is called *Island #5*. This island is illustrated without its tie lines in Figure 5-17. Five generators, 11 loads and 30 transmission paths make up this electric island.

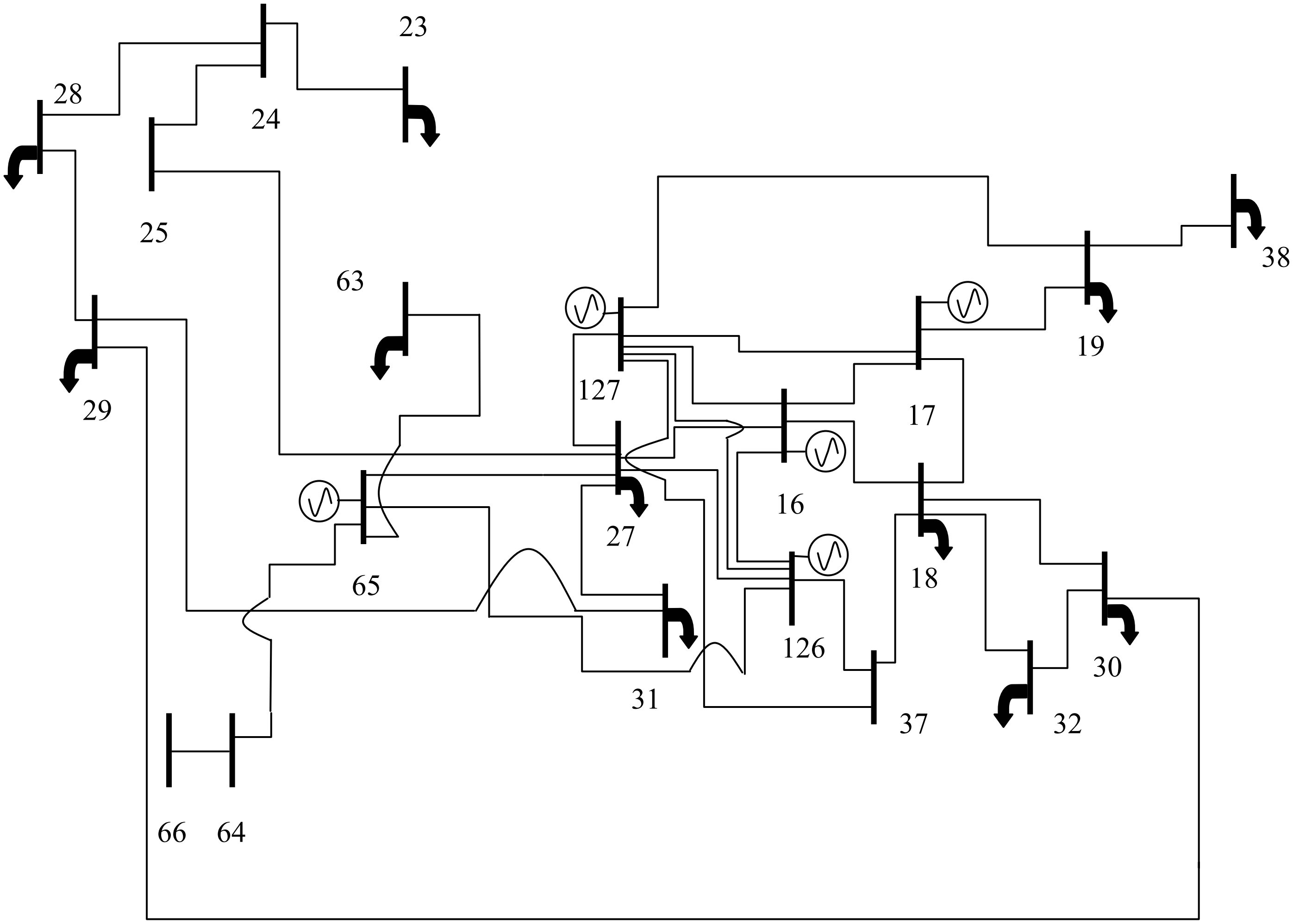


Figure 5-17 One Line Diagram of Electric Island #5

Table 5-6 shows the transmission line path's associated number.

Table 5-6 Transmission Paths of Electric Island #5

Bus	*Bus*	*Transmission Path Number*
17	19	56
29	31	92
27	31	84
65	126	160
27	126	88
37	127	104
17	18	55

16	17	50
27	65	86
37	126	103
16	126	53
16	27	52
28	29	90
24	25	76
30	32	93
24	28	77
18	37	61
18	32	60
19	38	63
23	24	74
18	30	59
19	127	65
25	27	80
17	127	58
16	18	51
16	127	54
27	127	89
63	65	157
29	30	91
126	127	244

The sixth electric island that makes up the transmission test system is called *Island #6*. It is illustrated without its tie lines in Figure 5-18. Two generators, 15 loads and 26 transmission paths make up this electric island.

Table 5-7 presents the transmission path numbers. The associated numbers will be used by the IRS to identify the paths. These numbers are also used to train the ANNs and develop the SSP.

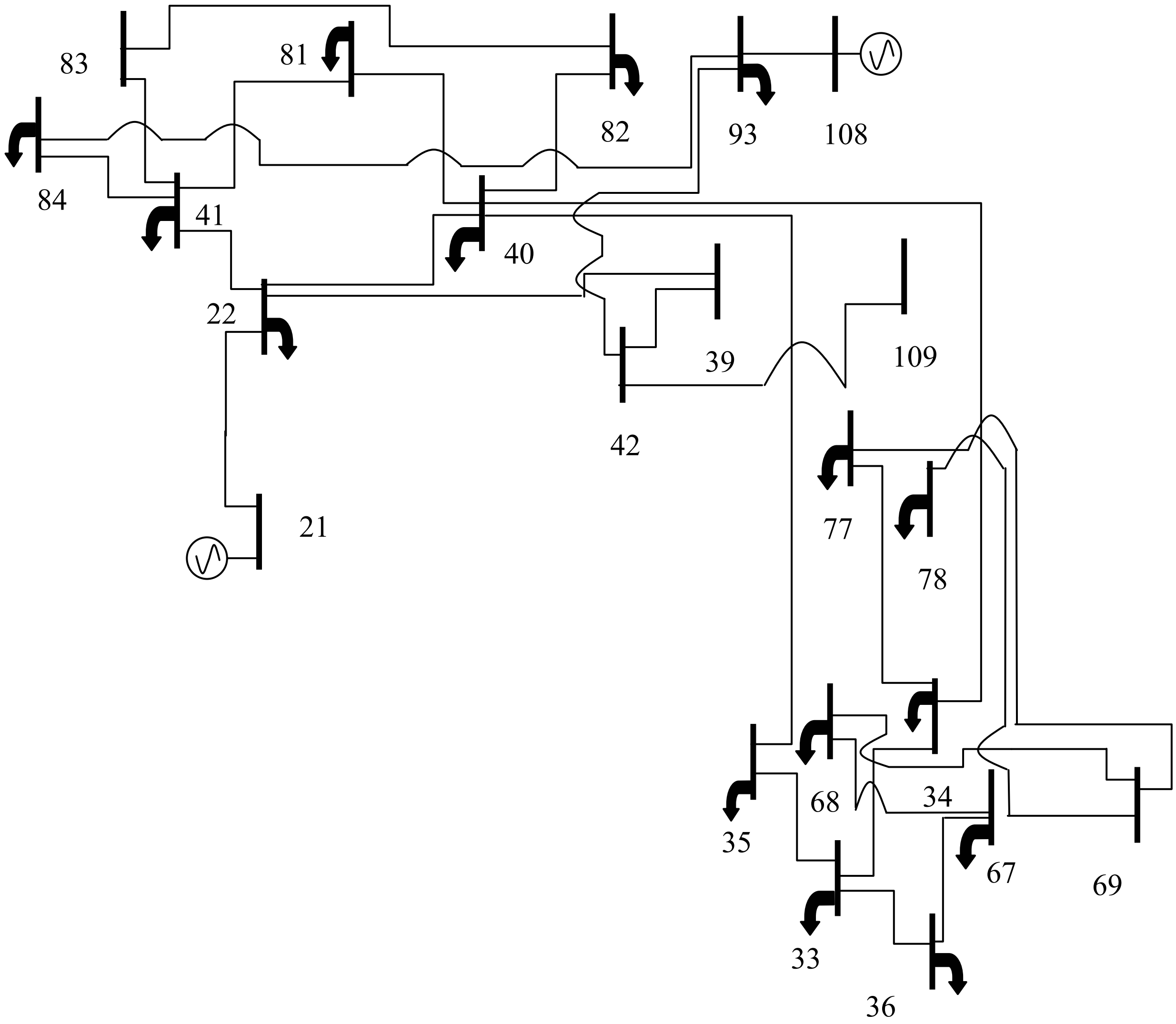


Figure 5-18 One Line Diagram of Electric Island #6

Table 5-7 Transmission Paths of Electric Island #6

Bus	*Bus*	*Transmission Path Number*
82	83	181
41	83	109
27	31	84
22	39	71
39	42	105
42	109	111
34	40	98
40	81	106
42	93	195
35	40	100

41	81	108
22	40	72
67	68	162
34	77	99
33	35	96
36	67	101
33	36	97
68	69	163
40	82	107
33	34	95
69	77	164
69	78	165
22	41	73
41	84	110
93	108	196
21	22	68

The seventh electric island that composes the transmission test system is called *Island #7*. This Island is illustrated without its tie lines in Figure 5-19. One generator, 17 loads and 29 transmission paths make up this electric island. Table 5-8 presents the transmission path numbers.

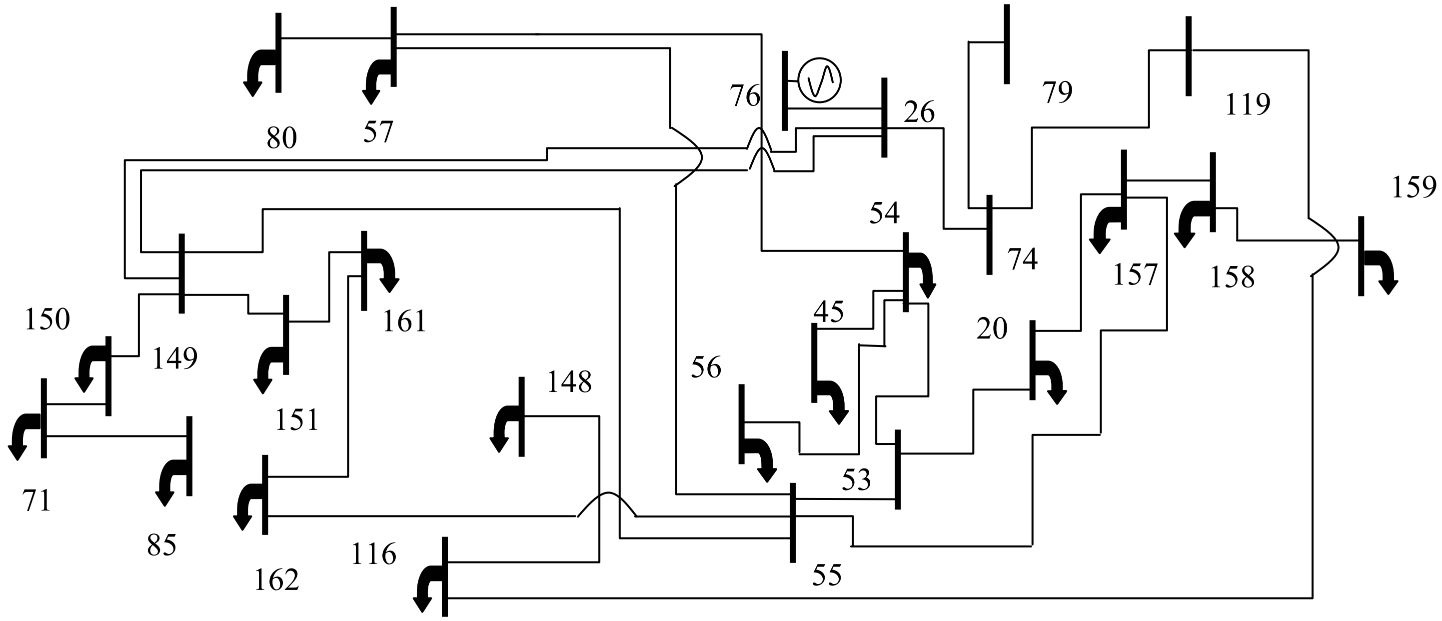


Figure 5-19 One Line Diagram of Electric Island #7

Table 5-8 Transmission Paths of Electric Island #7

Bus	*Bus*	*Transmission Path Number*
45	54	118
54	56	138
55	57	140
53	55	137
55	157	280
53	54	136
158	159	282
20	157	67
74	119	175
157	158	281
26	74	81
20	53	66
44	149	141
55	162	142
57	80	144
71	85	170
54	57	139
71	150	171
149	151	269
161	162	284
149	150	268
116	148	265
151	161	271
74	79	180
116	119	233
26	149	267
26	149	266
26	76	83

The eighth electric island that makes up the test transmission system is called *Island #8*. This Island is illustrated without its tie lines in Figure 5-20. As in the case of other electric islands, this island configuration was chosen due to its generation/load balance. Two generators, 13 loads and 16 transmission paths make up this electric island. Table 5-9 presents the transmission path numbers.

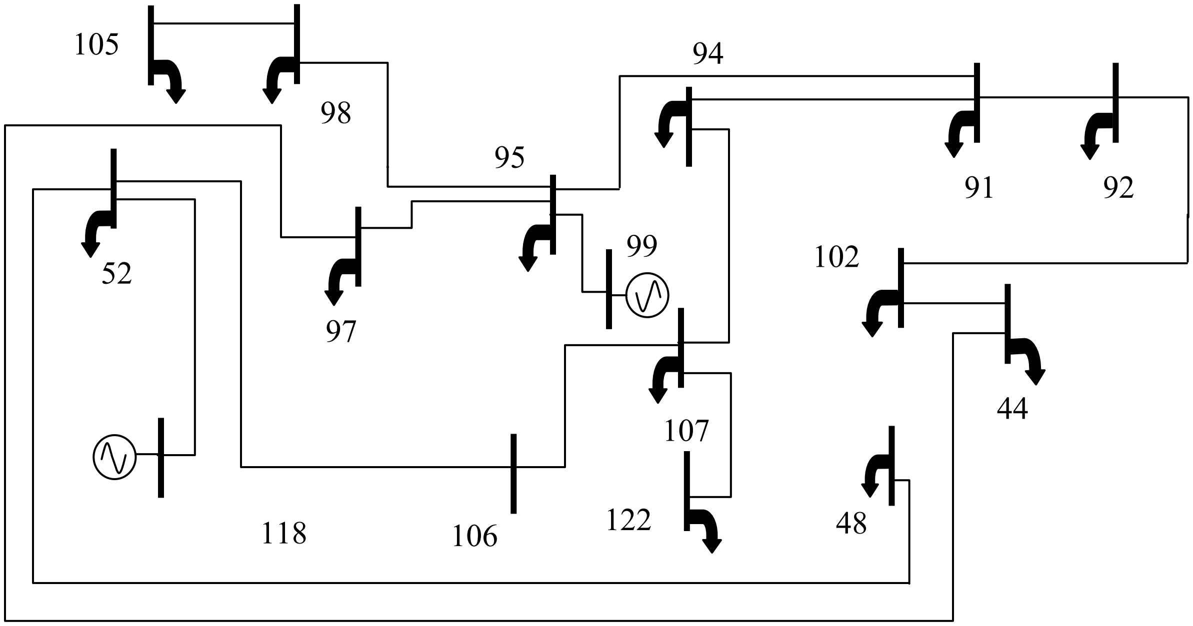


Figure 5-20 One Line Diagram of Electric Island #8

Table 5-9 Transmission Paths of Electric Island #8

Bus	*Bus*	*Transmission Path Number*
91	94	193
44	97	207
91	95	200
91	92	191
94	107	198
106	107	216
107	122	217
95	98	203
95	97	202
98	105	209
52	106	131
44	102	116
92	102	194
52	118	134
95	99	204
48	52	124

The ninth electric island that makes up the test transmission system is called *Island #9*. This Island is illustrated without its tie lines in Figure 5-21. One generator, 5 loads and 8 transmission paths make up this electric island. Table 5-10 presents the transmission path numbers.

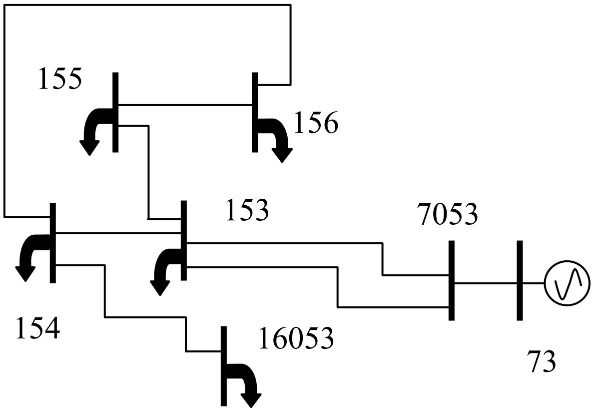


Figure 5-21 One Line Diagram of Electric Island #9

Table 5-10 Transmission Paths of Electric Island #9

Bus	*Bus*	*Transmission Path Number*
155	156	278
153	155	275
153	154	274
154	156	276
154	160	277
70	153	272
70	153	273
70	73	167

The tenth electric island that makes up the test transmission system is called *Island #10*. This Island is illustrated without its tie lines in Figure 5-22. One generator, 9 loads and 11 transmission paths make up this electric island. Table 5-11 presents the transmission path numbers.

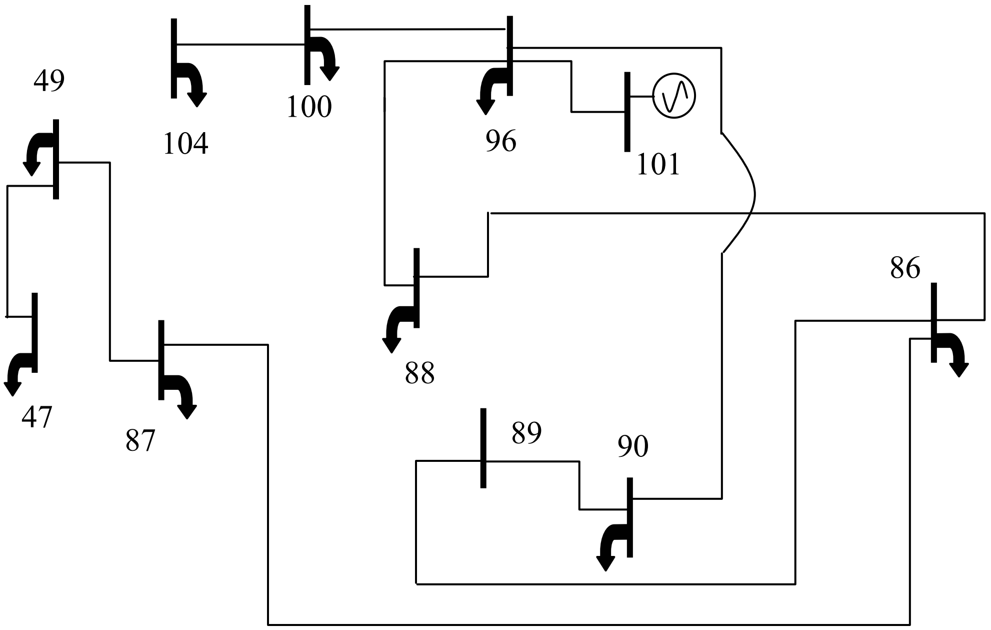


Figure 5-22 One Line Diagram of Electric Island #10

Table 5-11 Transmission Paths of Electric Island #10

Bus	*Bus*	*Transmission Path Number*
91	94	193
44	97	207
91	95	200
91	92	191
94	107	198
106	107	216
107	122	217
95	98	203
95	97	202
98	105	209
52	106	131
44	102	116

Under normal system operation, the ten electric islands previously presented will be interconnected through normally closed transmission tie lines forming one whole connected electric system. However, for restoration considerations it is more suitable to treat the transmission system as a union of isolated electric islands. The explanation for this consideration is that under a wide area disturbance the majority of the PSR schemes, including the one proposed here, suggest that the transmission system should restore its electric connections by reenergizing first its isolated electric islands in parallel. After restoring its electric islands, the tie lines can then be closed reconnecting the complete transmission system. Under these considerations, 10 IRS will make up the proposed PSR scheme. Each IRS will be created independently, however the PSR scheme is considered as the union of these IRS and will be installed as one in the EMS of the control center of the transmission system.

5.6. Breadth-Search Algorithm

A PSR breadth search algorithm was implemented in order to create island restoration configurations. The PSR breadth search algorithm was used together with the load flow program ANAREDE to create the training and validation patterns for the 2nd ANNs of each of the 10 IRS of the PSR scheme. The program was also used to provide processing time estimates of the PSR plan development that were later compared to the processing times of the proposed PSR scheme.

The PSR breadth search algorithm will generate output vectors that represent final restored system configurations of each island of the test system. To generate these island configurations the program takes into account the system structure, the number of transmission paths used, the generation capability of each machine and the load demands at each bus. The island configurations generated by the program do not guarantee that the resulting restored system is able to pick up 100% of the load, even if in the program simulation all loads are energized. Since the program does not take into account load flow constraints, some islands configurations will not be able to pick up the entire load. In order to find the percentage of load that can be picked up, the island configuration generated by the program will be tested in the load flow software ANAREDE. In Figure 5-23 the block diagram of the PSR breadth search algorithm is presented.

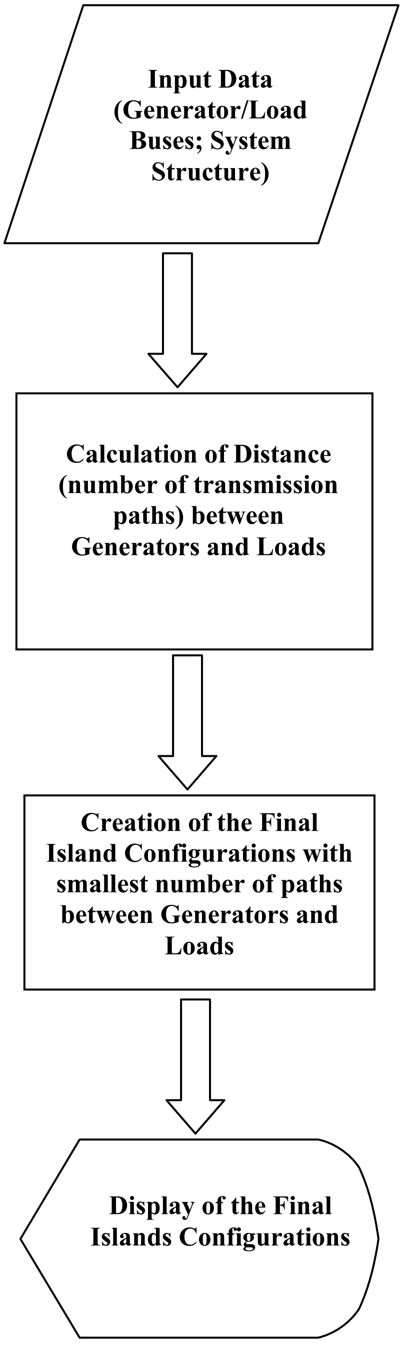


Figure 5-23 Block Diagram of PSR Breadth-Search Algorithm

The PSR breadth search algorithm uses as input three files. The first file possesses the generators bus numbers and their respective generation capability. This file will provide to the program the generation location in the transmission system and their respective capability. Table 5-12 illustrates this input file.

Table 5-12 Input Generation File Information

Bus Number	*Generation Capability (MW)*
6	913
15	280
16	94
17	116.5
21	69.8
62	365.6
65	26.3
73	147
76	655
99	450
101	380
108	650
114	281
118	490
121	720
124	271
125	488
126	520
127	152.6
130	700
131	575

The second input file used by the breadth search program contains the load bus numbers and their respective value. This file will provide to the program the location of the loads in the transmission system and their size. Table 5-13 illustrates this input file. The third input file used by the program contains the bus numbers and the transmission path numbers between them. This third file will provide to the program the actual transmission system structure. This file will contain only available paths for use in the restoration plan. Thus, unavailable transmission paths and transmission tie lines will not be provided as available paths in the file. Tables 5-2 through 5-11 illustrate the information contained in the third input file of the breadth search algorithm.

Table 5-13 Input Load File Information

Bus #	*Load (MW)*	*Bus #*	*Load (MW)*	*Bus #*	*Load (MW)*	*Bus #*	*Load (MW)*	*Bus #*	*Load (MW)*
3	370	38	14.8	72	427	102	16.5	143	21.1
8	398	40	52.9	77	26.4	103	322	144	12.4
10	226	41	39.2	78	79.1	104	31.5	145	10.8
12	793	43	41.5	80	15.8	105	24.8	146	21.3
13	404	44	16.3	81	50.9	107	35.4	147	216.4
14	11	45	20	82	62.3	111	65.4	148	120
18	34.4	46	65.3	84	37.9	113	32.7	150	4.8
19	64.4	47	4.8	85	40.5	115	17.3	151	24
20	37.9	48	33.8	86	50.7	116	56.1	152	6
22	17.4	49	6.8	87	16.9	117	101.9	153	4
23	63.5	50	99.7	88	60.6	122	47.3	154	28
27	324	52	218.2	90	50.2	123	165	155	12
28	38.5	54	70.3	91	51.2	132	159	156	8
29	28.3	56	25.3	92	36.1	133	30.1	157	32
30	101.2	57	48.5	93	103.8	134	17.5	158	16
31	72.5	59	84.4	94	164	135	20.1	159	8
32	52.7	60	244	95	117.2	136	20.1	160	14.4
33	45.2	63	59.1	96	119.2	137	20.1	161	32
34	14.2	67	22.5	97	22.8	139	10.1	162	20
35	54.5	68	40.4	98	151.1	140	13.5		
36	32	71	29.9	100	23.2	142	27.1		

The breadth search algorithm starts with a distance calculation between the first generator of the input file and all the buses of its respective island. A breadth search throughout the electric system performs this task where bus distances to the corresponding generator are associated. Thus each bus of the island will have a distance value associated with it that will represent a minimum number of transmission paths necessary in order that the generator be connected to the respective load bus.

After associating a distance value to each bus, the program will save the transmission path sequence from the respective generator to the first load (highest priority load) in the input load file. This sequence will be saved in the final island restoration configuration vector. After picking up this first load, the program reduces the generation capability of the generator to a value equal to the initial capability minus the load demand of the respective load bus. In case that the generation capability is larger than the load, the load is considered by the program as picked up and will be taken out of a load vector that informs the program which loads need to be energized. In case that the load is larger that the generation capability, the generator unit is considered totally used up and has its generation capability assigned a zero value. In this case the load demand is reduced to the previous value minus the earlier generation capability of the respective unit. After this step is completed, if there is still generation capability left in the unit, the program includes in the final island restoration configuration vector the transmission path sequence connecting the generator to the next load in the load vector. The transmission paths included in the restoration configuration vector are only the ones different from the paths already utilized. In case that the generation unit capability is not bigger than zero the program will consider the next generator in the generation vector as the one to be used. In this case, first the program will recalculate all the bus distances to the new generator unit. After reassigning distances for each bus, the program will save into the final restoration configuration the transmission path sequence that connects the generator unit to the first non-zero load in the load vector. Again, only transmission paths different from the ones already in the restoration vector are included. This process will repeat itself until all generation is used up or all loads are energized, whichever comes first.

As output the breadth search restoration program will provide the island restoration configuration, the processing time used to achieve the plans, and the final load and generation capabilities of the system. The source code of the breadth search restoration program is presented in appendix B.

5.7. Training the Artificial Neural Networks of each Island Restoration Scheme

As stated in an earlier section, the proposed PSR scheme is made up of 10 IRS. Each IRS will be developed to generate PSR plans for their respective island when the 162-bus transmission test system is considered to have undergone a wide area disturbance. Two ANNs and one SSP compose each IRS. The first ANN of each IRS will be responsible for a restoration load forecast. The output of this 1st ANN will be a scalar number associated with island restoration load patterns. In this study we assume that the restoration load distribution and values throughout the island would be equal to the pre disturbance load distribution and values.

Also in this study are considered three main pre disturbances system operating conditions. The first operating condition is called the *summer load* system operating condition. This case has a system real load demand pattern illustrated in table 5-13. The generation real power outputs of the system generating units for this operating condition are illustrated in table 5-12.

The second pre disturbance system operating condition is called the *light load* operating condition. In this operating condition the system load demand pattern is considered to be half the *summer load* operating condition load demand pattern. In order to adjust to this system load pattern, the generation power output of the system units for the *light load* system operating condition is decreased to half of the *summer load* generation power output pattern.

The third pre disturbance system operating condition considered is called the *winter load* operating condition. The load pattern of this system operating condition is considered 10 percent higher than the *summer load* demand pattern. The generation output of the system units for this operating condition is also increased by 10 percent to satisfy this higher load demand.

The scalar desired outputs of the 1^{st} ANNs are assigned values that reflect this system load demand pattern relationship between each operating condition. The *summer load* operating condition is assigned the scalar value of **0.5**. The *light load* operating condition will be assigned a scalar value equal to half of the previous scalar value, i.e., the *light load* operating condition will be assigned a scalar value equal to **0.25**. The *winter load* operating condition will be assigned a scalar value equal to 10 percent higher than the *summer load* operating condition assigned scalar value, i.e., the *winter load* operating condition will be assigned a scalar value equal to **0.55**.

As mentioned earlier, the input vectors of each load forecast ANN will be equal to the respective island's pre disturbance normalized loads. Due to the different load patterns in each electric island of the 162-bus transmission system, the normalizing values will be different. The normalizing value for each load forecast ANN is defined as the maximum pre disturbance *summer load* of the respective island increased by 10 percent.

The back-propagation training algorithm was used to train all the MLN of each IRS of the proposed PSR scheme. The load forecast ANN of the IRS responsible for the restoration of *Island #1* as well as all other ANNs of the restoration scheme were trained with the *Stuttgart Neural Network Simulator v. 4.1* (SNNS) [101]. Two sets of patterns, training and validation sets were used to train and choose the best neural network topology of each ANN used in the PSR scheme.

The load forecast ANN of the IRS of *Island #1* was trained with training patterns containing input vectors with 14 elements (corresponding to 14 normalized loads) and output vectors with one element. The training set was generated using the pre disturbance island load patterns and the respective desired associated output values from the three system operating conditions previously described. The normalizing value used to normalize the input training vectors was equal to 469.7. This value is equal to the summer load of bus 72 (highest island load) increased by 10%. The validation set was generated using different pre disturbance system operating conditions. In table 5-14 the number of training and validation set used is presented.

Table 5-14 Number of Training and Validation Patterns of the 1st ANN of IRS - Island#1

	Number of Patterns
Training Set	7
Validation Set	6

In order to find the best topology for this ANN several different architectures were tried. The architecture that generated the best results had an input layer with 14 processing units, two hidden layers with eight and four processing units respectively, and an output layer with one processing unit. A fixed learning rate was used in the training of this ANN. In table 5-15 the sum of the squared errors (SSE) progression during the training of the chosen ANN is shown.

Table 5-15 SSE progress during the Training of 1st ANN 14-8-4-1 of IRS – Island #1

Epoch	*SSE*
Train15000	0.10468
Validation 15000	0.03283
Train13500	0.04249
Validation 13500	0.0165
Train12000	0.00742
Validation 12000	0.00273
Train10500	0.00026
Validation 10500	0.00006
Train 9000	0.00005
Validation 9000	0.00001
Train 7500	0.00004
Validation 7500	0.00001
Train 6000	0.00004
Validation 6000	0.00001
Train 4500	0.00004
Validation 4500	0.00001
Train 3000	0.00004
Validation 3000	0.00001
Train 1500	0.00004
Validation 1500	0.00001
Train 1	0.00004
Validation 1	0.00001

The island restoration load forecast ANN of all other IRSs was trained following the same strategy described previously. All ANNs responsible for the island restoration load forecast were trained using the back-propagation algorithm with a fixed learning rate and using the SNNS program. The final topological selection for each ANN was chosen after several architectures were tested. The number of training and validation patterns used in the learning stage of each island restoration load forecast ANN was equal to seven and six respectively. In table 5-15 is shown the final SSE of the remaining ANNs responsible for the island restoration load forecast, and their respective architecture.

Table 5-16 Final SSE of the Island Restoration Load Forecast ANNs

	Final SSE of the Training Set	*Final SSE of the Validation Set*	*Architecture of the ANN*
1st ANN of IRS – Island #2	0.00003	0.00001	7-5-1
1st ANN of IRS – Island #3	0.00003	0.00001	4-3-1
1st ANN of IRS – Island #4	0.00003	0.00000	8-5-1
1st ANN of IRS – Island #5	0.00003	0.00001	11-5-1
1st ANN of IRS – Island #6	0.00004	0.00002	15-5-1
1st ANN of IRS – Island #7	0.00004	0.00002	17-5-1
1st ANN of IRS – Island #8	0.00004	0.00001	13-5-1
1st ANN of IRS – Island #9	0.00003	0.00001	5-2-1
1st ANN of IRS – Island #10	0.00003	0.00001	9-3-1

In table 5-16 the architecture of each ANN used for restoration load forecast is given in the last column. In this column the first element represents the number of processing units in the input layer, the second element represents the number of processing units in the hidden layer, and the third element represents the number of processing units in the output layer. The ANN responsible for the restoration plan development in the IRS of *Island#1* was also trained using the back-propagation algorithm using the SNNs program. In order to find the best topology several ANNs were tested and had their results compared. The training vector for this ANN was composed of input vectors with normalized restoration load forecasts, normalized buses and transmission paths representing unavailable transmission paths in the post disturbance transmission system scenario, and normalized output vectors representing final restoration island configurations together with their respective percentage load pick up value. The transmission paths used in the final restoration configuration are assigned a scalar value equal to **1.0** and the unused transmission paths are assigned a scalar value equal to **0**. The training and validation patterns were generated with the use of the PSR breadth-search algorithm and the ANAREDE load flow program. All patterns used in the training phase were tested generating feasible operating conditions. In table 5-17 the number of training and validation patterns used in the learning phase is presented.

Table 5-17 Number of Training and Validation Patterns of the 2nd ANN of IRS - Island#1

	Number of Patterns
Training Set	106
Validation Set	8

In the back-propagation training phase a decreasing (0.9-0.1) learning rate was used to avoid local minima. For the 2nd ANN of IRS of *Island #1* a bus normalization value equal to 162 was chosen together with a line normalization value equal to 284. The two normalizing values are selected to be equal to the maximum of bus number value and transmission path number value of the island. These values were defined in the system data file. Several different topologies were tested. Table 5-18 presents the final architecture chosen and the final SSE encountered at the end of the learning phase for the 2nd ANN of IRS of *Island #1*

Table 5-18 Architecture and Final SSE of 2nd ANN of IRS of *Island #1*

	Architecture of the ANN	**Final SSE**
1st ANN of the IRS–Island #1	4-65-40-26	0.03

The ANNs responsible for the restoration plan development of the remaining IRS were trained using the same strategy described earlier. Again the training phase was done using the SNNS program, a decreasing learning rate was also used and several different topologies were tried. Table 5-19 presents the final SSE results encountered for the training set of the remaining

ANNs, the respective architecture chosen, the number of training sets, and the normalization values used to generate these training and validation sets.

Table 5-19 Final Characteristics of the remaining 2nd ANNs of IRSs - Islands #2 to #10

	Final ANN Architecture	*Final SSE*	*Bus Normalization Value*	*Line Normalization Value*	*Number of Training Patterns*
2nd ANN of IRS-Island #2	4-30-45-26	0.01020	132	246	140
2nd ANN of IRS-Island #3	4-30-45-17	0.01067	62	152	68
2nd ANN of IRS-Island #4	4-30-45-17	0.01008	146	264	76
2nd ANN of IRS-Island #5	4-30-45-31	0.01009	127	244	124
2nd ANN of IRS-Island #6	4-30-45-27	0.00829	109	196	108
2nd ANN of IRS-Island #7	4-30-45-29	0.01240	162	284	112
2nd ANN of IRS-Island #8	4-30-45-27	0.0093	122	217	68
2nd ANN of IRS-Island #9	4-30-45-9	0.0072	160	278	32
2nd ANN of IRS-Island #10	4-30-45-12	0.0080	104	210	44

Having chosen the ANNs that make up the IRSs, each IRS can be built by interconnecting its respective ANNs with the SSP containing the pre-determined restoration path sequences (database) of the island. With the IRSs built, the PSR scheme is formed by considering it to be the union of the IRSs. The next chapter will present the PSR scheme performance under unseen restoration conditions and a discussion of its results.

Chapter 6. Results

In this chapter test results of the proposed PSR scheme are presented and analyzed. Different restoration conditions in a 162-bus transmission system are generated and used to test the proposed PSR scheme capabilities. The PSR scheme is tested in a 162-bus transmission system and is made up of 10 IRS, each one being responsible for the restoration plan development of its respective island. In order to better present and analyze the test results each IRS will have its performance discussed. After the test results for each IRS are presented, a comparison between the CPU processing times of the proposed PSR scheme and the PSR breadth-search scheme for the same restoration conditions is shown.

To analyze and present the test results of each IRS independently some issues need to be considered:

- While only the restoration plan developed by one ISR is presented and discussed, it is understood that the other IRSs of the PSR scheme have also developed restoration plans for their respective islands under the same restoration scenario.

- The test conditions presented here assume that the 162-bus transmission system is undergoing a wide-area disturbance and has already applied the *all open* islanding strategy.

- The proposed PSR scheme strategy applies the parallel island restoration technique. In this technique, each pre-defined electric island will be restored in parallel with the other electric islands of the transmission system without the use of the transmission tie-lines. It is assumed in these tests that these transmission lines will remain open during the parallel restoration implementation. In these tests it is also assumed that the transmission tie-lines will only be closed after each island is restored. This final stage of the system restoration is considered to be implemented after the electric islands are restored.

- After obtaining the restoration plans of each IRS, the island configurations were independently tested for operating feasibility and also as a complete transmission system with all transmission tie-lines closed. In all the presented test results the system operating condition feasibility was checked through the use of the load flow program ANAREDE.

In the next section the test results of the proposed PSR scheme are presented.

6.1. Island #1 Restoration Plan Development Under Unseen Restoration Conditions

The IRS responsible for the restoration plan development of *Electric Island #1* (IRS #1) is formed by two ANNs and one SSP. The two ANNs of this IRS were trained and analyzed previously. The SSP algorithm was also previously analyzed. However, even using the methodology discussed earlier, each SSP is developed exclusively for a single island. In the following the main differences between each SSP are pointed out.

- The restoration path database used by each SSP contains only paths of the respective island. This choice is made in order to take advantage of the faster processing time obtained with a smaller restoration path database.

- Each SSP will contain only structural information of that one island.

The source code of each SSP is presented in appendix C. Several tests were performed to check IRS #1 generalization capability. As an example suppose that table 6-1 represents the pre disturbance load pattern (real load demand (MW) of the load buses of *Island #1*) of *Island #1*.

Table 6-1 Pre Disturbance Load Pattern of Island #1

Bus Number	*Load Demand (MW)*
111	68.7
115	18.2
140	14.2
137	21.1
134	18.4
135	21.2

133	31.6
136	21.1
139	10.6
145	11.3
72	448.4
152	6.3
117	107
147	227.2

Suppose also that due to an equipment failure in one of the circuit breakers of the transmission line between buses 111 and 115, this line is unavailable for use in the PSR plan and identified as such local EMS applications. Table 5-21 will present this post disturbance data.

Table 6-2 Post Disturbance Data of Island #1

Bus Number	*Bus Number*	*Transmission Path Identification Number*
111	115	226

In order that the data expressed in tables 6-1 and 6-2 can be used by IRS #1 they must be first normalized. This normalization of the input data can be achieved with the pre-determined normalization values for Island # 1. The following table presents the input vector of ANN #1 (pre disturbance normalized data) and the partial (missing the output scalar element generated from ANN #1) input vector of ANN #2 (post disturbance normalized data) of IRS #1.

Table 6-3 Input Pattern of IRS #1 for a Specific Power System Restoration Scenario

Input Vector of ANN #1	*Partial Input Vector of ANN #2*
0.1462	0.7958
0.0386	0.6852
0.0301	0.7099
0.0449	-
0.0392	-
0.0449	-
0.0673	-
0.0449	-
0.0226	-
0.0242	-
0.9546	-
0.0134	-

0.2277	-
0.4837	-

ANN #1 of IRS #1 will process its input vector and generate a scalar output. In Table 6-4 the scalar output generated by ANN #1 when processing the input vector illustrated in Table 6-3 is presented.

Table 6-4 Output Pattern of ANN #1 for a Specific Power System Restoration Scenario

Output of ANN #1
0.52548

With the output of ANN #1 calculated, the input pattern of ANN #2 is formed by including this value into the already normalized post disturbance vector. The input vector of ANN #2 is presented in Table 6-5.

Table 6-5 Input Pattern of ANN #2 for a Specific Power System Restoration Scenario

Partial Input Vector of ANN #2
0.79580
0.52548
0.68520
0.70990

ANN #2 will process this input pattern and generate an output vector representing the final restoration configuration and the load percentage that can be picked-up with this configuration. Table 6-6 illustrates the output vector generated by ANN #2 of IRS #1.

Table 6-6 Output Pattern of ANN #2 for a Specific Power System Restoration Scenario

Output Vector of ANN #2
1.00000
0.00005
0.99862
1.00000
0.99695
0.99716
1.00000
0.99676

0.99995
1.00000
0.00005
1.00000
0.99995
1.00000
1.00000
0.00002
1.00000
0.99997
0.00007
0.99802
1.00000
0.99653
0.99853
1.00000
0.99595
0.71540

The output vector generated by ANN #2 with the exception of the last element that represents the load percentage pick-up will pass by a threshold function. The threshold function that is used by all IRSs is illustrated in Figure 6-1.

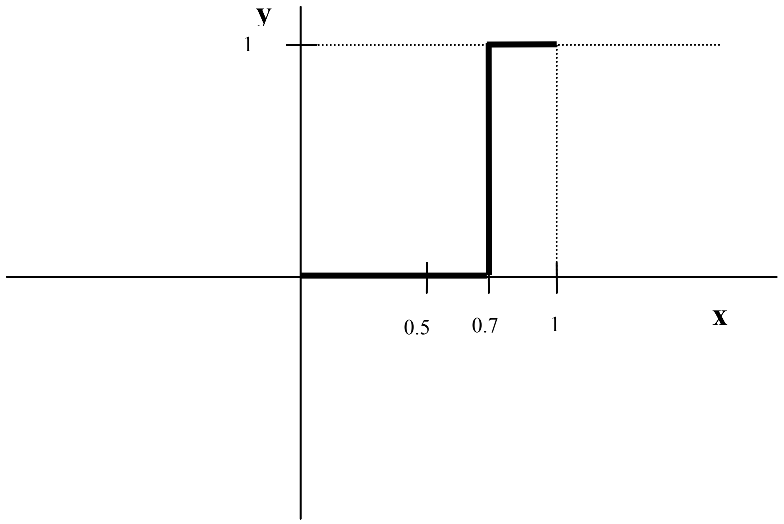


Figure 6-1 Threshold Function

For this threshold function the output is defined as,

$$y(x) = \begin{cases} 1 & \text{if } x \geq 0.7 \\ 0 & \text{if } x < 0.7 \end{cases} \qquad (6\text{-}1)$$

Where:

- y is a variable representing the output of the threshold function.
- x is a variable representing the input of the threshold function.

The position of each element in the output vector generated by ANN #2 is directly connected with a transmission path of the island or with the load restoration pick up percentage of the restored island. The last element of the output vector generated by ANN#2 corresponds to the load restoration pick up percentage value. The other elements of the output vector are related to the island transmission paths in the order illustrated in Table 5-3. For example, the first element of the output vector of ANN #2 expresses the status of transmission path number 221 in the final restoration configuration. The input/output of the threshold function for the input vector illustrated in Table 6-6 (without the last element) is presented in Table 6-7.

Table 6-7 Output Pattern of Threshold Function for a Specific Power System Restoration Scenario

Input Vector of Threshold Function	***Output Vector of Threshold Function***
1.00000	1.00000
0.00005	0.00000
0.99862	1.00000
1.00000	1.00000
0.99695	1.00000
0.99716	1.00000
1.00000	1.00000
0.99676	1.00000
0.99995	1.00000
1.00000	1.00000
0.00005	0.00000
1.00000	1.00000
0.99995	1.00000
1.00000	1.00000
1.00000	1.00000
0.00002	0.00000
1.00000	1.00000
0.99997	1.00000
0.00007	0.00000

0.99802	1.00000
1.00000	1.00000
0.99653	1.00000
0.99853	1.00000
1.00000	1.00000
0.99595	1.00000

The output vector of the threshold function, illustrated in Table 6-7, is used as an input vector by the SSP of IRS #1 to generate the restoration sequence of transmission paths for *Island #1*. The output vector generated by the SSP for the input vector illustrated in Table 6-7 is presented in Table 6-8.

Table 6-8 Output Pattern of the SSP for a Specific Power System Restoration Scenario

Restoration Sequence	***Transmission Path Number***
1	228
2	14
3	15
4	231
5	235
6	223
7	222
8	227
9	237
10	245
11	174
12	254
13	256
14	257
15	224
16	247
17	250
18	255
19	221
20	251
21	249

This energizing sequence vector illustrated in Table 6-8 and the load restoration pick up value generated by ANN #2 are the output of the IRS #1 for the inputs presented. The output of IRS #1 recommends a restoration sequence together with a load percentage pick up value of *Island #1* to the system operator. The restoration sequence generated by IRS #1 presents an energizing sequence of transmission paths to restore the connections of the island. This information also informs the system operator that the final island configuration (created after all transmission paths are energized) will generate a feasible operating condition if the load picked up is equal to the load percentage pick up value. The load percentage pick up value is a percentage of the forecasted load that can be restored. The forecasted restoration load is considered in this research to be equal to the pre disturbance load, information that is also available to the system operator. In Figure 6-2 the final configuration for island restoration is illustrated.

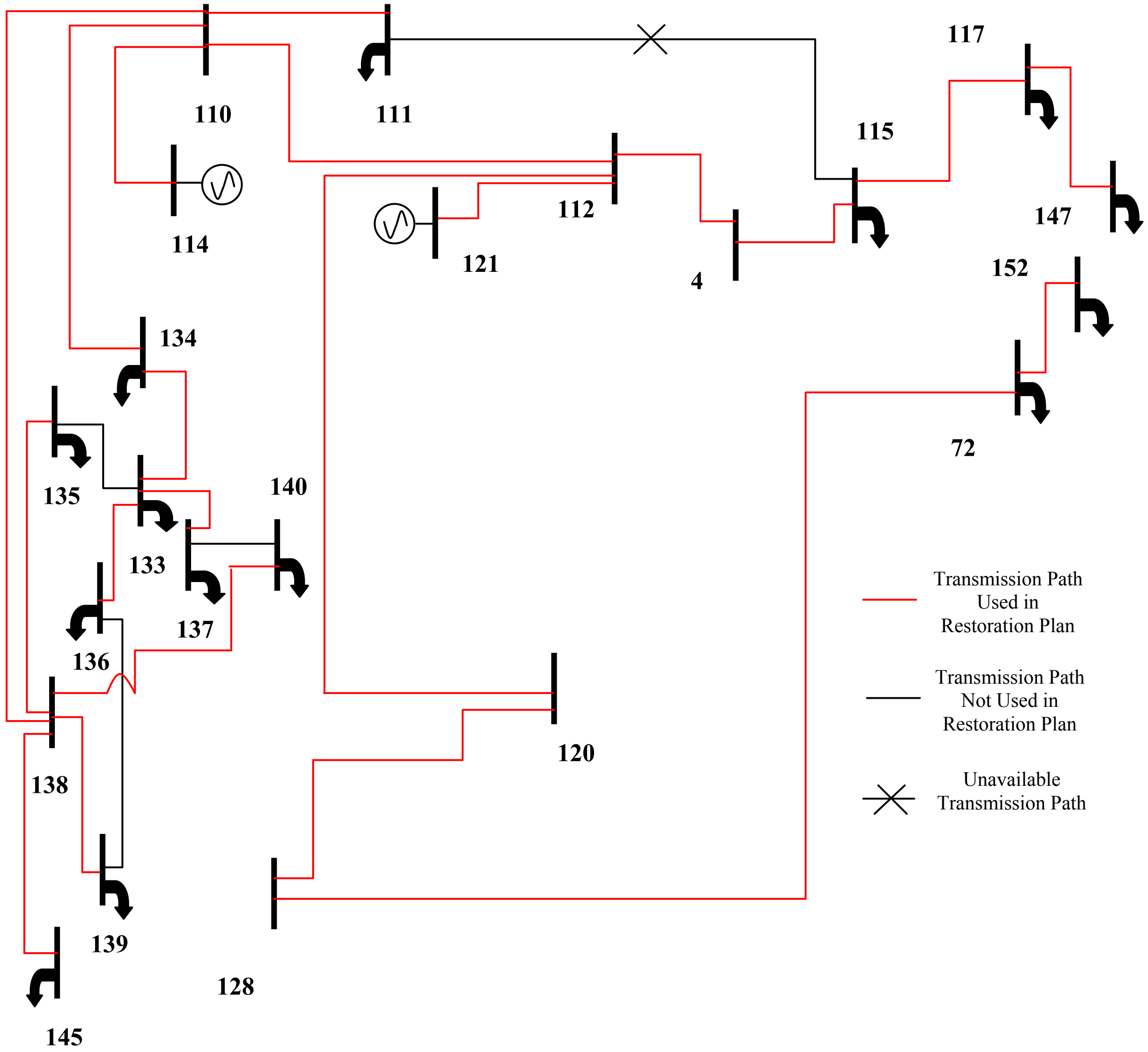


Figure 6-2 Restored Island Configuration Generated by IRS #1

The IRS #1 output for the given restoration scenario also provides to the system operator the load restoration percentage pick up value of 71.54% for this configuration. Thus only 71.54 % of the load can be restored. In order to check the feasibility of the operating condition generated by the proposed restoration plan of IRS #1 for this restoration scenario the island restoration final configuration together with the load restoration pick up value were tested using the load flow program ANAREDE. Table 6-9 illustrates the results of the load flow analysis.

Table 6-9 Load Flow Analysis of the Proposed IRS #1 Restoration Plan for a Specific Power System Restoration Scenario

Bus# / Name	*Bus Type*	*Voltage Magnitude / Angle*	*Generation MW/ MVar*	*Load MW/ MVar*	*Shunt/ Equivalent*
4 BOONIL3	0 345	0.972 -35.5	0 0	0 0	0 0
72 S1209 5	0 161	0.987 -32.3	-320 -82	0 0	0 0
110 CBLUFS5	0 161	1.015 -27.9	0 0	0 0	0 0
111 AVOC 5	0 161	0.993 -30.5	0 0	49.1 12.5	0 0
112 CBLUFS3	0 345	1.016 -27.3	0 0	0 0	-0.5 0
114 C.BL12G	1 14	1 -23.4	98 34.8	0 0	0 0
115 BOONIL5	0 161	0.959 -38.4	0 0	13 2.5	0 0
117 ASHAA 5	0 161	0.945 -40.7	0 0	76.5 15	0 0
120 S3456 3	0 345	1.011 -28	0 0	0 0	0 0
121 C.BL 3G	2 24	1 -20	643 209.3	0 0	0 0
128 S3459 3	0 345	1.004 -28.9	0 0	0 0	0 0
133 S701 8	0 69	1.03 -30	0 0	22.6 4.5	0 0
134 S701 5	0 161	1.01 -28.8	0 0	13.1 2.5	0 0
135 S702 8	0 69	1.001 -29.7	0 0	15.1 3	0 0
136 S703 8	0 69	1.021 -30.8	0 0	15.1 3	0 0

137	0	1.027	0	15.1	0
S704 8	69	-30.4	0	3	0
138	0	1.012	0	0	0
CBLUFS8	69	-28.8	0	0	0
139	0	1.009	0	7.6	0
S706 8	69	-29.1	0	1.5	0
140	0	1.008	0	10.2	0
S705 8	69	-29.3	0	2	0
145	0	1.001	0	8.2	0
GWOOD 8	69	-29.8	0	1.6	0
147	0	0.935	0	162.5	0
WABASH5	161	-42.5	0	32.1	0
152	0	0.99	-4.5	0	0
TEKAMA5	161	-32.7	2.1	0	0

The results from the load flow analysis illustrated in Table 6-9 reveal that no voltage, angle difference or generation capability constraints were violated. Table 6-10 presents the complementary results of the load flow analysis. This table will present the real and reactive power flowing through the transmission paths of island #1 and the specified thermal limits of the transmission paths.

Table 6-10 Power Flow through Transmission Paths of the Restoration Plan for a Specific Power System Restoration Scenario

Bus # / Name	*Bus Type*	*Voltage Magnitude / Angle*	*To Bus # / Name*	*Voltage / Circuit #*	*Real Flow (MW)*	*Reactive Flow (MVar)*	*Tap*	*Power Flow Limit (MVar)*
4	0	0.972						
BOONIL3	345	-35.5						
			112 CBLUFS3	345 1	-254.1	-75		3450
			115 BOONIL5	161 1	254	75	1	500
72	0	0.987						
S1209 5	161	-32.3						
			128 S3459 3	345 1	-324.2	-78.6		500
			152 TEKAMA5	161 1	3.6	-2.5		-
110	0	1.015						
CBLUFS5	161	-27.9						
			111 AVOC 5	161 1	49.7	10.3		180
			112 CBLUFS3	345 1	-59	-6	1	500
			114 C.BL12G	14 1	-98	-26.5	1.04	150
			134 S701 5	161 1	66.2	14		520
			138 CBLUFS8	69 1	41.2	8.3		160
111	0	0.993						
AVOC 5	161	-30.5						

			110 CBLUFS5	161 1	-49.1	-12.4		180
112	0	1.016						
CBLUFS3	345	-27.3						
			4 BOONIL3	345 1	258.2	22.9		3450
			110 CBLUFS5	161 1	59	6.7		500
			120 S3456 3	345 1	325.7	92.3		3450
			121 C.BL 3G	24 1	-643	-122.5	1.05	720
114	1	1						
C.BL12G	14	-23.4						
			110 CBLUFS5	161 1	98	34.8		150
115	0	0.959						
BOONIL5	161	-38.4						
			4 BOONIL3	345 1	-254	-61.3		500
			117 ASHAA 5	161 1	241	58.8		1030
117	0	0.945						
ASHAA 5	161	-40.7						
			115 BOONIL5	161 1	-239.7	-51.4		1030
			147 WABASH5	161 1	162.4	36.6		520
120	0	1.011						
S3456 3	345	-28						
			112 CBLUFS3	345 1	-325.2	-94.8		3450
			128 S3459 3	345 1	325.1	94.8		2474
121	2	1						
C.BL 3G	24	-20						
			112 CBLUFS3	345 1	643	209.3		720
128	0	1.004						
S3459 3	345	-28.9						
			72 S1209 5	161 1	324.7	99.2	1	500
			120 S3456 3	345 1	-324.7	-99.2		2474
133	0	1.03						
S701 8	69	-30						
			134 S701 5	161 1	-52.9	-10.6	1.025	160
			136 S703 8	69 1	15.2	3.1		39
			137 S704 8	69 1	15.1	3		60
134	0	1.01						
S701 5	161	-28.8						
			110 CBLUFS5	161 1	-66	-14.2		520
			133 S701 8	69 1	52.9	11.7		160
135	0	1.001						
S702 8	69	-29.7						
			138 CBLUFS8	69 1	-15.1	-3		39
136	0	1.021						
S703 8	69	-30.8						
			133 S701 8	69 1	-15.1	-3		39
137	0	1.027						
S704 8	69	-30.4						
			133 S701 8	69 1	-15.1	-3		60
138	0	1.012						
CBLUFS8	69	-28.8						
			110 CBLUFS5	161 1	-41.2	-7.6	1	160

			135 S702 8	69 1	15.2	3.1	39
			139 S706 8	69 1	7.6	1.4	39
			140 S705 8	69 1	10.2	1.9	60
			145 GWOOD 8	69 1	8.3	1.2	39
139	0	1.009					
S706 8	69	-29.1					
			138 CBLUFS8	69 1	-7.6	-1.5	39
140	0	1.008					
S705 8	69	-29.3					
			138 CBLUFS8	69 1	-10.2	-2	60
145	0	1.001					
GWOOD 8	69	-29.8					
			138 CBLUFS8	69 1	-8.2	-1.5	39
147	0	0.935					
WABASH5	161	-42.5					
			117 ASHAA 5	161 1	-161.8	-32.1	520
152	0	0.99					
TEKAMA5	161	-32.7					
			72 S1209 5	161 1	-3.6	2.6	-

By analyzing the results of Table 6-10, one can observe that the power flow thermal constraints of all transmission paths were respected. In general, Tables 6-9 and 6-10 show that the restoration plan proposed by the IRS #1 for the presented restoration scenario will generate a feasible operating condition.

Several other restoration scenarios were presented to IRS #1 and had their outputs checked for operating feasibility by load flow analysis using the load flow program ANAREDE. All restoration scenarios presented to IRS#1 were different from the ones used to train the ANNs composing the respective IRS. In Table 6-11 the results produced by the application of these tests are presented.

Table 6-11 Feasibility Check of Restoration Plans generated by IRS #1 for Test Restoration Scenarios

Test Restoration Scenarios #	*Feasible Restoration Plans*	*Unfeasible Restoration Plans*
150	150	0

From these results it is concluded that IRS #1 is capable of generating feasible PSR plans even when different restoration scenarios are tested.

6.2. Island #2 Restoration Plan Development Under Unseen Restoration Conditions

Electric Island # 2 is composed of 3 generators, 7 loads and 26 transmission paths. IRS #2 is responsible for a restoration plan builder for this island when a wide-area disturbance occurs. In order to check the capability of IRS #2 to generate feasible restoration plans when new restoration scenarios are presented, several tests were conducted. As an example, consider the test restoration scenario with a pre disturbance load pattern as presented in Table 6-12.

Table 6-12 Pre Disturbance Load Pattern of Island #2

Bus Number	*Load Demand (MW)*
12	475.8
8	238.8
132	95.4
13	242.4
3	222.0
14	6.6
113	19.6

Assume also that due to a permanent fault in the transmission path between buses 9 and 75, this path is unavailable for use in the restoration of the island as shown in Table 6-13.

Table 6-13 Post Disturbance Data of Island #2

Bus Number	*Bus Number*	*Transmission Path Identification Number*
9	75	28

With the post and pre disturbance data obtained, the input data of the IRS #2 can be calculated by the normalization of these values using the pre-determined normalization constraints. Table 6-14 presents the inputs of ANN #1 and #2 for the restoration scenario. Again the input vector of ANN #2 will be formed with the addition of ANN #1 scalar output.

Table 6-14 Input Pattern of IRS #2 for a Specific Power System Restoration Scenario

Input Vector of ANN #1	*Partial Input Vector of ANN #2*
0.5455	0.1138

0.2393	0.0682
0.1094	0.5682
0.2779	-
0.2545	-
0.0076	-
0.0225	-

With the input pattern provided ANN #1 can calculate the forecast restoration load. The output of ANN #1 for the input vector illustrated in Table 6-14 is presented in Table 6-15.

Table 6-15 Output Pattern of ANN #1 for a Specific Power System Restoration Scenario

Output of ANN #1
0.29815

With the output of ANN #1 calculated, the input pattern of ANN #2 is formed by including this value in the already normalized post disturbance vector. The input vector of ANN #2 is shown in Table 6-16.

Table 6-16 Input Pattern of ANN #2 for a Specific Power System Restoration Scenario

Partial Input Vector of ANN #2
0.11380
0.29815
0.06820
0.56820

ANN #2 will process this input pattern and generate an output vector representing the final restoration configuration and the percentage load that can be picked-up with this configuration. Table 6-17 illustrates the output vector generated by ANN #2 of IRS #2.

Table 6-17 Output Pattern of ANN #2 for a Specific Power System Restoration Scenario

Output Vector of ANN #2
1.00000
1.00000
1.00000
1.00000
0.00037

0.00000
1.00000
0.00075
0.00000
0.00000
1.00000
0.00179
0.00153
0.00000
1.00000
0.99992
1.00000
0.00000
1.00000
0.00000
0.00137
0.00137
0.00105
1.00000
1.00000
0.46037

The output vector generated by ANN #2 without the last element that represents the load percentage pick-up will pass through a threshold function. Table 6-18 illustrates the input/output of the threshold function.

Table 6-18 Output Pattern of Threshold Function for a Specific Power System Restoration Scenario

Input Vector of Threshold Function	***Output Vector of Threshold Function***
1.00000	1.00000
1.00000	1.00000
1.00000	1.00000
1.00000	1.00000
0.00037	0.00000
0.00000	0.00000
1.00000	1.00000
0.00075	0.00000
0.00000	0.00000
0.00000	0.00000
1.00000	1.00000
0.00179	0.00000
0.00153	0.00000

0.00000	0.00000
1.00000	1.00000
0.99992	1.00000
1.00000	1.00000
0.00000	0.00000
1.00000	1.00000
0.00000	0.00000
0.00137	0.00000
0.00137	0.00000
0.00105	0.00000
1.00000	1.00000
1.00000	1.00000

The output vector of the threshold function, illustrated in Table 6-18, is used as an input vector by the SSP of IRS #2 to generate the energizing restoration sequence of transmission paths for *Island #2*. The output vector generated by the SSP for the input vector illustrated in Table 6-18 is presented in Table 6-19.

Table 6-19 Output Pattern of the SSP for a Specific Power System Restoration Scenario

Restoration Sequence	***Transmission Path Number***
1	5
2	2
3	1
4	37
5	19
6	4
7	7
8	8
9	18
10	246
11	27
12	229

With the output vector generated by the SSP, the restoration plan from IRS #2 is established. In Figure 6-3 the final restoration configuration generated for IRS #2 is illustrated in the one line diagram of Island #2.

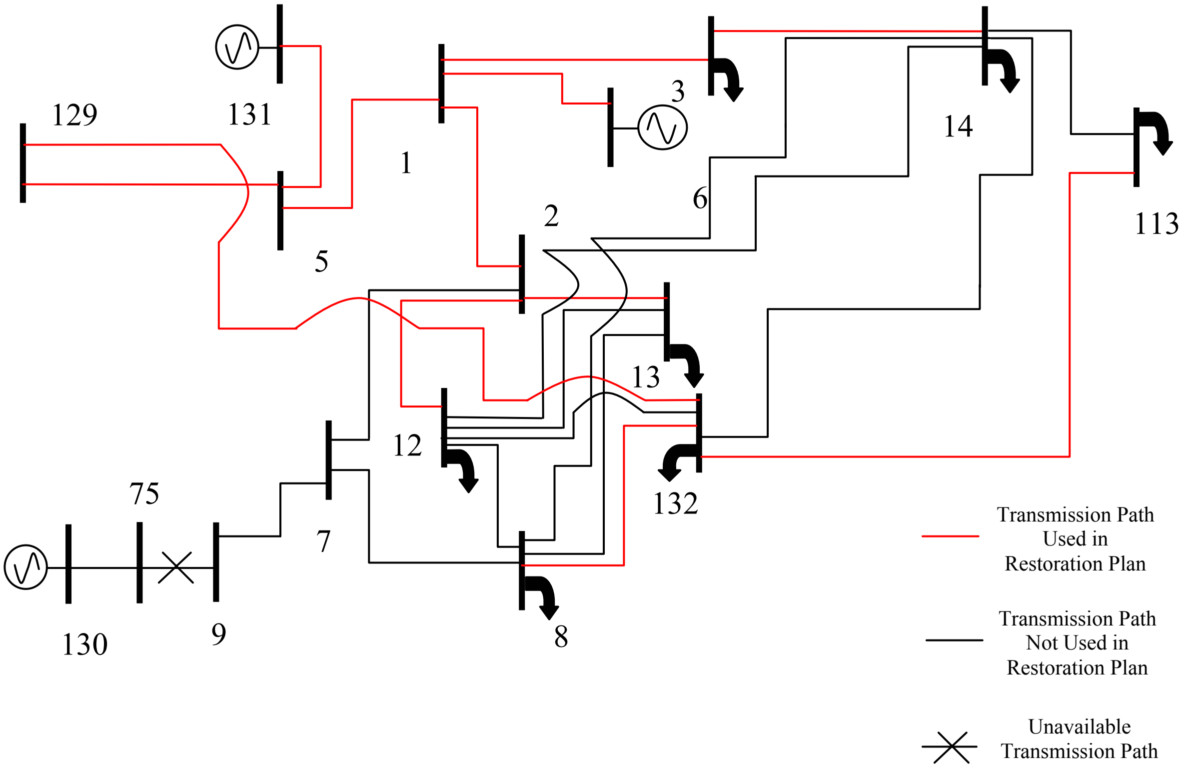


Figure 6-3 Restored Island Configuration Generated by IRS #2

The configuration of the restored island together with the load pick-up value was tested for system operating feasibility using the load flow program ANAREDE. Table 6-20 presents the complex voltages of the island and the generation/load at each bus resulting from the load flow analysis.

Table 6-20 Load Flow Analysis of the Proposed IRS #2 Restoration Plan for a Specific Power System Restoration Scenario

Bus# / Name	*Bus Type*	*Voltage Magnitude / Angle*	*Generation MW/ MVar*	*Load MW/ MVar*	*Shunt/ Equivalent*
1	0	1.06	0	0	-1.1
COOPR 3	345	-22.3	0	0	0
2	0	1.07	0	0	0
MOOR 3	345	-27.8	0	0	0
3	0	1.06	545.5	646.4	0
STJO712	161	-24.1	0	26.4	0

5	0	1.052	0	0	-0.6
NEBCY 3	345	-22.3	0	0	0
6	2	1	441.2	0	0
6R1G	22	-19	-46.4	0	0
8	0	0.932	-108	0	0
8ER7	115	-45.1	-5.2	0	0
12	0	1.093	-215	0	0
SHELON7	115	-31.9	1.6	0	0
13	0	1.076	-110	0	0
GR ILD3	345	-30.1	-10.2	0	0
14	0	1.037	-3	0	0
S1206 5	161	-25.5	-1.7	0	0
113	0	1.046	-8.9	0	0
S1211 5	161	-27.9	6.9	0	0
129	0	1.041	0	0	0
S3455 3	345	-24.6	0	0	0
131	1	1.018	156.8	0	0
NEBCY1G	18	-21.3	-68.2	0	0
132	0	1.031	-43.4	0	0
S1255 5	161	-26.3	-9.9	0	0

The results from the load flow analysis illustrated in Table 6-20 reveal that no voltage, angle difference or generation capability constraints were violated. Table 6-21 presents the line power flow results of the load flow analysis. These are the real and reactive powers flowing through the transmission paths of island #2 and the specified thermal limits of the transmission paths.

Table 6-21 Power Flow through Transmission Paths of the Restoration Plan for a Specific Power System Restoration Scenario

Bus # / Name	*Bus Type*	*Voltage Magnitude / Angle*	*To Bus # / Name*	*Voltage / Circuit #*	*Real Flow (MW)*	*Reactive Flow (MVar)*	*Tap*	*Power Flow Limit (MVar)*
1	0	1.06						
COOPR 3	345	-22.3						
			2 MOOR 3	354 1	329.3	-82.6		3450
			3 STJO712	161 1	104.3	-49.8		3709
			5 NEBCY 3	345 1	7.7	58.7		4002
			6 6R1G	22 1	-441.2	72.6	1.052	900
2	0	1.07						
MOOR 3	345	-27.8						
			1 COOPR 3	345 1	-325.8	52.7		3450
			12 SHELON7	115 1	215.3	13.7		336
			13 GR ILD3	345 1	110.5	-66.4		3450

3	0	1.06						
STJO712	161	-24.1						
			1 COOPR 3	345 1	-103.9	-28.2		3709
			14 S1206 5	161 1	3	1.8		-
5	0	1.052						
NEBCY 3	345	-22.3						
			1 COOPR 3	345 1	-7.6	-80.6		4002
			129 S3455 3	345 1	164.4	8.3		2474
			131 NEBCY1G	18 1	-156.8	71.8	1.025	710
6	2	1						
6R1G	22	-19						
			1 COOPR 3	345 1	441.2	-46.4		900
8	0	0.932						
8ER7	115	-45.1						
			132 S1255 5	161 1	-107.9	-4.9		-
12	0	1.093						
SHELON7	115	-31.9						
			2 MOOR 3	345 1	-215	1.6	1.025	336
13	0	1.076						
GR ILD3	345	-30.1						
			2 MOOR 3	345 1	-110	-10.2		3450
14	0	1.037						
S1206 5	161	-25.5						
			3 STJO712	161 1	-3	-1.7		-
113	0	1.046						
S1211 5	161	-27.9						
			132 S1255 5	161 1	-8.9	6.9		-
129	0	1.041						
S3455 3	345	-24.6						
			5 NEBCY 3	345 1	-163.9	-52		
			132 S1255 5	161 1	163.9	52	1	500
131	1	1.018						
NEBCY1G	18	-21.3						
			5 NEBCY 3	345 1	156.8	-68.2		4002

By analyzing the results of Table 6-21, it is possible to observe that the power flow thermal constraints of all transmission paths of the island were respected. The load flow results in Tables 6-20 and 6-21 shows that the restoration plan proposed by IRS #2 for the restoration scenario will generate a feasible operating condition.

Several other restoration scenarios were presented to IRS #2 and had their restoration plans checked for operating feasibility by load flow analysis using the load flow program ANAREDE. All restoration scenarios presented to IRS#2 were different from the ones used to train the ANNs of the respective IRS. In Table 6-22 the results encountered by the application of these tests are presented.

Table 6-22 Feasibility Check of Restoration Plans generated by IRS #2 for Test Restoration Scenarios

Test Restoration Scenarios #	*Feasible Restoration Plans*	*Unfeasible Restoration Plans*
156	156	0

From these results it is concluded that IRS #2 is capable of generating feasible PSR plans even when new restoration scenarios are presented.

6.3. Island #3 Restoration Plan Development Under Unseen Restoration Conditions

Electric Island # 3 is composed of 2 generators, 4 loads and 16 transmission paths. IRS #3 is responsible for a restoration plan builder for this island when a wide-area disturbance occurs. In order to check the capability of IRS #3 to generate feasible restoration plans when new restoration scenarios are presented, again several tests were conducted. As an example, consider the test restoration scenario with a pre disturbance load pattern as presented in Table 6-23.

Table 6-23 Pre Disturbance Load Pattern of Island #3

Bus Number	*Load Demand (MW)*
60	219.6
10	203.4
59	76
49	6.1

Assume also that due to an equipment failure in one of the circuit breakers of the transmission line between buses 9 and 75, this line is unavailable for use in the restoration of the island as shown in Table 6-24.

Table 6-24 Post Disturbance Data of Island #3

Bus Number	*Bus Number*	*Transmission Path Identification Number*
60	62	149

With the post and pre disturbance data obtained, the input data of the IRS #3 can be calculated by the normalization of these values using the pre-determined normalization constraints. Table 6-25 presents the inputs of ANN #1 and #2 for the presented restoration scenario. Again the input vector of ANN #3 will be formed with the addition of ANN #1 scalar output.

Table 6-25 Input Pattern of IRS #3 for a Specific Power System Restoration Scenario

Input Vector of ANN #1	*Partial Input Vector of ANN #2*
0.8182	0.9803
0.7578	0.9677
0.2831	1.0000
0.2190	-

With the input pattern provided ANN #1 can calculate the forecast restoration load. The output of ANN #1 for the input vector illustrated in Table 6-25 is presented in Table 6-26.

Table 6-26 Output Pattern of ANN #1 for a Specific Power System Restoration Scenario

Output of ANN #1
0.45289

With the output of ANN #1 calculated, the input pattern of ANN #2 if formed by including this value in the already normalized post disturbance vector. The input vector of ANN #2 is presented in Table 6-27.

Table 6-27 Input Pattern of ANN #2 for a Specific Power System Restoration Scenario

Partial Input Vector of ANN #2
0.9803
0.45289
0.9677
1.0000

ANN #2 will process this input pattern and generate an output vector representing the final restoration configuration and the percentage load that can be picked-up with this configuration. Table 6-28 illustrates the output vector generated by ANN #2 of IRS #3.

Table 6-28 Output Pattern of ANN #2 for a Specific Power System Restoration Scenario

Output Vector of ANN #2
0.00000
0.00003
1.00000
1.00000
0.99995
0.00005
0.00008
0.00171
0.99437
0.99996
0.00523
0.00004
0.99994
0.99996
0.00006
0.00007
0.14471

The output vector generated by ANN #2 without the last element that represents the load percentage pick-up will pass through a threshold function. Table 6-29 illustrates the input/output of the threshold function.

Table 6-29 Output Pattern of Threshold Function for a Specific Power System Restoration Scenario

Input Vector of Threshold Function	*Output Vector of Threshold Function*
0.00000	0.00000
0.00003	0.00000
1.00000	1.00000
1.00000	1.00000
0.99995	1.00000
0.00005	0.00000
0.00008	0.00000
0.00171	0.00000

0.99437	1.00000
0.99996	1.00000
0.00523	0.00000
0.00004	0.00000
0.99994	1.00000
0.99996	1.00000
0.00006	0.00000
0.00007	0.00000

The output vector of the threshold function, illustrated in Table 6-29, is used as an input vector by the SSP of IRS #3 to generate the energizing restoration sequence of transmission paths for *Island #3*. The output vector generated by the SSP for the input vector illustrated in Table 6-29 is presented in Table 6-30.

Table 6-30 Output Pattern of the SSP for a Specific Power System Restoration Scenario

Restoration Sequence	***Transmission Path Number***
1	31
2	47
3	48
4	33
5	34
6	152
7	146

With the output vector generated by the SSP, the restoration plan from IRS #3 is established. In Figure 6-4 the final restoration configuration generated for IRS #3 is illustrated in the one line diagram of Island #3.

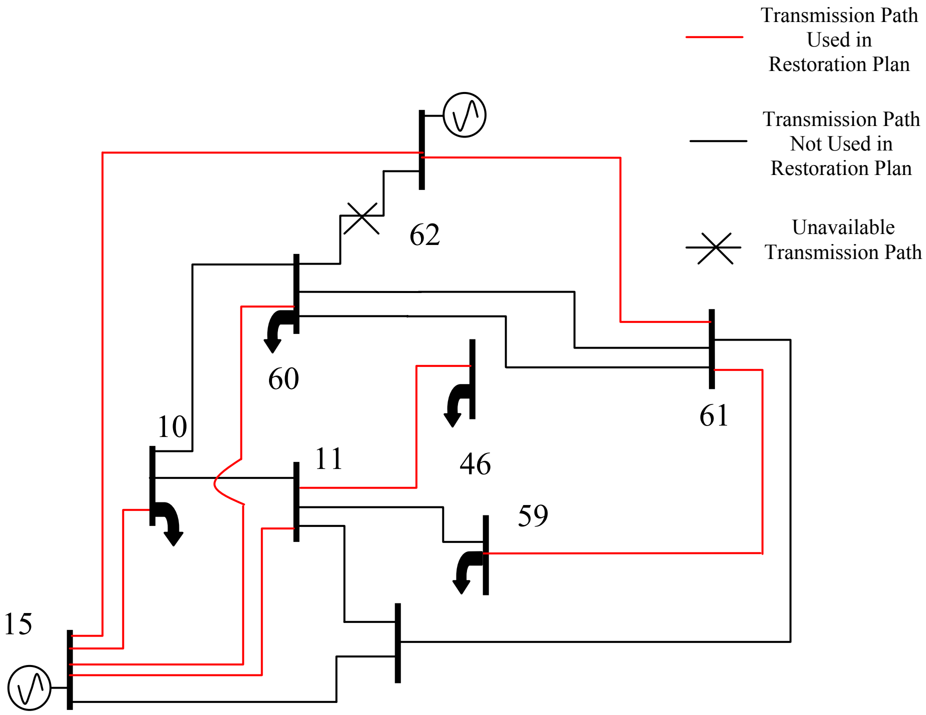


Figure 6-4 Restored Island Configuration Generated by IRS #3

The configuration of the restored island together with the load pick-up value was tested for system operating feasibility using the load flow program ANAREDE. Table 6-31 presents the complex voltages of the island and the generation/load at each bus resulting from the load flow analysis.

Table 6-31 Load Flow Analysis of the Proposed IRS #3 Restoration Plan for a Specific Power System Restoration Scenario

Bus# / Name	*Bus Type*	*Voltage Magnitude / Angle*	*Generation MW/ MVar*	*Load MW/ MVar*	*Shunt/ Equivalent*
10	0	0.967	-29.4	0	0
TWINCH4	230	-37.2	1.5	0	0
11	0	1.053	0	0	0
SX CY 4	230	-27.4	0	0	0
15	2	1.018	155.6	185.1	0
FTRAD 4	230	-25	-76.6	0	0
46	0	1.044	0	21.5	0.3

DENIN 5	161	-28.8	0	15.8	0
59	0	1.079	0	24	0
EAGL 4	230	-26.3	0	16.5	0
60	0	0.929	-5.7	0	0
SX FLL7	115	-30	-3.4	0	0
61	0	1.088	0	0	0
SIOXLS4	230	-25.5	0	0	0
62	0	1.052	112.7	0	0
FTTHMP4	230	-22.4	9.2	0	0

The results from the load flow analysis illustrated in Table 6-31 reveal that no voltage, angle difference or generation capability constraints were violated. Table 6-32 presents the line power flow results of the load flow analysis. These are the real and reactive powers flowing through the transmission paths of island #3 and the specified thermal limits of the transmission paths.

Table 6-32 Power Flow through Transmission Paths of the Restoration Plan for a Specific Power System Restoration Scenario

Bus # / Name	*Bus Type*	*Voltage Magnitude / Angle*	*To Bus # / Name*	*Voltage / Circuit #*	*Real Flow (MW)*	*Reactive Flow (MVar)*	*Tap*	*Power Flow Limit (MVar)*
10	0	0.967						
TWINCH4	230	-37.2						-
			15 FTRAD 4	230 1	-29.4	1.5		-
11	0	1.053						
SX CY 4	230	-27.4						
			15 FTRAD 4	230 1	-21.4	5.3		-
			46 DENIN 5	161 1	21.7	-5		-
15	2	1.018						
FTRAD 4	230	-25						
			10 TWINCH4	230 1	30.6	5		-
			11 SX CY 4	230 1	21.7	-41		-
			60 SX FLL7	115 1	5.9	4.3		-
			62 FTTHMP4	230 1	-87.6	-44.8		-
46	0	1.044						
DENIN 5	161	-28.8						
			11 SX CY 4	230 1	-21.7	-15.1		-
59	0	1.079						
EAGL 4	230	-26.3						
			61 SIOXLS4	230 1	-24	-16.5		-
60	0	0.929						
SX FLL7	115	-30						
			15 FTRAD 4	230 1	-5.7	-3.4		-

61	0	1.088						
SIOXLS4	230	-25.5						
			59 EAGL 4	230	1	24.1	2.7	-
			62 FTTHMP4	230	1	-24.1	-2.7	552
62	0	1.052						
FTTHMP4	230	-22.4						
			15 FTRAD 4	230	1	88.4	50.3	
			61 SIOXLS4	230	1	24.3	-41.1	552

By analyzing the results of Table 6-32, it is possible to observe that the power flow thermal constraints of all transmission paths of the island were respected. The load flow results in Tables 6-31 and 6-32 shows that the restoration plan proposed by IRS #3 for the restoration scenario will generate a feasible operating condition.

Several other restoration scenarios were presented to IRS #3 and had their restoration plans checked for operating feasibility by load flow analysis using the load flow program ANAREDE. All restoration scenarios presented to IRS#3 were different from the ones used to train the ANNs of the respective IRS. In Table 6-33 the results encountered by the application of these tests are presented.

Table 6-33 Feasibility Check of Restoration Plans generated by IRS #3 for Test Restoration Scenarios

Test Restoration Scenarios #	*Feasible Restoration Plans*	*Unfeasible Restoration Plans*
96	96	0

From these results it is concluded that IRS #3 is capable of generating feasible PSR plans even when new restoration scenarios are presented.

6.4. Island #4 Restoration Plan Development Under Unseen Restoration Conditions

Electric Island # 4 is composed of 2 generators, 8 loads and 18 transmission paths. IRS #4 is responsible for a restoration plan builder for this island when a wide-area disturbance occurs. In order to check the capability of IRS #4 to generate feasible restoration plans when new restoration scenarios are presented several tests were conducted. Before presenting the test results, it will be presented one detailed example. Consider the test restoration scenario with a pre disturbance load pattern as presented in Table 6-34.

Table 6-34 Pre Disturbance Load Pattern of Island #4

Bus Number	*Load Demand (MW)*
103	338.1
123	173.3
50	104.7
146	22.4
142	28.5
143	22.2
144	13
43	43.6

Assume also that due to an equipment failure in one of the circuit breakers of the transmission path between buses 103 and 123, this path is unavailable for use in the restoration of the island as shown in Table 6-35.

Table 6-35 Post Disturbance Data of Island #4

Bus Number	*Bus Number*	*Transmission Path Identification Number*
103	123	211

With the post and pre disturbance data obtained, the input data of the IRS #4 can be calculated by the normalization of these values using the pre-determined normalization constraints. Table 6-36 presents the inputs of ANN #1 and #2 for the restoration scenario. Again the input vector of ANN #2 will be formed with the addition of ANN #1 scalar output.

Table 6-36 Input Pattern of IRS #4 for a Specific Power System Restoration Scenario

Input Vector of ANN #1	*Partial Input Vector of ANN #2*
0.9545	0.7992
0.4891	0.7054
0.2956	0.8425
0.0631	-
0.0803	-
0.0625	-

0.0368	-
0.1230	-

With the input pattern provided ANN #1 can calculate the forecast restoration load. The output of ANN #1 for the input vector illustrated in Table 6-36 is presented in Table 6-37.

Table 6-37 Output Pattern of ANN #1 for a Specific Power System Restoration Scenario

Output of ANN #1
0.52574

With the output of ANN #1 calculated, the input pattern of ANN #2 is formed by including this value in the already normalized post disturbance vector. The input vector of ANN #2 is shown in Table 6-38.

Table 6-38 Input Pattern of ANN #2 for a Specific Power System Restoration Scenario

Partial Input Vector of ANN #2
0.7992
0.52574
0.7054
0.8425

ANN #2 will process this input pattern and generate an output vector representing the final restoration configuration and the percentage of load that can be picked-up with this configuration. Table 6-39 illustrates the output vector generated by ANN #2 of IRS #4.

Table 6-39 Output Pattern of ANN #2 for a Specific Power System Restoration Scenario

Output Vector of ANN #2
0.00005
0.99999
0.99831
0.99999
1.00000
0.00129
0.00001
0.00000
1.00000

0.00000
0.99998
0.99997
0.00000
0.99879
0.99971
0.99991
0.00000
0.99999
0.28284

The output vector generated by ANN #2 without the last element that represents the load percentage pick-up will pass through a threshold function. Table 6-40 illustrates the input/output of the threshold function.

Table 6-40 Output Pattern of Threshold Function for a Specific Power System Restoration Scenario

Input Vector of Threshold Function	***Output Vector of Threshold Function***
0.00005	0.00000
0.99999	1.00000
0.99831	1.00000
0.99999	1.00000
1.00000	1.00000
0.00129	0.00000
0.00001	0.00000
0.00000	0.00000
1.00000	1.00000
0.00000	0.00000
0.99998	1.00000
0.99997	1.00000
0.00000	0.00000
0.99879	1.00000
0.99971	1.00000
0.99991	1.00000
0.00000	0.00000
0.99999	1.00000

The output vector of the threshold function, illustrated in Table 6-40, is used as an input vector by the SSP of IRS #4 to generate the energizing restoration sequence of transmission paths for *Island #4*. The output vector generated by the SSP for the input vector illustrated in Table 6-40 is presented in Table 6-41.

Table 6-41 Output Pattern of the SSP for a Specific Power System Restoration Scenario

Restoration Sequence	*Transmission Path Number*
1	213
2	241
3	128
4	126
5	258
6	259
7	129
8	262
9	260
10	240
11	115

With the output vector generated by the SSP, the restoration plan from IRS #4 is established. In Figure 6-5 the final restoration configuration generated for IRS # is illustrated in the one line diagram of Island #4.

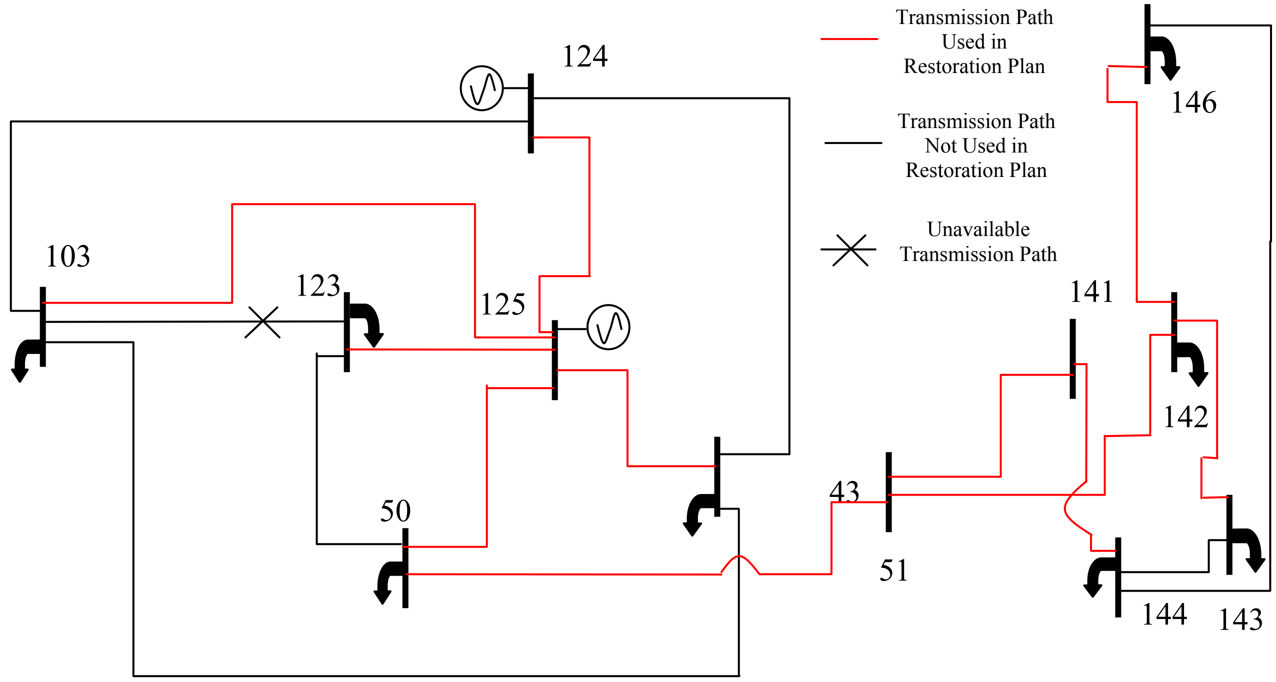


Figure 6-5 Restored Island Configuration Generated by IRS #4

The configuration of the restored island together with the load pick-up value was tested for system operating feasibility using the load flow program ANAREDE. Table 6-42 presents the complex voltages of the island and the generation/load at each bus resulting from the load flow analysis.

Table 6-42 Load Flow Analysis of the Proposed IRS #4 Restoration Plan for a Specific Power System Restoration Scenario

Bus# / Name	*Bus Type*	*Voltage Magnitude / Angle*	*Generation MW/ MVar*	*Load MW/ MVar*	*Shunt/ Equivalent*
43	0	1.031	-12.3	0	0
CLINON5	161	-4.8	5.1	0	0
50	0	0.941	-29.4	0	0
MARY 12	161	-20.7	7	0	0
51	0	0.935	0	0	0
CLRNA 5	161	-22.1	0	0	0
103	0	1.002	-95.6	0	0
DAVNRT5	161	-10.8	13.6	0	0
123	0	1.031	-48.9	0	0
WAPELO5	161	-6.9	16.2	0	0
124	0	0.955	763.4	594	0
DVNPT 3	345	16.2	0	27	0
125	2	1.02	647.4	594	0
PALM710	345	0	79.3	0	0
141	0	0.935	0	0	0
HSTNGS5	161	-22.4	0	0	0
142	0	0.994	0	8	0
CLRNDA8	69	-24.4	0	1.6	0
143	0	0.98	0	6.3	0
R.OAK 8	69	-25.8	0	1.2	0
144	0	0.958	0	3.7	0
HSTNGS8	69	-22.6	0	0.6	0
146	0	0.98	0	6.3	0
SHENDO8	69	-25.8	0	1.2	0

The results from the load flow analysis illustrated in Table 6-42 reveal that no voltage, angle difference or generation capability constraints were violated. Table 6-43 presents the line power flow results of the load flow analysis. These are the real and reactive powers flowing through the transmission paths of island #4 and the specified thermal limits of the transmission paths.

Table 6-43 Power Flow through Transmission Paths of the Restoration Plan for a Specific Power System Restoration Scenario

Bus # / Name	Bus Type	Voltage Magnitude / Angle	To Bus # / Name	Voltage / Circuit #	Real Flow (MW)	Reactive Flow (MVar)	Tap	Power Flow Limit (MVar)
43	0	1.031						
CLINON5	161	-4.8						
			125 PALM710	345 1	-12.3	5.1		-
50	0	0.941						
MARY 12	161	-20.7						
			51 CLRNA 5	161 1	24.5	-2.9		-
			125 PALM710	345 1	-53.9	9.9		-
51	0	0.935						
CLRNA 5	161	-22.1						
			50 MARY 12	161 1	-24.3	-0.1		-
			141 HSTNGS5	161 1	3.7	-3.2		264
			142 CLRNDA8	69 1	20.5	3.5		83
103	0	1.002						
DAVNRT5	161	-10.8						
			125 PALM710	345 1	-95.6	13.6		-
123	0	1.031						
WAPELO5	161	-6.9						
			125 PALM710	345 1	-48.9	16.2		-
124	0	0.955						
DVNPT 3	345	16.2						
			125 PALM710	345 1	169.4	-27		-
125	2	1.02						
PALM710	345	0						
			43 CLINON5	161 1	12.5	-4		-
			50 MARY 12	161 1	58.5	10.6		-
			103 DAVNRT5	161 1	98.2	4.7		-
			123 WAPELO5	161 1	50	-10.1		-
			124 DVNPT 3	345 1	-165.8	78.2		-
141	0	0.935						
HSTNGS5	161	-22.4						
			51 CLRNA 5	161 1	-3.7	-0.6		264
			144 HSTNGS8	69 1	3.7	0.6		80
142	0	0.994						
CLRNDA8	69	-24.4						
			51 CLRNA 5	161 1	-20.5	-2.6	1.07	83
			143 R.OAK 8	69 1	6.2	0.7		44
			146 SHENDO8	69 1	6.3	0.6		44
143	0	0.98						
R.OAK 8	69	-25.8						
			142 CLRNDA8	69 1	-6.1	-1.2		44
144	0	0.958						

HSTNGS8	69	-22.6							
			141 HSTNGS5	161	1	-3.7	-0.6	1.025	80
146	0	0.98							
SHENDO8	69	-25.8							
			142 CLRNDA8	69	1	-6.2	-1.2		44

By analyzing the results of Table 6-43, it is possible to observe that the power flow thermal constraints of all transmission paths of the island were respected. The load flow results in Tables 6-42 and 6-43 shows that the restoration plan proposed by IRS #4 for the restoration scenario will generate a feasible operating condition.

Several other restoration scenarios were presented to IRS #4 and had their restoration plans checked for operating feasibility by load flow analysis using the load flow program ANAREDE. All restoration scenarios presented to IRS#4 were different from the ones used to train the ANNs of the respective IRS. In Table 6-44 the results encountered by the application of these tests are presented.

Table 6-44 Feasibility Check of Restoration Plans generated by IRS #4 for Test Restoration Scenarios

Test Restoration Scenarios #	*Feasible Restoration Plans*	*Unfeasible Restoration Plans*
108	108	0

From these results it is concluded that IRS #4 is capable of generating feasible PSR plans even when new restoration scenarios are presented.

6.5. Island #5 Restoration Plan Development Under Unseen Restoration Conditions

Electric Island # 5 of composed by 5 generators, 11 loads and 30 transmission paths. IRS #5 is responsible for a restoration plan builder for this island when a wide-area disturbance occurs. In order to check the capability of IRS #5 to generate feasible restoration plans when new restoration scenarios are presented several tests were conducted. Again, before presenting the final test results, it will be presented one detailed example. Consider the test restoration scenario with a pre disturbance load pattern as presented in Table 6-45.

Table 6-45 Pre Disturbance Load Pattern of Island #5

Bus Number	*Load Demand (MW)*
31	43.5
32	31.6
30	60.7
18	20.6
19	38.6
38	8.9
27	194.4
29	17
28	23.1
23	38.1
63	35.5

Assume also that due to a permanent fault the transmission path between buses 19 and 127, this path is unavailable for use in the restoration of the island as shown in Table 6-46.

Table 6-46 Post Disturbance Data of Island #5

Bus Number	*Bus Number*	*Transmission Path Identification Number*
19	127	65

With the post and pre disturbance data obtained, the input data of the IRS #5 can be calculated by the normalization of these values using the pre-determined normalization constraints. Table 6-47 presents the inputs of ANN #1 and #2 for the restoration scenario. Again the input vector of ANN #2 will be formed with the addition of ANN #1 scalar output.

Table 6-47 Input Pattern of IRS #5 for a Specific Power System Restoration Scenario

Input Vector of ANN #1	*Partial Input Vector of ANN #2*
0.1221	0.2664
0.0887	0.1496
0.1704	1.0000
0.0579	-
0.1084	-
0.0249	-
0.5455	-
0.0476	-

0.0648	-
0.1069	-
0.0995	-

With the input pattern provided ANN #1 can calculate the forecast restoration load. The output of ANN #1 for the input vector illustrated in Table 6-47 is presented in the Table 6-48.

Table 6-48 Output Pattern of ANN #1 for a Specific Power System Restoration Scenario

Output of ANN #1
0.29818

With the output of ANN #1 calculated, the input pattern of ANN #2 is formed by including this value in the already normalized post disturbance vector. The input vector of ANN #2 is shown in Table 6-49.

Table 6-49 Input Pattern of ANN #2 for a Specific Power System Restoration Scenario

Partial Input Vector of ANN #2
0.2664
0.29818
0.1496
1.0000

ANN #2 will process this input pattern and generate an output vector representing the final restoration configuration and the percentage of load that can be picked-up with this configuration. Table 6-50 illustrates the output vector generated by ANN #2 of IRS #5.

Table 6-50 Output Pattern of ANN #2 for a Specific Power System Restoration Scenario

Output Vector of ANN #2
0.99707
1.00000
1.00000
0.99958
0.99990
0.00008
1.00000
0.99712

0.00037
0.00000
0.99494
0.00049
0.00000
1.00000
0.00001
1.00000
0.00000
1.00000
1.00000
1.00000
0.99359
0.00288
1.00000
0.00016
0.99987
0.00067
0.99948
1.00000
0.00023
0.00252
0.21471

The output vector generated by ANN #2 without the last element that represents the load percentage pick-up will pass through a threshold function. Table 6-51 illustrates the input/output of the threshold function.

Table 6-51 Output Pattern of Threshold Function for a Specific Power System Restoration Scenario

Input Vector of Threshold Function	***Output Vector of Threshold Function***
0.99707	1.00000
1.00000	1.00000
1.00000	1.00000
0.99958	1.00000
0.99990	1.00000
0.00008	0.00000
1.00000	1.00000
0.99712	1.00000
0.00037	0.00000
0.00000	0.00000
0.99494	1.00000

0.00049	0.00000
0.00000	0.00000
1.00000	1.00000
0.00001	0.00000
1.00000	1.00000
0.00000	0.00000
1.00000	1.00000
1.00000	1.00000
1.00000	1.00000
0.99359	1.00000
0.00288	0.00000
1.00000	1.00000
0.00016	0.00000
0.99987	1.00000
0.00067	0.00000
0.99948	1.00000
1.00000	1.00000
0.00023	0.00000
0.00252	0.00000

The output vector of the threshold function, illustrated in Table 6-51, is used as an input vector by the SSP of IRS #5 to generate the energizing restoration sequence of transmission paths for *Island #5*. The output vector generated by the SSP for the input vector illustrated in Table 6-51 is presented in Table 6-52.

Table 6-52 Output Pattern of the SSP for a Specific Power System Restoration Scenario

Restoration Sequence	*Transmission Path Number*
1	55
2	59
3	50
4	51
5	60
6	56
7	63
8	53
9	88
10	84
11	92
12	89
13	80
14	76
15	74
16	77

17	157
18	160

With the output vector generated by the SSP, the restoration plan from IRS #5 is established. In Figure 6-6 the final restoration configuration generated for IRS #5 is illustrated in the one line diagram of Island #5.

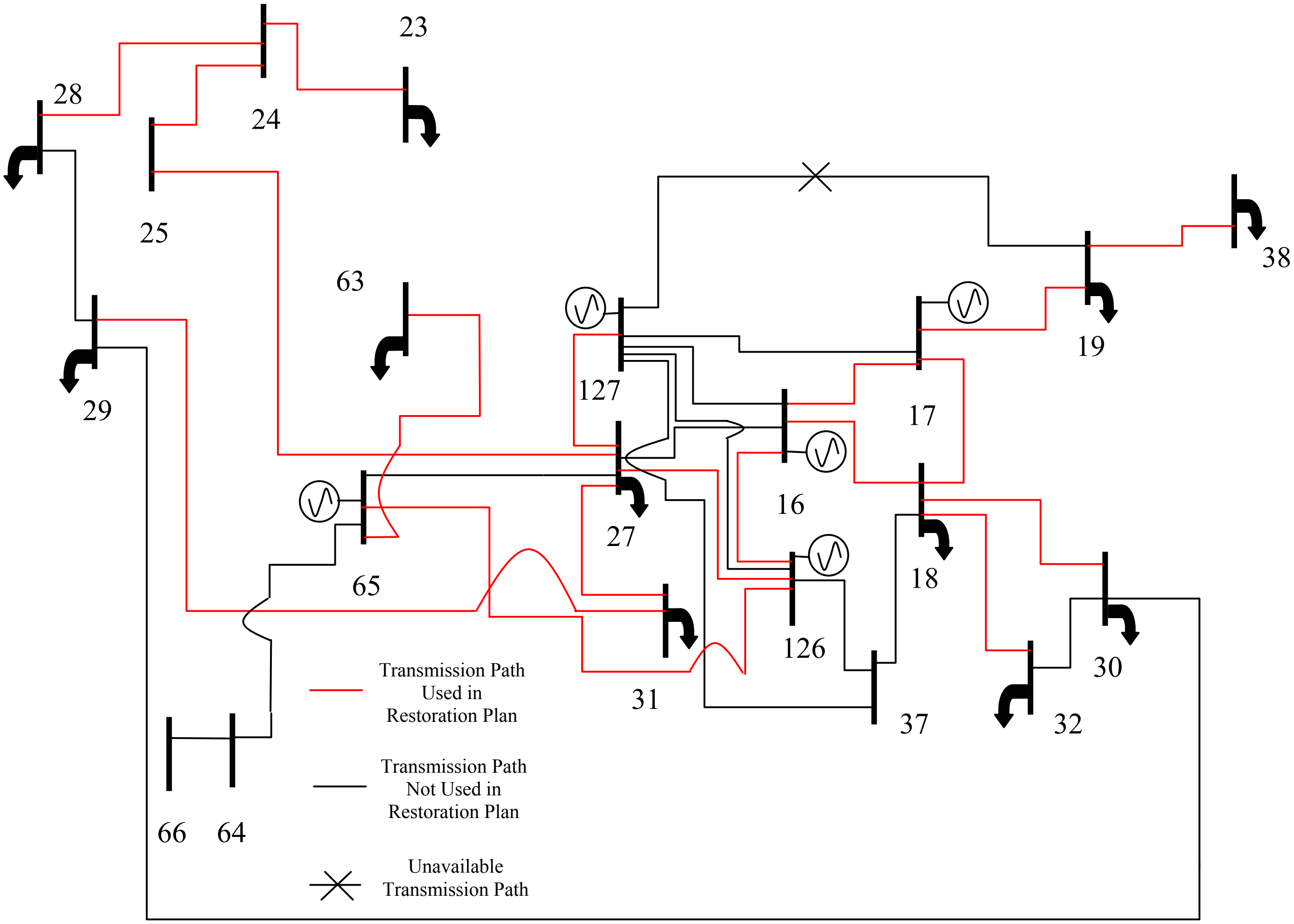


Figure 6-6 Restored Island Configuration Generated by IRS #5

The configuration of the restored island together with the load pick-up value was tested for system operating feasibility using the load flow program ANAREDE. Table 6-53 presents the complex voltages of the island and the generation/load at each bus resulting from the load flow analysis.

Table 6-53 Load Flow Analysis of the Proposed IRS #5 Restoration Plan for a Specific Power System Restoration Scenario

Bus# / Name	*Bus Type*	*Voltage Magnitude / Angle*	*Generation MW/ MVar*	*Load MW/ MVar*	*Shunt/ Equivalent*
16	0	0.986	12.2	0	0
ROCHTR5	161	-6.9	-6	0	0
17	0	0.977	26.1	0	0
HARMNY5	161	-8.5	-10	0	0
18	0	0.976	0	0	0
ADAM 5	161	-9.1	0	0	0
19	0	0.951	-14.5	0	0
DUBUUE5	161	-17.5	-0.9	0	0
23	0	1.056	-14.3	0	0
HRN K 5	161	-2.8	-4.8	0	0
24	0	1.06	0	0	0
LAKFD 5	161	-2.4	0	0	0
25	0	1.038	0	0	-0.5
LAKFD 3	345	-2	0	0	0
27	0	1.023	337.3	0	0
WILMRT3	345	-1.4	0	0	0
28	0	1.057	0	0	0
FOX K 5	161	-2.7	0	0	0
29	0	1.022	0	0	0
WINBGO5	161	-3.3	0	0	0
30	0	0.966	0	0	0.1
HAYWD 5	161	-10.5	0	0	0
31	0	1.024	-16.3	0	0
RAPIAN5	161	-3	0.7	0	0
32	0	0.973	0	0	0.2
LIMECK5	161	-9.9	0	0	0
38	0	0.952	0	0	0
DUNDE 5	161	-17.8	0	0	0
63	0	0.968	-13.3	0	0
HANLN 4	230	-17.3	3.6	0	0
65	0	0.969	5.9	0	0
WTRTWN3	345	-0.7	-25.9	0	0
126	2	1.011	589	0	0
PR ILD3	345	0	-33.9	0	0
127	0	0.956	11.8	0	0
LACRSS3	345	9	-14.6	0	0

The results from the load flow analysis illustrated in Table 6-53 reveal that no voltage, angle difference or generation capability constraints were violated. Table 6-54 presents the line power flow results of the load flow analysis. These are the real and reactive powers flowing through the transmission paths and of island #5 and the specified thermal limits of the transmission paths.

Table 6-54 Power Flow through Transmission Paths of the Restoration Plan for a Specific Power System Restoration Scenario

Bus # / Name	*Bus Type*	*Voltage Magnitude / Angle*	*To Bus # / Name*	*Voltage / Circuit #*	*Real Flow (MW)*	*Reactive Flow (MVar)*	*Tap*	*Power Flow Limit (MVar)*
16	0	0.986						
ROCHTR5	161	-6.9						
			17 HARMNY5	161 1	1.8	-0.1		-
			18 ADAM 5	161 1	33.6	-2.3		269
			126 PR ILD3	345 1	-23.2	1.4		-
17	0	0.977						
HARMNY5	161	-8.5						
			16 ROCHTR5	161 1	-1.8	0.1		-
			18 ADAM 5	161 1	9.2	-4.3		361
			19 DUBUUE5	161 1	18.6	-0.8		-
18	0	0.976						
ADAM 5	161	-9.1						
			16 ROCHTR5	161 1	-33.3	-1.7		269
			17 HARMNY5	161 1	-9.2	-1.7		361
			30 HAYWD 5	161 1	22.9	2.9		362
			32 LIMECK5	161 1	11.8	-2.1		361
19	0	0.951						
DUBUUE5	161	-17.5						
			17 HARMNY5	161 1	-17.8	3.6		-
			38 DUNDE 5	161 1	3.3	-4.5		354
23	0	1.056						
HRN K 5	161	-2.8						
			24 LAKFD 5	161 1	-14.3	-4.8		361
24	0	1.06						
LAKFD 5	161	-2.4						
			23 HRN K 5	161 1	14.3	2.3		361
			25 LAKFD 3	345 1	-23.1	-3.1	1.022	225
			28 FOX K 5	161 1	8.7	0.8		361
25	0	1.038						
LAKFD 3	345	-2						
			24 LAKFD 5	161 1	23.1	3.3		225
			27 WILMRT3	345 1	-23.1	-3.8		-
27	0	1.023						

WILMRT3	345	-1.4						
			25 LAKFD 3	345	1	23.1	-84.4	-
			31 RAPIAN5	161	1	22.8	-2.1	-
			126 PR ILD3	345	1	-107.2	66.3	-
			127 LACRSS3	345	1	-11.5	7.1	-
28	0	1.057						
FOX K 5	161	-2.7						
			24 LAKFD 5	161	1	-8.7	-3	361
29	0	1.022						
WINBGO5	161	-3.3						
			31 RAPIAN5	161	1	-6.4	-2	269

By analyzing the results of Table 6-54, it is possible to observe that the power flow thermal constraints of all transmission paths of the island were respected. The load flow results in Tables 6-53 and 6-54 shows that the restoration plan proposed by IRS #5 for the restoration scenario will generate a feasible operating condition.

Several other restoration scenarios were presented to IRS #5 and had their restoration plans checked for operating feasibility by load flow analysis using the load flow program ANAREDE. All restoration scenarios presented to IRS#5 were different from the ones used to train the ANNs of the respective IRS. In Table 6-55 the results encountered by the application of these tests are presented.

Table 6-55 Feasibility Check of Restoration Plans generated by IRS #5 for Test Restoration Scenarios

Test Restoration Scenarios #	*Feasible Restoration Plans*	*Unfeasible Restoration Plans*
180	180	0

From these results it is concluded that IRS #5 is capable of generating feasible PSR plans even when new restoration scenarios are presented.

6.6. Island #6 Restoration Plan Development Under Unseen Restoration Conditions

Electric Island # 6 is composed of 2 generators, 15 loads and 26 transmission paths. IRS #6 is responsible for a restoration plan builder for this island when a wide-area disturbance occurs. In order to check the capability of IRS #6 to generate feasible restoration plans when new restoration scenarios are presented several tests were again conducted. Before presenting the final test results, it will be presented one detailed example. Consider the test restoration scenario with a pre disturbance load pattern as presented in Table 6-56.

Table 6-56 Pre Disturbance Load Pattern of Island #6

Bus Number	*Load Demand (MW)*
93	93.4
82	56.1
81	45.8
40	47.6
41	35.3
84	34.1
77	23.8
78	71.2
68	36.4
35	49.1
33	40.7
36	28.8
67	20.3
34	12.8
22	15.7

Assume also that due to a permanent fault the transmission path between buses 67 and 68, this path is unavailable for use in the restoration of the island as shown in Table 6-57.

Table 6-57 Post Disturbance Data of Island #6

Bus Number	*Bus Number*	*Transmission Path Identification Number*
67	68	162

With the post and pre disturbance data obtained, the input data of the IRS #6 can be calculated by the normalization of these values using the pre-determined normalization constraints. Table 6-58 presents the inputs of ANN #1 and #2 for the restoration scenario. Again the input vector of ANN #2 will be formed with the addition of ANN #1 scalar output.

Table 6-58 Input Pattern of IRS #6 for a Specific Power System Restoration Scenario

Input Vector of ANN #1	*Partial Input Vector of ANN*

	#2
0.8182	0.8265
0.4911	0.6147
0.4012	0.6239
0.4170	-
0.3090	-
0.2987	-
0.2081	-
0.6235	-
0.3184	-
0.4296	-
0.3563	-
0.2522	-
0.1774	-
0.1119	-
0.1372	-

With the input pattern provided ANN #1 can calculate the forecast restoration load. The output of ANN #1 for the input vector illustrated in Table 6-58 is presented in Table 6-59.

Table 6-59 Output Pattern of ANN #1 for a Specific Power System Restoration Scenario

Output of ANN #1
0.45316

With the output of ANN #1 calculated, the input pattern of ANN #2 is formed by including this value in the already normalized post disturbance vector. The input vector of ANN #2 is shown in Table 6-60.

Table 6-60 Input Pattern of ANN #2 for a Specific Power System Restoration Scenario

Partial Input Vector of ANN #2
0.8265
0.45316
0.6147
0.6239

ANN #2 will process this input pattern and generate an output vector representing the final restoration configuration and the percentage of load that can be picked-up with this configuration. Table 6-61 illustrates the output vector generated by ANN #2 of IRS #6.

Table 6-61 Output Pattern of ANN #2 for a Specific Power System Restoration Scenario

Output Vector of ANN #2
1.00000
1.00000
1.00000
0.99888
0.99895
0.00014
0.99999
0.00001
0.99876
0.99984
0.99913
1.00000
0.00101
1.00000
0.00121
1.00000
1.00000
0.99659
0.00001
1.00000
1.00000
1.00000
0.00012
1.00000
1.00000
1.00000
0.43075

The output vector generated by ANN #2 without the last element that represents the load percentage pick-up will pass through a threshold function. Table 6-62 illustrates the input/output of the threshold function.

Table 6-62 Output Pattern of Threshold Function for a Specific Power System Restoration Scenario

Input Vector of Threshold Function	*Output Vector of Threshold Function*
1.00000	1.00000
1.00000	1.00000
1.00000	1.00000

0.99888	1.00000
0.99895	1.00000
0.00014	0.00000
0.99999	1.00000
0.00001	0.00000
0.99876	1.00000
0.99984	1.00000
0.99913	1.00000
1.00000	1.00000
0.00101	0.00000
1.00000	1.00000
0.00121	0.00000
1.00000	1.00000
1.00000	1.00000
0.99659	1.00000
0.00001	0.00000
1.00000	1.00000
1.00000	1.00000
1.00000	1.00000
0.00012	0.00000
1.00000	1.00000
1.00000	1.00000
1.00000	1.00000

The output vector of the threshold function, illustrated in Table 6-62, is used as an input vector by the SSP of IRS #6 to generate the energizing restoration sequence of transmission paths for *Island #6*. The output vector generated by the SSP for the input vector illustrated in Table 6-62 is presented in Table 6-63.

Table 6-63 Output Pattern of the SSP for a Specific Power System Restoration Scenario

Restoration Sequence	*Transmission Path Number*
1	196
2	182
3	110
4	109
5	181
6	108
7	195
8	105
9	71
10	72
11	98
12	100

13	95
14	97
15	101
16	99
17	164
18	163
19	165
20	68

With the output vector generated by the SSP, the restoration plan from IRS #6 is established. In Figure 6-7 the final restoration configuration generated for IRS #6 is illustrated in the one line diagram of Island #6.

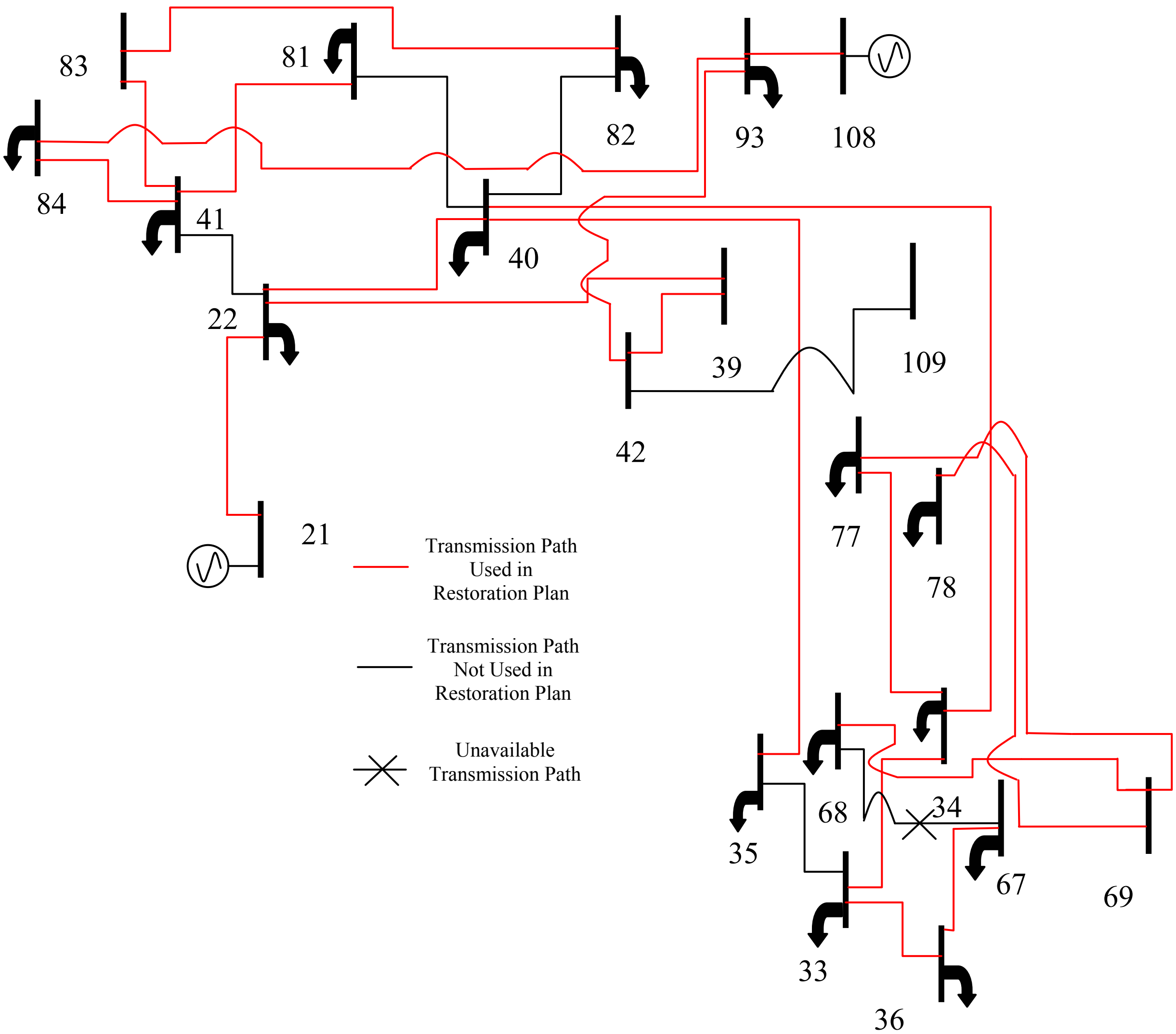


Figure 6-7 Restored Island Configuration Generated by IRS #6

The configuration of the restored island together with the load pick-up value was tested for system operating feasibility using the load flow program ANAREDE. Table 6-64 presents the complex voltages of the island and the generation/load at each bus resulting from the load flow analysis.

Table 6-64 Load Flow Analysis of the Proposed IRS #6 Restoration Plan for a Specific Power System Restoration Scenario

Bus# / Name	*Bus Type*	*Voltage Magnitude / Angle*	*Generation MW/ MVar*	*Load MW/ MVar*	*Shunt/ Equivalent*
21	0	1.086	27.1	0	0
POSTIL5	161	-7.1	-9	0	0
22	0	1.086	0	6.8	0
HAZLON5	161	-9.3	0	2	0
33	0	0.965	0	17.5	0.2
MASNTY5	161	-25.8	0	5.8	0
34	0	0.981	0	5.5	0
FRANKN5	161	-23.1	0	2	0
35	0	1.031	0	21.1	0.1
FLOY 5	161	-16	0	5.7	0
36	0	0.962	0	12.4	0
GARNR 5	161	-26.4	0	3.4	0
39	0	1.001	0	0	0
HAZLON3	345	-5.5	0	0	0
40	0	1.04	0	20.5	0
BLKHK 5	161	-14.5	0	6.8	0
41	0	1	0	15.2	0
WSHBN 5	161	-7.3	0	5	0
42	0	1.009	0	0	0
ARNOD 3	345	-4.1	0	0	0
67	0	0.96	0	8.7	0.1
BURT 5	161	-26.9	0	2.7	0
68	0	0.956	0	15.7	0.1
HOPE 5	161	-27.6	0	4.9	0
69	0	0.959	0	0	0
HOPET 5	161	-27.3	0	0	0
77	0	0.964	0	10.3	0
WRIGT 5	161	-26.2	0	3.4	0
78	0	0.955	0	30.7	0
FT.DDG5	161	-28.1	0	0	0
81	0	0.967	0	19.7	0.2
WATELO8	69	-11.5	0	6.5	0

82	0	0.995	0	24.2	0.1
WATELO5	161	-8	0	7.8	0
83	0	0.998	0	0	0
WTR OGT	161	-7.6	0	0	0
84	0	1.014	0	14.7	0
DYSAT 5	161	-5.4	0	3.7	0
93	0	1.04	0	40.3	0
ARNOD 5	161	-2.2	0	13.4	0
108	2	1	247.7	0	0
AROL 1G	22	0	67	0	0

The results from the load flow analysis illustrated in Table 6-64 reveal that no voltage, angle difference or generation capability constraints were violated. Table 6-65 presents the line power flow results of the load flow analysis. These are the real and reactive powers flowing through the transmission paths of island #6 and the specified thermal limits of the transmission paths.

Table 6-65 Power Flow through Transmission Paths of the Restoration Plan for a Specific Power System Restoration Scenario

Bus # / Name	*Bus Type*	*Voltage Magnitude / Angle*	*To Bus # / Name*	*Voltage / Circuit #*	*Real Flow (MW)*	*Reactive Flow (MVar)*	*Tap*	*Power Flow Limit (MVar)*
21	0	1.086						
POSTIL5	161	-7.1						
			22 HAZLON5	161 1	27.1	-9		387
22	0	1.086						
HAZLON5	161	-9.3						
			21 POSTIL5	161 1	-26.9	0.9		387
			39 HAZLON3	345 1	-132.1	-36.9	1.108	225
			40 BLKHK 5	161 1	152.1	34.1		362
33	0	0.965						
MASNTY5	161	-25.8						
			34 FRANKN5	161 1	-38.6	-5.5		180
			36 GARNR 5	161 1	21.1	-0.1		349
34	0	0.981						
FRANKN5	161	-23.1						
			33 MASNTY5	161 1	39	2.4		180
			40 BLKHK 5	161 1	-102.2	-7.4		325
			77 WRIGT 5	161 1	57.5	3		269
35	0	1.031						
FLOY 5	161	-16						
			40 BLKHK 5	161 1	-21.1	-5.6		179
36	0	0.962						
GARNR 5	161	-26.4						

			33 MASNTY5	161 1	-21.1	-2	349
			67 BURT 5	161 1	8.5	-1.4	349
39	0	1.001					
HAZLON3	345	-5.5					
			22 HAZLON5	161 1	132.1	46.6	225
			42 ARNOD 3	345 1	-132.1	-46.6	1656
40	0	1.04					
BLKHK 5	161	-14.5					
			22 HAZLON5	161 1	-148.2	-22.9	362
			34 FRANKN5	161 1	106.5	16.8	325
			35 FLOY 5	161 1	21.2	-0.7	179
41	0	1					
WSHBN 5	161	-7.3					
			81 WATELO8	69 1	19.9	7.4	81
			83 WTR OGT	161 1	24.3	5.5	-
			84 DYSAT 5	161 1	-59.3	-17.9	406
42	0	1.009					
ARNOD 3	345	-4.1					
			39 HAZLON3	345 1	132.4	17.7	1656
			93 ARNOD 5	161 1	-132.4	-17.7	400
67	0	0.96					
BURT 5	161	-26.9					
			36 GARNR 5	161 1	-8.5	-2.6	349
68	0	0.956					
HOPE 5	161	-27.6					
			69 HOPET 5	161 1	-15.3	-4.8	351
69	0	0.959					
HOPET 5	161	-27.3					
			68 HOPE 5	161 1	15.3	3.4	351
			77 WRIGT 5	161 1	-45.5	-1.5	269
			78 FT.DDG5	161 1	30	-1.4	180
77	0	0.964					
WRIGT 5	161	-26.2					
			34 FRANKN5	161 1	-56.7	-3.8	269
			69 HOPET 5	161 1	45.7	0.8	269
78	0	0.955					
FT.DDG5	161	-28.1					
			69 HOPET 5	161 1	-29.9	0	180
81	0	0.967					
WATELO8	69	-11.5					
			41 WSHBN 5	161 1	-19.7	-6.3	81
82	0	0.995					
WATELO5	161	-8					
			83 WTR OGT	161 1	-24.2	-7.7	-
83	0	0.998					
WTR OGT	161	-7.6					
			41 WSHBN 5	161 1	-24.2	-6.6	-
			82 WATELO5	161 1	24.2	6.6	-
84	0	1.014					
DYSAT 5	161	-5.4					

			41 WSHBN 5	161	1	59.6	17.2		406
			93 ARNOD 5	161	1	-74.3	-20.9		406
93	0	1.04							
ARNOD 5	161	-2.2							
			42 ARNOD 3	345	1	132.4	22.2	1.025	400
			84 DYSAT 5	161	1	75	21.2		406
			108 AROL 1G	22	1	-247.7	-56.8	1.05	600
108	2	1							
AROL 1G	22	0							
			93 ARNOD 5	161	1	247.7	67		600

By analyzing the results of Table 6-65, it is possible to observe that the power flow thermal constraints of all transmission paths of the island were respected. The load flow results in Tables 6-64 and 6-65 shows that the restoration plan proposed by IRS #6 for the restoration scenario will generate a feasible operating condition.

Several other restoration scenarios were presented to IRS #6 and had their restoration plans checked for operating feasibility by load flow analysis using the load flow program ANAREDE. All restoration scenarios presented to IRS#6 were different from the ones used to train the ANNs of the respective IRS. In Table 6-66 the results encountered by the application of these tests are presented.

Table 6-66 Feasibility Check of Restoration Plans generated by IRS #6 for Test Restoration Scenarios

Test Restoration Scenarios #	*Feasible Restoration Plans*	*Unfeasible Restoration Plans*
156	156	0

From these results it is concluded that IRS #6 is capable of generating feasible PSR plans even when new restoration scenarios are presented.

6.7. Island #7 Restoration Plan Development Under Unseen Restoration Conditions

Electric Island # 7 is composed of 1 generator, 17 loads and 29 transmission paths. IRS #7 is responsible for a restoration plan builder for this island when a wide-area disturbance occurs. In order to check the capability of IRS #7 to generate feasible restoration plans when new restoration scenarios are presented several tests were again conducted. Before presenting the final test results, it will be presented one detailed example. Consider the test restoration scenario with a pre disturbance load pattern as presented in Table 6-67.

Table 6-67 Pre Disturbance Load Pattern of Island #7

Bus Number	*Load Demand (MW)*
159	4.8
158	9.6
157	19.2
20	22.7
54	42.2
45	12.0
56	15.2
80	9.5
57	29.1
161	19.2
151	14.4
162	12.0
150	2.9
85	24.3
71	17.9
116	33.7
148	72.0

Assume also that due to equipment failure in one of circuit breakers of the transmission path between buses 74 and 79, this path is unavailable for use in the restoration of the island as shown in Table 6-68.

Table 6-68 Post Disturbance Data of Island #7

Bus Number	*Bus Number*	*Transmission Path Identification Number*
74	79	180

With the post and pre disturbance data obtained, the input data of the IRS #7 can be calculated by the normalization of these values using the pre-determined normalization constraints. Table 6-69 presents the inputs of ANN #1 and #2 for the restoration scenario. Again the input vector of ANN #2 will be formed with the addition of ANN #1 scalar output.

Table 6-69 Input Pattern of IRS #7 for a Specific Power System Restoration Scenario

Input Vector of ANN #1	*Partial Input Vector of ANN #2*
0.0364	0.6338
0.0727	0.4568
0.1455	0.4877
0.1723	-
0.3195	-
0.0909	-
0.1150	-
0.0718	-
0.2205	-
0.1455	-
0.1091	-
0.0909	-
0.0218	-
0.1841	-
0.1359	-
0.2550	-
0.5455	-

With the input pattern provided ANN #1 can calculate the forecast restoration load. The output of ANN #1 for the input vector illustrated in Table 6-69 is presented in Table 6-70.

Table 6-70 Output Pattern of ANN #1 for a Specific Power System Restoration Scenario

Output of ANN #1
0.29794

With the output of ANN #1 calculated, the input pattern of ANN #2 is formed by including this value in the already normalized post disturbance vector. The input vector of ANN #2 is shown in Table 6-71.

Table 6-71 Input Pattern of ANN #2 for a Specific Power System Restoration Scenario

Partial Input Vector of ANN #2
0.6338
0.29794
0.4568
0.4877

ANN #2 will process this input pattern and generate an output vector representing the final restoration configuration and the percentage of load that can be picked-up with this configuration. Table 6-72 illustrates the output vector generated by ANN #2 of IRS #7.

Table 6-72 Output Pattern of ANN #2 for a Specific Power System Restoration Scenario

Output Vector of ANN #2
1.00000
1.00000
0.99995
1.00000
1.00000
1.00000
0.00000
1.00000
0.99930
1.00000
0.99923
1.00000
1.00000
1.00000
0.99996
0.99780
0.00000
1.00000
1.00000
0.00000
1.00000
0.99917
1.00000
0.00005
0.99933
0.00000
1.00000
1.00000
0.99996

The output vector generated by ANN #2 without the last element that represents the load percentage pick-up will pass through a threshold function. Table 6-73 illustrates the input/output of the threshold function.

Table 6-73 Output Pattern of Threshold Function for a Specific Power System Restoration Scenario

Input Vector of Threshold Function	***Output Vector of Threshold Function***
1.00000	1.00000
1.00000	1.00000
0.99995	1.00000
1.00000	1.00000
1.00000	1.00000
1.00000	1.00000
0.00000	0.00000
1.00000	1.00000
0.99930	1.00000
1.00000	1.00000
0.99923	1.00000
1.00000	1.00000
1.00000	1.00000
1.00000	1.00000
0.99996	1.00000
0.99780	1.00000
0.00000	0.00000
1.00000	1.00000
1.00000	1.00000
0.00000	0.00000
1.00000	1.00000
0.99917	1.00000
1.00000	1.00000
0.00005	0.00000
0.99933	1.00000
0.00000	0.00000
1.00000	1.00000
1.00000	1.00000

The output vector of the threshold function, illustrated in Table 6-73, is used as an input vector by the SSP of IRS #7 to generate the energizing restoration sequence of transmission paths for *Island #7*. The output vector generated by the SSP for the input vector illustrated in Table 6-73 is presented in Table 6-74.

Table 6-74 Output Pattern of the SSP for a Specific Power System Restoration Scenario

Restoration Sequence	*Transmission Path Number*
1	83
2	81
3	175
4	233
5	265
6	266
7	141
8	137
9	136
10	118
11	138
12	66
13	140
14	144
15	280
16	281
17	282
18	142
19	268
20	171
21	170
22	269
23	271

With the output vector generated by the SSP, the restoration plan from IRS #7 is established. In Figure 6-8 the final restoration configuration generated for IRS #7 is illustrated in the one line diagram of Island #7.

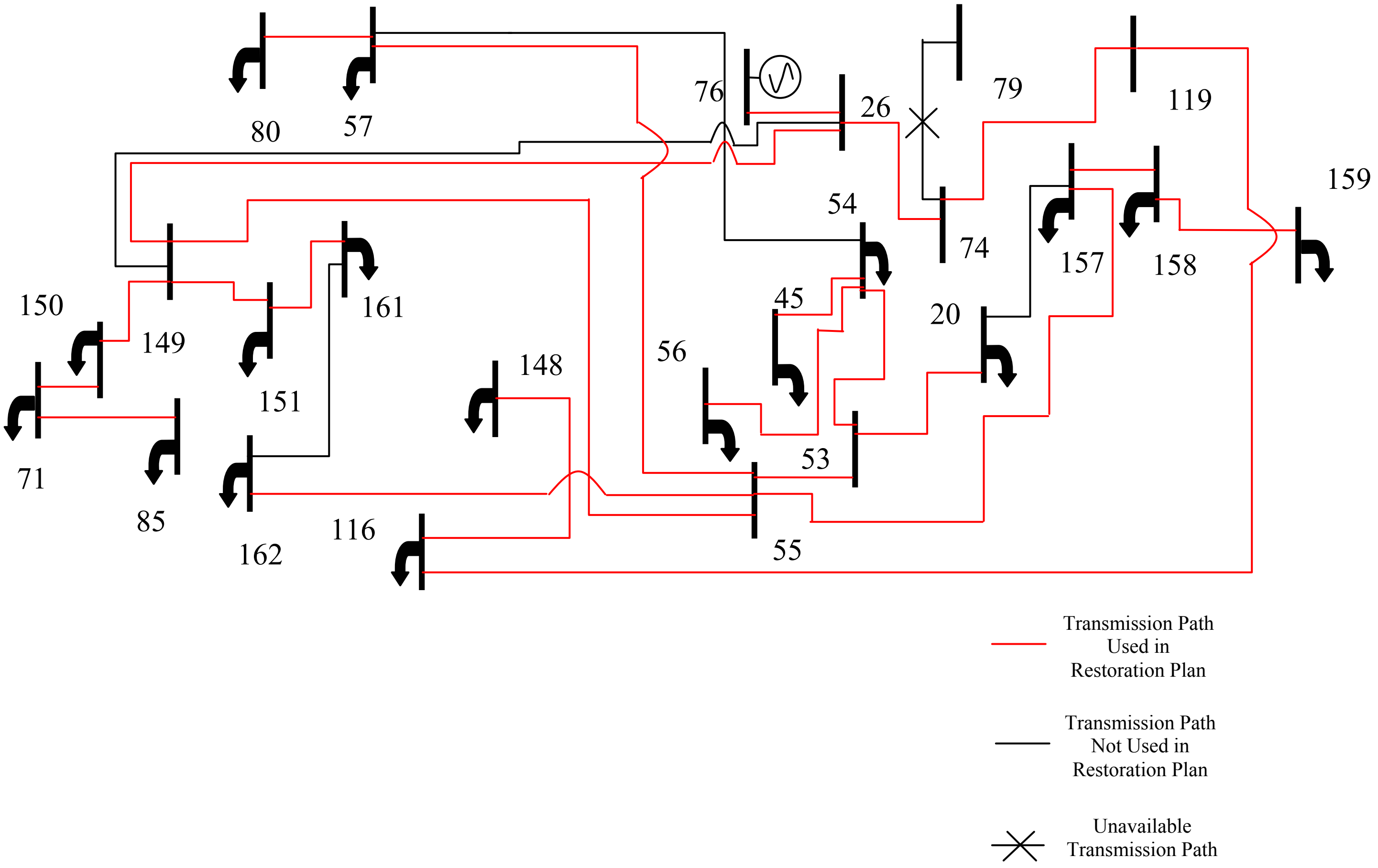


Figure 6-8 Restored Island Configuration Generated by IRS #7

The configuration of the restored island together with the load pick-up value was tested for system operating feasibility using the load flow program ANAREDE. Table 6-75 presents the complex voltages of the island and the generation/load at each bus resulting from the load flow analysis.

Table 6-75 Load Flow Analysis of the Proposed IRS #7 Restoration Plan for a Specific Power System Restoration Scenario

Bus# / Name	*Bus Type*	*Voltage Magnitude*	*Generation MW/*	*Load MW/*	*Shunt/ Equivalent*

		/ Angle	*MVar*	*MVar*	
20	0	0.973	0	22.7	0
HINTON8	69	-15.7	0	7.5	0
26	0	1.042	0	0	-0.5
RAUN 3	345	-1.7	0	0	0
45	0	0.977	0	12	0
TRIBJI5	161	-23	0	3.2	0
53	0	0.982	0	0	0
SX CY 5	161	-14.2	0	0	0
54	0	0.977	14.2	56.4	0
WISDM 5	161	-22.5	5.4	17.7	0
55	0	0.982	0	0	0
PLYMH 5	161	-14	0	0	0
56	0	0.976	0	15.2	0
OSGOD 5	161	-23.4	0	4.4	0
57	0	0.975	0	29.1	0
SAC 5	161	-18.3	12	9.4	0
71	0	1.006	0	17.9	0.1
MONOA 5	161	-9.7	0	7.1	0
74	0	1.061	0	0	0
LEHIH 3	345	-5.2	0	0	0
76	2	1	369.8	0	0
NEAL34G	24	0	-12.4	0	0
80	0	0.971	0	9.5	0
POMEOY5	161	-18.9	0	3.1	0
85	0	0.994	0	24.3	0.1
CARRLL5	161	-11.7	-0.1	6.7	0
116	0	1.071	0	33.6	0
SYCAOR5	161	-7.4	0	6.7	0
119	0	1.049	0	0	0
SYCAOR3	345	-6.9	0	0	0
148	0	1.061	0	72	0
SYCAOR8	69	-8.9	0	14.4	0
149	0	1.021	0	0	0
RAUN 5	161	-7.2	0	0	0
150	0	1.02	0	2.9	0
NEAL4 5	161	-7.4	0	1	0
151	0	1.017	0	14.4	0
INTRCG5	161	-7.7	0	4.8	0
157	0	0.972	0	19.2	0
PLYMTH8	69	-15.7	0	6.2	0
158	0	0.958	0	9.6	0
LOGANP8	69	-16.8	0	3.4	0
159	0	0.956	0	4.8	0
MCCOOK8	69	-17	0	1.4	0
161	0	1.016	0	19.2	0
KELOG 5	161	-7.8	0	6.2	0
162	0	0.981	0	12	0

LEEDS 5	161	-14.2	0	3.8	0

The results from the load flow analysis illustrated in Table 6-75 reveal that no voltage, angle difference or generation capability constraints were violated. Table 6-76 presents the line power flow results of the load flow analysis. These are the real and reactive power flowing through the transmission paths of island #7 and the specified thermal limits of the transmission paths.

Table 6-76 Power Flow through Transmission Paths of the Restoration Plan for a Specific Power System Restoration Scenario

Bus # / Name	*Bus Type*	*Voltage Magnitude / Angle*	*To Bus # / Name*	*Voltage / Circuit #*	*Real Flow (MW)*	*Reactive Flow (MVar)*	*Tap*	*Power Flow Limit (MVar)*
20	0	0.973						
HINTON8	69	-15.7						
			53 SX CY 5	161 1	-22.7	-7.5	1	75
26	0	1.042						
RAUN 3	345	-1.7						
			74 LEHIH 3	345 1	106.7	-91.4		2484
			76 NEAL34G	24 1	-369.8	23.6	1.04	1250
			149 RAUN 5	161 1	263.1	67.3		
45	0	0.977						
TRIBJI5	161	-23						
			54 WISDM 5	161 1	-12	-0.2		354
53	0	0.982						
SX CY 5	161	-14.2						
			20 HINTON8	69 1	22.7	8.2		75
			54 WISDM 5	161 1	70.9	-7.2		177
			55 PLYMH 5	161 1	-93.6	-1		538
54	0	0.977						
WISDM 5	161	-22.5						
			45 TRIBJI5	161 1	12	-2.3		354
			53 SX CY 5	161 1	-69.4	8.2		177
			56 OSGOD 5	161 1	15.2	-3.5		354
55	0	0.982						
PLYMH 5	161	-14						
			53 SX CY 5	161 1	93.6	1		538
			57 SAC 5	161 1	39.4	-8.7		375
			149 RAUN 5	161 1	-178.7	-7.3		357
			157 PLYMTH8	69 1	33.7	12.1		150
			162 LEEDS 5	161 1	12	2.9		538
56	0	0.976						
OSGOD 5	161	-23.4						
			54 WISDM 5	161 1	-15.2	-0.4		354

57	0	0.975						
SAC 5	161	-18.3						
			55 PLYMH 5	161 1	-38.6	3.9		375
			80 POMEOY5	161 1	9.5	-1.3		180
71	0	1.006						
MONOA 5	161	-9.7						
			85 CARRLL5	161 1	24.5	0.5		351
			150 NEAL4 5	161 1	-42.4	-7.5		361
74	0	1.061						
LEHIH 3	345	-5.2						
			26 RAUN 3	345 1	-105.9	-4		2484
			119 SYCAOR3	345 1	105.9	4		3450
76	2	1						
NEAL34G	24	0						
			26 RAUN 3	345 1	369.8	-12.4		1250
80	0	0.971						
POMEOY5	161	-18.9						
			57 SAC 5	161 1	-9.5	-3.1		180
85	0	0.994						
CARRLL5	161	-11.7						
			71 MONOA 5	161 1	-24.3	-6.7		351
116	0	1.071						
SYCAOR5	161	-7.4						
			119 SYCAOR3	345 1	-105.6	-53.2	1.025	1000
			148 SYCAOR8	69 1	72	26.5		160
119	0	1.049						
SYCAOR3	345	-6.9						
			74 LEHIH 3	345 1	-105.6	-54.4		3450
			116 SYCAOR5	161 1	105.6	54.4		1000
148	0	1.061						
SYCAOR8	69	-8.9						
			116 SYCAOR5	161 1	-72	-24.4	1	160
149	0	1.021						
RAUN 5	161	-7.2						
			26 RAUN 3	345 1	-263.1	-41	1	300
			55 PLYMH 5	161 1	183.8	26.5		357
			150 NEAL4 5	161 1	45.7	5.4		538
			151 INTRCG5	161 1	33.7	9.2		538
150	0	1.02						
NEAL4 5	161	-7.4						
			71 MONOA 5	161 1	42.7	4.5		361
			149 RAUN 5	161 1	-45.6	-5.5		538
151	0	1.017						
INTRCG5	161	-7.7						
			149 RAUN 5	161 1	-33.6	-10.3		538
			161 KELOG 5	161 1	19.2	5.5		538
157	0	0.972						
PLYMTH8	69	-15.7						
			55 PLYMH 5	161 1	-33.7	-11	1	150
			158 LOGANP8	69 1	14.5	4.8		50

158	0	0.958						
LOGANP8	69	-16.8						
			157 PLYMTH8	69	1	-14.4	-4.7	50
			159 MCCOOK8	69	1	4.8	1.3	50
159	0	0.956						
MCCOOK8	69	-17						
			158 LOGANP8	69	1	-4.8	-1.4	50
161	0	1.016						
KELOG 5	161	-7.8						
			151 INTRCG5	161	1	-19.2	-6.2	538
162	0	0.981						
LEEDS 5	161	-14.2						
			55 PLYMH 5	161	1	-12	-3.8	538

By analyzing the results of Table 6-76, it is possible to observe that the power flow thermal constraints of all transmission paths of the island were respected. The load flow results in Tables 6-75 and 6-76 shows that the restoration plan proposed by IRS #7 for the restoration scenario will generate a feasible operating condition.

Several other restoration scenarios were presented to IRS #7 and had their restoration plans checked for operating feasibility by load flow analysis using the load flow program ANAREDE. All restoration scenarios presented to IRS#7 were different from the ones used to train the ANNs of the respective IRS. In Table 6-77 the results encountered by the application of these tests are presented.

Table 6-77 Feasibility Check of Restoration Plans generated by IRS #7 for Test Restoration Scenarios

Test Restoration Scenarios #	*Feasible Restoration Plans*	*Unfeasible Restoration Plans*
174	174	0

From these results it is concluded that IRS #7 is capable of generating feasible PSR plans even when new restoration scenarios are presented.

6.8. Island #8 Restoration Plan Development Under Unseen Restoration Conditions

Electric Island # 8 is composed of 2 generators, 13 loads and 16 transmission paths. IRS #8 is responsible for a restoration plan builder for this island when a wide-area disturbance occurs. In order to check the capability of IRS #8 to generate feasible restoration plans when new restoration scenarios are presented several tests were conducted. Before presenting the final test results, it will be presented one detailed example. Consider the test restoration scenario with a pre disturbance load pattern as presented in Table 6-78.

Table 6-78 Pre Disturbance Load Pattern of Island #8

Bus Number	*Load Demand (MW)*
92	32.5
91	46.1
94	147.6
95	105.5
107	31.9
97	20.5
98	136.0
105	22.3
122	42.6
44	14.7
102	14.9
52	196.4
48	30.4

Assume also that due to a permanent fault in the transmission path between buses 52 and 118, this path is unavailable for use in the restoration of the island as shown in Table 6-79.

Table 6-79 Post Disturbance Data of Island #8

Bus Number	*Bus Number*	*Transmission Path Identification Number*
52	118	134

With the post and pre disturbance data obtained, the input data of the IRS #8 can be calculated by the normalization of these values using the pre-determined normalization constraints. Table 6-80 presents the inputs of ANN #1 and #2 for the restoration scenario. Again the input vector of ANN #2 will be formed with the addition of ANN #1 scalar output.

Table 6-80 Input Pattern of IRS #8 for a Specific Power System Restoration Scenario

Input Vector of ANN #1	*Partial Input Vector of ANN #2*
0.1355	0.6175
0.1922	0.4262
0.6155	0.9672
0.4399	-
0.1329	-
0.0856	-
0.5671	-
0.0931	-
0.1775	-
0.0612	-
0.0619	-
0.8189	-
0.1269	-

With the input pattern provided ANN #1 can calculate the forecast restoration load. The output of ANN #1 for the input vector illustrated in Table 6-80 is presented in Table 6-81.

Table 6-81 Output Pattern of ANN #1 for a Specific Power System Restoration Scenario

Output of ANN #1
0.45318

With the output of ANN #1 calculated, the input pattern of ANN #2 is formed by including this value in the already normalized post disturbance vector. The input vector of ANN #2 is presented in Table 6-82.

Table 6-82 Input Pattern of ANN #2 for a Specific Power System Restoration Scenario

Partial Input Vector of ANN #2
0.6175
0.45318
0.4262
0.9672

ANN #2 will process this input pattern and generate an output vector representing the final restoration configuration and the percentage of load that can be picked-up with this configuration. Table 6-83 illustrates the output vector generated by ANN #2 of IRS #8.

Table 6-83 Output Pattern of ANN #2 for a Specific Power System Restoration Scenario

Output Vector of ANN #2
0.99968
0.99798
1.00000
1.00000
0.99890
0.99891
0.99978
1.00000
1.00000
1.00000
0.99877
1.00000
0.00000
0.00109
1.00000
0.99876
0.18587

The output vector generated by ANN #2 without the last element that represents the load percentage pick-up will pass through a threshold function. Table 6-84 illustrates the input/output of the threshold function.

Table 6-84 Output Pattern of Threshold Function for a Specific Power System Restoration Scenario

Input Vector of Threshold Function	*Output Vector of Threshold Function*
0.99968	1.00000
0.99798	1.00000
1.00000	1.00000
1.00000	1.00000
0.99890	1.00000
0.99891	1.00000
0.99978	1.00000
1.00000	1.00000

1.00000	1.00000
1.00000	1.00000
0.99877	1.00000
1.00000	1.00000
0.00000	0.00000
0.00109	0.00000
1.00000	1.00000
0.99876	1.00000

The output vector of the threshold function, illustrated in Table 6-84, is used as an input vector by the SSP of IRS #8 to generate the energizing restoration sequence of transmission paths for *Island #8*. The output vector generated by the SSP for the input vector illustrated in Table 6-84 is presented in Table 6-85.

Table 6-85 Output Pattern of the SSP for a Specific Power System Restoration Scenario

Restoration Sequence	***Transmission Path Number***
1	204
2	200
3	191
4	193
5	198
6	216
7	131
8	124
9	217
10	202
11	207
12	116
13	203
14	209

With the output vector generated by the SSP, the restoration plan from IRS #8 is established. In Figure 6-9 the final restoration configuration generated for IRS #8 is illustrated in the one line diagram of Island #8.

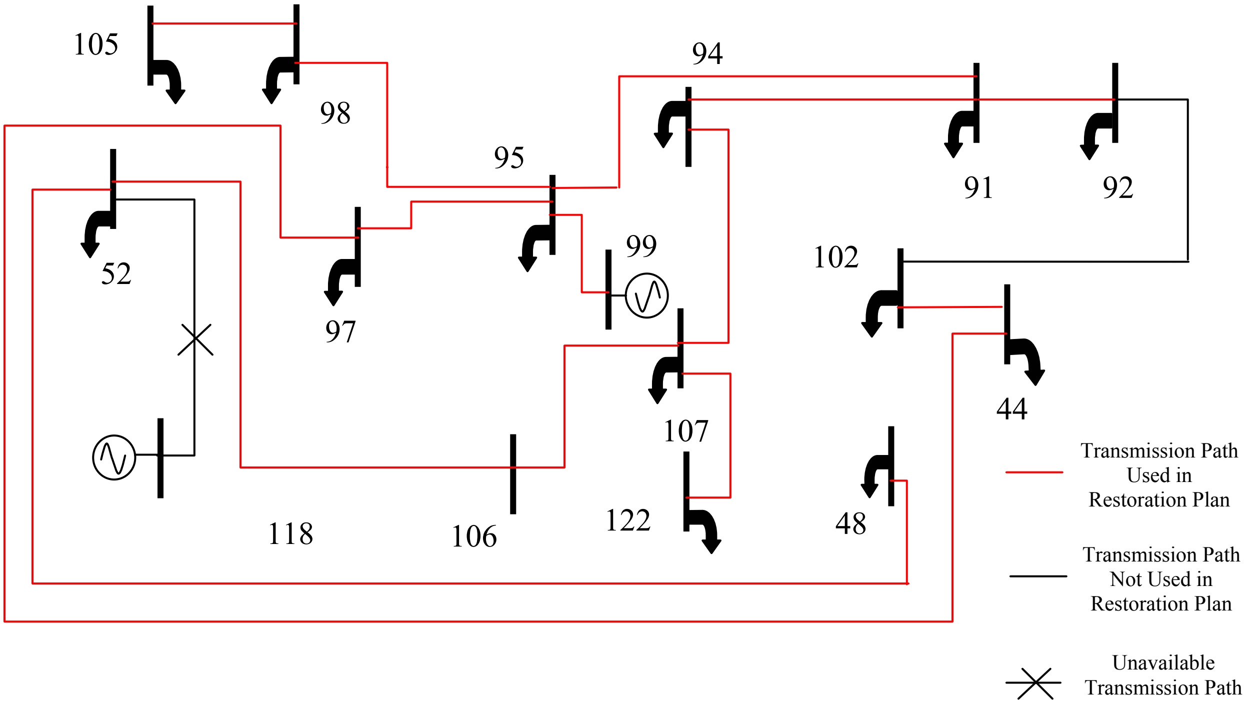


Figure 6-9 Restored Island Configuration Generated by IRS #8

The configuration of the restored island together with the load pick-up value was tested for system operating feasibility using the load flow program ANAREDE. Table 6-86 presents the complex voltages of the island and the generation/load at each bus resulting from the load flow analysis.

Table 6-86 Load Flow Analysis of the Proposed IRS #8 Restoration Plan for a Specific Power System Restoration Scenario

Bus# / Name	*Bus Type*	*Voltage Magnitude / Angle*	*Generation MW/ MVar*	*Load MW/ MVar*	*Shunt/ Equivalent*
44	0	0.987	0	2.7	0
CALUS 5	161	-8.3	0	0.6	0
48	0	0.942	10.1	15.7	0
CRESN 5	161	-25.3	5	3.8	0
52	0	0.938	0	36.5	0
D.MON 5	161	-24.5	0	7.2	0
91	0	0.992	0	8.6	0

CDRPS 5	161	-9.1	0	2.1	0
92	0	0.992	0	6	0
WYOMG 5	161	-9.4	0	1.5	0
94	0	0.982	0	27.5	0
HILL 5	161	-14	0	1.1	0
95	0	1.019	0	19.6	0
PRARCK7	115	-6.4	0	6.5	0
97	0	1.011	0	3.8	0
CALUS 7	115	-8	0	0.9	0
98	0	1.016	0	25.3	0
SIX T 7	115	-7.1	5	8.4	0
99	2	1	161.2	0	0
PRARK4G	18	0	25.2	0	0
102	0	0.986	0	2.8	0
MQOKTA5	161	-8.4	0	0.7	0
105	0	1.012	0	4.2	0
DUNDE 7	115	-7.8	0	1	0
106	0	0.947	0	0	0
MONRE 5	161	-22.6	0	0	0
107	0	0.954	0	5.9	0
POWAHK5	161	-20.9	0	0.9	0
122	0	0.952	0	7.9	0
OSKLOS5	161	-21.2	0	1.6	0

The results from the load flow analysis illustrated in Table 6-86 reveal that no voltage, angle difference or generation capability constraints were violated. Table 6-87 presents the line power flow results of the load flow analysis. These are the real and reactive powers flowing through the transmission paths of island #8 and the specified thermal limits of the transmission paths.

Table 6-87 Power Flow through Transmission Paths of the Restoration Plan for a Specific Power System Restoration Scenario

Bus # / Name	*Bus Type*	*Voltage Magnitude / Angle*	*To Bus # / Name*	*Voltage / Circuit #*	*Real Flow (MW)*	*Reactive Flow (MVar)*	*Tap*	*Power Flow Limit (MVar)*
44	0	0.987						
CALUS 5	161	-8.3						
			97 CALUS 7	115 1	-5.5	1		75
			102 MQOKTA5	161 1	2.8	-1.6		
48	0	0.942						
CRESN 5	161	-25.3						2484
			52 D.MON 5	161 1	-5.5	1.2		1250
52	0	0.938						

D.MON 5	161	-24.5						
			48 CRESN 5	161 1	5.5	-7.7		
			106 MONRE 5	161 1	-41.6	0.7		354
91	0	0.992						
CDRPS 5	161	-9.1						
			92 WYOMG 5	161 1	6	-2.2		75
			94 HILL 5	161 1	87.4	-1		177
			95 PRARCK7	115 1	-102	1.1		538
92	0	0.992						
WYOMG 5	161	-9.4						
			91 CDRPS 5	161 1	-6	-1.5		354
94	0	0.982						177
HILL 5	161	-14						354
			91 CDRPS 5	161 1	-86.3	3.8		
			107 POWAHK5	161 1	58.8	-4.9		
95	0	1.019						538
PRARCK7	115	-6.4						375
			91 CDRPS 5	161 1	102.6	4.1	1.02	357
			97 CALUS 7	115 1	9.4	-3		150
			98 SIX T 7	115 1	29.6	-0.7		538
			99 PRARK4G	18 1	-161.2	-6.9	1.03	
97	0	1.011						
CALUS 7	115	-8						354
			44 CALUS 5	161 1	5.5	-0.7	1.025	
			95 PRARCK7	115 1	-9.3	-0.2		
98	0	1.016						375
SIX T 7	115	-7.1						180
			95 PRARCK7	115 1	-29.5	-1.3		
			105 DUNDE 7	115 1	4.2	-2.1		
99	2	1						351
PRARK4G	18	0						361
			95 PRARCK7	115 1	161.2	25.2		
102	0	0.986						
MQOKTA5	161	-8.4						2484
			44 CALUS 5	161 1	-2.8	-0.7		3450
105	0	1.012						
DUNDE 7	115	-7.8						
			98 SIX T 7	115 1	-4.2	-1		1250
106	0	0.947						
MONRE 5	161	-22.6						180
			52 D.MON 5	161 1	42.1	-2.1		
			107 POWAHK5	161 1	-42.4	2.5		
107	0	0.954						351
POWAHK5	161	-20.9						
			94 HILL 5	161 1	-56.6	3.8		
			106 MONRE 5	161 1	42.8	-3.7		1000
			122 OSKLOS5	161 1	7.9	-1		160
122	0	0.952						
OSKLOS5	161	-21.2						
			107 POWAHK5	161 1	-7.9	-1.6		3450

By analyzing the results of Table 6-87, it is possible to observe that the power flow thermal constraints of all transmission paths of the island were respected. The load flow results in Tables 6-86 and 6-87 shows that the restoration plan proposed by IRS #8 for the restoration scenario will generate a feasible operating condition.

Several other restoration scenarios were presented to IRS #8 and had their restoration plans checked for operating feasibility by load flow analysis using the load flow program ANAREDE. All restoration scenarios presented to IRS#8 were different from the ones used to train the ANNs of the respective IRS. In Table 6-88 the results encountered by the application of these tests are presented.

Table 6-88 Feasibility Check of Restoration Plans generated by IRS #8 for Test Restoration Scenarios

Test Restoration Scenarios #	*Feasible Restoration Plans*	*Unfeasible Restoration Plans*
96	96	0

From these results it is concluded that IRS #8 is capable of generating feasible PSR plans even when new restoration scenarios are presented.

6.9. Island #9 Restoration Plan Development Under Unseen Restoration Conditions

Electric Island # 9 is composed of 1 generator, 5 loads and 8 transmission paths. IRS #9 is responsible for a restoration plan builder for this island when a wide-area disturbance occurs. In order to check the capability of IRS #9 to generate feasible restoration plans when new restoration scenarios are presented several tests were again conducted. Before presenting the final test results, it will be presented again one detailed example. Consider the test restoration scenario with a pre disturbance load pattern as presented in Table 6-89.

Table 6-89 Pre Disturbance Load Pattern of Island #9

Bus Number	***Load Demand (MW)***
154	29.4
160	15.1
153	4.2

156	8.4
155	12.6

Assume also that due to a permanent fault in the transmission path between buses 155 and 156, this path is unavailable for use in the restoration of the island as shown in Table 6-90.

Table 6-90 Post Disturbance Data of Island #9

Bus Number	*Bus Number*	*Transmission Path Identification Number*
155	156	278

With the post and pre disturbance data obtained, the input data of the IRS #9 can be calculated by the normalization of these values using the pre-determined normalization constraints. Table 6-91 presents the inputs of ANN #1 and #2 for the restoration scenario. Again the input vector of ANN #2 will be formed with the addition of ANN #1 scalar output.

Table 6-91 Input Pattern of IRS #9 for a Specific Power System Restoration Scenario

Input Vector of ANN #1	*Partial Input Vector of ANN #2*
0.9545	1.0000
0.4909	0.9688
0.1364	0.9750
0.2727	-
0.4091	-

With the input pattern provided ANN #1 can calculate the forecast restoration load. The output of ANN #1 for the input vector illustrated in Table 6-91 is presented in Table 6-92.

Table 6-92 Output Pattern of ANN #1 for a Specific Power System Restoration Scenario

Output of ANN #1
0.52488

With the output of ANN #1 calculated, the input pattern of ANN #2 is formed by including this value in the already normalized post area disturbance vector. The input vector of ANN #2 is presented in Table 6-93.

Table 6-93 Input Pattern of ANN #2 for a Specific Power System Restoration Scenario

Partial Input Vector of ANN #2
1.0000
0.52488
0.9688
0.9750

ANN #2 will process this input pattern and generate an output vector representing the final restoration configuration and the percentage of load that can be picked-up with this configuration. Table 6-94 illustrates the output vector generated by ANN #2 of IRS #9.

Table 6-94 Output Pattern of ANN #2 for a Specific Power System Restoration Scenario

Output Vector of ANN #2
0.00052
1.00000
1.00000
0.99962
0.99950
1.00000
0.00000
0.99997
0.76968

The output vector generated by ANN #2 without the last element that represents the load percentage pick-up will pass through a threshold function. Table 6-95 illustrates the input/output of the threshold function.

Table 6-95 Output Pattern of Threshold Function for a Specific Power System Restoration Scenario

Input Vector of Threshold Function	*Output Vector of Threshold Function*
0.00052	0.00000
1.00000	1.00000
1.00000	1.00000
0.99962	1.00000
0.99950	1.00000

1.00000	1.00000
0.00000	0.00000
0.99997	1.00000

The output vector of the threshold function, illustrated in Table 6-95, is used as an input vector by the SSP of IRS #9 to generate the energizing restoration sequence of transmission paths for *Island #9*. The output vector generated by the SSP for the input vector illustrated in Table 6-95 is presented in Table 6-96.

Table 6-96 Output Pattern of the SSP for a Specific Power System Restoration Scenario

Restoration Sequence	***Transmission Path Number***
1	167
2	272
3	275
4	274
5	276
6	277

With the output vector generated by the SSP, the restoration plan from IRS #9 is established. In Figure 6-10 the final restoration configuration generated for IRS #9 is illustrated in the one line diagram of Island #9.

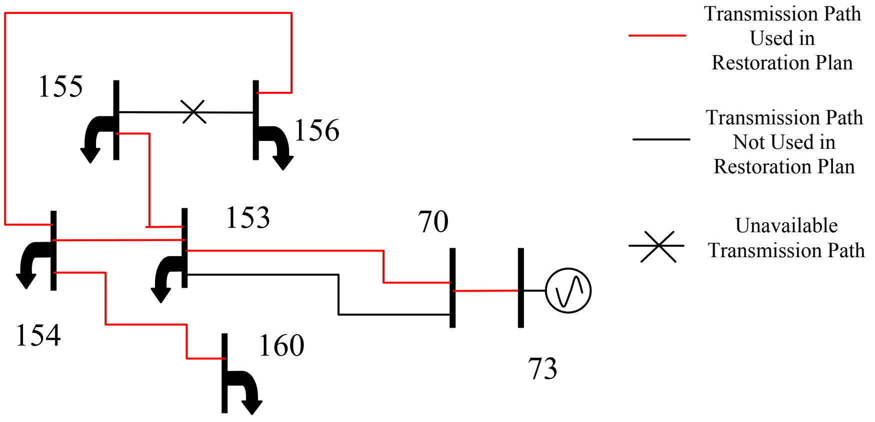


Figure 6-10 Restored Island Configuration Generated by IRS #9

The configuration of the restored island together with the load pick-up value was tested for system operating feasibility using the load flow program ANAREDE. Table 6-97 presents the complex voltages of the island and the generation/load at each bus resulting from the load flow analysis.

Table 6-97 Load Flow Analysis of the Proposed IRS #9 Restoration Plan for a Specific Power System Restoration Scenario

Bus# / Name	*Bus Type*	*Voltage Magnitude / Angle*	*Generation MW/ MVar*	*Load MW/ MVar*	*Shunt/ Equivalent*
70 NEAL 5	0 161	1.035 -0.6	0 0	0 0	0 0
73 NEAL12G	2 20	1 0	55.1 26.8	0 0	0 0
153 NEAL 8	0 69	1.013 -3.4	0 0	3.2 1.3	0 0
154 KELLOG8	0 69	0.936 -9.8	0 0	22.6 7.8	0.1 0
155 M SIDE8	0 69	1.003 -4.3	0 0	9.7 3.2	0 0
156 E SIDE8	0 69	0.934 -10	0 0	6.5 1.9	0 0
160 PRARCK7	0 115	0.933 -6.4	0 0	11.6 6.5	0 0

The results from the load flow analysis illustrated in Table 6-97 reveal that no voltage, angle difference or generation capability constraints were violated. Table 6-98 presents the line power flow results of the load flow analysis. These are the real and reactive powers flowing through the transmission paths of island #9 and the specified thermal limits of the transmission paths.

Table 6-98 Power Flow through Transmission Paths of the Restoration Plan for a Specific Power System Restoration Scenario

Bus # / Name	*Bus Type*	*Voltage Magnitude / Angle*	*To Bus # / Name*	*Voltage / Circuit #*	*Real Flow (MW)*	*Reactive Flow (MVar)*	*Tap*	*Power Flow Limit (MVar)*
70	0	1.035						

NEAL 5	161	-0.6						
			73 NEAL12G	20 1	-55.1	-26	1.04	495
			153 NEAL 8	69 1	55.1	26		93
73	2	1						
NEAL12G	20	0						
			70 NEAL 5	161 1	55.1	26.8		495
153	0	1.013						
NEAL 8	69	-3.4						
			70 NEAL 5	161 1	-55.1	-22.8	1	93
			154 KELLOG8	69 1	42.1	18.6		50
			155 M SIDE8	69 1	9.7	3		66
154	0	0.936						
KELLOG8	69	-9.8						
			153 NEAL 8	69 1	-40.7	-13.2		50
			156 E SIDE8	69 1	6.5	1.9		50
			160 SC WST8	69 1	11.6	3.8		50
155	0	1.003						
M SIDE8	69	-4.3						
			153 NEAL 8	69 1	-9.7	-3.2		66
156	0	0.934						
E SIDE8	69	-10						
			154 KELLOG8	69 1	-6.5	-1.9		50
160	0	0.933						
SC WST8	69	-10.1						
			154 KELLOG8	69 1	-11.5	-3.8		50

By analyzing the results of Table 6-98, it is possible to observe that the power flow thermal constraints of all transmission paths of the island were respected. The load flow results in Tables 6-97 and 6-98 shows that the restoration plan proposed by the IRS #9 for the restoration scenario will generate a feasible operating condition.

Several other restoration scenarios were presented to IRS #9 and had their restoration plans checked for operating feasibility by load flow analysis using the load flow program ANAREDE. All restoration scenarios presented to IRS#9 were different from the ones used to train the ANNs of the respective IRS. In Table 6-99 the results encountered by the application of these tests are presented.

Table 6-99 Feasibility Check of Restoration Plans generated by IRS #9 for Test Restoration Scenarios

Test Restoration Scenarios #	*Feasible Restoration Plans*	*Unfeasible Restoration Plans*

48	48	0

From these results it is concluded that IRS #9 is capable of generating feasible PSR plans even when new restoration scenarios are presented.

6.10. Island #10 Restoration Plan Development Under Unseen Restoration Conditions

Electric Island # 10 is composed of 1 generator, 9 loads and 11 transmission paths. IRS #10 is responsible for a restoration plan builder for this island when a wide-area disturbance occurs. In order to check the capability of IRS #10 to generate feasible restoration plans when new restoration scenarios are presented several tests were conducted. Before presenting the final test results, it will be presented again one detailed example. Consider the test restoration scenario with a pre disturbance load pattern as presented in Table 6-100.

Table 6-100 Pre Disturbance Real Load Pattern of Island #10

Bus Number	*Load Demand (MW)*
87	17.7
104	33.1
100	24.4
96	125.2
88	63.6
90	52.7
86	53.2
49	7.1
47	5.0

Assume also that due to equipment failure in one of the circuit breakers of the transmission path between buses 90 and 96, this path is unavailable for use in the restoration of the island as shown in Table 101.

Table 6-101 Post Disturbance Data of Island #10

Bus Number	*Bus Number*	*Transmission Path Identification Number*
90	96	190

With the post and pre disturbance data obtained, the input data of the IRS #10 can be calculated by the normalization of these values using the pre-determined normalization constraints. Table 6-102 presents the inputs of ANN #1 and #2 for the restoration scenario. Again the input vector of ANN #2 will be formed with the addition of ANN #1 scalar output.

Table 6-102 Input Pattern of IRS #10 for a Specific Power System Restoration Scenario

Input Vector of ANN #1	*Partial Input Vector of ANN #2*
0.1353	0.9048
0.2522	0.8654
0.1858	0.9231
0.9545	-
0.4853	-
0.4020	-
0.4060	-
0.0545	-
0.0384	-

With the input pattern provided ANN #1 can calculate the forecast restoration load. The output of ANN #1 for the input vector illustrated in Table 6-102 is presented in Table 6-103.

Table 6-103 Output Pattern of ANN #1 for a Specific Power System Restoration Scenario

Output of ANN #1
0.52463

With the output of ANN #1 calculated, the input pattern of ANN #2 is formed by including this value in the already normalized post disturbance vector. The input vector of ANN #2 is shown in Table 6-104.

Table 6-104 Input Pattern of ANN #2 for a Specific Power System Restoration Scenario

Partial Input Vector of ANN #2
0.9048
0.52463
0.8654
0.9231

ANN #2 will process this input pattern and generate an output vector representing the final restoration configuration and the percentage of load that can be picked-up with this configuration. Table 6-105 illustrates the output vector generated by ANN #2 of IRS #10.

Table 6-105 Output Pattern of ANN #2 for a Specific Power System Restoration Scenario

Output Vector of ANN #2
0.00179
0.99915
0.99860
0.99941
0.99841
0.99956
1.00000
1.00000
1.00000
1.00000
0.99988
0.26040

The output vector generated by ANN #2 without the last element that represents the load percentage pick-up will pass through a threshold function. Table 6-106 illustrates the input/output of the threshold function.

Table 6-106 Output Pattern of Threshold Function for a Specific Power System Restoration Scenario

Input Vector of Threshold Function	***Output Vector of Threshold Function***
0.00179	0.00000
0.99915	1.00000
0.99860	1.00000
0.99941	1.00000
0.99841	1.00000
0.99956	1.00000
1.00000	1.00000
1.00000	1.00000
1.00000	1.00000
1.00000	1.00000
0.99988	1.00000

The output vector of the threshold function, illustrated in Table 6-106, is used as an input vector by the SSP of IRS #10 to generate the energizing restoration sequence of transmission paths for *Island #10*. The output vector generated by the SSP for the input vector illustrated in Table 6-106 is presented in Table 6-107.

Table 6-107 Output Pattern of the SSP for a Specific Power System Restoration Scenario

Restoration Sequence	*Transmission Path Number*
1	206
2	186
3	185
4	188
5	189
6	184
7	125
8	121
9	205
10	210

With the output vector generated by the SSP, the restoration plan from IRS #10 is established. In Figure 6-11 the final restoration configuration generated for IRS #10 is illustrated in the one line diagram of Island #10.

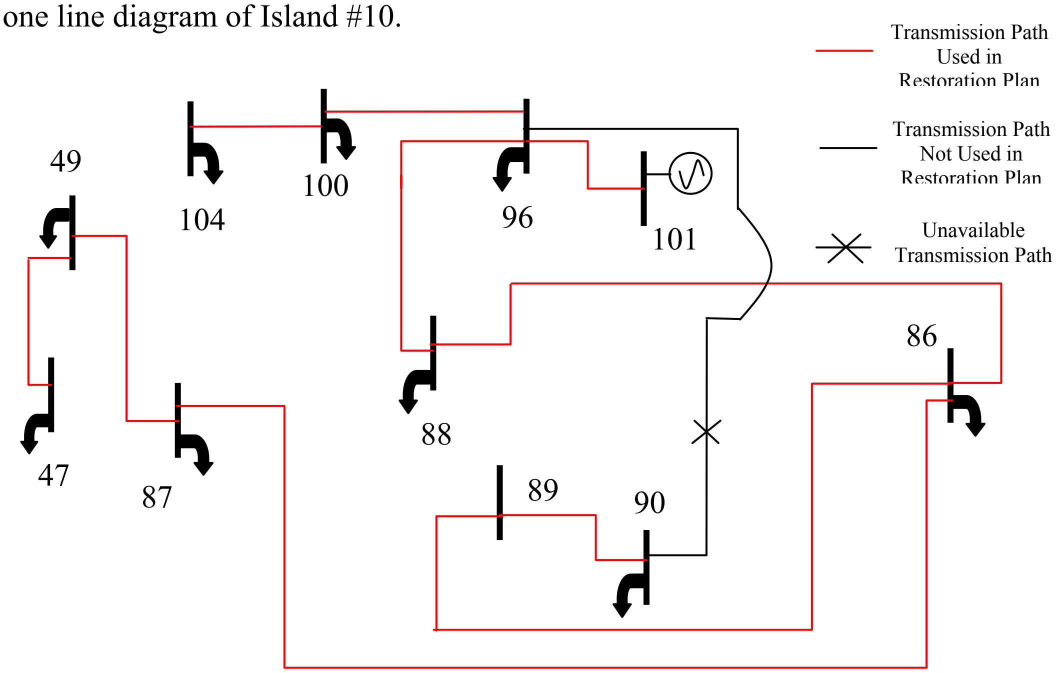


Figure 6-11 Restored Island Configuration Generated by IRS #10

The configuration of the restored island together with the load pick-up value was tested for system operating feasibility using the load flow program ANAREDE. Table 6-108 presents the complex voltages of the island and the generation/load at each bus resulting from the load flow analysis.

Table 6-108 Load Flow Analysis of the Proposed IRS #10 Restoration Plan for a Specific Power System Restoration Scenario

Bus# / Name	*Bus Type*	*Voltage Magnitude / Angle*	*Generation MW/ MVar*	*Load MW/ MVar*	*Shunt/ Equivalent*
47	0	0.986	0	1.3	0
ANITTP5	161	-19.4	0	0.4	0
49	0	0.987	0	1.9	0
ANIT 5	161	-19.4	0	0.5	0
86	0	0.984	0	13.9	0.1
GR JT 5	161	-18.7	0	3.6	0
87	0	0.986	0	4.6	0
GUTHIE7	115	-19.3	0	1.1	0
88	0	0.992	0	16.6	0
JASPR 8	69	-13.9	0	1.2	0
89	0	1.007	0	0	0
GR JT 7	115	-19.2	0	0	0
90	0	0.992	0	13.7	0.1
BOON 7	115	-20.1	0	4.6	0
96	0	1.023	0	32.6	0
MTOW 7	115	-6.1	0	0	0
100	0	1.009	0	6.4	0
WELSRG7	115	-7.4	0	1.9	0
101	2	1	102.6	0	0
MTOW 3G	14	0	12	0	0
104	0	1.001	0	8.6	0.1
IA FS 7	115	-8	0	2.9	0

The results from the load flow analysis illustrated in Table 6-108 reveal that no voltage, angle difference or generation capability constraints were violated. Table 6-109 presents the line power flow results of the load flow analysis. These are the real and reactive power flowing through the transmission paths of island #10 and the specified thermal limits of the transmission paths.

Table 6-109 Power Flow through Transmission Paths of the Restoration Plan for a Specific Power System Restoration Scenario

Bus # / Name	Bus Type	Voltage Magnitude / Angle	To Bus # / Name	Voltage / Circuit #	Real Flow (MW)	Reactive Flow (MVar)	Tap	Power Flow Limit (MVar)
47	0	0.986						
ANITTP5	161	-19.4						
			49 ANIT 5	161 1	-1.3	-0.4		-
49	0	0.987						
ANIT 5	161	-19.4						
			47 ANITTP5	161 1	1.3	-0.1		-
			87 GUTHIE7	115 1	-3.2	-0.4		-
86	0	0.984						
GR JT 5	161	-18.7						
			87 GUTHIE7	115 1	7.7	-6.3		325
			88 JASPR 8	69 1	-35.3	-0.3		180
			89 GR JT 7	115 1	13.6	3.3		90
87	0	0.986						
GUTHIE7	115	-19.3						
			49 ANIT 5	161 1	3.2	-2.2		-
			86 GR JT 5	161 1	-7.7	1.1		325
88	0	0.992						
JASPR 8	69	-13.9						
			86 GR JT 5	161 1	35.9	-7.4		180
			96 MTOW 7	115 1	-52.6	6.3		69
89	0	1.007						
GR JT 7	115	-19.2						
			86 GR JT 5	161 1	-13.6	-3.2	1.025	90
			90 BOON 7	115 1	13.6	3.4		69
90	0	0.992						
BOON 7	115	-20.1						
			89 GR JT 7	115 1	-13.4	-4.5		69
96	0	1.023						
MTOW 7	115	-6.1						
			88 JASPR 8	69 1	54.8	-0.6		69
			100 WELSRG7	115 1	15.2	1.6		69
			101 MTOW 3G	14 1	-102.6	-1	1.03	96
100	0	1.009						
WELSRG7	115	-7.4						
			96 MTOW 7	115 1	-15	-3.1		69
			104 IA FS 7	115 1	8.6	1.2		69
101	2	1						
MTOW 3G	14	0						
			96 MTOW 7	115 1	102.6	12		96
104	0	1.001						
IA FS 7	115	-8						

	100 WELSRG7	115 1	-8.6	-2.8	69

By analyzing the results of Table 6-109, it is possible to observe that the power flow thermal constraints of all transmission paths of the island were respected. The load flow results in Tables 6-108 and 6-109 shows that the restoration plan proposed by the IRS #10 for the restoration scenario will generate a feasible operating condition.

Several other restoration scenarios were presented to IRS #10 and had their restoration plans checked for operating feasibility by load flow analysis using the load flow program ANAREDE. All restoration scenarios presented to IRS#10 were different from the ones used to train the ANNs of the respective IRS. In Table 6-110 the results encountered by the application of these tests are presented.

Table 6-110 Feasibility Check of Restoration Plans generated by IRS #10 for Test Restoration Scenarios

Test Restoration Scenarios #	*Feasible Restoration Plans*	*Unfeasible Restoration Plans*
66	66	0

From these results it is concluded that IRS #10 is capable of generating feasible PSR plans even when new restoration scenarios are presented.

The test results presented previously show that each IRS is capable of developing feasible PSR plans even when new restoration scenarios are presented. The test results also indicate that the proposed PSR scheme has generalization capabilities, an important and necessary feature of successful PSR techniques. In the following section a comparison between the proposed PSR scheme and the PSR breadth search scheme will be presented. The focus of this comparison will be on the processing time required by both schemes to develop PSR plans. The following comparison tests intend to show the high processing speed of the proposed scheme.

6.11. Power System Restoration Breadth Search Scheme vs. ANN-Based Power System Restoration Scheme

The PSR breadth search scheme was used to generate training and validation patterns for ANNs #2 of each IRS of the proposed PSR scheme. The breadth search scheme generates island restoration configurations for any chosen restoration scenario. As previously explained, the breadth search scheme does not take into account the system non-linear equations, and is therefore unable to predict a load restoration pick up value. This value is only determined with the additional use of a load flow program and an exhaustive search for a percentage of load pick-up value that will generate a feasible operating condition. Since each island of the system will have its own final restoration configuration, this procedure must be carried out for each island. For the 162-bus system of study, the procedure must be carried out 10 times (for the10 islands) for each output of the breadth-search scheme.

The ANN-based scheme does not have this limitation. The scheme provides as an output the final restoration island configuration and the load pick up value for each electric island. Thus the PSR breadth search scheme does not provide the same information that the ANN-based scheme does. Aside from these differences, the processing time of the breadth search scheme will be compared with that of the ANN-based PSR scheme.

In order to compare the processing time used by each scheme to reach the PSR plan several tests were performed. The set of tests implemented correspond to a subset of the tests described in the previous sections. Before presenting the final results one example will be discussed in detail.

Consider that after a wide-area disturbance in the 162-bus test system a possible restoration scenario is as shown in Table 6-111.

Table 6-111 Unavailable Transmission Paths

Bus Number	*Bus Number*	*Transmission Path Identification Number*
135	138	251
12	14	39

58	61	145
51	141	129
16	27	52
22	40	72
20	53	66
44	102	116

Also assume that the pre disturbance load is as shown in Table 6-112.

Table 6-112 Pre Disturbance Load Pattern

Bus #	*Load (MW)*	*Bus #*	*Load (MW)*	*Bus #*	*Load (MW)*	*Bus #*	*Load (MW)*	*Bus #*	*Load (MW)*
3	333	38	13.3	72	384.3	102	14.9	143	19
8	358.2	40	47.6	77	23.8	103	289.8	144	11.2
10	203.4	41	35.3	78	71.2	104	28.4	145	9.7
12	813.7	43	37.4	80	14.2	105	22.3	146	19.2
13	363.6	44	14.7	81	45.8	107	31.9	147	194.8
14	9.9	45	18	82	56.1	111	58.9	148	108
18	31	46	58.8	84	34.1	113	29.4	150	4.3
19	58	47	4.3	85	36.5	115	15.6	151	21.6
20	34.1	48	30.4	86	45.6	116	50.5	152	5.4
22	15.7	49	6.1	87	15.2	117	91.7	153	3.6
23	57.1	50	89.7	88	54.5	122	42.6	154	25.2
27	291.6	52	196.4	90	45.2	123	148.5	155	10.8
28	34.6	54	63.3	91	46.1	132	143.1	156	7.2
29	25.5	56	22.8	92	32.5	133	27.1	157	28.8
30	91.1	57	43.6	93	93.4	134	15.8	158	14.4
31	65.3	59	76	94	147.6	135	18.1	159	7.2
32	47.4	60	219.6	95	105.5	136	18.1	160	13
33	40.7	63	53.2	96	107.3	137	18.1	161	28.8
34	12.8	67	20.3	97	20.5	139	9.1	162	18
35	49.1	68	36.4	98	136	140	12.2		
36	28.8	71	26.9	100	20.9	142	24.4		

With this information the breadth search program will calculate the final restoration configuration for each island. The output of the breadth search program is presented in Table 6-113.

Table 6-113 Output File of the Breadth Search Scheme for a Specific Restoration Scenario

```
Number of Islands Formed:
 10

 Buses in Islands:
-  0    0    0    0    0    0    0    1    2    3    5    6    7    8    9   12   13   14   75
113  129  130  131  132
-  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0   10   11   15
46   59   60   61   62
-  0    0    0    0    0    0   16   17   18   19   23   24   25   27   28   29   30   31   32
38   63   65  126  127
- 20   26   45   53   54   55   56   57   71   74   76   80   85  116  119  148  149  150  151
157  158  159  161  162
-  0    0    0    0    0   21   22   33   34   35   36   40   41   67   68   69   77   78   81
82   83   84   93  108
-  0    0    0    0    0    0    0    0    0    0    0    0    0   43   50   51  103  123  124
125  142  143  144  146
-  0    0    0    0    0    0    0    0   44   48   52   91   92   94   95   97   98   99  102
105  106  107  118  122
-  0    0    0    0    0    0    0    0    0    0    0    0    0    0   47   49   86   87   88
90   96  100  101  104
-  0    0    4   72  110  111  112  114  115  117  120  121  128  133  134  135  136  137  138
139  140  145  147  152
-  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0   70   73
153  154  155  156  160

 Lines in Islands:
-  0    0    0    0    0    0    1    2    4    5    6    7   18   19   20   21   25   27   28
37   44  177  246
-  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0   31   33   34
48  146  149  152
-  0    0    0    0    0   51   53   55   60   63   65   74   76   77   80   84   88   89   92
93  157  160  244
- 67   81   83  118  136  137  138  140  141  142  144  170  171  175  233  265  266  268  269
271  280  281  282
-  0    0    0    0    0   68   73   95   97   98   99  100  101  106  108  109  110  163  164
165  181  182  196
-  0    0    0    0    0    0    0    0    0    0    0  115  126  128  211  212  213  240  241
258  259  260  261
-  0    0    0    0    0    0    0    0  124  131  134  191  193  194  198  200  202  203  204
207  209  216  217
-  0    0    0    0    0    0    0    0    0    0    0    0    0    0  121  125  184  185  186
190  205  206  210
-  0   14   15  174  221  222  223  224  226  227  228  231  235  237  245  247  248  249  250
254  255  256  257
-  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0  167  272
274  275  276  277

 Final Generation(MW):
   6.00   15.00   16.00   17.00   21.00   62.00   65.00   73.00   76.00   99.00  101.00  108.00
114.00  118.00  121.00  124.00  125.00  126.00  127.00  130.00  131.00
   0.00    0.00    0.00    0.00    0.00   23.20    0.00   72.50   48.50    0.00   14.50   36.70
22.00    4.60    0.00   43.90    0.00    1.60    0.00   18.30    0.00

 Final Load(MW):
   3.00    8.00   10.00   12.00   13.00   14.00   16.00   18.00   19.00   20.00   22.00   23.00
27.00   28.00   29.00   30.00   31.00   32.00   33.00   34.00   35.00   36.00   38.00   40.00
41.00   43.00   44.00   45.00   46.00   47.00   48.00   49.00   50.00   52.00   54.00   56.00
57.00   59.00   60.00   63.00   67.00   68.00   71.00   72.00   77.00   78.00   80.00   81.00
82.00   84.00   85.00   86.00   87.00   88.00   90.00   91.00   92.00   93.00   94.00   95.00
96.00   97.00   98.00  100.00  102.00  103.00  104.00  105.00  107.00  111.00  113.00  115.00
116.00  117.00  122.00  123.00  132.00  133.00  134.00  135.00  136.00  137.00  139.00  140.00
142.00  143.00  144.00  145.00  146.00  147.00  148.00  150.00  151.00  152.00  153.00  154.00
155.00  156.00  157.00  158.00  159.00  160.00  161.00  162.00
   0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
```

```
0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00

 Running Time(s):
   233.8800
```

The Simulation was performed in a personal computer equipped with a Pentium III 720 MHz processor and with 512 MB of RAM. As can be observed from the output file, the breadth search scheme used 233.8 s of CPU time to develop the final island restoration configurations. For the same restoration scenario, the proposed ANN-based scheme generates the restoration plan information illustrated in Table 6-114.

Table 6-114 Output of the ANN-Based PSR Scheme for a Specific Restoration Scenario

	Island#1	*Island#2*	*Island#3*	*Island#4*	*Island#5*	*Island#6*	*Island#7*	*Island#8*	*Island#9*	*Island#10*
Path #1	228	5	31	213	55	196	83	204	167	206
Path #2	14	2	149	212	60	182	81	200	272	190
Path #3	15	1	33	211	93	110	175	191	275	186
Path #4	231	37	34	241	65	109	233	193	274	185
Path #5	235	19	48	128	244	181	265	194	276	125
Path #6	226	4	152	126	63	108	266	134	277	121
Path #7	223	7	146	258	88	68	141	131	-	205
Path #8	222	177	-	259	84	73	137	216	-	210
Path #9	221	28	-	260	92	106	136	198	-	-
Path #10	227	21	-	240	89	98	118	203	-	-
Path #11	237	6	-	261	80	95	138	209	-	-
Path #12	245	18	-	115	76	100	140	124	-	-
Path #13	174	246	-	-	74	97	144	217	-	-
Path #14	254	27	-	-	77	101	280	202	-	-
Path #15	257	20	-	-	157	99	281	207	-	-
Path #16	224	25	-	-	160	164	282	-	-	-
Path #17	247	44	-	-	53	163	142	-	-	-
Path #18	250	-	-	-	51	165	67	-	-	-
Path #19	255	-	-	-	-	-	268	-	-	-
Path #20	249	-	-	-	-	-	171	-	-	-
Path #21	248	-	-	-	-	-	170	-	-	-
Path #22	-	-	-	-	-	-	269	-	-	-
Path #23	-	-	-	-	-	-	271	-	-	-
Pick Up	83.33 %	83.33%	16.67%	27.03%	12.5%	17.09%	66.67%	16.67%	83.33%	31.33%
Time(s)	2.5	2.28	2.05	2.28	2.71	5.63	4.42	2.39	2.11	2.17
Total (s)	28.54									

The proposed ANN-based scheme generates as an output the final restoration switching sequence and the load percentage pick-up value. The total CPU time taken by the scheme to achieve the restoration plan was equal to 28.54 s. Comparing this value with the processing time taken by the breadth search program for the same restoration scenario it is clear that the ANN-based scheme is about 10 times faster. Further tests resulted in the same behavior pattern, the ANN-based scheme needed a much smaller processing time to achieve the restoration plan than the breadth search scheme under equal restoration scenarios. Table 6-115 presents additional 50 test results.

Table 6-115 CPU Processing Time for Specific Restoration Scenarios

	Breadth-Search Scheme	*ANN-Based Scheme*
Average CPU Processing Time(s)	155.5575	28.3334

In all the tests in which the processing time was measured, the proposed scheme was much faster than the breadth-search scheme. Thus it is concluded that in addition to providing more restoration plan information the ANN-based scheme also uses less processing time than the breadth-search scheme. The fast development of feasible restoration plans is an important feature for successful power system restoration techniques. The previously presented test results show that the proposed scheme is capable of generating feasible restoration plans using a minimum CPU time. With this speed of performance, the ANN-based technique is an excellent candidate for on-line EMS applications

Chapter 7. Conclusions

7.1. Conclusions

Power System Restoration is an area of great importance for today's society. Wide-area disturbances are rare events, however when they occur the effects on industries, commerce and the everyday life of the general population can be quit severe. In the aftermath of a blackout is of extreme importance to restore the electric power system in the shortest possible time.

In order to improve the system restoration when a system blackout occurs the majority of electric utilities contain pre-established restoration procedures and guidelines to advise the system operator to restore the system. However, these restoration guidelines and procedures have not enabled the system operator to achieve successful restoration plans when unforeseen restoration scenarios are encountered. The main factor that explains this lack of success is that after the occurrence of a wide-area disturbance the system operator is under intense pressure to restore the system in the minimum time possible. The inability to deal with this pressure and the appearance of unexpected restoration scenarios not covered in the restoration guidelines are known to lead the system operators to unsuccessful restoration attempts and the prolongation of the system disturbance.

In order to create feasible power system restoration plans to advise the system operator when a system blackout occurs, several restoration techniques have been recently proposed. In this research a systematic study of the application of artificial neural networks in power system restoration is performed. The proposed technique is composed of island restoration schemes that under the occurrence of a system blackout will generate feasible island restoration plans and present them to the system operator. The ANN-based scheme is considered to be one of the advanced applications of the energy management system of the power system control center.

The proposed restoration scheme applies the parallel restoration technique. In this technique the electric system is divided into a number of isolated islands that will be restored in parallel. These islands will remain electrically isolated from each other until each island is completely restored and stable. After the islands are restored, the tie-lines are closed. The restoration scheme uses pre and post disturbance data to generate the power system restoration plans for each island. The pre disturbance data is composed of the load pattern distribution in the power system. The local load pattern data will be used by the first artificial neural network of the island restoration scheme to forecast a restoration island load. The output of this first artificial neural network is a scalar value. In this research the restoration load pattern is assumed to be equal to the pre disturbance load. This scalar value will be used by the second artificial neural network together with the post disturbance data to generate a final restoration island configuration and a load percentage pick up value. A switching sequence program is used in each island restoration scheme to generate the final switching sequence that will lead to the island restoration. The proposed power system restoration scheme was tested through several new restoration scenarios to check its generalization capability. The test results showed that the scheme is capable of generating feasible restoration plans even when unseen restoration scenarios are presented. Further tests were made to check the proposed system's response time. In order to provide a reference parameter as well as a pattern generator a power system restoration breadth-search program was developed. The test results comparing the two schemes showed the proposed artificial neural network-based restoration scheme is faster than the breadth-search scheme. In addition, the ANN-based scheme presents a restoration plan with more information. It is concluded that the artificial neural network based power system restoration scheme is a fast and a reliable technique that can assist system operators following the occurrence of a system blackout.

7.2. Contributions

The work in this dissertation contributes in several ways to the field of electrical power engineering. The main contributions of this research are summarized as follows:

- An exhaustive literature review of power system restoration techniques, their limitations and constraints was performed.

- A new technique of using of artificial neural networks in power system restoration was proposed and implemented in this research.

- A power system restoration breadth search program was implemented, and was used to generate patterns for future researches and as comparison reference.

- Several switching sequence programs were proposed and implemented in this research. The use of a switching sequence program allows the proposed power system restoration scheme to energize high priority loads first by positioning the respective energizing path sequences at the beginning of the database. This technique will prove to be useful to future power system restoration researchers.

- A data base for the 162-bus (reduced Iowa) transmission system with the final restoration configurations for islands and their respective load pick-up values was created in this research.

- A database used by the switching sequence programs containing energizing paths connecting island generator buses to island load buses of the 162-bus (reduced Iowa) system was proposed and implemented in this research.

7.3. Future Work

The following are some suggestions for future work that could help promote the practical applications of this technique.

1. Select a cold load pick up model for the 162-bus transmission system that assumes undiversified restoration load. With this model retrain the restoration load forecast ANNs of each IRS. Test the restoration scheme for new restoration scenarios.

2. Implement a graphical user interface to better display the ANN-based power system restoration scheme.

3. Consider more than one unavailable transmission path per Island. Retrain the 2nd ANNs of each IRS. Test the restoration scheme for new restoration scenarios.

4. Consider applications and tests on larger systems with different characteristics.

5. Create real-time application software for EMS systems.

References

1. M. M. Adibi, “ Power System Restoration – A Task Force Report”, IEEE Transactions on Power Systems, Vol. 2, No. 2, pp. 271-277, May 1987.
2. D. N. Ewart, “Whys and Wherefores of Power System Blackouts”, IEEE Spectrum Magazine, pp. 36-41, April 1978.
3. M. M. Adibi. Power System Restoration Methodologies & Implementation Strategies, IEEE Press Power Engineering Series, 2000.
4. A. Bretas, and A. Phadke. Power System Restoration Methodologies & Implementation Strategies, Book Review, IEEE Computer Applications in Power, Vol. 14, pp. 58-59, January 2001.
5. F. A. Arnold, “ Summary of the System Restoration Plan for the Pacific Northwest Power System”, Proceedings of the IEEE Winter Power Meeting, January 1982.
6. E. Mariani, F. Mastroianni, V. Romano, “ Field Experiences in Reenergization of Electrical Networks from Thermal and Hydro Units”, IEEE Transactions in Power Apparatus & Systems, Vol. 103, No. 7, pp. 1707-1713, July 1984.
7. D. Scheurer, “System Restoration at Philadelphia Electric Company”, 8th IEEE Biennial Workshop on Real-Time Monitoring and Control of Power Systems, October 1984.
8. G. Morin, “ Service Restoration Following a Major Failure on the Hydro-Quebec Power System”, IEEE Transactions on Power Delivery, Vol. 2, No. 2, pp. 454-462, April 1987.
9. J. Gutiérrez, M. Staropolsky, A. Garcia, “ Policies for Restoration of a Power System”, IEEE Transactions on Power Systems, Vol. 2, No. 2, pp. 436-442, May 1987.
10. R. Kearsley, “ Restoration in Sweden and Experience from the Blackout of 1983”, IEEE Transactions on Power Systems, Vol. 2, No. 2, pp. 422-428, May 1987.
11. C. C. M. Trotignon, E. Corradi, G. Bortoni, M. Stubbe and J. Deuse, “ Major Incidents on the French Electric System: Potentiality and Curative Measures Studies” IEEE Transactions on Power Systems, Vol. 8, No. 3, pp. 879-886, August 1993.

12. L. Fink, and K. Carlsen, “ Operating Under Stress and Strain”, IEEE Spectrum, March 1978.

13. Y. Kojima, S. Nakamura, and K. Matsumoto, “Development of a Guidance Method for Power System Restoration”, IEEE Transactions in Power Apparatus & Systems, Vol. 4, No. 3, pp. 1219-1227, August 1989.

14. K. Nielsen, “System Operations Challenges”, IEEE Transactions on Power Systems, Vol. 3, No. 1, pp. 118-124, February 1998.

15. K. Matsumoto, T. Sakaguchi, R. Kafka and M. M. Adibi, “Knowledge-Based Systems as Operational Aids in Power System Restoration”, Proceedings of the IEEE, Vol. 80, No.5, pp. 689-697, May 1992.

16. K. L. Liou, C. C. Liu and R. Chu, “Tie Line Utilization During Power System Restoration”, IEEE Transactions on Power Systems, Vol. 10, No. 1, pp. 192-199, February 1995.

17. F. F. WU and A. Monticelli, “Analytical Tools for Power System Restoration – Conceptual Design”, IEEE Transactions on Power Systems, Vol. 3, No. 1, pp. 10-16, February 1988.

18. T. Nagata, H. Sasaki and R. Yokoyama, “Power System Restoration by Joint Usage of Expert System and Mathematical Programming Approach”, IEEE Transactions on Power Systems, Vol. 10, No. 3, pp. 1473-1479, August 1995.

19. L. Fink, K. L. Liou and C. C. Liu, “ From Generic restoration actions to Specific Restoration Strategies”, IEEE Transactions on Power Systems, Vol. 10, No. 2, pp. 745-751, May 1995.

20. M.M. Adibi, “ New Approaches in Power System Restoration”, IEEE Transactions on Power Systems, Vol. 7, No. 4, pp. 1428-1434, February 1992.

21. K. Komai and T. Sakaguchi, “Analysis and Evaluation of Human Knowledge for Power System Restoration by Mathematical Programming Method”, Transactions of IEE Japan, Vol. 107-B, No. 6, pp. 269-275, 1987.

22. A. L. Morelato and A. Monticelli, “Heuristic Search Approach to Distribution System Restoration”, IEEE Transactions on Power Delivery, Vol. 4, No. 4, pp. 2235-2241, October 1989.

23. T. Nagata, S. Hatakeyama, M. Yasouka and H. Sasaki, “An efficient method for power distribution system restoration based on mathematical programming and operation strategy”, Proceedings of the International Conference on Power System Technology, Vol. 3, pp.1545-1550, 2000.

24. T. Sakaguchi and K. Matsumoto, “Development of a Knowledge Based System for Power System Restoration”, IEEE Transactions in Power Apparatus & Systems, Vol. PAS-102, No. 2, pp. 320-329, February 1983.

25. Y. Kojima, S. Warashina, M. Kato and H. Watanabe, “The Development of a Power System Restoration Method for a Bulk Power System by Applying Knowledge Engineering Techniques”, IEEE Transactions on Power Systems, Vol. 4, No. 3, pp. 1228-1235, August 1989.

26. K. Hotta, H. Nomura, H. Takemoto, K. Suzuki, S. Nakamura and S. Fukui, “ Implementation of a Real-Time Expert System for a Restoration Guide in a Dispatching Center”, IEEE Transactions on Power Systems, Vol. 5, No. 3, pp. 1032-1038, August 1990.

27. D. S. Kirschen and T. L. Volkmann, “ Guiding a Power System restoration with an Expert System”, IEEE Transactions on Power Systems, Vol. 6, No. 2, pp. 558-566, May 1991.

28. T. K. Ma, C.C. Liu, M. S. Tsai, R. Rogers, S. L. Muchlinski and J. Dodge, “ Operational experience and maintenance of an On-Line Expert System for Customer Restoration and Fault Testing”, IEEE Transactions on Power Systems, Vol. 7, No. 2, pp. 835-842, May 1992.

29. K. Shimakura, J. Inagaki, Y. Matsunoki, M. Ito, S. Fukui and S. Hori, “ A Knowledge-Based Method for Making Restoration Plan of Bulk Power System”, IEEE Transactions on Power Systems, Vol. 7, No. 2, pp. 914-920, May 1992.

30. C.C. Liu, K.L. Liou, R. F. Chu, and A. T. Holsen, “ Generation Capability Dispatch for Bulk Power System Restoration: A Knowledge Based Approach”, IEEE Transactions on Power Systems, Vol. 8, No. 1, pp. 316-325, February 1993.

31. Y. M. Park and K. H. Lee, “Application of Expert System to Power System restoration in Sub-Control Center”, IEEE Transactions on Power Systems, Vol. 12, No. 2, pp. 629-635, May 1997.

32. M. M. Adibi, R. J. Kafka and D.P. Milanicz, “Expert System requirements for Power System Restoration”, IEEE Transactions on Power Systems, Vol. 9, No. 3, pp. 1592-1600, August 1994.

33. Wu J.S., Liu C.C., Liou K.L. and Chu R.F., “A Petri Net Algorithm for Scheduling of Generic Restoration Actions”, IEEE Transactions on Power Systems, Vol. 12, No. 1, pp. 69-76, February 1997.

34. N.A. Fountas, N. D. Hatziargyriou and K.P. Valavanis, “ Hierarchical Time-Extended Petri Nets as a generic Tool for Power System Restoration”, IEEE Transactions on Power Systems, Vol. 12, No. 2, pp. 837-843, May 1997.

35. J. S. Wu, “A Petri-net Algorithm for Multiple Contingencies of Distribution System Operation”, IEEE Transactions on Power Systems, Vol. 13, No. 3 , pp. 1164-1171, August 1998.

36. C. M. Huang, H. L. Jiang, H. T. Yang, W. Y. Chang and C. L. Huang, “A Petri Nets Model for Fast Substation Service Restoration”, Proceedings of the International Conference on Energy Management and Power Delivery, pp. 473-478, Vol. 2, 1998.

37. M. M. Adibi, “ Special Considerations in Power System Restoration”, IEEE Transactions on Power Systems, Vol. 7, No. 4, pp. 1419-1427, November 1992.

38. Y. Y. Hsu and H. M. Huang, “Distribution System Service Restoration using the Artificial Neural Network Approach and Pattern Recognition Method”, IEE Proceedings of Generation Transmission and Distribution, Vol. 142, No. 3, May 1995.

39. A. Bretas, and A. Phadke, “ Power System Restoration using Artificial Neural Networks”, 33rd North American Power Symposium, October, 2001.

40. M. M. Adibi and R. J. Kafka, “ Power System Restoration Issues”, IEEE Computer Applications in Power, Vol. 4, No.2, pp. 19-24, April, 1991.

41. M. M. Adibi, D. Barrie, M. E. Cooper, K. W. Heussner, M. E. Robertson, J. L. Scheidt and D. Scheurer, “ System Operations Challenges”, IEEE Transactions on Power Systems, Vol. 3, No. 1, pp. 118-124, February 1988.

42. R. J. Kafka, D. R. Penders, S. H. Bouchey, M. M. Adibi, “ System Restoration Plan Development for a Metropolitan Electric System”, IEEE Transactions on Power Apparatus and Systems, Vol. PAS-100, No. 8, pp. 3703-3713, August 1981.

43. M. M. Adibi, “Special Consideration in Power System Restoration. The Second Working Group Report”, IEEE Transactions on Power Systems, Vol. 9, No. 1, pp. 15-21, February 1994.

44. M. M. Adibi, R. W. Alexander and B. Avramovic, “ Overvoltage Control during Restoration”, IEEE Transactions on Power Systems, Vol. 7, No. 4, pp. 1464-1470, November 1992.

45. R. W. Alexander, “ Minimum Source Consideration when Restoring the PJM 500 kV System”, PEA System Operation Committee, January 1991.

46. L. S. Mercer, “Reactive Output of PJM’s Large Generating Units”, PJM Reactive Study, July 1983.

47. M. M. Adibi and D. P. Milanicz, “ Reactive Capability Limitation of Synchronous Machines”, IEEE Transactions on Power Systems, Vol. 9, No. 1, pp. 29-40, February 1994.

48. D. Prasetijo, W. R. Lachs, D. Sutanto, “A New Load Shedding scheme for Limiting Underfrequency”, IEEE Transactions on Power Systems, Vol. 9, No. 3, pp. 1371-1378, August 1994.

49. M. M. Adibi, J. N. Borkowski and R. J. Kafka, “ Analytical Tool Requirements for Power System Restoration”, paper 94 WM 222-0-PWRS, presented at IEEE/PES 1994 WPM, New York, NY, January 1994.

50. J. J. Ancona, " A Framework for Power System Restoration following a Major Power Failure", IEEE Transactions on Power Systems, Vol. 10, No. 3, pp. 1480-1485, August 1995.

51. R. J. Kafka, "Active and Reactive Power Balance – Potomac Electric Power Company", EPRI/ECC Power System Restoration Seminar, Denver, September 1993.

52. A. Bretas and N. Hadjsaid, "Fault Diagnosis in Deregulated Distribution Systems using an Artificial Neural Network", Power Engineering Society Winter Meeting, 2001 IEEE , Vol.2 , pp. 821-823, 2001.

53. T. Baldwin, F. Renovich Jr., L. F. Saunders, and D. Lubkeman, "Fault Locating in Ungrounded and High-Resistance Grounded Systems", IEEE Transactions on Industry Applications, Vol. 37, No. 4, pp. 1152-1159, July 2001.

54. Z. Bo, G. Weller, and M. Redfern, "Accurate Fault Location Technique for Distribution System using Fault-generated High-Frequency Transient Voltage Signals", IEE Proceedings of Generation Transmission Distribution., Vol. 146, No. 1, pp. 73-79, January 1999.

55. D. Hazarika, and A. K. Sinha, "An Algorithm for Standing Phase Angle Reduction for Power System Restoration", IEEE Transactions on Power Systems, Vol. 14, No. 4, pp. 1213-1218, November 1999.

56. K. Ketabi, and A. M. Ranjbar, "New Approach to Standing Phase Angle Reduction for Power System Restoration**",** Proceedings of the International Conference in Electric Power Engineering, Powertech, pp. 78, Budapest, 1999.

57. D. Hazarika, and A. K. Sinha, "Standing Phase Angle Reduction for Power System Restoration", IEE proceedings of the Generation, Transmission and Distribution, Vol. 145, No. 1, pp. 82-88, January 1998.

58. S. Wunderlich, M. M. Adibi, R. Fischl and C. O. D. Nwankpa, "An Approach to Standing Phase Angle Reduction**",** IEEE Transactions on Power Systems, Vol. 9, No. 1, pp. 470-478, February 1994.

59. H. B. Ross, N. Zhu, J. Giri and B. Kindel, “ An AGC Implementation for System Islanding and Restoration Conditions”, IEEE Transactions on Power Systems, Vol. 9, No. 3, pp. 1399-1410, August 1994.

60. K. L. Lieu, C. C. Liu, R. F. Chu, “Tie Line Utilization during Power System Restoration”, IEEE Transactions on Power Systems, Vol. 10, No. 1, pp. 192-199, February 1995.

61. S. L. Rueckert, “Transferring Electrical Power Between Utilities”, IEEE Potentials, Vol. 7, No. 4, pp. 13-14, December 1988.

62. M. M. Adibi and L. Fink, “ Power System Restoration Planning”, IEEE Transactions on Power Systems, Vol. 9, No. 1, pp. 22-28, February 1994.

63. A. M. Bruning, “Cold Load Pickup”, IEEE Transactions on Power Apparatus and Systems, Vol. 98, No. 4, pp 1384-1386, July 1979.

64. S. Ihara and F. C. Schweppe, “Physically Based Modeling of Cold Load Pickup”, IEEE Transactions on Power Apparatus and Systems, Vol. 100, No. 9, pp 4142-4150, September 1981.

65. E. Agneholm and J. Daalder, “Cold Load Pick-up of Residential Load”, IEE Proceedings of the Generation, Transmission and Distribution, Vol. 147, No. 1, pp. 44-50, January 2000.

66. T. Babnik, S. Gasperic, A. Gubina and F. Gubina, “Influence of Load Behavior on Service Restoration”, Proceedings of the International Conference on Electric Power Engineering, pp. 116, Budapest 1999.

67. O. H. Mirza, “Usage of CLPU Curve to Deal with the Cold Load Pickup Problem”, IEEE Transactions on Power Delivery, Vol. 12, No. 2, pp. 660-667, April, 1997.

68. M. M. Adibi, R. W. Alexander and D. P. Milanicz, “Energizing High and Extra –High Voltages Lines during Restoration”, IEEE Transactions on Power Systems, Vol. 14, No. 3, pp. 1121-1126, August 1999.

69. O. I. Elgerd, Electric Energy Systems Theory: An Introduction, McGraw-Hill, 1971.

70. H. W. Dommerl, Transmission Program User’s Manual, UBC Publication, August 1998.

71. West Virginia University Electric Industry Restructuring Research Group, Transmission Enhancement and Expansion, Interim Report No. 5, January 1998.

72. M. M. Adibi and D. P. Milanicz, “Protective System Issues during Restoration”, IEEE Transactions on Power Systems, Vol. 10, No. 3, pp. 1492-1497, August 1995.

73. Y. Xue, T. Van Cutsem and M. Ribbens-Pavella, “A Simple Direct Method for Fast Transient Stability Assessment of Large Power Systems”, IEEE Transactions on Power Systems, Vol. 3, No. 2, pp. 400-412, May 1988.

74. L. Wehenkel, T. Van Cutsem and M. Ribbens-Pavella, “An Artificial Intelligence Framework for online Transient Stability Assessment of Power Systems”, IEEE Transactions on Power Systems, Vol. 4, No. 2, pp. 789-800, May 1989.

75. L. Wehenkel, M. Pavella, E. Euxibie and B. Heilbronn, “Decision Tree based Transient Stability Method a Case Study”, IEEE Transactions on Power Systems, Vol. 9, No. 1, pp. 459-469, February 1994.

76. M. Ilic, “ Network Theoretic Conditions for Existence and Uniqueness of Steady State Solutions to Electric Power Circuits”, Proceedings of the ICAS, vol. 6, pp. 2821-2828, 1992.

77. M. Hasler, C. Wang, M. Ilic and A. Zobian, “Computation of Static Stability margins in Power Systems using Monotonicity”, Proceedings of the ICAS, vol. 4, pp. 2196-2199, 1993.

78. R. D. Garzon, High Voltage Circuit Breakers-Design and Applications, Marcel Dekker, New York, 1997.

79. C. H. Flurscheim, Power Circuit Breaker Theory and design, Peter Peregrinus, England, 1975.

80. M. M. Adibi, J. N. Borkoski and R. J. Kafka, “Power System Restoration-The Second Task Report”, IEEE Transactions on Power Systems, Vol. 2, No. 4, pp. 927-933, November 1987.

81. T. Dalstein and B. Kulicke, “Neural Network Approach to Fault Classification for High Speed Protective Relaying”, IEEE Transactions on Power Delivery, v. 10, n. 2, pp. 1002-1011, April 1995.

82. T. Dalstein, T. Friedrich, B. Kulicke and D. Sobajic, “Multi Neural Network based Fault Area Estimation for High Speed Protective Relaying”, IEEE Transactions on Power Delivery, v. 11, n. 2, pp. 740-747, April 1996.

83. Z. Q. Bo, R. K. Aggarwal, A. T. Johns, H. Y. Li and Y. H. Song, “A New Approach to Phase Selection using Fault Generated High Frequency Noise and Neural Networks”, IEEE Transactions on Power Delivery, v. 12, n. 1, pp. 106-115, January 1997.

84. A. G. Jongepier, and L. Van Der Sluis, “Adaptive Distance Protection of Double-Circuit Lines using Artificial Neural Networks. IEEE Transactions on Power Delivery, v.12, n. 1, pp. 97-105, January 1997.

85. D. V. Coury and D. C. Jorge, “Artificial Neural Network Approach to Distance Protection of Transmission Lines”, IEEE Transactions on Power Delivery, v.13, n. 1, pp. 102-108, January 1998.

86. A. Bretas, A. B. Delbem, L. F. C. Alberto, A. P. Leon and D. Coury, “Implementation and Tests of a Distance Relay Using Artificial Neural Networks”, Proceedings of the International Conference on Engineering Applications of Neural Networks, Stockholm 1997.

87. A. Bretas and D. Coury, “A New Proposal for Directional Protection of Transmission Lines based on Artificial Neural Networks”, Proceedings of the II - IEEE International Conference on Intelligent Processing Systems, Sidney 1998.

88. S. Haykin, Neural Networks – A Comprehensive Foundation, 2nd Edition, Prentice Hill, 1999.

89. J. Hertz, A. Krogh and R. G. Palmer, Introduction to the Theory of Neural Computation, Santa Fe Institute Studies in the Sciences of Complexity, v. 1, Addison-Wesley, 1991.

90. M. Beale and M. T. Hagan, Neural Network Design, PWS, Boston, 1996.

91. D. E. Rumelhart and J. L. McClelland, Parallel Distributed Processing - Explorations in the Micro Structure of Cognition, MIT Press, Cambridge, 1986.

92. W. H. Van Zee and R. J. Felton, "500KV System Relaying-Design and Operating Experience", CIGRÉ No. 34-07, Paris, 1978.

93. G. Kinderman, Short Circuit, Sagra-Luzzato, Brazil, 1992.

94. T. Takagi, Y. Yamakoshi, M. Yamaura, R. Kndow and T. Matsushima, "Development of a New Type Fault Locator Using the One-Terminal Voltage and Current Data", IEEE Transactions on Power Systems, Vol. 101, No.8, pp. 2892-2898, August 1982.

95. A. Phadke and J. Thorp, Computer Relaying for Power Systems, RSP, England, 1988.

96. O. Elgerd, Electric Energy Systems Theory: An Introduction, McGraw-Hill, New York, 1971.

97. R. Shultz and R. Smith, Introduction to Electric Power Engineering, Harper & Row, New York, 1985.

98. Centro de Pesquisas de Energia Elétrica (CEPEL), Programa de Análise de Redes – Manual do Usuário, Rio de Janeiro, 1994.

99. D. H. Kuo and A. Bose, "A Generation Rescheduling Method to Increase the Dynamic Security of Power Systems", IEEE Transactions on Power Systems, Vol. 10, No.1, pp. 68-76, February 1995.

100. Z. Feng, V. Ajjirapu and D. J. Maratukulam, "A Practical Minimum Load Shedding Strategy to Mitigate Voltage Collapse", IEEE Transactions on Power Systems, Vol. 13, No.4, pp. 1285-1290, November 1998.

101. University of Stuttgart, Stuttgart Neural Network Simulator v. 4.1, 1995.

Appendix A

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TITU
IEEE WORKING GROUP   01/02/90 S 17-GEN  CASE
DBAR
(No) O TB(   nome   )G( V)( A)( Pg)( Qg)( Qn)( Qm)( Bc)( Pl)( Ql)( Sh)(A
   1   0 COOPR 3  345 1033 -250.0000.000               0.0000.000-1.00 1
   2   0 MOOR  3  345 1022 -300.0000.000               0.0000.0000.000 1
   3   0 STJO712  161 1000 -32 20000.000                237096.900.000 1
   4   0 BOONIL3  345 1019 -340.0000.000               0.0000.0000.000 1
   5   0 NEBCY 3  345 1034 -250.0000.000               0.0000.000-0.50 1
   6   1    6R1G   22 1000 -19794.0180.8 -200400.0     0.0000.0000.000 1
   7   0    7LN3  345 1019 -300.0000.000               0.0000.0000.000 1
   8   0    8ER7  115 1034 -34 -398-19.2               0.0000.0000.000 1
   9   0    94 3  345 1026 -280.0000.000               0.0000.0000.000 1
  10   0 TWINCH4  230  993 -36 -22611.50               0.0000.0000.000 1
  11   0 SX CY 4  230 1000 -320.0000.000               0.0000.0000.000 1
  12   0 SHELON7  115 1038 -34 -1935.900               0.0000.0000.000 1
  13   0 GR ILD3  345 1015 -31 -204-37.3               0.0000.0000.000 1
  14   0 S1206 5  161 1028 -31 -381-56.3               0.0000.0000.000 1
  15   0 FTRAD 4  230 1018 -25 15005.900                14200.0000.000 1
  16   0 ROCHTR5  161 1014 -3054.20-26.7               0.0000.0000.000 1
  17   0 HARMNY5  161 1006 -29116.5-44.7               0.0000.0000.000 1
  18   0 ADAM  5  161 1035 -340.0000.000               34.4011.670.000 1
  19   0 DUBUUE5  161  999 -38-64.4-3.78               0.0000.0000.000 1
  20   0 HINTON8   69  979 -330.0000.000               37.9012.500.000 1
  21   0 POSTIL5  161 1008 -3069.80-23.2               0.0000.0000.000 1
  22   0 HAZLON5  161 1034 -380.0000.000               17.395.2700.000 1
  23   0 HRN K 5  161  988 -35-63.5-21.4               0.0000.0000.000 1
  24   0 LAKFD 5  161 1009 -330.0000.000               0.0000.0000.000 1
  25   0 LAKFD 3  345 1001 -290.0000.000               0.0000.000-0.50 1
  26   0 RAUN  3  345 1032 -210.0000.000               0.0000.000-0.50 1
  27   0 WILMRT3  345  998 -30 15000.000                182457.900.000 1
  28   0 FOX K 5  161  988 -360.0000.000               38.4713.170.000 1
  29   0 WINBGO5  161  988 -380.0000.000               28.319.0300.000 1
  30   0 HAYWD 5  161  998 -400.0000.000               101.232.520.150 1
  31   0 RAPIAN5  161  990 -37-72.53.100               0.0000.0000.000 1
  32   0 LIMECK5  161 1005 -410.0000.000               52.7015.060.200 1
  33   0 MASNTY5  161  998 -430.000-0.10               45.1715.060.200 1
  34   0 FRANKN5  161  998 -430.0000.000               14.185.2500.032 1
  35   0 FLOY  5  161  989 -440.0000.000               54.4814.630.050 1
  36   0 GARNR 5  161  996 -430.0000.000               31.968.6800.030 1
  37   0 ADAM  3  345  987 -310.0000.000               0.0000.0000.000 1
  38   0 DUNDE 5  161 1018 -380.0000.000               14.764.0800.015 1
  39   0 HAZLON3  345  987 -330.0000.000               0.0000.0000.000 1
  40   0 BLKHK 5  161 1000 -420.0000.000               52.8817.600.000 1
  41   0 WSHBN 5  161 1007 -400.0000.000               39.2012.800.000 1
  42   0 ARNOD 3  345 1004 -330.0000.000               0.0000.0000.000 1
  43   0 CLINON5  161 1012 -36-41.517.20               0.0000.0000.000 1
  44   0 CALUS 5  161 1007 -360.0000.000               16.323.7100.000 1
  45   0 TRIBJI5  161  996 -360.0000.000               20.025.4100.019 1
  46   0 DENIN 5  161  999 -390.0000.000               65.3122.300.262 1
  47   0 ANITTP5  161  991 -420.0000.000               4.8201.5600.000 1
  48   0 CRESN 5  161 1000 -4160.0029.97               93.7622.860.000 1
  49   0 ANIT  5  161  989 -420.0000.000               6.8201.7800.000 1
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 50   0 MARY 12  161  996 -40-99.723.40               0.0000.0000.000 1
 51   0 CLRNA 5  161  992 -380.0000.000               0.0000.0000.000 1
 52   0 D.MON 5  161 1015 -390.0000.000               218.242.800.000 1
 53   0 SX CY 5  161  995 -310.0000.000               0.0000.0000.000 1
 54   0 WISDM 5  161  988 -3823.709.000               94.0429.570.000 1
 55   0 PLYMH 5  161  996 -300.0000.000               0.0000.0000.000 1
 56   0 OSGOD 5  161  991 -400.0000.000               25.297.2600.032 1
 57   0 SAC   5  161  998 -380.00020.00               48.4815.610.000 1
 58   0 UTICJC4  230 1008 -290.0000.000               0.0000.0000.000 1
 59   0 EAGL  4  230  984 -330.0000.000               84.4327.050.000 1
 60   0 SX FLL7  115  992 -34 -244-26.0               0.0000.0000.000 1
 61   0 SIOXLS4  230  983 -310.0000.000               0.0000.0000.000 1
 62   0 FTTHMP4  230 1023 -18865.670.80               0.0000.0000.000 1
 63   0 HANLN 4  230  988 -30-59.12.900               0.0000.0000.000 1
 64   0 SIOXLS   345 1015 -290.0000.000               0.0000.0000.000 1
 65   0 WTRTWN3  345  997 -2526.30 -116               0.0000.0000.000 1
 66   0 SX CY 3  345 1000 -310.0000.000               0.0000.000-0.50 1
 67   0 BURT  5  161 1000 -420.0000.000               22.547.0300.060 1
 68   0 HOPE  5  161 1013 -400.0000.000               40.4212.680.120 1
 69   0 HOPET 5  161 1020 -390.0000.000               0.0000.0000.000 1
 70   0 NEAL  5  161 1026 -240.0000.000               0.0000.0000.000 1
 71   0 MONOA 5  161  992 -320.0000.000               29.8711.930.120 1
 72   0 S1209 5  161 1017 -31 -427 -110               0.0000.0000.000 1
 73   1 NEAL12G   20 1000 -18447.085.84-72.0267.0     0.0000.0000.000 1
 74   0 LEHIH 3  345 1012 -340.0000.000               0.0000.0000.000 1
 75   0 FT.CL 3  345 1030 -250.0000.000               0.0000.000-0.50 1
 76   1 NEAL34G   24 1000 -16 1055136.3 -170605.0     0.0000.0000.000 1
 77   0 WRIGT 5  161 1011 -400.000-0.10               26.418.7800.047 1
 78   0 FT.DDG5  161 1023 -380.0000.000               79.120.0000.000 1
 79   0 LEHIH 5  161 1032 -360.0000.000               0.0000.0000.000 1
 80   0 POMEOY5  161 1010 -380.0000.000               15.765.2500.028 1
 81   0 WATELO8   69 1001 -460.0000.000               50.8816.800.221 1
 82   0 WATELO5  161  999 -420.0000.000               62.2820.260.104 1
 83   0 WTR OGT  161 1003 -410.0000.000               0.0000.0000.000 1
 84   0 DYSAT 5  161 1010 -380.0000.000               37.909.4900.026 1
 85   0 CARRLL5  161  971 -410.000-0.10               40.5211.260.120 1
 86   0 GR JT 5  161  970 -450.0000.000               50.7313.350.120 1
 87   0 GUTHIE7  115  980 -440.0000.000               16.914.2300.000 1
 88   0 JASPR 8   69  989 -450.0000.000               60.604.4400.000 1
 89   0 GR JT 7  115  991 -460.0000.000               0.0000.0000.000 1
 90   0 BOON  7  115  961 -490.0000.000               50.2116.760.100 1
 91   0 CDRPS 5  161 1012 -370.0000.000               51.2412.830.000 1
 92   0 WYOMG 5  161 1002 -380.0000.000               36.129.0500.000 1
 93   0 ARNOD 5  161 1029 -330.0000.000               103.834.560.000 1
 94   0 HILL  5  161 1026 -370.0000.000               164.06.4900.000 1
 95   0 PRARCK7  115 1030 -370.0000.000               117.239.010.000 1
 96   0 MTOW  7  115 1001 -450.0000.000               119.20.0000.000 1
 97   0 CALUS 7  115 1027 -370.0000.000               22.845.7100.000 1
 98   0 SIX T 7  115 1044 -350.00030.00               151.150.350.000 1
 99   1 PRARK4G   18 1000 -31130.95.210-60.675.60     0.0000.0000.000 1
100   0 WELSRG7  115  987 -460.0000.000               23.216.9000.030 1
101   1 MTOW 3G   14 1000 -4082.0030.34-24.438.60     0.0000.0000.000 1
102   0 MQOKTA5  161 1003 -370.0000.000               16.544.0800.000 1
103   0 DAVNRT5  161 1015 -35 -32245.80               0.0000.0000.000 1
104   0 IA FS 7  115  993 -450.000-0.10               31.5210.460.056 1
105   0 DUNDE 7  115 1034 -390.0000.000               24.846.2300.017 1
106   0 MONRE 5  161  995 -430.0000.000               0.0000.0000.000 1
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 107   0 POWAHK5  161  991 -440.0000.000               35.415.4100.000 1
 108   2 AROL 1G   22 1000 -28551.1155.8               0.0000.0000.000 1
 109   0 HILL  3  345 1013 -330.0000.000               0.0000.0000.000 1
 110   0 CBLUFS5  161 1027 -300.0000.000               0.0000.0000.000 1
 111   0 AVOC  5  161 1005 -340.0000.000               65.4116.720.000 1
 112   0 CBLUFS3  345 1027 -270.0000.000               0.0000.000-0.50 1
 113   0 S1211 5  161 1025 -31-32.795.20               0.0000.0000.000 1
 114   1 C.BL12G   14 1000 -24131.022.29-25.033.00     0.0000.0000.000 1
 115   0 BOONIL5  161 1017 -360.0000.000               17.323.3400.000 1
 116   0 SYCAOR5  161 1024 -370.0000.000               56.0811.200.000 1
 117   0 ASHAA 5  161 1014 -380.0000.000               101.920.060.000 1
 118   1 DPS 57G   14 1000 -34173.059.75-44.0100.0     0.0000.0000.000 1
 119   0 SYCAOR3  345 1010 -350.0000.000               0.0000.0000.000 1
 120   0 S3456 3  345 1024 -270.0000.000               0.0000.0000.000 1
 121   1 C.BL 3G   24 1000 -20620.0150.9 -120250.0     0.0000.0000.000 1
 122   0 OSKLOS5  161  988 -460.0000.000               47.289.3600.000 1
 123   0 WAPELO5  161 1000 -46 -16554.67               0.0000.0000.000 1
 124   0 DVNPT 3  345 1009 -31 25710.000                200090.900.000 1
 125   1 PALM710  345 1020 -29 2388-22.9-1099 9900      20000.0000.000 1
 126   0 PR ILD3  345 1011 -27 246763.80                20000.0000.000 1
 127   0 LACRSS3  345  985 -3052.60-65.0               0.0000.0000.000 1
 128   0 S3459 3  345 1024 -270.0000.000               0.0000.0000.000 1
 129   0 S3455 3  345 1024 -270.0000.000               0.0000.0000.000 1
 130   1 FT.CL1G   22 1030 -19455.0123.4 -144288.0     0.0000.0000.000 1
 131   1 NEBCY1G   18 1018 -20575.094.51 -265320.0     0.0000.0000.000 1
 132   0 S1255 5  161 1020 -30 -159-36.1               0.0000.0000.000 1
 133   0 S701  8   69 1035 -320.0000.000               30.106.0200.000 1
 134   0 S701  5  161 1023 -310.0000.000               17.463.3400.000 1
 135   0 S702  8   69 1032 -320.0000.000               20.064.0100.000 1
 136   0 S703  8   69 1025 -320.0000.000               20.064.0100.000 1
 137   0 S704  8   69 1029 -320.0000.000               20.064.0100.000 1
 138   0 CBLUFS8   69 1031 -310.0000.000               0.0000.0000.000 1
 139   0 S706  8   69 1026 -320.0000.000               10.102.0100.000 1
 140   0 S705  8   69 1028 -320.0000.000               13.582.6800.000 1
 141   0 HSTNGS5  161 1003 -340.0000.000               0.0000.0000.000 1
 142   0 CLRNDA8   69 1028 -410.0000.000               27.095.3500.000 1
 143   0 R.OAK 8   69 1006 -390.0000.000               21.074.0100.000 1
 144   0 HSTNGS8   69 1022 -360.0000.000               12.372.0100.000 1
 145   0 GWOOD 8   69 1019 -340.0000.000               10.832.2100.000 1
 146   0 SHENDO8   69 1010 -400.0000.000               21.334.0100.000 1
 147   0 WABASH5  161 1010 -390.0000.000               216.442.800.000 1
 148   0 SYCAOR8   69 1013 -400.0000.000               120.024.000.000 1
 149   0 RAUN  5  161 1026 -240.0000.000               0.0000.0000.000 1
 150   0 NEAL4 5  161 1023 -240.0000.000               4.8001.6000.000 1
 151   0 INTRCG5  161 1010 -270.0000.000               24.008.0000.000 1
 152   0 TEKAMA5  161 1023 -27-6.002.800               0.0000.0000.000 1
 153   0 NEAL  8   69 1018 -260.0000.000               4.0001.6000.000 1
 154   0 KELLOG8   69  975 -320.0000.000               28.009.6000.060 1
 155   0 M SIDE8   69  985 -300.0000.000               12.004.0000.000 1
 156   0 E SIDE8   69  979 -320.0000.000               8.0002.4000.000 1
 157   0 PLYMTH8   69  980 -330.0000.000               32.0010.400.000 1
 158   0 LOGANP8   69  968 -330.0000.000               16.005.6000.030 1
 159   0 MCCOOK8   69  968 -330.0000.000               8.0002.4000.000 1
 160   0 SC WST8   69  971 -330.0000.000               14.404.8000.030 1
 161   0 KELOG 5  161 1004 -280.0000.000               32.0010.400.000 1
 162   0 LEEDS 5  161 1000 -290.0000.000               20.006.4000.000 1
9999
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DLIN
   1       2      0.350 3.210 54.38                         3450
   1       3      0.340 3.260 72.24                         3709
   1       4      0.640 6.210 98.70                         3450
   1       5      0.110 1.190 20.12                         4002
   1       6      0.000 1.330  0.001.052                     900
   2       7      0.140 1.250 21.22                         3709
   2      13      0.460 4.170 70.58                         3450
   3      14     23.610101.220  0.0
   3      50      3.89016.990  0.00
   3     103     10.740180.230  0.0
   3     123     28.830167.190  0.0
   3     124      1.40064.830  0.00
   3     125      0.84011.390  0.00
   4     112      0.590 5.680 92.50                         3450
   4     115      0.000 1.850  0.001.000                     500
   4     119      0.140 1.190 20.50                         3450
   5     120      0.220 2.240 37.92                         4002
   5     129      0.220 2.680 46.12                         2474
   5     131      0.000 1.270  0.001.025                     710
   7       8      0.040 1.890  0.000.975                     672
   7       9      0.170 1.690 28.72                         2474
   8      10     45.910107.030  0.0
   8      12      1.060 5.740  0.00
   8      13     12.74047.840  0.00
   8      14      4.73039.560  0.00
   8      15     50.350174.330  0.0
   8     132      2.52028.800  0.00
   9      75      0.130 1.500 26.82                         2474
  10      11      0.510 3.700  7.16                          736
  10      13     12.99062.200  0.00
  10      15     12.75070.330  0.00
  10      60     25.250122.420  0.0
  11      15      2.85017.930 34.84
  11      46      1.42012.250 18.76
  11      58      1.70010.700 20.74
  11      59      0.710 4.710  8.52
  12       2      0.080 3.770  0.001.025                     336
  12      13     10.38031.370  0.00
  12      14     15.98064.150  0.00
  12     132     44.860157.730  0.0
  13      15      4.40032.270  0.00
  13      62      0.98012.210  0.00
  14      72      1.070 8.280  0.00
  14     113      0.630 3.820  0.00
  14     132      0.570 3.740  0.00
  15      58      1.150 7.320 14.20
  15      60     39.070167.530  0.0
  15      62      0.840 5.880  0.00
  15      63     17.040145.550  0.0
  16      17     60.170143.730  0.0
  16      18      2.97010.700  5.46                          269
  16      27     15.74088.710  0.00
  16     126     10.53051.320  0.00
  16     127      9.58052.760  0.00
  17      18      2.13010.130  6.42                          361
  17      19     23.14076.780  0.00
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17      21      4.71026.650  0.00
17     127      2.87026.370  0.00
18      30      2.07010.880  5.20                          362
18      32      2.34012.200  5.82                          361
18      37      0.000 4.560  0.001.119                     225
19      21     38.670190.050  0.0
19      38      2.39012.500  5.96                          354
19      43      6.03025.720  0.00
19     127     10.74068.090  0.00
20      53      0.00011.400  0.001.000                      75
20     157      1.130 2.790  0.04                           44
21      22      3.12016.290  7.78                          387
21     127      1.05064.140  0.00
22      38      1.400 5.400  2.50                          362
22      39      0.000 4.930  0.001.108                     225
22      40      1.880 7.170  3.28                          362
22      41      1.720 8.500  4.04                          351
23      24      1.740 5.110  2.30                          361
23      60      6.60030.930  0.00
24      25      0.000 3.400  0.001.022                     225
24      28      2.490 7.250  2.02                          361
24      45      1.370 7.250  3.40                          359
25      26      0.590 5.830 93.02                         4105
25      27      0.440 4.100 83.84                         2484
26      74      0.630 6.070 93.00                         2484
26      75      0.300 3.220 50.38                         3709
26      76      0.000 0.820  0.001.040                    1250
27      31      1.01012.730  0.00
27      62      1.73058.100  0.00
27      65      1.05027.640  0.00
27     125      3.500168.450  0.0
27     126      0.220 2.250  0.00
27     127     15.060143.550  0.0
28      29      2.400 9.650  4.44                          269
29      30      3.80015.000  6.96                          177
29      31      2.060 8.330  3.84                          269
30      32      2.49010.050  4.58                          325
32      33      1.140 4.480  2.08                          325
33      34      2.80011.400  5.20                          180
33      35      2.16010.700  5.10                          387
33      36      1.020 5.360  2.54                          349
34      40      3.97015.170  6.90                          325
34      77      2.350 8.960  4.08                          269
35      40      2.71013.410  6.38                          179
36      67      1.760 9.240  4.40                          349
37      39      0.390 3.790 67.00                         1656
37     126      0.400 3.810 67.00                         2484
37     127      0.400 4.030 68.32                         3312
39      42      0.200 1.860 32.00                         1656
40      81      3.00034.500  0.38                           81
40      82      0.400 1.900  1.08                          351
41      81      3.70037.200  0.58                           81
41      83      0.520 2.560  1.24
41      84      0.570 5.800  2.92                          406
42     109      0.190 1.960 33.30                         3795
43      44      1.880 7.510  3.48                          269
43     103      3.24017.020  0.00
```

```
43     124      2.93017.660  0.00
43     125     14.49065.090  0.00
44     102      1.300 5.000  2.36                           180
44     103      1.270 5.100  2.44                           180
45      54      1.080 5.700  2.72                           354
46      47      3.10013.780  6.22                           177
47      48      2.51011.140  5.02                           177
47      49      0.300 1.200  0.54
48      50      3.36016.600  7.80
48      51      4.20013.000  5.70
48      52      5.40016.800  7.40                           261
49      87      1.400 6.800  2.66
50      51      3.000 9.000  4.10
50     123     40.710185.430  0.0
50     125     13.37060.310  0.00
51     141      3.23010.000  4.42                           264
52      79      6.23021.260  9.40                           269
52     106      2.310 7.170  3.14                           269
52     116      0.600 4.870  2.56                           515
52     117      1.170 4.930  2.30                           337
52     118      0.000 5.200  0.001.043                      200
53      11      0.050 2.000  0.001.000                      375
53      54      2.75019.610  9.56                           177
53      55      0.050 0.260  0.22                           538
54      56      1.740 9.100  4.30                           354
54      57      2.50012.370  5.88                           387
55      57      4.62017.630  8.02                           375
55     149      1.530 6.710  3.12                           357
55     162      0.400 1.890  0.98                           538
56      67      1.700 8.940  4.24                           349
57      80      2.72010.370  4.72                           180
58      61      1.33010.180 18.42                           276
59      61      1.060 7.060 12.10
60      61      0.270 6.530 -0.221.025                      100
60      61      0.200 3.930  0.001.025                      200
60      62     36.74096.400  0.00
60      65     10.41041.440  0.00
60     126     53.670182.950  0.0
61      62      2.96022.750 39.96                           552
61      63      0.430 4.220  7.64                           345
62      63      1.58017.020  0.00
62      65      0.400 7.400  0.00
62     126      0.44029.690  0.00
63      65     24.090196.000  0.0
64      65      0.500 5.710 90.98                          4140
64      66      0.330 3.810 60.66                          4140
65     126      0.31015.360  0.00
66      11      0.000 1.180  0.001.000                      500
67      68      1.93010.130  4.82                           349
68      69      0.680 3.530  1.68                           351
69      77      0.980 3.740  1.70                           269
69      78      1.140 4.340  1.96                           180
69      79      0.520 4.330  2.20                           522
70      73      0.000 1.970  0.001.040                      495
70     149      0.020 0.180  0.10                           538
70     149      0.020 0.180  0.10                           538
71      85      3.04015.060  7.16                           351
```

```
  71    150      1.960 9.700  4.62                           361
  72    113      0.220 1.300  0.00
  72    132      0.280 1.680  0.00
  72    152      3.85018.000  0.00
  74    119      0.310 3.100 48.22                          3450
  75    128      0.080 0.870 16.60                          2474
  75    130      0.040 2.420  0.001.025                      578
  78     79      0.510 3.360  1.82                           456
  78     80      2.440 9.300  4.22                           180
  79     74      0.000 1.800  0.001.025                      500
  82     83      0.530 2.490  1.30
  84     93      1.250 8.260  4.14                           406   0
  85     86      2.11010.460  4.98                           387
  86     87      2.80011.200  5.38                           325
  86     88      4.40022.800 10.90                           180
  88     96      7.40025.000  1.42                            48
  88    106      0.790 4.680  2.32                           173
  89     86      0.000 5.700  0.001.025                       90
  89     90      6.90013.400  1.40                            69
  90     96     18.37035.900  3.70                            92
  91     92      1.560 8.190  3.76                           270
  91     93      1.430 8.950  4.50                           523
  91     94      1.450 9.570  4.80                           406
  92    102      1.500 6.100  2.92                           270
  93     42      0.000 2.600  0.001.025                      400
  93    108      0.000 1.540  0.001.050                      600
  94    103      2.27013.330  6.60                           359
  94    107      6.13018.910  8.36                           269
  94    109      0.000 3.500  0.001.025                      300
  95     91      0.540 4.580 -0.361.020                      250
  95     96      8.70021.200  8.60                           136
  95     97     12.89028.090  3.34                            58
  95     98      0.710 4.300  2.24                           460
  95     99      0.000 6.850  0.001.030                      150
  96    100      6.90016.100  1.86                            69
  96    101      0.00010.310  0.001.030                       96
  97     44      0.51010.070 -0.251.025                       84
  98     93      0.060 2.140 -3.411.025                      504
  98    105     14.85029.300  3.10                            69
 100    104      6.20014.500  1.66                            69
 103    123     18.20075.100  0.00
 103    124      0.020 1.670  0.00
 103    125      2.79019.720  0.00
 104     34      0.800 6.370 -0.331.000                      106
 105     38      0.00011.600  0.001.025                       45
 106    107      1.960 6.110  2.68                           269
 107    122      1.300 6.210  2.96                           366
 109    119      0.600 5.770 92.90                          3450
 109    124      0.200 2.220 37.82                          3616
 109    125      0.700 6.200100.00                          3450
 110    111      2.300 9.900  4.60                           180
 110    112      0.000 1.850  0.001.000                      500
 110    114      0.000 7.680  0.001.040                      150
 110    134      0.320 2.560  1.34                           520
 110    141      2.100 6.490  2.88                           264
 111    115      5.27022.150 10.30                           337
 112    120      0.050 0.440  7.20                          3450
```

```
112     121      0.000 1.900  0.001.050                     720
113     132      4.59029.110  0.00
113     134      0.080 0.720  0.38                          520
115     117      0.190 1.540  3.30                         1030
116     117      0.480 3.910  2.14                          520
116     119      0.000 0.900  0.001.025                    1000
116     147      0.350 2.860  1.56                          520
117     147      0.220 1.750  1.00                          520
120      14      0.030 1.880  0.000.975                     500
120     128      0.040 0.510 10.00                         2474
120     129      0.030 0.380  6.52                         2474
122     123      1.750 8.350  3.98                          349
123     125      4.23024.410  0.00
124     125      1.13015.850  0.00
124     126      5.77082.560  0.00
125     126      2.01059.150  0.00
126     127      8.77070.490  0.00
128      72      0.040 1.800  0.001.000                     500
129     132      0.040 1.980  0.001.000                     500
133     134      0.000 4.100  0.001.025                     160
133     135      1.090 2.590  0.04                           44
133     136      3.900 9.900  0.16                           39
133     137      1.340 5.040  0.10                           60
135     138      4.66011.820  0.20                           39
136     139      2.600 6.500  0.10                           39
137     140      0.410 1.560  0.04                           60
138     110      0.000 4.100  0.001.000                     160
138     139      2.600 6.500  0.10                           39
138     140      2.510 9.410  0.18                           60
138     145      9.23023.380  0.38                           39
142      51      0.00017.280  0.001.070                      83
142     143     15.82039.190  0.68                           44
142     146     16.18038.610  0.70                           44
143     144      9.27023.220  0.20                           44
144     141      0.000 8.200  0.001.025                      80
144     145      8.90022.100  0.32                           39
144     146      6.80029.060  0.58                           60
148     116      0.000 4.100  0.001.000                     160
149      26      0.000 3.860  0.001.000                     300
149      26      0.000 3.860  0.001.000                     300
149     150      0.100 0.850  0.20                          538
149     151      0.390 2.620  1.38                          538
149     152      2.53011.680  5.44                          328
151     161      0.210 1.380  0.74                          538
153      70      0.000 9.160  0.001.000                      93
153      70      0.000 9.160  0.001.000                      93
153     154      7.10028.410  0.54                           50
153     155      4.30018.560  0.38                           66
154     156      1.550 3.790  0.08                           50
154     160      1.020 4.290  0.10                           50
155     156      1.760 8.220  0.14                           66
156     157      5.30012.730  0.22                           33
157      55      0.000 8.270  0.001.000                     150
157     158      4.89014.040  0.28                           50
158     159      3.390 6.640  0.12                           50
159     160      1.900 8.110  1.20                           50
161     162      0.220 1.030  0.54                          538
```

```
9999
EXLF NEWT
ULOG
2
Iowa.ard
ARQV INIC IMPR
SIM
ARQV GRAV IMPR SUBS
01
ULOG
4
Iowa.REL
RELA FILE 80CO RBAR RLIN
FIM
```

Appendix B

```
clear all

% PROGRAM TO CALCULATED POSSIBLE RESTORATION PATHS
% BREADTH-SEARCH TECHNIQUE
% AUTHOR: ARTURO SUMAN BRETAS

begin_time=cputime; % Beginning of time measurement

% Input Generated Trees

%Trees=load('treebin.txt');
%c=size(Trees);
%number_of_trees=c(1,1);

% Input Generation Buses

Gen_Bus=load('genbus162.txt');
d=size(Gen_Bus);
number_of_generators=d(1,2);

% Input Load Buses

Load_Bus=load('loadbus162.txt');
f=size(Load_Bus);
number_of_loads=f(1,2);

% Buses and their Directly Connected Buses

Line_Bus_Bus=load('b162isl2-1.txt');
d=size(Line_Bus_Bus);
number_of_lines=d(1,1);

for i = 1:number_of_lines
    Line(i)=Line_Bus_Bus(i,1);
    Bus_of_Column1(i)=Line_Bus_Bus(i,2);
    Bus_of_Column2(i)=Line_Bus_Bus(i,3);
end

Bus(1)=1; % First Bus
Final_Bus=max(max(Bus_of_Column1),max(Bus_of_Column2));
Final_Line=max(Line);
for i = 1:Final_Bus
    Bus(i)=i; % Bus Numeration
end

for i = 1:Final_Bus
    p=1;
    for j = 1:number_of_lines
       if (Bus(i)==Bus_of_Column1(j))%Bus(i) equal to Bus in the second
column
          bus_connected(i,p)=Bus_of_Column2(j); % Bus connected to Bus(i)
          p=p+1;
       end
       if (Bus(i)==Bus_of_Column2(j))%Bus(i) equal to Bus in the third column
```

```
          bus_connected(i,p)=Bus_of_Column1(j); %Bus Connected to Bus(i)
          p=p+1;
       end
    end
end

d=size(bus_connected);
Max_number_of_Connected_Buses=d(1,2);

% Connections Check

for i = 1:number_of_generators
    for j = 1:Final_Bus
    Bus_Connections(i,j)=0;%Initial Condition of zero distance between
Generator and Buses
    end
end

for i = 1:number_of_generators
    Bus_Connections(i,Gen_Bus(1,i))=1;  % Buses in which generators are
connected
end

cont=0;
 for c = 1:number_of_generators
  for h = 1:Final_Bus
  while (Bus_Connections(c,h)==0)&(cont<=number_of_lines+1)%Check if any bus
isn't checked
  cont=cont+1;                                     % And if the generator
isn't in a
    for i = 1:number_of_generators                 % island
     for n = 1:Final_Bus
       if (Bus_Connections(i,n)==cont)% n = Last Bus Visited
          for d = 1:Max_number_of_Connected_Buses
            if
(bus_connected(n,d)~=0)&(Bus_Connections(i,bus_connected(n,d))==0)
            Bus_Connections(i,bus_connected(n,d))=cont+1;%Bus at distance not
visited
            elseif
(bus_connected(n,d)~=0)&(Bus_Connections(i,bus_connected(n,d))~=0)
            visited_bus=Bus_Connections(i,bus_connected(n,d));

Bus_Connections(i,bus_connected(n,d))=min(cont+1,visited_bus);%Bus already
visited
            end
          end
       end
     end
   end
  end
 end
end

% Calculation of Electrical Distance between Generation and Load

for i = 1:Final_Bus
    for j = 1: Final_Bus
```

```
        Distance(i,j)=0; % All Initial Distances are set to zero
    end
end

cont=1;
for i = 1:number_of_generators
    Distance(Gen_Bus(1,i),Gen_Bus(1,i))=1;%Distance until the generator at
position i in the input
 for n = 1:Final_Bus
     if (n==Gen_Bus(1,i))
      for d = 1:Max_number_of_Connected_Buses
          if (bus_connected(n,d)~=0)
             Distance(Gen_Bus(1,i),bus_connected(n,d))=cont+1;%Distance to
bus linked to generator
          end                                                 %Bus at
Distance 2 to generator
      end
     end
 end
end

for i = 1:number_of_generators
    for n = 1:Final_Bus
      if (Distance(Gen_Bus(1,i),n)==cont+1) % Connected Buses to Generator
          for d = 1:Max_number_of_Connected_Buses
          if
(bus_connected(n,d)~=0)&(Distance(Gen_Bus(1,i),bus_connected(n,d))==0)
          Distance(Gen_Bus(1,i),bus_connected(n,d))=cont+2;%Bus at distance 3
to generator
          elseif
(bus_connected(n,d)~=0)&(Distance(Gen_Bus(1,i),bus_connected(n,d))~=0)
          old_distance=Distance(Gen_Bus(1,i),bus_connected(n,d));

Distance(Gen_Bus(1,i),bus_connected(n,d))=min(cont+2,old_distance);%Bus
already visited
          end
          end
     end
    end
end


 for c = 1:number_of_generators
  for h = 1:Final_Bus
  while (Distance(Gen_Bus(1,c),h)==0)&(cont<=number_of_lines+1)%Check if any
bus isn't assign a distance to the generator
  cont=cont+1;
    for i = 1:number_of_generators
     for n = 1:Final_Bus
       if (Distance(Gen_Bus(1,i),n)==cont+1)% n = Last Bus Visited
          for d = 1:Max_number_of_Connected_Buses
            if
(bus_connected(n,d)~=0)&(Distance(Gen_Bus(1,i),bus_connected(n,d))==0)
            Distance(Gen_Bus(1,i),bus_connected(n,d))=cont+2;%Bus at distance
not visited
            elseif
(bus_connected(n,d)~=0)&(Distance(Gen_Bus(1,i),bus_connected(n,d))~=0)
```

```
            old_distance=Distance(Gen_Bus(1,i),bus_connected(n,d));

Distance(Gen_Bus(1,i),bus_connected(n,d))=min(cont+2,old_distance);%Bus
already visited
            end
          end
       end
     end
   end
  end
 end
end

% Path Trace

gen=0;
for n = 1:number_of_generators
   for i = 1:number_of_loads

   if (Distance(Gen_Bus(1,n),Load_Bus(1,i))~=0)
   gen=gen+1;
   m=Distance(Gen_Bus(1,n),Load_Bus(1,i));%Distance between Load i &
generator n

   Path_load_generator(gen,m)=Load_Bus(1,i);% First Bus of the Path is the
Load-Bus
    while (Distance(Gen_Bus(1,n),Path_load_generator(gen,m))~=1)
    cont=1;
     for j = 1:Final_Bus
         if (Distance(Gen_Bus(1,n),j)==m-1)&(cont==1)
             for f = 1:Max_number_of_Connected_Buses
               if (bus_connected(j,f)==Path_load_generator(gen,m))%Check to
see if
                   m=m-1;                        %bus with lower dist. is
con-

                   Path_load_generator(gen,m)=j;  %nected to the previous
bus.
                   cont=cont+1;
               end
             end
      end
     end
  end
  end
   end
end

% Calculation of the Tree (All Loads Picked up)
d=size(Path_load_generator);
Maximum_Path=d(1,2);
Maximum_Path_Connections=d(1,1);
i=1;
f=1;
while i <= number_of_loads
    cont=1;
    for c = 1:number_of_generators
```

```
       if (Gen_Bus(2,c)~=0)&(cont==1)&(Distance...
             (Gen_Bus(1,c),Load_Bus(1,i))~=0)
      m=Distance(Gen_Bus(1,c),Load_Bus(1,i));%First Generator with non zero
     cont=2;                   %generation capability being used
     end
    end
    for p = 1:number_of_generators
    contador=p;
       if (Distance(Gen_Bus(1,p),Load_Bus(1,i))...%Generator with minimum
             <=m)&(Gen_Bus(2,p)>0)&(Distance...  %distance to the Load
             (Gen_Bus(1,p),Load_Bus(1,i))~=0)   % and still connected to
        m=Distance(Gen_Bus(1,p),Load_Bus(1,i)); % the  load
        n=p;
       end
   end
        if (contador==number_of_generators)&(cont==2)%There is still
generation
            for a = 1:Maximum_Path_Connections   %Creation of Final Path
              if Path_load_generator(a,1)==Gen_Bus(1,n)
               for k = 1:Maximum_Path
                  if k == Maximum_Path
                    if Path_load_generator(a,k)==Load_Bus(1,i)
                       Path_Used(f)=a;  %Path Used in the Restoration
                       f=f+1;
                   end
                  elseif k<Maximum_Path
                    if (Path_load_generator(a,k)==Load_Bus(1,i))...
                     &(Path_load_generator(a,k+1)==0)
                      Path_Used(f)=a;
                      f=f+1;            %Path Used in the Restoration
                    end
                  end
              end
              end
              end
         if (Load_Bus(2,i)-Gen_Bus(2,n))>0
             Load_Bus(2,i)=Load_Bus(2,i)-Gen_Bus(2,n);%Remaining Load
             Gen_Bus(2,n)=0;                          %Generator at its
capacity
             i=i-1;                                   %Continue on that Load
         elseif (Load_Bus(2,i)-Gen_Bus(2,n))<0
             Gen_Bus(2,n)=Gen_Bus(2,n)-Load_Bus(2,i); %Remaining Generation
             Load_Bus(2,i)=0;
         else                                         %Case where generation
             Load_Bus(2,i)=0;                         %is equal the load
             Gen_Bus(2,n)=0;
         end
        end

  i=i+1;
end

l=size(Path_Used);
Total_Number_of_Paths=l(1,2);  %Total Number of Paths used
k=1;
for p = 1:Total_Number_of_Paths
 for i = 1:Maximum_Path_Connections
```

```
   if Path_Used(1,p)==i
      for j = 1:Maximum_Path
         if Path_load_generator(i,j)~=0
            Final_Path(p,j)=Path_load_generator(i,j); %Matrix
         end                              %with the paths used
      end
   end
  end
end

% Number and connections of islands


d=size(Final_Path);
Maximum_Final_Path_Connections=d(1,2);

for i = 1:1  %First Line of Final Path is equal to the island #1
    for j = 1:Maximum_Final_Path_Connections
          if Final_Path(i,j)~=0
             Island(i,j)=Final_Path(i,j);
          end
    end
end

d=size(Island);
actual_number_of_buses_island=d(1,2);
number_of_islands=d(1,1);
t=1;
cont=0;
k=1;
contador=1;
entrance=1;
visited_path(1)=1;
Island_Lines(1,1)=1;
cont_line=1;
f=1;
q=1;
d=d+1;
number_of_paths_visited=0;
another_cont=0;
another_cont_again=1;
final=0;

while (number_of_paths_visited<Total_Number_of_Paths)
cc=1;
if((actual_number_of_buses_island-d)==0)%Check if island increased or not
 number_of_islands=number_of_islands+1;%If not increased create another
island

 for e = 1:Total_Number_of_Paths

      another_cont=0;
      pp=size(visited_path);
      size_of_visited_path=pp(1,2);

     if(another_cont==0)
      for g = 1:size_of_visited_path
```

```
        if (e~=visited_path(g))&(cc==1)% First Line not visited before.
            if another_cont_again==size_of_visited_path
               cc=2;
               % visited_path(size_of_visited_path+1)=e;

                for ii = e:e  %First Line not visited of Final Path is equal
to the island
                     for jj = 1:Maximum_Final_Path_Connections
                        if Final_Path(ii,jj)~=0
                         Island(number_of_islands,jj)=Final_Path(ii,jj);%New
Island
                         actual_number_of_buses_island=jj;
                        end
                     end
                end
            end
        another_cont_again=another_cont_again+1;

        else

        another_cont_again=1;
        break
        end
      end
    another_cont=1;

    end

 end
end


 d=actual_number_of_buses_island;  %if it did, the search should continue

for i = 2:Total_Number_of_Paths

    for j = 1:Maximum_Final_Path_Connections
       if (Final_Path(i,j)~=0)

           for r = number_of_islands:number_of_islands

               for f = 1:actual_number_of_buses_island
                   for w = 1:t

                    if i~=visited_path(w)    %Check if path was visited
before
                        cont=cont+1;
                     if cont==t
                      entrance=1;
                      for v = 1:actual_number_of_buses_island

                      if
(Final_Path(i,j)==Island(r,v))&(entrance==1)%Comparation of bus and island
                          w=w+1;

                          t=w;
```

```
                          visited_path(t)=i;
                          cont_line=cont_line+1;

Island_Lines(number_of_islands,cont_line)=visited_path(t);

                          while
(Final_Path(i,k)~=0)&(k<=Maximum_Final_Path_Connections)...
                                 &(final==0)

                           if
(Final_Path(i,k)~=Island(r,contador))&(contador==...
                                   actual_number_of_buses_island)

                              Island(r,actual_number_of_buses_island+1)=...
                              Final_Path(i,k);  %Restoration Path gathered in
island
                              actual_number_of_buses_island=...
                              actual_number_of_buses_island+1;%Number of
buses in island is increased

                               if k==Maximum_Final_Path_Connections
                                  final=1; %If we reached the final bus of
the Path and this bus is also
                               end         %in the final column of Final_Path
we finish the gathering

                               if k~=Maximum_Final_Path_Connections
                                 k=k+1;
                               end


                              contador=1;
                           elseif Final_Path(i,k)==Island(r,contador)
                              Island(r,contador);

                                if k==Maximum_Final_Path_Connections
                                  final=1;  %If we reached the final bus of
the Path and this bus is also
                                end         %in the final column of
Final_Path we finish the gathering

                                if k~=Maximum_Final_Path_Connections
                                k=k+1;
                                end

                                contador=1;
                           else

                               contador=contador+1;

                           end

                          end
                       contador=1;
                       k=1;
                       entrance=2;
```

```
                      final=0;

                     end
                     end
                     cont=0;
                    end
                  else

                  cont=0;    %Path was visited
                  break
                  end
                 end

             end
         end
       end
    end
end

number_of_paths_visited=t;
end

% Finding the lines used in the restoration of each island



Line_Used(1)=0;
size_of_line_used=1;
d=size(Island);
maximum_number_of_buses_island=d(1,2);
p=1;
cont=0;
anot_cont=1;
%m=1;
pat=1;

for s = 1:Total_Number_of_Paths
    for e = 1:Maximum_Final_Path_Connections-1

       while (Final_Path(s,e+1)~=0)

            for j = 1:number_of_lines
                if (Final_Path(s,e)==Bus_of_Column1(j))&...%If Bus used in
restoration is equal to Bus in Column 1
                (Final_Path(s,e+1)==Bus_of_Column2(j))%If Bus used in
restoration is equal to Bus in Column2
                    for c = 1:size_of_line_used
                        if Line(j)~=Line_Used(c)
                        cont=cont+1;
                            if cont==size_of_line_used

                              for isl = 1:number_of_islands
                                while pat<=Total_Number_of_Paths
                                    if s==Island_Lines(isl,pat)

Final_Island_Line(isl,anot_cont)=Line(j);%Lines used in the island
                                        anot_cont=anot_cont+1;
```

```
                                end
                                pat=pat+1;
                              end
                          pat=1;
                          end
                          pat=1;

                        Line_Used(p)=Line(j);%Line correspondent is used



                        q=size(Line_Used);
                        size_of_line_used=q(1,2);
                        p=p+1;
                        cont=0;
                        end
                    else
                    cont=0;
                    break
                    end
                end
            elseif (Final_Path(s,e)==Bus_of_Column2(j))&...%If Bus used
in restoration is equal to Bus in Column 2
            (Final_Path(s,e+1)==Bus_of_Column1(j))%If Bus used in
restoration is equal to Bus in Column1
                for c = 1:size_of_line_used
                    if Line(j)~=Line_Used(c)
                    cont=cont+1;
                        if cont==size_of_line_used

                        for isl = 1:number_of_islands
                            while pat<=Total_Number_of_Paths

                                if s==Island_Lines(isl,pat)

Final_Island_Line(isl,anot_cont)=Line(j);%Lines used in the island
                                    anot_cont=anot_cont+1;
                                end
                                pat=pat+1;
                              end
                          pat=1;
                          end
                          pat=1;

                        Line_Used(p)=Line(j);%Line correspondent is used



                        q=size(Line_Used);
                        size_of_line_used=q(1,2);
                        p=p+1;
                        cont=0;
                        end
                    else
                    cont=0;
                    break
                    end
```

```
                    end

                end
            end

       break
      end
    end
end

% Eliminating the zero elements from the matrix Final_Island_Line

d=size(Final_Island_Line);
number_of_islands_with_lines=d(1,1);

for i = 1:number_of_islands_with_lines
Island_Line(i,1)=0;% First Lines will be the first one used in the island
end


for i = 1:number_of_islands_with_lines
cont=1;
size_of_Island_Line=1;
    for j = 1:size_of_line_used
       if (Final_Island_Line(i,j)~=0) %Don't consider the zero elements of
the matrix
           anot_cont=1;
           for k = 1:size_of_Island_Line

                if (Final_Island_Line(i,j)~=Island_Line(i,k))%If Line wasn't
already saved in the Island
                    if (anot_cont==size_of_Island_Line)
                    Island_Line(i,cont)=Final_Island_Line(i,j);%Save Line in
new matrix
                    cont=cont+1;
                    size_of_Island_Line=cont-1;
                    end
                    anot_cont=anot_cont+1;

                end
           end
        end
   end
end

% Exporting the data for a text file

d=size(Island_Line);
size_of_Island_Line=d(1,2);

a=sort(Island,2);
Island=a;
a=sort(Island_Line,2);
Island_Line=a;

end_time=cputime;
Running_Time=end_time-begin_time
```

```
fid=fopen('Output.txt','w');
flineid=fopen('linenotused.txt','w');
fbusid=fopen('busnotused.txt','w');

ftotalbusid=fopen('bustnotused.txt','w');
ftotallineid=fopen('linetnotused.txt','w');

fprintf(fid,' Number of Islands Formed:\n');
fprintf(fid,'%3i\n',number_of_islands);
fprintf(fid,'\n Buses in Islands:');
for i = 1:number_of_islands
    fprintf(fid,'\n-');
    for j = 1:maximum_number_of_buses_island
      fprintf(fid,'%3i  ',Island(i,j));
    end
end

% Creation of the input of anarede.m

% Creation of busnotused file

for i = 1:number_of_islands
    fprintf(fbusid,'\n-');
    for j = 1:Final_Bus
        cont=1;
        while cont<=maximum_number_of_buses_island
        if (j~=Island(i,cont))&(cont==maximum_number_of_buses_island)
            fprintf(fbusid,'%3i  ',j);
        elseif j==Island(i,cont)
            cont=maximum_number_of_buses_island+1;
        end
        cont=cont+1;
        end
    end
end

% Creation of bustnotused file


   for j = 1:Final_Bus
        cont=1;
        k=1;

    while cont<=maximum_number_of_buses_island

       if (j~=Island(k,cont))&(cont==maximum_number_of_buses_island)&...
               (k==number_of_islands)

          fprintf(ftotalbusid,'%3i  ',j);
       elseif j==Island(k,cont)

          cont=maximum_number_of_buses_island+1;


       end
       if (cont==maximum_number_of_buses_island)&(k<number_of_islands)
```

```
          k=k+1;
          cont=0;
       end

       cont=cont+1;

       end

     end


% Creation of linenotused file

for i = 1:number_of_islands_with_lines
    fprintf(flineid,'\n-');
    for j = 1:Final_Line % Plus 4 only for 162 Bus System (Four Parallel
Lines)
        cont=1;
        while cont<=size_of_Island_Line
        if (j~=Island_Line(i,cont))&(cont==size_of_Island_Line)...
           &(j~=148)&(j~=169)&(j~=267)&(j~=273)
            fprintf(flineid,'%3i  ',j);
        elseif j==Island_Line(i,cont)
            cont=size_of_Island_Line+1;

        end
        cont=cont+1;
        end
    end
end

% Creation of linetnotused file

%for i = 1:number_of_islands_with_lines
%    fprintf(flineid,'\n-');
    for j = 1:Final_Line % Plus 4 only for 162 Bus System (Four Parallel
Lines)
        i=1;
        cont=1;
        while cont<=size_of_Island_Line
        if (j~=Island_Line(i,cont))&(cont==size_of_Island_Line)...

&(j~=148)&(j~=169)&(j~=267)&(j~=273)&(i==number_of_islands_with_lines)...

&(j~=225)&(j~=176)&(j~=236)&(j~=17)&(j~=238)&(j~=263)&(j~=16)&(j~=3)&...%Tie
Lines

(j~=133)&(j~=234)&(j~=232)&(j~=82)&(j~=10)&(j~=12)&(j~=11)&(j~=13)&...

(j~=8)&(j~=9)&(j~=43)&(j~=172)&(j~=41)&(j~=42)&(j~=30)&(j~=26)&...

(j~=22)&(j~=49)&(j~=135)&(j~=119)&(j~=154)&(j~=150)&(j~=151)&(j~=75)&...

(j~=153)&(j~=161)&(j~=85)&(j~=155)&(j~=156)&(j~=242)&(j~=219)&(j~=243)&...

(j~=220)&(j~=87)&(j~=117)&(j~=197)&(j~=239)&(j~=122)&(j~=64)&(j~=112)&...
```

```
(j~=263)&(j~=187)&(j~=62)&(j~=57)&(j~=94)&(j~=102)&(j~=104)&(j~=69)&...

(j~=79)&(j~=78)&(j~=75)&(j~=192)&(j~=208)&(j~=70)&(j~=199)&(j~=218)&...

(j~=178)&(j~=179)&(j~=97)&(j~=143)&(j~=166)&(j~=279)&(j~=283)&(j~=270)&...

(j~=168)&(j~=183)&(j~=132)&(j~=192)&(j~=197)&(j~=201)&(j~=215)&(j~=130)&...
              (j~=120)
           fprintf(ftotallineid,'%3i  ',j);
        elseif j==Island_Line(i,cont)
            cont=size_of_Island_Line+1;

        end
        if (cont==size_of_Island_Line)&(i<number_of_islands_with_lines)
            i=i+1;
            cont=0;
        end
        cont=cont+1;
        end
    end
    %end

% Output Information File

fprintf(fid,'\n\n Lines in Islands:');
for i = 1:number_of_islands_with_lines
    fprintf(fid,'\n-');
    for j = 1:size_of_Island_Line
        fprintf(fid,'%3i  ',Island_Line(i,j));
    end
end


fprintf(fid,'\n\n Final Generation(MW):');
for i = 1:2
    fprintf(fid,'\n');
    for j = 1:number_of_generators
        fprintf(fid,'%7.2f ',Gen_Bus(i,j));
    end
end

fprintf(fid,'\n\n Final Load(MW):');
for i = 1:2
    fprintf(fid,'\n');
    for j = 1:number_of_loads
        fprintf(fid,'%7.2f ',Load_Bus(i,j));
    end
end

fprintf(fid,'\n\n Running Time(s):\n');
fprintf(fid,'   %6.4f',Running_Time);
status=fclose(fid);
status=fclose(flineid);
status=fclose(fbusid);
status=fclose(ftotalbusid);
status=fclose(ftotallineid);
```

Appendix C

```
clear all
% Switching Sequence Program of IRS #1
% Load the Paths
begin_time=cputime;

Paths=load('Paths_Island#1.txt');
d=size(Paths);
number_of_paths=d(1,1);
max_path=d(1,2);

% Load the Tree (lines used)

Tree=load('Tree_Island#1tes.txt');

l=size(Tree);
max_tree=l(1,2);


% Lines in Island

Isl(1)=221;
Isl(2)=226;
Isl(3)=222;
Isl(4)=254;
Isl(5)=227;
Isl(6)=237;
Isl(7)=224;
Isl(8)=245;
Isl(9)=247;
Isl(10)=14;
Isl(11)=248;
Isl(12)=251;
Isl(13)=249;
Isl(14)=255;
Isl(15)=256;
Isl(16)=252;
Isl(17)=15;
Isl(18)=250;
Isl(19)=253;
Isl(20)=231;
Isl(21)=257;
Isl(22)=174;
Isl(23)=235;
Isl(24)=228;
Isl(25)=223;

a=size(Isl);
number_of_lines_in_island=a(1,2);

% Lines and there respective buses

Line_Bus_Bus=load('b162isl-paral.txt');
d=size(Line_Bus_Bus);
number_of_lines=d(1,1);
```

```
for i = 1:number_of_lines
    Line(i)=Line_Bus_Bus(i,1);
    Bus_of_Column1(i)=Line_Bus_Bus(i,2);
    Bus_of_Column2(i)=Line_Bus_Bus(i,3);
end

% Buses Used
l=1;
for i = 1 : max_tree
  for j = 1 : number_of_lines
    l=1;
   if (Tree(1,i)==Line_Bus_Bus(j,1))
      Bus_Used(i,l)=Line_Bus_Bus(j,2);
      Bus_Used(i,l+1)=Line_Bus_Bus(j,3);
   end

  end
end

cont=1;
Buses(1)=0;
l=1;
f=0;
for i = 1 : max_tree
   for j = 1 : 2
      cont=1;
      if f>=2
         l=f;
      end
      for d = 1 : l
         if (Buses(d)~=Bus_Used(i,j))&(d==l)&(cont~=100)
             f=f+1;
            Buses(f)=Bus_Used(i,j);

         elseif (Buses(d)==Bus_Used(i,j))
            cont==100;
            break
         end
      end
   end
end
d=size(Buses);
number_of_buses_used=d(1,2);

% Identificacao das Linhas nao Utilizadas na Arvore de Restauracao

m=0;
n=0;
cont=1;
for i = 1 : number_of_lines_in_island
   cont=1;
   for j = 1 : max_tree
      if (Isl(i)==Tree(j))&(cont~=100)
         cont=100;
         n=n+1;
         Line_Used(n)=Isl(i);
```

```
      elseif (Isl(i)~=Tree(j))&(cont~=100)&(j==max_tree)
         cont=100;
         m=m+1;
         Line_Not_Used(m)=Isl(i);
      end
   end
end

% Identification of Paths that contain Lines Not Used

Path_Not_Used(1)=0;
d=0;
for i = 1 : m
   for k = 1 : number_of_paths
      for z = 1 : max_path
         if (Line_Not_Used(i)==Paths(k,z))
            d=d+1;
            Path_Not_Used(d)=k;
         end
       end
   end
end
d=size(Path_Not_Used);
number_of_paths_not_used=d(1,2);

% Creation of a Matrix with only Paths Used

u=1;
cont=1;

for t = 1 : number_of_paths
   cont2=1;
   cont3=1;
    for i = 1 : number_of_paths_not_used
      cont=1;
        for m = 1 : max_path
           if (Path_Not_Used(i)~=t)&(cont2==number_of_paths_not_used)...
                 &(cont3~=100)
              matx_with_paths_used(u,m)=Paths(t,m);
              if cont==max_path
                 u=u+1;
              end
              cont=cont+1;
           elseif(Path_Not_Used(i)==t)
              cont3=100;
           end
        end
     cont2=cont2+1;
     end
end

ll=size(matx_with_paths_used);
number_of_paths_used=ll(1,1);

% Energization of the most priority Load
```

```
energ_list=zeros(1,number_of_paths_used); % List of Energized Paths
swit=zeros(1,max_tree);% Final Switching Sequence
m=1;
cont2=1;
cont3=1;
for i = 1 : number_of_paths_used
   cont=1;
      for n = 1 : number_of_paths_used
         if (i~=energ_list(1,n))&(n==number_of_paths_used)&(cont~=100)
            cont==100;
            energ_list(1,cont2)=i;
            cont2=cont2+1;
            for j = 1 : max_path
               cont3=1;
               for n = 1 : max_tree
                  if ((matx_with_paths_used(i,j)~=swit(1,n))&...
                  (matx_with_paths_used(i,j)~=0)&(n==max_tree)&(cont3~=100))
                  swit(1,m)=matx_with_paths_used(i,j);
                  m=m+1;
                  elseif (matx_with_paths_used(i,j)==swit(1,n))
                     cont3==100;
                     break
                  end
                end
             end
          elseif (i==energ_list(n))
             cont==100;
          end
      end
end

end_time=cputime;
Running_Time=end_time-begin_time


clear all
begin_time=cputime;

% Switching Sequence Program of IRS #2
% Load the Paths
Paths=load('Paths_Island#2.txt');
d=size(Paths);
number_of_paths=d(1,1);
max_path=d(1,2);

% Load the Tree (lines used)

Tree=load('Tree_Island#2tes.txt');

l=size(Tree);
max_tree=l(1,2);


% Lines in Island

Isl(1)=2;
```

```
Isl(2)=4;
Isl(3)=18;
Isl(4)=246;
Isl(5)=6;
Isl(6)=23;
Isl(7)=37;
Isl(8)=25;
Isl(9)=40;
Isl(10)=38;
Isl(11)=1;
Isl(12)=39;
Isl(13)=20;
Isl(14)=24;
Isl(15)=27;
Isl(16)=8;
Isl(17)=7;
Isl(18)=44;
Isl(19)=229;
Isl(20)=45;
Isl(21)=21;
Isl(22)=28;
Isl(23)=177;
Isl(24)=5;
Isl(25)=19;

a=size(Isl);
number_of_lines_in_island=a(1,2);

% Lines and there respective buses

Line_Bus_Bus=load('b162isl-paral.txt');
d=size(Line_Bus_Bus);
number_of_lines=d(1,1);

for i = 1:number_of_lines
    Line(i)=Line_Bus_Bus(i,1);
    Bus_of_Column1(i)=Line_Bus_Bus(i,2);
    Bus_of_Column2(i)=Line_Bus_Bus(i,3);
end

% Buses Used
l=1;
for i = 1 : max_tree
  for j = 1 : number_of_lines
    l=1;
   if (Tree(1,i)==Line_Bus_Bus(j,1))
      Bus_Used(i,l)=Line_Bus_Bus(j,2);
      Bus_Used(i,l+1)=Line_Bus_Bus(j,3);
   end

  end
end

cont=1;
Buses(1)=0;
l=1;
f=0;
```

```
for i = 1 : max_tree
   for j = 1 : 2
      cont=1;
      if f>=2
         l=f;
      end
      for d = 1 : l
         if (Buses(d)~=Bus_Used(i,j))&(d==l)&(cont~=100)
             f=f+1;
            Buses(f)=Bus_Used(i,j);

         elseif (Buses(d)==Bus_Used(i,j))
            cont==100;
            break
         end
      end
   end
end
d=size(Buses);
number_of_buses_used=d(1,2);

% Identificacao das Linhas nao Utilizadas na Arvore de Restauracao

m=0;
n=0;
cont=1;
for i = 1 : number_of_lines_in_island
   cont=1;
   for j = 1 : max_tree
      if (Isl(i)==Tree(j))&(cont~=100)
         cont=100;
         n=n+1;
         Line_Used(n)=Isl(i);
      elseif (Isl(i)~=Tree(j))&(cont~=100)&(j==max_tree)
         cont=100;
         m=m+1;
         Line_Not_Used(m)=Isl(i);
      end
   end
end

% Identification of Paths that contain Lines Not Used

Path_Not_Used(1)=0;
d=0;
for i = 1 : m
   for k = 1 : number_of_paths
      for z = 1 : max_path
         if (Line_Not_Used(i)==Paths(k,z))
            d=d+1;
            Path_Not_Used(d)=k;
         end
       end
   end
end
d=size(Path_Not_Used);
number_of_paths_not_used=d(1,2);
```

```
% Creation of a Matrix with only Paths Used

u=1;
cont=1;

for t = 1 : number_of_paths
   cont2=1;
   cont3=1;
    for i = 1 : number_of_paths_not_used
      cont=1;
        for m = 1 : max_path
           if (Path_Not_Used(i)~=t)&(cont2==number_of_paths_not_used)...
                 &(cont3~=100)
              matx_with_paths_used(u,m)=Paths(t,m);
              if cont==max_path
                 u=u+1;
              end
              cont=cont+1;
           elseif(Path_Not_Used(i)==t)
              cont3=100;
           end
        end
     cont2=cont2+1;
     end
end

ll=size(matx_with_paths_used);
number_of_paths_used=ll(1,1);

% Energization of the most priority Load


energ_list=zeros(1,number_of_paths_used); % List of Energized Paths
swit=zeros(1,max_tree);% Final Switching Sequence
m=1;
cont2=1;
cont3=1;
for i = 1 : number_of_paths_used
   cont=1;
      for n = 1 : number_of_paths_used
         if (i~=energ_list(1,n))&(n==number_of_paths_used)&(cont~=100)
            cont==100;
            energ_list(1,cont2)=i;
            cont2=cont2+1;
            for j = 1 : max_path
               cont3=1;
               for n = 1 : max_tree
                  if ((matx_with_paths_used(i,j)~=swit(1,n))&...
                  (matx_with_paths_used(i,j)~=0)&(n==max_tree)&(cont3~=100))
                  swit(1,m)=matx_with_paths_used(i,j);
                  m=m+1
                  elseif (matx_with_paths_used(i,j)==swit(1,n))
                     cont3==100;
                     break
                  end
                end
```

```
             end
          elseif (i==energ_list(n))
             cont==100;
          end
      end
end

end_time=cputime;
Running_Time=end_time-begin_time


clear all
begin_time=cputime;

% Switching Sequence Program of IRS #3
% Load the Paths
Paths=load('Paths_Island#3.txt');
d=size(Paths);
number_of_paths=d(1,1);
max_path=d(1,2);

% Load the Tree (lines used)

Tree=load('Tree_Island#3tes.txt');

l=size(Tree);
max_tree=l(1,2);


% Lines in Island

Isl(1)=32;
Isl(2)=29;
Isl(3)=31;
Isl(4)=48;
Isl(5)=34;
Isl(6)=46;
Isl(7)=35;
Isl(8)=36;
Isl(9)=47;
Isl(10)=33;
Isl(11)=149;
Isl(12)=145;
Isl(13)=152;
Isl(14)=146;
Isl(15)=147;
Isl(16)=148;

a=size(Isl);
number_of_lines_in_island=a(1,2);

% Lines and there respective buses

Line_Bus_Bus=load('b162isl-paral.txt');
d=size(Line_Bus_Bus);
number_of_lines=d(1,1);
```

```
for i = 1:number_of_lines
    Line(i)=Line_Bus_Bus(i,1);
    Bus_of_Column1(i)=Line_Bus_Bus(i,2);
    Bus_of_Column2(i)=Line_Bus_Bus(i,3);
end

% Buses Used
l=1;
for i = 1 : max_tree
  for j = 1 : number_of_lines
    l=1;
   if (Tree(1,i)==Line_Bus_Bus(j,1))
      Bus_Used(i,l)=Line_Bus_Bus(j,2);
      Bus_Used(i,l+1)=Line_Bus_Bus(j,3);
   end

  end
end

cont=1;
Buses(1)=0;
l=1;
f=0;
for i = 1 : max_tree
   for j = 1 : 2
      cont=1;
      if f>=2
         l=f;
      end
      for d = 1 : l
         if (Buses(d)~=Bus_Used(i,j))&(d==l)&(cont~=100)
             f=f+1;
            Buses(f)=Bus_Used(i,j);

         elseif (Buses(d)==Bus_Used(i,j))
            cont==100;
            break
         end
      end
   end
end
d=size(Buses);
number_of_buses_used=d(1,2);

% Identificacao das Linhas nao Utilizadas na Arvore de Restauracao

m=0;
n=0;
cont=1;
for i = 1 : number_of_lines_in_island
   cont=1;
   for j = 1 : max_tree
      if (Isl(i)==Tree(j))&(cont~=100)
         cont=100;
         n=n+1;
         Line_Used(n)=Isl(i);
      elseif (Isl(i)~=Tree(j))&(cont~=100)&(j==max_tree)
```

```
         cont=100;
         m=m+1;
         Line_Not_Used(m)=Isl(i);
      end
   end
end

% Identification of Paths that contain Lines Not Used

Path_Not_Used(1)=0;
d=0;
for i = 1 : m
   for k = 1 : number_of_paths
      for z = 1 : max_path
         if (Line_Not_Used(i)==Paths(k,z))
            d=d+1;
            Path_Not_Used(d)=k;
         end
       end
   end
end

d=size(Path_Not_Used);
number_of_paths_not_used=d(1,2);

% Creation of a Matrix with only Paths Used

u=1;
cont=1;

for t = 1 : number_of_paths
   cont2=1;
   cont3=1;
    for i = 1 : number_of_paths_not_used
      cont=1;
        for m = 1 : max_path
           if (Path_Not_Used(i)~=t)&(cont2==number_of_paths_not_used)...
                 &(cont3~=100)
              matx_with_paths_used(u,m)=Paths(t,m);
              if cont==max_path
                 u=u+1;
              end
              cont=cont+1;
           elseif(Path_Not_Used(i)==t)
              cont3=100;
           end
        end
     cont2=cont2+1;
     end
end

ll=size(matx_with_paths_used);
number_of_paths_used=ll(1,1);

% Energization of the most priority Load
```

```
energ_list=zeros(1,number_of_paths_used); % List of Energized Paths
swit=zeros(1,max_tree);% Final Switching Sequence
m=1;
cont2=1;
cont3=1;
for i = 1 : number_of_paths_used
   cont=1;
      for n = 1 : number_of_paths_used
         if (i~=energ_list(1,n))&(n==number_of_paths_used)&(cont~=100)
            cont==100;
            energ_list(1,cont2)=i;
            cont2=cont2+1;
            for j = 1 : max_path
               cont3=1;
               for n = 1 : max_tree
                  if ((matx_with_paths_used(i,j)~=swit(1,n))&...
                  (matx_with_paths_used(i,j)~=0)&(n==max_tree)&(cont3~=100))
                  swit(1,m)=matx_with_paths_used(i,j);
                  m=m+1
                  elseif (matx_with_paths_used(i,j)==swit(1,n))
                     cont3==100;
                     break
                  end
                end
             end
          elseif (i==energ_list(n))
             cont==100;
          end
      end
end

end_time=cputime;
Running_Time=end_time-begin_time


clear all
begin_time=cputime;

% Switching Sequence Program of IRS #4
% Load the Paths
Paths=load('Paths_Island#4.txt');
d=size(Paths);
number_of_paths=d(1,1);
max_path=d(1,2);

% Load the Tree (lines used)

Tree=load('Tree_Island#4tes.txt');

l=size(Tree);
max_tree=l(1,2);


% Lines in Island
```

```
Isl(1)=212;
Isl(2)=213;
Isl(3)=240;
Isl(4)=241;
Isl(5)=128;
Isl(6)=211;
Isl(7)=113;
Isl(8)=114;
Isl(9)=115;
Isl(10)=127;
Isl(11)=126;
Isl(12)=129;
Isl(13)=264;
Isl(14)=260;
Isl(15)=259;
Isl(16)=258;
Isl(17)=261;
Isl(18)=262;

a=size(Isl);
number_of_lines_in_island=a(1,2);

% Lines and there respective buses

Line_Bus_Bus=load('b162isl-paral.txt');
d=size(Line_Bus_Bus);
number_of_lines=d(1,1);

for i = 1:number_of_lines
    Line(i)=Line_Bus_Bus(i,1);
    Bus_of_Column1(i)=Line_Bus_Bus(i,2);
    Bus_of_Column2(i)=Line_Bus_Bus(i,3);
end

% Buses Used
l=1;
for i = 1 : max_tree
  for j = 1 : number_of_lines
    l=1;
   if (Tree(1,i)==Line_Bus_Bus(j,1))
      Bus_Used(i,l)=Line_Bus_Bus(j,2);
      Bus_Used(i,l+1)=Line_Bus_Bus(j,3);
   end

  end
end

cont=1;
Buses(1)=0;
l=1;
f=0;
for i = 1 : max_tree
   for j = 1 : 2
      cont=1;
      if f>=2
         l=f;
      end
```

```
      for d = 1 : l
         if (Buses(d)~=Bus_Used(i,j))&(d==l)&(cont~=100)
             f=f+1;
            Buses(f)=Bus_Used(i,j);

         elseif (Buses(d)==Bus_Used(i,j))
            cont==100;
            break
         end
      end
   end
end
d=size(Buses);
number_of_buses_used=d(1,2);

% Identificacao das Linhas nao Utilizadas na Arvore de Restauracao

m=0;
n=0;
cont=1;
for i = 1 : number_of_lines_in_island
   cont=1;
   for j = 1 : max_tree
      if (Isl(i)==Tree(j))&(cont~=100)
         cont=100;
         n=n+1;
         Line_Used(n)=Isl(i);
      elseif (Isl(i)~=Tree(j))&(cont~=100)&(j==max_tree)
         cont=100;
         m=m+1;
         Line_Not_Used(m)=Isl(i);
      end
   end
end

% Identification of Paths that contain Lines Not Used

Path_Not_Used(1)=0;
d=0;
for i = 1 : m
   for k = 1 : number_of_paths
      for z = 1 : max_path
         if (Line_Not_Used(i)==Paths(k,z))
            d=d+1;
            Path_Not_Used(d)=k;
         end
       end
   end
end

d=size(Path_Not_Used);
number_of_paths_not_used=d(1,2);

% Creation of a Matrix with only Paths Used

u=1;
cont=1;
```

```
for t = 1 : number_of_paths
   cont2=1;
   cont3=1;
    for i = 1 : number_of_paths_not_used
      cont=1;
        for m = 1 : max_path
           if (Path_Not_Used(i)~=t)&(cont2==number_of_paths_not_used)...
                 &(cont3~=100)
              matx_with_paths_used(u,m)=Paths(t,m);
              if cont==max_path
                 u=u+1;
              end
              cont=cont+1;
           elseif(Path_Not_Used(i)==t)
              cont3=100;
           end
        end
     cont2=cont2+1;
     end
end

ll=size(matx_with_paths_used);
number_of_paths_used=ll(1,1);

% Energization of the most priority Load


energ_list=zeros(1,number_of_paths_used); % List of Energized Paths
swit=zeros(1,max_tree);% Final Switching Sequence
m=1;
cont2=1;
cont3=1;
for i = 1 : number_of_paths_used
   cont=1;
      for n = 1 : number_of_paths_used
         if (i~=energ_list(1,n))&(n==number_of_paths_used)&(cont~=100)
            cont==100;
            energ_list(1,cont2)=i;
            cont2=cont2+1;
            for j = 1 : max_path
               cont3=1;
               for n = 1 : max_tree
                  if ((matx_with_paths_used(i,j)~=swit(1,n))&...
                  (matx_with_paths_used(i,j)~=0)&(n==max_tree)&(cont3~=100))
                  swit(1,m)=matx_with_paths_used(i,j);
                  m=m+1
                  elseif (matx_with_paths_used(i,j)==swit(1,n))
                     cont3==100;
                     break
                  end
                end
             end
          elseif (i==energ_list(n))
             cont==100;
          end
      end
```

```
end

end_time=cputime;
Running_Time=end_time-begin_time


clear all
begin_time=cputime;

% Switching Sequence Program of IRS #5
% Load the Paths
Paths=load('Paths_Island#5.txt');
d=size(Paths);
number_of_paths=d(1,1);
max_path=d(1,2);

% Load the Tree (lines used)

Tree=load('Tree_Island#5tes.txt');

l=size(Tree);
max_tree=l(1,2);


% Lines in Island

Isl(1)=56;
Isl(2)=92;
Isl(3)=84;
Isl(4)=160;
Isl(5)=88;
Isl(6)=104;
Isl(7)=55;
Isl(8)=50;
Isl(9)=86;
Isl(10)=103;
Isl(11)=53;
Isl(12)=52;
Isl(13)=90;
Isl(14)=76;
Isl(15)=93;
Isl(16)=77;
Isl(17)=61;
Isl(18)=60;
Isl(19)=63;
Isl(20)=74;
Isl(21)=59;
Isl(22)=65;
Isl(23)=80;
Isl(24)=58;
Isl(25)=51;
Isl(26)=54;
Isl(27)=89;
Isl(28)=157;
Isl(29)=91;
Isl(30)=244;
```

```
a=size(Isl);
number_of_lines_in_island=a(1,2);

% Lines and there respective buses

Line_Bus_Bus=load('b162isl-paral.txt');
d=size(Line_Bus_Bus);
number_of_lines=d(1,1);

for i = 1:number_of_lines
    Line(i)=Line_Bus_Bus(i,1);
    Bus_of_Column1(i)=Line_Bus_Bus(i,2);
    Bus_of_Column2(i)=Line_Bus_Bus(i,3);
end

% Buses Used
l=1;
for i = 1 : max_tree
  for j = 1 : number_of_lines
    l=1;
   if (Tree(1,i)==Line_Bus_Bus(j,1))
      Bus_Used(i,l)=Line_Bus_Bus(j,2);
      Bus_Used(i,l+1)=Line_Bus_Bus(j,3);
   end

  end
end

cont=1;
Buses(1)=0;
l=1;
f=0;
for i = 1 : max_tree
   for j = 1 : 2
      cont=1;
      if f>=2
         l=f;
      end
      for d = 1 : l
         if (Buses(d)~=Bus_Used(i,j))&(d==l)&(cont~=100)
             f=f+1;
            Buses(f)=Bus_Used(i,j);

         elseif (Buses(d)==Bus_Used(i,j))
            cont==100;
            break
         end
      end
   end
end
d=size(Buses);
number_of_buses_used=d(1,2);

% Identificacao das Linhas nao Utilizadas na Arvore de Restauracao

m=0;
n=0;
```

```
cont=1;
for i = 1 : number_of_lines_in_island
   cont=1;
   for j = 1 : max_tree
      if (Isl(i)==Tree(j))&(cont~=100)
         cont=100;
         n=n+1;
         Line_Used(n)=Isl(i);
      elseif (Isl(i)~=Tree(j))&(cont~=100)&(j==max_tree)
         cont=100;
         m=m+1;
         Line_Not_Used(m)=Isl(i);
      end
   end
end

% Identification of Paths that contain Lines Not Used

Path_Not_Used(1)=0;
d=0;
for i = 1 : m
   for k = 1 : number_of_paths
      for z = 1 : max_path
         if (Line_Not_Used(i)==Paths(k,z))
            d=d+1;
            Path_Not_Used(d)=k;
         end
       end
   end
end

d=size(Path_Not_Used);
number_of_paths_not_used=d(1,2);

% Creation of a Matrix with only Paths Used

u=1;
cont=1;

for t = 1 : number_of_paths
   cont2=1;
   cont3=1;
    for i = 1 : number_of_paths_not_used
      cont=1;
        for m = 1 : max_path
           if (Path_Not_Used(i)~=t)&(cont2==number_of_paths_not_used)...
                 &(cont3~=100)
              matx_with_paths_used(u,m)=Paths(t,m);
              if cont==max_path
                 u=u+1;
              end
              cont=cont+1;
           elseif(Path_Not_Used(i)==t)
              cont3=100;
           end
        end
     cont2=cont2+1;
```

```
     end
end

ll=size(matx_with_paths_used);
number_of_paths_used=ll(1,1);

% Energization of the most priority Load


energ_list=zeros(1,number_of_paths_used); % List of Energized Paths
swit=zeros(1,max_tree);% Final Switching Sequence
m=1;
cont2=1;
cont3=1;
for i = 1 : number_of_paths_used
   cont=1;
      for n = 1 : number_of_paths_used
         if (i~=energ_list(1,n))&(n==number_of_paths_used)&(cont~=100)
            cont==100;
            energ_list(1,cont2)=i;
            cont2=cont2+1;
            for j = 1 : max_path
               cont3=1;
               for n = 1 : max_tree
                  if ((matx_with_paths_used(i,j)~=swit(1,n))&...
                  (matx_with_paths_used(i,j)~=0)&(n==max_tree)&(cont3~=100))
                  swit(1,m)=matx_with_paths_used(i,j);
                  m=m+1;
                  elseif (matx_with_paths_used(i,j)==swit(1,n))
                     cont3==100;
                     break
                  end
                end
             end
          elseif (i==energ_list(n))
             cont==100;
          end
      end
end

end_time=cputime;
Running_Time=end_time-begin_time



clear all
begin_time=cputime;

% Switching Sequence Program of IRS #6
% Load the Paths
Paths=load('Paths_Island#6.txt');
d=size(Paths);
number_of_paths=d(1,1);
max_path=d(1,2);

% Load the Tree (lines used)
```

```
Tree=load('Tree_Island#6tes.txt');

l=size(Tree);
max_tree=l(1,2);


% Lines in Island

Isl(1)=181;
Isl(2)=109;
Isl(3)=182;
Isl(4)=71;
Isl(5)=105;
Isl(6)=111;
Isl(7)=98;
Isl(8)=106;
Isl(9)=195;
Isl(10)=100;
Isl(11)=108;
Isl(12)=72;
Isl(13)=162;
Isl(14)=99;
Isl(15)=96;
Isl(16)=101;
Isl(17)=97;
Isl(18)=163;
Isl(19)=107;
Isl(20)=95;
Isl(21)=164;
Isl(22)=165;
Isl(23)=73;
Isl(24)=110;
Isl(25)=196;
Isl(26)=68;

a=size(Isl);
number_of_lines_in_island=a(1,2);

% Lines and there respective buses

Line_Bus_Bus=load('b162isl-paral.txt');
d=size(Line_Bus_Bus);
number_of_lines=d(1,1);

for i = 1:number_of_lines
    Line(i)=Line_Bus_Bus(i,1);
    Bus_of_Column1(i)=Line_Bus_Bus(i,2);
    Bus_of_Column2(i)=Line_Bus_Bus(i,3);
end

% Buses Used
l=1;
for i = 1 : max_tree
  for j = 1 : number_of_lines
    l=1;
   if (Tree(1,i)==Line_Bus_Bus(j,1))
      Bus_Used(i,l)=Line_Bus_Bus(j,2);
```

```
      Bus_Used(i,l+1)=Line_Bus_Bus(j,3);
   end

  end
end

cont=1;
Buses(1)=0;
l=1;
f=0;
for i = 1 : max_tree
   for j = 1 : 2
      cont=1;
      if f>=2
         l=f;
      end
      for d = 1 : l
         if (Buses(d)~=Bus_Used(i,j))&(d==l)&(cont~=100)
             f=f+1;
            Buses(f)=Bus_Used(i,j);

         elseif (Buses(d)==Bus_Used(i,j))
            cont==100;
            break
         end
      end
   end
end
d=size(Buses);
number_of_buses_used=d(1,2);

% Identificacao das Linhas nao Utilizadas na Arvore de Restauracao

m=0;
n=0;
cont=1;
for i = 1 : number_of_lines_in_island
   cont=1;
   for j = 1 : max_tree
      if (Isl(i)==Tree(j))&(cont~=100)
         cont=100;
         n=n+1;
         Line_Used(n)=Isl(i);
      elseif (Isl(i)~=Tree(j))&(cont~=100)&(j==max_tree)
         cont=100;
         m=m+1;
         Line_Not_Used(m)=Isl(i);
      end
   end
end

% Identification of Paths that contain Lines Not Used

Path_Not_Used(1)=0;
d=0;
for i = 1 : m
   for k = 1 : number_of_paths
```

```
      for z = 1 : max_path
         if (Line_Not_Used(i)==Paths(k,z))
            d=d+1;
            Path_Not_Used(d)=k;
         end
       end
   end
end

d=size(Path_Not_Used);
number_of_paths_not_used=d(1,2);

% Creation of a Matrix with only Paths Used

u=1;
cont=1;

for t = 1 : number_of_paths
   cont2=1;
   cont3=1;
    for i = 1 : number_of_paths_not_used
      cont=1;
        for m = 1 : max_path
           if (Path_Not_Used(i)~=t)&(cont2==number_of_paths_not_used)...
                 &(cont3~=100)
              matx_with_paths_used(u,m)=Paths(t,m);
              if cont==max_path
                 u=u+1;
              end
              cont=cont+1;
           elseif(Path_Not_Used(i)==t)
              cont3=100;
           end
        end
     cont2=cont2+1;
     end
end

ll=size(matx_with_paths_used);
number_of_paths_used=ll(1,1);

% Energization of the most priority Load


energ_list=zeros(1,number_of_paths_used); % List of Energized Paths
swit=zeros(1,max_tree);% Final Switching Sequence
m=1;
cont2=1;
cont3=1;
for i = 1 : number_of_paths_used
   cont=1;
      for n = 1 : number_of_paths_used
         if (i~=energ_list(1,n))&(n==number_of_paths_used)&(cont~=100)
            cont==100;
            energ_list(1,cont2)=i;
            cont2=cont2+1;
            for j = 1 : max_path
```

```
                  cont3=1;
                  for n = 1 : max_tree
                     if ((matx_with_paths_used(i,j)~=swit(1,n))&...
                     (matx_with_paths_used(i,j)~=0)&(n==max_tree)&(cont3~=100))
                     swit(1,m)=matx_with_paths_used(i,j);
                     m=m+1
                     elseif (matx_with_paths_used(i,j)==swit(1,n))
                        cont3==100;
                        break
                     end
                   end
                end
             elseif (i==energ_list(n))
                cont==100;
             end
          end
end

end_time=cputime;
Running_Time=end_time-begin_time


clear all
begin_time=cputime;

% Switching Sequence Program of IRS #7
% Load the Paths
Paths=load('Paths_Island#7.txt');
d=size(Paths);
number_of_paths=d(1,1);
max_path=d(1,2);

% Load the Tree (lines used)

Tree=load('Tree_Island#7tes.txt');

l=size(Tree);
max_tree=l(1,2);


% Lines in Island

Isl(1)=118;
Isl(2)=138;
Isl(3)=140;
Isl(4)=137;
Isl(5)=280;
Isl(6)=136;
Isl(7)=282;
Isl(8)=67;
Isl(9)=175;
Isl(10)=281;
Isl(11)=81;
Isl(12)=66;
Isl(13)=141;
Isl(14)=142;
```

```
Isl(15)=144;

Isl(16)=170;
Isl(17)=139;
Isl(18)=171;
Isl(19)=269;
Isl(20)=284;
Isl(21)=268;
Isl(22)=265;
Isl(23)=271;
Isl(24)=180;
Isl(25)=233;
Isl(26)=267;
Isl(27)=266;
Isl(28)=83;

a=size(Isl);
number_of_lines_in_island=a(1,2);

% Lines and there respective buses

Line_Bus_Bus=load('b162isl-paral.txt');
d=size(Line_Bus_Bus);
number_of_lines=d(1,1);

for i = 1:number_of_lines
    Line(i)=Line_Bus_Bus(i,1);
    Bus_of_Column1(i)=Line_Bus_Bus(i,2);
    Bus_of_Column2(i)=Line_Bus_Bus(i,3);
end

% Buses Used
l=1;
for i = 1 : max_tree
  for j = 1 : number_of_lines
    l=1;
   if (Tree(1,i)==Line_Bus_Bus(j,1))
      Bus_Used(i,l)=Line_Bus_Bus(j,2);
      Bus_Used(i,l+1)=Line_Bus_Bus(j,3);
   end

  end
end

cont=1;
Buses(1)=0;
l=1;
f=0;
for i = 1 : max_tree
   for j = 1 : 2
      cont=1;
      if f>=2
         l=f;
      end
      for d = 1 : l
         if (Buses(d)~=Bus_Used(i,j))&(d==l)&(cont~=100)
             f=f+1;
```

```
            Buses(f)=Bus_Used(i,j);

         elseif (Buses(d)==Bus_Used(i,j))
            cont==100;
            break
         end
      end
   end
end
d=size(Buses);
number_of_buses_used=d(1,2);

% Identificacao das Linhas nao Utilizadas na Arvore de Restauracao

m=0;
n=0;
cont=1;
for i = 1 : number_of_lines_in_island
   cont=1;
   for j = 1 : max_tree
      if (Isl(i)==Tree(j))&(cont~=100)
         cont=100;
         n=n+1;
         Line_Used(n)=Isl(i);
      elseif (Isl(i)~=Tree(j))&(cont~=100)&(j==max_tree)
         cont=100;
         m=m+1;
         Line_Not_Used(m)=Isl(i);
      end
   end
end

% Identification of Paths that contain Lines Not Used

Path_Not_Used(1)=0;
d=0;
for i = 1 : m
   for k = 1 : number_of_paths
      for z = 1 : max_path
         if (Line_Not_Used(i)==Paths(k,z))
            d=d+1;
            Path_Not_Used(d)=k;
         end
       end
   end
end

d=size(Path_Not_Used);
number_of_paths_not_used=d(1,2);

% Creation of a Matrix with only Paths Used

u=1;
cont=1;

for t = 1 : number_of_paths
   cont2=1;
```

```
   cont3=1;
    for i = 1 : number_of_paths_not_used
      cont=1;
        for m = 1 : max_path
           if (Path_Not_Used(i)~=t)&(cont2==number_of_paths_not_used)...
                 &(cont3~=100)
              matx_with_paths_used(u,m)=Paths(t,m);
              if cont==max_path
                 u=u+1;
              end
              cont=cont+1;
           elseif(Path_Not_Used(i)==t)
              cont3=100;
           end
        end
     cont2=cont2+1;
     end
end

ll=size(matx_with_paths_used);
number_of_paths_used=ll(1,1);

% Energization of the most priority Load


energ_list=zeros(1,number_of_paths_used); % List of Energized Paths
swit=zeros(1,max_tree);% Final Switching Sequence
m=1;
cont2=1;
cont3=1;
for i = 1 : number_of_paths_used
   cont=1;
      for n = 1 : number_of_paths_used
         if (i~=energ_list(1,n))&(n==number_of_paths_used)&(cont~=100)
            cont==100;
            energ_list(1,cont2)=i;
            cont2=cont2+1;
            for j = 1 : max_path
               cont3=1;
               for n = 1 : max_tree
                  if ((matx_with_paths_used(i,j)~=swit(1,n))&...
                  (matx_with_paths_used(i,j)~=0)&(n==max_tree)&(cont3~=100))
                  swit(1,m)=matx_with_paths_used(i,j);
                  m=m+1;
                  elseif (matx_with_paths_used(i,j)==swit(1,n))
                     cont3==100;
                     break
                  end
                end
             end
          elseif (i==energ_list(n))
             cont==100;
          end
      end
end

end_time=cputime;
```

```
Running_Time=end_time-begin_time


clear all
begin_time=cputime;

% Switching Sequence Program of IRS #8
% Load the Paths
Paths=load('Paths_Island#8.txt');
d=size(Paths);
number_of_paths=d(1,1);
max_path=d(1,2);

% Load the Tree (lines used)

Tree=load('Tree_Island#8tes.txt');

l=size(Tree);
max_tree=l(1,2);


% Lines in Island

Isl(1)=193;
Isl(2)=207;
Isl(3)=200;
Isl(4)=191;
Isl(5)=198;
Isl(6)=216;
Isl(7)=217;
Isl(8)=203;
Isl(9)=202;
Isl(10)=209;
Isl(11)=131;
Isl(12)=116;
Isl(13)=194;
Isl(14)=134;
Isl(15)=204;
Isl(16)=124;

a=size(Isl);
number_of_lines_in_island=a(1,2);

% Lines and there respective buses

Line_Bus_Bus=load('b162isl-paral.txt');
d=size(Line_Bus_Bus);
number_of_lines=d(1,1);

for i = 1:number_of_lines
    Line(i)=Line_Bus_Bus(i,1);
    Bus_of_Column1(i)=Line_Bus_Bus(i,2);
    Bus_of_Column2(i)=Line_Bus_Bus(i,3);
end

% Buses Used
l=1;
```

```
for i = 1 : max_tree
  for j = 1 : number_of_lines
    l=1;
   if (Tree(1,i)==Line_Bus_Bus(j,1))
      Bus_Used(i,l)=Line_Bus_Bus(j,2);

      Bus_Used(i,l+1)=Line_Bus_Bus(j,3);
   end

  end
end

cont=1;
Buses(1)=0;
l=1;
f=0;
for i = 1 : max_tree
   for j = 1 : 2
      cont=1;
      if f>=2
         l=f;
      end
      for d = 1 : l
         if (Buses(d)~=Bus_Used(i,j))&(d==l)&(cont~=100)
             f=f+1;
            Buses(f)=Bus_Used(i,j);

         elseif (Buses(d)==Bus_Used(i,j))
            cont==100;
            break
         end
      end
   end
end
d=size(Buses);
number_of_buses_used=d(1,2);

% Identificacao das Linhas nao Utilizadas na Arvore de Restauracao

m=0;
n=0;
cont=1;
for i = 1 : number_of_lines_in_island
   cont=1;
   for j = 1 : max_tree
      if (Isl(i)==Tree(j))&(cont~=100)
         cont=100;
         n=n+1;
         Line_Used(n)=Isl(i);
      elseif (Isl(i)~=Tree(j))&(cont~=100)&(j==max_tree)
         cont=100;
         m=m+1;
         Line_Not_Used(m)=Isl(i);
      end
   end
end
```

```
% Identification of Paths that contain Lines Not Used

Path_Not_Used(1)=0;
d=0;
for i = 1 : m
   for k = 1 : number_of_paths
      for z = 1 : max_path
         if (Line_Not_Used(i)==Paths(k,z))
            d=d+1;
            Path_Not_Used(d)=k;
         end
       end
   end
end

d=size(Path_Not_Used);
number_of_paths_not_used=d(1,2);

% Creation of a Matrix with only Paths Used

u=1;
cont=1;

for t = 1 : number_of_paths
   cont2=1;
   cont3=1;
    for i = 1 : number_of_paths_not_used
      cont=1;
        for m = 1 : max_path
           if (Path_Not_Used(i)~=t)&(cont2==number_of_paths_not_used)...
                 &(cont3~=100)
              matx_with_paths_used(u,m)=Paths(t,m);
              if cont==max_path
                 u=u+1;
              end
              cont=cont+1;
           elseif(Path_Not_Used(i)==t)
              cont3=100;
           end
        end
     cont2=cont2+1;
     end
end

ll=size(matx_with_paths_used);
number_of_paths_used=ll(1,1);

% Energization of the most priority Load


energ_list=zeros(1,number_of_paths_used); % List of Energized Paths
swit=zeros(1,max_tree);% Final Switching Sequence
m=1;
cont2=1;
cont3=1;
for i = 1 : number_of_paths_used
   cont=1;
```

```
      for n = 1 : number_of_paths_used
         if (i~=energ_list(1,n))&(n==number_of_paths_used)&(cont~=100)
            cont==100;
            energ_list(1,cont2)=i;
            cont2=cont2+1;
            for j = 1 : max_path
               cont3=1;
               for n = 1 : max_tree
                  if ((matx_with_paths_used(i,j)~=swit(1,n))&...
                  (matx_with_paths_used(i,j)~=0)&(n==max_tree)&(cont3~=100))
                  swit(1,m)=matx_with_paths_used(i,j);
                  m=m+1;
                  elseif (matx_with_paths_used(i,j)==swit(1,n))
                     cont3==100;
                     break
                  end
                end
             end
          elseif (i==energ_list(n))
             cont==100;
          end
      end
end

end_time=cputime;
Running_Time=end_time-begin_time



clear all
begin_time=cputime;

% Switching Sequence Program of IRS #9
% Load the Paths
Paths=load('Paths_Island#9.txt');
d=size(Paths);
number_of_paths=d(1,1);
max_path=d(1,2);

% Load the Tree (lines used)

Tree=load('Tree_Island#9tes.txt');

l=size(Tree);
max_tree=l(1,2);


% Lines in Island

Isl(1)=278;
Isl(2)=275;
Isl(3)=274;
Isl(4)=276;
Isl(5)=277;
Isl(6)=272;
Isl(7)=273;
Isl(8)=167;
```

```
a=size(Isl);
number_of_lines_in_island=a(1,2);

% Lines and there respective buses

Line_Bus_Bus=load('b162isl-paral.txt');
d=size(Line_Bus_Bus);
number_of_lines=d(1,1);

for i = 1:number_of_lines
    Line(i)=Line_Bus_Bus(i,1);
    Bus_of_Column1(i)=Line_Bus_Bus(i,2);
    Bus_of_Column2(i)=Line_Bus_Bus(i,3);
end

% Buses Used
l=1;
for i = 1 : max_tree
  for j = 1 : number_of_lines
    l=1;
   if (Tree(1,i)==Line_Bus_Bus(j,1))
      Bus_Used(i,l)=Line_Bus_Bus(j,2);
      Bus_Used(i,l+1)=Line_Bus_Bus(j,3);
   end

  end
end

cont=1;
Buses(1)=0;
l=1;
f=0;
for i = 1 : max_tree
   for j = 1 : 2
      cont=1;
      if f>=2
         l=f;
      end
      for d = 1 : l
         if (Buses(d)~=Bus_Used(i,j))&(d==l)&(cont~=100)
             f=f+1;
            Buses(f)=Bus_Used(i,j);

         elseif (Buses(d)==Bus_Used(i,j))
            cont==100;
            break
         end
      end
   end
end
d=size(Buses);
number_of_buses_used=d(1,2);

% Identificacao das Linhas nao Utilizadas na Arvore de Restauracao

m=0;
```

```
n=0;
cont=1;
for i = 1 : number_of_lines_in_island
   cont=1;
   for j = 1 : max_tree
      if (Isl(i)==Tree(j))&(cont~=100)
         cont=100;
         n=n+1;
         Line_Used(n)=Isl(i);
      elseif (Isl(i)~=Tree(j))&(cont~=100)&(j==max_tree)
         cont=100;
         m=m+1;
         Line_Not_Used(m)=Isl(i);
      end
   end
end

% Identification of Paths that contain Lines Not Used

Path_Not_Used(1)=0;
d=0;
for i = 1 : m
   for k = 1 : number_of_paths
      for z = 1 : max_path
         if (Line_Not_Used(i)==Paths(k,z))
            d=d+1;
            Path_Not_Used(d)=k;
         end
       end
   end
end

d=size(Path_Not_Used);
number_of_paths_not_used=d(1,2);

% Creation of a Matrix with only Paths Used

u=1;
cont=1;

for t = 1 : number_of_paths
   cont2=1;
   cont3=1;
    for i = 1 : number_of_paths_not_used
      cont=1;
        for m = 1 : max_path
           if (Path_Not_Used(i)~=t)&(cont2==number_of_paths_not_used)...
                 &(cont3~=100)
              matx_with_paths_used(u,m)=Paths(t,m);
              if cont==max_path
                 u=u+1;
              end
              cont=cont+1;
           elseif(Path_Not_Used(i)==t)
              cont3=100;
           end
        end
```

```
     cont2=cont2+1;
     end
end

ll=size(matx_with_paths_used);
number_of_paths_used=ll(1,1);

% Energization of the most priority Load


energ_list=zeros(1,number_of_paths_used); % List of Energized Paths
swit=zeros(1,max_tree);% Final Switching Sequence
m=1;
cont2=1;
cont3=1;
for i = 1 : number_of_paths_used
   cont=1;
      for n = 1 : number_of_paths_used
         if (i~=energ_list(1,n))&(n==number_of_paths_used)&(cont~=100)
            cont==100;
            energ_list(1,cont2)=i;
            cont2=cont2+1;
            for j = 1 : max_path
               cont3=1;
               for n = 1 : max_tree
                  if ((matx_with_paths_used(i,j)~=swit(1,n))&...
                  (matx_with_paths_used(i,j)~=0)&(n==max_tree)&(cont3~=100))
                  swit(1,m)=matx_with_paths_used(i,j);
                  m=m+1;
                  elseif (matx_with_paths_used(i,j)==swit(1,n))
                     cont3==100;
                     break
                  end
                end
             end
          elseif (i==energ_list(n))
             cont==100;
          end
      end
end

end_time=cputime;
Running_Time=end_time-begin_time


clear all
% Switching Sequence Program of IRS #10
% Load the Paths
begin_time=cputime;
Paths=load('Paths_Island#10.txt');
d=size(Paths);
number_of_paths=d(1,1);
max_path=d(1,2);

% Load the Tree (lines used)

Tree=load('Tree_Island#10.txt');
```

```
l=size(Tree);
max_tree=l(1,2);


% Lines in Island

Isl(1)=190;
Isl(2)=210;
Isl(3)=189;
Isl(4)=186;
Isl(5)=188;
Isl(6)=205;
Isl(7)=121;
Isl(8)=184;
Isl(9)=125;
Isl(10)=185;
Isl(11)=206;

a=size(Isl);
number_of_lines_in_island=a(1,2);

% Lines and there respective buses

Line_Bus_Bus=load('b162isl-paral.txt');
d=size(Line_Bus_Bus);
number_of_lines=d(1,1);

for i = 1:number_of_lines
    Line(i)=Line_Bus_Bus(i,1);
    Bus_of_Column1(i)=Line_Bus_Bus(i,2);
    Bus_of_Column2(i)=Line_Bus_Bus(i,3);
end

% Buses Used
l=1;
for i = 1 : max_tree
  for j = 1 : number_of_lines
    l=1;
   if (Tree(1,i)==Line_Bus_Bus(j,1))
      Bus_Used(i,l)=Line_Bus_Bus(j,2);
      Bus_Used(i,l+1)=Line_Bus_Bus(j,3);
   end

  end
end


cont=1;
Buses(1)=0;
l=1;
f=0;
for i = 1 : max_tree
   for j = 1 : 2
      cont=1;
      if f>=2
         l=f;
      end
```

```
      for d = 1 : l
         if (Buses(d)~=Bus_Used(i,j))&(d==l)&(cont~=100)
             f=f+1;
            Buses(f)=Bus_Used(i,j);

         elseif (Buses(d)==Bus_Used(i,j))
            cont==100;
            break
         end
      end
   end
end
d=size(Buses);
number_of_buses_used=d(1,2);

% Identificacao das Linhas nao Utilizadas na Arvore de Restauracao

m=0;
n=0;
cont=1;
for i = 1 : number_of_lines_in_island
   cont=1;
   for j = 1 : max_tree
      if (Isl(i)==Tree(j))&(cont~=100)
         cont=100;
         n=n+1;
         Line_Used(n)=Isl(i);
      elseif (Isl(i)~=Tree(j))&(cont~=100)&(j==max_tree)
         cont=100;
         m=m+1;
         Line_Not_Used(m)=Isl(i);
      end
   end
end

% Identification of Paths that contain Lines Not Used

Path_Not_Used(1)=0;
d=0;
for i = 1 : m
   for k = 1 : number_of_paths
      for z = 1 : max_path
         if (Line_Not_Used(i)==Paths(k,z))
            d=d+1;
            Path_Not_Used(d)=k;
         end
       end
   end
end

d=size(Path_Not_Used);
number_of_paths_not_used=d(1,2);

% Creation of a Matrix with only Paths Used

u=1;
cont=1;
```

```
for t = 1 : number_of_paths
   cont2=1;
   cont3=1;
    for i = 1 : number_of_paths_not_used
      cont=1;
        for m = 1 : max_path
           if (Path_Not_Used(i)~=t)&(cont2==number_of_paths_not_used)...
                 &(cont3~=100)
              matx_with_paths_used(u,m)=Paths(t,m);
              if cont==max_path
                 u=u+1;
              end
              cont=cont+1;
           elseif(Path_Not_Used(i)==t)
              cont3=100;
           end
        end
     cont2=cont2+1;
     end
end

ll=size(matx_with_paths_used);
number_of_paths_used=ll(1,1);

% Energization of the most priority Load


energ_list=zeros(1,number_of_paths_used); % List of Energized Paths
swit=zeros(1,max_tree);% Final Switching Sequence
m=1;
cont2=1;
cont3=1;
for i = 1 : number_of_paths_used
   cont=1;
      for n = 1 : number_of_paths_used
         if (i~=energ_list(1,n))&(n==number_of_paths_used)&(cont~=100)
            cont==100;
            energ_list(1,cont2)=i;
            cont2=cont2+1;
            for j = 1 : max_path
               cont3=1;
               for n = 1 : max_tree
                  if ((matx_with_paths_used(i,j)~=swit(1,n))&...
                  (matx_with_paths_used(i,j)~=0)&(n==max_tree)&(cont3~=100))
                  swit(1,m)=matx_with_paths_used(i,j);
                  m=m+1;
                  elseif (matx_with_paths_used(i,j)==swit(1,n))
                     cont3==100;
                     break
                  end
                end
             end
          elseif (i==energ_list(n))
             cont==100;
          end
      end
```

```
end

end_time=cputime;
Running_Time=end_time-begin_time
```

VITA

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Publications

1. A. S. Bretas and N. Hadjsaid "Fault Diagnosis in Deregulated Distribution Systems using an Artificial Neural Network" IEEE - Power Engineering Society Winter Meeting, 2001, Columbus, Ohio.
3. A. S. Bretas and A. Phadke "Power System Restoration Methodologies and Implementation Strategies- Book Review" IEEE Computer Applications in Power, 2001.
4. A. S. Bretas and A. Phadke "Power System Restoration using Artificial Neural Networks" 33rd Annual North American Power Symposium, 2001, College Station., Texas.
5. A. S. Bretas, and D. V. Coury "A New Proposal for Directional Protection of Transmission Lines based on Artificial Neural Networks" II - IEEE International Conference on Intelligent Processing Systems (ICIPS),1998, Sidney, Australia.
6. A. S. Bretas and D. V. Coury "Directional Protection using Artificial Neural Networks" III – INDUSCON, 1998, São Paulo, Brazil.

7. A. S. Bretas and D. V. Coury “Artificial Neural Networks Applications in Directional Protection” XIV - Seminario Nacional de Producao e Transmissao de Energia Eletrica (SNPTEE), 1997, Belem, Brazil.

8. A. S. Bretas, A. B. Delbem, L. F. Carvalho, A. P. Leon, and D. V. Coury “Implementation and Tests of a Distance Relay Using Artificial Neural Networks” International Conference on Engineering Applications of Neural Networks, 1997, Stockholm, Sweden.

9. A. S. Bretas, A. B. Delbem, L. F. Carvalho, A. P. Leon and D. V. Coury “ Distance Protection Scheme using ANN” III - Simposio Brasileiro de Redes Neurais, 1996, Recife, Brazil.

10. D. V. Coury and A. S. Bretas “Simulation of Permanent Faults in High Voltage Transmission Lines using the Fourier Transform” XVI - Iberian Latin American Conference on Computational Methods for Engineering, 1995, Curitiba, Brazil.

11. A. S. Bretas and D. V. Coury “Digital Directional Protection” XII - Congresso de Iniciacão Cientifica e Tecnologica, 1994, Sao Carlos, Brazil.

12. A. S. Bretas and D. V. Coury “Software for Simulation of Transmission Lines in Faulty Conditions” XI - Congresso de Iniciacão Cientifica e Tecnologica, 1993, Sao Carlos, Brazil.