

Robust Electric Power Infrastructures. Response and Recovery during Catastrophic Failures.

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**ROBUST ELECTRIC POWER INFRASTRUCTURES.
RESPONSE AND RECOVERY DURING CATASTROPHIC
FAILURES.**

ARTURO SUMAN BRETAS

ABSTRACT

This dissertation is a systematic study of artificial neural networks (ANN) applications in power system restoration (PSR). PSR is based on available generation and load to be restored analysis. A literature review showed that the conventional PSR methods, i.e. the pre-established guidelines, the expert systems method, the mathematical programming method and the petri-net method have limitations such as the necessary time to obtain the PSR plan. ANN may help to solve this problem presenting a reliable PSR plan in a smaller time.

Based on actual and past experiences, a PSR engine based on ANN was proposed and developed. Data from the Iowa 162 bus power system was used in the implementation of the technique. Reactive and real power balance, fault location, phase angles across breakers and intentional islanding were taken into account in the implementation of the technique. Constraints in PSR as thermal limits of transmission lines (TL), stability issues, number of TL used in the restoration plan and lockout breakers were used to create feasible PSR plans. To compare the time necessary to achieve the PSR plan with another technique a PSR method based on a breadth-search algorithm was implemented. This algorithm was also used to create training and validation patterns for the ANN used in the scheme. An algorithm to determine the switching sequence of the breakers was also implemented. In order to determine the switching sequence of the breakers the algorithm takes into account the most priority loads and the final system configuration generated by the ANN.

The PSR technique implemented is composed by several pairs of ANN, each one assigned to an individual island of the system. The restoration of the system is done in parallel in

each island. After each island is restored the tie lines are closed. The results encountered shows that ANN based schemes can be used in PSR helping the operators restore the system under the stressful conditions following a blackout.

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This Dissertation is dedicated to

My lovely family

Especially to my son Leonardo

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List of Symbols

PSR	Power System Restoration
SCADA	Supervisory Control and Data Acquisition System
EMS	Energy Management System
PN	Petri Net
ANN	Artificial Neural Network
CLPU	Cold Load Pick Up
EHV	Extra High Voltage
SVC	Static Var Compensator
MFN	Multilayer Feedforward Network
IRS	Island Restoration Scheme
LRLF	Local Restoration Load Forecast
DFT	Discrete Fourier Transform
SSP	Switching Sequence Program
SNNS	Stuttgart Neural Network Simulator
SSE	Sum of the Squared Errors
P_{ij}	Real Power Transmitted through Buses i and j
V_i	Voltage of Bus i
X	reactance of the transmission line between buses i and j
δ_{ij}	Angle difference between buses i and j
M	Inertial constant of the machine
D	Damping constant of the machine
P_m	Constant mechanical power input of the machine
P_e	Electric power output of the machine
ω	Rotor angular velocity of machine
ω_R	Reference angular velocity
θ_{ij}	Angle difference between the rotors at buses i and j
u_k	Total input
w_{kj}	Weighted input j of neuron k
x_j	Input j
i_k	Induced local field
b_k	The bias
$e_j(n)$	Error of output of neuron j at iteration n
$d_j(n)$	Desired output of neuron j at iteration n
$y_j(n)$	Output of neuron j at iteration n
$v_j(n)$	Induced local field of neuron j at iteration n .
$w_{ji}(n)$	Weight of connection between input i and neuron j .
$y_i(n)$	i^{th} input of neuron j at iteration n .
m	Total number of inputs
φ_j	Activation function of neuron j
Δw_{ji}	Weight connection correction.
η	Learning-rate parameter
$\delta_j(n)$	Local gradient at iteration n

a	Constant greater than zero
b	Positive constant
$o_j(n)$	Obtained output in iteration n .
$d_j(n)$	Desired output in iteration n
W	Total number of free parameters in the network
ϵ	Fraction of classification errors permitted on the test data
$O(.)$	Order of quantity enclosed within
E_F ,	Voltage phasor at the fault
E_S	Voltage phasor at the sending end bus
E_R	Voltage phasor at the receiving end bus
Z_S	Complex impedance of the equivalent system behind the sending end bus
Z_R	Complex impedance of the equivalent system behind the receiving end bus
V_R	Thevenin voltage of the system behind the receiving end bus
V_S	Thevenin voltage of the system behind the sending end bus
I_S	Phasor current at the sending end
I_R	Phasor current at the receiving end
I_F	Phasor current at the at the fault
k	Fault distance from the sending end bus
ΔI_S	Variation of the sending end terminal current
d	Constant value
E_{Si}	Sending end real pos-fault voltage phasor
E_{Sr}	Sending end imaginary pos-fault voltage phasor
I_{Si}	Sending end imaginary pos-fault current phasor
I_{Sr}	Sending end real pos-fault current phasor
X	imaginary part of the total transmission line impedance
R	Real part of the total transmission line impedance
ΔI_{Si}	Sending end imaginary current variation
ΔI_{Sr}	Sending end real current variation
ϑ	Sampling angle
I_n	Phasor representing current injected in node n
V_n	Phasor representing voltage of bus n
Y_{nn}	Self admittance of bus n
Y_{nm}	Mutual admittances between buses n and m
P_i	Real power injected at bus i
Q_i	Reactive power injected at bus i
y	Variable representing the output of the threshold function
x	Variable representing the input of the threshold function

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