4 Determination of Supervisory & Hidden Failure Schemes

4.1 Vote Logic Scheme

The vote logic requires that a majority of protection schemes for a device operate before the device is removed from service. To use this scheme, the device must have at least 3 levels of protection. For devices with less than three levels of protection, it is still very important to provide some sort of relay supervision during emergency conditions. The vote logic algorithm pushes theses devices into the normal hidden failure supervision.

4.1.1 Line Relays

All transmission lines in this model use the vote logic when the RSS is in emergency mode. All the transmission lines have 3 levels of protection: one primary protection, and two backup protections.

4.1.2 Transformer Relays

Transformer relays are supervised by a hidden failure check. No vote scheme can be implemented, since the transformers in this model are only protected by differential relays.

4.1.3 Breaker Failure Relays

Breaker failure relays are supervised by a hidden failure check. No vote scheme can be implemented, since the breaker failure relays essentially consist of an overcurrent relay and a timer.

4.2 Hidden Failure

The RSS attempts to prevent inadvertent trips due to hidden failures of the existing protection system, by duplicating the relay calculation for every existing relay that operates. The RSS acts as a permissive scheme to allow removal of the affected circuit element.

It is not always possible to perform a calculation exactly duplicating the existing relay scheme. This is especially true in cases where the relay schemes rely on communication signals from the remote end to operate properly. A discussion of the various calculation methods used in the model follows.

4.2.1 Step-Distance Supervision

Step-Distance supervision uses a distance relay with a mho circle characFigure 9: Mho Circleteristic, as shown in Figure 9. This supervises all zones of a distance relay. The mho circle characteristic is described by:

$$|Z| = Z_r \cos(\theta + \alpha)$$

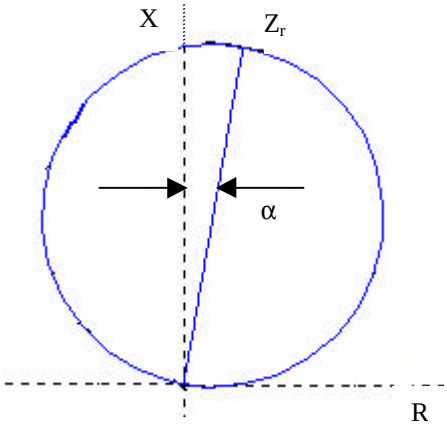

Figure 9: Mho Circle

Z_r is the reach setting for this particular zone in secondary ohms, and a is the maximum torque angle with respect to the reactance axis. Any calculated fault impedance within this circle is a fault condition, and allows a device operation.

Two mho circle calculations are necessary to provide a distance relay zone that uses a timer. The first calculation verifies that a fault exists at the present moment in time. If a fault exists at this point, the relay retrieves the stored waveform samples equivalent to the length of the timer setting. A second calculation is performed using this data, verifying a fault existed when the timer started. If both calculations agree, device operation is permitted.

4.2.2 Extended Zone 1 Supervision

The extended zone 1 method supervises relay schemes that rely on communications signals between ends of the line. Upon receiving a trip signal, the method performs a zone 1 (under-reaching) mho relay calculation. The method permits a device operation if the fault is in this zone. If a fault is not in zone 1, the method performs a zone 2 (over-reaching) mho relay calculation. The zone 2 calculation has a timer set to coordinate with relays protecting the over-reached line. The method permits a device operation if the fault is in this zone. This method allows an instantaneous trip for faults that are definitely on the protected line. It also covers the whole line with the zone 2 calculation, while allowing for coordination with protection schemes at the other end that may clear the fault.

4.2.3 Directional Supervision

Both voltage and current polarization supervise directional elements of specific relays. Voltage polarization compares the zero sequence line voltage to the zero sequence line current. Current polarization compares the neutral current from wye-grounded transformers to the zero sequence line current. If both voltage polarization and current polarization agree that the fault is in the forward direction, device operation is permitted.

4.2.4 Transformer Differential Supervision

A percentage harmonic restraint differential method supervises transformer differential relays. The method calculates the differential current between the high side and low side currents of the transformer. For normal conditions, this value should be zero. If this value is non-zero, the method allows a device operation. The model restrains operation, however, if large

2^{nd} harmonics are present (indicating inrush) or large 5^{th} harmonics are present (indicating overexcitation).

4.2.5 Timer Supervision

A separate timer supervises the timer of specific existing relays. This timer starts at the same time as the existing relay timer starts. The timer must time out to permit device operation.

4.3 Determination of Hidden Failure Supervision Method

The appropriate supervision method to use for the various protection schemes found in the system is determined by the possible hidden failure modes of the protection scheme. It is important to know not only what the hidden failure modes are, but also the hidden failure modes the RSS can actually supervise. See Appendix I for a complete hidden failure analysis.

4.3.1 Distance Relay

Step-Distance supervision exactly duplicates all zones of a distance relay. Every zone of the Step-Distance supervision has identical zone reach settings to the zones of the existing distance relay. The RSS actually supervises the under-reaching, instantaneous first zone of a distance relay, even though it has no hidden failure modes. The timer setting for Step-Distance supervision is identical to the zone timers of the existing distance relay.

Table 8: Hidden Failure Supervision of Step-Distance Relay

Hidden Failure	Trip At Local End	Region of Vulnerability	Supervision Method
Timer 2 fails closed	Yes	Zone 2 reach beyond remote bus	Step-distance timer
Timer 3 fails closed	Yes	Zone 3 reach beyond remote bus	Step-distance timer

4.3.2 Directional Comparison Blocking (DCB)

The zone 1 extension method supervises the directional comparison blocking scheme. The DCB scheme can not be exactly duplicated, since the scheme relies on a blocking signal transmitted from the remote end to prevent an inadvertent trip. Zone 1 extension provides complete coverage of the line, while coordinating any over-reach at the remote line terminal. It is necessary to check the entire line length, without over-reaching the remote end, to verify the correct operation.

Table 9: Hidden Failure Supervision of DCB Relay

Hidden Failure	Trip At Local End	Region of Vulnerability	Supervision Method
FD can not pick up	No	None	None
T fails to transmit	No	None	None
R can not pick up	Yes	Distance relay reach beyond remote bus	Extended Zone 1

4.3.3 Phase Comparison Blocking (PCB)

The zone 1 extension method supervises the phase comparison blocking scheme. The PCB scheme can not be exactly duplicated, since the scheme relies on a comparison signal transmitted from the remote end. Zone 1 extension provides complete coverage of the line, while coordinating any over-reach of the remote line terminal. It is necessary to check the entire line length, without over-reaching the remote end, to verify the correct operation.

Table 10: Hidden Failure Supervision of PCB Relay

Hidden Failure	Trip At Local End	Region of Vulnerability	Supervision Method
Loss of signal	Yes	Fault current > High set Fault Detector	Extended Zone 1
FD_{LA} continuously picks up	Yes	Fault current > High set Fault Detector	Extended Zone 1
FD_{LA} can not pick up	No	None	None

4.3.4 Directional Overcurrent

Voltage and current polarization supervises directional overcurrent relays. Directional overcurrent relays compare input from a polarizing source or coil to the zero sequence current to determine fault direction. Voltage and current polarization exactly duplicates the directional overcurrent method for determining fault direction.

Table 11: Hidden Failure Supervision Directional Overcurrent

Hidden Failure	Consequence	Region of Vulnerability	Supervision Method
Polarizing source or coil shorted	Yes	Fault current > setting	Voltage and current polarization
Polarizing source or coil open	No	None	None

4.3.5 Transformer Differential

The transformer differential method supervises transformer differential relays. Transformer differential supervision exactly duplicates the existing transformer differential relays.

Table 12: Hidden Failure Supervision for Transformer Differential Relay

Hidden Failure	Consequence	Region of Vulnerability	Supervision Method
Restraint coil shorted	Yes	Load current dependant	Transformer differential

4.3.6 Breaker Failure

The RSS uses a timer to supervise breaker failure relays. Breaker failure relays are overcurrent relays that pick up on fault current, starting a timer to trip other breakers. The overcurrent relays drop out when the breaker opens, resetting the timer. The RSS timer exactly duplicates the breaker failure timer.

Table 13: Hidden Failure Supervision for Breaker Failure Relay

Hidden Failure	Consequence	Region of Vulnerability	Supervision Method
Timer fails picked up	Lockout relay trips without time delay	Any relay zone for breaker	Timer