Application of the line differential protection scheme for radial transmission lines

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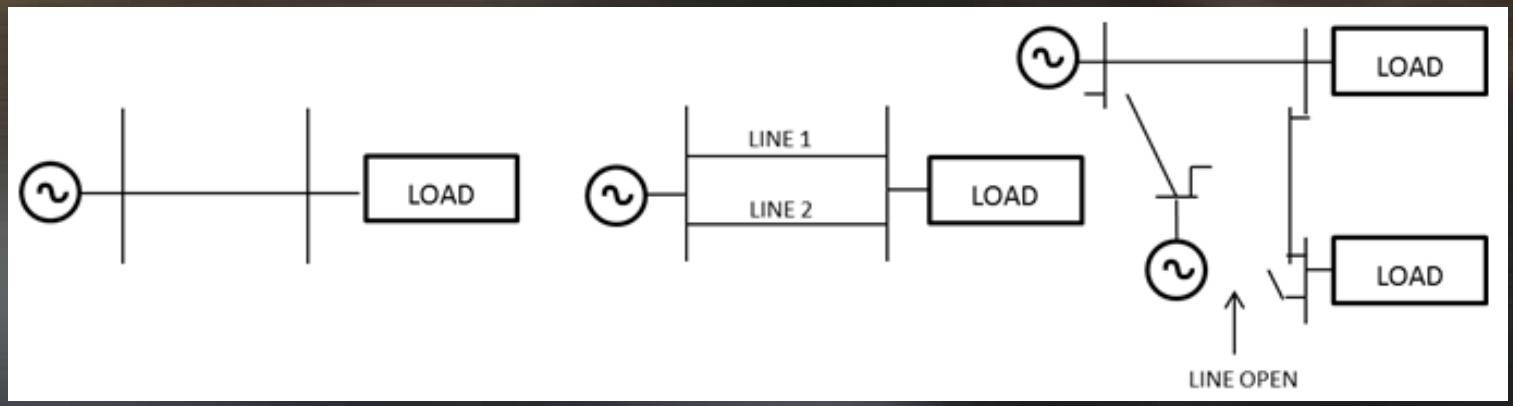
Outline

- Overview of 87L application for radial lines
- Complications of radial applications
- Options of 87L supervisory elements at weak remote end
- Fault case studies
- Practical solutions for 87L supervision

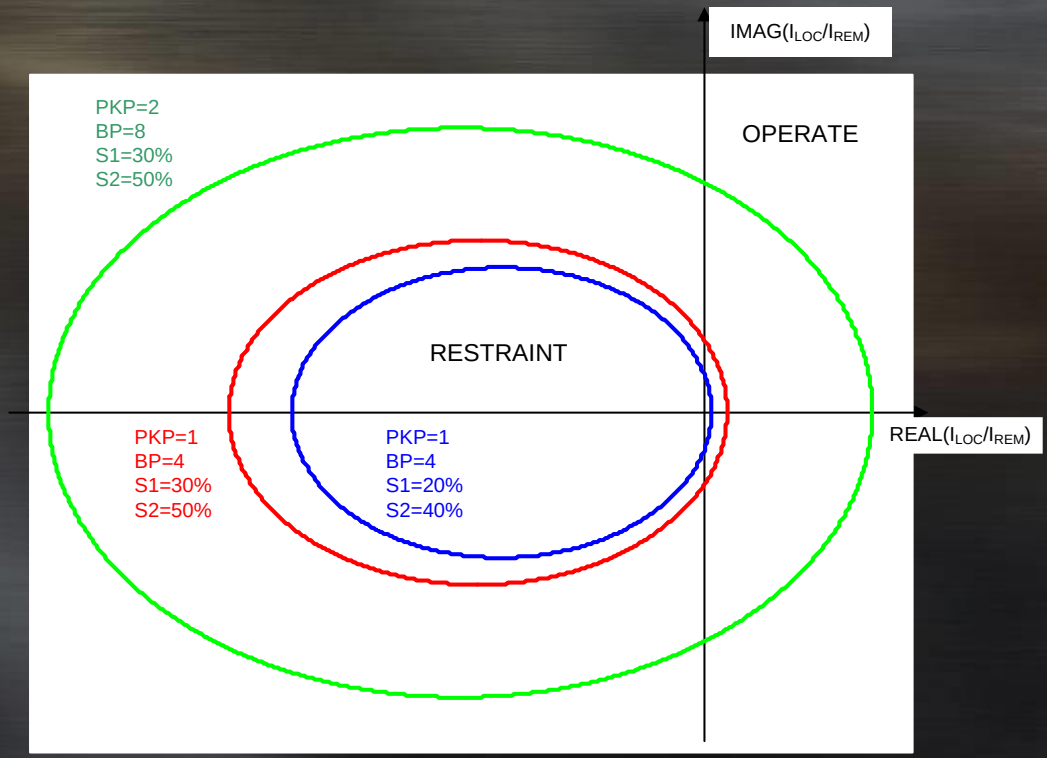
Radial Applications in Transmission

- Mainly used in large countries where relevant loads are sometimes located in remote areas
- Radial double circuit
- Small ring network could become a radial line if one of the lines is open



87L Practices

- Operating current is the sum of all currents that bound the differential zone
- 87L schemes applied among modern relays has some obvious similarities and some important differences
- An adaptive restraint component which caters noise, transients, harmonics, and inaccuracy in DSP measurements, clock and asynchronous sampling
- An example of impact of settings on operation characteristics



87L Security

- 87L scheme is intrinsically secure, however need to further improve its security by addressing the challenges:
  - Data corruption
  - Data misalignment
  - CT saturation
  - Human error – incorrect settings
  - Specific application requirements
  - Major hardware or software relay failure

87L Security – Solutions

- Bias characteristics
- Adaptive restraint component
- Synchronization techniques
- CRC 32 against communications errors
- GPS compensation

- Independent supervisory element

87L Supervisory Element

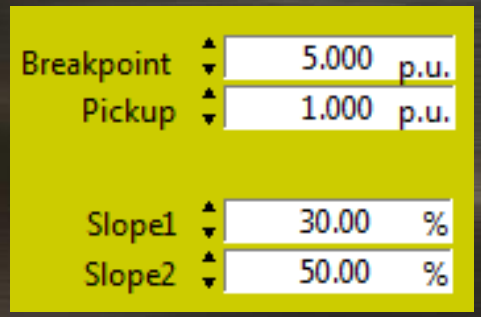
- To enhance 87L security
- Current disturbance detector is used to compare actual symmetrical component current values to the values of several cycles before
- Usually not phase segregated

87L for Radial Lines – Complications

- Remote line end has either no infeed or weak infeed fault current contribution
- Voltage collapse
- Radial lines in remote area
- Radial lines are prone to high impedance faults
- CT saturation
  - During an internal fault, there is a higher risk of CT saturation at the source end
  - For an external fault on the remote end side, a high fault level could develop CT saturation if fault is located at the HV side of transformer

87L for Radial Lines – High Imp Fault

- Tool to evaluate the dependability for high impedance faults



87L for Radial Lines – CT Saturation

- Tool to evaluate the security during CT saturation caused by external faults

Analyze

External Fault Behind: CT4 stem Frequency: 60 Hz

CT Parameters	CT1	CT2	CT3	CT4	
Inverse of sat. curve slope	25	25	25	25	
ec. voltage (Vs) at 10A exc. current	800	800	800	800	V
CT Primary	1200	1200	1200	1200	A
CT Secondary	5A	5A	5A	5A	
Primary system X/R ratio	35	35	35	35	
Total CT burden resistance	1	1	1	1	ohms
CT burden reactance	0.01	0.01	0.01	0.01	ohms
er unit DC offset in primary current	1	1	1	1	
Per unit remanence	0	0	0	0	

Pickup	0.2	pu
Restraint 1	30	%
Restraint 2	50	%
Break point	2	pu

Impact of Radial Application to 87L Supervisory

- Impact of radial application to 87L supervisory element has a dramatic performance difference between the source and remote end

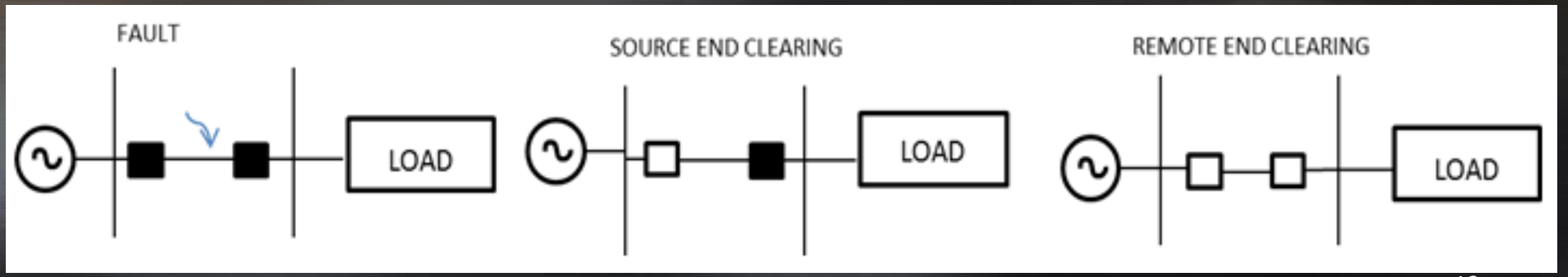
- Fault current contribution is drawn mainly from the source side. Although the 87L scheme works satisfactory in this scenario, remote end current detector could potentially no operate, hence inhibit or delay the 87L operation

87L Supervision at Remote

- No modification to the standard 87L supervisory current detector
  - Embrace need of standardization of protection schemes, simplification of design and cost reduction
  - If a credible current change or contribution from the remote end is not foreseen for likely fault scenarios, other means to satisfy the 87L supervisory operation should be investigated

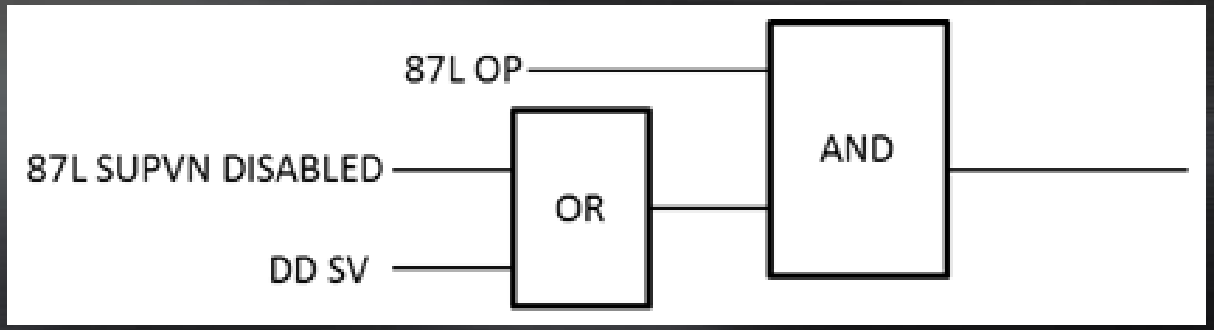
87L Supervision at Remote

- Sequential trip
  - Fault will be cleared by the source end anyway which eventually drops on all the phases the current to zero
  - Rely on a minimum connected load
  - Delay the fault clearing time of 80-100 ms at remote end



87L Supervision at Remote

- Disable 87L supervision
  - Communication performance may jeopardize the 87L security
  - In general, the importance of continuity of supply and security for the 87L scheme still applies to radial line as for meshed application
  - Use of the 87L supervisory element is encouraged

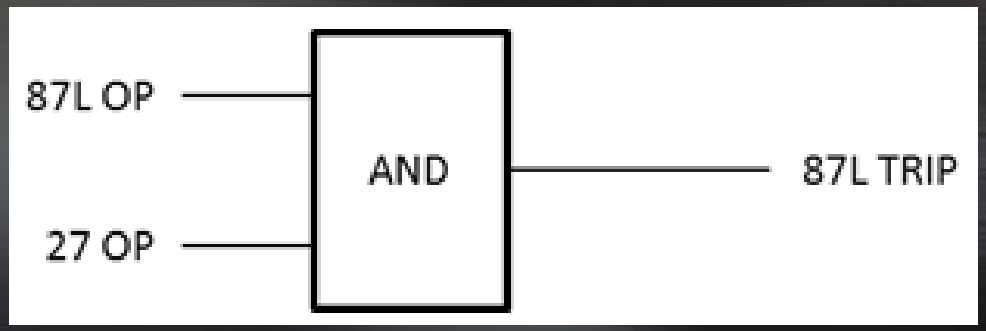


87L Supervision at Remote

- Decrease the threshold of current detector
  - Increase detection sensitivity
  - Risk of an unwelcomed disturbance detector pick up during normal load current fluctuation

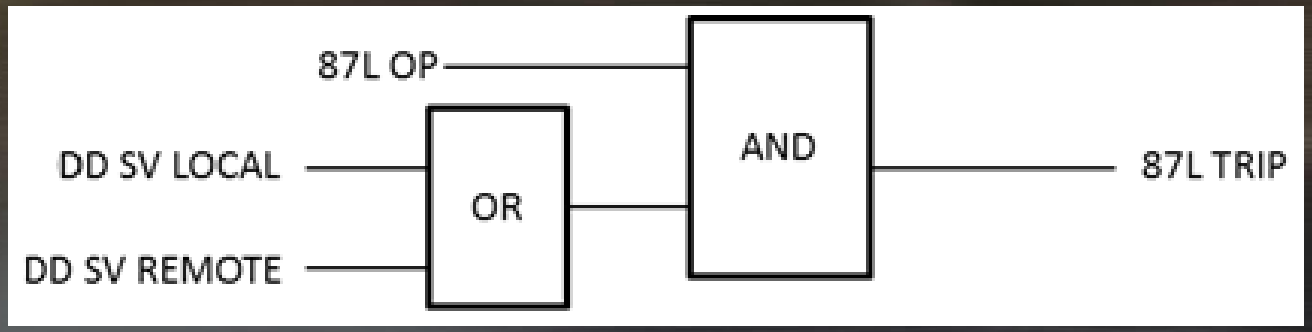
87L Supervision at Remote

- Undervoltage detection
  - Work correctly for a large variety of fault scenarios
  - Design of UV pick up should consider the maximum expected fault resistance on the line and voltage dip during the worst credible motor starting scenario



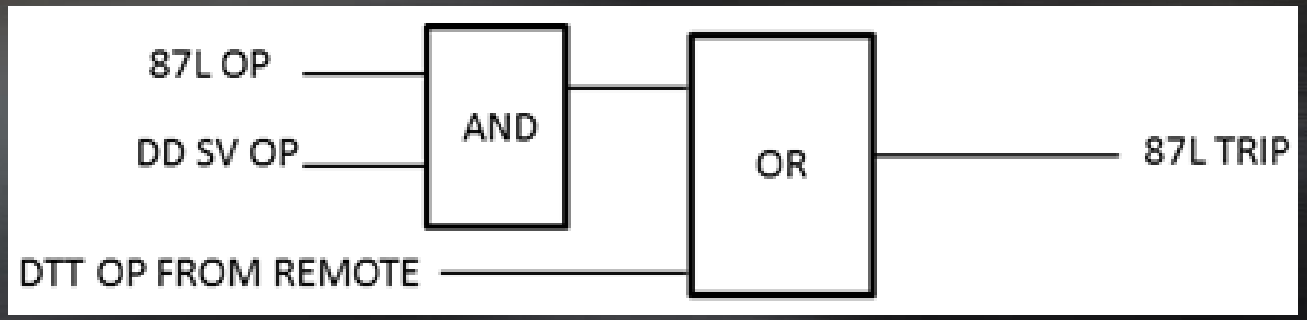
87L Supervision at Remote

- Supervision signal from source end
  - The remote supervision signal will be contained in the first 87L packets with no risk of delay the 87L operation



87L Supervision at Remote

- Direct Transfer Trip
  - DTT signal is generated by the other end 87L trip operation
  - Some users always enable this function all the time for redundancy and simplicity purposes
  - It is not biased for security as the corruption of the single DTT bit, the remote end will trip with no any other safeguard



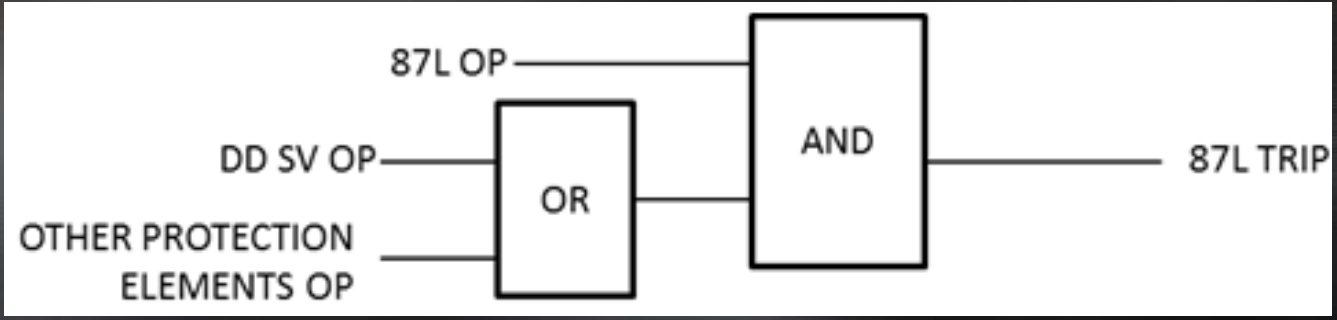
87L Supervision at Remote

- Use of current angle change detector
  - 87L supervision in very weak infeed application
  - In parallel with the traditional current magnitude change detector as an alternative method

  - Limitation in the event that the current is still lower than the relay current threshold.

87L Supervision at Remote

- Use redundant protection element
  - It is common that the distance or directional elements are enabled to provide either redundant protection or back protection
  - Due to the weak infeed at remote end, distance and directional overcurrent do not have better dependability of the dedicated 87L current detector. Therefore, this option is unconvincing.

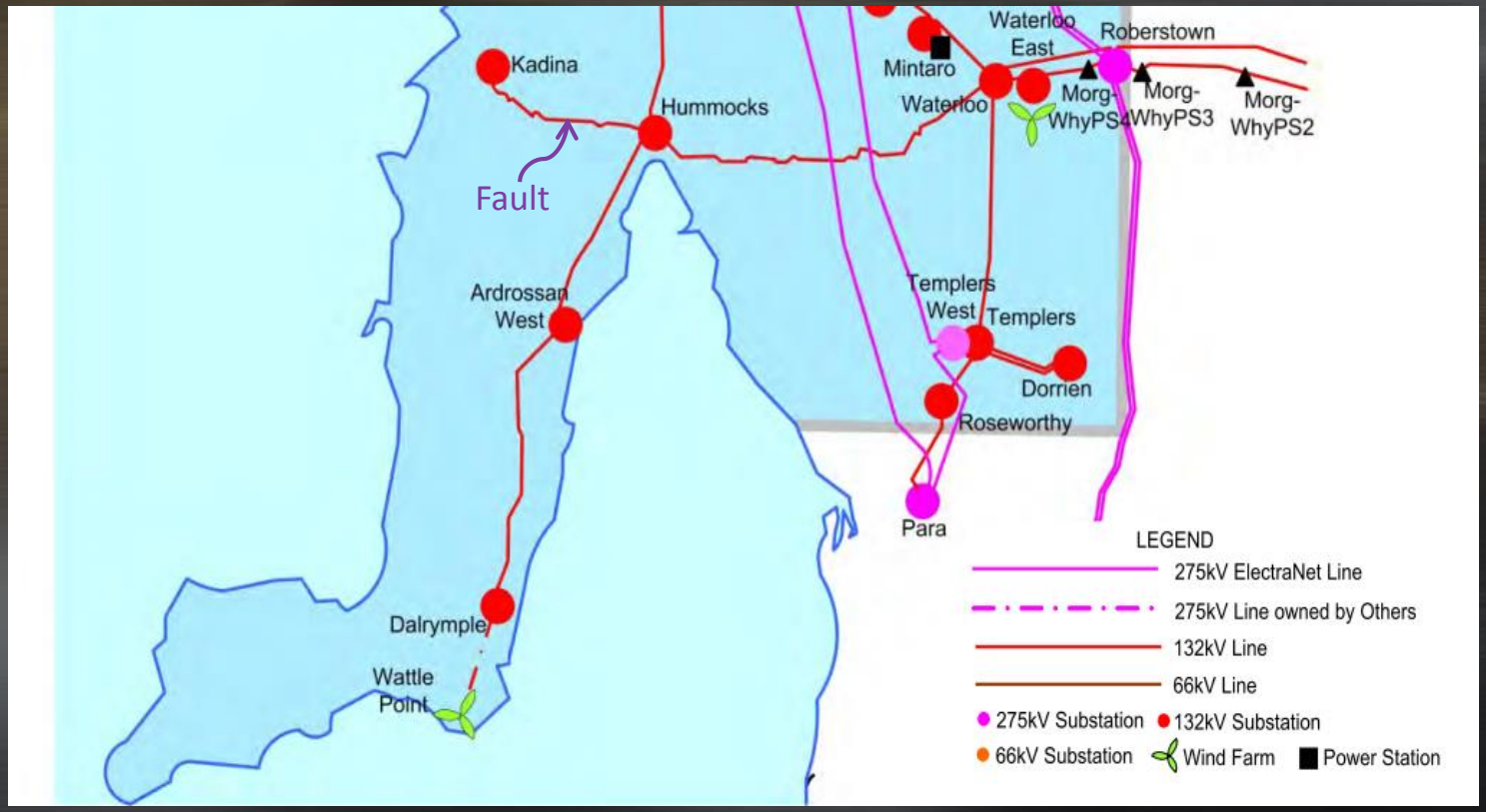


87L Supervision at Remote

- Combination of two or more options
  - Provide enough flexibility to cover different scenarios
  - Potential risk to overly complicate the design, commissioning and maintenance of the scheme with subsequent impact on dependability

Case Study – System

- Two phase-to-ground faults between Kadina and Hummocks, 132kV, 40kM



Case Study – Fault Current

Event	CT ratio at both ends	Pre-fault load current (A)	Fault current from Source end (A)	Fault current from remote Phase A (A)	Fault current from remote Phase B (A)	Fault current from remote Phase C (A)	Remote Io change (A)	Remote DD opera-tion	Vol at source (pu)	Vol at remote (pu)
2011 A-G fault	600/1	34	2950	480	410	480	455	Yes	0.31	0.25
2014 C-G fault	600/1	31	2260	330	390	390	368	Yes	0.4	0.25

- Fault current contribution ratio between the source and remote end is about 6
- The tertiary winding of the transformer generates current changes even on the healthy phases

Case Study – Analysis

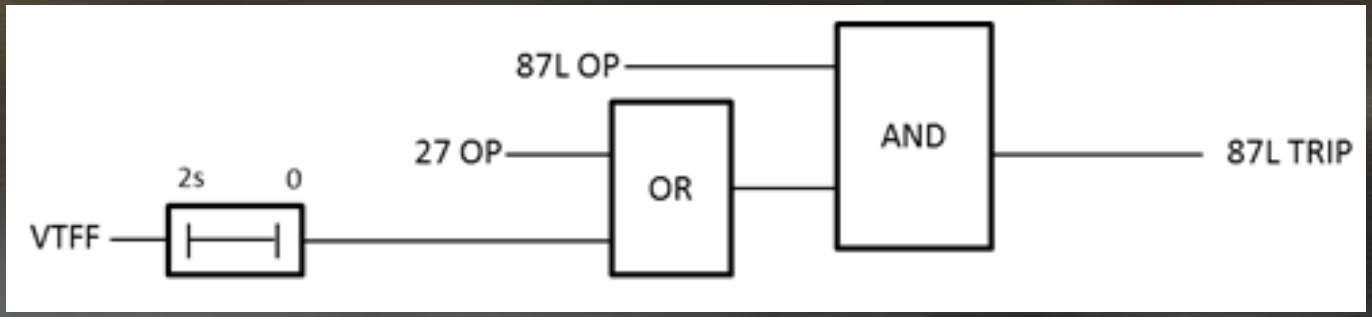
- 87L operated correctly for both fault events
- At the source end the disturbance detector will definitely operate for any type of fault
- At the remote end the disturbance detector dependability is also very high due to the significant zero sequence current provided by the tertiary winding of the transformer
- Assuming a current contribution ratio of 15 and a high impedance fault of 1.3 kA close to Hummocks Substation, there is still a satisfactory 82 A of fault current drawn from Kadina East.

Case Study – How about three-phase faults

- Contribution ratio between the positive sequence impedances of the source of remote end is very high, hence reducing the fault contribution to a few amperes
- The disturbance detector at the remote end may not pick up
- Four practical solutions are proposed

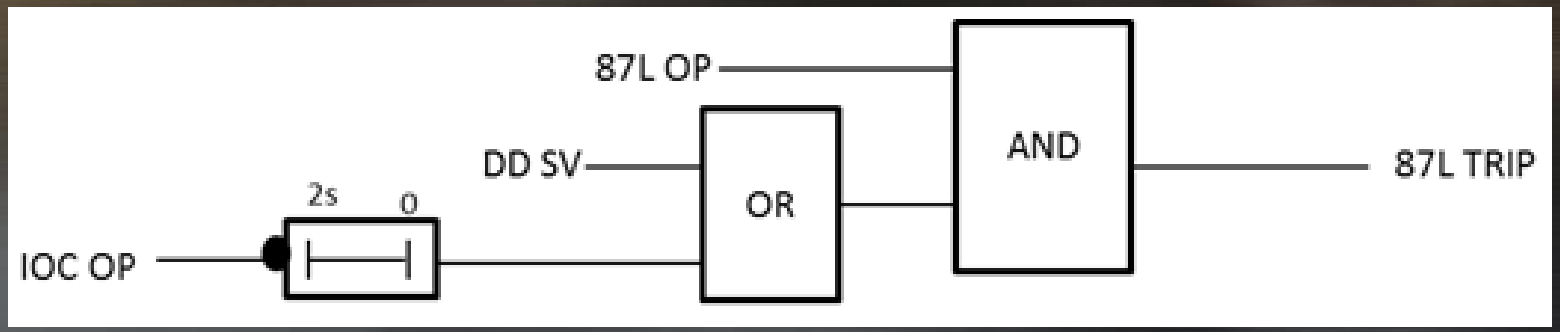
87L Supervision Solutions – 1

- Use of the undervoltage element to supervise 87L OP
- Bypass UV by using VTFF



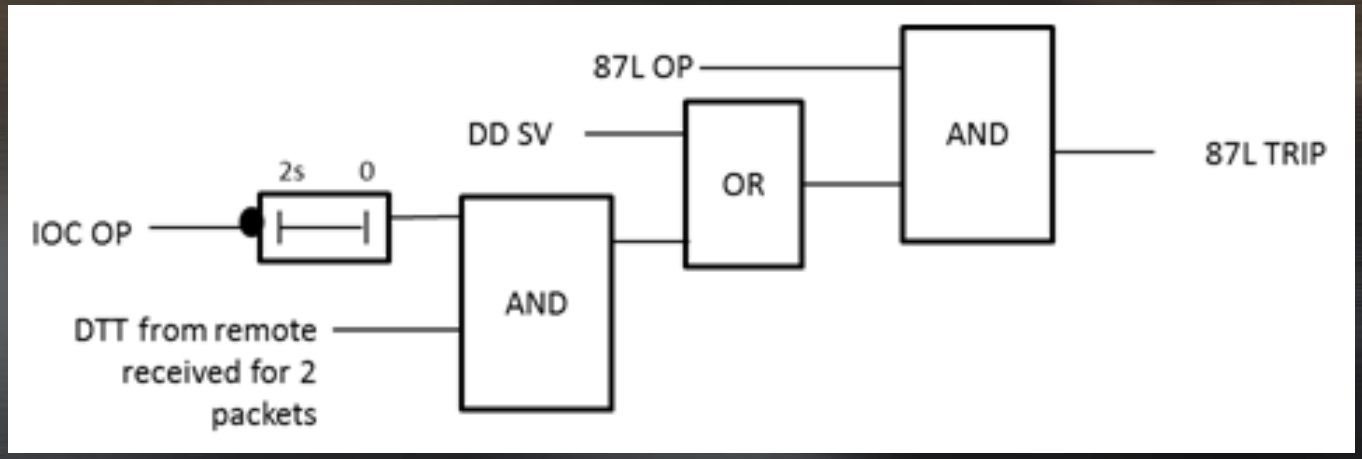
87L Supervision Solutions – 2

- Use of the current disturbance detector to supervise 87L OP
- Bypass DD in the event of phase current being below a user definable threshold



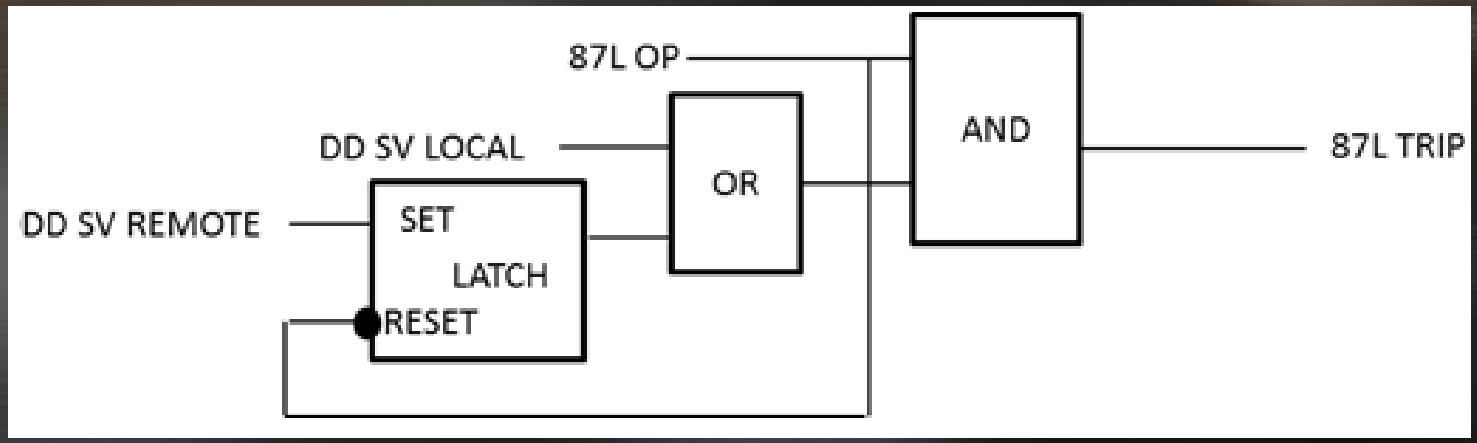
87L Supervision Solutions – 3

- Use of the current disturbance detector to supervise 87L OP
- Bypass DD in the event of phase current being below a user definable threshold and DTT received from the stronger source



87L Supervision Solutions – 4

- A robust, simple, secure and dependable solution
- Use of the current disturbance detectors from both ends to supervise 87L OP
- Can be implemented to any ends and applied as standard feature for any 87L application



Conclusions

- 87L schemes can be implemented in a dependable and secure manner to either transmission line in a meshed network as well as to radial application
- Dependability of traditional current detector is affected by weak or absent current contribution from remote end
- Several 87L supervision options are investigated
- Use of current disturbance detectors from both ends meets the need of increasing the dependability of the 87L without affecting security, simplicity and speed of operation

Thank You

Questions?