Utilizing Single Phase Operation Scheme on Untransposed 765kV lines for a Stability-Limited Plant

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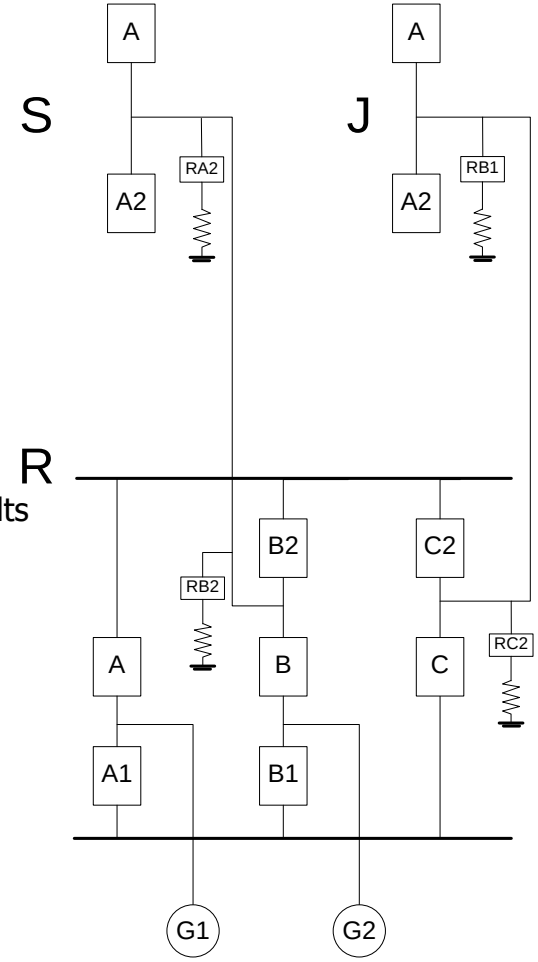
Outline

- Overview of the Stability-Limited Plant
- Secondary Arc Extinction Requirements
- Single Phase Operation (SPO) Implementation
- Fast Valving Coordination to Maintain Unit Stability
- Special Controls to Improve System Reliability
- Conclusion

Overview of R-Plant Facilities

- Two Generating Units – 2 x 1320 MW
- Two 765 kV Transmission Lines
  - R – J 765 kV line Connecting to 765 kV Network
  - R – S 765 kV line Connecting to 345 kV Network
- R-plant is a stability-limited plant
- Challenges to protect the R-plant
  - Improve the plant stability performance by utilizing Single Phase Operation (SPO)
    - Most of EHV line faults are temporary single phase to ground faults
    - Only switching out the faulty phase for a single-phase-to-ground fault
  - Secondary arc extinction during SPO
  - System imbalance due to untransposed 765kV lines



History of R-Plant Stability Event

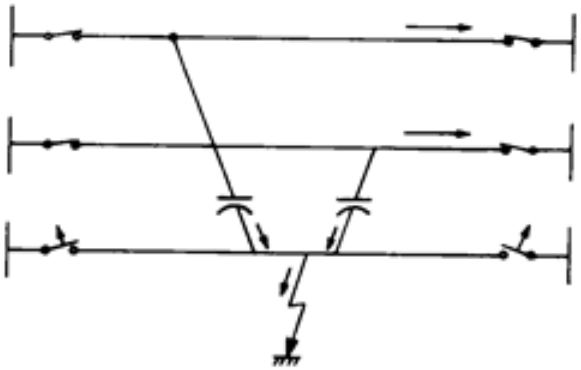
- August 4, 2007 Event
  - Six sequential faults in 2.5 minutes at J-765kV station
  - R – J 765 kV line tripped
  - R-Plant stability controls operated as designed; however the multiple fault scenario above was outside scope of the design, resulting in the tripping of R-Plant Units 1 & 2 (2640 MW)
- NERC Event Analysis Team Recommendation
  - A total of 9 recommendations
  - Message: To the extent possible, avoid a trip-out of R-Plant at full output (2,640 MW), even under sequential multiple fault conditions

Complexity of R-Plant Protection Scheme

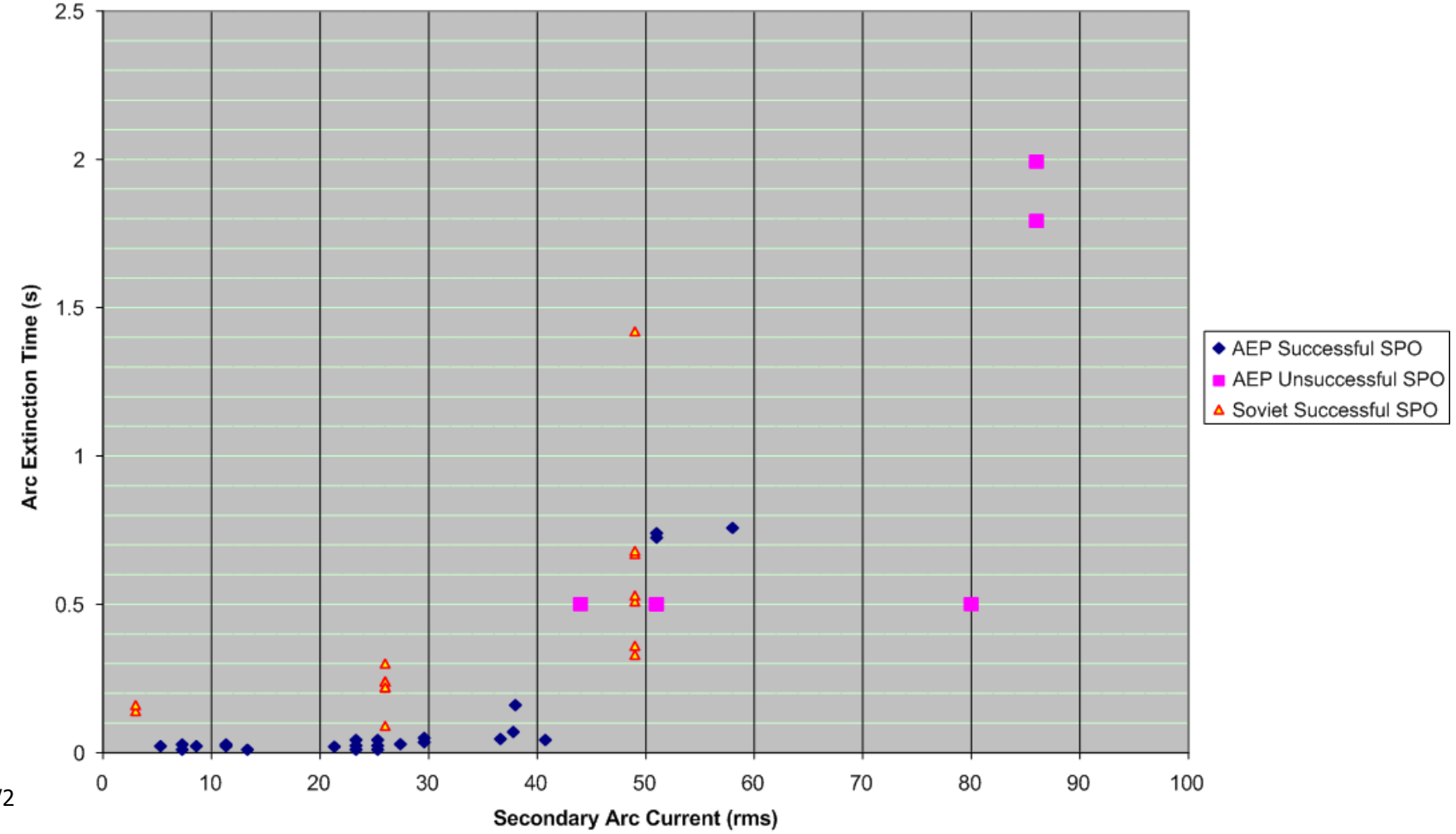
- The protective scheme was implemented with a combination of the improved line Single Phase Operation, Reactor Cross-Phase Switching, Quick Reactor Switching (QRS) and unit Fast Valving (FV) special protection system
- Coordination between SPO and Quick Reactor Switching (QRS) on the adjacent 765kV line
- Coordination between SPO and the plant unit Fast Valving
  - Boiler pressures and the number of FV operations allowed
- Consideration on unusual series of sequential faults
  - Breaker Operation Limiter (BOL) Function
  - CT Flashover Protection Function

Secondary Arc Extinction

- The opened faulty phase coupling to the remaining healthy load-carrying phases
- The secondary arc current continues to flow in the original primary arc channel
- The coupling, if not compensated, can maintain the secondary arc in the path and prevent successful high speed reclosing
- Requirements for a successful SPO with a 0.5 second reclosing time
  - Secondary arc current < ~35 A
  - Rate of rise of the recovery voltage < 10kV/ms
- Compensation required to meet the requirements

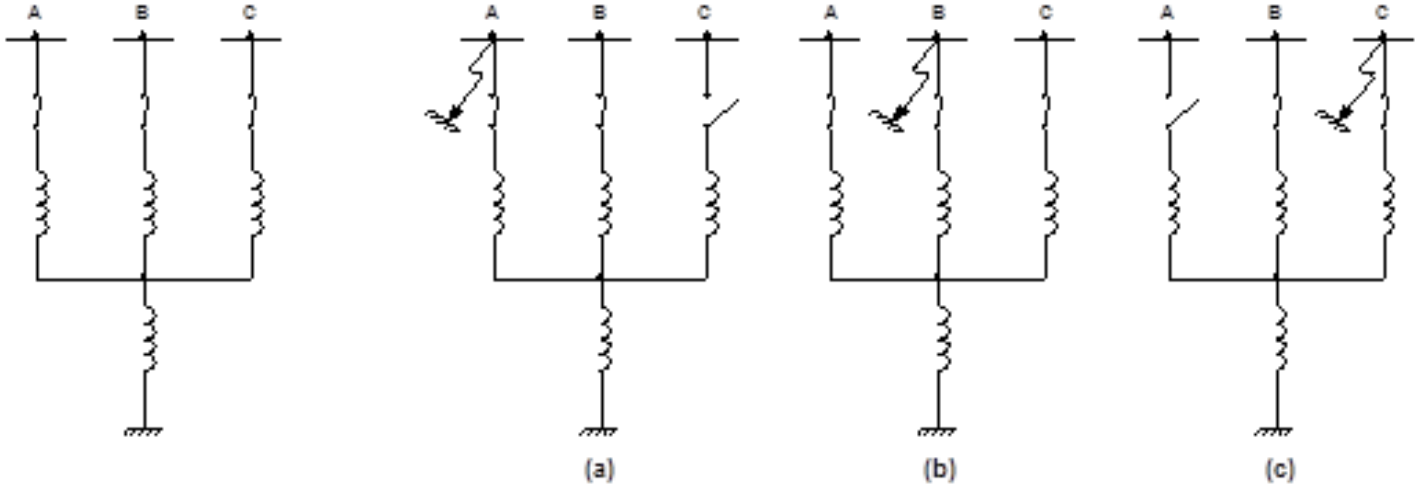


Testing of Single Phase Reclosing



Conventional 4-Legged Reactor vs. Modified 4-Legged Reactor

- Use conventional 4-legged reactor bank can be for transposed lines
  - Reduce the secondary arc current and shorter arc extinction time
- Modified 4-legged reactor bank is required for AEP 765 kV lines due to its unbalanced nature
  - Compensate unequal phase-to-phase line capacitances
- Cross-Phase Reactor Switching is integrated into the line protection logic



765kV Line Protection Scheme

- AEP 765kV line protection standards – Three sets of protective relays
  - Two primary systems – PS1 & PS2 on DCB scheme
  - One backup system – BS1
- R – J & R – S 765kV lines Relaying Uniqueness:
  - PS1 – Directional Carrier Blocking (DCB) + Stepped Distance (Backup)
  - PS2 – Permissive Overreaching Transfer Trip (POTT) + Stepped Distance
  - BS1 – Stepped Distance Backup
  - Three forward looking zones + One reverse looking zone for both phase and ground distance protections
- Line reactor breaker relaying scheme – Cross-Phase Reactor Switching for the untransposed line
  - Line Phase A 1LG faults, the single pole tripping relays will trip Phase C reactor breaker (1 pole)
  - Line phase B 1LG faults, no reactor breaker poles are tripped
  - Line Phase C 1LG faults, the single pole tripping relays will trip Phase A reactor breaker (1 pole)

Single Phase Operation Implementation

- Switch open the faulty phase breakers for a 1LG fault
- Three-pole trip is enabled for 5 seconds after a reclose
  - Switch open three phases for a subsequent 1LG fault within 5 seconds of a reclose
- Other conditions to enable the three-pole trip
  - Phase Distance Zone 2 operates
  - Phase Distance Zone 3 operates
  - Ground Distance Zone 2 operates
  - Ground Distance Zone 3 operates
  - Ground Time Overcurrent operates
  - Select switch turn on three-pole trip
- If a reactor bank is out of service prior to a 1LG fault, the line relays issue a three-phase close signal to switch the reactor bank back in service
  - Help reduce the secondary arc current during the line SPO
- Schedule the reactor bank outage when the line loading is not heavy

Single Phase Operation Sequence

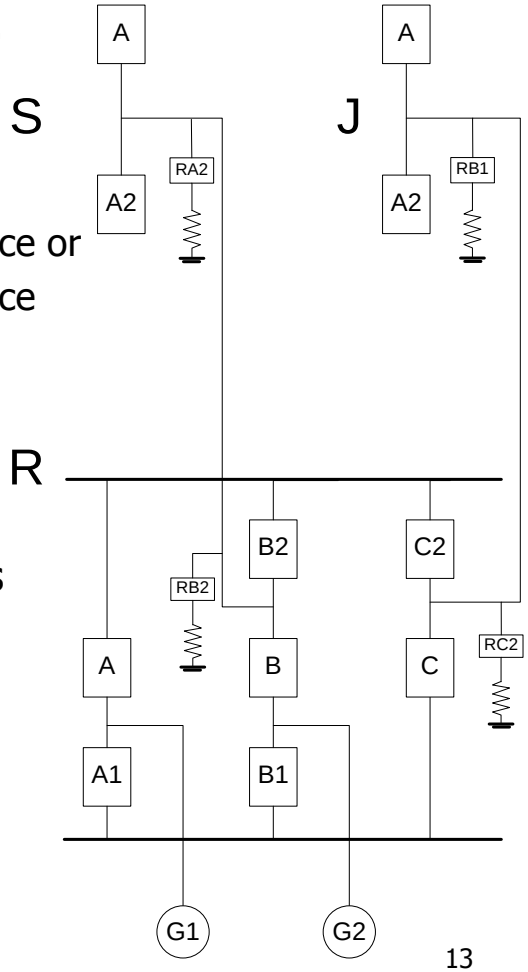
Sequence of Events	Time (~Cycles)
1. Single line-to-ground fault initiates	t1
2. Breaker poles of the faulted phase opens	t1 + 3
3. Proper reactor switch opens	t1 + 3
4. Line breaker poles reclose	t1 + 30
5. If line breaker poles reclose unsuccessfully, open three phases	t1 + 33
5. Reactor switch recloses	t1 + 35

Fast Valving to Maintain Unit Stability

- Fast Valving allows the plant to generate its rated MW capability
- Always enabled on both units, but may not be available based on steam pressure
  - Provides temporary, rapid closing of turbine valves to pre-determined positions
    - Over 50% reduction in electrical power within one second of initiation
  - Valves return to original positions in about nine seconds after initiation
  - Electrical power (Pe) restored to original level in less than ten seconds after initiation

Fast Valving Control Specifications

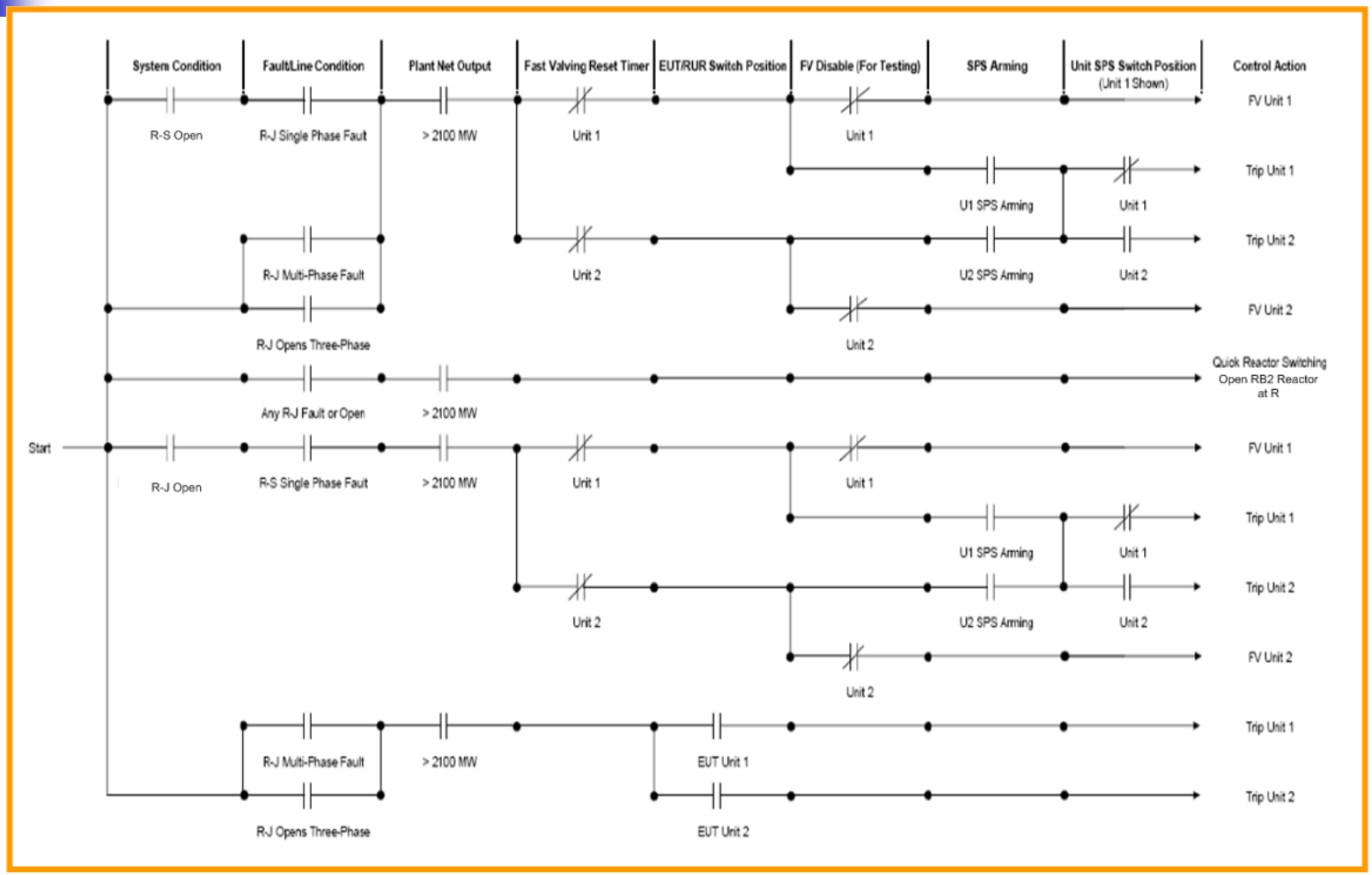
- Fast Valving is initiated if the plant generation exceeds 2100 MW AND
  - Multi-Phase fault or line current/MVA on R–J 765kV falls below 450A/600MVA or
  - Single-phase fault of R–J 765kV when R–S 765kV is out of service or
  - Single-phase fault of R–S 765kV when R–J 765kV is out of service
- Allows for multiple FV operations:
  - Up to three FV operations in three minutes
  - No less than five seconds apart
- If the steam generator pressure or the throttle pressure is above a limiting threshold value, the unit power relief valves may operate during the next FV event, and a unit must be tripped
  - Unit SPS Trip triggered



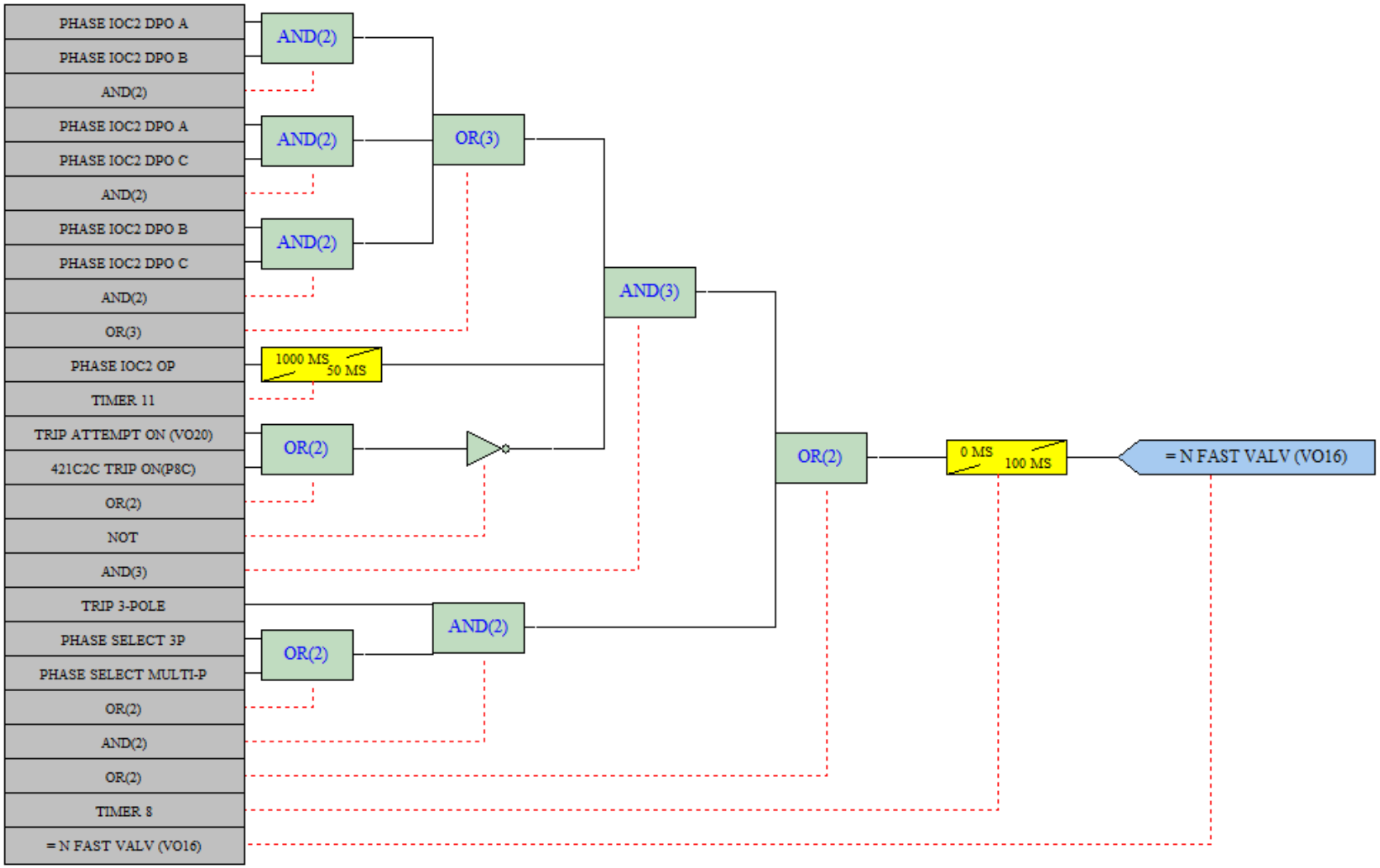
Additional Controls to Maintain R-Plant Stability

- Special Protection System Trip
  - Fast Valving has been triggered **AND**
  - 3 Fast Valving operations have already occurred within 3 minutes
  - Excessive steam generator boiler or throttle pressure exists when a Fast Valving initiate is processed
  - SPS Trip unlikely because multiple FV operations should be available
- Removed time-delayed closes on both R-Station line terminals for hot bus/dead line following a three-phase trip
  - Allow such closings with a hot line only at R-Station

Functional Logic Diagram of R-Plant Stability Control

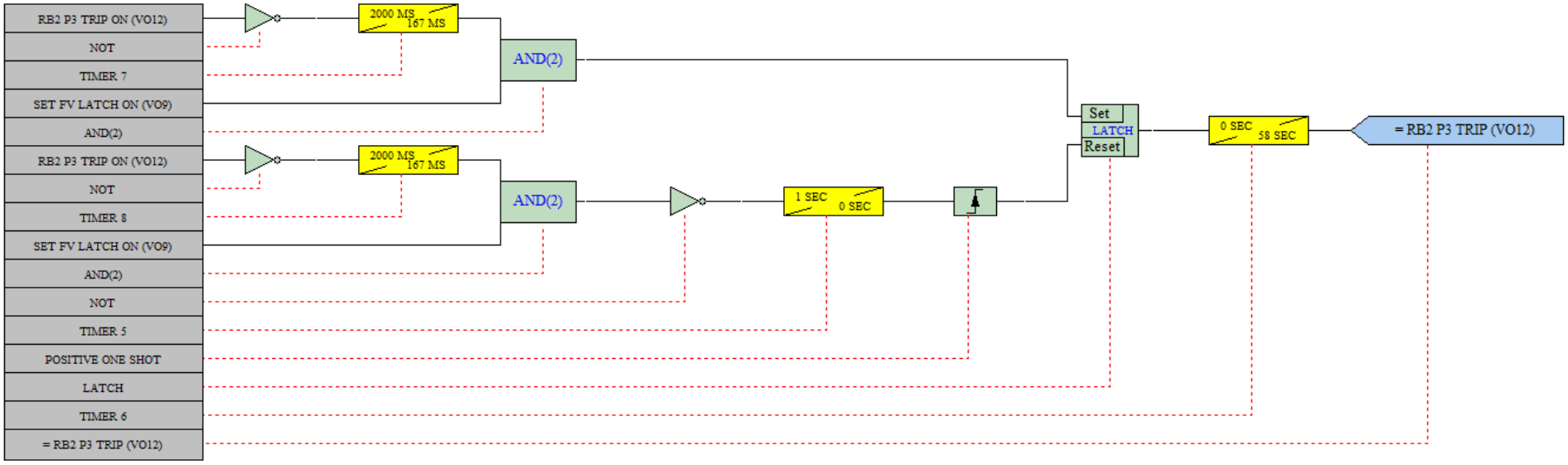


Fast Valving Initiation Logic for R – J 765kV Line



Quick Reactor Switching to Maintain Plant Exit Voltage

- Quick Reactor Switching (QRS) on R – S Line
  - R – J line relaying initiates the signal to trip the line reactor breaker RB2
  - Boost the 765kV voltage at the plant exit during a disturbance
  - Reclose Reactor RB2 after 60 seconds
  - 1-shot Logic for multiple QRS events



Special Controls to Improve System Reliability

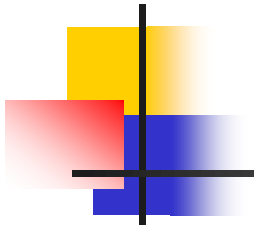
- Breaker Operation Limiter (BOL) & CT Flashover Scheme
  - Limit 3 recloses in the initial 30 minutes period plus one reclose allowed per every additional 30 minutes period
  - Provide CT ground flash over protection by operating associated lockout relays without time delay
  - Isolate column CT faults to ground from all sources and prevent automatic reclosing of adjacent transmission lines
- Enhanced POTT Scheme Security
  - Past practice – Permission Trip Window
    - Give permission trip to the relay for a 150 milliseconds window if the carrier set that sees a loss of signal
    - Did not account for a momentary loss of signal during an external line fault
  - Enhanced security for the POTT scheme
    - Add a loss of signal delay timer (20 ms) to the power line carrier loss-of-signal (i.e. loss of guard & low level) logic

Conclusion

- Benefits of Single Phase Operation
  - Improve power system reliability performance by maintaining system integrity
  - Maximize the availability of a stability-limited plant or a critical heavily-loaded line
    - Avoiding pre-contingency curtailments
    - Avoiding plant shutdown for temporary SLG faults on the only in-service line
    - Providing economic benefit to asset owners
  - Maintain stability of the plant in conjunction with other SPS controls
  - Reduce torsional stress in the turbine-generator shaft
    - By avoiding unnecessary three-phase switching, the shaft system responds to lower torsional torques that might occur upon SPO

Conclusion – Cont.

- Enhancements from the original design
  - Reduced the reliance on Fast Valving at R-plant
    - SPS operations can be avoided during temporary SLG faults on one of the two 765kV lines when both lines are in service
  - Added Breaker Operation Limiter
  - Modified CT ground flash over protection
  - Enhanced POTT scheme security
- The SPO scheme can be modified to facilitate Independent Phase Operation (IPO)
  - IPO – An operating condition that a line would remain in service for certain period of time with two phases only (e.g., 30minutes) following a sustained single-phase fault
  - Allow dispatcher to re-distribute power before taking the line out
  - Additional studies on the IPO impacts on system operations, protections, equipment, ground wire capability requirements and ground path



Questions?