Open Phase Detection
NRC Presentation

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Byron Station Event Descriptions

Unit 2

- January 30, 2012
- Mechanical failure of 345 kV under-hung porcelain insulator on System Auxiliary Transformer (SAT) A-frame structure creates a line to ground fault on the feed side of the SAT
- Open phase condition that protective relaying was not designed to detect
- Simultaneous adverse impact on both redundant safety trains
- Reactor trip on Reactor Coolant Pump (RCP) undervoltage
- Loss of off-site power (LOOP)
- Unusual Event

Unit 1

- February 28, 2012
- Mechanical failure of under-hung porcelain insulator on SAT A-frame structure creating a line to ground fault on the system side
- Protective relaying isolated the faulted component and transferred power to the alternate supply
- Systems worked as designed and station remained on-line
- Loss of off-site power (LOOP)
- Unusual Event

- **Ohio Brass insulator manufacturing defect**
- **Design vulnerability - failure to automatically detect an open phase condition**

Exelon Fleet Actions Summary

- This event was significant because it revealed a design vulnerability where an open phase or open phase grounded condition would not be detected by the existing protective relaying
- Operability Evaluations were completed at all sites
- Sites implemented interim compensatory measures including enhancements to existing alarms, simulator training and posting of designated operators as appropriate
- A project team staffed with best expertise drawn from across Exelon, specialty engineering vendors and academia was convened to develop a technical solution to resolve the issue
- The project team developed an innovative microprocessor based relaying scheme capable of reliably detecting and isolating an open phase / open phase grounded condition before it can adversely impact plant equipment or operations
- The protective relaying has been deployed in “alarm only” mode at five units with balance of the fleet to be deployed throughout 2013 and early 2014
- Lessons learned are openly shared with the industry via NEI working group

Technical Solution Summary

- The problem was solved by programming highly reliable and well vetted microprocessor based protective relays with an innovative detection algorithm
  - Detection algorithm based on zero sequence current theory
  - Connected to transformer primary side (HV) bushing current transformers (CTs)
  - Designed to automatically separate faulted off-site power source from station medium voltage buses and allow emergency diesel generators to supply vital AC power
  - Less complex and more reliable than the comparable analog protection schemes
  - Proof of concept validation testing was completed in July of 2012 and project was transitioned to detailed design and fleetwide deployment

Relay Platform Selection

- The Schweitzer Engineering Laboratories (SEL) 451 relay was selected for this application for the following reasons:
  - Ability to implement custom detection algorithm
  - Well vetted and highly reliable platform
  - Ability to detect high impedance faults
  - High speed data collection and fault/event recording
  - Synchrophasor measurements to validate load flow and fault models using instantaneous voltage angles
  - Comprehensive diagnostics
  - Complete overcurrent protection
  - High-speed breaker failure detection for two breakers

Schweitzer Engineering Laboratories (SEL) Relay

Large display facilitates installation and diagnostics, eliminating the need for panel meters.

Built-in phasor measurement unit.

Display navigation controls make more information readily accessible.

Detailed, programmable targets, with user-configurable labels, provide fast and simple information to assist dispatchers and line crews for rapid power restoration.

EIA-232 front serial port for quick, convenient system setup, checkout, and local access.

Independent breaker trip/close pushbuttons with indication operate even if the relay is not powered.

SEL provides a worldwide, ten-year product warranty and –40° to +85°C temperature range—best in the industry.

One thousand lines of custom automation logic available.

High-accuracy (±0.5% of reading) RMS metering.

Programmable control pushbuttons and configurable labels provide local switches to replace traditional panel switches.

Relay pushbuttons and serial communications use 32 latching switches, 32 local switches, and 32 remote switches for your automation system.

Byron Single Open Phase Detection Cabinet

Description of the Detection/Protection Algorithm

- The algorithm for the wye-wye configured transformers contains two separate logic strings:
  - The first logic string (L1) provides detection of the open phase grounded condition and compares the relay calculated zero sequence current to a value established in the Electromagnetic Transient Program (EMTP) analytical model
  - The second logic string (L2) provides detection of the open phase condition
    - L2 compares the measured phase currents and tests for the unique characteristic of an open phase condition
  - Security against false actuation is provided by negative sequence current or positive sequence current

- Algorithm for delta-wye wound transformers is currently under development and will be deployed at Limerick, Peach Bottom and Oyster Creek

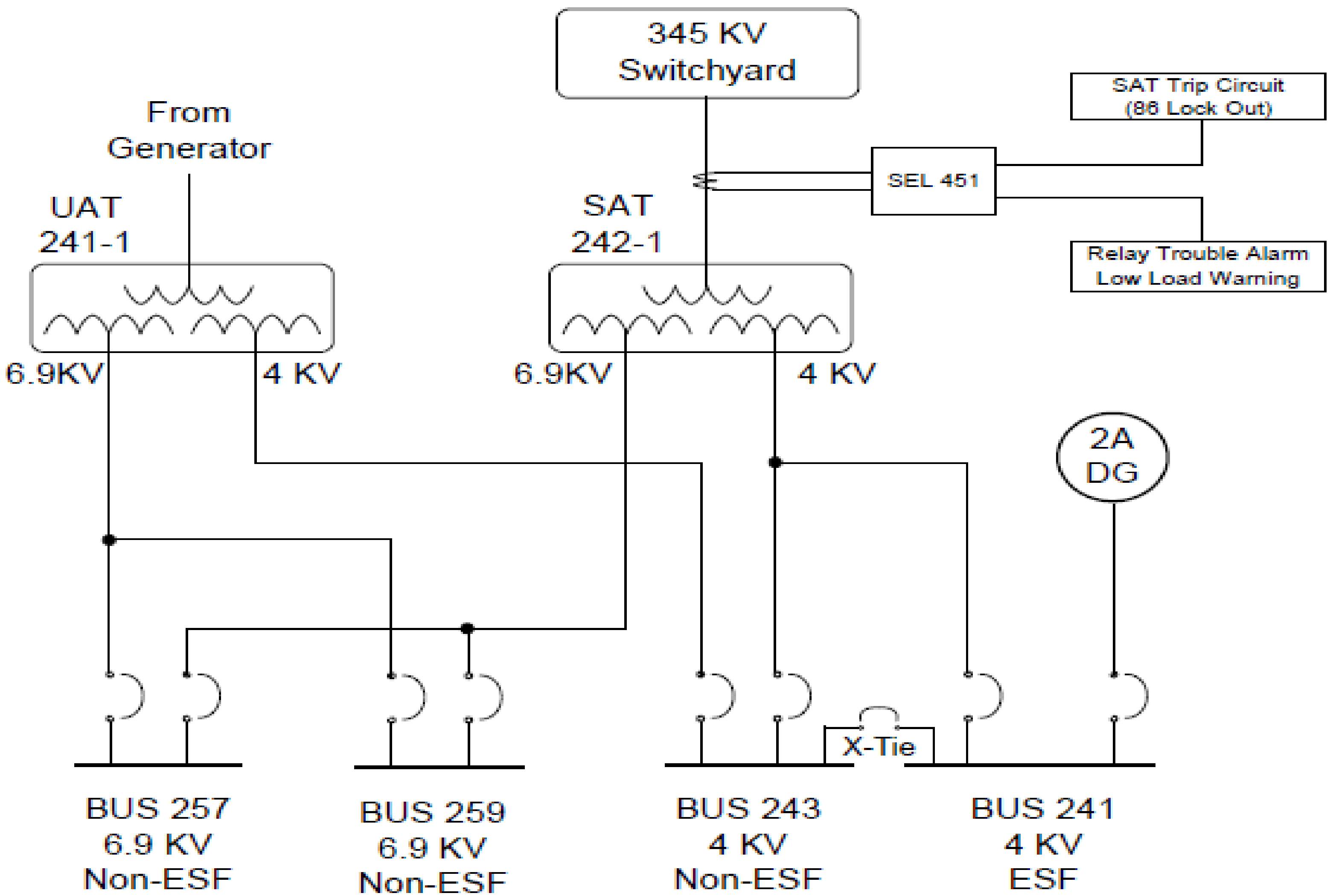
Summary Of Software Validation Protocol

- The software package is comprised of two distinct elements
  - The detection algorithm unique to this application
  - The relay firmware on which the detection algorithm executes
- Detection Algorithm Validation
  - More than 200 EMTP analytical models are constructed for each unit to predict the dynamic behavior of both the off-site power system and the auxiliary power system of each station
  - The EMTP models are used to generate dynamic waveform test cases which are applied to each relay to confirm proper operation
  - The Exelon project team subjects each relay to a formal Factory Acceptance Test (FAT) to ensure that each device is properly configured and performs in accordance with the approved design
- Firmware Validation
  - The SEL software quality assurance process was subjected to a comprehensive audit to ensure processes used in the development of the core product are consistent with the requirements of IEEE-1012 (IEEE Standard for Software Verification and Validation)
- Comprehensive testing of both the detection algorithm and the firmware on which that algorithm operates provides a high degree of confidence in the software integrity

Defending Against Spurious Operation

- True fault condition must persist for a predetermined number of cycles
  - Delay is sufficiently long to allow primary and backup protection schemes to clear upstream faults (coordination with T&D protective relaying)
  - Delay is sufficiently short to isolate fault prior to inducing a plant transient
- Trip function is blocked while energizing the transformer to preclude spurious operation from unbalanced harmonic oscillations that can occur when the transformer is energized but unloaded
- The SEL relay is highly reliable with a mean time to failure (MTTF) of 304 years and the design includes a control room diagnostic warning alarm to alert control room staff of relay malfunction
- Trip function is automatically blocked if a diagnostic alarm is activated – designed to fail conservatively
- In the event that current drops below the analyzed limit of 0.8 amps primary current, a Control Room warning alarm is triggered to alert operators that current is approaching the minimum detection threshold of the relay

Simplified Schematic (Single SAT shown)



Safety Classification

The design is implemented via a non-safety related modification:

- The modification is intended to detect and mitigate the consequences of a failure mode in the non-safety related portion of the offsite power circuit
- A non-safety related design is consistent with the protection schemes already in place for the transformer and switchyard protective relay functions
- A non-safety related modification is less complex and, therefore, more reliable than a safety related modification
- The modification protects both the safety and non-safety related equipment against an open phase condition

A safety related solution is not preferred because:

- The protection scheme would have to be implemented on each medium voltage bus increasing the quantity of relays required and complexity of the existing degraded voltage protection scheme
- It may not be feasible to develop the highly complex algorithms that would be required to detect a open phase condition by monitoring parameters on the low voltage side of the transformers
- May introduce new failure modes for each of the 4kV safety related buses beyond those previously evaluated in the original plant design
- Implementing a microprocessor based solution on the safety related buses requires compliance to ISG-6 and would delay implementation by several years

Deployment Status

- Fleet implementation schedule is based on operational impact from a single phase event and ability to remove transformers from service during maintenance outages
- Relays have been deployed at the following stations
    - Byron Unit 2 (October 2012)
    - Byron Unit 1 (November 2012)
    - Dresden Unit 3 (November 2012)
    - Braidwood Units 1 (January 2013)
    - Braidwood Units 2 (January 2013)
- Remaining site installations scheduled throughout 2013 and early 2014
- Trip functions will be enabled after a successful monitoring period that includes an outage period