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FENOC
FirstEnergy Nuclear Operating Company

Davis-Besse Nuclear Power Station

Briefing on:

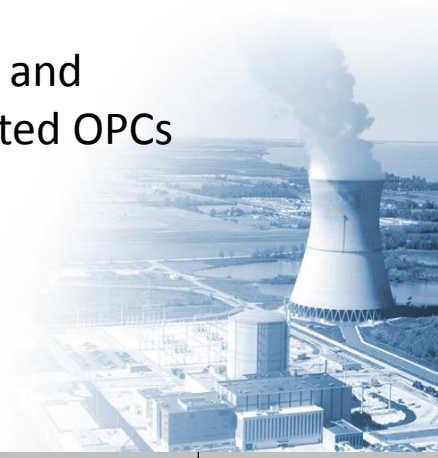
Open Phase Protection for Offsite Power Sources

NRC Public Meeting
December 7-8, 2016

Safety. Teamwork. Performance. Pride.

Objective

- Summarize the actions **FENOC** has taken at **Davis-Besse Nuclear Power Station (lead plant)** to address lessons learned from the January 2012, Open Phase Condition (OPC) that occurred at Byron as well as the other relevant industry operating experience identified since the Byron event
- FENOC's actions include:
  - Enhanced plant operating procedures to help operators diagnose and respond to potential open phase conditions
  - Performed a scoping study to understand the site specific design vulnerabilities and evaluated alternative solutions
  - Procured and installed an open phase protection system (OPPS) on both start-up transformers
  - Performed detailed analytical analyses to establish OPPS setpoints and ensure plant equipment will not be adversely impacted by postulated OPCs
  - Updated UFSAR and plant Technical Specification Bases
  - OPPS currently in monitoring mode

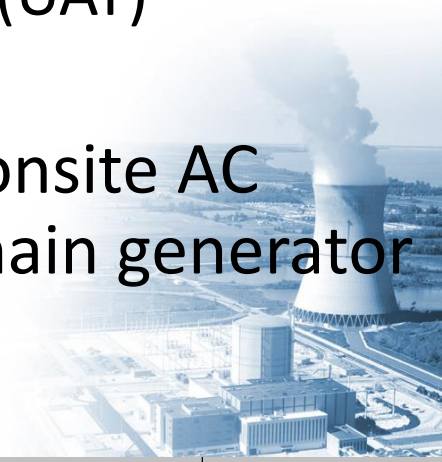


Presentation Contents

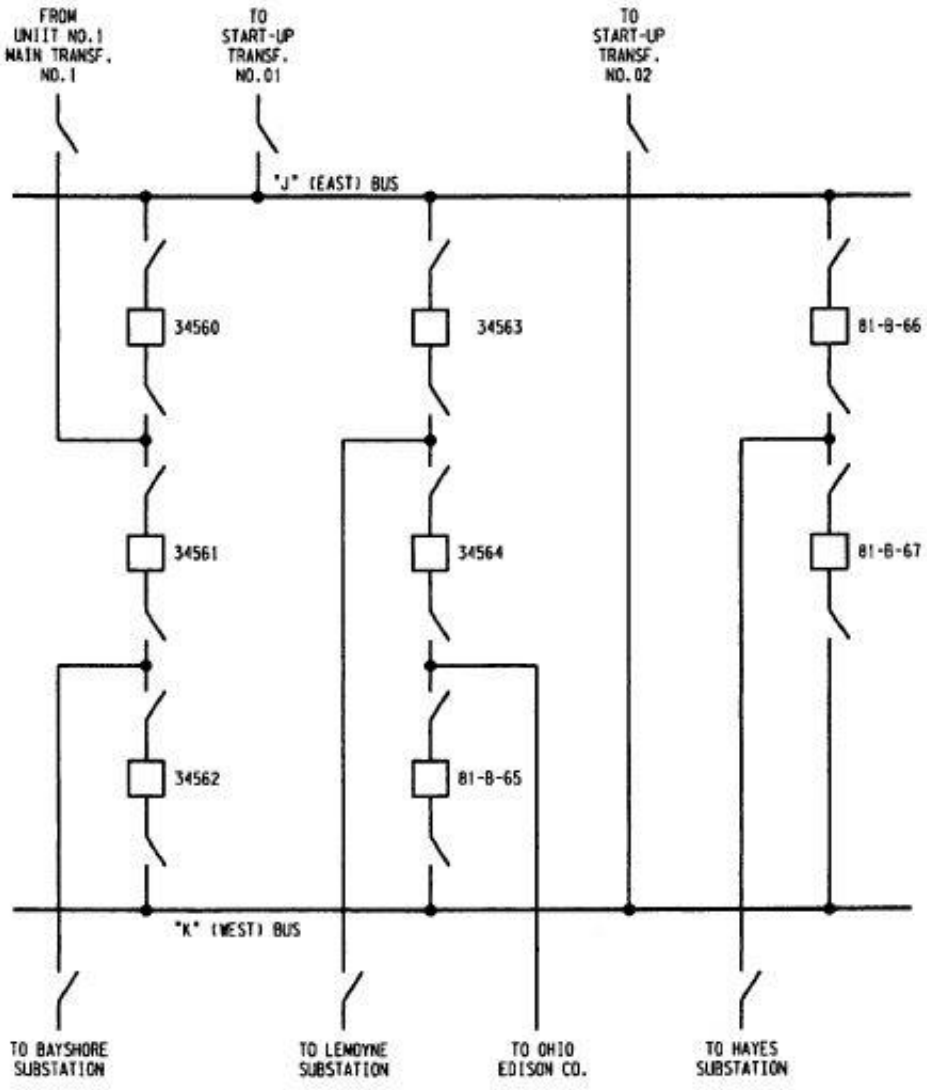
- Davis-Besse AC Power System
- Summary of Interim Corrective Actions
- Selection of Design Solution (PSStech Equipment) and its Key Functional Design Elements
- Equipment Specification
- Overview of Design Modification
- Four Functional Criteria
- Factory Acceptance Testing
- Equipment Status and Monitoring Plan
- Summary and Conclusions

Davis-Besse AC Power System

- Four overhead 345kV transmission lines feed the Davis-Besse switchyard.
- Three (3) separate overhead 345 kV circuits connect the switchyard to the onsite AC power system:
  - One independent circuit to each of the two (2) Start-up Transformers (SUTs), and
  - Third circuit connects to the 980 MVA Main Power Transformer (MPT), which in turn is connected to the Main Generator and the Unit Auxiliary Transformer (UAT) via isolated phase bus duct
- Manual removable links enable back feed of onsite AC power system via the MPT & UAT when the main generator is off-line



Davis-Besse – 345kV Switchyard One Line Diagram



Start-up transformer 01 is fed from Bus J and start-up transformer 02 is fed from Bus K

Switchyard is fed from four 345kV overhead transmission lines.

The Ohio Edison line and Hayes line share a common right away.

Davis-Besse AC Power System - continued

- The onsite AC power system consist of two non-safety related 2000 Amp, 13.8 kV buses (designated A and B).
- Each 13.8 kV bus feeds a 12/16 MVA, 13.8 kV – 4.16 kV Bus Tie Transformer which provides power to the safety and non-safety related 2000 Amp, 4.16 kV buses
- Unit Auxiliary Transformer is capable of carrying full (safety and non-safety) station auxiliary loads
- Each Start-up Transformer is capable of carrying full station auxiliary loads, as long as both bus tie transformers are functioning
- Onsite Class 1E AC distribution system is divided into redundant load groups (trains) so that the loss of any one group does not prevent the minimum safety functions from being performed
- Two essential, Class 1E 4.16 kV buses (designated C1 and D1) provide power to the engineered safety features equipment
- Standby AC power is provided to Buses C1 and D1 by separate, independent 2600 kW, 4.16 kV emergency diesel generators (EDGs)

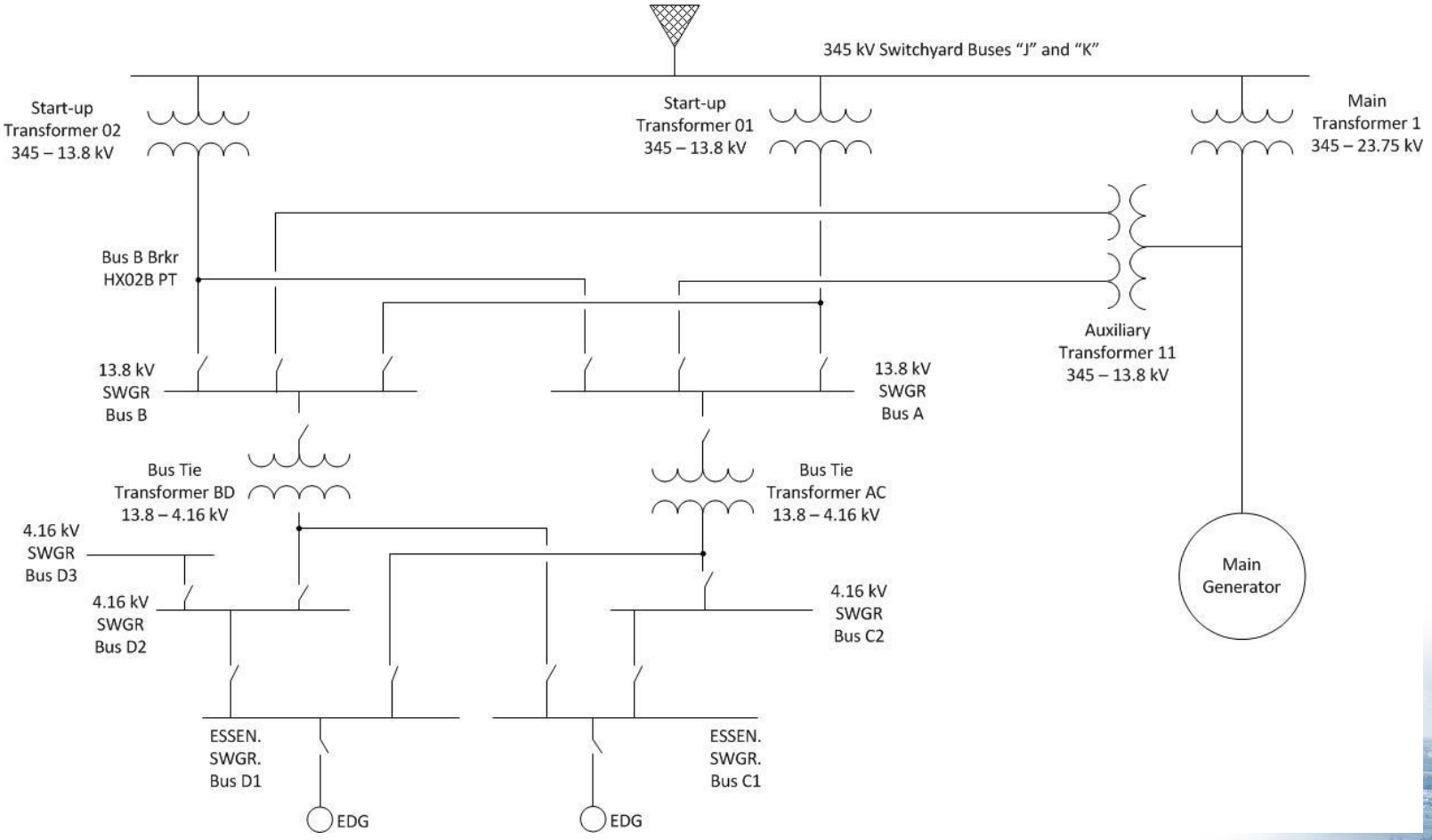
Davis-Besse AC Power System - continued

- Two (2) qualified circuits between offsite transmission network and onsite Class 1E distribution system and separate and independent EDGs for each train ensure availability of power required for safe shutdown
- A qualified offsite to onsite circuit consists of one 345 kV – 13.8 kV startup transformer, one 13.8 kV bus, one 13.8 kV - 4.16 kV tie transformer, and the respective circuit paths, including the nonessential bus and feeder breakers, to one 4.16 kV essential bus (Tech Spec Bases)
- The Davis-Besse startup transformers are three phase, shell type units with five position no load tap changers. Each unit is rated at:

39/52/65 MVA OA/FOA/FOA

HV:	345 kV Grd Y	
XV:	13.8 kV Grd Y	
YV:	13.3 kV buried-Delta	
Z pos (%)	H-X	9.44 (39 MVA base)
	H-Y	11.81 (13.65 MVA base)
	X-Y	6.04 (13.65 MVA base)

Davis-Besse AC Power System – One Line Diagram



Davis-Besse AC Power System – Startup Transformers

Summary of Interim Corrective Actions at Davis-Besse

- Following January 2012 open phase event at Byron Station Unit 2, Davis-Besse entered issue into site's Corrective Action Program (Condition Report 2012-03738) and implemented a number of interim corrective actions
- **Interim actions consisted of the following:**
  - Operator walkdowns of the switchyard are performed (three times per week at a minimum) to identify potential open phase condition vulnerabilities
  - Bus transfer procedures were revised to ensure three phase voltages are checked prior to planned transfers to an offsite power circuit
  - Periodic surveillance (seven day Technical Specification frequency) include steps to identify an open phase condition on the offsite power supply circuits
  - Operator training on interim actions
- Plant's existing operating procedures already addressed actions to be taken if a degraded source is identified

See Davis-Besse's 90-day response to NRC Bulletin 2012-01 (ML12299A468) and response to NRC request for additional information (ML14034A049)

Scoping Study

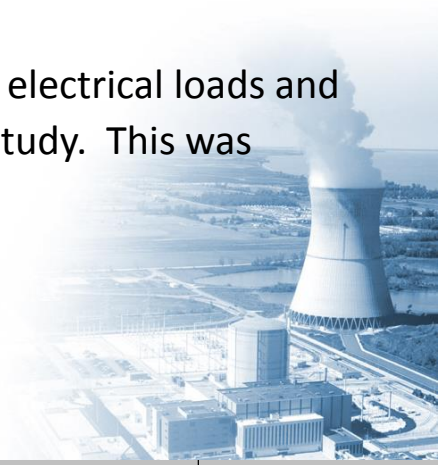
- In May 2013, FENOC completed a preliminary scoping analysis to:
  - Evaluate impact of a postulated open phase conductor on capability of Davis-Besse startup transformers to perform their intended function, and
  - Determine whether such conditions would be detected by existing plant instrumentation
- Some key conclusions from scoping analysis:
  1. Open phase with ground conditions are more readily detectable than open phase without a ground
  2. Under no load conditions there is negligible change in phase voltages on low voltage side (13.8 kV) of startup transformer with an open phase without ground on high voltage side (345 kV)
     - Energized, but unloaded is normal startup transformer alignment during plant operating Mode 1 (on-line, power operation)
     - The existing voltage monitoring potential transformers on 13.8 kV side of startup transformers will not be able to detect this condition and therefore an open phase condition on the offsite source could go undetected

- (ML14034A049)

Scoping Study - continued

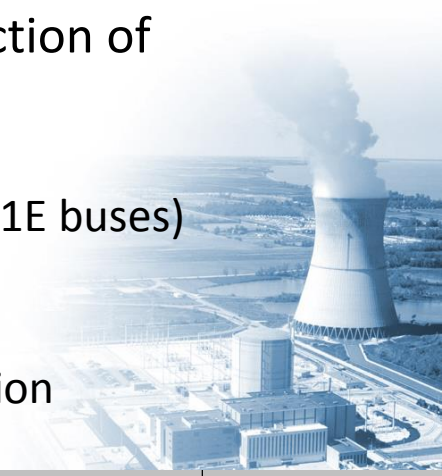
- Key conclusions from scoping analysis (continued):

3. The small changes in phase voltages on 13.8 kV side of startup transformer due to an OPC may not be distinguishable from what would be consider the normal maximum expected 345 kV transmission system phase voltage imbalance
4. During moderate and light startup transformer loading conditions (such as during plant startup, shutdown, and refueling conditions), an open phase without ground may not be detectable by existing monitoring equipment
5. During high startup transformer loading conditions associated with design basis accident block loading or post-SFAS or SFRCS actuation, an open phase condition would be detected by degraded voltage relaying on 4160 V safety buses C1 or D1. This would transfer safety related loads on effected train to its emergency diesel generator
    - Note: Impact of postulated OPCs on performance of individual plant electrical loads and associated protective relaying not evaluated in preliminary scoping study. This was addressed later



Selection of Design Change Solution

- Key elements for selecting a design change solution:
  - Understand response of plant systems and components under various postulated open phase conditions for each of various modes of plant operation
  - Ensure that plant structures, systems, and components (SSCs) important to safety can perform their intended functions under postulated open phase conditions or are otherwise protected and isolated from such conditions (Open Phase Protection)
  - Provide reasonable assurance that operable status of offsite sources credited in plant's technical specifications and credited in plant's safety analyses can be determined under postulated open phase conditions (Open Phase Detection)
  - Satisfy the goals of NEI Open Phase Initiative
  - Meet requirements of 10CFR50, Appendix A, General Design Criterion 17 for LWR Electric Power Systems
- Key Davis-Besse AC system design features that influenced selection of design change solution:
  - Davis-Besse has two immediately available, non-Class 1E offsite to onsite AC power circuits (the preferred power supply for 1E buses)
  - Under normal plant operation, non-1E start-up transformers are energized but unloaded. Therefore, secondary side solutions can only detect OPC after plant trip or automatic SFAS or SFRCS actuation

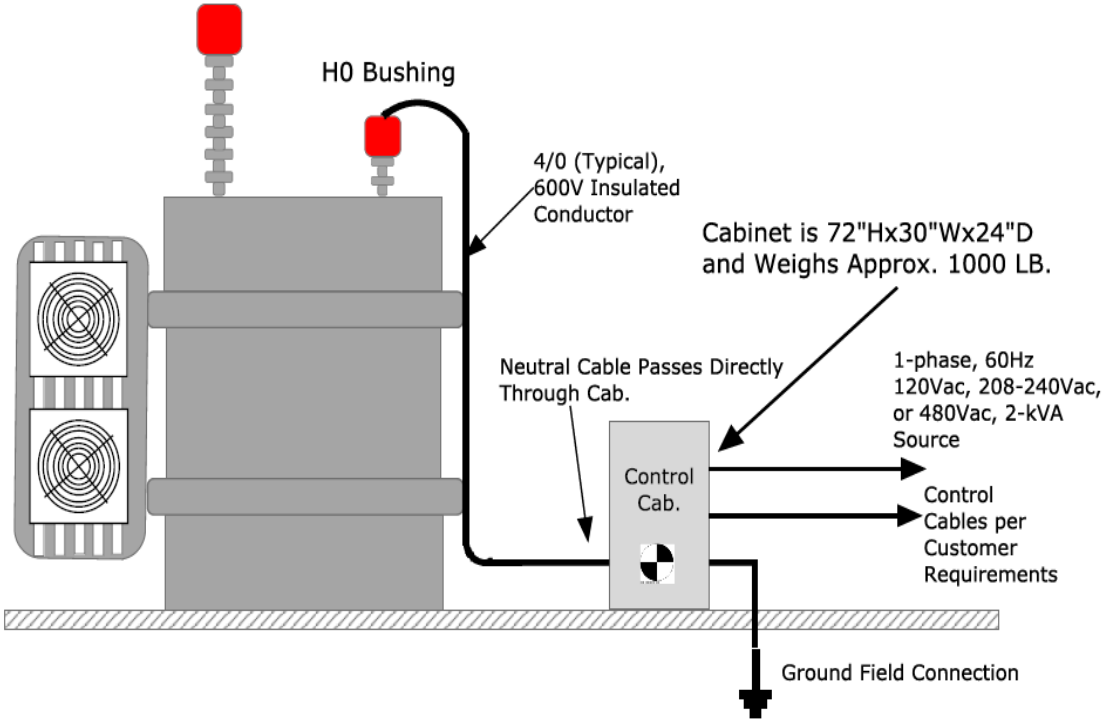


Selected Solution

- **Davis-Besse selected a single channel PSStech Open Phase Protection system** which consists of an active neutral injection detection system (based on EPRI technology) and a passive neutral overcurrent detection system.
  - PSStech system injects a current (set between 70 and 110 Hz) into a transformer high-side neutral ground cable
  - PSStech system measures high-side neutral current using two current probes: a high-sensitivity probe to measure neutral injection current and a less sensitive probe to measure the 60 Hz neutral current
  - Active injection system monitors zero sequence impedance as seen from transformer high-side neutral
  - Active detection system is primarily intended for no load and light load conditions when the neutral current may not be detectable by the passive detection
  - Passive neutral overcurrent (50N) detection is used for protection when there is higher load on transformer or when the open phase has a ground
  - PSStech system also monitors the 5th harmonic content of neutral ground current, which increases significantly in the presence of an open phase
  - System alarm and tripping is based on OR logic combination of the (active detection signal and the 5th harmonic signal) OR (passive detection)

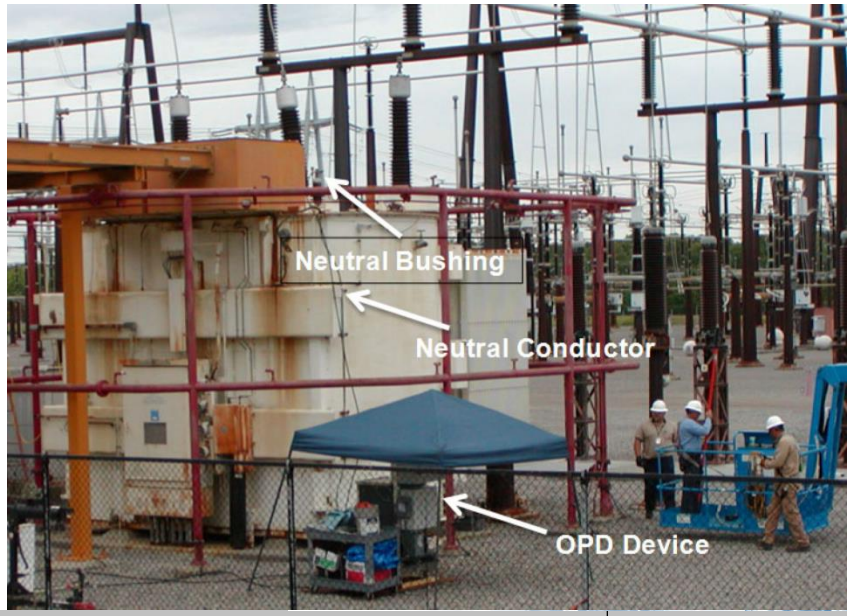
Selected Solution - continued

- PSStech Open Phase Protection system selected for Davis-Besse also includes:
  - Digital signal controller implements both active and passive detection schemes
  - PSStech system is equipped with sequential event recording, local alarm annunciation, data logging, and satellite clock
  - Self diagnostics continuously monitors system functionality. If a failure occurs an alarm is generated.



Proof of Concept Field Testing of EPRI / PSStech Solution at Bellefonte

- In May 2014, a field test of the EPRI / PSStech open phase protection (OPP) system was conducted at Tennessee Valley Authority's Bellefonte Nuclear Plant
- OPP system installed on neutral lead of primary winding of one of the offsite power supply transformers
  - Transformer rated 36 MVA, 161kV to 13.8/6.9 kV,
  - Unit a four winding transformer with wye-primary with grounded neutral, wye-secondary and tertiary with impedance grounded neutral and a buried delta winding
- A single 161 kV conductor removed to create an open phase condition; transformer re-energized after removing phase conductor
- System successfully detected open phase conditions for:
  - No load conditions
  - Loaded conditions, and
  - Motor starting conditions



See: Interim Report: EPRI Open-Phase Detection Method; EPRI, Palo Alto, CA; 2014; 3002004432

Equipment Specification for Open Phase Protection System

- A detailed equipment specification was development for the Davis-Besse Open Phase Protection System. Specification for the **single channel PSStech system** includes requirements for the following topical areas:
  - System functional design requirements and ratings
  - Applicable codes and standard
  - Site and service conditions, including applicable outdoor environmental conditions
  - Seismic hazards (i.e., IEEE 693-1997, IEEE Recommended Practice for Seismic Design of Substations)
  - NEMA 4X lockable enclosure for outdoor use.
  - Vendor's Quality Assurance / Quality Control program, although system is a considered non-Class 1E and 10CFR50, Appendix B is not applicable
  - Software quality assurance including configuration management and verification and validation
  - FENOC classification of the application software is Category B
  - Cyber security and digital asset controls
  - Electromagnetic compatibility (EMC) requirements provide protection against the effects of: EMI, Radio Frequency Interference (RFI), Electrostatic Discharge (ESD) and Electrical Surge Withstand Capability (SWC)

Overview of Design Modification

- An Engineering Change Package was issued to install a PSStech Open Phase Protection system on each of the two start-up transformers at Davis-Besse. Modification consisted of:
  - Concrete pad outside the transformer dike wall
  - Fastening the PSStech cabinet on the pad
  - Replacing the start-up transformer high neutral ground cable with an insulated conductor
  - Power to the PSStech cabinet from the existing start-up transformer MCCs
  - Routing the PSStech cabinet alarm output to the existing local transformer alarm panel
  - Routing the PSStech trip outputs to the existing local transformer control panel

Analysis Supporting Design Modification

- As part of the design modification, an EMTP-RV model of the Davis-Besse AC power system was developed. Model was used to simulated various postulated open phase conditions and establish setpoints for PSStech system
  - Active open phase detection setpoint (OPD)
  - OPD definite timer setting
  - Passive neutral overcurrent setpoint (50N)
  - 50 N definite timer setting (50NDT)
- Open phase conditions considered:
  - Single open phase, conductor ungrounded
  - Single open phase, solidly grounded on transformer side
  - Single open phase, impedance grounded on transformer side
  - Double open phase, conductors ungrounded
  - Double open phase, solidly grounded on transformer side
  - Double open phase, impedance grounded on transformer side

Analysis Supporting Design Modification - continued

- Wide range of electrical system alignments, operating and loading conditions considered, including:
  - Grid voltages and impedance
  - Transformer and plant loading conditions (no load, light load, accident loading)
  - System faults

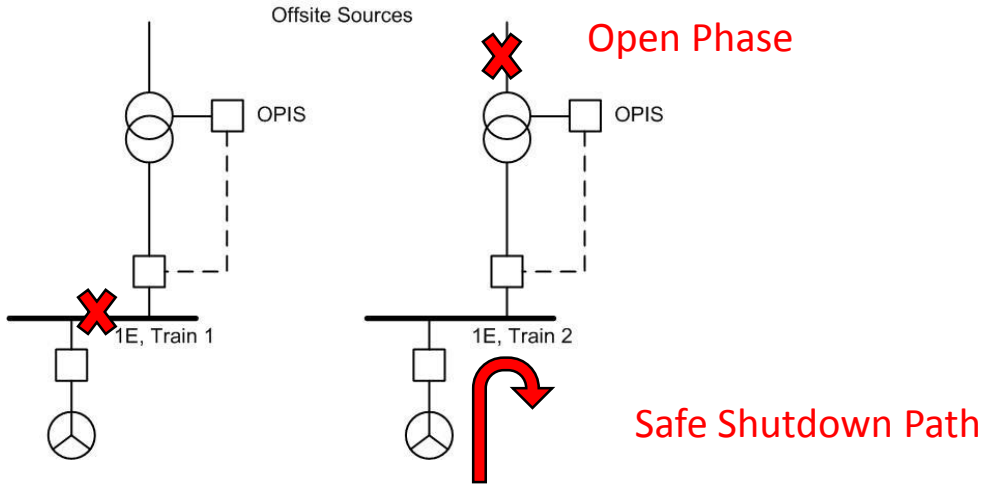
- Simulation cases broadly classified into four categories:
  - Non-open phase cases for determining range of active OPD setpoints that will not trigger false trips (security cases)
  - Open phase cases for assessing open phase detectability based on active OPD setpoint (reliability cases)
  - Non-open phase cases for determining range of passive 50N setpoints that will not trigger false trips (security cases)
  - Open phase cases for assessing open phase detectability based on passive 50N setpoint (reliability cases)

Four Functional Criteria

1. The first of the four functional requirements addresses single failures. Specifically, the November 25, 2014 NRC staff letter to NEI states that:

   "The design should address single failure criteria as outlined in the GDCs or the principal design criteria specified in the updated final safety analysis report for the specific nuclear power plant (i.e., for an OPC, a non-Class 1E circuit should not preclude the onsite electrical power system from being able to perform its safety function given a single failure in the onsite power system)."

Davis-Besse Open Phase Protection System will prevent the coincident failure of both the offsite and onsite AC power sources assuming an open phase event occurs coincident with the most limiting single failure in the Class 1E onsite power system

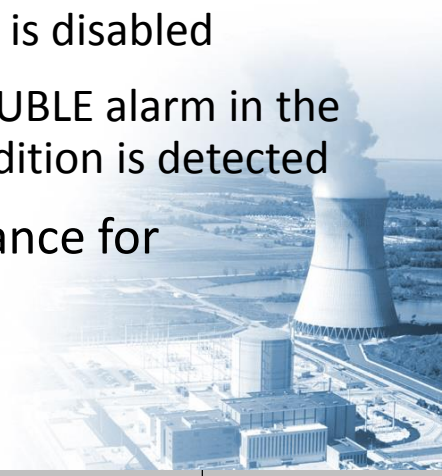


Four Functional Criteria - continued

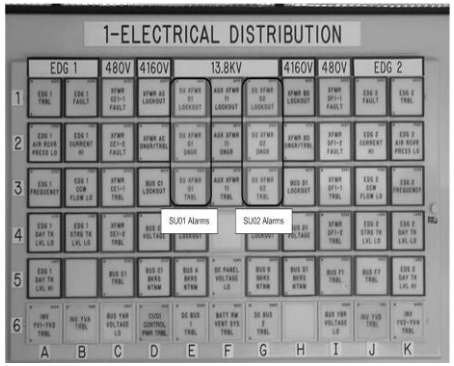
2. The second of the four functional requirements addresses detection and annunciation of OPCs. Specifically, the November 25, 2014 NRC staff letter to NEI states that:

   "The OPC should be automatically detected and alarmed in the main control room under all operating electrical system configurations and loading conditions."

- The Davis-Besse OPP system has a channel function switch that allows switching between the following functional modes: Off, Alarm Only, and Normal
  - OFF – The OPP system open phase alarming and tripping are disabled. A Channel Nonfunctional alarm is active in this mode
  - ALARM ONLY – The OPP system will activate a local alarm when an open phase condition is detected. This will in turn be annunciated in the main control room as a transformer TROUBLE alarm. In this position the OPP trip function is disabled
  - NORMAL – The OPP system will activate a local alarm and the TROUBLE alarm in the control room, and trip the lockout relays when an open phase condition is detected
- Alarm response procedures updated to provide additional guidance for response to transformer TROUBLE alarm



Control Room Alarm Panel and Local PSStech Alarm Panel



Start Up Transformer X02						
OPPS Event	**OPPS Contact**	**From OPPS To**	**Control Room (Alarm Only Mode)**	**Control Room (Trip Mode)**	**Associated Computer Point**	**Breakers (Trip Mode)**
General Equipment Failure	2411-OUT	Alarm Panel C3094B Annunciator 910 Cluster 74X/Q983	Ann. 1-3-G SU 02 XFMR TRBL	Ann. 1-3-G SU 02 XFMR TRBL	Q983	None
Indication of Normal Switch Setting	CS1**					
Active Injection Abnormal, Channel Function Switch in the Off Position, & General Alarms	CR108					
Open Phase Alarm***	LOR306					
Open Phase Trip	LOR312	63X1 Trip Relay, Parallel to Sudden Pressure Contact	None	Ann. 1-1-G SU 02 XFMR LOCK OUT	Q984	HX02A/B ACB34562 8-B-65 8-B-67

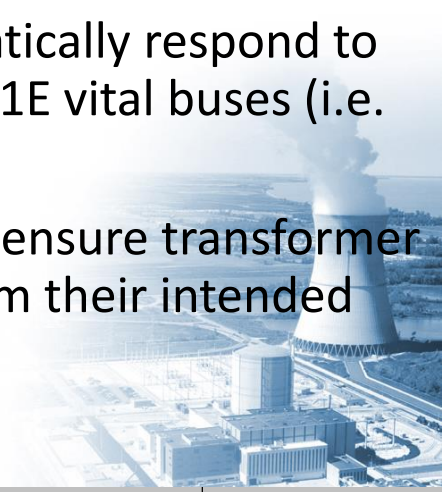
Four Functional Criteria - continued

3. The third functional requirement addresses the automatic transfer upon detection of OPCs. Specifically, the November 25, 2014 NRC staff letter to NEI states that:

   "If offsite power circuits are degraded due to OPC, the power source should be transferred automatically to the onsite power system within the time assumed in the accident analysis and without actuating any protective devices, given a concurrent design basis event."

Davis-Besse Open Phase Protection System will detect and automatically respond to an OPC on the GDC 17 offsite high voltage power supplies to Class 1E vital buses (i.e. offsite high voltage supply to the startup transformers)

The OPP system make use of startup transformer lockout relays to ensure transformer with OPC is isolated, thereby allowing the Class 1E buses to perform their intended safety function



Four Functional Criteria - continued

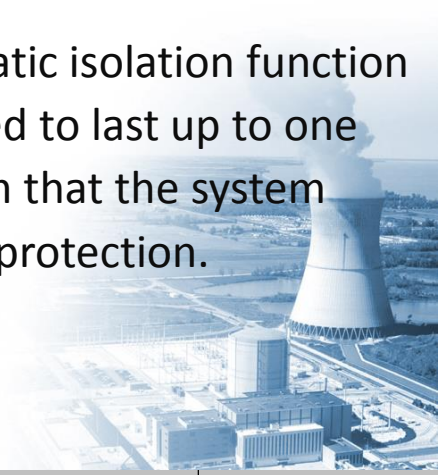
4. The fourth functional requirement addresses plant Technical Specifications (TS). Specifically, the November 25, 2014 NRC staff letter to NEI states that:

   "TS Surveillance Requirement and Limiting Condition of Operation for equipment used for mitigation of OPC should be consistent with the operability requirements specified in the existing plant TSs."

Section 8 of the Davis-Besse USFAR and Section B3.8.1 of the Davis-Besse Technical Specification Bases were updated

UFSAR Change

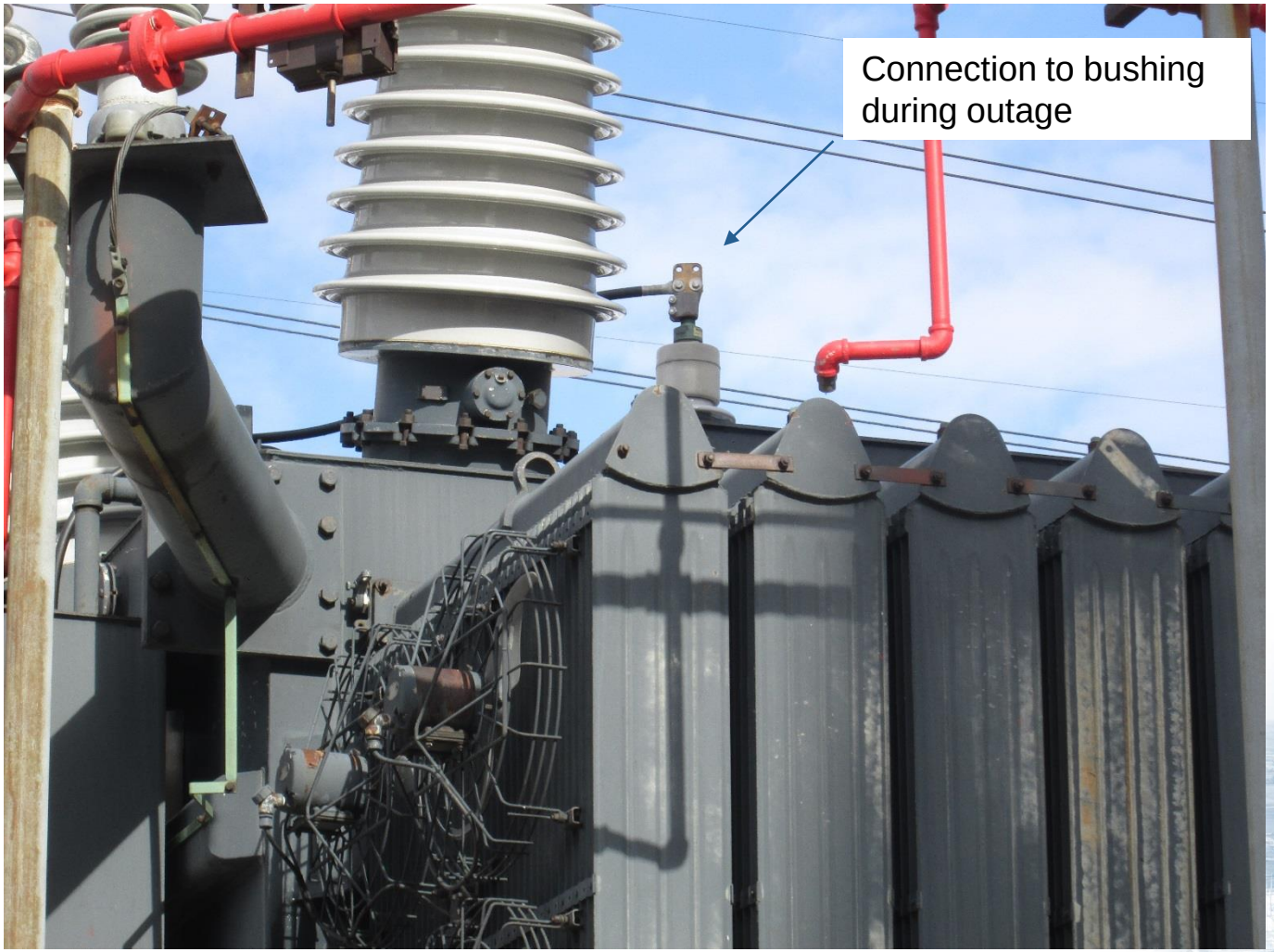
- UFSAR Section 8.3.1.1.1 change
  - The impact of open phase conditions on the capability of the startup transformers to perform their function was evaluated. The conditions analyzed consisted of a single (one of three) and a double (two of three) open phase conductor on the high voltage (345 kV) side of the startup transformers. The analysis considered open phase conditions with and without a ground. Open phase detection and isolation systems for the startup transformers were installed to ensure that plant structures, systems and components important to safety can perform their intended functions under postulated open phase conditions. Upon detection of an open phase condition the system will isolate the affected startup transformer and provide operator indication of the open phase condition.
  - After initial installation, the OPPS will be operated with the automatic isolation function of the OPPS disabled for initial monitoring period, which is expected to last up to one operating fuel cycle. The monitoring period will be used to confirm that the system performance and associated setpoints provide the correct level of protection.



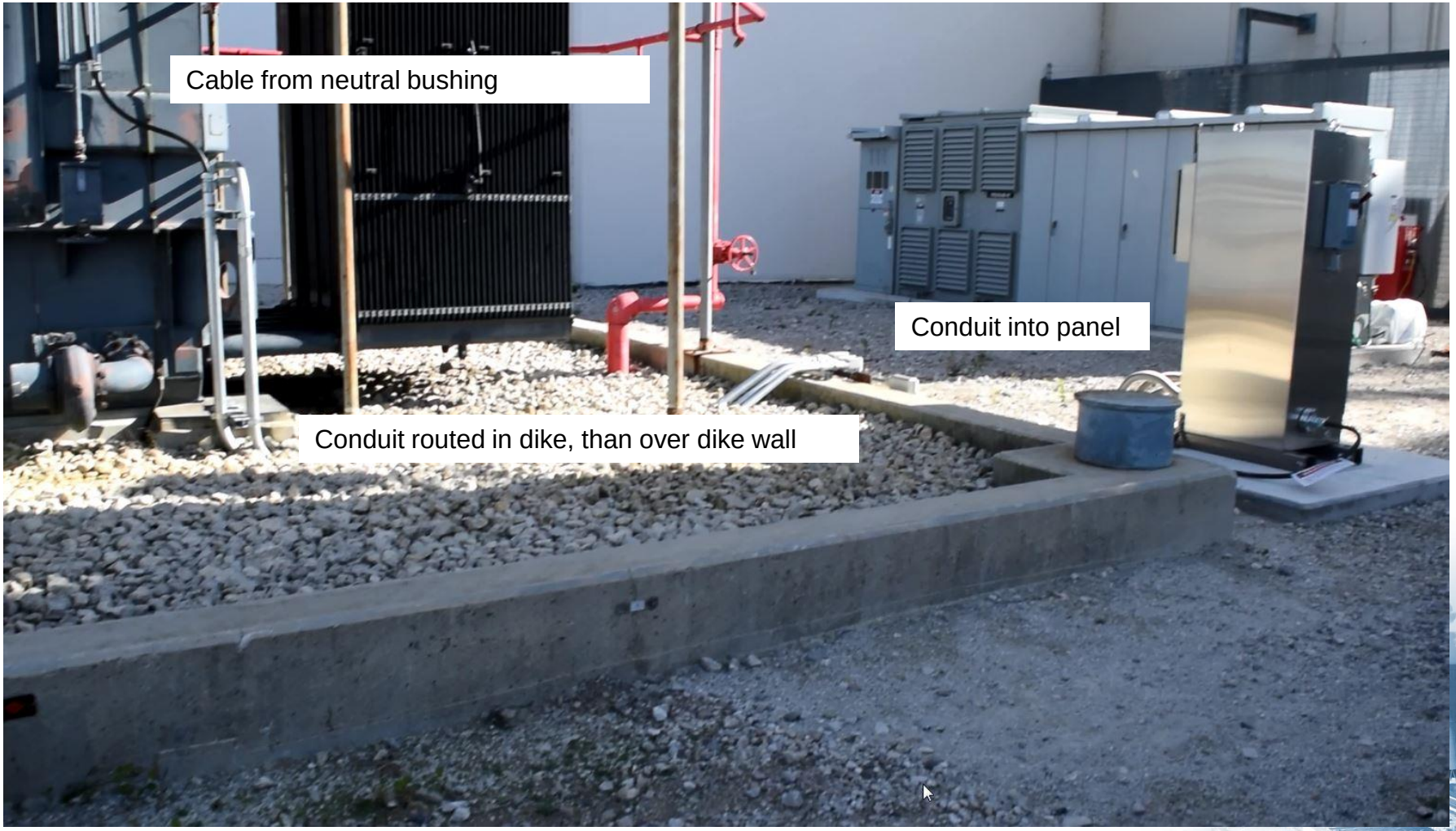
Technical Specification Bases B3.8.1 Change

- An offsite circuit with an open phase condition can adversely impact the capability of the startup transformers to perform their function. Open Phase Protection Systems (OPPS) for the startup transformers were installed to (a) provide reasonable assurance that the OPERABLE status of offsite sources can be determined under postulated open phase conditions and (b) detect postulated open phase conditions and isolate the affected source if it is unable to perform its intended function in the event of a design basis event.
- After initial installation, the OPPS will be operated with the automatic isolation function of the OPPS disabled for initial monitoring period, which is expected to last up to one operating fuel cycle. The monitoring period will be used to confirm that the system performance and associated setpoints provide the correct level of protection.

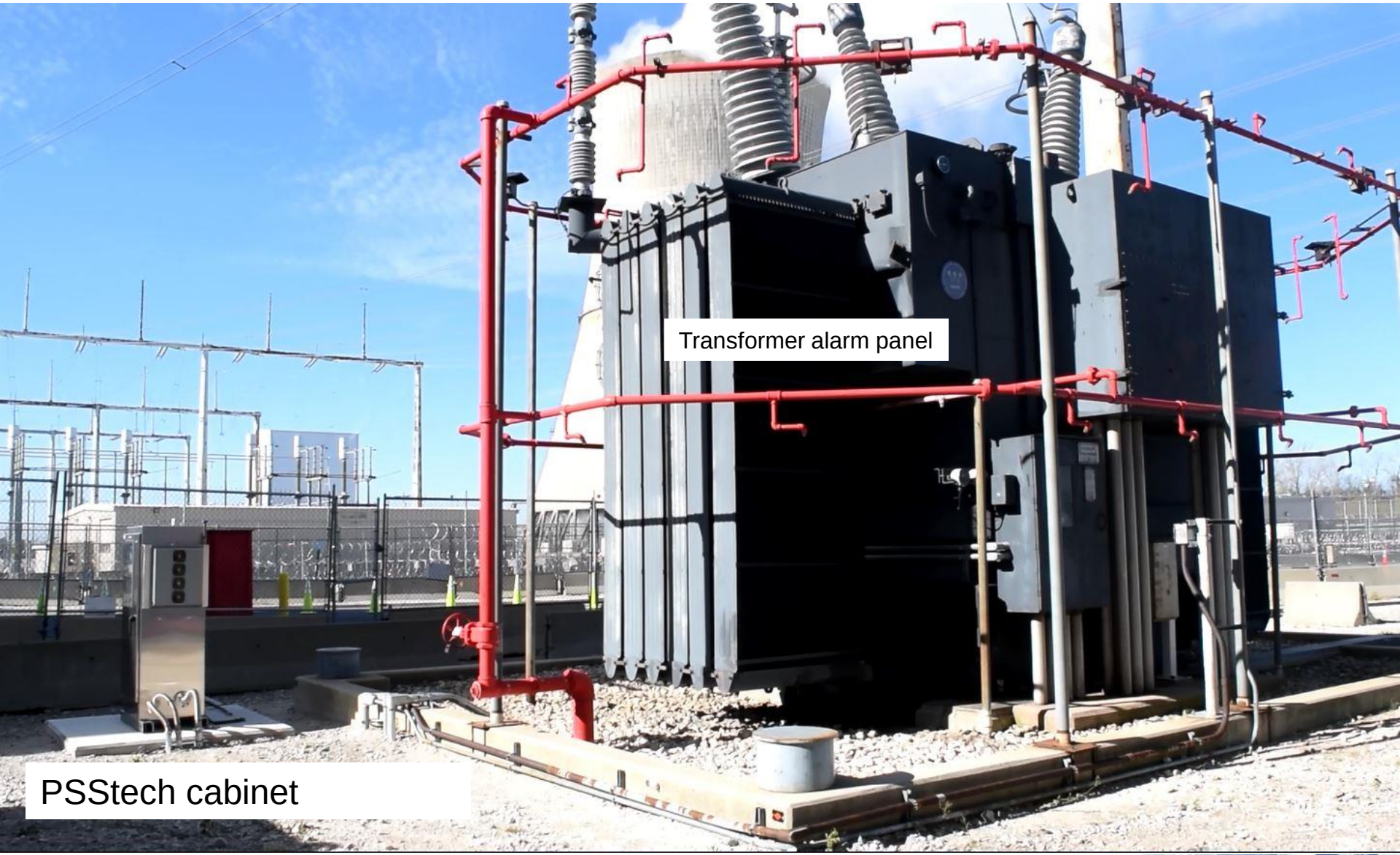
Overview of Design Modification – Installation



Overview of Design Modification – Installation (continued)



Overview of Design Modification – Installation (continued)



Overview of Design Modification – Installation (continued)

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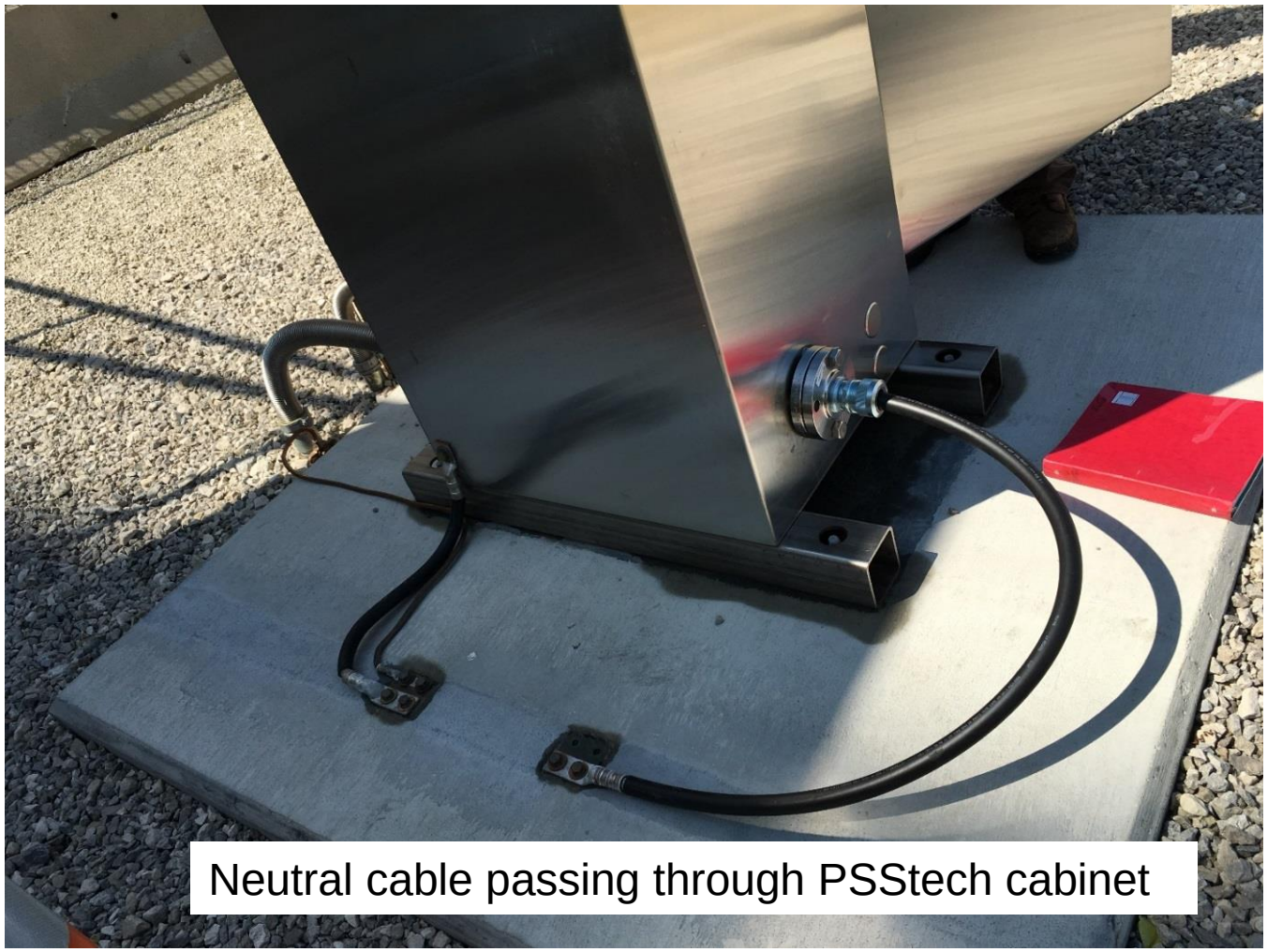


Neutral cable passing through PSStech cabinet

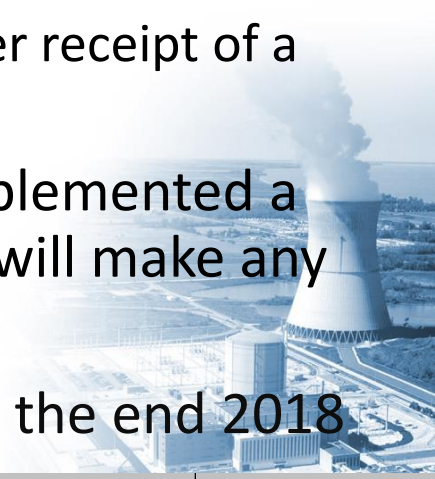
Factory Acceptance Testing

- A Factory Acceptance Test (FAT) of the PSStech equipment for Davis-Besse was conducted in January 2016. The FAT included the following:
  - Completion of a System Integration Checklist (SIL) to validated as-built system configuration, and hardware and software configurable settings
  - SIL also included a 100 hour burn-in period
  - Hardware verification test (HVT) verified system hardware satisfied the PSSTech OPP system Basis of Design Document (BODD) requirements
  - Software verification test (SVT) verified system satisfied system requirements defined in the PSSTech OPP system BODD and the system cyber security plan
  - Functional tests included:

Protection settings	Neutral Voltage Multiplier Setup
Active Pickup Element Test	Active Timing and Trip Tests
Passive Pickup Element Test	Passive Timing and Trip Tests
5th Harmonic Element Test	Failure Mode Tests
High Current Test	Alarm Function Tests

Equipment Status and Monitoring Plan

- At present, the PSStech system is in a monitoring mode (i.e., trip is disabled)
- PSStech CompactRIO processor outputs events and certain analog signals for trending and review to a Schweitzer Engineering Laboratories SEL-2411 programmable controller. The SEL-2411 records the following three types of information:
  - Sequence of Events Recording (SER): Continual recording of state changes and alarm signals for up to 512 events
  - Analog Signal Profiling: Continual recording of analog inputs every 5 minutes into a memory that can store approximately 14 days of data
  - Event Report: Triggered recording of the analog inputs after receipt of a preprogrammed trigger signal from the controller
- Following installation of the PSStech system, FENOC implemented a monitoring plan. During the monitoring phase, FENOC will make any necessary adjustments to the system setpoints
- FENOC expects to enable the automatic trip features by the end 2018



Summary and Conclusions

- FENOC has taken steps to address potential design vulnerabilities due to postulated open phase conditions at **Davis-Besse Nuclear Power Station** consistent with the NEI Open Phase Initiative and the NRC's four functional criteria.
- FENOCs approach includes:
  - Enhanced plant operating procedures to help operators diagnose and respond to potential open phase conditions
  - Performed a scoping study to understand the site specific design vulnerabilities and evaluated alternative solutions
  - Procured and installed an open phase protection system (OPPS) on both start-up transformers
  - Performed detailed analyses to establish OPPS setpoints and ensure plant equipment will not be adversely impacted by postulated OPCs
  - Updated UFSAR and plant Technical Specification Bases
- OPPS currently in monitoring mode. FENOC expects to enable the automatic trip features by end of 2018

Questions