

## OPEN PHASE DETECTION SYSTEM



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# Excerpt from GDC 17 - "Electric power systems"

- ▶ "Criterion 17—Electric power systems. An onsite electric power system and an offsite electric power system shall be provided to permit functioning of structures, systems, and components important to safety. The safety function for each system (assuming the other system is not functioning) shall be to provide sufficient capacity and capability to assure that (1) specified acceptable fuel design limits and design conditions of the reactor coolant pressure boundary are not exceeded as a result of anticipated operational occurrences and (2) the core is cooled and containment integrity and other vital functions are maintained in the event of postulated accidents.
- ▶ The onsite electric power supplies, including the batteries, and the onsite electric distribution system, shall have sufficient independence, redundancy, and testability to perform their safety functions assuming a single failure.
- ▶ Electric power from the transmission network to the onsite electric distribution system shall be supplied by two physically independent circuits (not necessarily on separate rights of way) designed and located so as to minimize to the extent practical the likelihood of their simultaneous failure under operating and postulated accident and environmental conditions. A switchyard common to both circuits is acceptable. Each of these circuits shall be designed to be available in sufficient time following a loss of all onsite alternating current power supplies and the other offsite electric power circuit, to assure that specified acceptable fuel design limits and design conditions of the reactor coolant pressure boundary are not exceeded. One of these circuits shall be designed to be available within a few seconds following a loss-of-coolant accident to assure that core cooling, containment integrity, and other vital safety functions are maintained.
- ▶ **Provisions shall be included to minimize the probability of losing electric power from any of the remaining supplies as a result of, or coincident with, the loss of power generated by the nuclear power unit, the loss of power from the transmission network, or the loss of power from the onsite electric power supplies."**

# NRC Functional Requirements

<p>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).</p>	<p>NSR OPD has coincident logic that does not adversely affect existing 1E circuits.</p>
<p>The OPC should be automatically detected and alarmed in the main control room under all operating electrical system configurations and loading conditions</p>	<p>OPD ties into existing Control Room transformer trouble alarm.</p>
<p>If offsite power circuits are degraded due to an 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.</p>	<p>OPD actuation times are coordinated with accident analysis and protective device actuation times.</p>
<p>TS Surveillance Requirements and Limiting Condition of Operation for equipment used for mitigation of an OPC should be consistent with the operability requirements specified in the existing plant TSs.</p>	<p>TS will not be affected by NSR OPD systems. OPD system will be governed by NERC PRC requirements. Anticipated applicable standards include PRC-005, PRC-004, and PRC-001</p>

# NERC Requirements

- ▶ PRC-005: Protection System, Automatic Reclosing, and Sudden Pressure Relaying Maintenance
- ▶ PRC-004: Protection System Misoperation Identification and Correction
- ▶ PRC-001: System Protection Coordination

# NEI Initiative Criteria

## Detection, Alarms and General Criteria

An open phase condition must be detected and alarmed in the control room unless it can be shown that the open phase condition does not prevent functioning of important-to-safety structures, systems and components.

OPC will tie into existing general transformer trouble alarms and trip logic.

If the licensee can demonstrate that the open phase condition does not prevent the functioning of important-to-safety structures, systems and components, then detection of the open phase condition should occur within a reasonably short period of time (e.g., 24 hours).

Detection is real time and will alarm or trip as needed.

The licensee must document how detection and correction of the open phase condition will occur.

Proprietary documentation is available.

Detection circuits for the open phase condition, which prevents the functioning of important-to-safety structures, systems and components, must be sensitive enough to identify an open phase condition for credited loading conditions (i.e., high and low loading).

Lab testing verifies more than adequate system OPC sensitivity. OPD is continuous from excitation to full load including during transfers.

It is recognized that some transformers have very low or no loading when in the standby mode. Automatic detection may not be possible in this condition; however, automatic detection must happen as soon as loads are transferred to this standby source.

OPD is operational under all loading and unloaded conditions. OPD is not affected by this requirement.

Additionally, if automatic detection is not possible, shiftily surveillance requirements must be established to look for evidence of an open phase.

Compensatory measures are currently in place at all sites if OPD is unavailable.

# NEI Initiative Criteria

OPC actuation circuits	
<p>If open phase condition actuation circuits are required, the design should minimize misoperation or spurious action that could cause separation from an operable off-site GDC 17 source.</p>	<p>Coincident logic is used to minimize misoperation or spurious action of separation of operable off-site GDC-17 sources.</p>
<p>Additionally, the protective scheme should not separate the operable off-site GDC 17 source in the range of voltage unbalance normally expected in the transmission system.</p>	<p>OPD has been tested to unbalance beyond that expected.</p>
<p>Licensees must demonstrate that the additional actuation circuit design does not result in lower overall plant operation reliability.</p>	<p>OPD is non-intrusive and actuation ties into existing transformer protection logic circuits.</p>
<p>These devices must be coordinated with other protective devices in both the transmission system and the plant's electrical system (e.g., fault protection, overcurrent, etc.).</p>	<p>OPD settings are coordinated with RTO protection relaying and plant loads and protective devices.</p>
<p>Detection and actuation circuits may be non-Class-1E. While it is recognized that a Class-1E solution is preferable, a non-Class-1E solution may be more effective. A non-Class-1E solution will enable timely implementation and will provide reasonable levels of reliable functionality given the low likelihood of adverse impacts from open phase events. Additionally, there is regulatory precedent in using non-Class-1E circuits in newly identified nuclear plant vulnerabilities (e.g., anticipated transient without scram (ATWS) circuits). New non-Class-1E circuits will not be allowed to replace existing Class-1E circuits.</p>	<p>OPD is NSR and has no direct connection with existing SR circuits or logic. The system is intentionally designed to prevent introducing additional failure modes into the SR systems.</p>
<p>The Updated Final Safety Analysis Report (UFSAR) must be updated to discuss the design features and analyses related to the effects of, and protection for, any open phase condition design vulnerability.</p>	<p>TS will not be affected by NSR OPD systems. OPD system will be governed by NERC PRC requirements. Anticipated applicable standards include PRC-005, PRC-004, and PRC-001</p>

# NEI Initiative Criteria

## Protective Actions

With no accident condition signal present, the licensee must demonstrate that:

- 1.1. The open phase condition does not adversely affect the function of important-to-safety structures, systems and components; or
- 1.2. Technical Specification (TS) Limiting Conditions for Operation (LCOs) are maintained or the associated TS Actions are met without entry into TS LCO 3.0.3 (or the equivalent). This provision applies to TS equipment affected by the open phase condition (i.e., not just the specifications related to the off-site power source); and
- 1.3. Important-to-safety equipment is not damaged by the open phase condition; and
- 1.4. Shutdown safety is not compromised.

NSR OPD is non-intrusive, ties into existing NSR transformer alarm/trip logic, and maintains existing boundaries between SR and NSR systems (i.e. safety-related (SR) diesel generators, SR buses, and SR equipment).

With an accident condition signal present, the licensee must demonstrate:

- 2.1. Automatic detection and actuation will transfer loads required to mitigate postulated accidents to an alternate source and ensure that safety functions are preserved, as required by the current licensing bases.
- 2.2. Alternatively, a licensee may show that all design basis accident acceptance criteria are met with the open phase condition, given other plant design features. Accident assumptions must still include licensing provisions associated with single failures. Typically, licensing bases will not permit consideration of the open phase condition as the single failure since this failure is in a non-safety system.

OPD is coordinated with accident analysis times to maintain accident mitigation functions.

# A Direct Solution for Open Phase Detection

PCS2000 Solutions has developed an open phase detection and identification system to meet the requirements set forth by the Nuclear Regulatory Commission at the June 2013 meeting. NRC identified the following conditions that must be detected on nuclear plant off site power sources:

- Any phase opened
- Any phase opened and grounded
- Any phase opened and impedance grounded
- Two phases opened
- Two phases opened and one grounded

# PCS OPD System in services

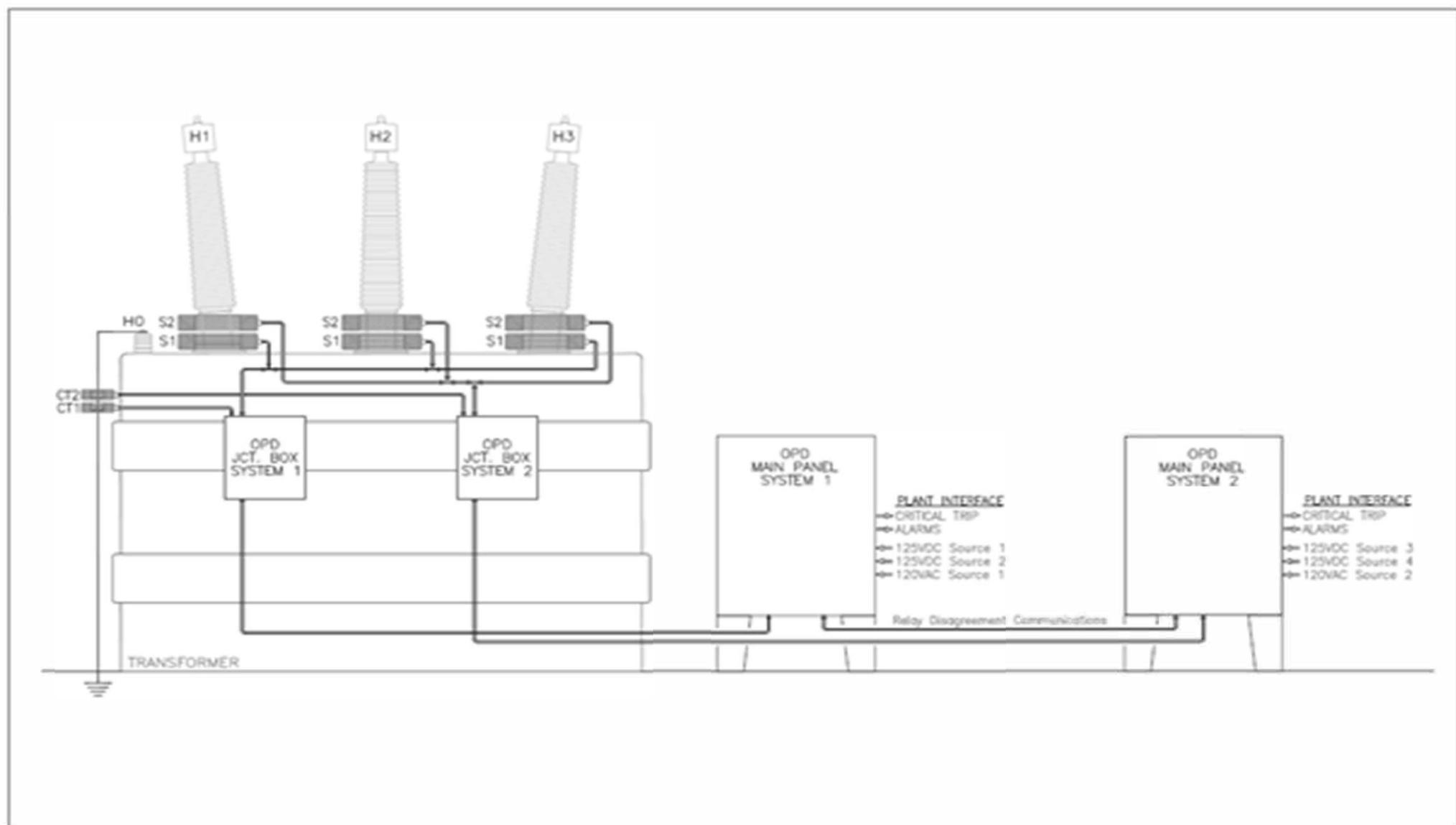
PCS2000 Solutions OPD Installations (2 systems per transformer)

- Riverbend – 2 systems installed Mar 2015
  - 230kV Y-Y no-load & light-load RSS transformer, 80mA exc.
- ANO – 2 systems installed Nov 2016
  - 22kV D-Y no-load & light-load transformer, 8 A exc.
- Palisades - 2 systems installed Oct 2015
  - 345kV Y-D no-load safeguard transformer, 50mA exc.
- Waterford - 4 systems installed Nov 2015
  - Two 230kV Y-D no-load & light-load SU transformer, 240/400 mA exc.
- Brunswick – 8 systems installed Mar 2015, 4 installed Mar 2016
  - Two 230kV Y-D no-load & light-load SU transformer, 260 mA exc.
  - Two 230kV Y-D step-up transformer backfeed NL, 1.2 A exc.

# PCS OPD System in progress

PCS2000 Solutions OPD projects (2 systems per transformer)

- ANO – 4 systems, D-Y no-load and Y-Y light-load
- VC Summer – 6 systems, D-ZZ no-load and Y-Y light-load
- Indian Point – 8 systems, D-Y and Y Auto
- Grand Gulf – 6 systems, Y-D light-load and Y-D-D no-load
- Palisades – 2 systems, Y-D no-load
- Riverbend – 2 systems, Y-Y no-load & light-load





## **A single system consists of the following:**

### **1. Control Cabinet**

- A. Located in the vicinity of the transformer and contains PCS2000 Solutions OPD System control, monitoring and relay equipment.
- B. Cabinet construction is NEMA 4X stainless steel dead front equipped with a swing out 19" rack panel and a sealed, vault-handled gasket door.
- C. Cabinet includes a thermostatically controlled space heater.

### **2. Major electronic components**

- A. Two Schweitzer Engineering Labs (SEL) model 451 microprocessor relays
- B. SEL Satellite clock and associated antenna
- C. SEL window-type annunciator to identify Open Phase and abnormal relay conditions
- D. SEL Industrial rack mount computer (for logging data only)
- E. States test switches compatible with Industry Standards for component testing, blocking of tripping and blocking of alarms as required.

### **3. Sensors**

- A. Sensors of the slipover type will be mounted on each high side bushing. (One sensor per high side bushing per system)
- B. Neutral sensor will be window type and located on the high side neutral bushing or grounding lead. (One per System)

### **4. External connections and power requirements**

- A. 125VDC typical at each cabinet for control power. Other voltages used when required.
- B. 120VAC will be required at each cabinet for cabinet heaters.
- C. A trip circuit can be wired to customers existing transformer protection circuit from each cabinet.
- D. An OPD general alarm can be wired to the existing transformer general alarm system.

# Main Features of PCS OPD System

- The PCS2000 Solutions OPD system monitors transformer primary current on each phase and neutral bushing from as low as **10% of no load excitation current up to full load current and fault conditions.**
- EHV transmission-class relay system with settings logic, algorithm, and tripping schemes as required to meet the customer's specific needs. A custom-designed program written with user programmable analog algorithms, variables, and logic is used to identify open phase conditions.
- No electrical connection to the transformer phase or neutral conductors are required.
- Continuous online monitoring, high speed event reports, SERs.

PCS Open Phase Detection System  
Software Testing and Documentation

Case #	Condition	Phase(s)	Load Scenario	Expected Result
1	Open Phase	A-phase ungrounded	Heavy Load	Trip
2	Open Phase	A-phase grounded	Heavy Load	Trip
3	Double Open Phase	A-phase ungrounded, B-phase ungrounded	Heavy Load	Trip
4	Double Open Phase	A-phase grounded, B-phase ungrounded	Heavy Load	Trip
5	Double Open Phase	A-phase grounded, B-phase grounded	Heavy Load	Trip
6	Open Phase	A-phase ungrounded	Minimum Load	Trip
7	Open Phase	A-phase grounded	Minimum Load	Trip
8	Double Open Phase	A-phase ungrounded, B-phase ungrounded	Minimum Load	Trip
9	Double Open Phase	A-phase grounded, B-phase ungrounded	Minimum Load	Trip
10	Double Open Phase	A-phase grounded, B-phase grounded	Minimum Load	Trip
11	Open Phase	A-phase ungrounded	No Load	Alarm or Trip
12	Open Phase	A-phase grounded	No Load	Alarm or Trip
13	Double Open Phase	A-phase ungrounded, B-phase ungrounded	No Load	Alarm or Trip
14	Double Open Phase	A-phase grounded, B-phase ungrounded	No Load	Alarm or Trip
15	Double Open Phase	A-phase grounded, B-phase grounded	No Load	Alarm or Trip
16	Normal Mode	None	No Load	No Alarm or Trip
17	Normal Mode	None	Light Load	No Alarm or Trip

\*In no load cases, alarm or trip as required by plant.

Since 2013, the PCS OPD system has undergone extensive testing, including the following:

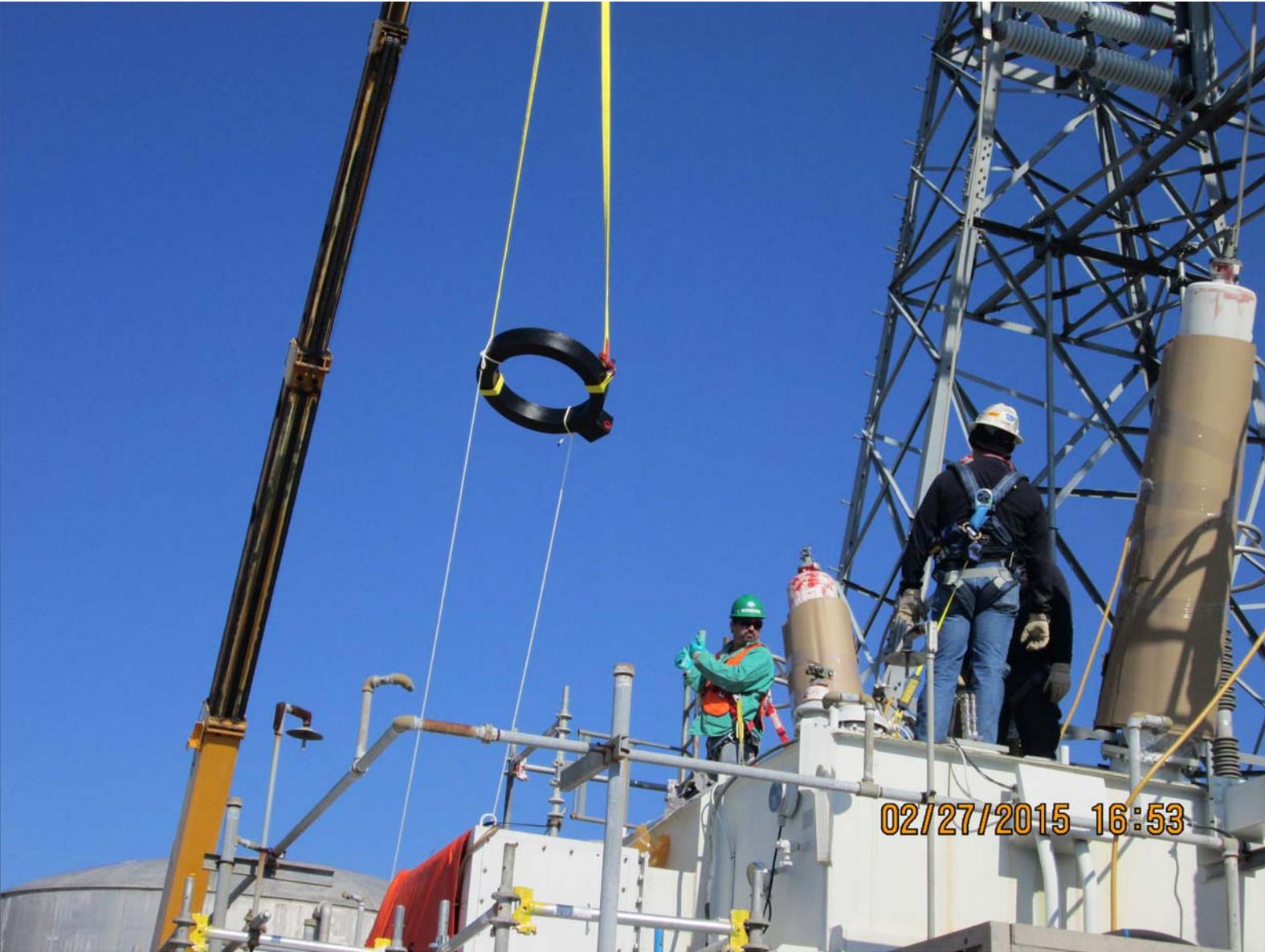
- PCS lab tests – 3500+ cases
- State simulator cases with primary injection using COMTRADE files – 5000+ cases

Testing covered all the NRC required cases plus open phase with capacitive-coupling.





# Entergy Fancy Point Line Differential Panel



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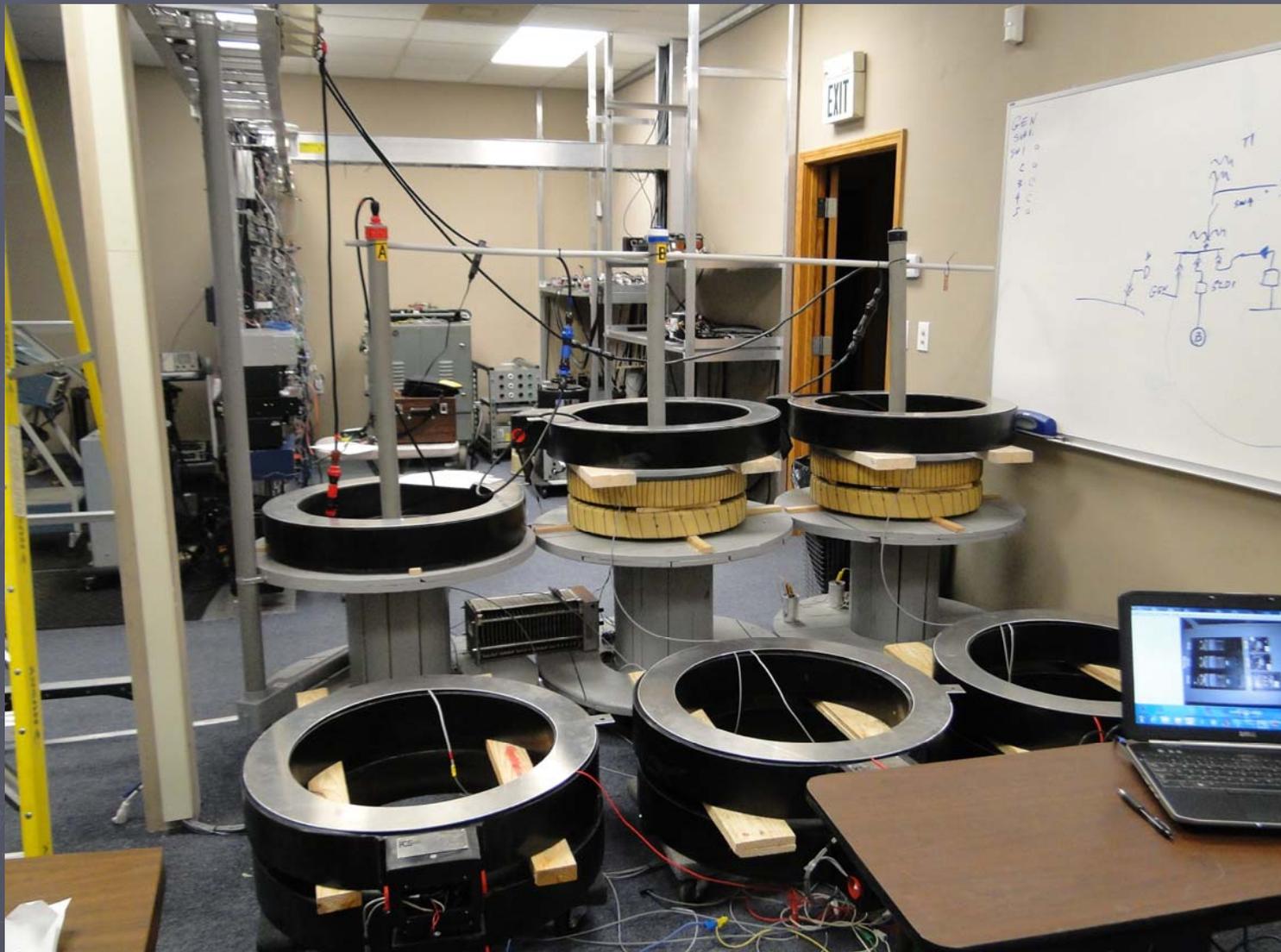


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# Michael L. McAnelly – Professional History

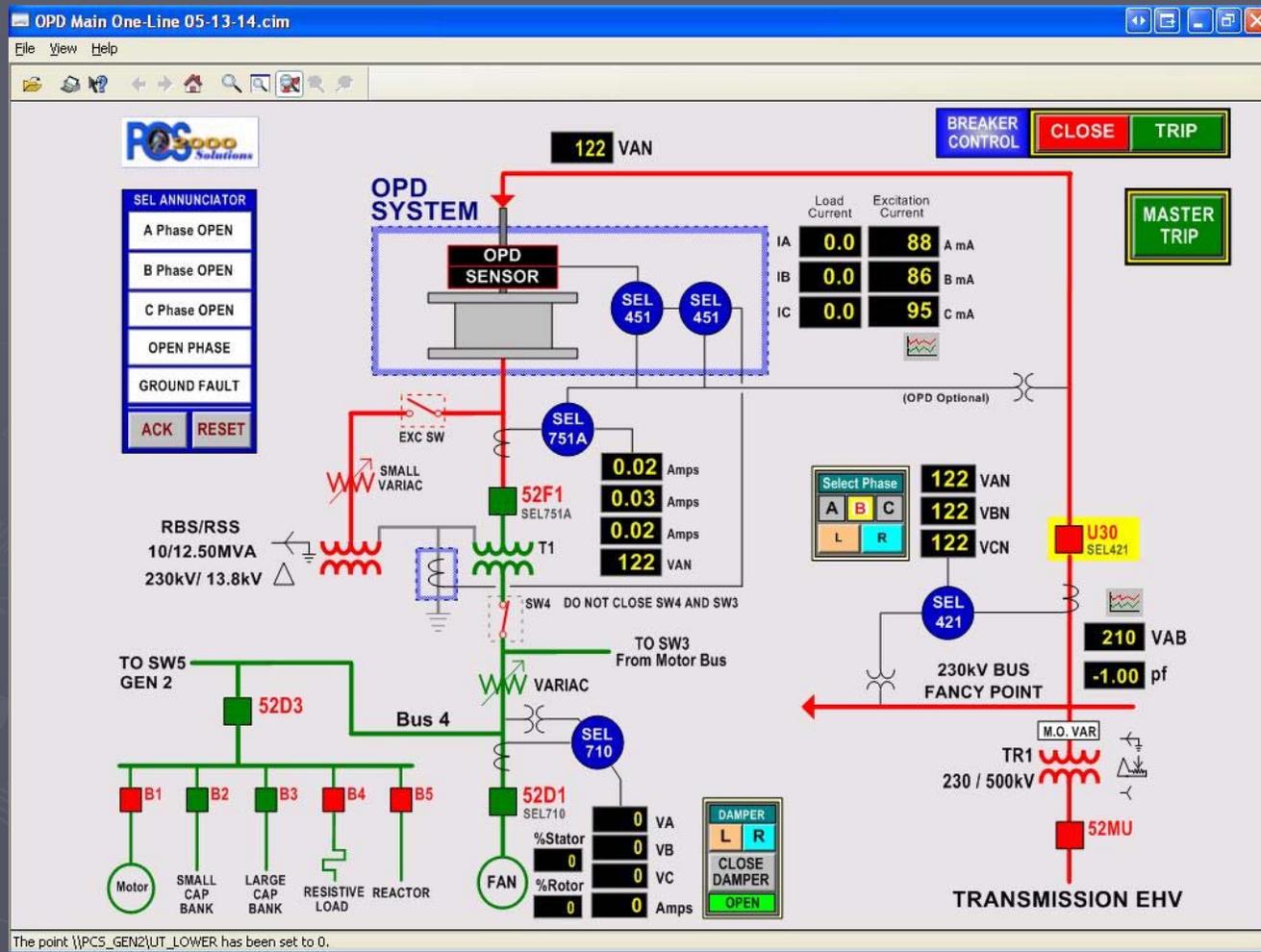
- ▶ MSU BSEE & MSEE, relay engineer at Mississippi Power & Light, **commissioned GGNS 500kV switchyard.**
- ▶ Adjunct faculty at LSU – courses on power system operation and power system relaying
- ▶ Founded PCS2000 (Power and Control Systems in 1983). Past and current projects include:
  - Distributed Generation studies, arc furnace studies, series comp line studies, etc.
  - UVLS system, voltage control systems,
  - SCADA system design and application, fault location systems, intelligent load shed, DFR & DDR installations
  - Housed and operated Entergy Hypersim supercomputer for two years
  - Large motor application – 25000 HP synchronous motors for natural gas compressor stations
  - Relay upgrades for generators ranging from 25 – 1000 MVA
  - Relay design and settings for transmission lines and substations
  - Power system upgrades in major industrial plants and refineries – multistage cap. start of 15k HP FCC airblower.
  - NERC PRC compliance testing and studies – system-wide fossil generation facilities
  - Single point vulnerability evaluations
  - Power system research lab – Beta and application testing performed for microprocessor relay manufacturers (Beckwith, SEL, GE, etc).



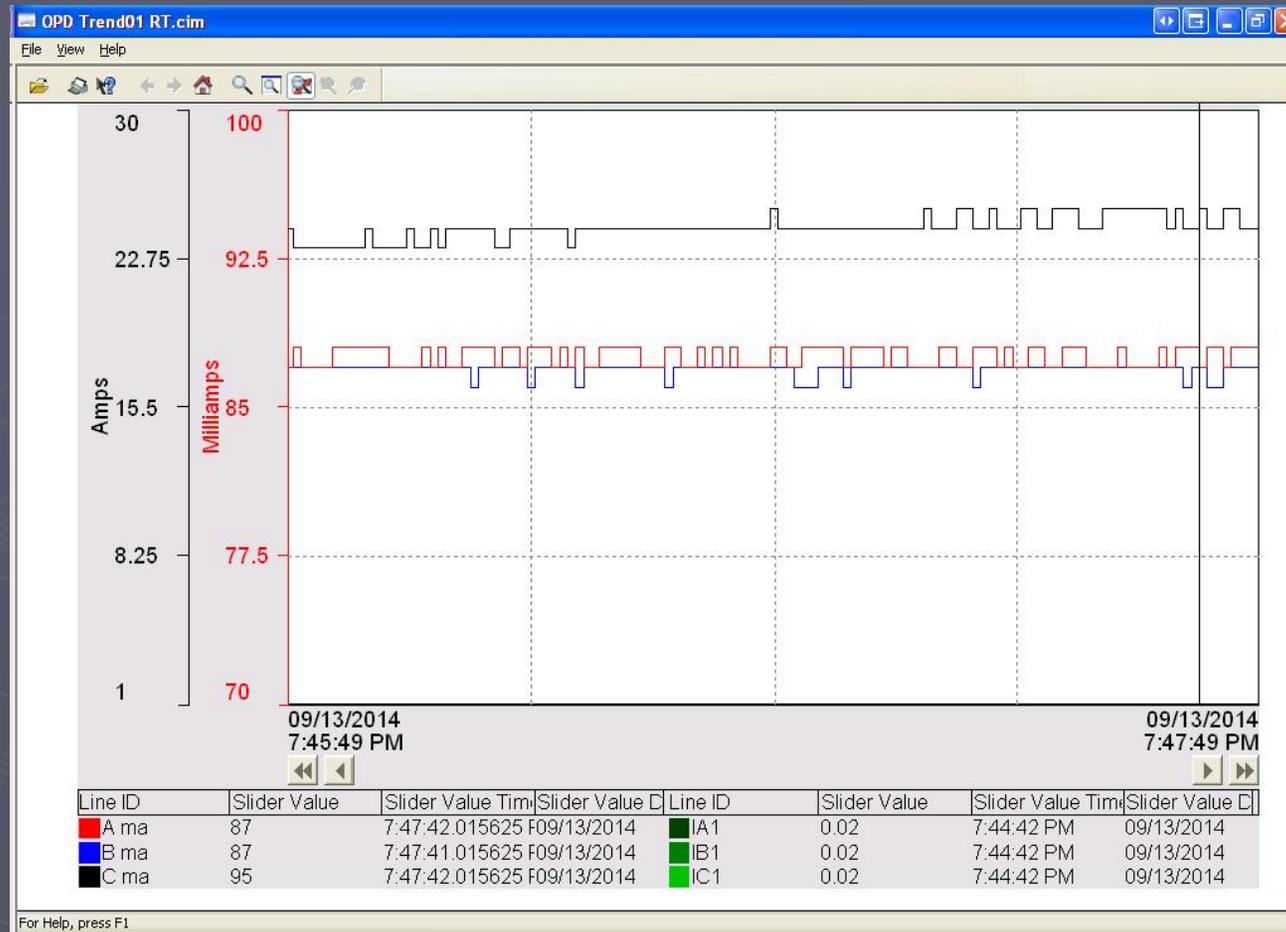




# OPD Lab HMI One-line Showing Excitation Current

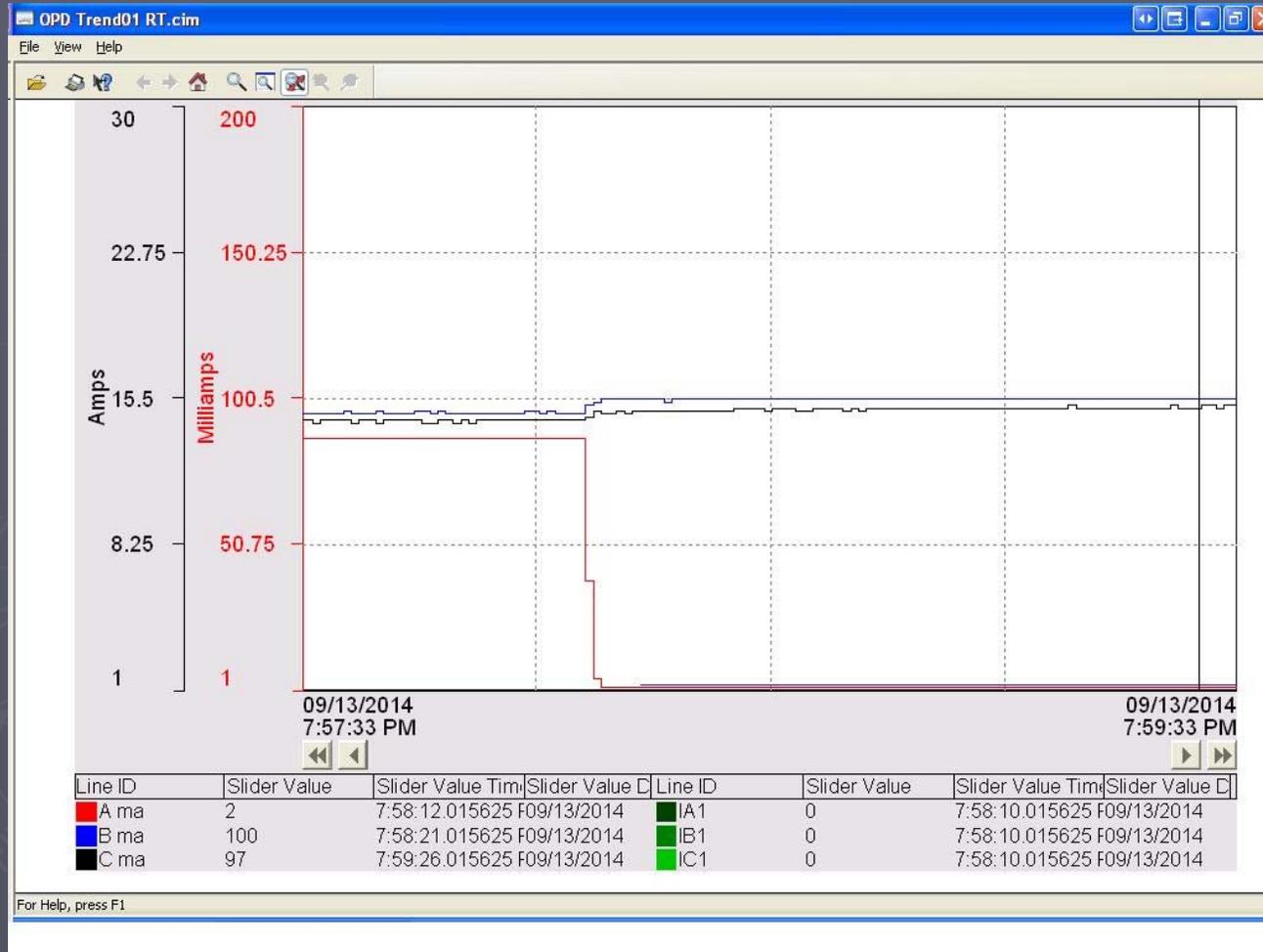


# OPD Lab HMI Trend Showing Excitation Current



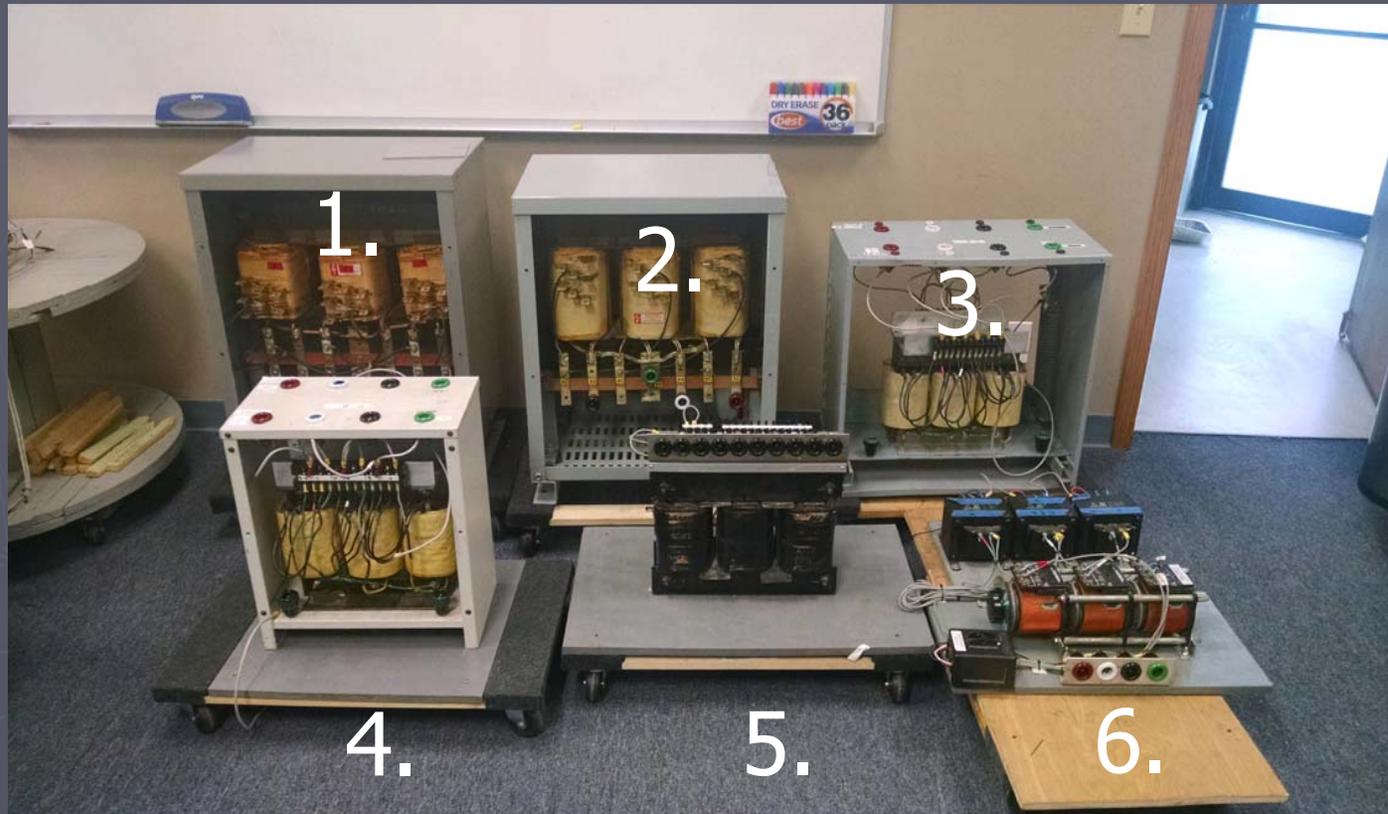


# OPD Lab HMI Trend A-Phase Open



# Examples of PCS transformers types and their exciting currents

## Configurable winding connections



1. 3 $\phi$  core form – 6000 mA  
Two winding & buried tertiary.
2. 3 $\phi$  core form – 4000 mA  
Two winding & buried tertiary.
3. 3 $\phi$  core form – 500 mA  
Two winding
4. 3 $\phi$  core form – 300 mA  
Two winding
5. 3 $\phi$  shell form – 300 mA  
Autotransformer
6. Three single-phase – 80 mA  
Two winding

# Example of Transformer Test Results Provided from Manufacturer

1RTX-XSR10B1D  
11500000

**REPORT OF TRANSFORMER TESTS**  
Form 402

**Westinghouse Electric Corporation**

Purchaser: Gulf States Utilities Company  
 Date of Test: 3-30-81 Purchaser's Order No. RBS-242112027 c.n. NYRM-11969 S.S. No. MCS0196  
 Type: SI GA/FA Phase 3 Cycle 50 Insulating Oil L. Spec. 2693316 Polarity Subt.  
 Winding: H.V. Winding L.V. Winding  
 Kva 10000/12500 Kva 10000/12500 Kva  
 Voltage 230000 Voltage 4160 Voltage  
 H.V. TAPS: 241300 235750 230000 224250 218100

**RESISTANCES, EXCITING CURRENT, LOSSES AND IMPEDANCE**—Based on normal rating, unless otherwise stated. Losses and regulation are based on wattmeter measurements. For three-phase transformers the tabulations are the sum of the three phases in series.

SERIAL NO.	RESISTANCE IN OHMS AT 85°C		EXCITING CURRENT AT 100% RATED VOLTAGE	NO LOAD LOSS WATTS AT 100% RATED VOLTAGE	LOAD LOSS WATTS AT 100% RATED VOLTAGE	% IMP. AT 100% RATED VOLTAGE	LOAD LOSS WATTS 85°C	% IMP. AT 85°C	LOAD LOSS WATTS 85°C	% IMP. AT 85°C
	H.V.	L.V.								
MCS0196-1	39.9321	.0099	0.329	22074	49298	6.57				
MCS0196-2	39.2726	.0102	0.342	22300	48403	6.50				
			@110%	@110%						
MCS0196-1			1.182	29038						
MCS0196-2			1.327	30436						
AVERAGE			0.3356	22187	71038	6.54				
GUARANTEE			1.87	23400	81400	6.27				

REGULATION AT 85°C

AVERAGE	GUARANTEE
.7020	.81
4.4336	4.36

TEMPERATURE RISES—Average rise in degrees C, corrected to ambient of transformer, with windings connected and loaded as follows:

Serial No. 6 H.V. Winding 218.500 Kv 26.5 L.V. Winding 4.160 Kv 1388.0

% LOAD	RISE OF WINDINGS BY RESISTANCE		GUARANTEE	TO FLUID RISE	AMBIENT TEMP			WATER RISE	GALLONS PER MIN.	POUNDS PRESSURE
	H.V.	L.V.			WINDING WATER	IDLER OR ROOM	RISE			
100	57.9	61.3	65	52.9						
125	57.7	60.3	65	48.5						

**INSULATION TESTS**

WINDING	VOLT RATED	TEST VOLTAGE APPLIED IN Kv	DURATION OF TEST IN SECONDS
H.V.	230000	50.0	60
L.V.	4160	19.0	60
Control	600	1.5	60

**APPLIED POTENTIAL TESTS**  
(Voltage applied between each winding and all other windings connected to core and ground.)

INDUCED POTENTIAL TEST: 325 KV SINGLE PHASE TEST AT 120 HERTZ HERTZ per second for 7200 CYCLES.

TEMPERATURE RISE DETERMINED FROM BASIC DESIGN DATA WHICH HAS BEEN VERIFIED BY TEST RESULTS OF SIMILAR TRANSFORMERS.

THE ABOVE IS A TRUE AND CORRECT RECORD OF DATA OBTAINED FROM TESTS AT THE SHEARON WORKS OF THE WESTINGHOUSE ELECTRIC CORPORATION.

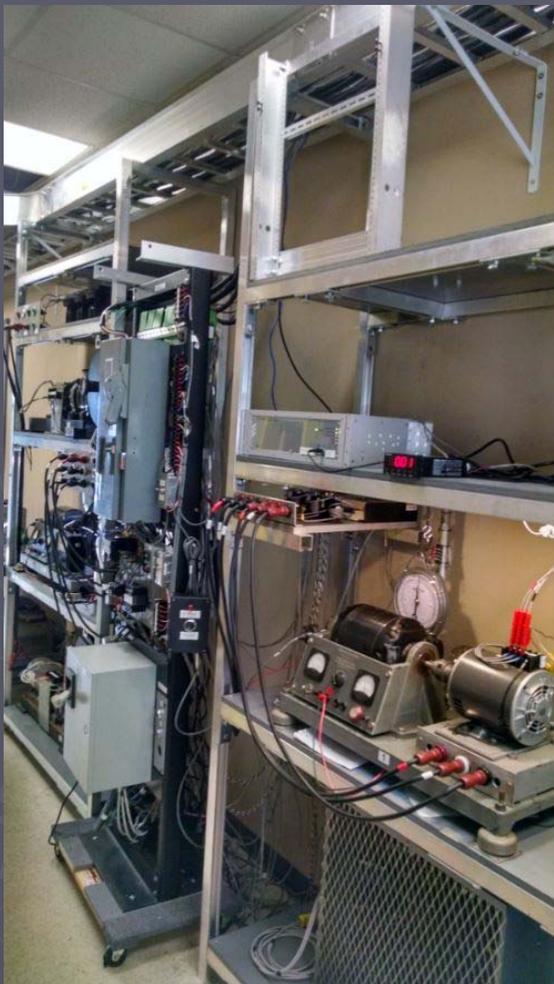
I hereby certify that this is a true report based on factory tests made in accordance with the latest Transformer Test Code CS7.2 of the American Standards Association, and that each transformer underwent the above insulation tests.

By: Mahesh Desai Date: 3-31-81 Approved: Carl M. Pandya  
Page 1 of 2 Pages

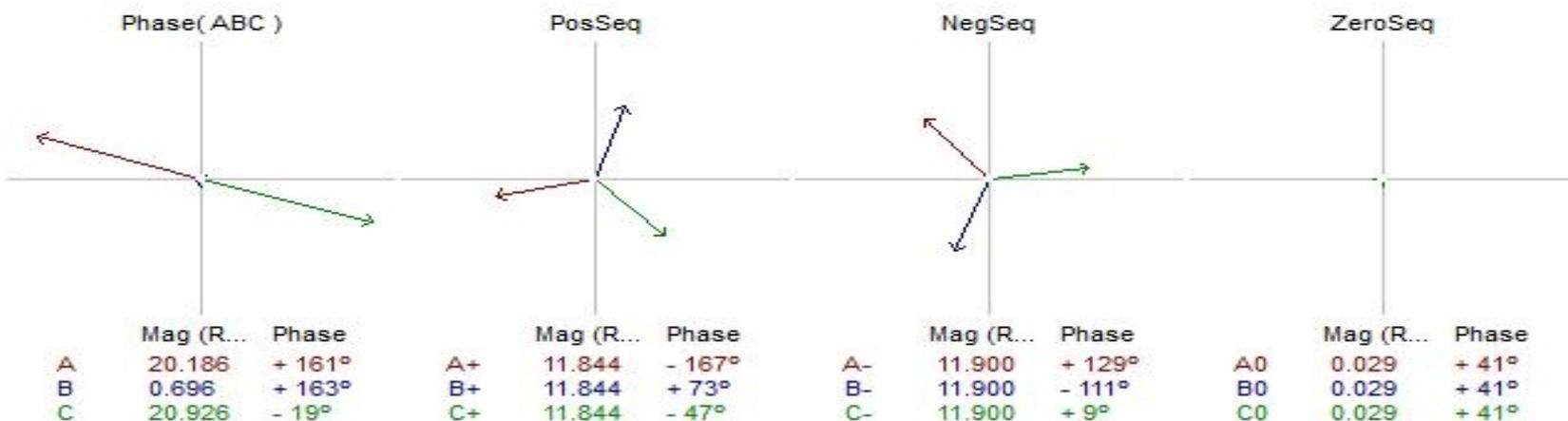
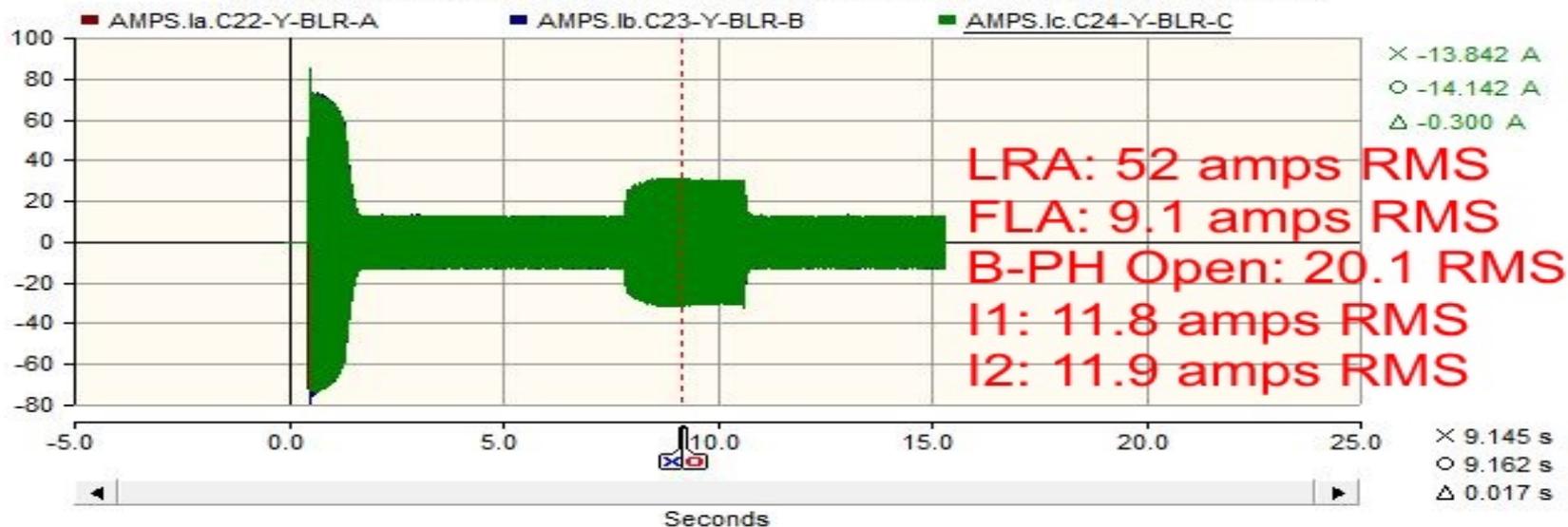
**IMPEDANCE**—Based on normal rating, unless otherwise stated. Losses and regulation are based on wattmeter measurements. For three-phase transformers the tabulations are the sum of the three phases in series.

85°C	% EXCITE CURRENT AT 100% RATED VOLTAGE	NO LOAD LOSS WATTS AT 100% RATED VOLTAGE	230 Kv		
			TO	TO	
			4.160 Kv		
			10000/12500 Kva		
			LOAD LOSS WATTS 85°C	% IMP 85°C	LOAD LOSS WATTS 85°C
	0.329	22074	49298	6.57	
	0.342	22300	48403	6.50	
	@110%	@110%			
	1.182	29038			
	1.327	30436			
			TOTAL LOSS	% IMP. 85°C	TOTAL LOSS
	0.3356	22187	71038	6.54	
	1.87	23400	81400	6.27	

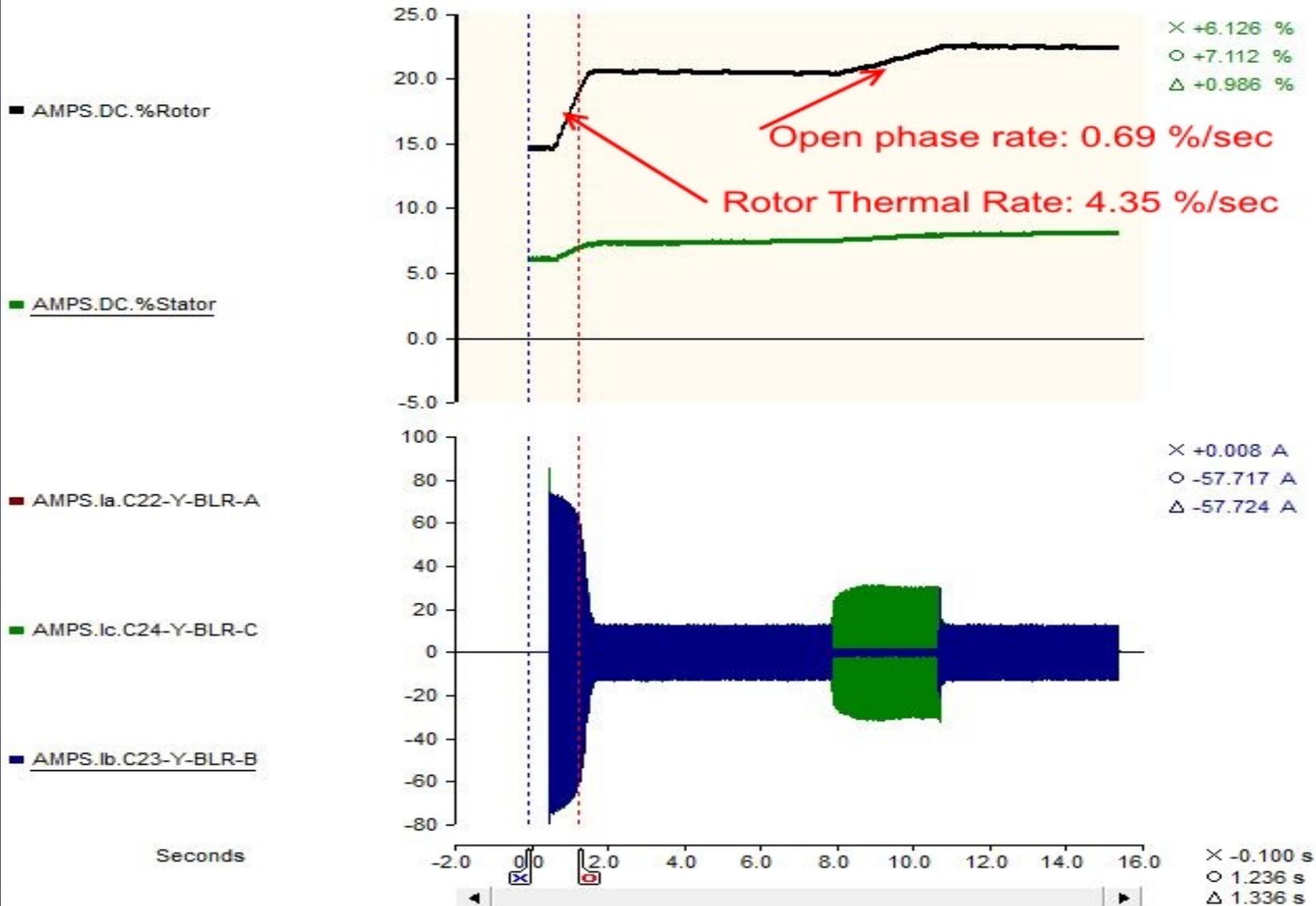
# Open Phase Motor Research



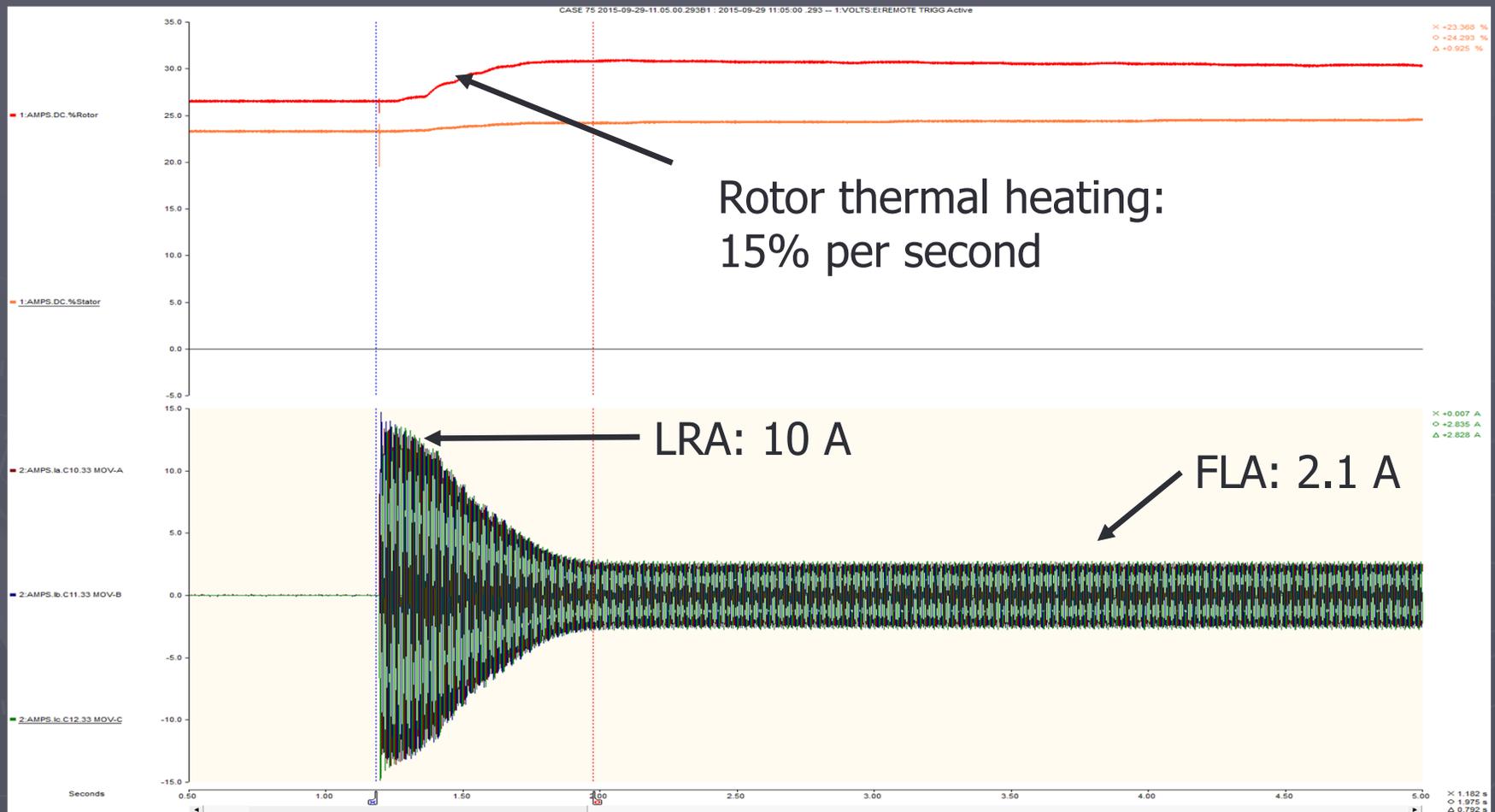
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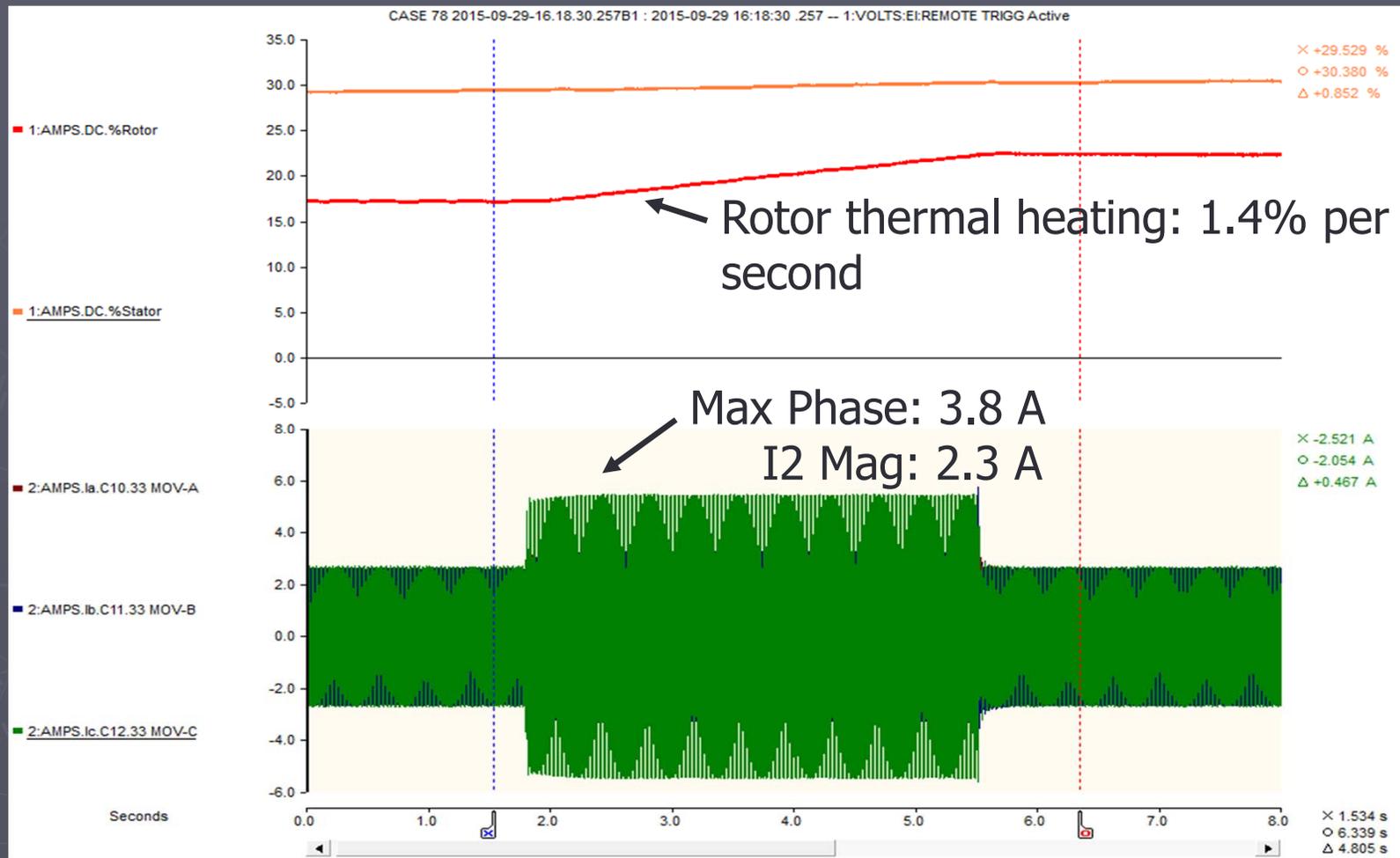
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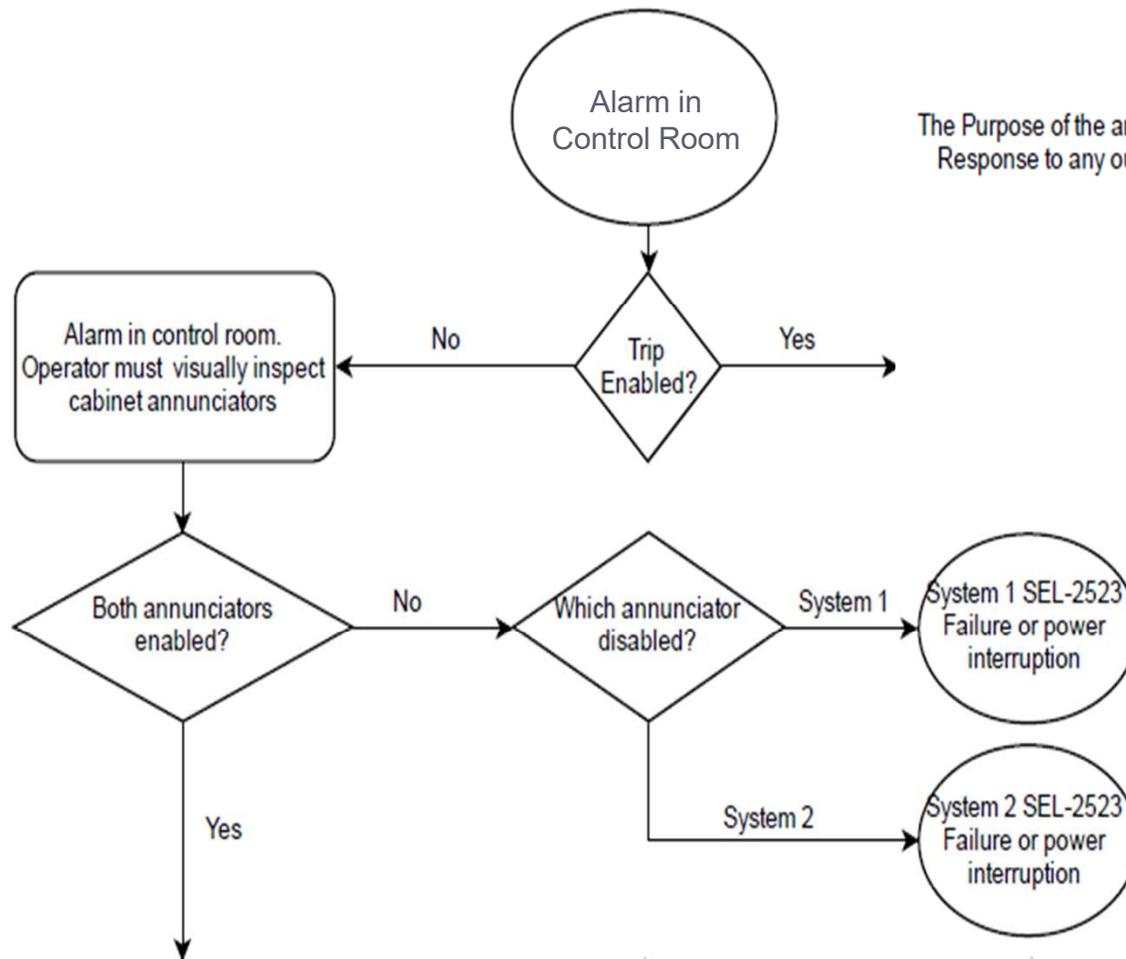
# Open Phase Motor Research – Locked Rotor Heating



# Open Phase Motor Research – Open Phase Heating



# OPD Response Chart Excerpt



The Purpose of the annunciator is to most efficiently provide a single alarm point to the control room. Response to any outputs generated by the OPD system must start with the system annunciators.

