EDGE SOLUTION FOR ASSET HEALTH MONITORING USING SYNCHROPHASORS

EPG PRESENTATION FOR NASPI PANEL

October 5, 2021

OUTLINE

- Introduction
- Need for Asset Health Monitoring using Synchrophasors
- EPG's iTAM Platform
- AEP Example – CCVT Failure Early Warning
- Use Cases
- Summary

ELECTRIC POWER GROUP (EPG) - INTRODUCTION

- Established in 2000 by an experienced team of electric utility executives
- EPG's team includes internationally acknowledged industry experts in phasor technology
- EPG portfolio of Synchrophasor Applications are designed to deliver value to Transmission Companies and System Operators for Asset Monitoring, Event Notification, and Situational Awareness
- EPG provides synchrophasor solutions to over 30 Grid Operators and Transmission Utilities in North America, Middle East and India

EPG SYNCHROPHASOR SOLUTIONS

Phasor Data Management

Collection & Synchronization | Storage | Integration | Validation & Conditioning

ePDC (Substation PDC) | ePDC (Control Center PDC) | PHASOR ARCHIVER | ICCP | IEC 104 | PI | DNP-3 | DATANXT | Algorithms | Models

Real-Time Analytics, Monitoring & Reports | Linear State Estimation | Grid Resiliency

RTDMS

GridSmarts

eGENS

eLSE | RTCA

enhanced Linear State Estimator

Analytics | Monitoring | Reports | Notifications | PhasorNXT Platform

Offline Analytics | Substation Applications | Training

Phasor Data Extractor

Phasor Grid Dynamics Analyzer

Automatic Event Miner

Big Data Analytics

Generator Model Validation (GMV)

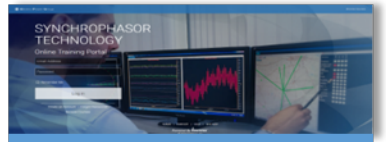
eGENS | PhasorSmart

iTAM — *intelligent* Transmission Asset Monitor

Edge Solutions

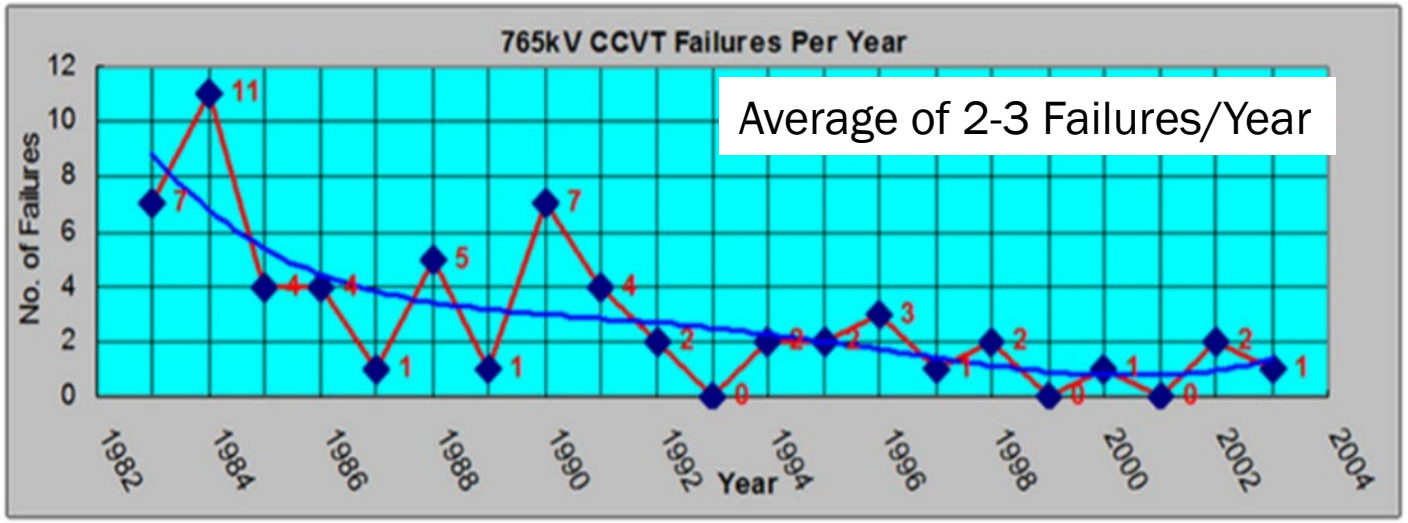
PSOT

Phasor Simulator For Operator Training



Synchrophasor Training Courses

NEED FOR ASSET HEALTH MONITORING USING SYNCHROPHASORS



AEP 765kV CCVT Failure Rate

~ 60 Reported Failures between 1982-2004

*T. Yang, Applying Substation Linear State Estimator to Instrument Transformer Health Monitoring and Management: Roadmap, CIGRE 2016.

Example from AEP of failing CCVT in a substation

INTELLIGENT TRANSMISSION ASSET MONITOR – *i*TAM

PROACTIVELY DETECTING PRECURSORS OF SUBSTATION EQUIPMENT FAILURE TO TAKE PREVENTIVE ACTION

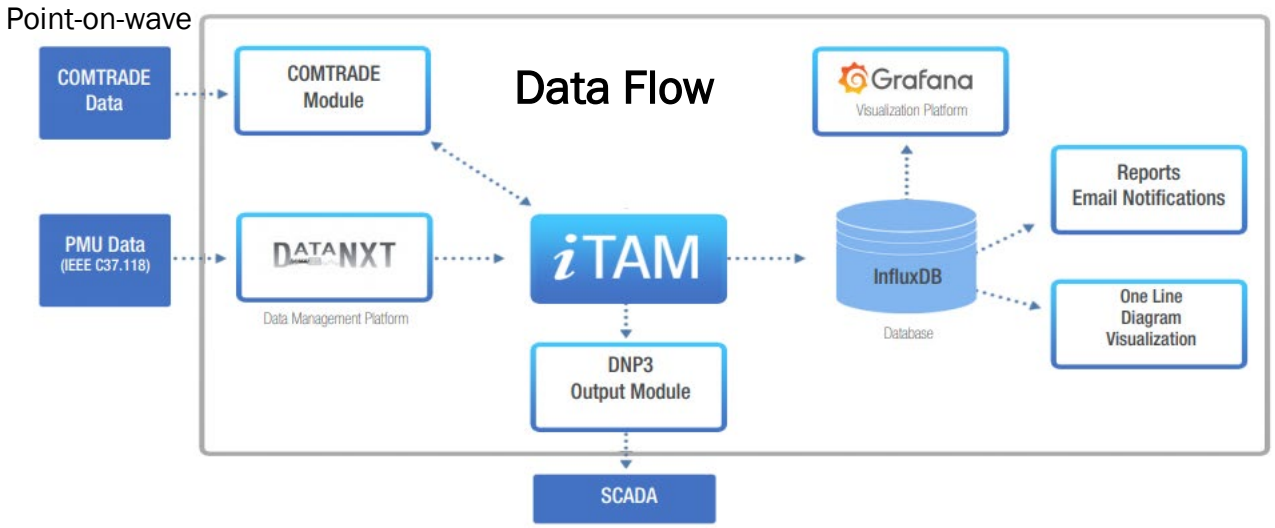
ITAM VALUE PROPOSITION

- Instrument Transformers such as PTs, CTs, and CCVTs are not monitored in substations
- Failures of PTs, CTs, and CCVTs have led to damage and/or explosions at substations, compromising personnel safety, affecting reliability, and causing outages
- The majority of failures in instrument transformers are electrical
- Electrical signatures can be analyzed using Synchrophasor data in real-time to identify anomalies and provide early warning.
- iTAM utilizes synchrophasor data and advanced analytics to monitor electrical signatures and issue alarms and alerts in real-time for timely operator action

Improve Safety, Increase Reliability, Prevent Customer Outages, Reduce Cost

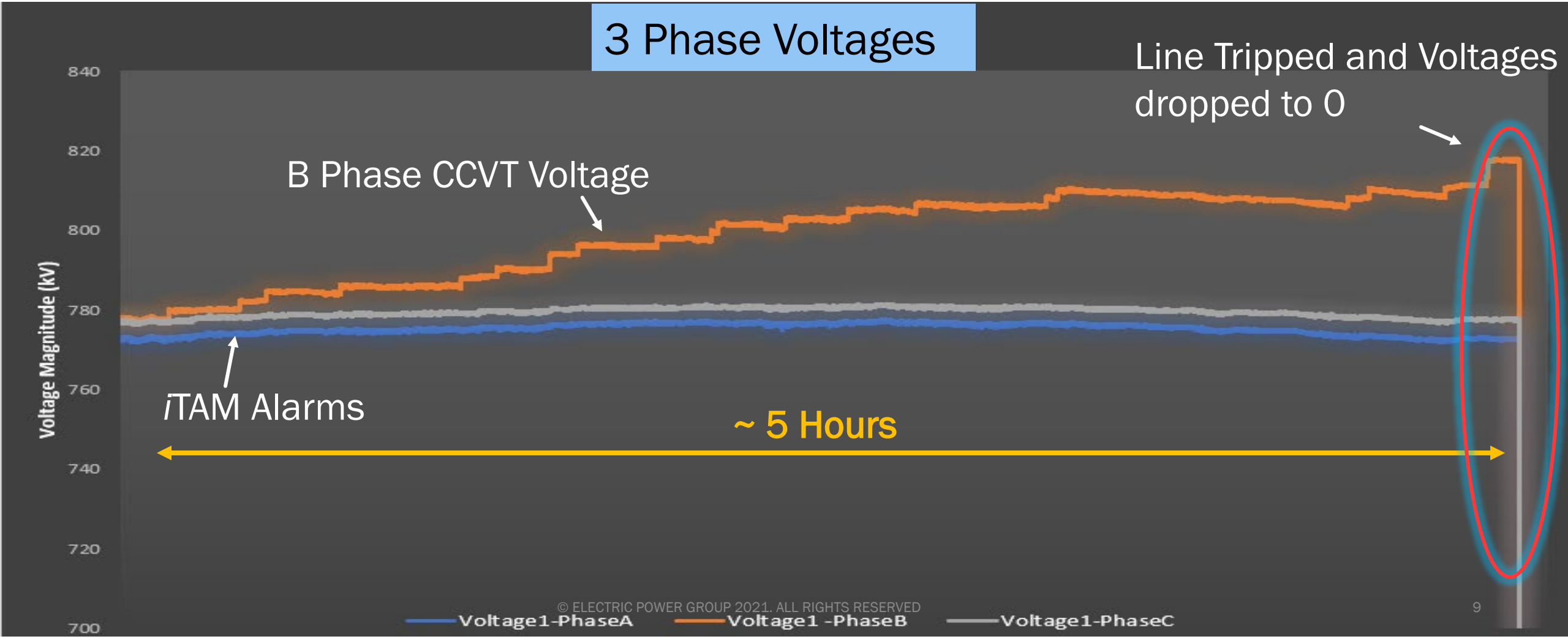
*i*TAM – PLATFORM FOR ASSET MONITORING

- **Platform**: EPG developed *i*TAM to detect precursors to Equipment Failure
- **Data**: PMU (C37.118) and point-on-wave DFR data (COMTRADE)
- **Equipment**: Instrument Transformers (CT, PT, CCVT)
- **Methodology:** Advanced Data Driven Methods based on moving windows and dynamic thresholds, Substation Linear State Estimator – Model Based method
- **Flexible**: Central Location or in substations
- **Field Tested**: Deployed and validated at two AEP substations (138 kV & 765kV).
- **Visualization:** One Line Diagrams, Dashboards
- **Automated Alarm Notifications**
- **Filter Out False Alarms:** Designed to filter out false alarms by distinguishing instrument transformer failures from:
  - System Events (Line Trip, Generation Trip, Transients)
  - Bad Data (Dropouts, Time Errors, Communication Issues)

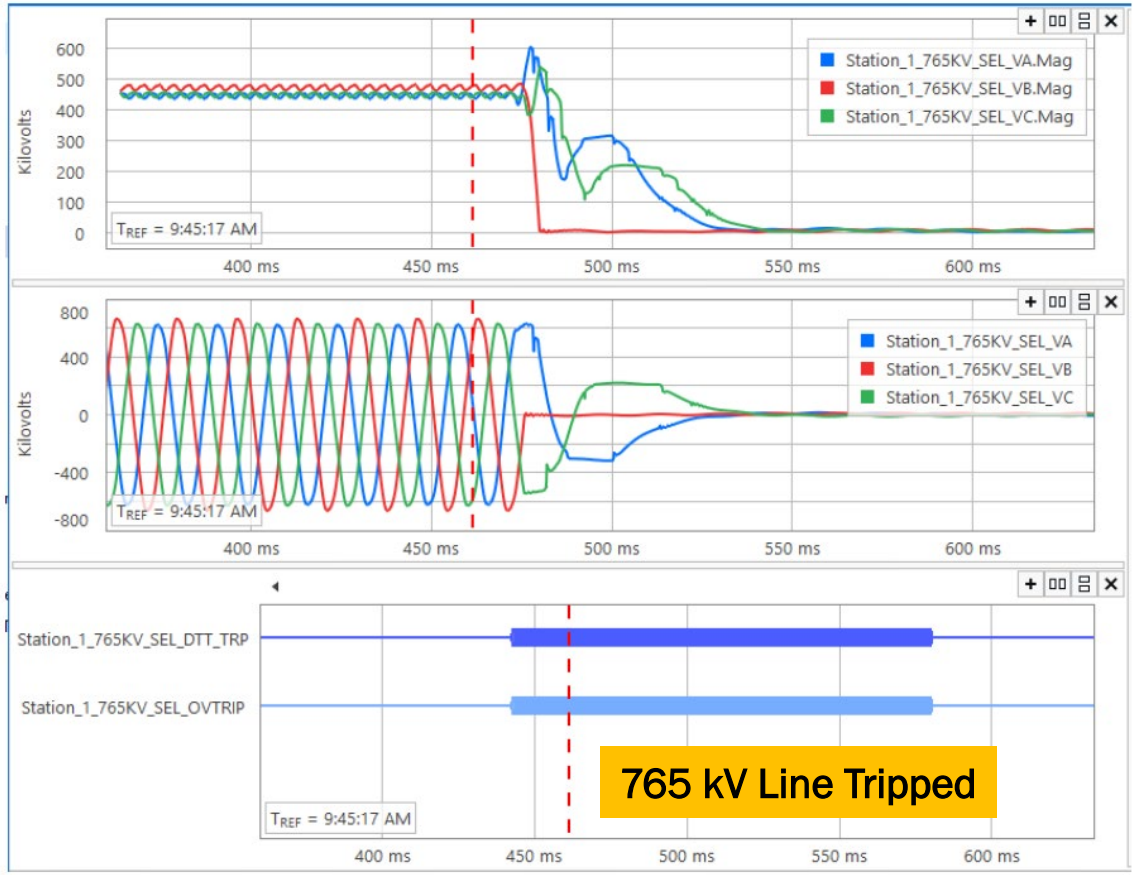


*i*TAM EXAMPLE – CCVT FAILURE EVENT REPLAY

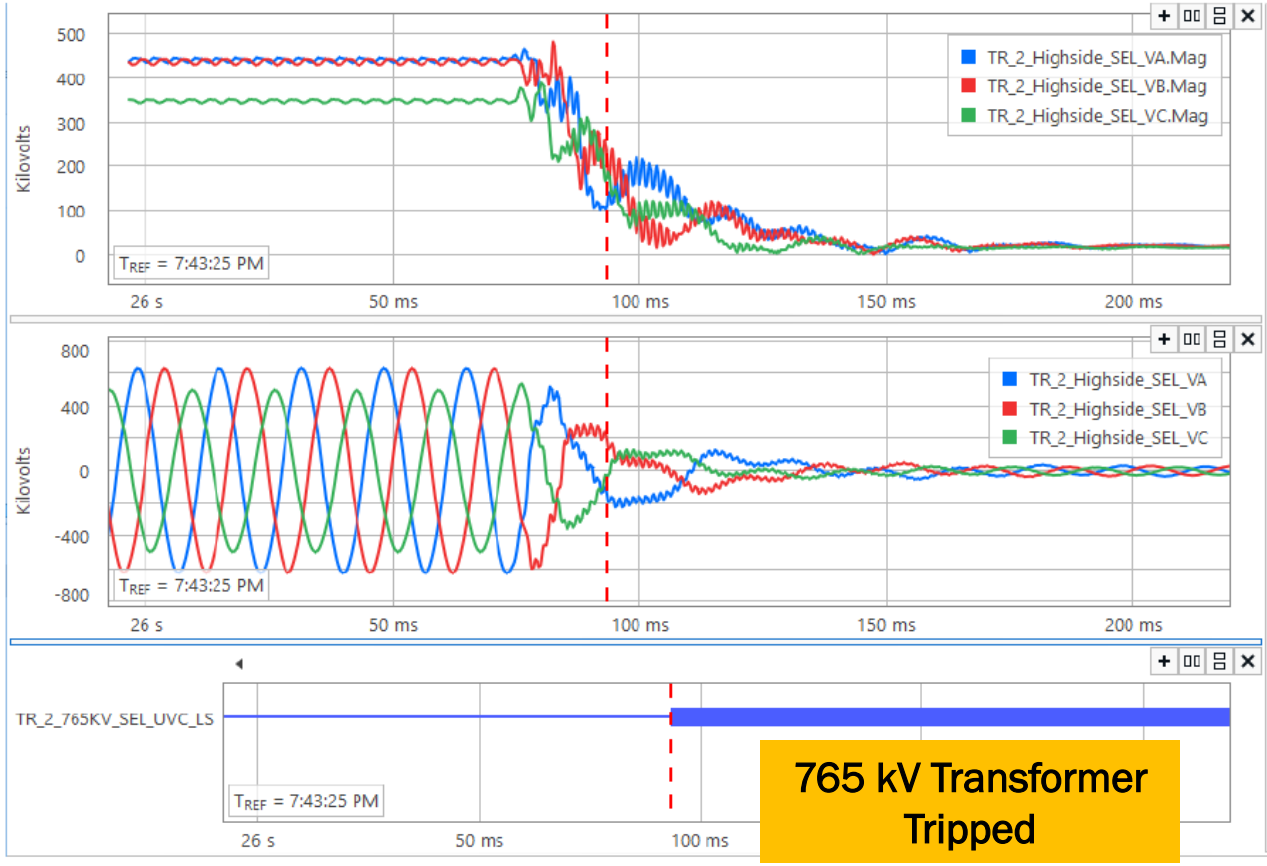
- CCVT Failure Event - B Phase Voltage has anomalies/precursors before equipment failed
- Can be detected 5 hours prior to failure, System is tuned to capture these failures and provide early warning



AEP EXAMPLES – CCVT FAILURE CAUSED 765KV LINE TRIP AND TRANSFORMER TRIP



Precursors Observed ~ 5 Hours Ahead



Precursors Observed ~ 5 Days Ahead

Source: Qiushi Wang et. al, 'CCVT Modelling Failure Mode Investigation and Impact on Relay Operation', CIGRE-US, 2020.

iTAM CAN DETECT DIFFERENT TYPES OF FAILURES

CCVT FAILURES THAT CAN BE DETECTED

CCVT Failure type	Detected with physical inspection?	Detected by iTAM?
Loose fuse connections in CCVT safety switch	✓	✓
Capacitor failure in high voltage stack of CCVT	✗	✓
Capacitor failure in low voltage grounding stack	✗	✓
Failure in voltage transformer and series reactor in CCVT	✗	✓
Filter circuit failure and spark gaps	✗	✓
Ferroresonance suppression circuit failure	✗	✓

TYPES OF FAILURES IN CT'S AND PT'S THAT CAN BE DETECTED

CT Failure type	Detected with physical inspection?	Detected by iTAM?
Polarity error	✓	✓
Loose or corroded connections	✓	✓
Open CT secondary	✓	✓
Turn-to-turns shortage within same coil	✕	✓
Turn-to-ground shortage	✕	✓
Turn-to-turn shortage between different coils	✕	✓
Ratio setting error	✕	✓
Saturation of CT core and dielectric breakdown	✕	✓

PT Failure type	Detected with physical inspection?	Detected by iTAM?
Blown Fuse	✓	✓
Loose connections	✓	✓
Primary winding issues	✕	✓
Secondary winding issues	✕	✓

JAN 11, 2019 - EASTERN INTERCONNECTION OSCILLATIONS

- NERC findings point to wiring issue in PT that triggered Interconnection Wide Oscillations
- Important to identify oscillations and locate source
- Also important to identify and address root-cause to prevent system wide impact

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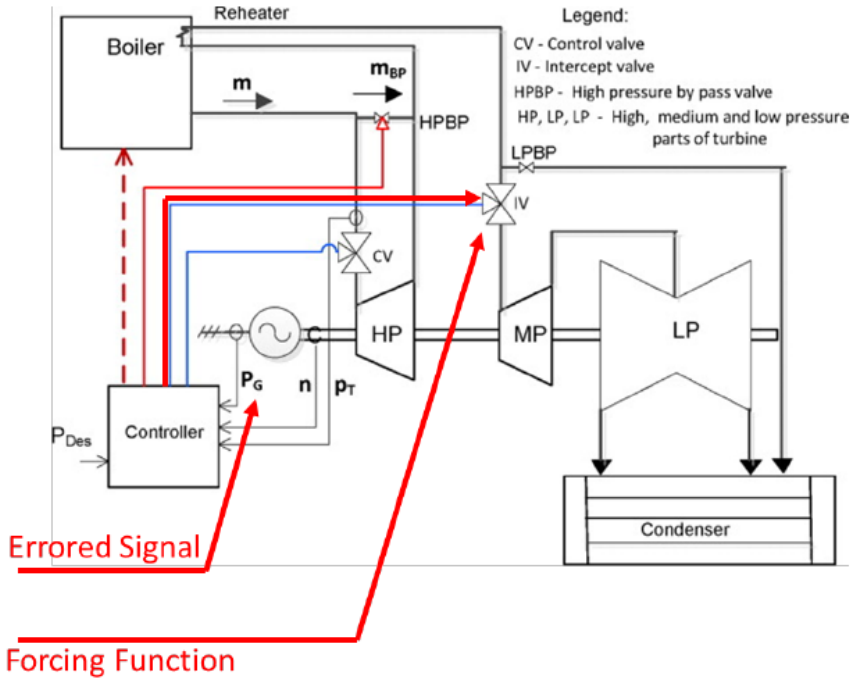
Forced Oscillation Source



- Steam turbine at combined cycle plant
- Power-load imbalance (PLI) controls
  - Failed voltage input to feedback
  - Measured P_{gen} reading 2/3 of actual
  - Perceived power-load imbalance
- PLI trigger shuts intercept valves
- 4 second timer to reopen valves
- Imbalance eliminated and valves reopen
- … and repeat …. and repeat
- Different voltage measurements for relaying and controls/metering
  - Hence no relay operation
- Plant manually tripped by operator
- Upon inspection, failed wiring in PT cabinet
- Damaged intercept valves
  - Replacement needed
  - Unit off-line for multiple weeks

Source: NERC, Oscillation Analysis Webinar, September 13, 2019

USE-CASE EXAMPLE

From NERC Lesson Learned Report

- NERC & NPCC Event Analysis Team Published a Report on April 14, 2020
- CCVT Failure Event caused a single-phase-to-ground fault
- CCVT had exhibited low, out-of-tolerance output prior to the event.
- Event caused communication equipment failure due to transient
- Primary and Back-up relay protection failed
- Fault continued for over 4 minutes causing significant damage

"Monitoring the output for "stair steps" can warn of developing failure"

https://www.nerc.com/pa/rrm/ea/Pages/Lessons-Learned.aspx

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Lesson Learned

Protracted Fault in a Transmission Substation

Primary Interest Groups
Transmission Operators (TOPs)
Transmission Owners (TOs)

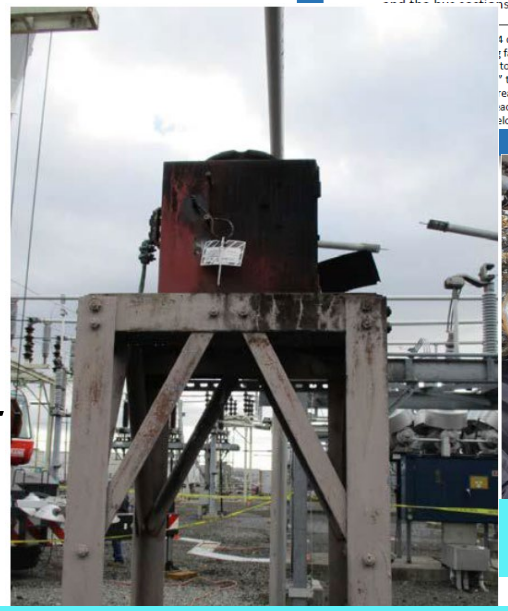
Problem Statement
Electronic communications equipment utilized to transmit and receive information from the remote terminals of a transmission line automatically shut down within milliseconds when a bus fault occurred at one terminal of the line. Neither the primary nor the back-up relay protection cleared the fault. The fault continued for over four minutes.

Details
A single-phase-to-ground fault occurred on an instrument voltage transformer connected to the bus section that serves as the transmission line's terminal at Substation 1. The instrument voltage transformer was a capacitive coupling voltage transformer (CCVT)[1], comprised of a stack of coupling capacitors that form a voltage divider that supplies approximately 5 kV to a small potential device that in turn steps down the voltage to 120 volts for utilization by metering and back-up protective relaying. (See **Figure 1**). This instrument voltage transformer had exhibited low, out-of-tolerance output prior to the event. Low output voltage is often thought to be a benign condition for coupling capacitor devices.[2] The output to metering and back-up relaying had been temporarily isolated prior to the event to preclude false readings and avoid the risk of relay misoperation, but the coupling capacitors remained connected[3] to the transmission bus.

Communications equipment shut down at the substation where the fault occurred because of an electrical transient associated with the fault. The communication channels carried information utilized by the line differential relaying essential to the protection of the line and the bus sections at the line terminals.

Figure 1: Typical CCVT

4 common substation equipment types listed in the NERC Event Analysis' "Addendum for Events with Failed Station
failure modes and mechanisms in reported events.
to fail in a CCVT, it is usually by shorting out of individual capacitor packs in the string. If packs short out above the
" the output voltage rises. If packs below the 'low voltage tap' short out, the output voltage would lower. In either
reased voltage stress across all the remaining capacitors in the string, accelerating their failure. As long as the string
ads to a continuous sequence of shorting packs out and eventual catastrophic failure. Monitoring the output for "stair
eloping failure.



Failed C Phase of CCVT

Remnants of Bus Insulators

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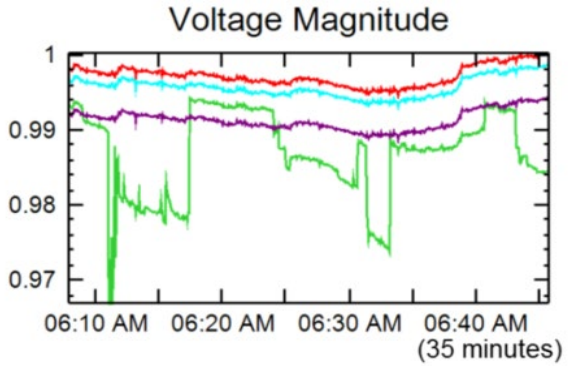
INSTRUMENT TRANSFORMER FAILURE EVENTS IN AUSTRALIA

- March 3, 2017 – CCVT Failure *Source: AEMO Incident report, 10 March 2017*
  - Explosive Failure of a CCVT in 275 kV Switchyard
  - Caused series of faults and tripping of Busbar and generator
  - Damage to generator disconnector
  - Loss of 610 MW generation across 5 units
  - CCVT was tested and physically/visually inspected 38 days before failure
- February 13, 2017 – CCVT Failure *Source: AEMO Incident report, 26 July 2017*
  - Explosive Failure of a CCVT associated with 275kV line
  - Caused single phase fault that developed into multiphase fault and tripping line
  - Loss of 475 MW of load
- October 3, 2013 – CCVT Circuit Failure *Source: AEMO Incident report, 16 December 2013*
  - Loose Fuse on secondary circuit of 330 kV line CCV
  - Caused overvoltage and line outage
- November 20, 2015 – CT Failure *Source: AEMO Incident report, August 2016*
  - Explosive Failure of Current Transformer (CT) at 330 kV
  - 330 kV Line Outage
  - 125 MW customer load loss

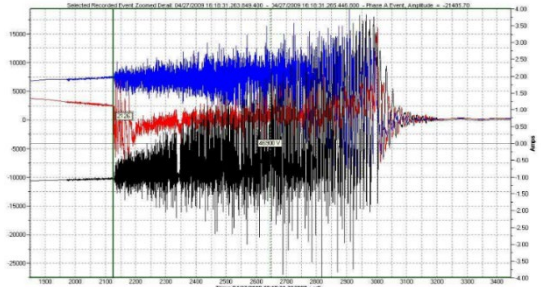
EXAMPLES OF *I*TAM DETECTION CAPABILITIES

LOOSE CONNECTIONS, WINDING ISSUES, BLOWN FUSES, ETC.

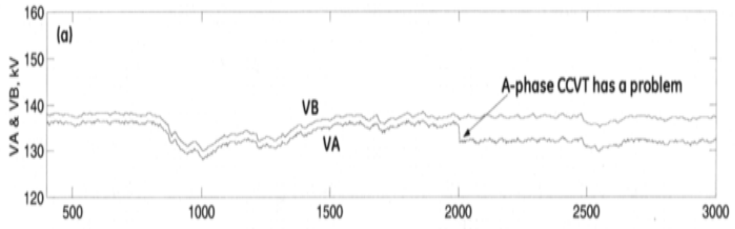
Loose Fuse Connections in CCVT Safety Switch – OG&E

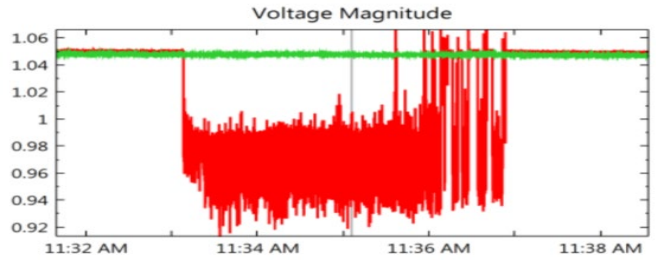


Switching Transients due to Ferroresonance

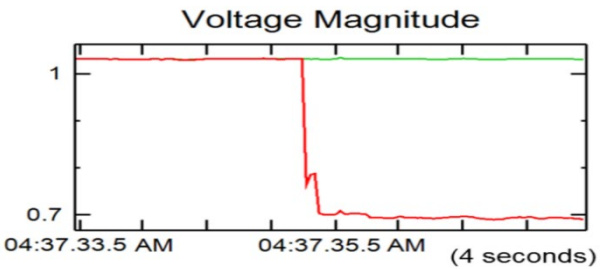


A - Phase CCVT Issue

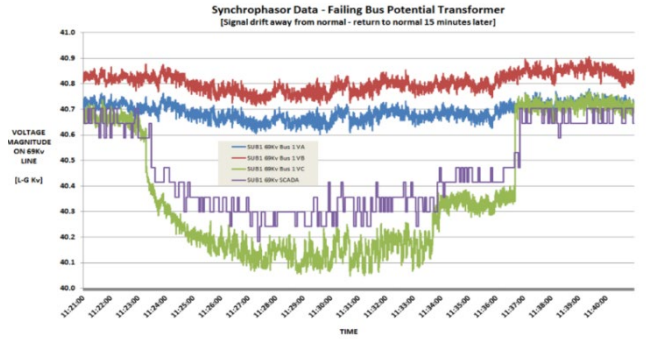




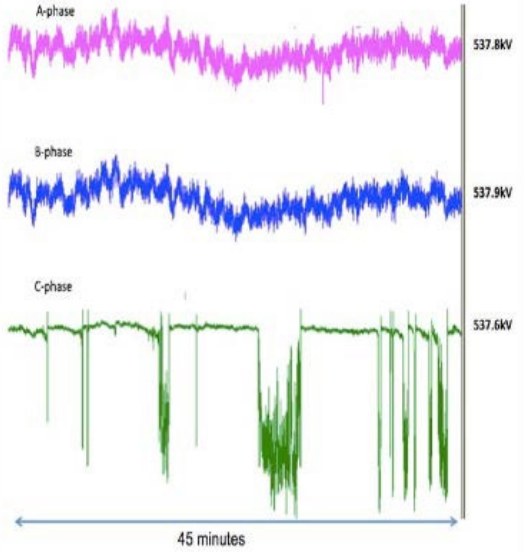
Loose Connection at PT feeding the PMU – OG&E



Blown fuse on One Phase of PT – OG&E



Internal Primary Winding Issue - ATC

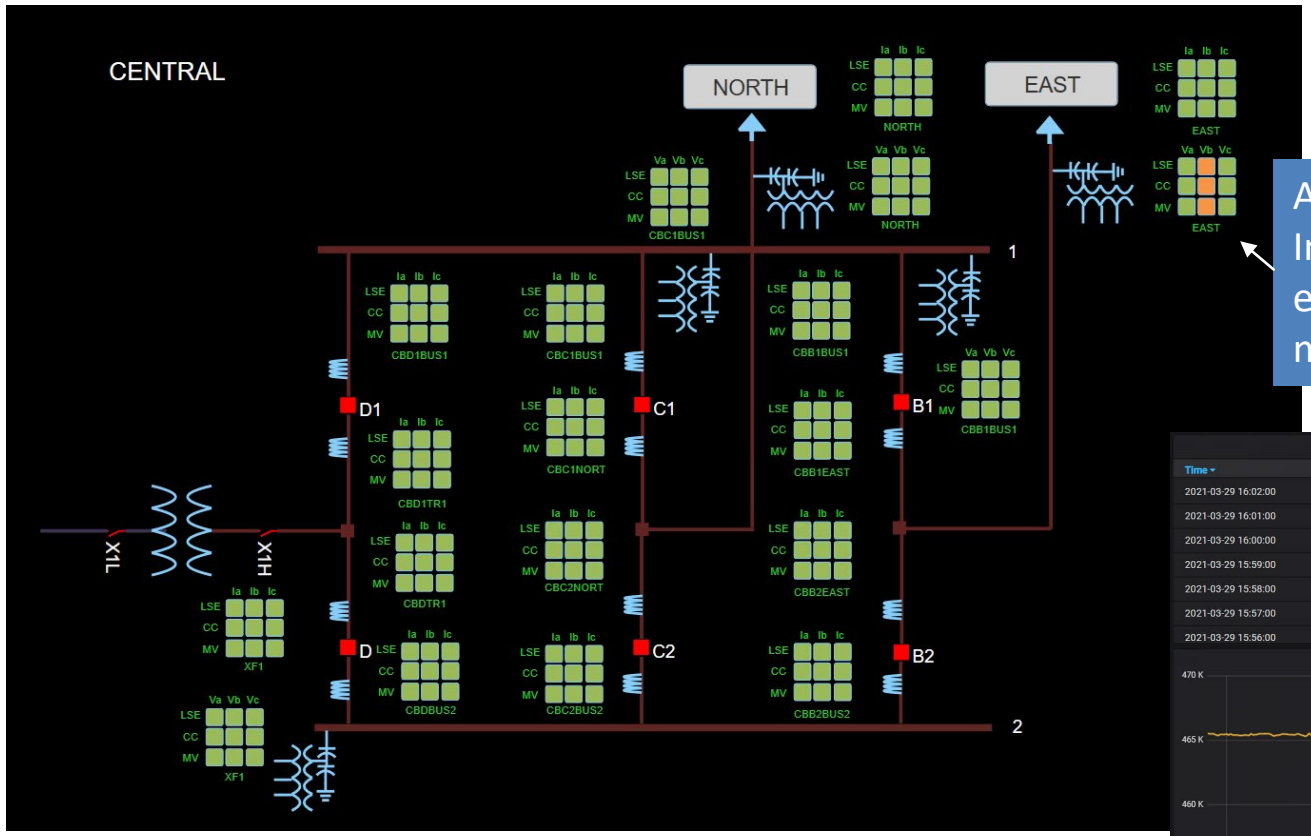


CCVT Failure example from Dominion – PMU Data showed precursors 4 days before alarms from SCADA system

References:

1) NASPI Technical Report, "Diagnosing Equipment Health and Mis-operations with PMU data", May 2015
2) Bogdan Kasztenny and Ian Stevens, "Monitoring Ageing CCVTs – Practical Solutions with Modern Relays to Avoid Catastrophic Failures", March 2007
3) David Shipp and Thomas Dionise, IEEE Tutorial, " Switching Transients, Transformer Failures, Practical Solutions", Feb 2016

ONE LINE DIAGRAMS AND VISUALIZATION DISPLAYS



Alarm Indicator for each device monitored

Analytics Screen
- Navigate between devices
- Navigate between time scales
- Dashboard with alarm history
- Trend charts with data, calculations, etc.

Alarms in real time displayed on one-line Diagrams

REPORTING AND ALARMING – EMAIL NOTIFICATIONS

Sample email notification

Wed 10/14/2020 9:20 AM

epg_test <test@electricpowergroup.com>

[Alerting] [redacted] Substation Health Alert ← Customizable Subject

To [redacted]

If there are problems with how this message is displayed, click here to view it in a web browser.

[Alerting] [redacted] Substation Health Alert ← Customizable Message

[redacted] Substation Health Monitoring detects abnormal behavior. For more information, check http://localhost:8085/d/VEPJgCdmk[redacted]substation-health-monitoring?orgId=1&refresh=5s&from=1602625914652&to=1602627714652. ← Web-based dashboard for more details

Metric name	Value
[redacted]_ma_master_flag.distinct ← Measurement & value triggered the alert	1.000

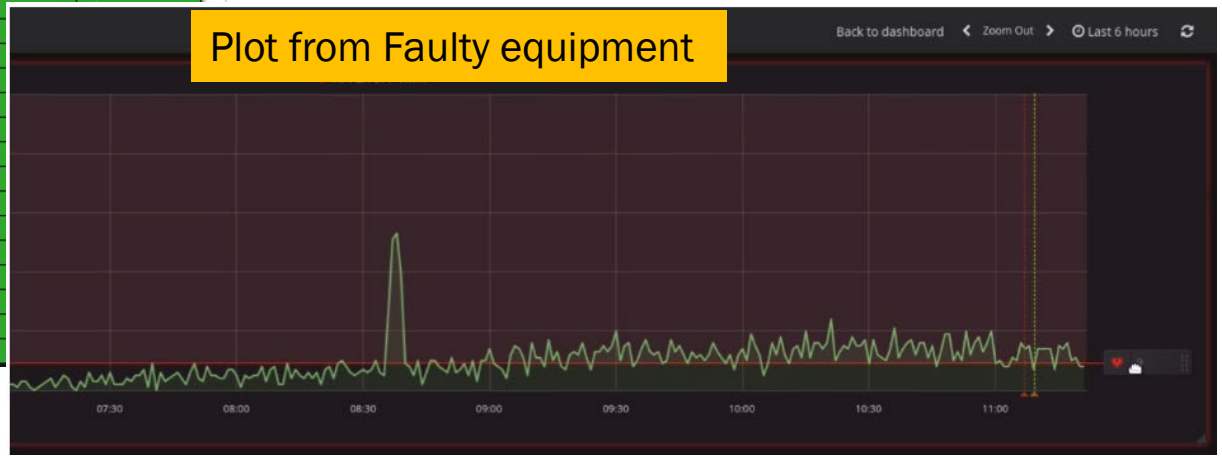
Master Alarm Panel — Last 15 minutes

Time	Va_LSE	Vb_LSE	Vc_LSE	Va_cc	Vb_cc	Vc_cc	Va_mv	Vb_mv	Vc_mv
2020-11-16 16:32:00	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear
2020-11-16 16:33:00	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	
2020-11-16 16:34:00	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	
2020-11-16 16:35:00	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	
2020-11-16 16:36:00	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	
2020-11-16 16:37:00	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	
2020-11-16 16:38:00	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	
2020-11-16 16:39:00	Flag	Clear	Clear	Flag	Clear	Clear	Flag	Clear	
2020-11-16 16:40:00	Flag	Clear	Clear	Clear	Clear	Clear	Clear	Clear	
2020-11-16 16:41:00	Flag	Clear	Clear	Clear	Clear	Clear	Clear	Clear	
2020-11-16 16:42:00	Flag	Clear	Clear	Clear	Clear	Clear	Clear	Clear	
2020-11-16 16:43:00	Flag	Clear	Clear	Clear	Clear	Clear	Clear	Clear	
2020-11-16 16:44:00	Flag	Clear	Clear	Clear	Clear	Clear	Clear	Clear	
2020-11-16 16:45:00	Flag	Clear	Clear	Clear	Clear	Clear	Clear	Clear	
2020-11-16 16:46:00	Flag	Clear	Clear	Clear	Clear	Clear	Clear	Clear	
2020-11-16 16:47:00	Flag	Clear	Clear	Clear	Clear	Clear	Clear	Clear	

Key Information:

- Substation effected
- Equipment alarming
- Faulty Phase
- Metric violated

Plot from Faulty equipment



SUMMARY

- iTAM – Synchrophasor Edge Solution for Asset Health Monitoring
- Complements Utility Asset Monitoring Systems
- Can be deployed at Individual Substations with alarms/results sent to other systems
- Designed to monitor instrument transformers (Current transformers, Voltage transformers, CCVT's) that are critical to substation protection
- Detects precursors to failure and issues alarms and email notifications to Asset Managers to take pro-active action
- Substation equipment failures are costly – iTAM can prevent outages, reduce equipment replacement cost, promote safety

THANK YOU

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