ASSET HEALTH MONITORING USING SYNCHROPHASOR TECHNOLOGY

PRESENTATION FOR

NASPI WEBINAR SERIES

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OUTLINE

- EPG Introduction
- Asset Health Monitoring Solution
  - Background and Need
  - Platform Features and Capabilities
  - Failure Types and Examples
  - Integration with WAMS Platform
- Summary and Looking Forward

EPG - INTRODUCTION

- Leading Provider of Synchrophasor Technology Solutions since 2000
- Comprehensive platform for real-time monitoring and grid analytics
  - WAMS
  - Oscillations
  - IBR Monitoring
  - LSE
  - Model Validation
  - WAMPAC
  - Real-Time and Offline Analytics
  - Advanced Applications
- Solutions in use at several grid operators, reliability coordinators and utilities in US and internationally

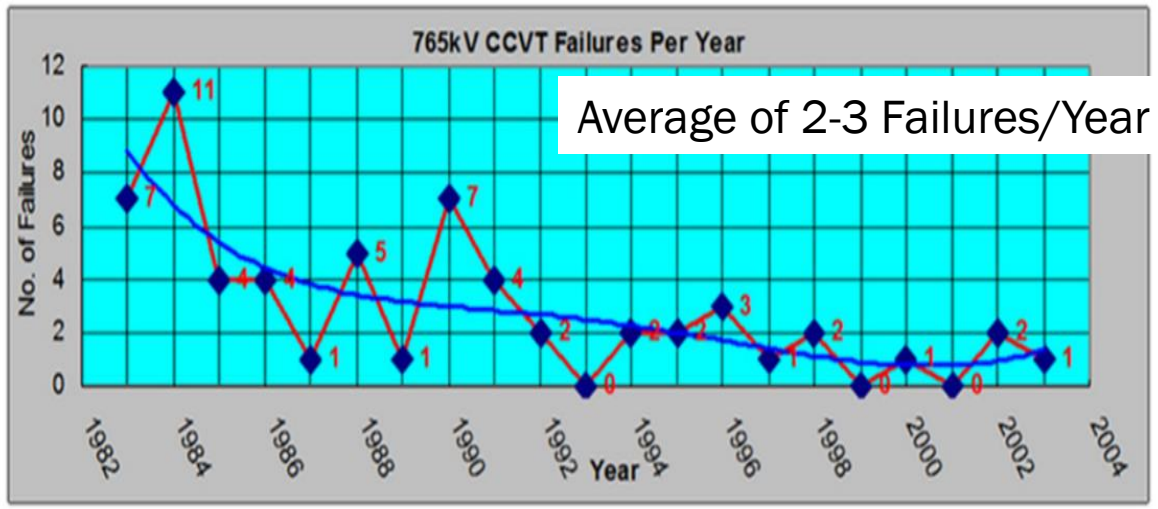
ASSET HEALTH MONITORING

- Utilities have invested billions of dollars in transmission equipment and substations
- Key substation assets include transformers, circuit breakers, instrument transformers (CTs, PTs, CCVTs) and Intelligent Electronic Device (Relays, PMU, DFRs)
- Proper functioning of substation assets is critical for power system operations, reliability and personnel safety
- T&D incidents are increasing:
  - Infrastructure is aging increasing vulnerability to equipment outages
  - Resource mix shifting to IBRs – more oscillation incidents
- Equipment Failures can cause increases in costs, outages and risk to personnel safety and system reliability
- Identifying precursors to equipment failure can help prevent failure and minimize the impact on the system
- PMUs can be used to detect precursors to equipment failureand complement existing asset health monitoring methods

TRANSMISSION EQUIPMENT FAILURE - COSTLY

EQUIPMENT DAMAGE, OUTAGE, PERSONNEL SAFETY

Example from AEP of failing CCVT in a substation



Average of 2-3 Failures/Year

AEP 765kV CCVT Failure Rate

~ 60 Reported Failures between 1982-2004

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

Reference: Joshua C, DE-OE0000850 Final Report, “Substation Secondary Asset Health Monitoring and Management System (SSHM)”, June 2020, Link

EHV INSTRUMENT TRANSFORMER FAILURES – TRANSMISSION COMPANY IN USA

Number of Failures in last 10 years

- CCVT – Over 50
- PT – 20 to 50
- CT – 6 to 20

Impact of Failures

Impact	Number of Events
Misoperation of Protection Relays	2 to 5
Outage	6 to 10
Equipment Damage	6 to 10
No Significant Impact	10 to 50

Cost of a Single Failure Event

$50,000 - $250,000

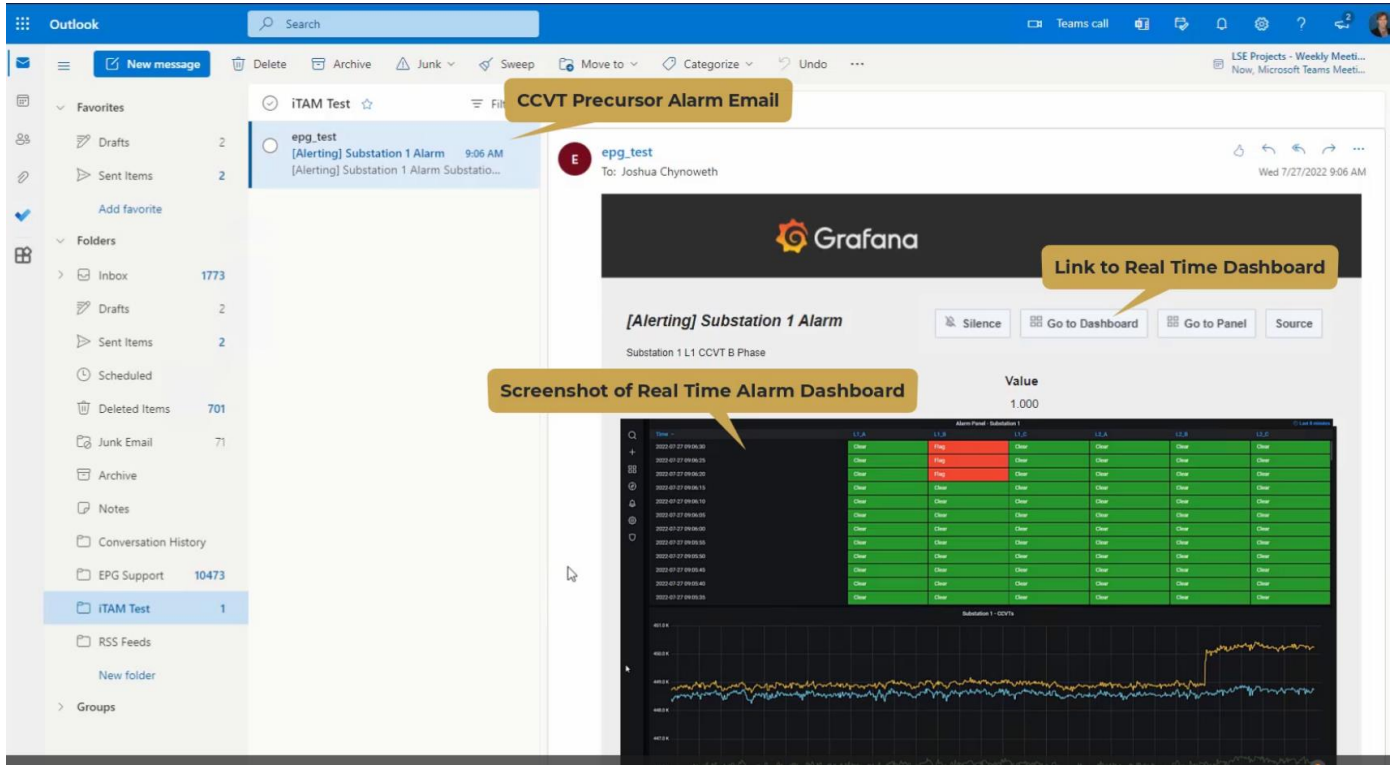
Time Required for Repairs

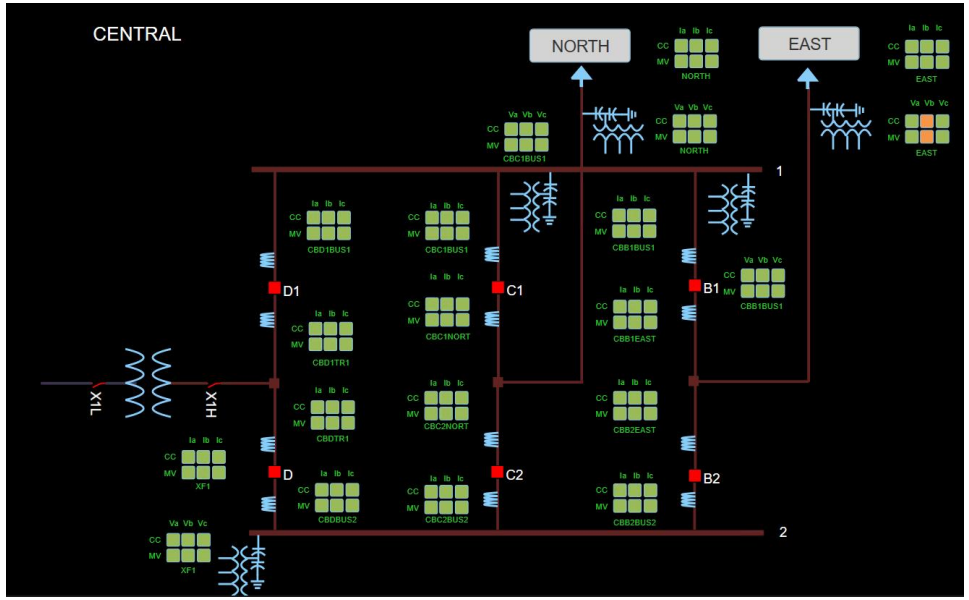
More than a week: could be more than a month if replacement equipment is not available

EPG'S ASSET MONITORING SOLUTION - OVERVIEW

- **Platform**: Detect precursors to Equipment Failure from Instrument Transformers (CT, PT, CCVT)
- **Data**: PMU C37.118 Stream
- **Methodology**
  - Real Time Advanced Analytics
  - Ability to filter out system events and bad data
- **Deployment**: Central Location or in substations
- **Visualization:** One Line Diagrams, Dashboards
- **Automated Real-time Alarm and Email Notifications**
- **Field Tested**
  - Validated for 138kV, 500kV and 765kV substations
- **Demonstrated at AEP**
- **Pilot Deployment at New York Power Authority (NYPA)**

REPORTING AND ALARMING – EMAIL NOTIFICATIONS





Email Provides Information on

- Substation effected
- Equipment (CT, PT, CCVT) alarming
- Faulty Phase
- Metric violated (Voltage or Current)

Identify faulty equipment on substation one-line diagrams

DEPLOYMENT OPTIONS

Standalone Asset Monitoring Platform – Substation Level

Asset Monitoring Platform

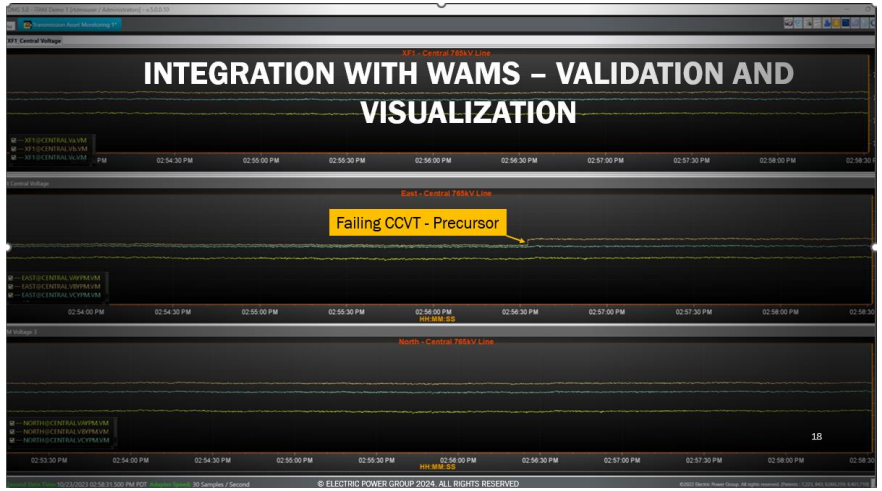
Deployed in Substation on a hardened PC

Standalone Asset Monitoring Platform – System Level

Asset Monitoring Platform

Deployed at a central location monitoring data from multiple substations

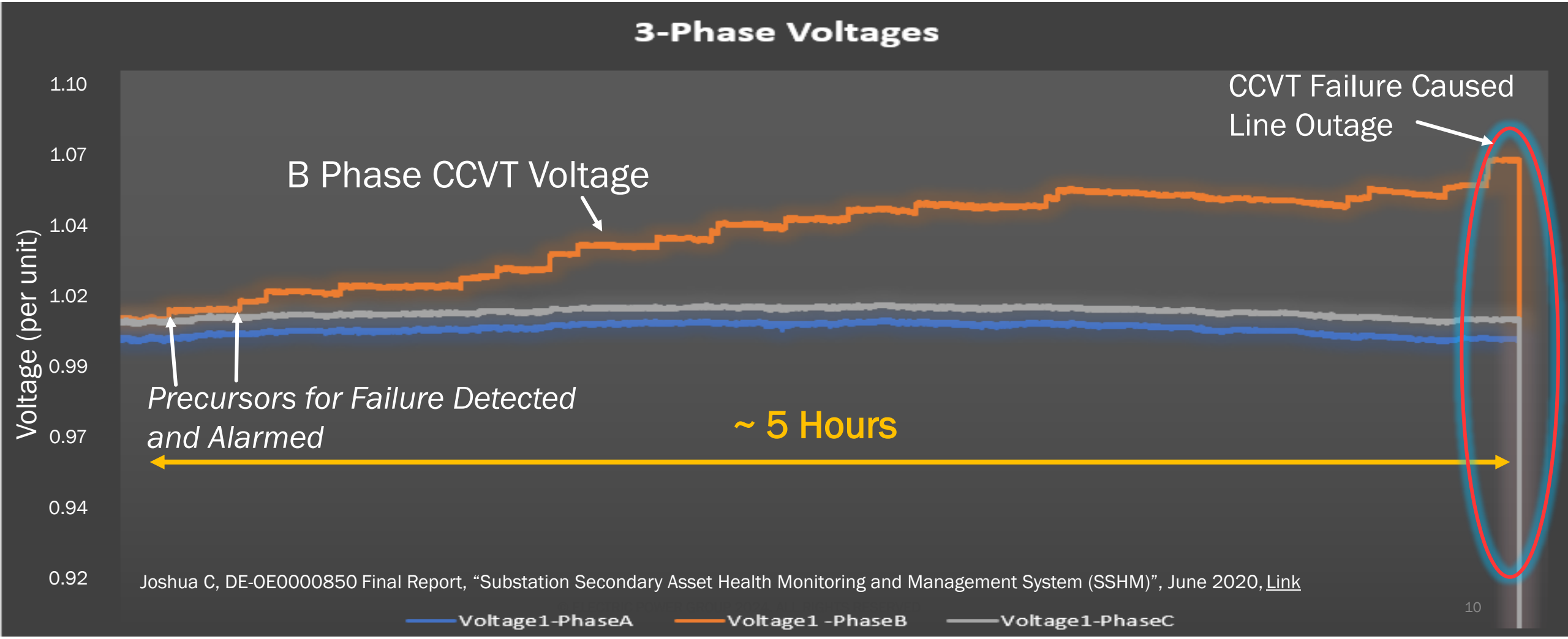
Integrated with WAMS



Deployed in a control center integrated with WAMS and other data analytics

AEP CCVT FAILURE EVENT - EXAMPLE

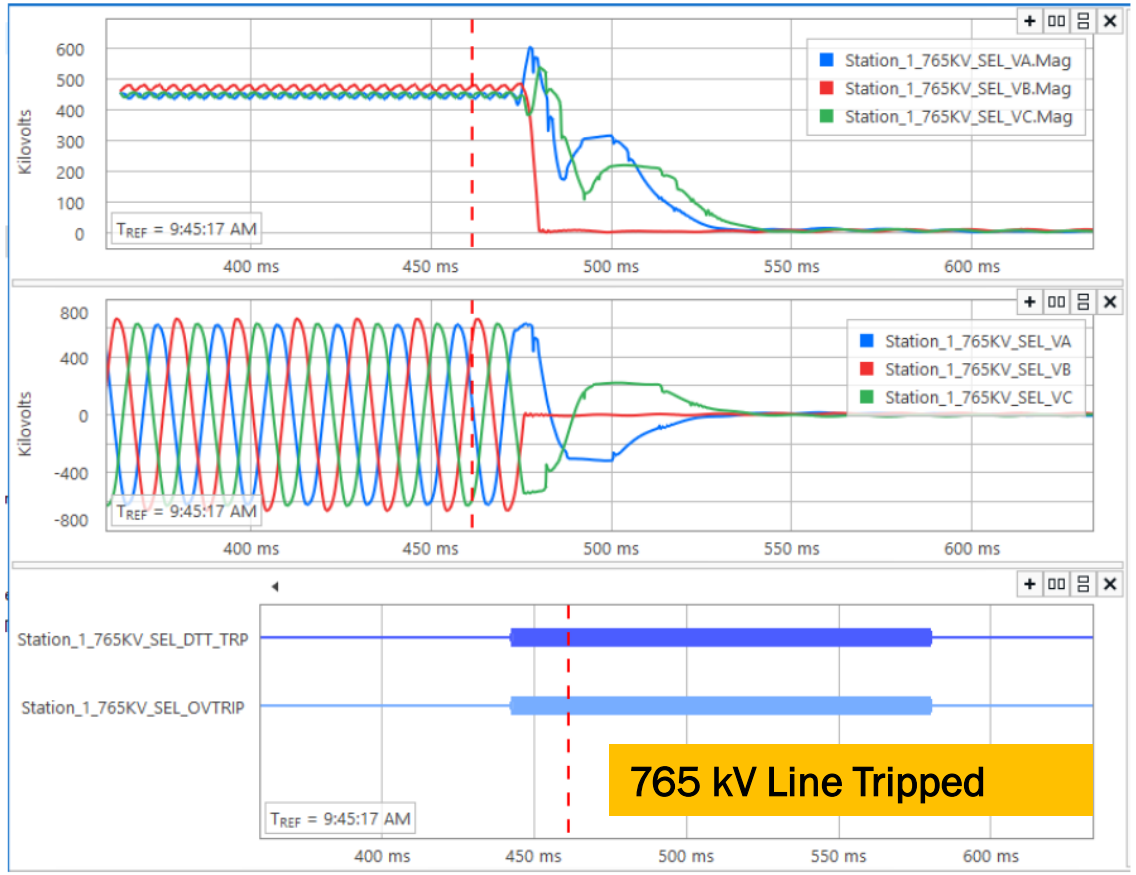
- CCVT Failure Event - B Phase Voltage has anomalies/precursors before equipment failed
- Can be detected 5 hours prior to failure, System is tuned to capture these failures and provide early warning



Joshua C, DE-OE0000850 Final Report, "Substation Secondary Asset Health Monitoring and Management System (SSHM)", June 2020, Link

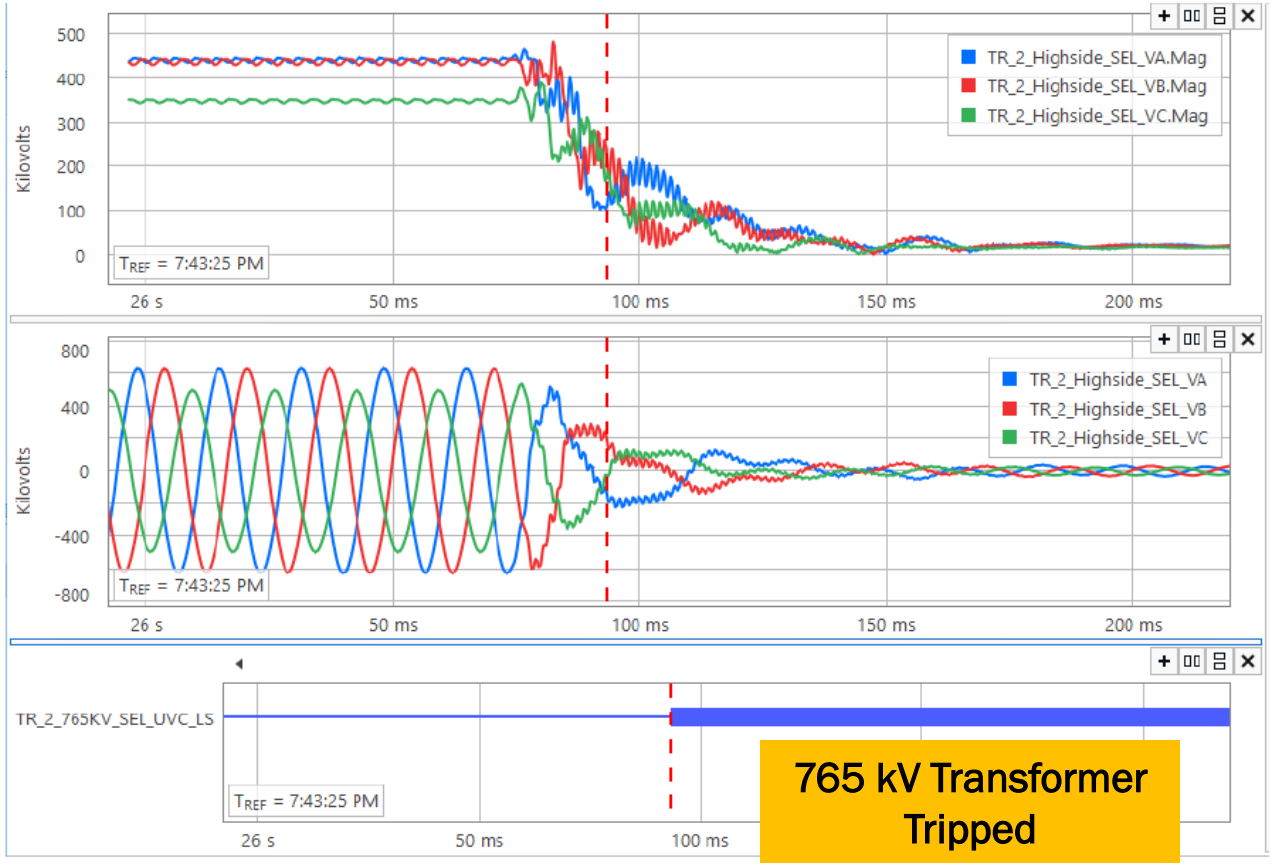
AEP EXAMPLES – CCVT FAILURE CAUSED 765KV LINE TRIP AND TRANSFORMER TRIP

Capacitor failure in high voltage stack of CCVT



Precursors Observed ~ 5 Hours Ahead

Capacitor failure in low voltage stack of CCVT



Precursors Observed ~ 5 Days Ahead

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

TYPES OF FAILURES IN CCVT'S THAT CAN BE DETECTED

CCVT Failure type	Detected with physical inspection?	Detected by EPG Solution
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	✗	✓

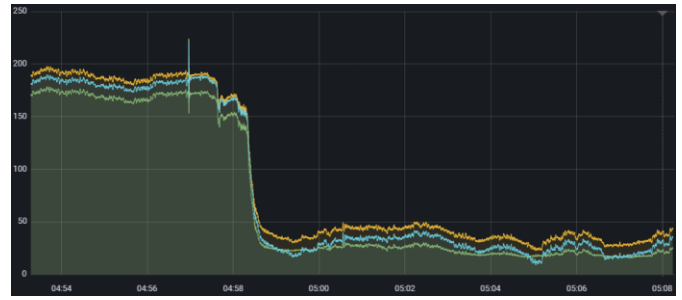
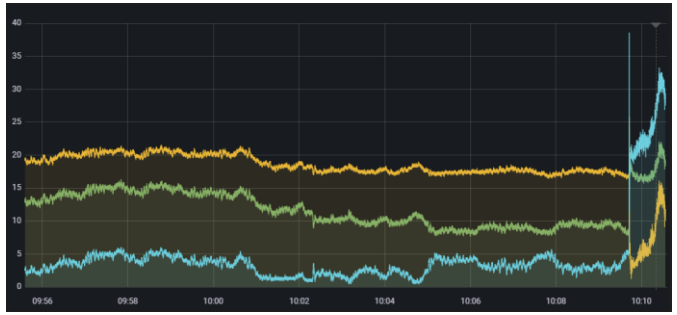
TYPES OF FAILURES IN CT'S AND PT'S THAT CAN BE DETECTED

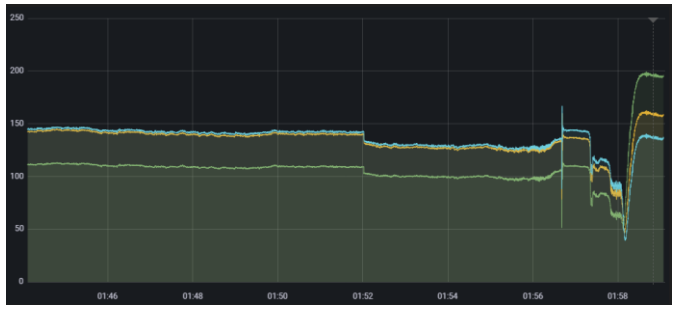
CT Failure type	Detected with physical inspection?	Detected by EPG Solution
Polarity error	✓	✓
Loose or corroded connections	✓	✓
Open CT secondary	✓	✓
Turn-to-turns shortage within same coil	✗	✓
Turn-to-ground shortage	✗	✓
Turn-to-turn shortage between different coils	✗	✓
Ratio setting error	✗	✓
Saturation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

PT Failure type	Detected with physical inspection?	Detected by EPG Solution
Blown Fuse	✓	✓
Loose connections	✓	✓
Primary winding issues	✗	✓
Secondary winding issues	✗	✓

DEPLOYMENT AT NYPA

- Deployed at a major 345 KV substation
- Monitoring 21 voltage transformers (CCVTs and PTS) and 27 CTs
- Alarms sent to NYPA personnel by email and includes screenshot of event/alarm with signatures
- Quick visual inspection before performing further investigation
- Used as supplementary Information along with other sources of information

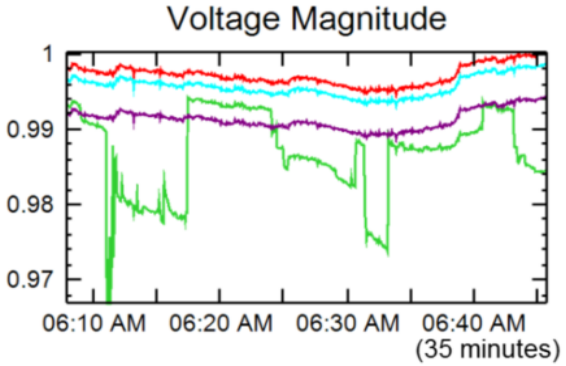






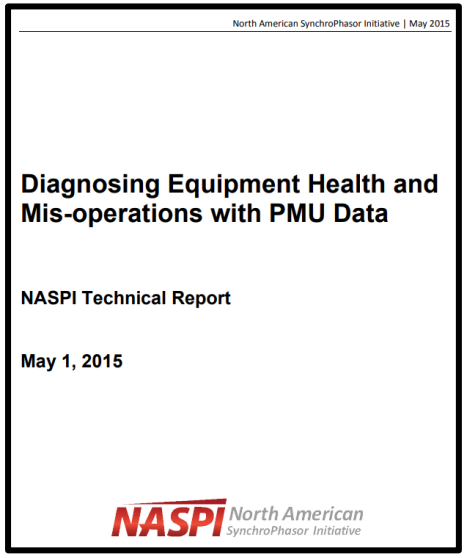
EXAMPLES OF INSTRUMENT TRANSFORMER FAILURES IN PMU DATA

LOOSE CONNECTIONS, WINDING ISSUES, BLOWN FUSES, ETC.

Loose Fuse Connections in CCVT Safety Switch – OG&E



Source: NASPI Technical Report, "Diagnosing Equipment Health and Mis-operations with PMU data", May 2015

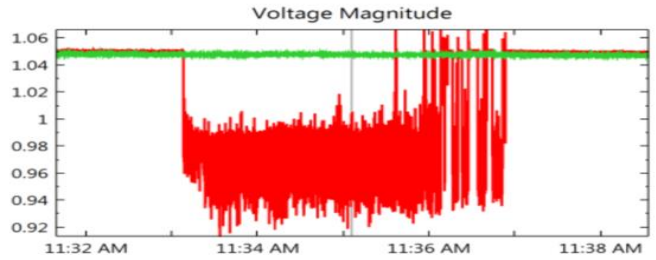

North American SynchroPhasor Initiative | May 2015

Diagnosing Equipment Health and Mis-operations with PMU Data

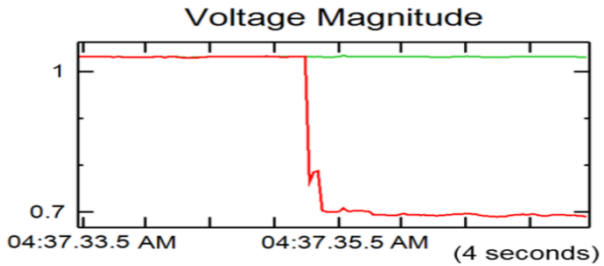
NASPI Technical Report

May 1, 2015

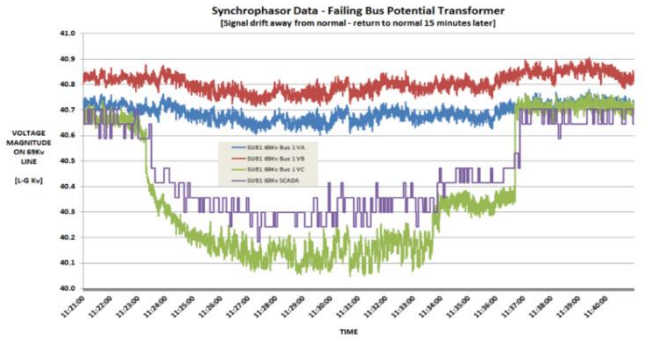
NASPI North American SynchroPhasor Initiative



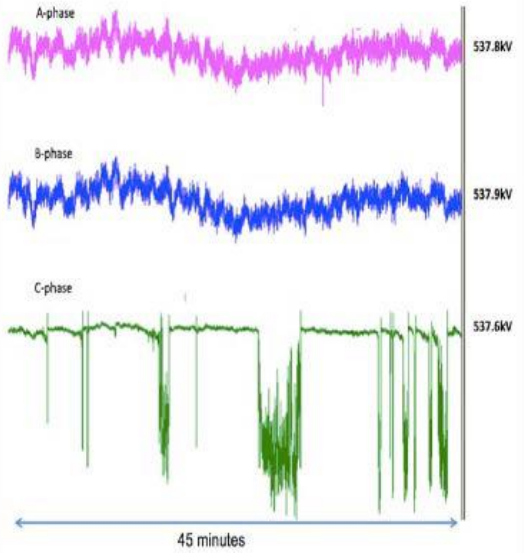
Loose Connection at PT feeding the PMU – OG&E



Blown fuse on One Phase of PT – OG&E



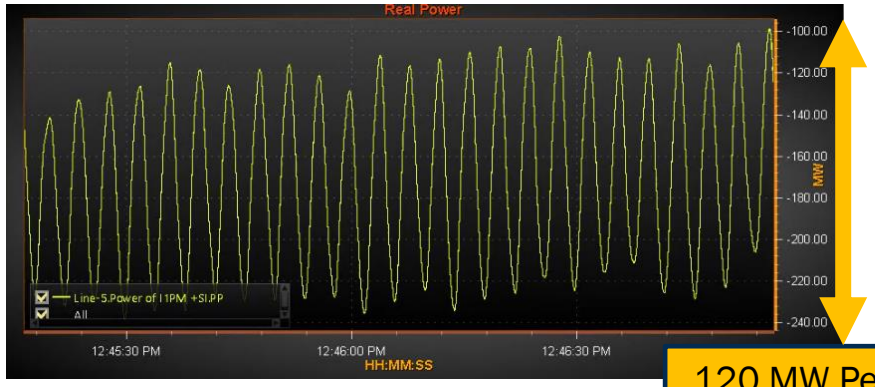
Internal Primary Winding Issue - ATC



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

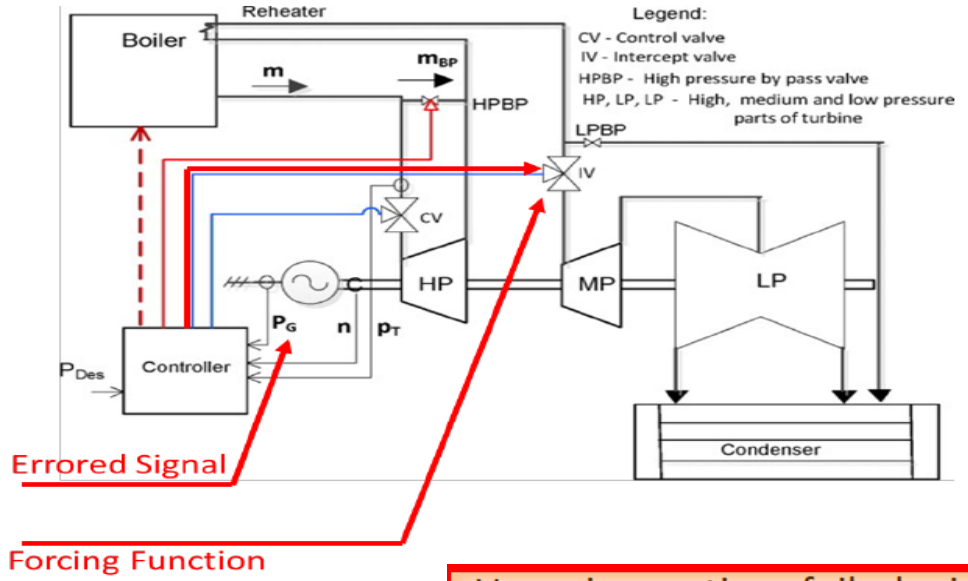
JAN 11, 2019 - EASTERN INTERCONNECTION OSCILLATIONS

- NERC findings point to failure of PT connection that triggered Interconnection Wide Oscillations
- Forced Oscillation at a plant caused eastern interconnection wide oscillations with large amplitudes (> 150 MW peak-peak)
- Important to identify oscillations and locate source
- Important to identify and address root-cause to prevent system wide impact



120 MW Peak-Peak

NERC
NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

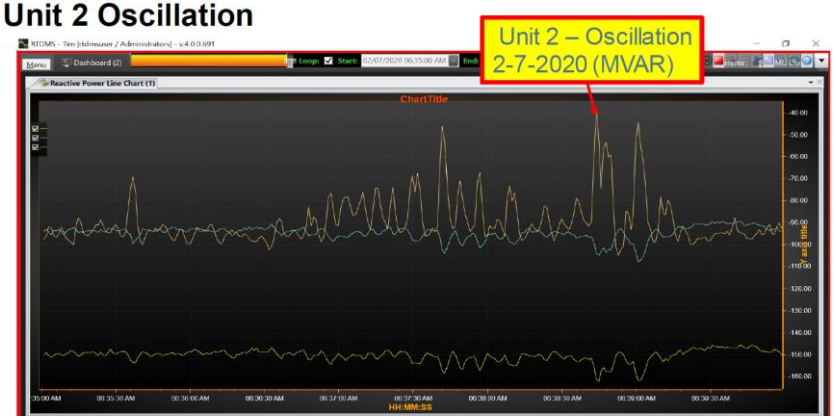


Upon inspection, failed wiring in PT cabinet

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

FAILING PT CAUSED MVAR OSCILLATIONS AT GENERATING STATION

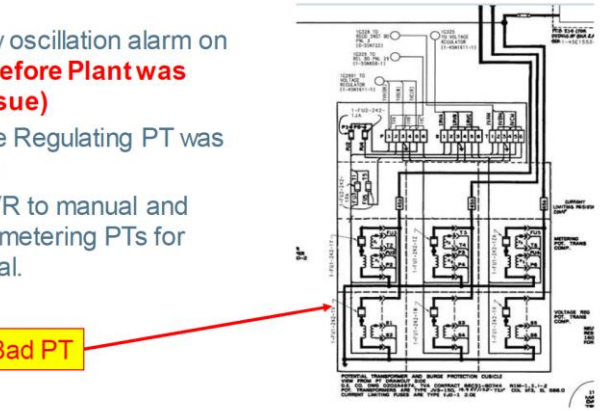
Unit 2 Oscillation



Source: Jonathan Sides, EPG Webinar, "Use of Synchrophasor Technology at TVA", October 2021

Unit 2- Bad PT

- Actually saw oscillation alarm on 2-7-2020 **(Before Plant was aware of issue)**
- The A-phase Regulating PT was the problem
- Switched AVR to manual and swapped to metering PTs for voltage signal.



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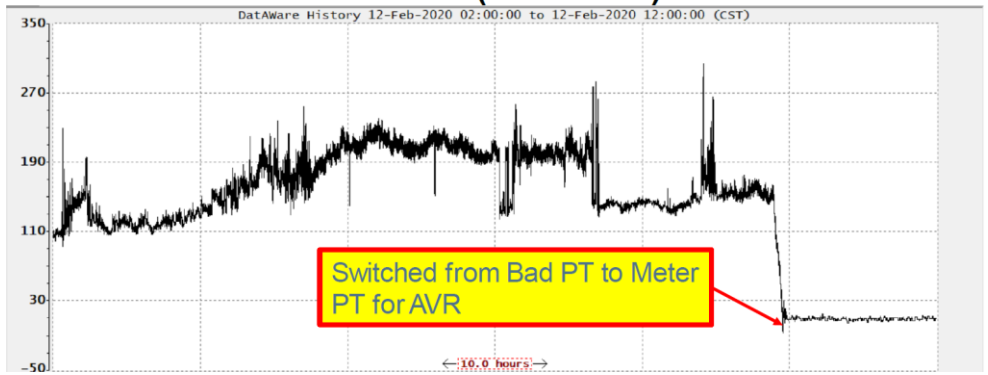
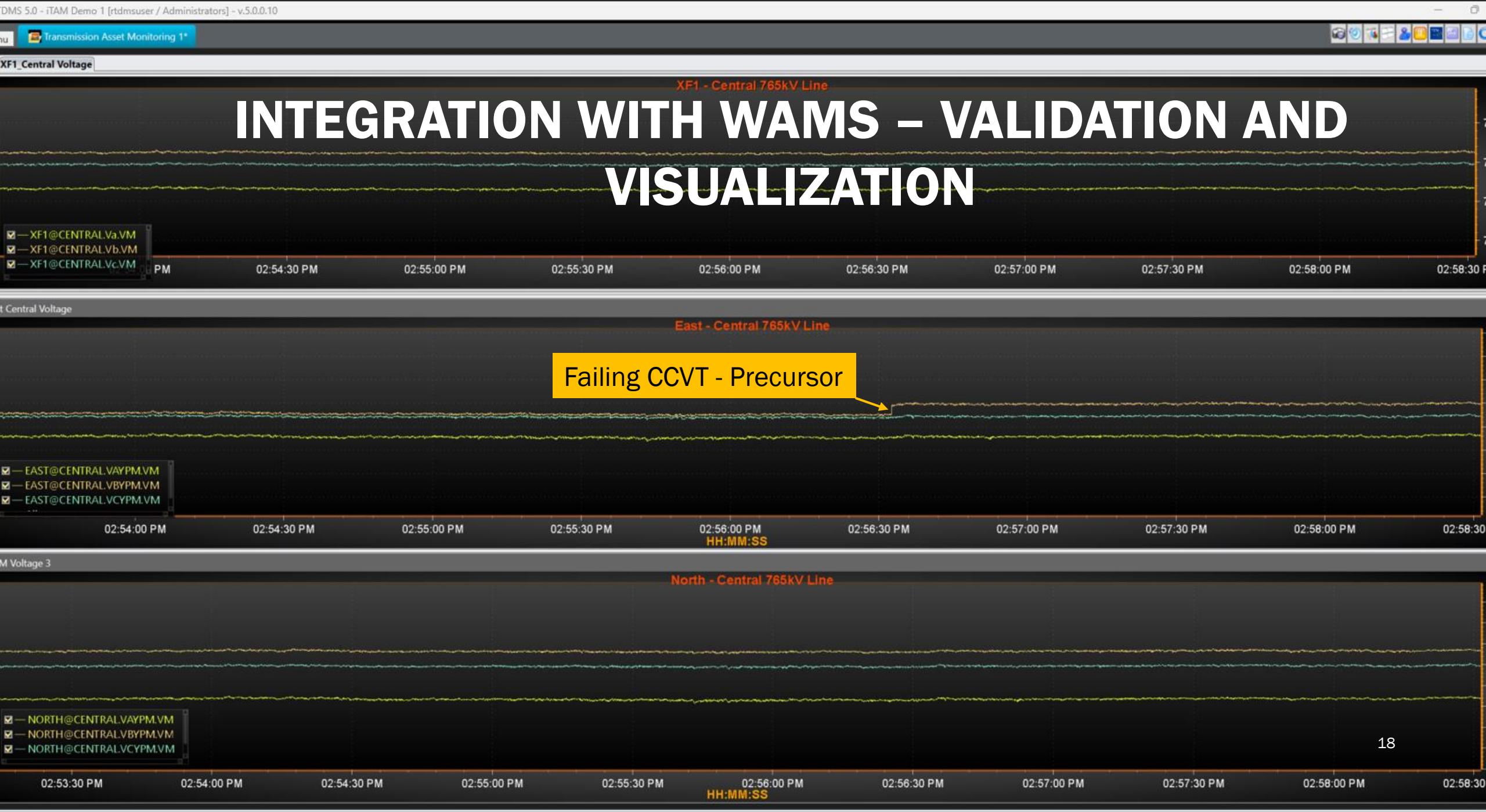
TVA TENNESSEE VALLEY AUTHORITY

Unit 2 MVAR – SCADA Data (2-12-2020)



Oscillations can reveal issues with asset/equipment

INTEGRATION WITH WAMS – VALIDATION AND VISUALIZATION



SUMMARY AND LOOKING FORWARD

- High Resolution Time-Synchronized Measurements can provide significant insights into equipment health and help detect precursors to equipment failure
- Compliment traditional asset management systems
- Further improvements and roadmap items:
  - Use of Machine Learning for categorization and root cause identification
  - Periodic Performance Reports for assisting asset management and preventative maintenance

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

THANK YOU

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