Synchrophasor Technology – PMU Use Case Examples

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NASPI Work Group meeting and first International Synchrophasor Symposium,
March 22-24, 2016, Atlanta, GA

Synchrophasor Technology – PMU Use Case Examples

Source: https://www.smartgrid.gov/files/CCET-SGDP-FTR_Feb_2015.pdf

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Use of Synchrophasor Technology for Managing Grid

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18th National Power Systems Conference
19th December, 2014, Guwahati, India

TECHNOLOGY SOLUTIONS
FOR WIND INTEGRATION IN ERCOT

FINAL TECHNICAL REPORT

Rev 0 Chg 1

February 23, 2015

SUBMITTED FOR COOPERATIVE AGREEMENT

DE-OE0000194

PREPARED FOR

U. S. Department of Energy
National Energy Technology Laboratory

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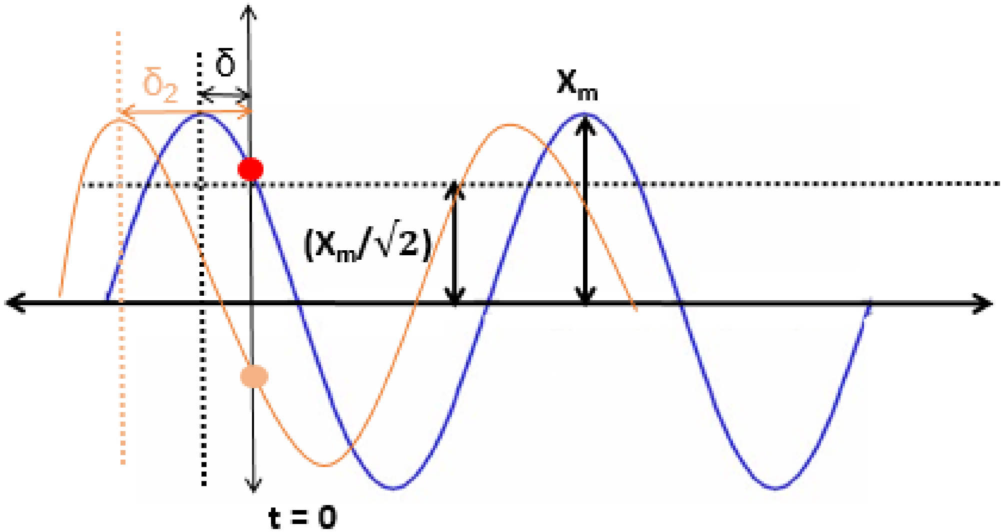
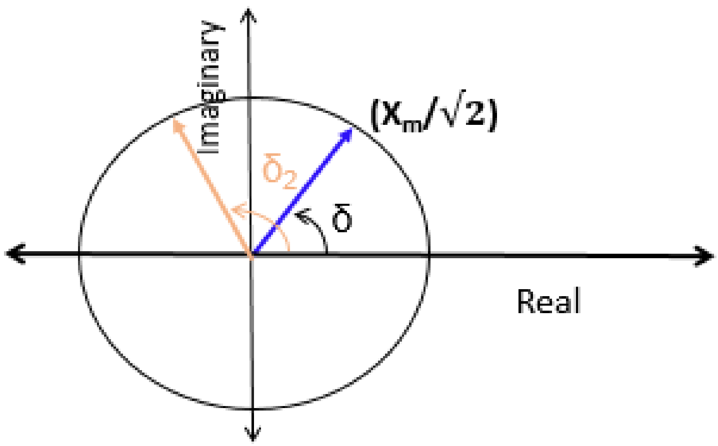
What is a Voltage Phasor ?





SYNCHROPHASOR TECHNOLOGY – PMU USE CASE EXAMPLES

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November 5, 2014

Prepared for CCET DAT Synchrophasor Team

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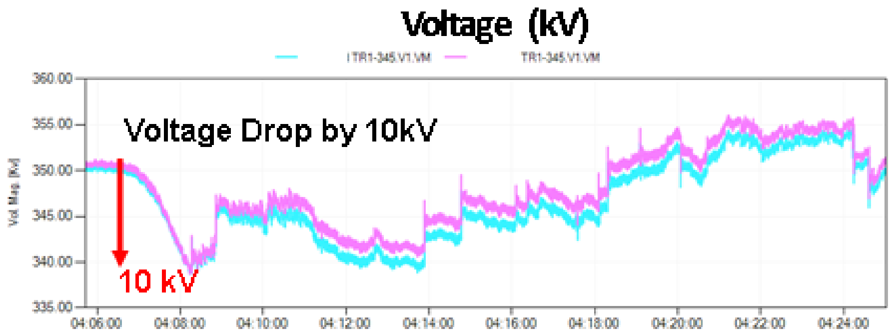
Use Case Overview

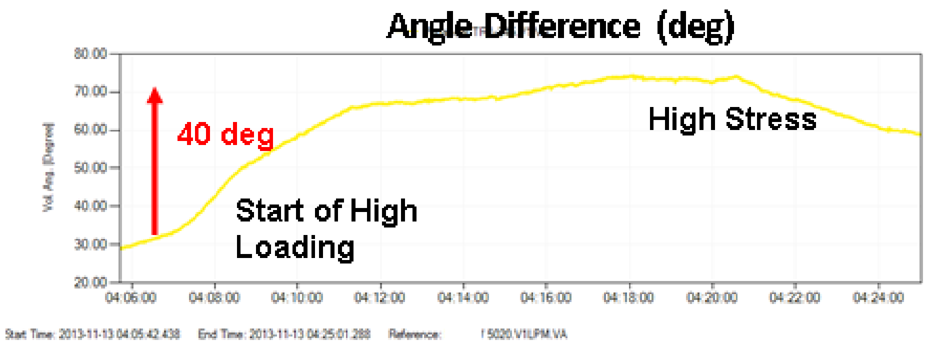
Use Case	Grid Scope	Streaming 30 samples/sec	Slow Speed 3 samples/min	Local Event Capture	Example of Application on ERCOT Grid
High Stress Across System (High Phase Angle) Observed	Wide Area	Yes	Yes		High Phase Angle from Valley - November 13, 2013
Small Signal Stability – Damping is Low	Wide Area	Yes			Control system oscillations from wind plant - January 9, 2014
Small Signal Stability – Emerging Oscillation Observed	Wide Area and Local	Yes			Slow System Oscillation Detected October 12,2014
Voltage Oscillation Observed	Regional	Yes			Wind Control System Oscillations in Valley - April 12-13, 2013
Voltage Instability Monitoring (real-time P-V or Q-V curve)	Regional	Yes			High Phase Angle in Valley - November 13, 2013
Detection of Subsynchronous Interactions (Not necessarily resonance, just below 60 hz)	Local Regional	Yes			
Integrate PMU Data Into State Estimator	Wide Area	Yes	Yes		Baselining Study confirmed correlation between PMU and State Estimator data
System Disturbance – Capture and Interpretation	Regional	Yes	Yes, not high resolution	Yes	Enhanced Event Analysis Capabilities - numerous examples
Generator Parameter Determination	Local	Yes		Yes	Wind plant oscillation and trip following line outage - September 2011, reported in 2012 IEEE PES paper
Major Load Parameter Determination	Local	Yes		Yes	
PMU-Based Fault Location	Local Regional	Yes		Yes	
Phase Angle Across Breaker for Reclosing Action		Yes	Yes		ERCOT operating studies identify need for monitoring phase angles
Subsynchronous Resonance Identification and Mitigation (PGRR027)	Regional	Yes			
Transmission Characteristics Determination	Regional	Yes		Yes	
Dynamic Transmission Line Ratings using PMU monitoring	Regional	Yes			
Validation of Control Devices (e.g. SVC) performance	Regional	Yes		Yes	

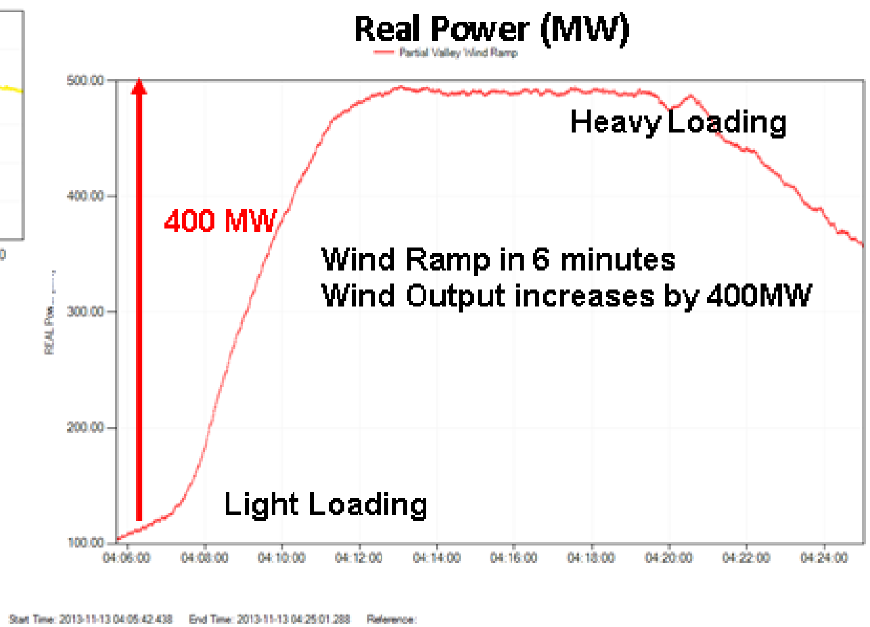
Use Case - High Stress Across System (High Phase Angle) Observed

- **Need:** PMU Phase Angle data can advise the Shift Engineer about the measured angle across wide area to provide early warnings on high power flow (high grid stress)
- **Example: High Phase Angle at Coast 3 (Valley) – Nov 13, 2013**
- **Possible Action:**
  - Shift Engineer reviews high phase angle, and examines possible consequences if an event aggravates this.
    - Online TSAT Study
    - Online VSAT study
    - Online Power flow study
  - Shift Engineer may recommend action to shift supervisor
    - Impose Transfer limit
    - Adjust generation pattern

Event Analysis – Impact of High Wind on System Performance Following Wind Ramp







Reference Angle: North 7

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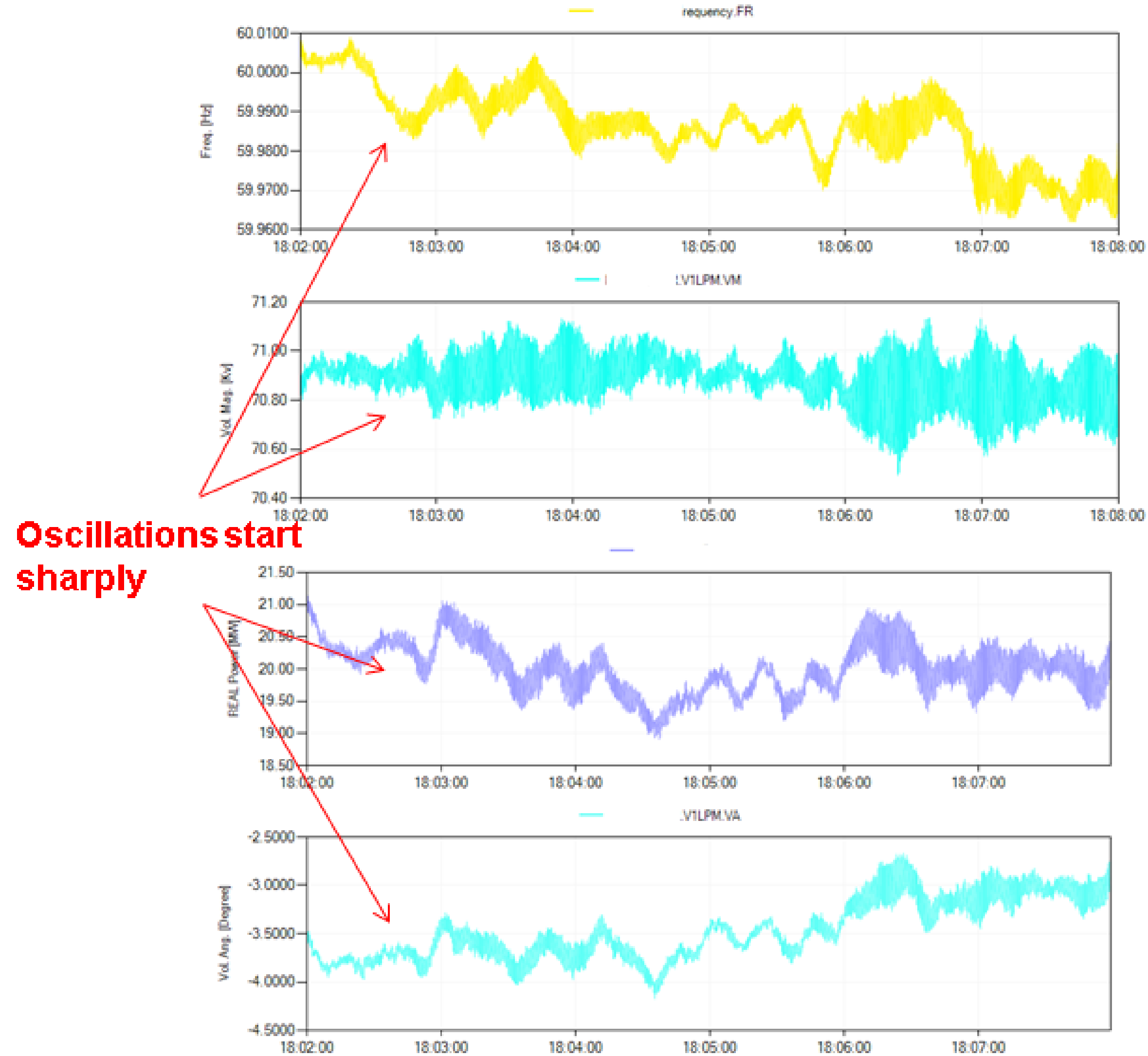
Use Case - Small Signal Stability – Low Damping

- **Need:** PMU data can advise the Shift Engineer about both known & unknown oscillations at location/s
- **Example: Control system oscillations from wind plant – January 9, 2014**
- **Possible Action:**
  - Shift engineer should review
    - Oscillatory frequency & damping
    - Determine type of oscillation (inter-area such as 0.6Hz North-South Mode, Local Control system such as 3.2Hz at West 10)
  - Shift Engineer may recommend action to shift supervisor
    - Reduce Transfer out of area
    - Reduce generation output
    - Revert control system settings to original value & restore output

PMU Data Illustrates Oscillation With Low Damping



Frequency (Hz)

Voltage (kV)

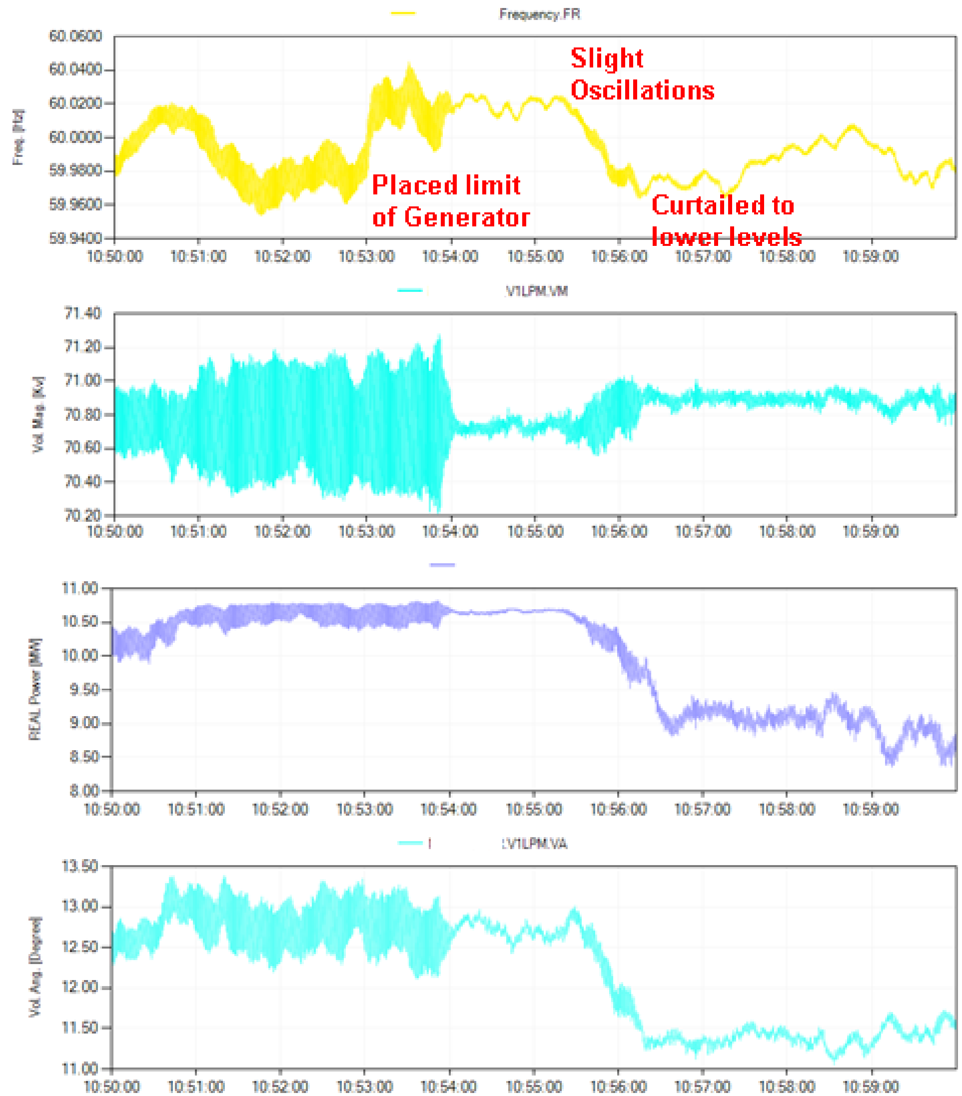
Real Power MW)

Angle Difference (deg)

Reference Angle: North 7

Phasor Grid Dynamic Analyzer (PGDA) plots

PMU Data Illustrates Oscillation With Low Damping



Frequency (Hz)

Voltage (kV)

Real Power MW)

Angle Difference (deg)

Reference Angle: North 7

Phasor Grid Dynamic Analyzer (PGDA) plots

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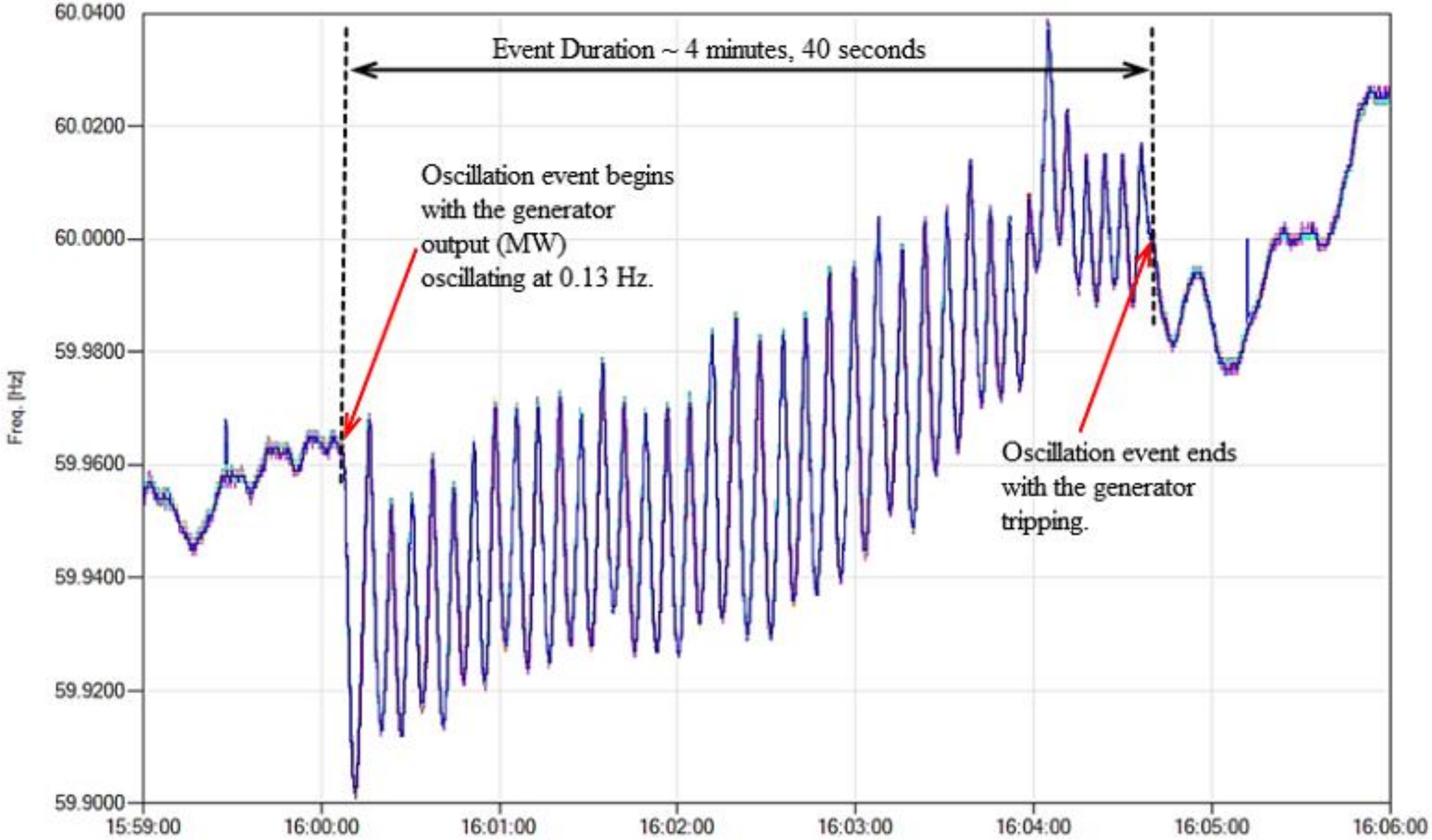
Use Case - Small Signal Stability – Emerging Oscillation Observed

- **Need: PMU data can advise the Shift Engineer about both known & unknown oscillations at location/s**
- **Example: System-Wide Oscillations Following Loss of Generation – October 12, 2014**
- **Possible Action:**
  - Shift engineer should review
    - Oscillatory frequency & damping
    - Determine type of oscillation (e.g. inter-area such as 0.6Hz North-South Mode or Local Control system such as 3.2Hz at West 10)
  - Shift Engineer may recommend action to shift supervisor
    - Reduce Transfer out of area
    - Reduce generation output
    - Block control system (to eliminate control system-driven oscillations)

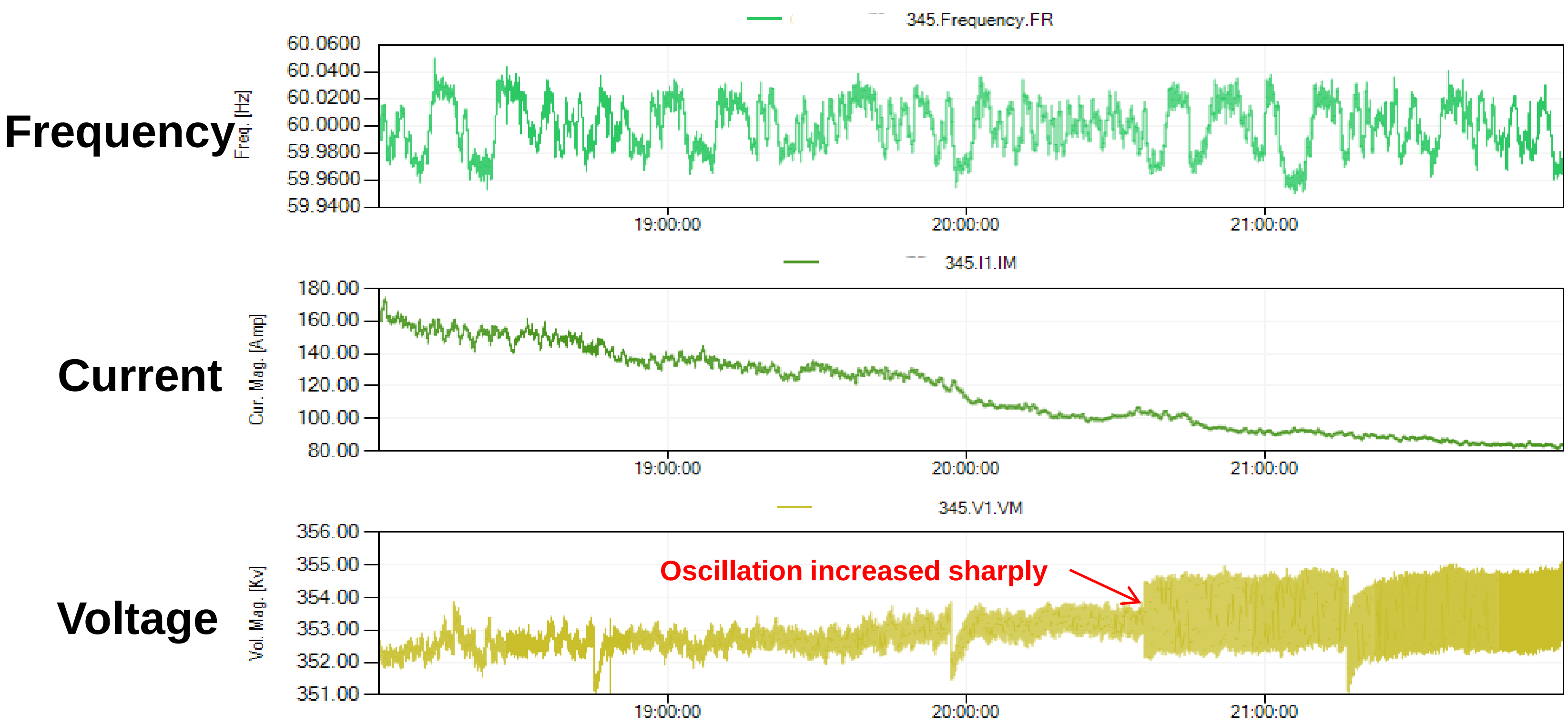
PMU Data Illustrates Emerging Oscillation



Use Case - Voltage Oscillation Observed

- **Need:** PMU Voltage Phasor can advise the Shift Engineer about the voltage oscillations at location/s due to fast voltage controllers at wind generators and other control devices in the grid
- **Example: Voltage Control oscillations from nearby wind plant – April 12-13, 2013**
- **Possible Action:**
  - Shift engineer should review location for possible causes
    - Low strength area (weak grid or low circuit ratio)
    - Incorrect settings on voltage controllers/voltage regulators
  - Shift Engineer may recommend action to shift supervisor
    - Reduce Transfer out of area
    - Reduce generation output
    - Restore outages

Nearby PMU Detects Voltage Oscillation



Screenshots of PGDA (Phasor Grid Dynamics Analyzer)

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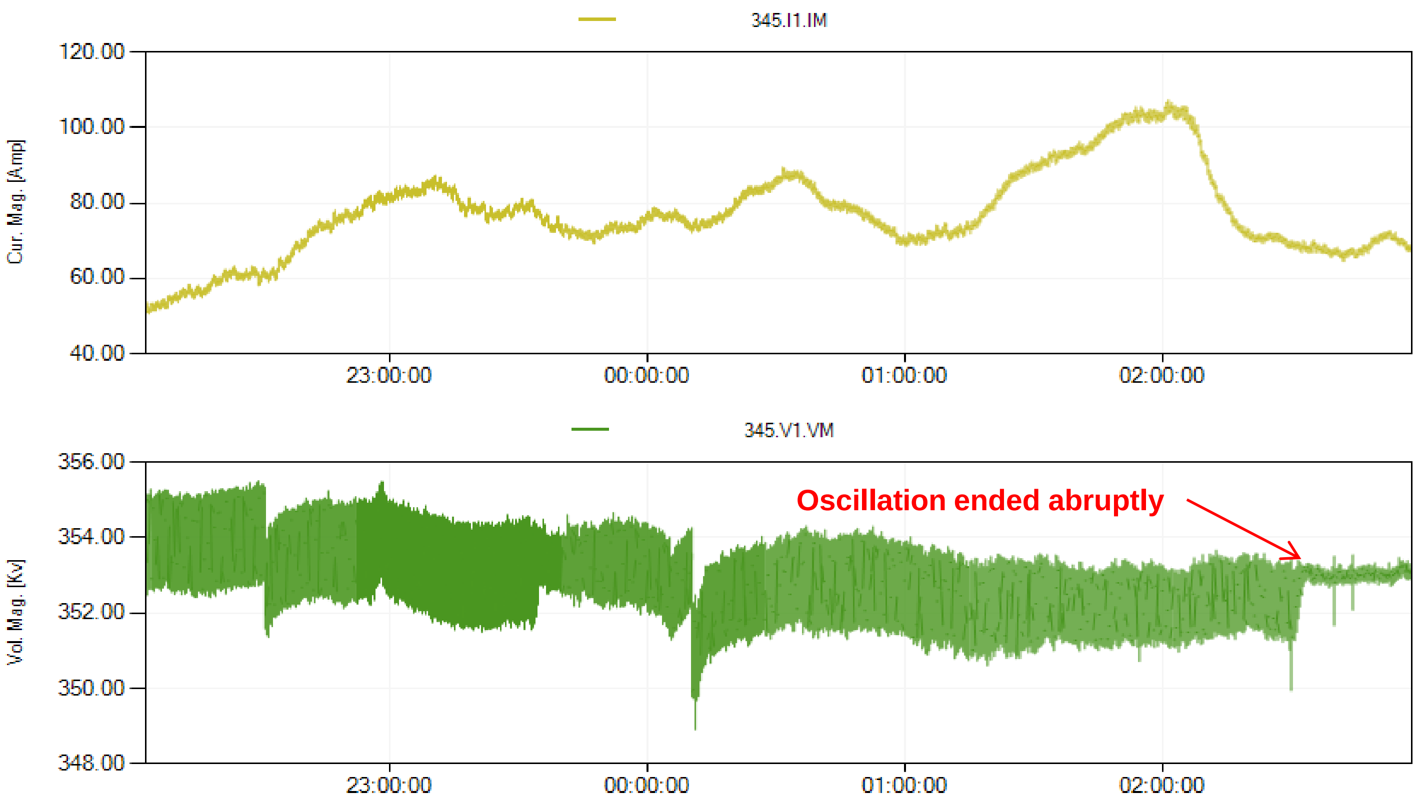
Nearby PMU Detects Voltage Oscillation

Current

Voltage

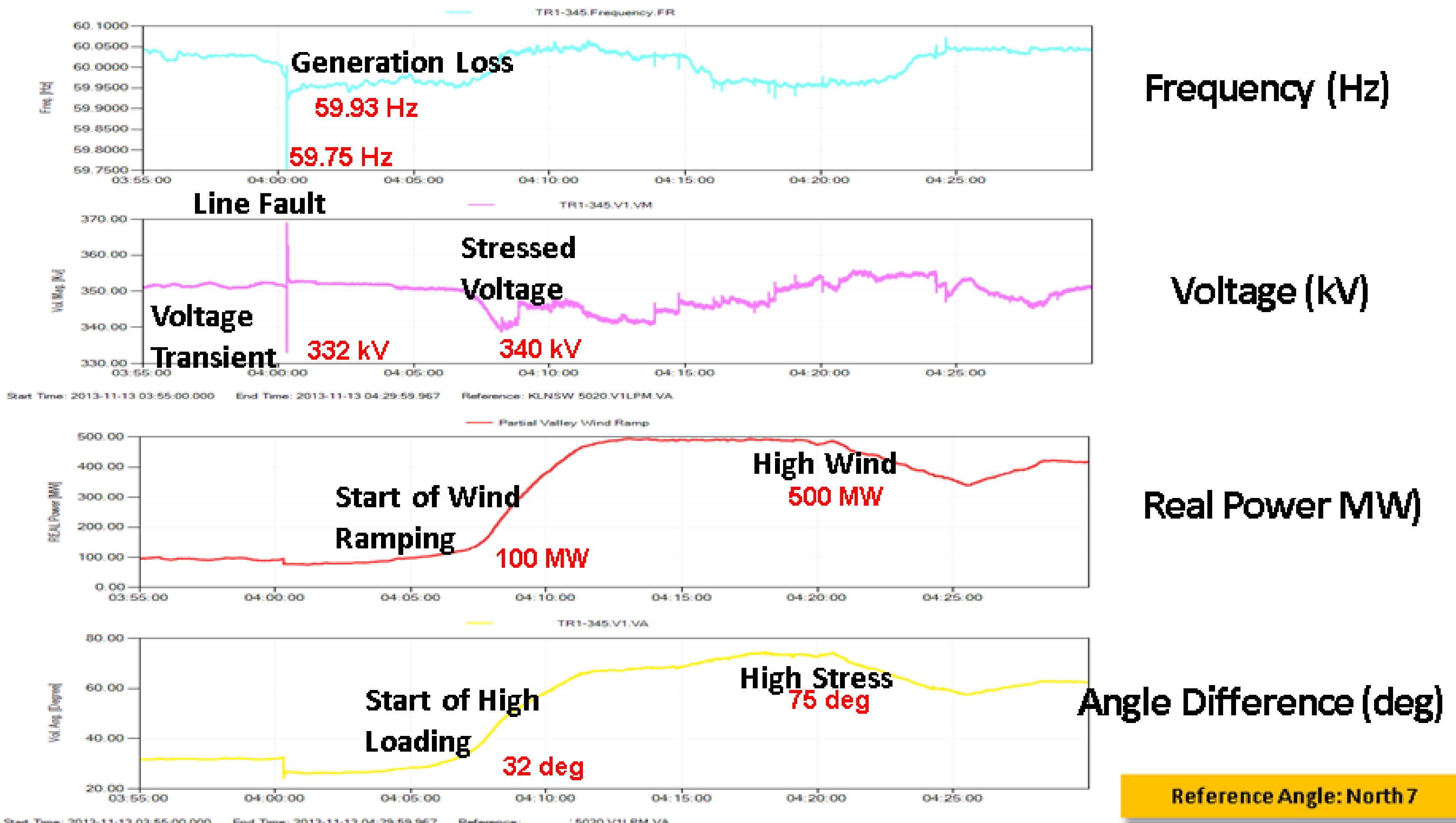


Screenshots of PGDA (Phasor Grid Dynamics Analyzer)

Use Case - Voltage Instability Monitoring (P-V, Q-V)

- **Need:** PMU data (Real, Reactive Power & Voltage) can advise the Shift Engineer indirectly on high grid stress under low voltage deteriorating conditions
- **Example: High Phase Angle at Coast 3 (Valley) – Nov 13, 2013**
- **Possible Action:**
  - Shift Engineer reviews P-V performance, compares to online VSAT study
  - Shift Engineer may recommend action to shift supervisor
    - Impose Transfer limit
    - Adjust generation pattern
  - Operations planning studies and benchmarking will be required to identify critical substations for voltage instability monitoring

PMU Data Illustrates Voltage Stress During Power Ramp



Using Phasor Grid Dynamic Analyzer (PGDA) plots

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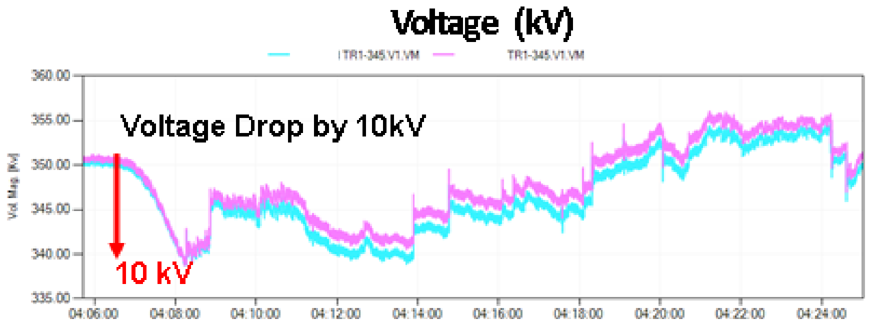
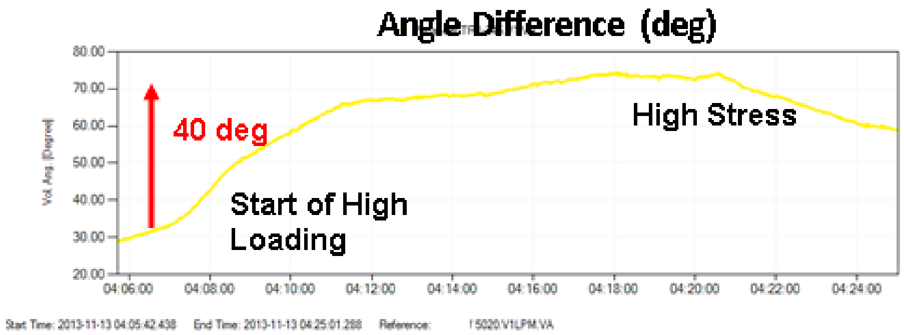
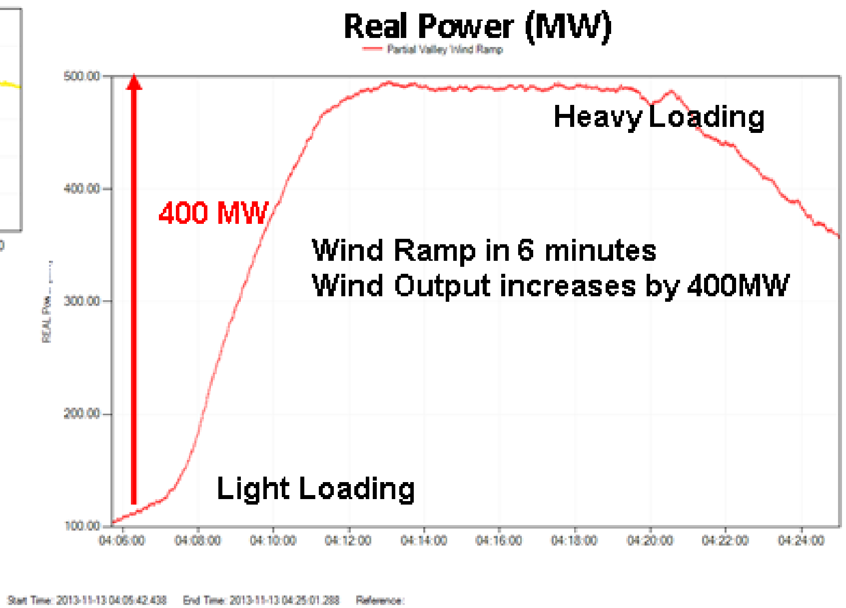
PMU Data Illustrates Voltage Stress During Power Ramp







Reference Angle: North 7

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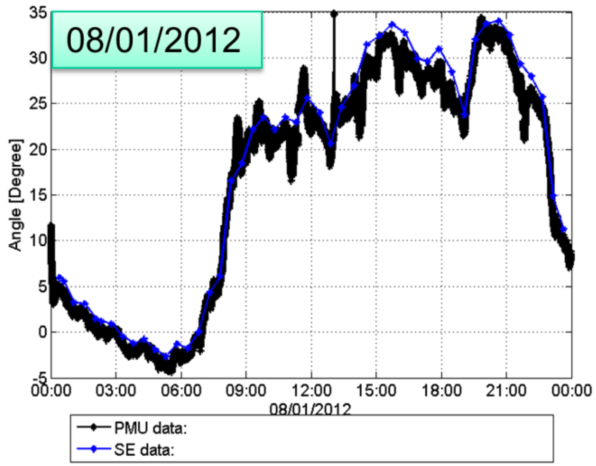
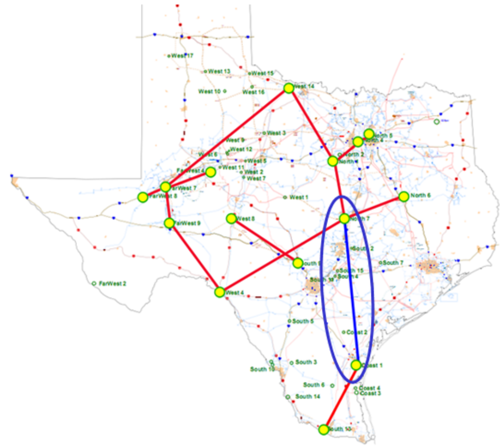
Use Case - Validate State Estimator Results Used in Control Rooms

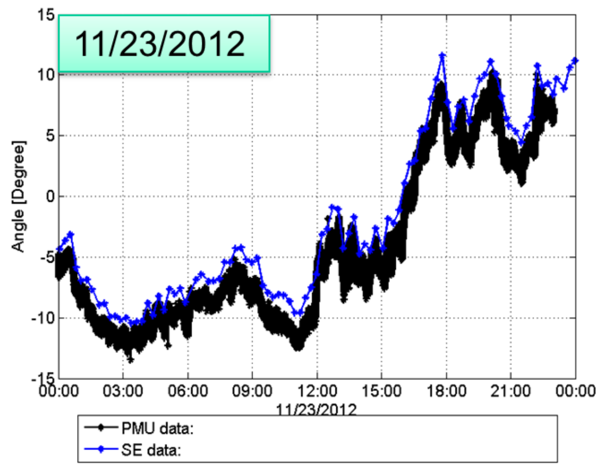
- **Need:** PMU Phase Angles can used to validate the state estimator results used in control rooms (locates differences which reflects anomalies in models used for state estimation)
- **Example: Baselining studies**
- Possible Action:
  - Identify the root cause for the mismatch and update models

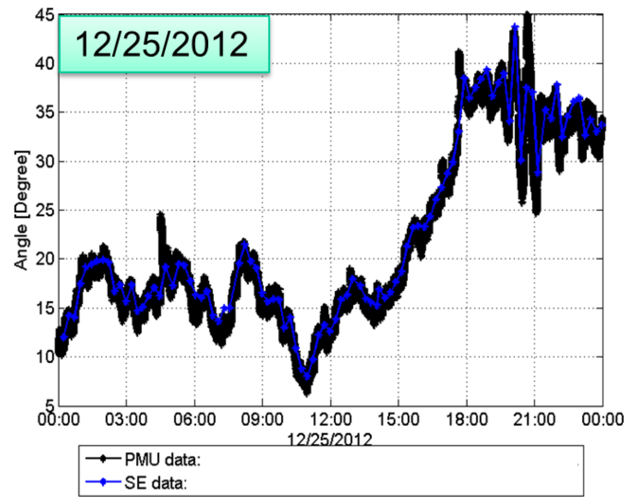
PMU Data vs SE Data Comparison

Coast 1-North 7







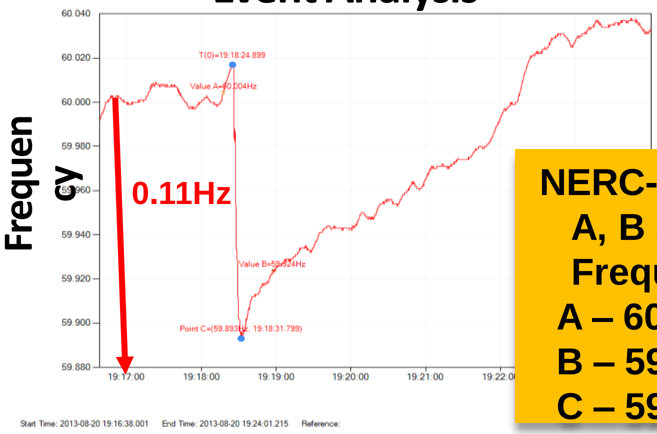


Use Case - System Disturbance – Cause & Interpretation

- **Need:** PMU data is useful for event analysis and determine root cause of the event and its location.
- **Example: Event Signatures of Generation Trip, Line trip & Oscillations**
- **Possible Action:**
  - Shift Engineer reviews network performance, including frequency dip and recovery, voltage dip and recovery, power dip (and phase angle) and recovery, and any transient oscillations and the associated ring-down characteristics
  - If recovery looks slow, refers to Advanced Network Applications expert or System Planning dynamics expert to determine if some action is recommended or for further review
  - If frequency, voltage, or power (and phase angle) dip looks too large or too small, or does not return to expected levels, refer to Advanced Network Applications expert or System Planning dynamics expert to investigate the reasons for abnormal grid responsiveness
  - Frequency response and/or transient voltage response of generation (including wind, solar, and conventional generation) should be monitored for compliance with standards
  - Should include an automatic reporting capability, providing a high-level review of the network performance

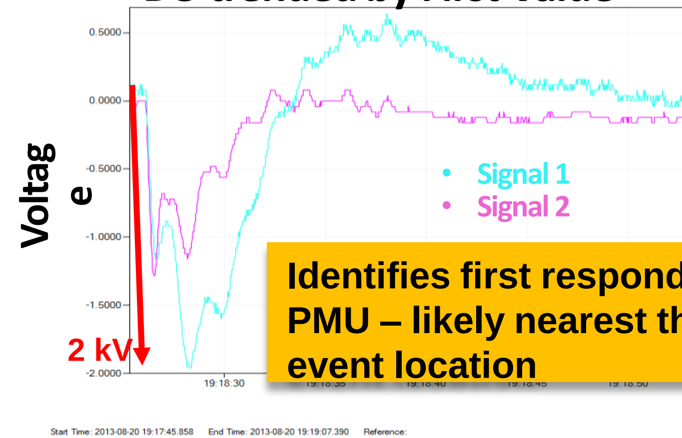
PMU Data Enables Effective Post-Event Analysis

Event Analysis



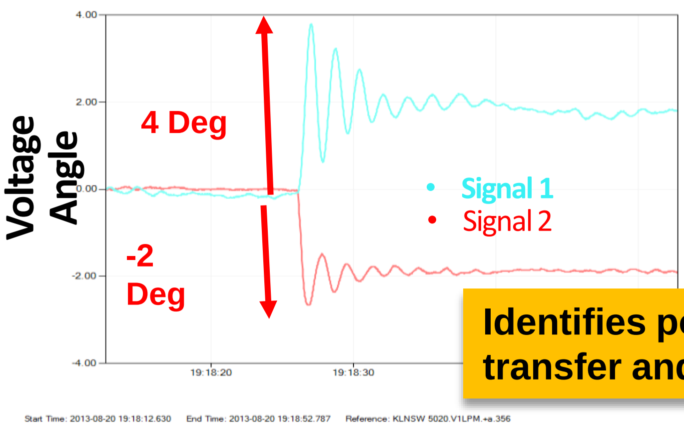
NERC-defined A, B and C Frequency
A – 60.004 Hz
B – 59.924 Hz
C – 59.893 Hz

De-trended by First Value



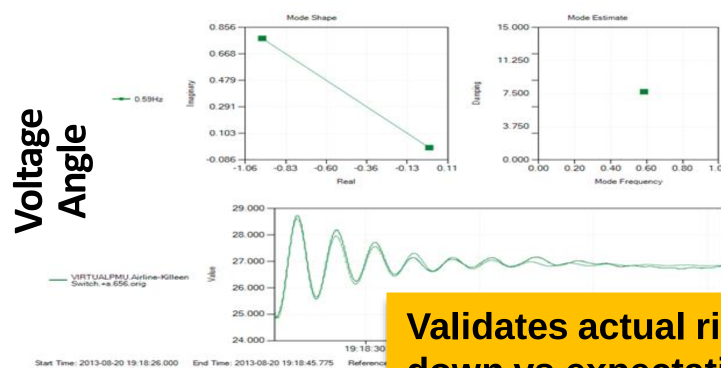
Identifies first responding PMU – likely nearest the event location

De-trended by First Value



Identifies power transfer and direction

Ringdown Analysis



Validates actual ring-down vs expectation

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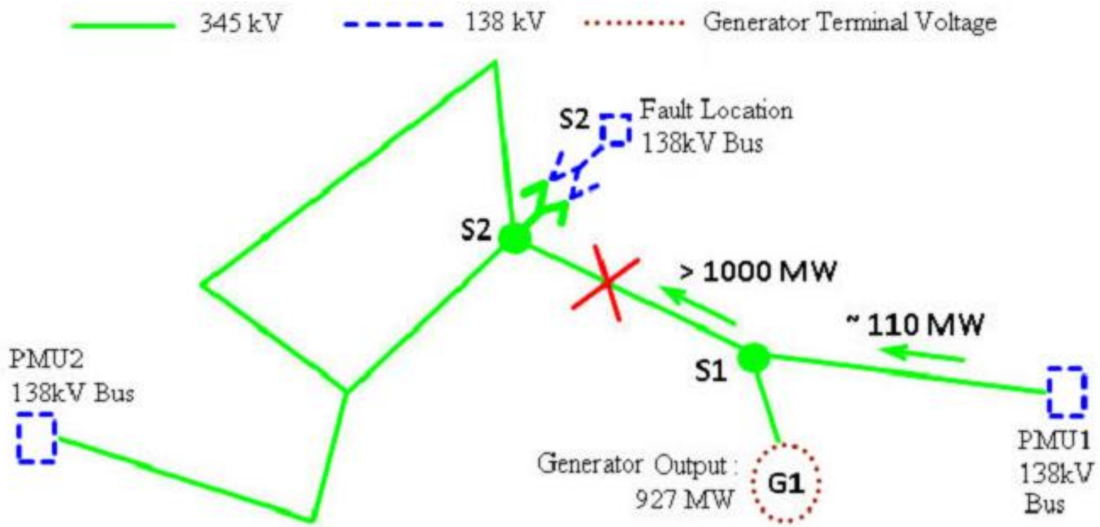
PMU Data Enables Effective Post-Event Analysis – Power Load Unbalance Circuit Example

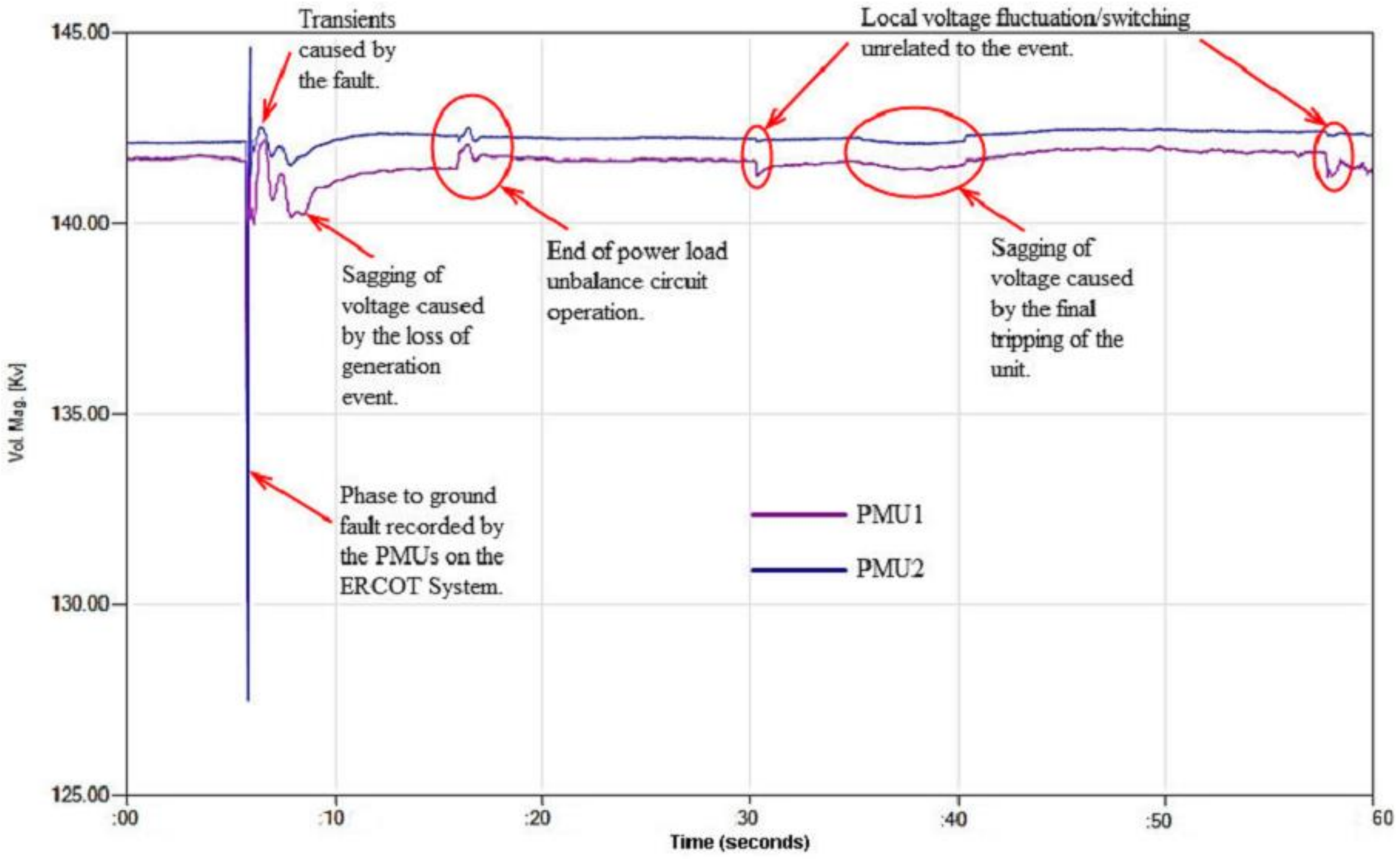
- **Predictive relaying**
  - Protection against possible over-speed of generator/turbine
- **Designed to rapidly close control/intercept valves under load imbalance conditions**
- **Relay checks for two conditions –**
  - Difference in mechanical and electrical loading
    - operates if the difference is greater than 40% (typically)
  - Rate of decrease of electrical load
- **After clearing of unbalanced condition –**
  - Wait for pre-set time delay
  - Reset PLU relay
  - Allow intercept valves to open again

Event Analysis - System Condition



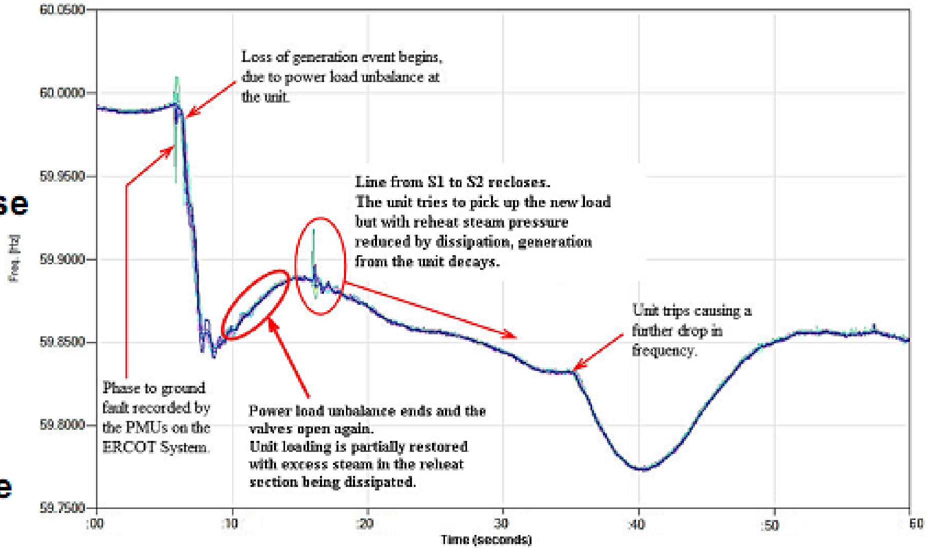
- **Generator 'G1' close to full output.**
- **Fault on 138kV bus section at sub-station 'S2'**
  - Fault cleared in ~5 cycles
  - Three 138kV circuits tripped as part of the fault clearing.
- **Fault detection and mis-operation of relay at substation 'S1'**
  - Line from 'S1' to 'S2' tripped due to mis-operation

Event Analysis - Fault



Event Analysis - Description

- **Following the fault and clearing –**
  - Due to loss of the 'S1' – 'S2' circuit, PLU initiated at unit 'G1'
  - Closing of control/intercept valves leading to ~575 MW loss
  - Frequency drop from 59.99 Hz to 59.846 Hz
- **Frequency decline arrested by inertial response**
  - PLU condition cleared
  - Intercept valves allowed to open again
  - Loading restored partially to ~500 MW
  - Excess steam in reheat dissipated
- **'S1' – 'S2' circuit reclosed 10 seconds after the fault**
  - Unit 'G1' loading increased after reclosing
  - Lack of sufficient pressure in reheat to sustain increased load
  - Generation decay – run back
- **Trip of Unit 'G1'**



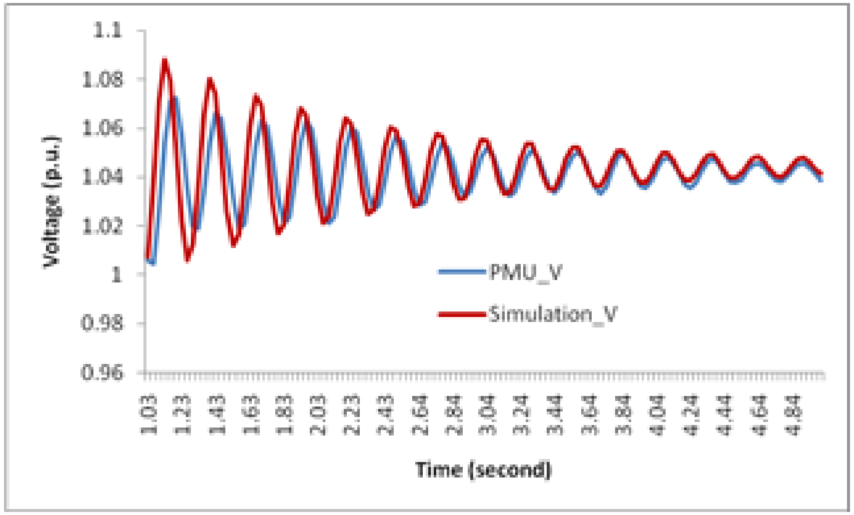
Event Analysis - Lessons Learned

- **New use-case for synchrophasor technology from ISO viewpoint**
  - Correction of incorrect design/operation of protection systems
- **Sequence of Events established by collaboration with Transmission Owner and Plant Operator**
  - Mis-operation of transmission relay leading to line trip
  - No mis-operation in PLU circuit, relay operated as designed
- **Unit tripping not the objective of PLU circuit**
- **Plant Operator in discussion with vendor to determine –**
  - whether unit trip was necessary
  - whether PLU circuit parameters need to be changed
- **Accurate representation of PLU relaying effects in modeling of contingencies in planning studies**
  - Investigate the possibility of other generators on the system having similar characteristics
  - Possible detailed dynamic studies to investigate improved modeling of this type of event.
  - Consider when these type studies would be appropriate.
    - Possibly as part of interconnection process.

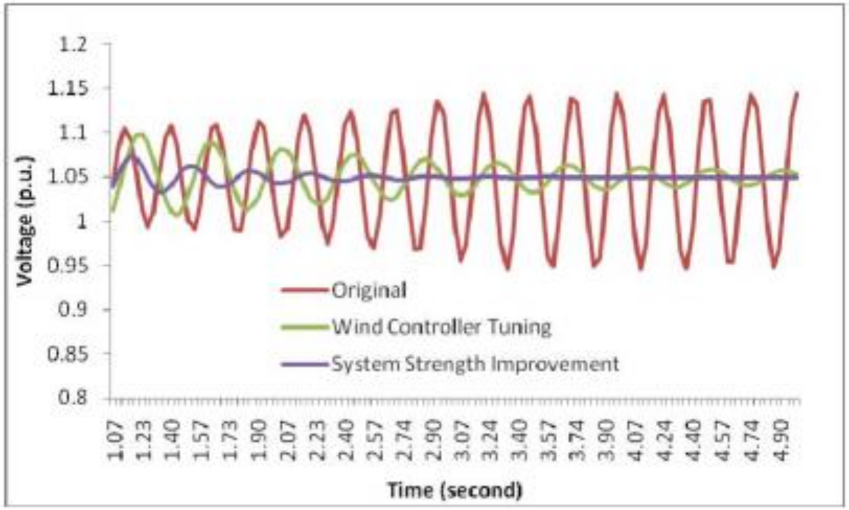
Use Case - Generator Parameter Determination

- **Need:** PMU data (Voltage Phasor, P & Q) can advise generator dynamic response following a nearby transient, compares results to simulated response (based on system planning models), and alerts if differences are significant (meaning that the generator response to the transient event was different from what was expected)
- **Example: PMU Data Used to Validate and Calibrate Generator Models**
- **Possible Action:**
  - Advance Network Applications expert or System Planning dynamics expert reviews the event and the generator response differences, and if necessary, triggers the capture of the current grid state for further study
  - System Planning dynamics expert coordinates with generator owner to investigate the reasons for unexpected generator response
  - System Planning – Dynamics Working Group utilizes the apparent unit parameters and system response data to tune/benchmark the dynamic model associated with the unit in the ERCOT DWG dynamic dataset

Generator Parameter Validation



Recorded vs Simulated Voltage Response at Wind Power Plant – Low power output



Recorded vs Simulated Voltage Response at Wind Power Plant – High power output – Improved performance after tuning wind controller settings

Source: Jian Chen, Prakash Shrestha, Shun-Hsien Huang, N.D.R. Sarma, John Adams, Diran Obadina, John Balance, “Use of Synchronized Phasor Measurements for Dynamic Stability Monitoring and Model Validation in ERCOT”, Proceedings of the 2012 IEEE PES General Meeting, San Diego, July 2012.

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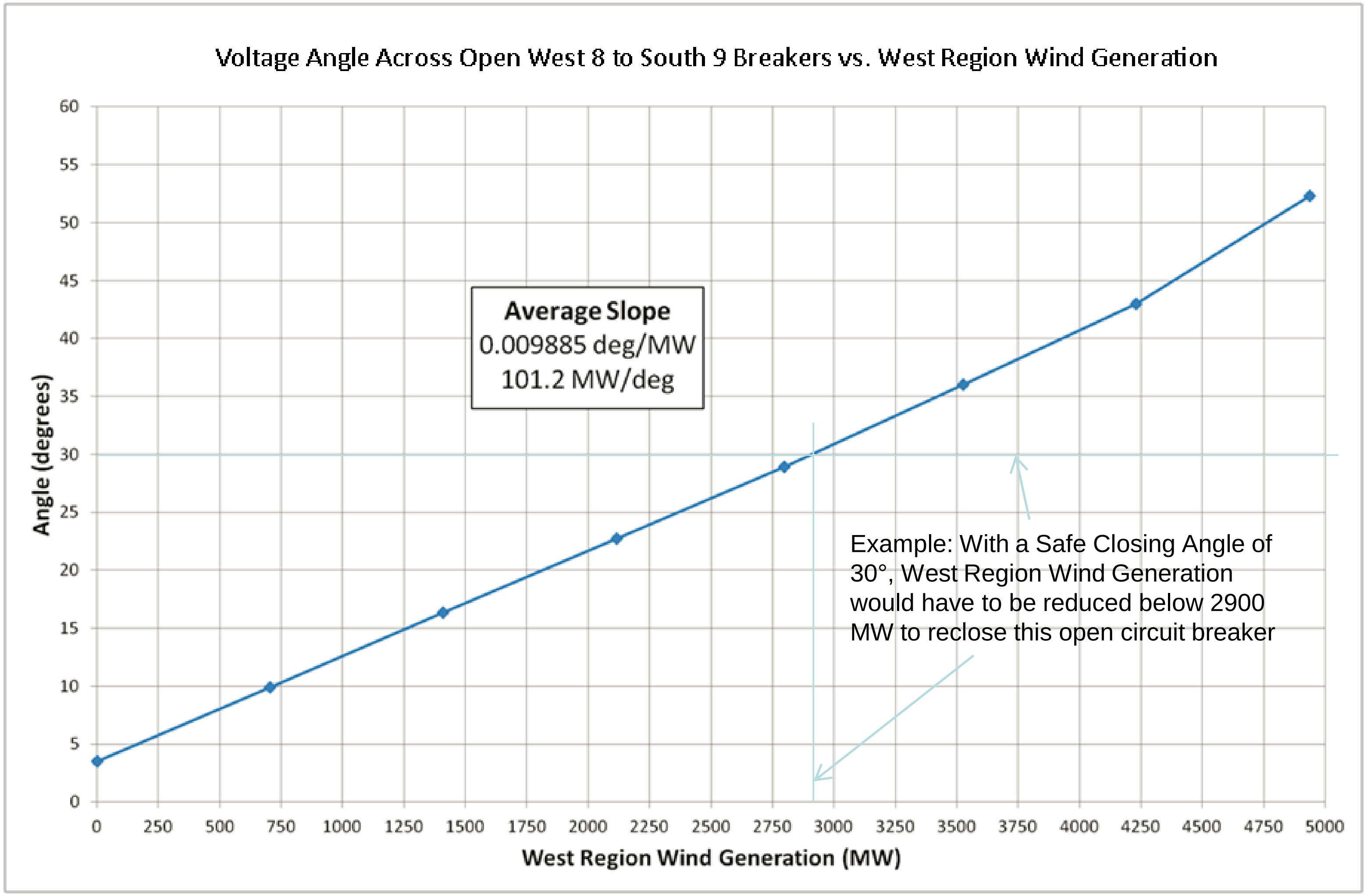
Use Case - Phase Angle Across Breaker for Reclosing Action

- **Need:** PMU data is useful during an event to identify stress across system, and validate safe restoration actions
- **Example: High Phase Angle Across Breaker**
- **Possible Action:**
  - Shift Engineer reviews PMU voltage phase angle differences between substations (with breaker open between them)
  - If voltage phase angle difference is within safe breaker reclosing limits, proceed with planned restoration of lines
  - If voltage phase angle difference looks too large, refer to Advanced Network Applications expert or System Planning dynamics expert to identify mitigation actions needed to reduce phase angle to within limits for restoration

Phase Angle Across Open Breaker - Example



Questions

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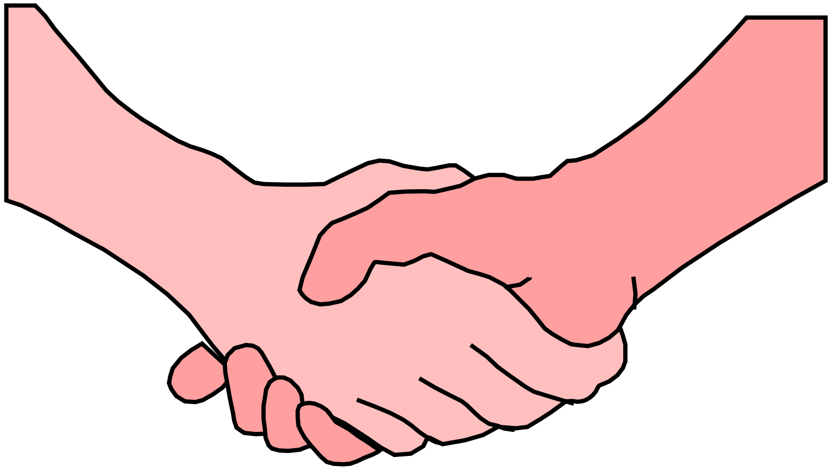

Thank U !!

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