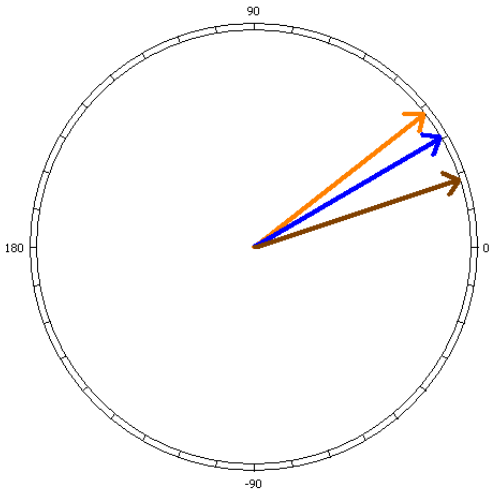
SynchroPhasor use at OG&E

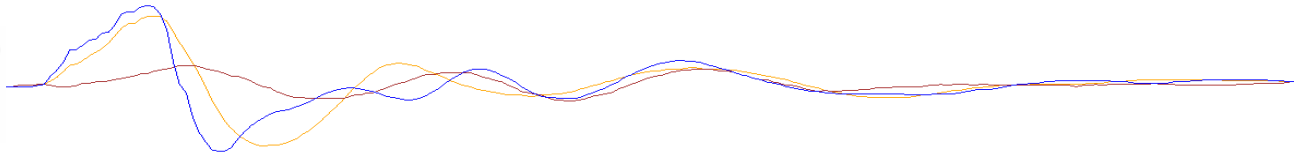


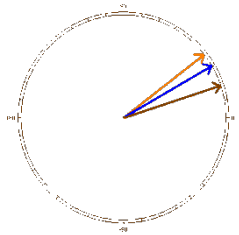
Austin D. White P.E.

Steven E. Chisholm

Oklahoma Gas & Electric

OG&E





Outline

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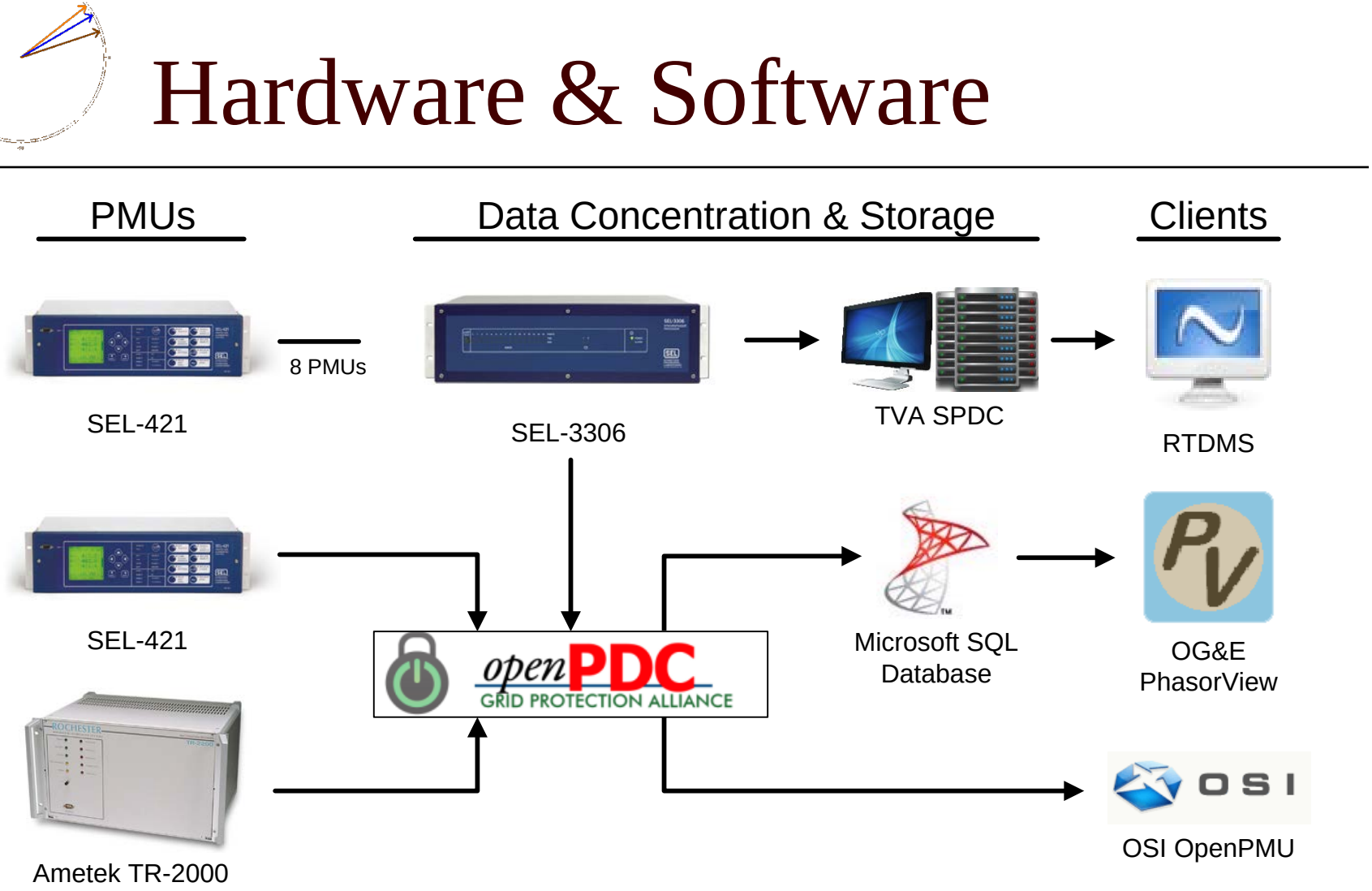
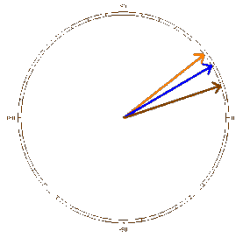
- Problems Solved & Interesting Findings
- Future Plans

Hardware & Software



Client Visualization Station



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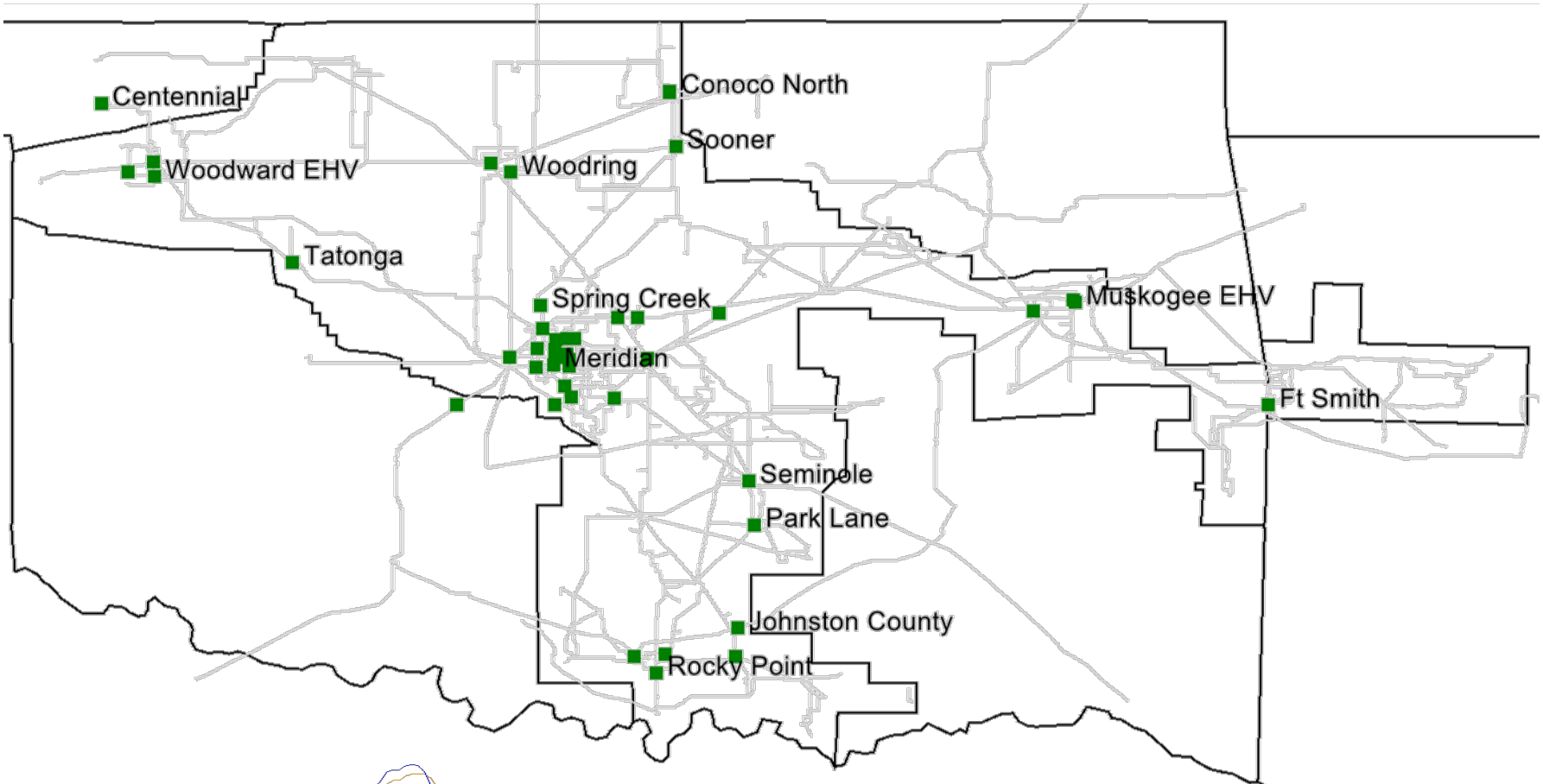
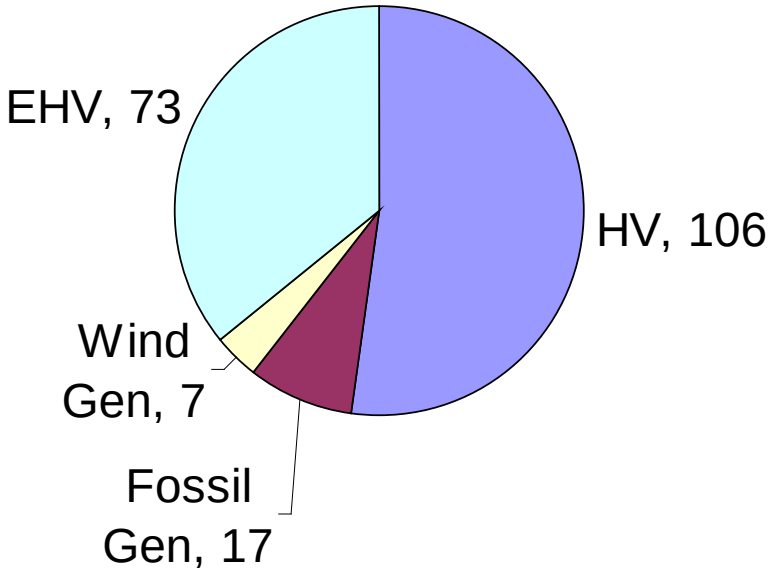
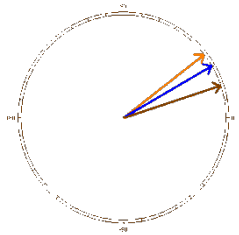
PMU Locations



PMU Coverage Stats

- 100% of EHV System
  - 53 Line Terminals, 20 Autotransformers
- 100% of Wind Farms
  - 1000MW, 7 Plants
- 90% of Fossil Generation
  - 6200MW, 17 Units
- 31% of HV System
  - 106 Line Terminals





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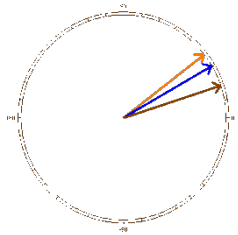
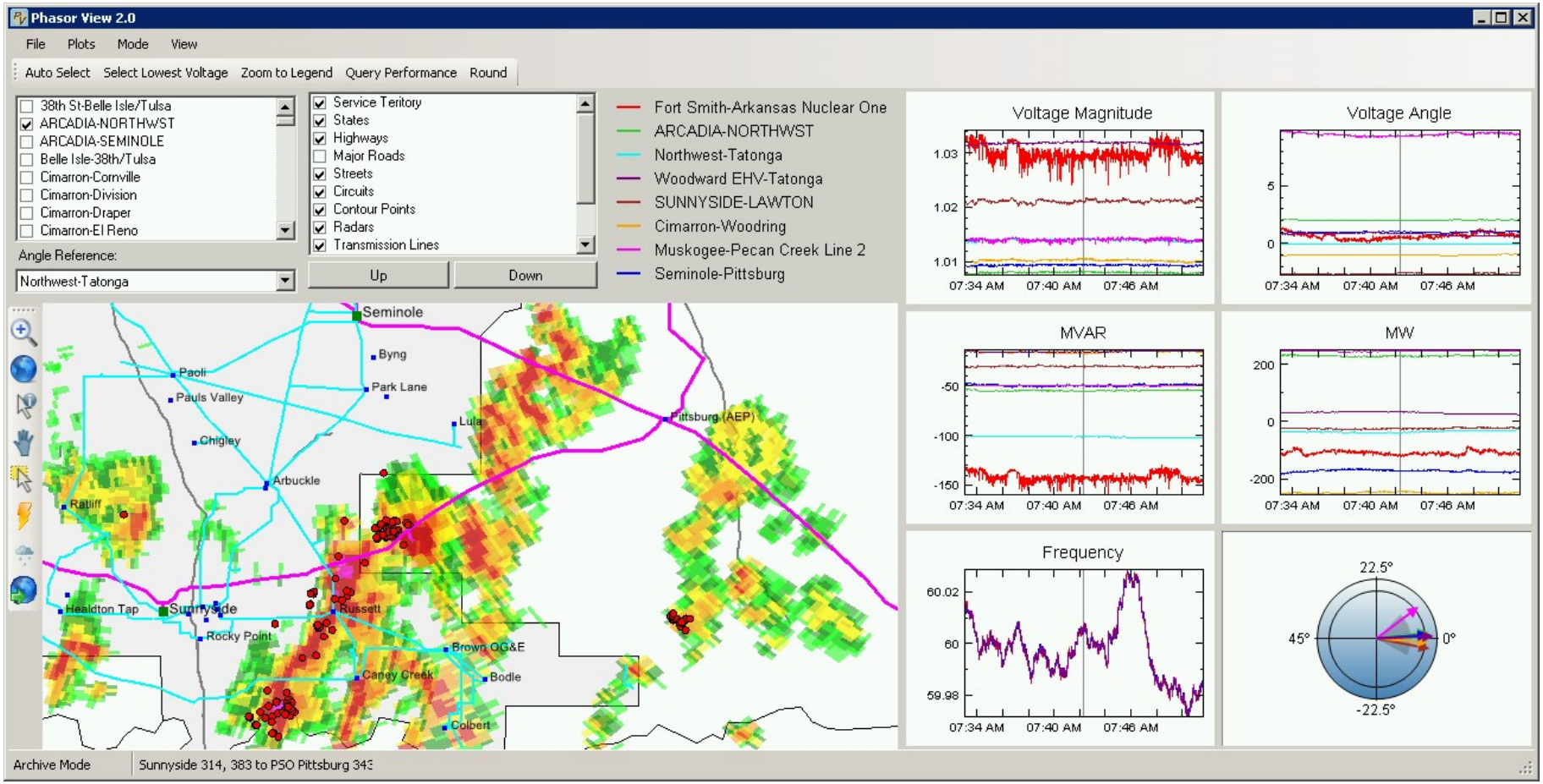


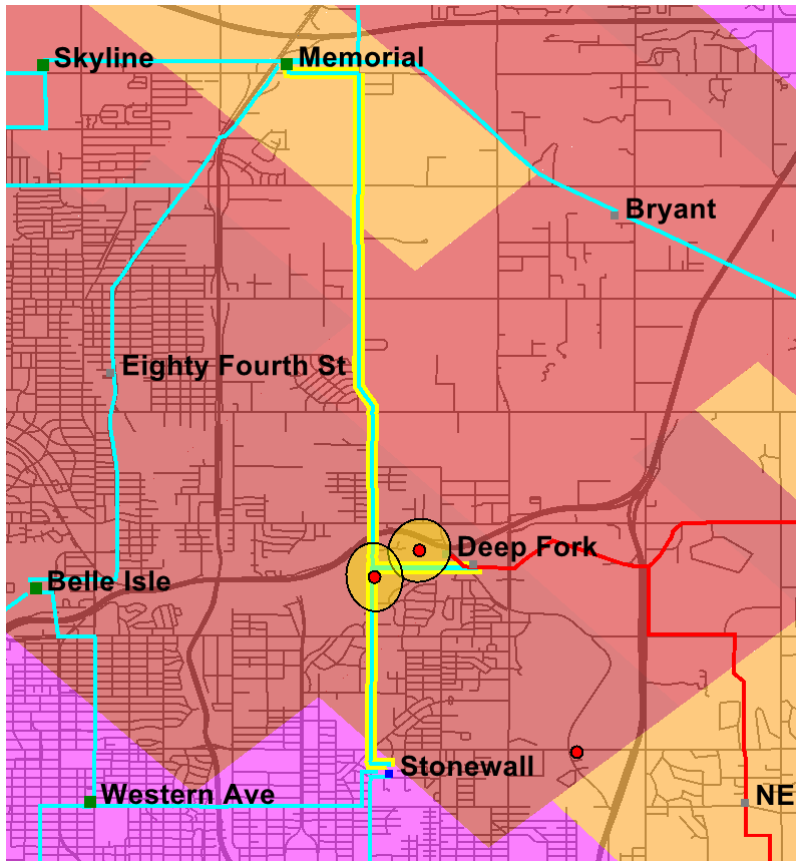
Use at OG&E

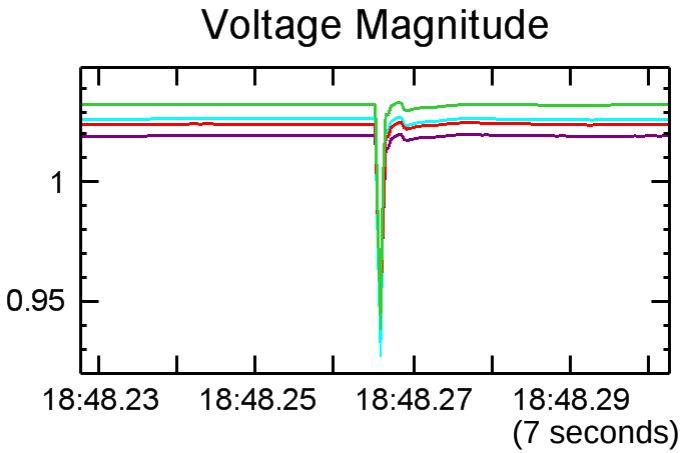
- Situational Awareness
- Disturbance/Misoperation Analysis
- State Estimator Enhancement
- Stability Assessment
- Proactively Find Equipment Problems
- Voltage Recovery Assessment (reactive reserves)
- Wind Farm Integration/Monitoring

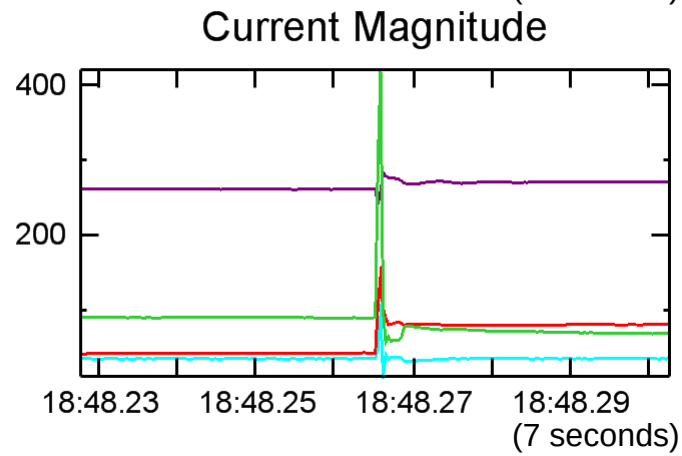
Situational Awareness - PhasorView



Disturbance/Misoperation Analysis with PhasorView

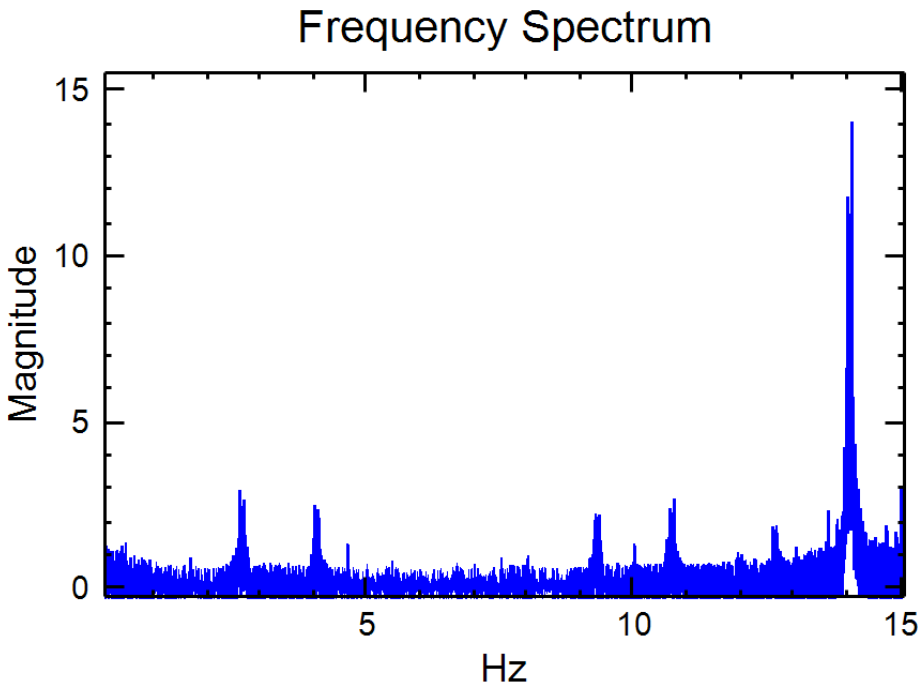






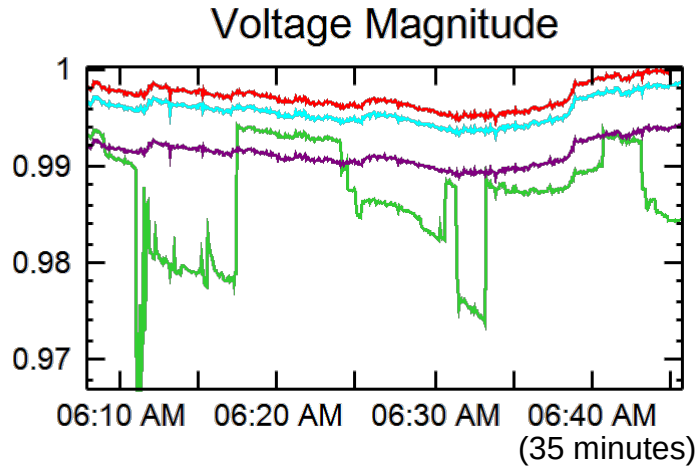
Stability Assessment - FFT

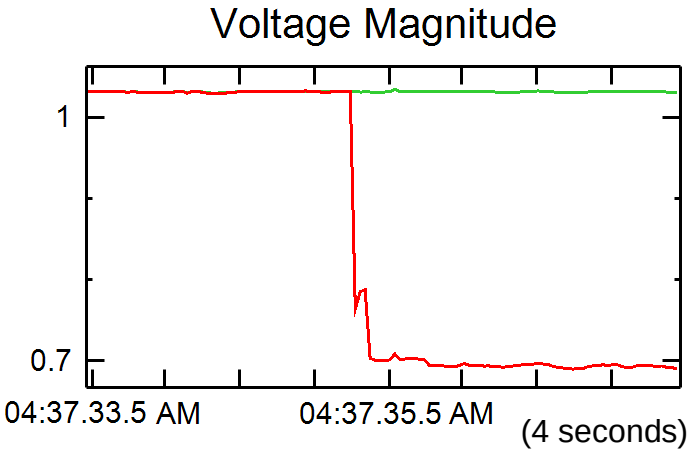
- FFT algorithm used to detect oscillations
- Sends email or text message when the oscillations reach an objectionable level
- This wind farm PMU shows many undesirable components, the worst at 14Hz



Discovery of Failing Equipment

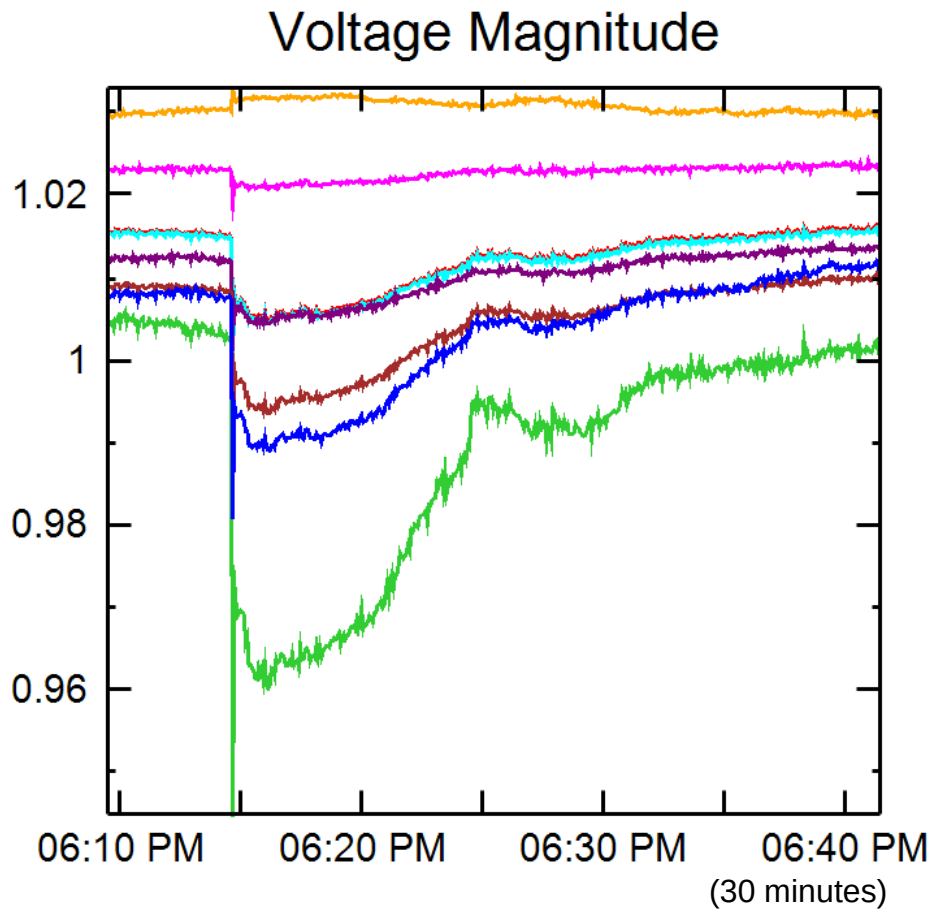
- Discovered many loose connections in the potential circuits at fuses or terminal blocks
- This has caused misoperations in the past (relays get confused)
- Proactively finding these helps prevent future outages and misoperations





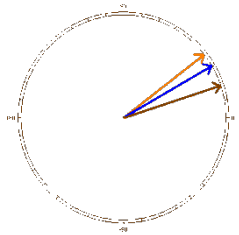
Voltage Recovery Assessment

- 6/11/2009 – A 520MW generator tripped on SPS system in the Texas Panhandle (Tolk)
- Caused low voltage in southern Oklahoma, which involved multiple transmission owners
- Loss of generation was over 300 miles away



Integration of Renewable Energy

- With over 28GW of wind power in the SPP interconnection queue, this is a big deal!
- OG&E requires a PMU at the point of interconnection for every wind farm
- We feel this is very important to monitor power quality and dynamic response



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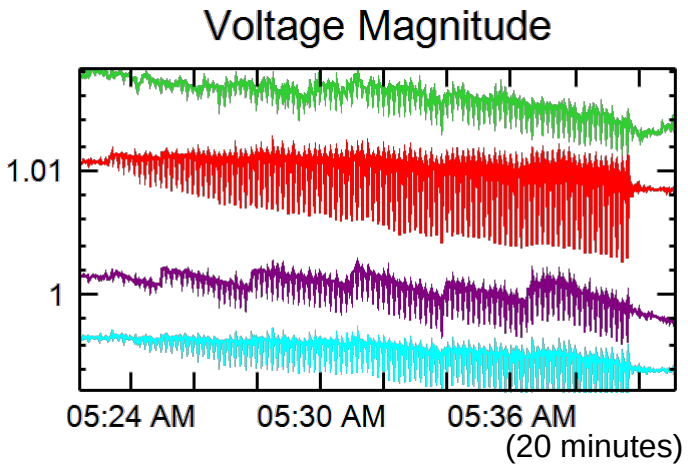
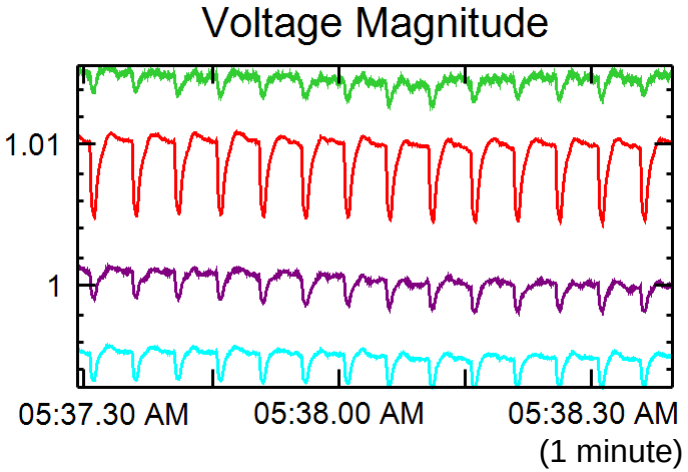
Stability Assessment - Redbud Oscillations (Solved)

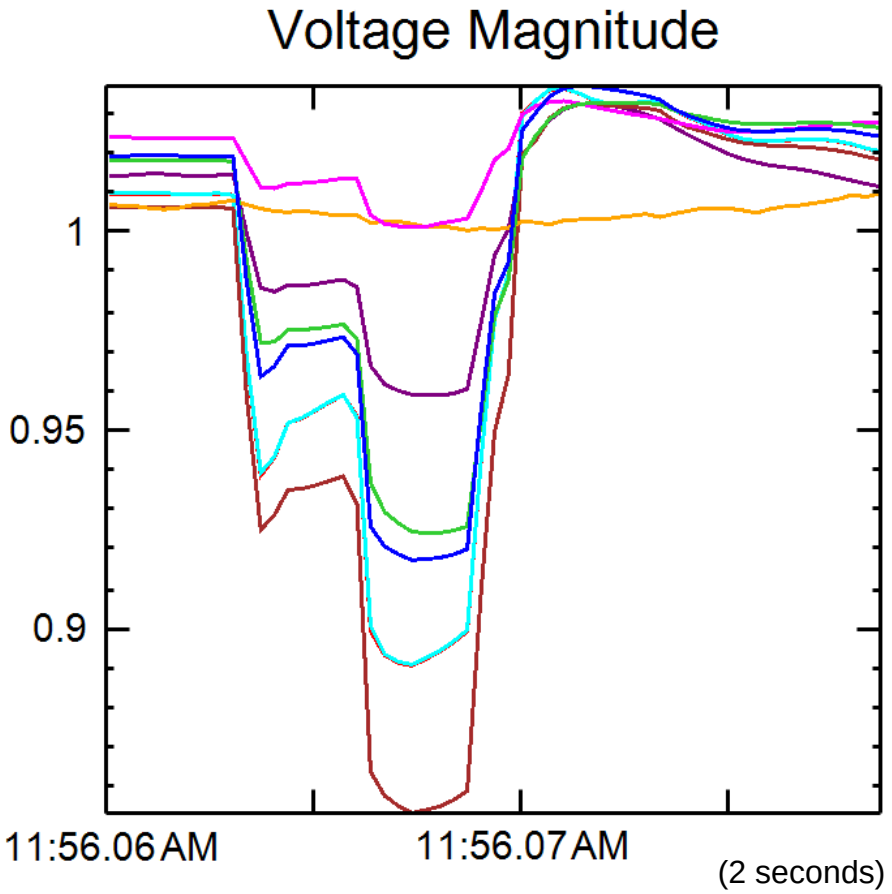
- Discovered voltage oscillations on EHV system (0.2Hz)
- Signal is most pronounced on the MVAR plot
- Suspected a generation problem
- Determined to be a problem with Redbud Unit 4 when in VAR control mode
- VAR control mode used during unit startup, oscillations stop when operator switches to voltage control scheme

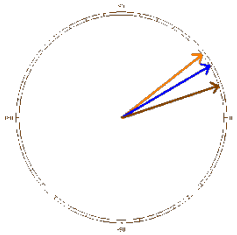




Voltage Depression during a fault

- 1/28/2009 - Fault in Oklahoma City can be seen on the entire EHV system
- Voltage pull downs are much worse when line communications (carrier) is turned off





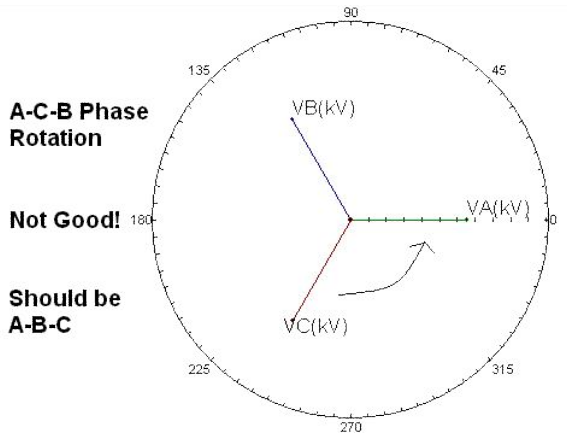
Discovered phasing error with OU Windspirit (Solved)

- SEL meter pm command showed voltage on all three phases, but zero positive sequence voltage
- Event report showed the presence of negative sequence voltage and improper ACB phase rotation

```
=>meter pm

SEL-421-3 S/N 2009061190                    Date: 09/24/2009  Time: 17:36:13.000
138kV OU Windspirit - Woodward District (PCB 111)     Serial Number: 2009061190

Time Quality   Maximum time synchronization error:     0.000 (ms)   TSOK = 1

Synchrophasors
                        Phase Voltages                  Pos. Sequence Voltage
                    VA          VB          VC                  V1
MAG (kV)        83.239      83.511      83.254              0.189
ANG (DEG)      -37.951      82.198    -157.712            -154.789
```

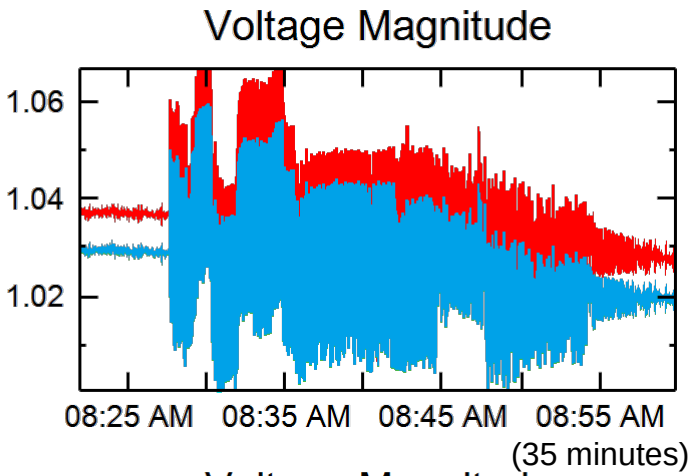
Voltage on all three phases

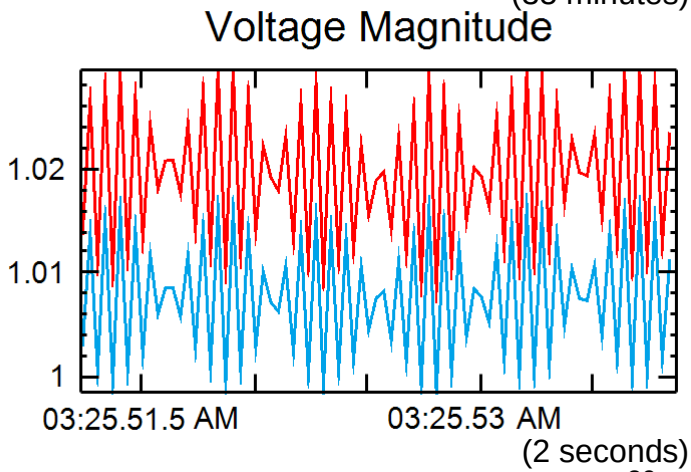
Positive Sequence Voltage near zero, but it should match the phase voltages in magnitude



Wind Farm Oscillations

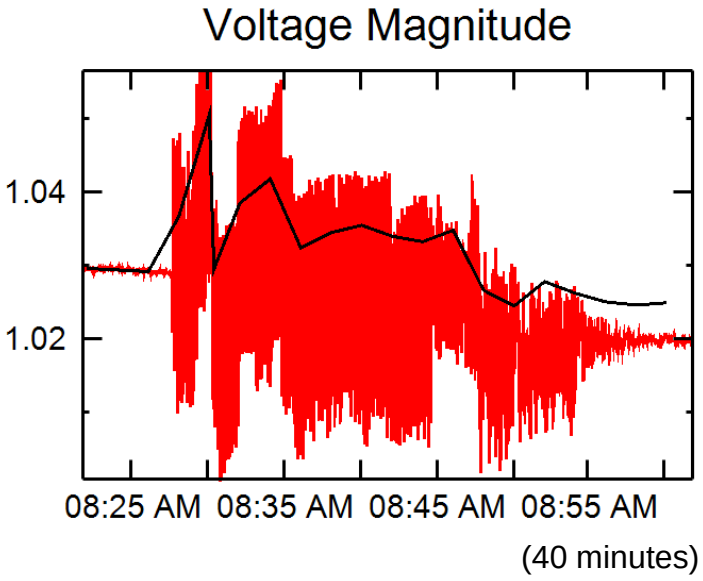
- Only during high winds
- FFT analysis shows 13-14Hz
- Voltage fluctuations as high as 5%
- Interaction between wind farms?
- Switching performed to electrically isolate the wind farms
- Determined it is a problem at different wind farms with the same turbine model
- The only solution is to curtail output





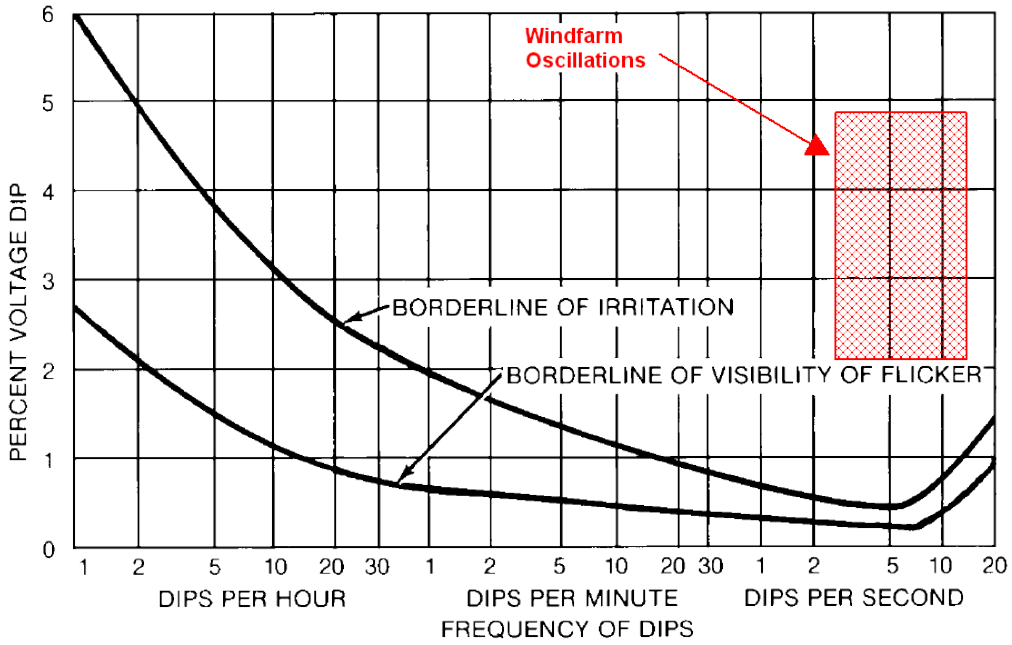
SCADA vs Synchrophasors

- Black trace shows the voltage magnitude reported by SCADA
- Red trace shows the synchrophasor data
- The oscillations are obviously undetectable with SCADA



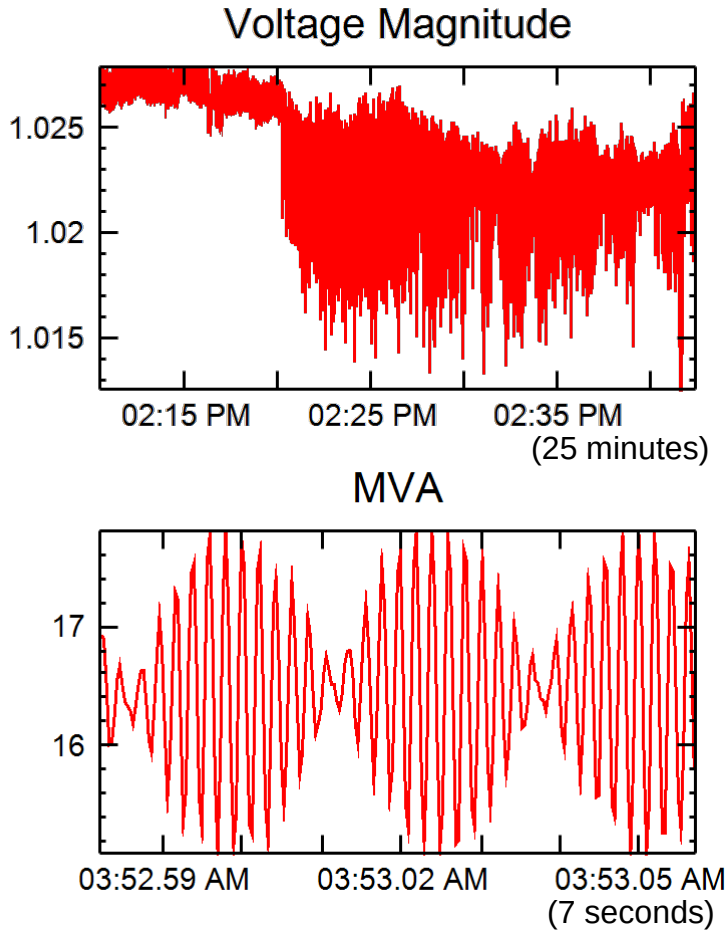
Customer Impact

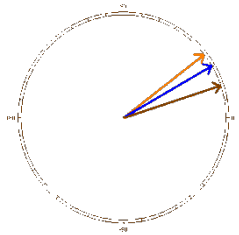
- Using IEEE 141, the oscillations were well into the objectionable flicker zone
- Called the Woodward service center to ask if they could see the lights flickering
- They confirmed visible flicker and noted numerous customer complaints
- We are currently working with the manufacturer to resolve the issue



Monitoring Power Quality

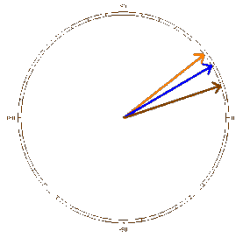
- It has been observed that large loads inject noise onto the system
- Large refineries and arc furnaces are the worst offenders
- Synchrophasors allow for real time power quality monitoring





Other Interesting Findings

- System is very dynamic – not as stable as we once thought?
- Most disturbances (faults) can be seen across the entire system
- OG&E transmission system typically varies from 10 to 45 degrees separation
- Customers don’t like it when their lights flicker for hours on end



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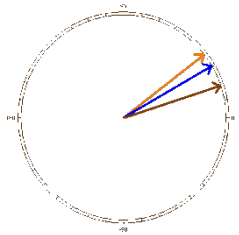
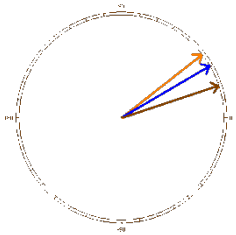


Future Plans

- Continue to bring new PMUs online!
- Design a 2nd generation system
  - Improve PMU data availability
  - Integrate system into control center operations
  - Meet current and future CIP standards
- Develop more automatic detection algorithms
- Dynamic line ratings?
- Model validation

OG&E



Questions?

- Thanks! Feel free to contact us if you have any questions.