SDG&E'S EXPERIENCES IN ENGINEERING ANALYSIS USING SYNCHROPHASORS

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INTRODUCTION

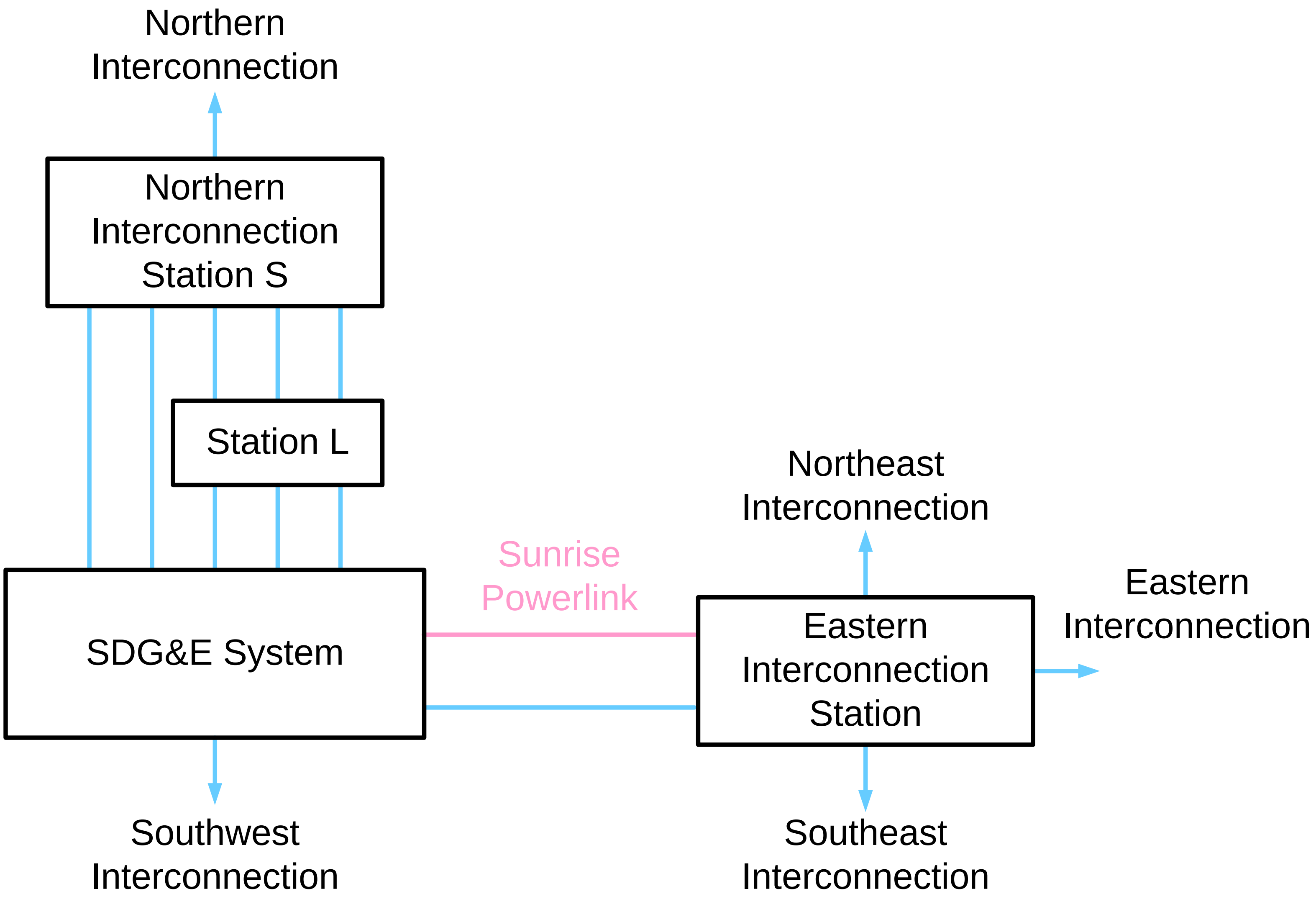
- System overview
- PMU in Service & Challenges
- Current Applications
- Future Applications
- Conclusion

SDG&E TRANSMISSION SYSTEM

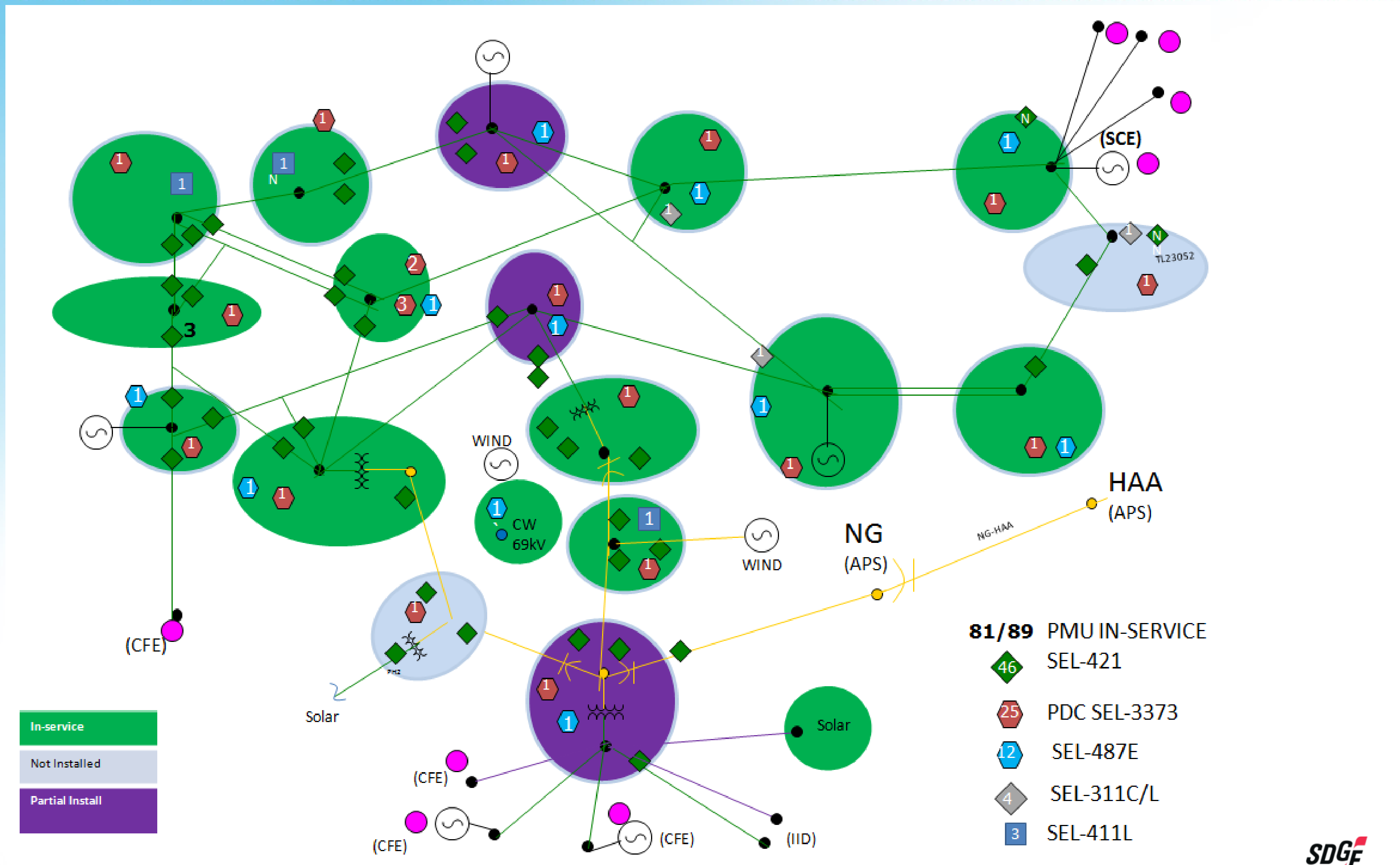
- Subsidiary of Sempra Energy
- Regulated public utility
- Provide safe and reliable energy service to 3.4 million consumers
  - 1.4 million electric meters
  - 800,000 natural gas meters
- 4,100 square mile service territory in San Diego and southern Orange Counties (25 cities)

- 1,800 miles of electric transmission lines and 21,600 miles of electric distribution lines
- Two compressor stations, 160 miles of natural gas transmission pipelines, 8,100 miles of distribution pipelines and 6,200 miles of service lines
- 4,500 employees

SDG&E TRANSMISSION SYSTEM INTERCONNECTIONS



SDG&E PMU MAP



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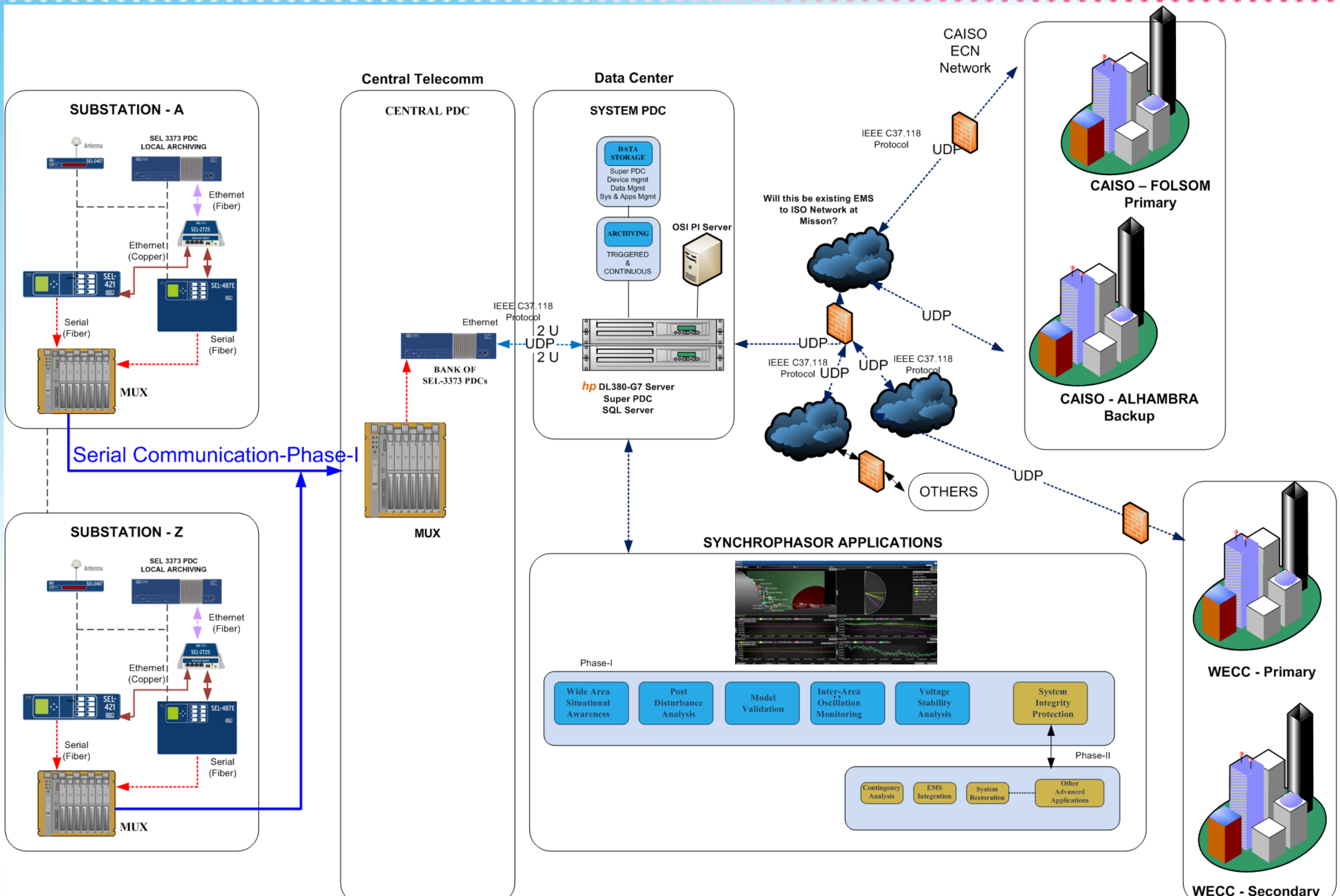
SYNCHROPHASOR ARCHITECTURE



EXAMPLE 1 - MONITOR PHASE ANGLE TO CLOSE LINE & REMOTE END 500KV LINES

- TL50001 Line Closing
- TL50001 Line Manual Trip
- This is also applied for TL50002

SDGE – APS Tie Line Closing

Example 1
50001 LINE CLOSING

Model Validation Using PMU Data

Steps in model validation:

(This is based on the methodology proposed by Dmitry Koserev and Steve Yang from BPA)

- Select a disturbance of significant magnitude
- Extract the measured data from PI database for Voltage, Frequency, Active Power, and Reactive Power at the point of interconnection
- Create a reduced Power flow and dynamic model for the machine as seen at Point of Interconnection
- Using the playback feature of PSLF, simulate the dynamic behavior of the machine for the measured voltages and frequencies
- Compare the measured values of active and reactive power at the Point of Interconnection with the simulation results

Model Validation Example:

The combustion turbine of a combined cycle plant (162 MW)
(The Referenced Disturbance is Shown Below)

Fig 1 -Diablo 2 tripped, Frequency dropped to:
59.87 Hz at 12:29:32.6 on February 02, 2014 (AZ)

Model Validation Example:

The combustion turbine of a combined cycle plant (162 MW) (Comparison of Active Power Dynamical Responses)

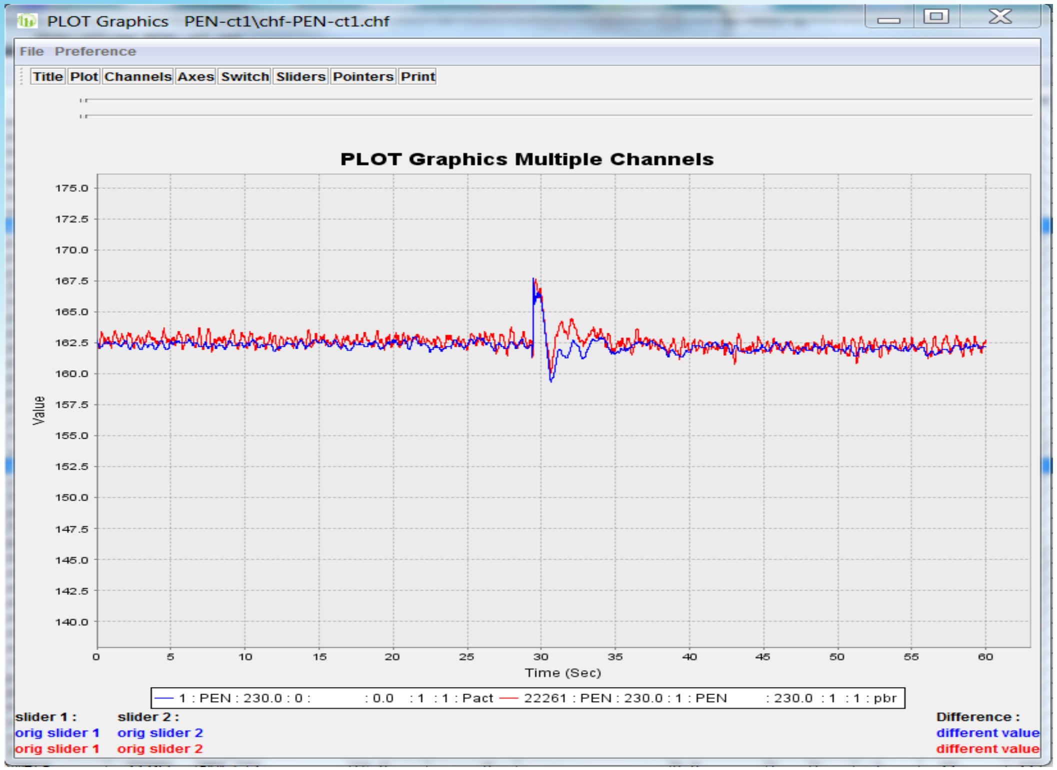


Fig 2 – Comparison of P-actual and P-simulated for CC (very good match)

Model Validation Example:

The combustion turbine of a combined cycle plant (162 MW)
(Comparison of Reactive Power Dynamical Responses)

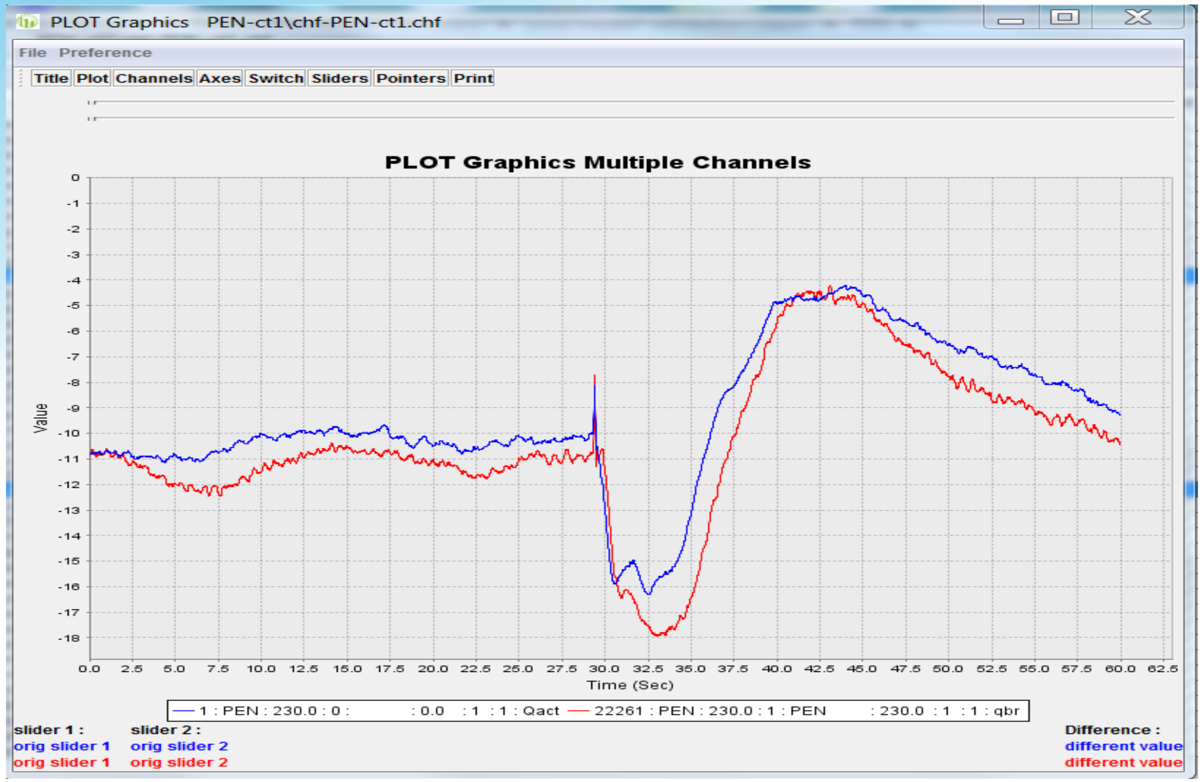


Fig 3 – Comparison of Q-actual and Q-simulated for CC (reasonably a good match)

Model Validation Example:

The Wind Turbine plant (265 MW)

(The Referenced Disturbance is Shown Below)

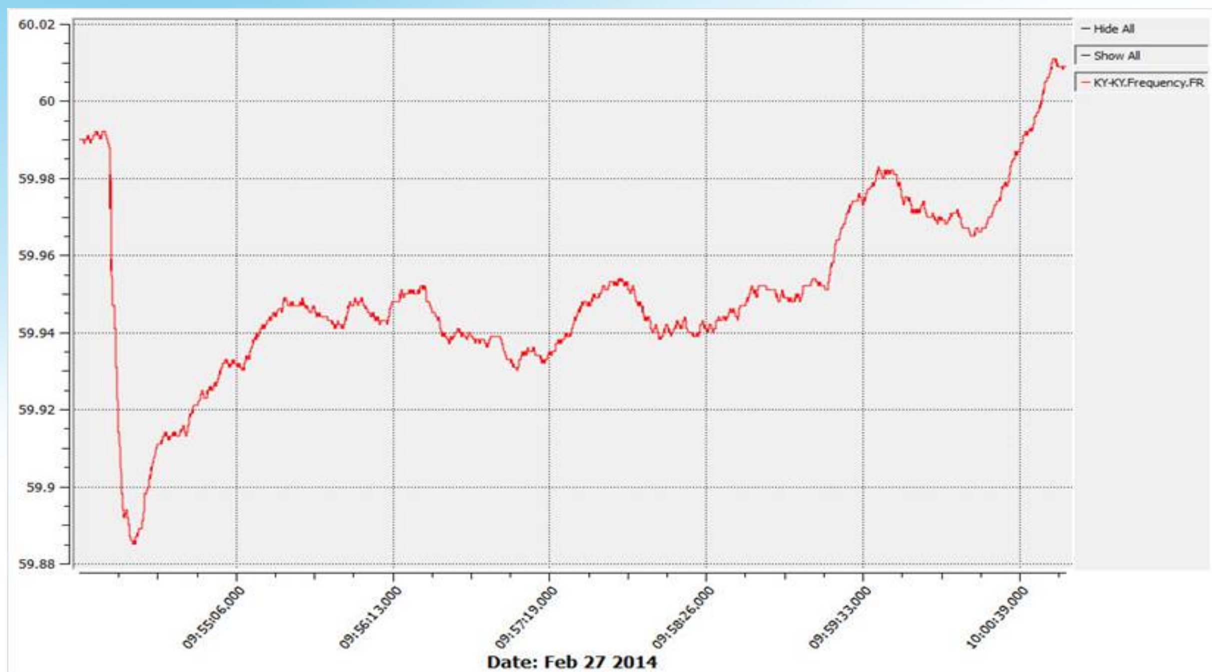


Fig 4 -Forced loss of generation at Intermountain Generating Station, Frequency dropped to:
59.88 Hz at 09:54:22.733 on February 27, 2014 (AZ)

Model Validation Example:

The Wind Turbine plant (265 MW)
(Comparison of Active Power Dynamical Responses)

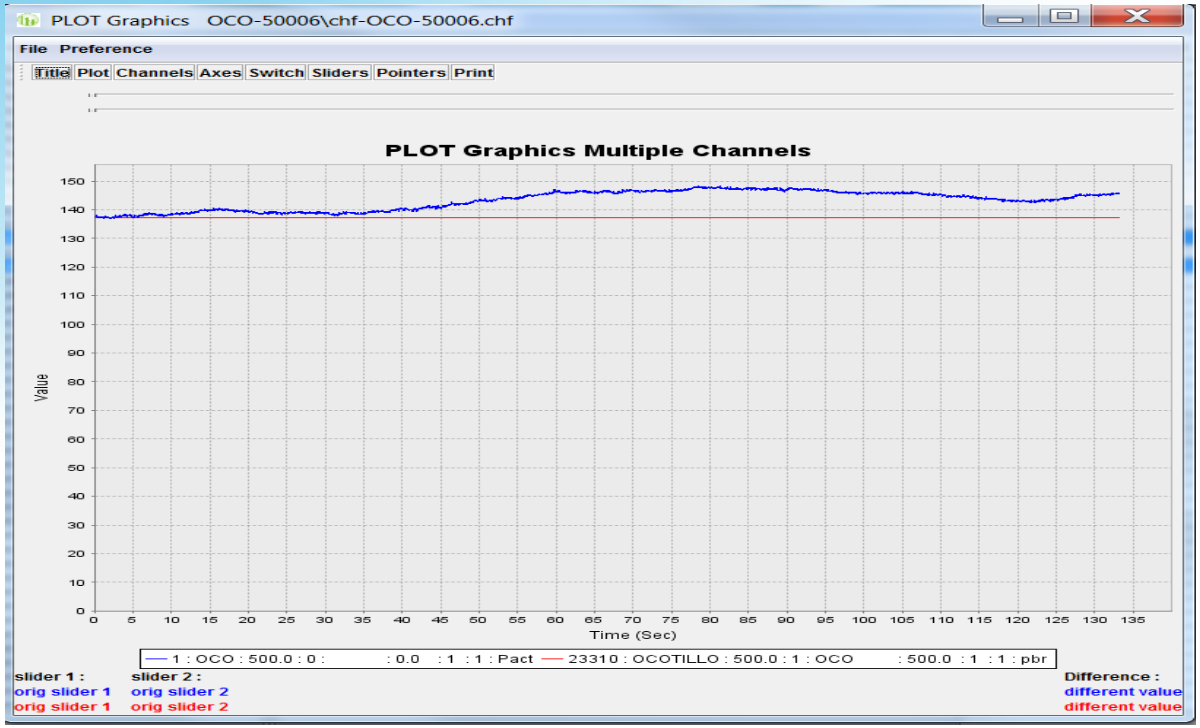


Fig 5 – Comparison of P-actual and P-simulated for WT
(The difference may be due to wind pick-up)

Model Validation Example:

The Wind Turbine plant (265 MW)
(Comparison of Reactive Power Dynamical Responses)

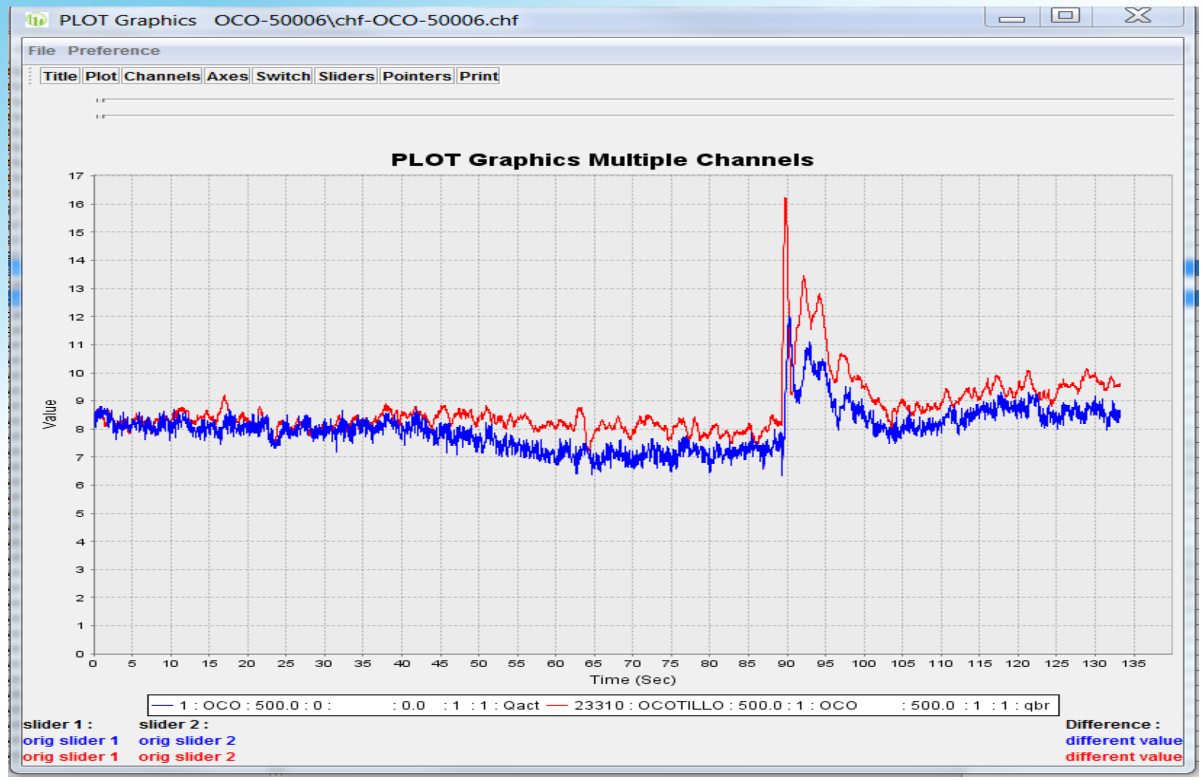


Fig 6 – Comparison of Q-actual and Q-simulated for WT
(reasonably a good match)

Model Validation Example:
The Solar PV plant (170 MW)
(The Referenced Disturbance is Shown Below)

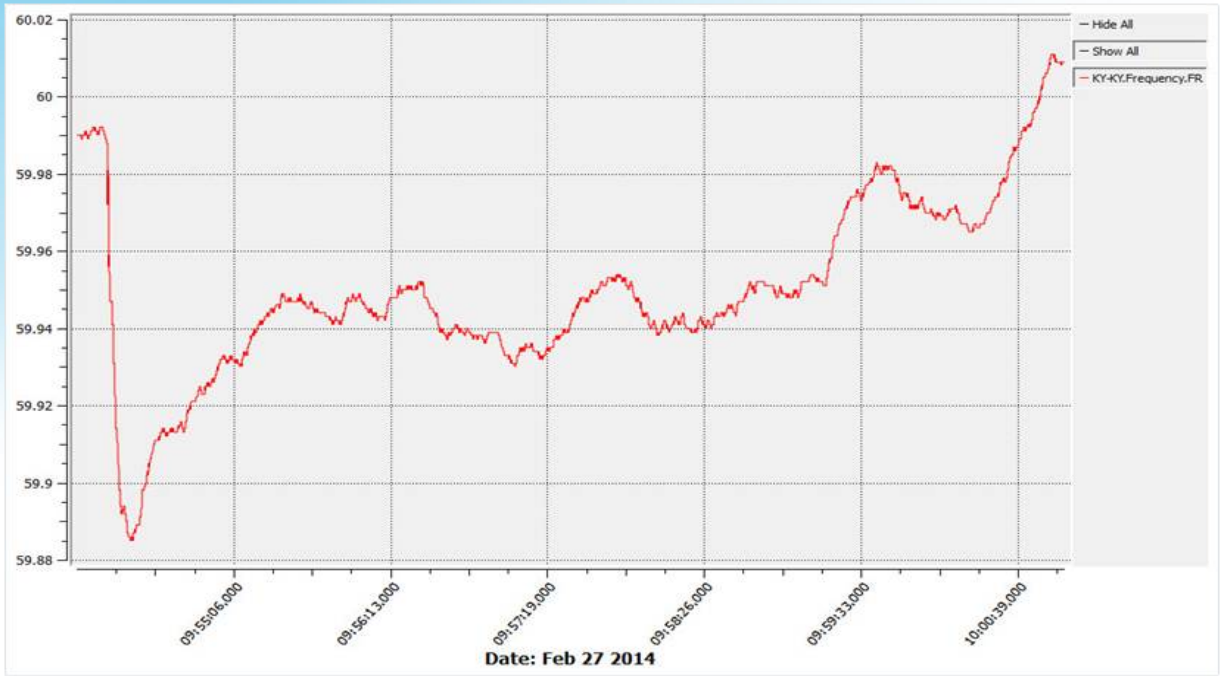


Fig 7 -Forced loss of generation at Intermountain Generating Station, Frequency dropped to:
59.88 Hz at 09:54:22.733 on February 27, 2014 (AZ)

Model Validation Example:

The Solar PV plant (170 MW)
(Comparison of Active Power Dynamical Responses)

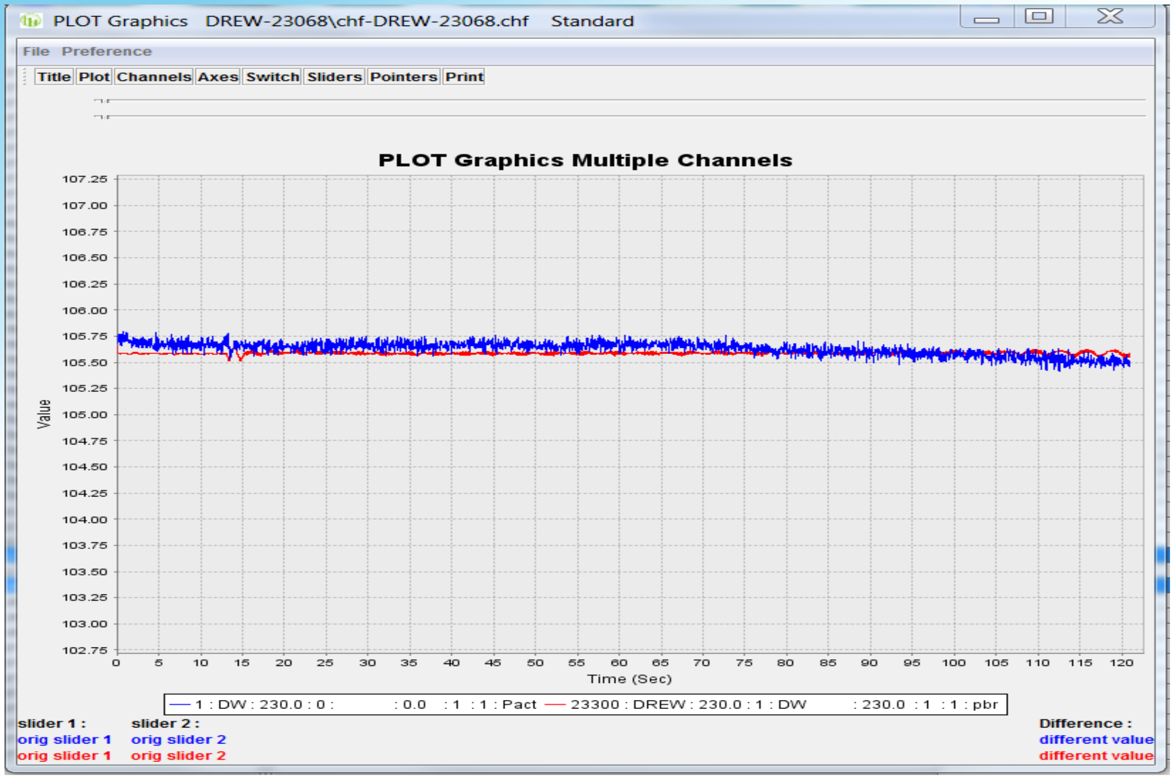


Fig 8 – Comparison of P-actual and P-simulated for PV (good match)

Model Validation Example:

The Solar PV plant (170 MW)
(Comparison of Reactive Power Dynamical Responses)

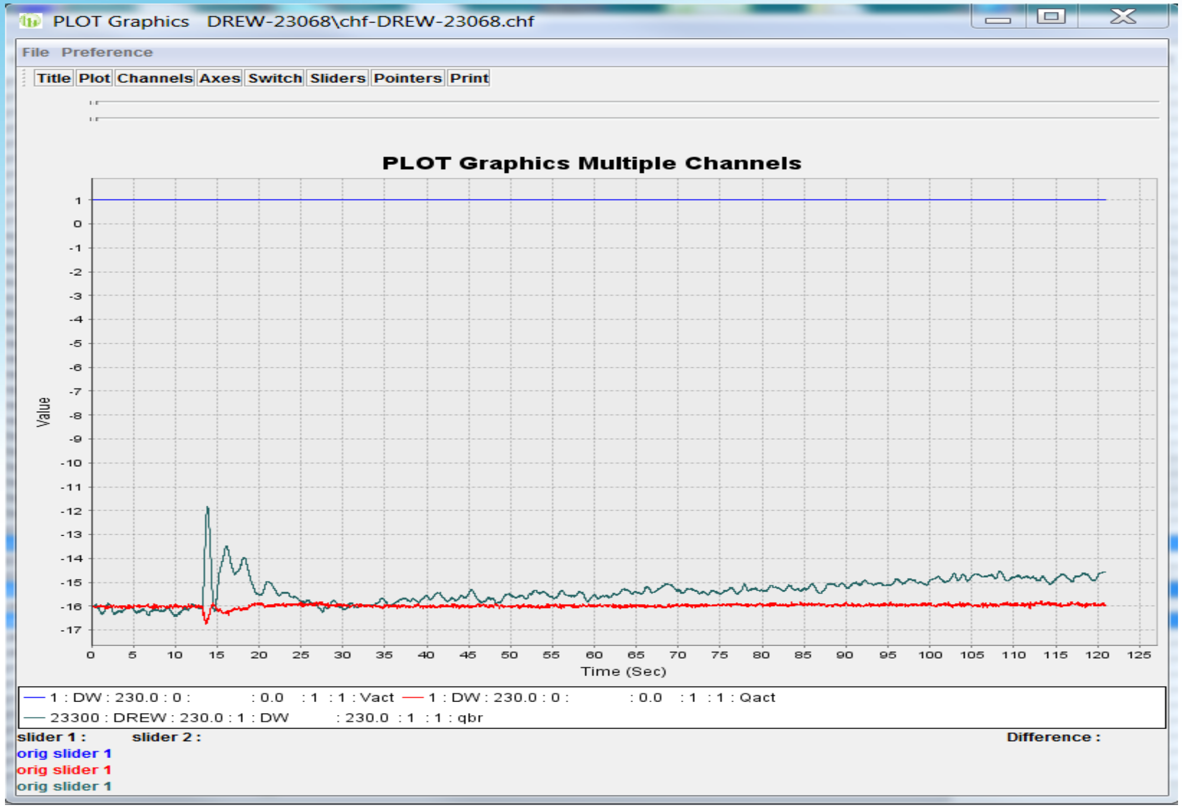


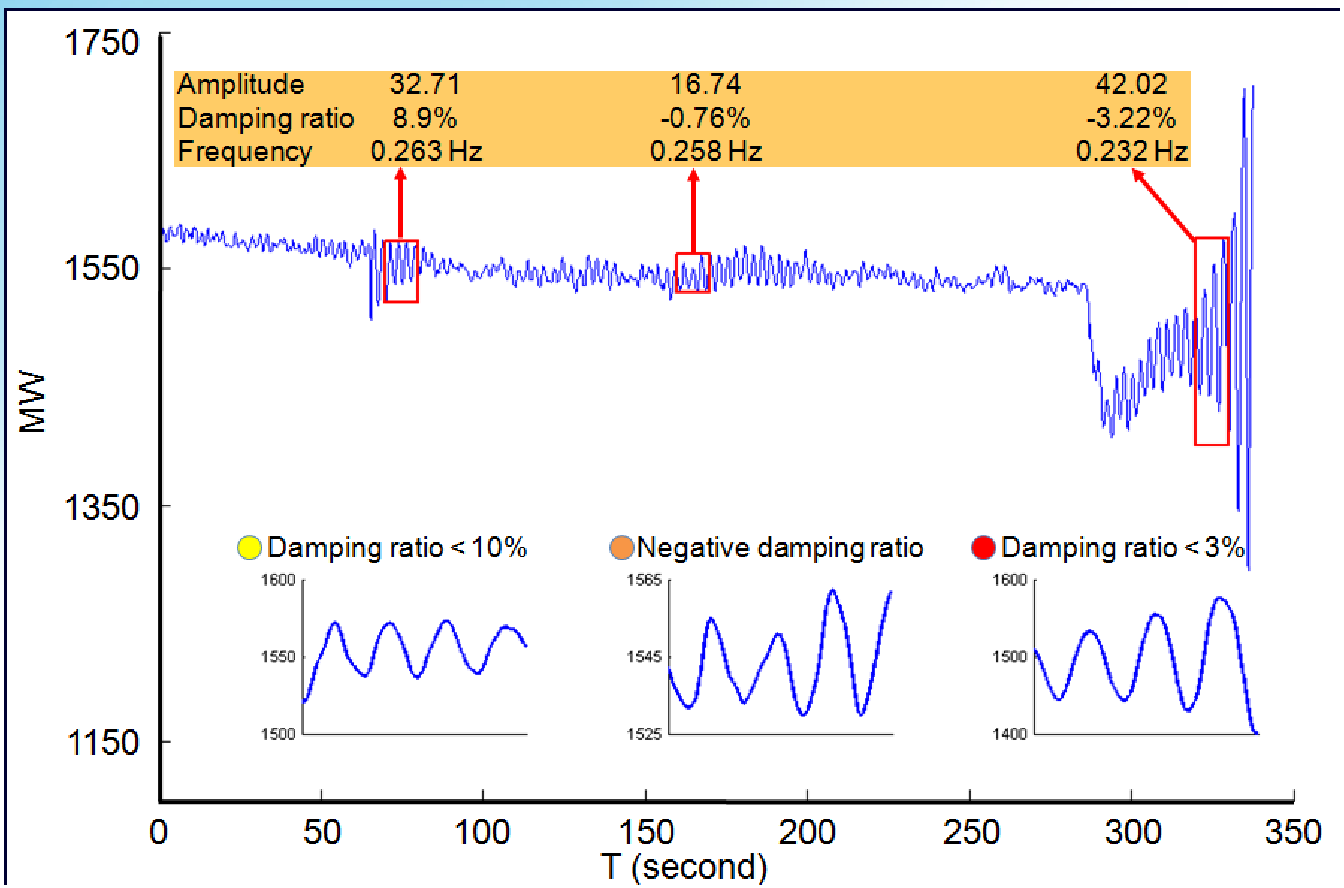
Fig 9 – Comparison of Q-actual and Q-simulated for WT (There seems to be some issues: either in the model or in the settings)

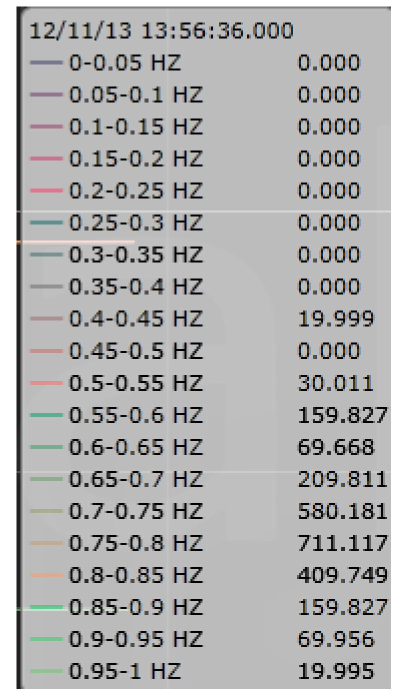
EXAMPLE 5 - MODAL ANALYSIS POWER SYSTEM OSCILLATIONS

- Power system small signal stability
- Insufficient damping of system oscillations
- Low-frequency oscillation: 0.1 ~ 2 Hz
- Contributing factors
    - Heavy power transfer
    - Loosely connected system
    - Excitation control system responses

EXAMPLE 5 - MODAL ANALYSIS POWER SYSTEM OSCILLATIONS

- **Local -Mode frequency: 0.7 ~ 2.0 Hz**
- **Global -Areas against areas Mode frequency < 0.7 Hz**





12/11/13 13:56:36.000	
0-0.05 HZ	0.000
0.05-0.1 HZ	0.000
0.1-0.15 HZ	0.000
0.15-0.2 HZ	0.000
0.2-0.25 HZ	0.000
0.25-0.3 HZ	0.000
0.3-0.35 HZ	0.000
0.35-0.4 HZ	0.000
0.4-0.45 HZ	19.999
0.45-0.5 HZ	0.000
0.5-0.55 HZ	30.011
0.55-0.6 HZ	159.827
0.6-0.65 HZ	69.668
0.65-0.7 HZ	209.811
0.7-0.75 HZ	580.181
0.75-0.8 HZ	711.117
0.8-0.85 HZ	409.749
0.85-0.9 HZ	159.827
0.9-0.95 HZ	69.956
0.95-1 HZ	19.995

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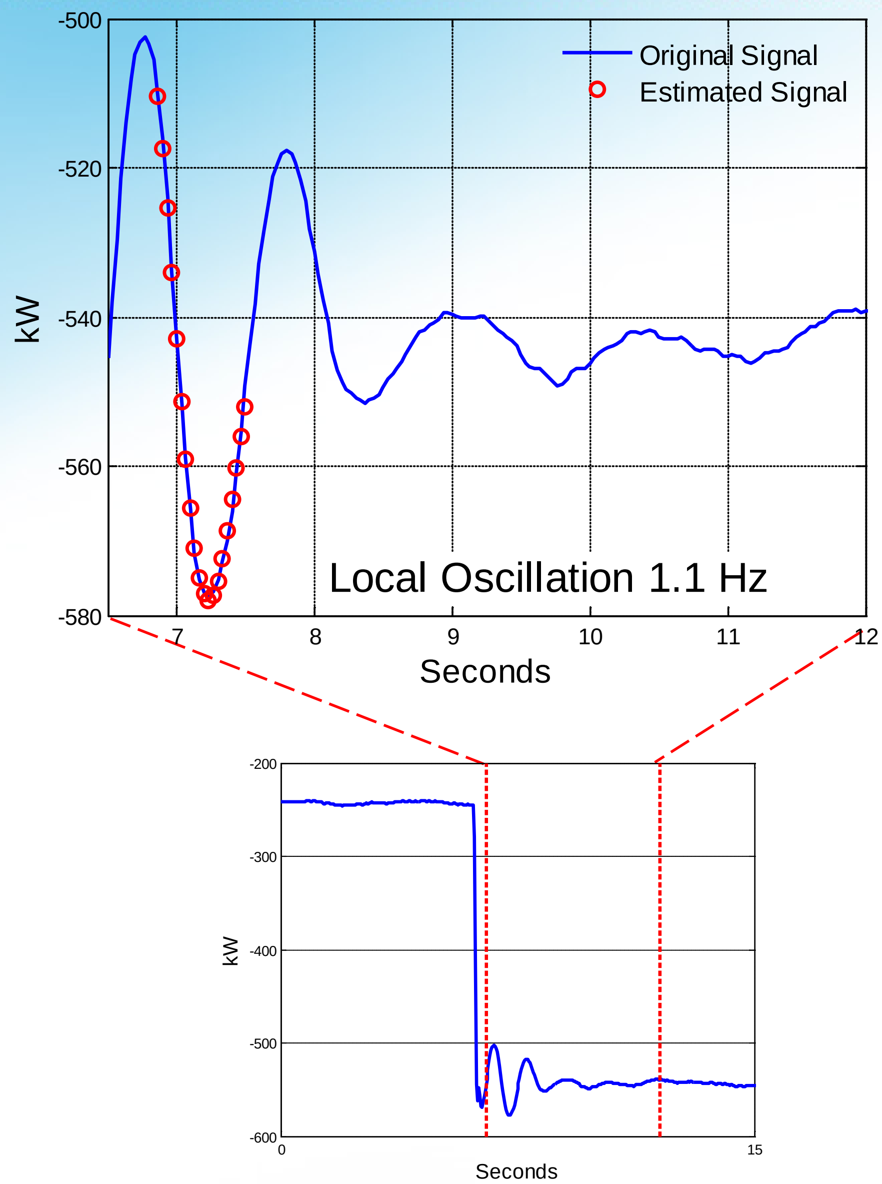
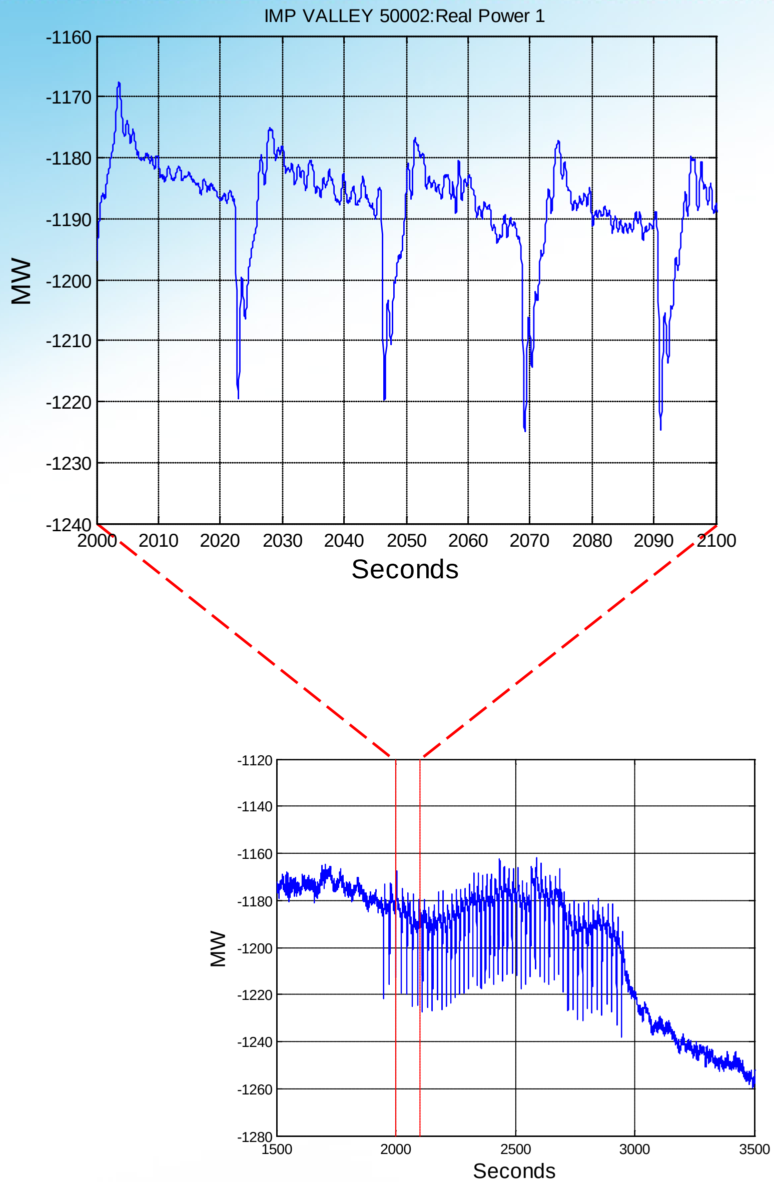
Identifies Proper Damping of Local Osc.



Identifies Potential System Problems



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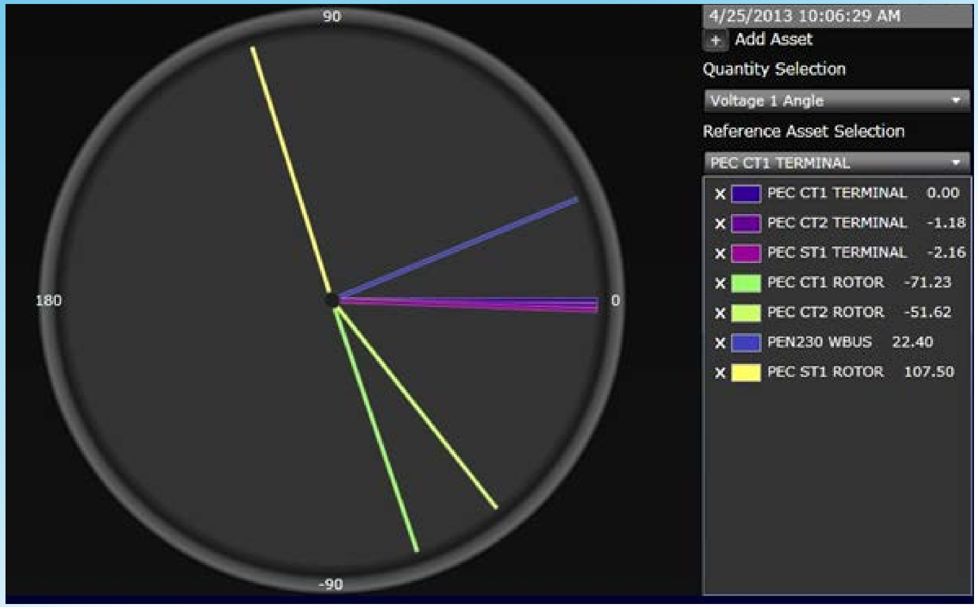
EXAMPLE - 6 GEN SHAFT ROTOR ANGLE MEASUREMENT



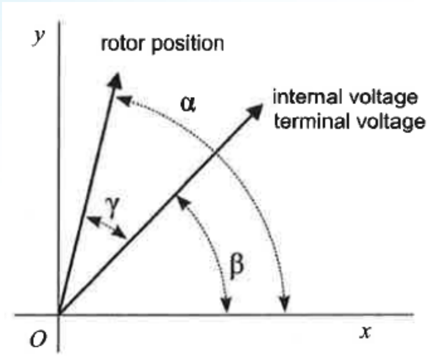


Figure 1: No Load

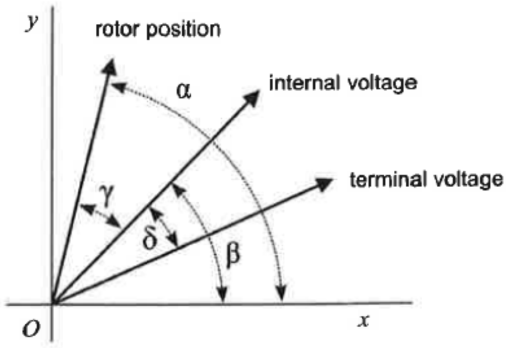


Figure 2: On Load

Initial Results
CT1 (γ) = 106 Deg
CT2 (γ) = 93 Deg
ST1 (γ) = -73 Deg

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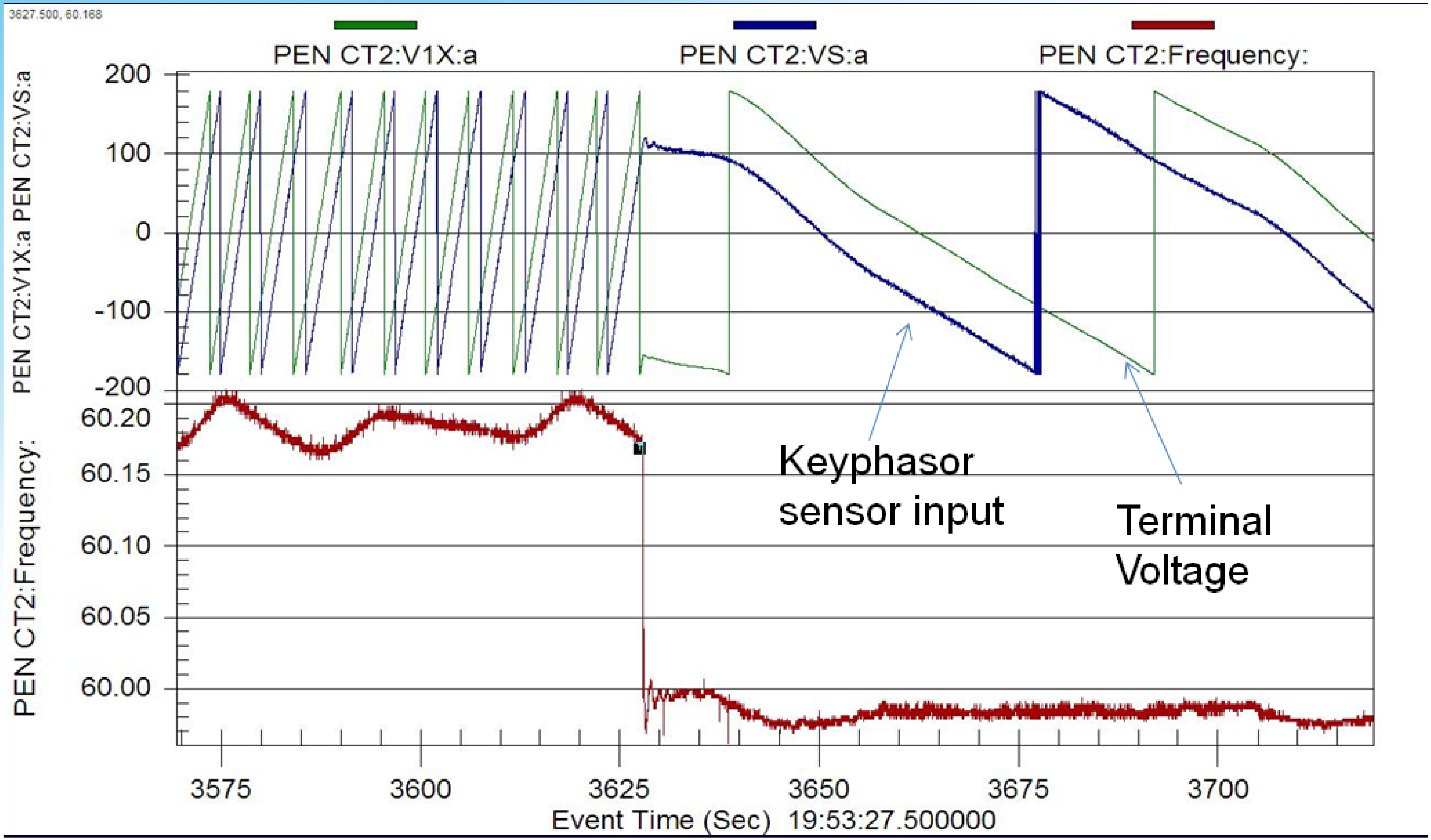
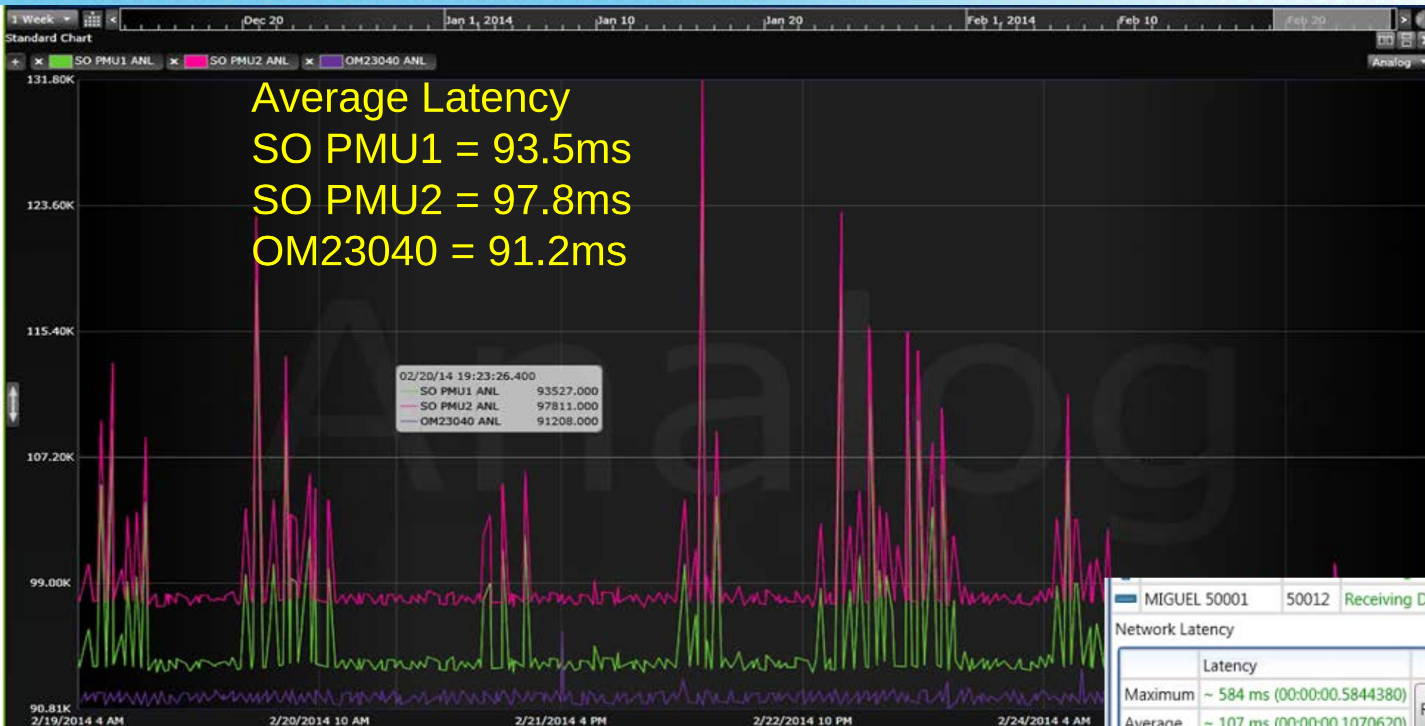
EXAMPLE - 6 GEN SHAFT ROTOR ANGLE MEASUREMENT



EXAMPLE 7 - SYSTEM LATENCY



- Max & Av Latency
- PDC
- PDC to Super PDC

MCCPDC1 to SPDC1	Sending Data	No	59235367

Network Latency

Input Connection	Average	Maximum	
SILVERGATE 23028	~ 105 ms	~ 406 ms	Reset
SILVERGATE 23029	~ 109 ms	~ 548 ms	Reset
SILVERGATE 23042	~ 108 ms	~ 603 ms	Reset
MIGUEL 23042	~ 109 ms	~ 548 ms	Reset
MIGUEL 50001	~ 108 ms	~ 603 ms	Reset
MIGUEL 23041	~ 108 ms	~ 548 ms	Reset
IMP VALLEY 50001	~ 108 ms	~ 603 ms	Reset
ML PMU2	~ 108 ms	~ 548 ms	Reset
Differences	~ 13 ms	~ 196 ms	

Frames

	# Frames	Timestamp	
Data	59235367	02/26/2014 19:12:20.466	Reset
Capability	0		
Configuration	1	02/03/2014 22:43:48.144	
Command	3	02/03/2014 22:43:48.321	

13ms = Latency difference
(1 sec average)

MIGUEL 50001	50012	Receiving Data	Normal	59224735

Network Latency

	Latency	
Maximum	~ 584 ms (00:00:00.5844380)	Reset
Average	~ 107 ms (00:00:00.1070620)	

Frames

	# Frames	Timestamp	
Data	59224735	02/26/2014 19:06:27.933	Reset
Missed Data	364	02/12/2014 22:40:32.133	
Duplicate Data	0		
Past Data	0		
Configuration	1	02/03/2014 22:43:38.037	
Command	3		

ML PMU2	31	Receiving Data	Normal	59225092
ML PMU3	32	Receiving Data	Normal	59225094
IMP VALLEY 50001	50011	Receiving Data	Normal	59225094

Network Latency

	Latency	
Maximum	~ 584 ms (00:00:00.5844290)	Reset
Average	~ 107 ms (00:00:00.1071110)	

Frames

	# Frames	Timestamp	
Data	59225094	02/26/2014 19:06:27.933	Reset
Missed Data	4	02/24/2014 17:14:24.566	
Duplicate Data	0		
Past Data	0		
Configuration	1	02/03/2014 22:43:38.059	
Command	3		

FUTURE APPLICATIONS & CHALLENGES

- Islanding Detection
- High Renewable, PV & Wind Penetration
- Oscillation Monitoring
- Voltage Stability Prediction
- Rotor Angle Shaft
- WAM & RAS Schemes

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