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
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

Line closed
13:26:37

50001 CAP In
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)

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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

| Amplitude | 32.71 | 16.74 | 42.02 |
| Damping ratio | 8.9% | -0.76% | -3.22% |
| Frequency | 0.263 Hz | 0.258 Hz | 0.232 Hz |

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Identifies Proper Damping of Local Osc.
Identifies Potential System Problems
EXAMPLE - 6 GEN SHAFT ROTOR ANGLE MEASUREMENT

Initial Results

CT1 ($\gamma$) = 106 Deg
CT2 ($\gamma$) = 93 Deg
ST1 ($\gamma$) = -73 Deg

Figure 1: No Load

Figure 2: On Load

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EXAMPLE - 6 GEN SHAFT ROTOR ANGLE MEASUREMENT
EXAMPLE 7 - SYSTEM LATENCY

Max & Av Latency

PDC

PDC to Super PDC

13ms = Latency difference (1 sec average)

Average Latency
SO PMU1 = 93.5ms
SO PMU2 = 97.8ms
OM23040 = 91.2ms
FUTURE APPLICATIONS & CHALLENGES

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