Improved State Estimation and Development of Real-Time Wide Area Monitoring and Control Test Bed

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Electrical utilities are vulnerable to natural catastrophes and physical disturbances. Failure of sensors or communication networks affects proper monitoring of power system.

Different state estimation algorithms need to be investigated to determine best possible algorithms with data loss in the presence of PMU data.

State estimation algorithms are integrated with Remedial Action Scheme (RAS) and Google map to develop standards driven CIM and SensorWeb based power system monitoring and control tool.

Development of real time test bed will allow validation of developed algorithms for power system monitoring, operation and control. Test bed can also be used to demonstrate fundamental concepts of power system to students.
STATE ESTIMATION WITH LOSS OF DATA

### Type of Measurement

<table>
<thead>
<tr>
<th>Type of Measurement</th>
<th>Value of standard deviation (σ) in per unit.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage</td>
<td>0.01</td>
</tr>
<tr>
<td>Real power injection</td>
<td>0.02</td>
</tr>
<tr>
<td>Reactive power injection</td>
<td>0.04</td>
</tr>
<tr>
<td>Real power line flow</td>
<td>0.02</td>
</tr>
<tr>
<td>Reactive power line flow</td>
<td>0.04</td>
</tr>
<tr>
<td>Voltage magnitude from PMU</td>
<td>0.0001</td>
</tr>
<tr>
<td>Voltage angle from PMU</td>
<td>0.006</td>
</tr>
<tr>
<td>Current magnitude from PMU</td>
<td>0.0001</td>
</tr>
<tr>
<td>Current angle from PMU</td>
<td>0.006</td>
</tr>
</tbody>
</table>

### Acknowledgements:

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STATE ESTIMATION WITH SCADA AND PHASOR MEASUREMENTS

|V|, P, Q

Form Measurement Vector

|V|,|v|, |I|, δi

Convert to rectangular co-ordinates

Form Measurement Vector

Measurement function ‘h’ for classical SE measurements

‘h’ for phasor measurements

‘h’ for combined measurements

Combined Measurement Set

Measurement Jacobian for classical SE measurements

Measurement Jacobian for phasor measurements

Jacobian for combined measurements

Acknowledgements:
This research work is sponsored by DoHS/ ORNL Funds: 63886
• Six generators.
• Four transformers.
• Forty one transmission lines.
• Twenty one loads.
• Three synchronous condensers
• PMU’s assumed to be present at buses 1 and 27.
• Weighted Least Square (WLS) algorithm is used to include phasor measurements.

IEEE 30 bus system
RESULTS FOR CLUSTERED DATA LOSS

% Redundancy Vs Error Index for bus voltages

L1 norm for voltages = \( \sum | V_{\text{actual}} - V_{\text{estimated}} | \)

L1 norm for angles = \( \sum | \delta_{\text{actual}} - \delta_{\text{estimated}} | \)

% Redundancy = (No. of measurements / No. of states) * 100

Error Index = L1 norm / 30

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RESULTS FOR SCATTERED DATA LOSS

% Redundancy Vs Error Index for bus voltages

% Redundancy Vs Error Index for bus angles

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Wide-Area Monitoring and Control Test Bed

Validating stability and protection algorithms

Performance comparison of PMU’s

Distributed State Estimation

Wide area monitoring using SensorWeb

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8-bus system in RSCAD

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8-bus system after fault in RSCAD

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Phasor Magnitudes in SynchroWave Console

<table>
<thead>
<tr>
<th>Station</th>
<th>Phasor</th>
<th>Magnitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>STATION A</td>
<td>YALPM</td>
<td>213570.36</td>
</tr>
<tr>
<td>STATION A</td>
<td>YBLPM</td>
<td>182591.73</td>
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<tr>
<td>STATION A</td>
<td>YCLPM</td>
<td>131166.81</td>
</tr>
</tbody>
</table>

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Phasor Angles in SynchroWave Console

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• The performance of state estimation with loss of clustered and scattered data was observed with and without PMUs.

• A test bed has been developed using RSCAD and SEL equipments.

• PMU response to disturbance in simulated power system in real time was observed in SEL SynchroWave console using developed test bed.

• Future work
  • Additional PMU in the test bed to obtain data for multiple test cases in RSCAD
  • To perform testing and validation in real time for other developed algorithms at PERL using developed test bed

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Thank You!

Questions????