Detection, Identification and Correction of Network Model Parameter Errors

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PANEL: Addressing Uncertainty, Data Quality and Accuracy in State Estimation
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Problem Statement and Challenges

How to detect bad parameters and distinguish parameter errors from measurement errors?

Can this be accomplished solely based on measurement residuals?

Once detected and identified, can the parameters be corrected efficiently?

Are there inherent limitations imposed by network topology, measurement system, loading, etc.?
Current Practice

- Select a “suspect set” of parameters
- Augment the state vector and simultaneously estimate the states and parameters

\[ v = \begin{bmatrix} x_1, x_2, \ldots, x_n \mid p_1, p_2, \ldots, p_{N_p} \end{bmatrix} \]

AUGMENTED STATE VECTOR

Shortcomings:
- No reliable way to predict the suspect set of parameters
- May require inclusion of too many parameters
Every network parameter is assumed to have an error:

\[ p = p_t + p_e \]
State and Parameter Estimation

\[
\begin{align*}
\min & \quad J(x, p_e) = \frac{1}{2} [z - h(x, p_e)]^T W [z - h(x, p_e)] \\
\text{s.t.} & \quad p_e = 0 \\
& \quad c(x, p_e) = 0
\end{align*}
\]

Associated Lagrangian will then be given by:

\[
L = \frac{1}{2} r^T W r - \mu^T c(x, p_e) - \lambda^T p_e
\]
Normalized Lagrange Multiplier and Normalized Residual (NLMN) Test


Start

State estimation

Compute $\lambda^N$ for each parameter and $r^N$ for each measurement

Largest $\lambda^N/r^N$ greater than the threshold?

Error correction

The param./meas. with the large $\lambda^N/r^N$ identified as in error

End

NLM: $\lambda^N_i = \frac{\lambda_i}{\sqrt{\Lambda_{ii}}}$

NR: $r^N_i = \frac{r_i}{\sqrt{\Omega_{ii}}}$
Computational Bottleneck

Matrix inversion and multiplication operations are computationally expensive!

Proposed Solution:

Instead of performing full computation, the necessary subset of $G^{-1}$ for computing the diagonal entries of $\Lambda$ is determined and computed.
Computing Diagonal Entries of Covariance Matrix $\Lambda$

Unidentifiable Errors

Transformer tap or voltage magnitude at bus 7259 may be wrong!

<table>
<thead>
<tr>
<th>Errors</th>
<th>( t_{(7262-7259)} )</th>
<th>( v_{(7259)} )</th>
<th>( z/p )</th>
<th>( r^N/\lambda^N )</th>
<th>( z/p )</th>
<th>( r^N/\lambda^N )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( t_{(7262-7259)} )</td>
<td>20.68</td>
<td>( v_{(7259)} )</td>
<td>23.81</td>
<td>( t_{(7262-7259)} )</td>
<td>23.81</td>
<td></td>
</tr>
<tr>
<td>( v_{(7259)} )</td>
<td>20.68</td>
<td>( r_{(7262-7259)} )</td>
<td>20.58</td>
<td>( t_{(7262-7259)} )</td>
<td>20.68</td>
<td></td>
</tr>
<tr>
<td>( r_{(7262-7259)} )</td>
<td>20.58</td>
<td>( r_{(7262-7259)} )</td>
<td>23.74</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( q_{(7262-7259)} )</td>
<td>6.955</td>
<td>( q_{(7262-7259)} )</td>
<td>7.705</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( q_{(7259)} )</td>
<td>5.595</td>
<td>( q_{(7259)} )</td>
<td>5.699</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

CANNOT BE IDENTIFIED
## Use of Multiple Scans

### MIS-IDENTIFICATION OF TRANSFORMER TAP ERROR

<table>
<thead>
<tr>
<th>Single Scan</th>
<th>Two Scans</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>z/p</strong></td>
<td><strong>r^N/\lambda^N</strong></td>
</tr>
<tr>
<td>( t_{(7262-7259)} )</td>
<td>20.68</td>
</tr>
<tr>
<td>( v_{(7259)} )</td>
<td>20.68</td>
</tr>
<tr>
<td>( r_t(7262-7259) )</td>
<td>20.58</td>
</tr>
<tr>
<td>( q_{(7262-7259)} )</td>
<td>6.955</td>
</tr>
<tr>
<td>( q_{(7259)} )</td>
<td>5.595</td>
</tr>
</tbody>
</table>

Detectability and Identifiability of Parameter and Measurement Errors

\[ \lambda = \Lambda p_e + Ae \]

Critical parameter pair: Errors detectable, but not identifiable

Critical parameter: Errors not detectable
Sensitivities of $\lambda^N$ to $p_e$

$$\left| E\left(\lambda^N_i\right) \right| = \sqrt{s\Lambda^s_{ii}} \left| p_{e,i} \right|$$

No of scans [a]  Related to the accuracy of measurements [b]


Undetectable Cases (Low Sensitivity)

Low sensitivity branch 12-13

Low sensitivity branch 7-8
## Parameter Error Sensitivities

<table>
<thead>
<tr>
<th>From Bus – To Bus</th>
<th>Resistance</th>
<th>Reactance</th>
<th>From Bus – To Bus</th>
<th>Resistance</th>
<th>Reactance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-2</td>
<td>1.916×10⁷</td>
<td>1.989×10¹⁰</td>
<td>7-8</td>
<td>5.010×10²</td>
<td>4.747×10²</td>
</tr>
<tr>
<td>1-5</td>
<td>3.820×10⁶</td>
<td>3.840×10⁶</td>
<td>7-9</td>
<td>4.250×10⁵</td>
<td>4.238×10⁵</td>
</tr>
<tr>
<td>2-5</td>
<td>3.188×10⁶</td>
<td>3.225×10⁸</td>
<td>9-10</td>
<td>3.117×10⁴</td>
<td>3.140×10⁴</td>
</tr>
<tr>
<td>2-4</td>
<td>5.725×10⁶</td>
<td>3.247×10⁸</td>
<td>9-14</td>
<td>1.658×10⁴</td>
<td>1.651×10⁴</td>
</tr>
<tr>
<td>2-3</td>
<td>5.675×10⁶</td>
<td>1.392×10⁸</td>
<td>10-11</td>
<td>7.476×10³</td>
<td>7.489×10³</td>
</tr>
<tr>
<td>3-4</td>
<td>6.949×10⁵</td>
<td>2.649×10⁸</td>
<td>6-11</td>
<td>1.776×10⁴</td>
<td>1.586×10⁸</td>
</tr>
<tr>
<td>5-6</td>
<td>5.941×10⁵</td>
<td>5.260×10⁵</td>
<td>6-12</td>
<td>1.752×10⁴</td>
<td>1.746×10⁴</td>
</tr>
<tr>
<td>4-5</td>
<td>1.057×10⁷</td>
<td>3.943×10⁹</td>
<td>6-13</td>
<td>1.435×10⁵</td>
<td>1.290×10⁸</td>
</tr>
<tr>
<td>4-9</td>
<td>7.348×10⁷</td>
<td>7.324×10⁴</td>
<td>12-13</td>
<td>2.735×10³</td>
<td>7.186×10⁷</td>
</tr>
<tr>
<td>4-7</td>
<td>4.697×10⁷</td>
<td>4.466×10⁵</td>
<td>13-14</td>
<td>5.847×10³</td>
<td>1.647×10⁷</td>
</tr>
</tbody>
</table>
Detection results for reactance of Branch 12-13

Detection results for reactance of Branch 7-8

![Graphs showing detection results for reactance of Branch 12-13 and Branch 7-8.](image)
Fast Correction of Parameters

\[ r = S e - S H_p p_e \]

\[ \lambda = \Lambda p_e - H_p^T R^{-1} S e \]

\[ p_{corr,i} = p_{bad,i} - \frac{\lambda_i}{\Lambda_{ii}} \]
<table>
<thead>
<tr>
<th></th>
<th>1st cycle</th>
<th>2nd cycle</th>
<th>3rd cycle</th>
<th>4th cycle</th>
<th>5th cycle</th>
<th>6th cycle</th>
<th>7th cycle</th>
<th>8th cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identified error</td>
<td>( r_{2840-2886} )</td>
<td>( x_{1898-1935} )</td>
<td>( t_{1289-1285} )</td>
<td>( p_{2886} )</td>
<td>( q_{287-1285} )</td>
<td>( v_{467} )</td>
<td>( x_{1898-1935} )</td>
<td>None</td>
</tr>
<tr>
<td>( \lambda^N / r^N )</td>
<td>190.8</td>
<td>97.39</td>
<td>49.99</td>
<td>26.35</td>
<td>26.29</td>
<td>19.61</td>
<td>11.80</td>
<td>-</td>
</tr>
<tr>
<td>True value</td>
<td>1.0108</td>
<td>0.03704</td>
<td>1.0304</td>
<td>-0.04305</td>
<td>0.01980</td>
<td>0.01457</td>
<td>0.03704</td>
<td>-</td>
</tr>
<tr>
<td>Erroneous value</td>
<td>1.0158</td>
<td>0.04704</td>
<td>0.9704</td>
<td>0.00695</td>
<td>0.02480</td>
<td>0.03457</td>
<td>0.03596</td>
<td>-</td>
</tr>
<tr>
<td>Estimated value</td>
<td>1.0108</td>
<td>0.03596</td>
<td>1.0304</td>
<td>-0.04267</td>
<td>0.01955</td>
<td>0.01441</td>
<td>0.03700</td>
<td>-</td>
</tr>
<tr>
<td>Estimation error</td>
<td>&lt;0.01%</td>
<td>2.92%</td>
<td>&lt;0.01%</td>
<td>0.88%</td>
<td>1.26%</td>
<td>1.10%</td>
<td>0.11%</td>
<td>-</td>
</tr>
</tbody>
</table>
Samples of Actual Cases

Several sets of single day / multiple scans covering different seasonal periods are used

All types of measurement and parameter errors were detected
ERROR IN 1384-1381 LINE REACTANCE ➔ DETECTED AND CORRECTED
Shunt Parameter Error at 2720:
Detected / Identified

Missing shunt reactor?
Improved metrics after correction of parameter errors

<table>
<thead>
<tr>
<th></th>
<th>Before Correction</th>
<th>After Correction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shunt susceptance at 2720</td>
<td>0</td>
<td>-2.78 p.u. (-278 Mvar)</td>
</tr>
<tr>
<td>Objective function</td>
<td>$3.287 \times 10^5$</td>
<td>$3.080 \times 10^5$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Measurement</th>
<th>$r^N/\lambda^N$ Before</th>
<th>$r^N/\lambda^N$ After</th>
</tr>
</thead>
<tbody>
<tr>
<td>S2720</td>
<td>144.05</td>
<td>4.595</td>
</tr>
<tr>
<td>Q2714</td>
<td>94.73</td>
<td>9.856</td>
</tr>
<tr>
<td>Q2702-2718</td>
<td>60.73</td>
<td>5.223</td>
</tr>
<tr>
<td>Q2671-2720</td>
<td>49.42</td>
<td>0.695</td>
</tr>
<tr>
<td>Q2720-2671</td>
<td>46.29</td>
<td>2.590</td>
</tr>
</tbody>
</table>
Company SE incorrectly flagged this as BD!

$X_T = 0.0057$

$X_T = -0.0070$

% drop in $J(x) = 4.7\%$
Advantages and Features

- Stand-alone code, no need to modify existing SE.
- Identifies incorrect network parameters along with any existing bad measurements.
- No need to specify apriori suspect parameter set.
- Suitable for even very large systems, but does not have to be executed on-line, can be used as an off-line tool.
Remarks and Conclusions

• The NLMNR test is a powerful tool for the joint detection and identification of parameter and measurement errors.

• The NLMNR test is developed, implemented and tested using actual state estimation save cases of an ISO with satisfactory results.

• Network model / parameter errors ought to receive equal attention as other sources of errors due to their significant impact on state estimation solution.

• Phasor measurements can facilitate parameter error identification for certain special topologies and insensitive parameter errors.
Acknowledgements

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Thank You

Any Questions?