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

$$v = \left[x_1, x_2, \ldots, x_n \mid p_1, p_2, \ldots, p_{Np}\right]$$ AUGMENTED STATE VECTOR

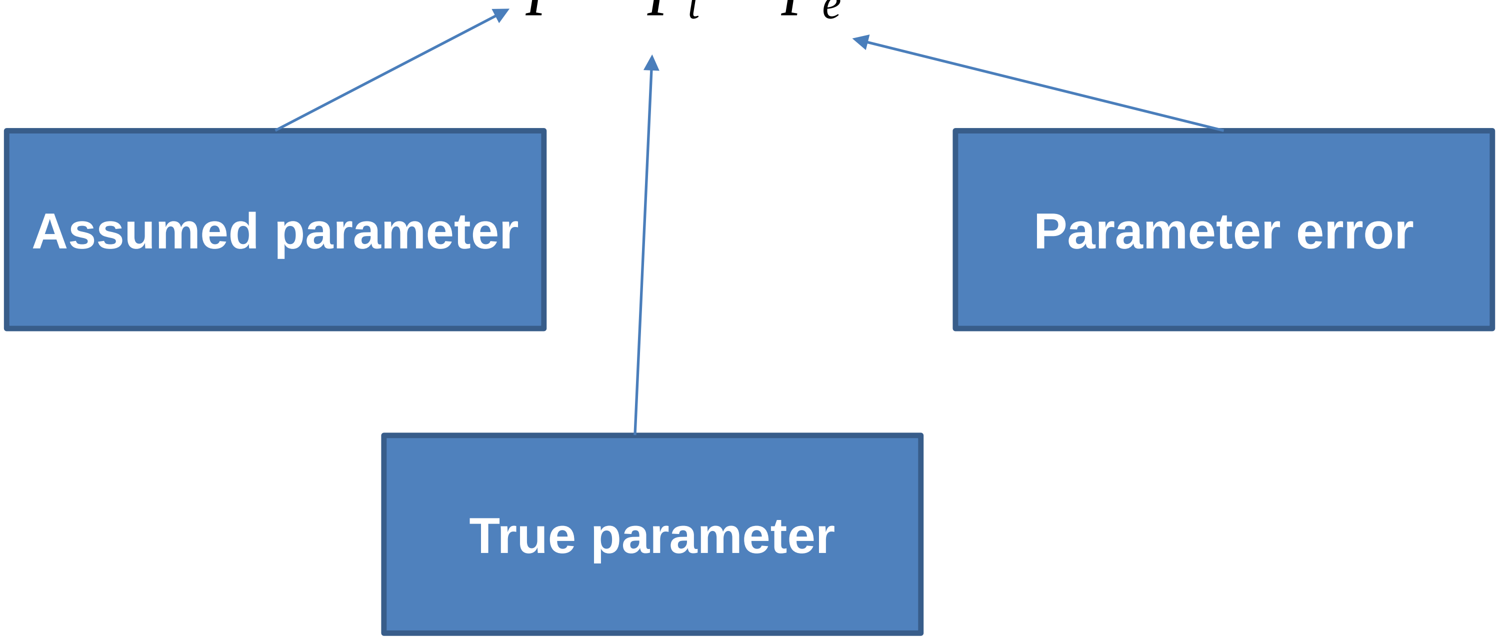
Shortcomings:

- No reliable way to predict the suspect set of parameters
- May require inclusion of too many parameters

Parameter Errors

Every network parameter is assumed to have an error:

$$p = p_t + p_e$$



State and Parameter Estimation

$$\min\ J(x, p_e) = \frac{1}{2}[z - h(x, p_e)]^T W [z - h(x, p_e)]$$

s.t. $p_e = 0$

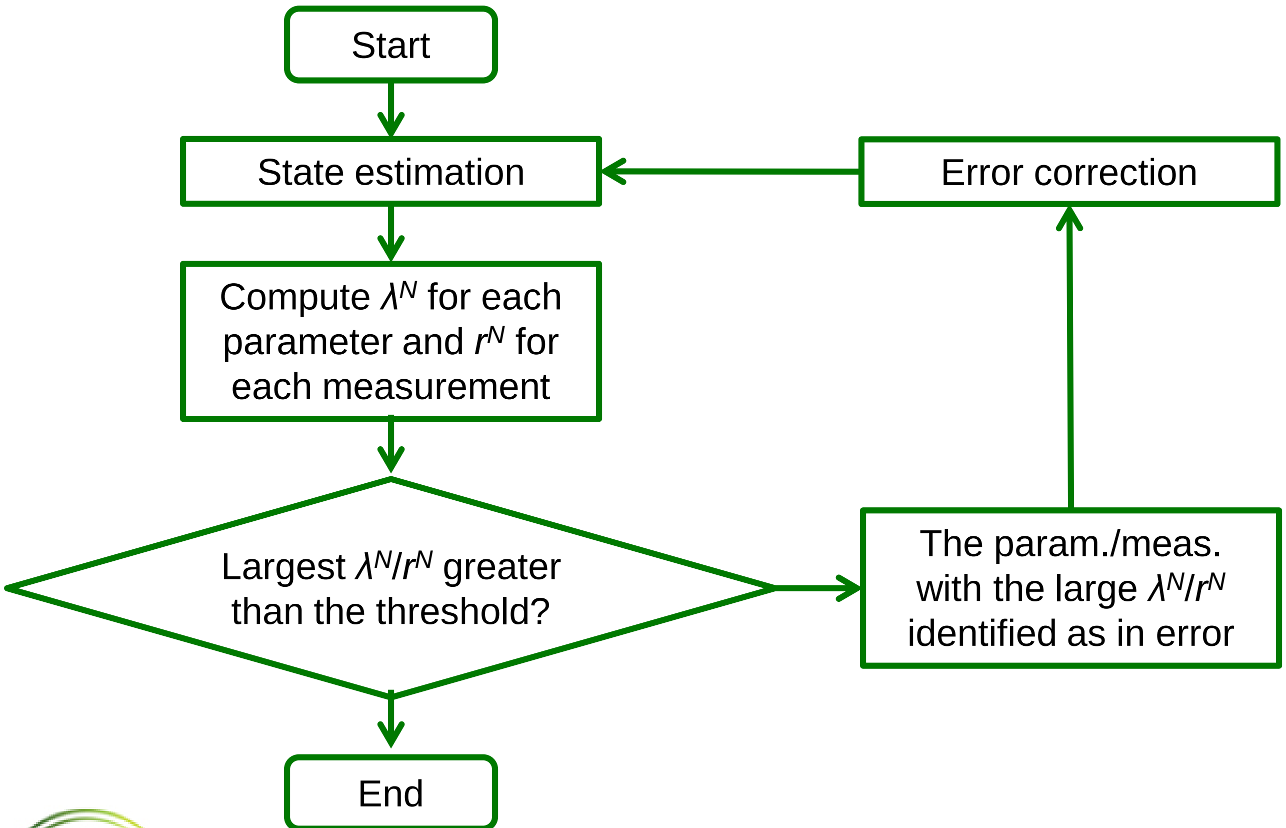
$c(x, p_e) = 0$

Associated Lagrangian will then be given by:

$$L = \frac{1}{2} r^T W r - \mu^T c\left(x, p_e\right) - \lambda^T p_e$$

Normalized Lagrange Multiplier and Normalized Residual (NLMNR) Test

J. Zhu and A. Abur, “Identification of network parameter errors”, *IEEE Trans. Power Systems*, vol. 21, no. 2, pp. 586-592, May, 2006.



NLM: (parameters) $$\lambda_i^N = \frac{\lambda_i}{\sqrt{\Lambda_{ii}}}$$

NR: (measurements) $$r_i^N = \frac{r}{\sqrt{\Omega_{ii}}}$$

Computational Bottleneck

$$\lambda_i^N = \frac{\lambda_i}{\sqrt{\Lambda_{ii}}}$$

$$\Lambda = H_p^T W H_p - H_p^T W H G^{-1} H^T W^T H_p$$

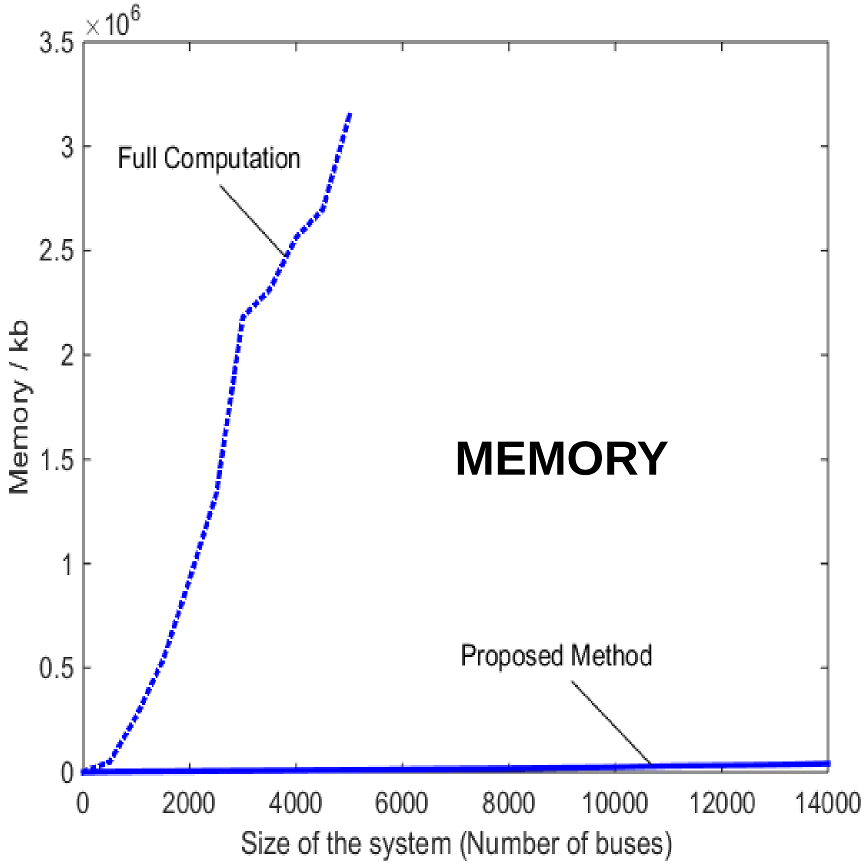
$$G^{-1} = \left(H^T W H\right)^{-1}$$

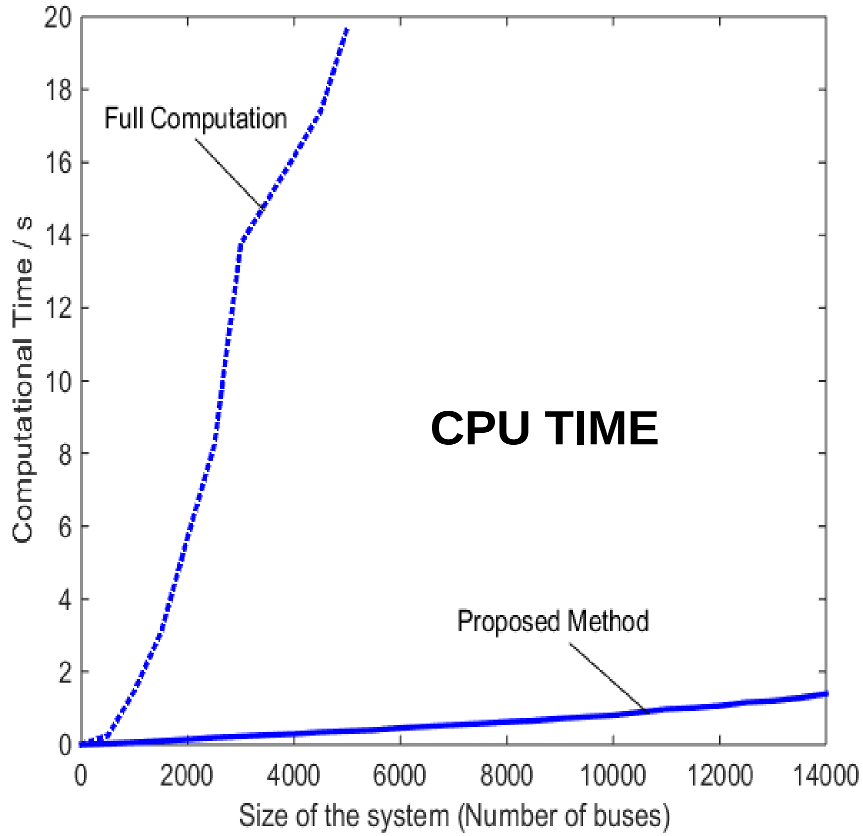
Matrix inversion and multiplication operations are computationally expensive !

<u>Proposed Solution:</u>

Instead of performing full computation, the necessary subset of *G* $^{-1}$ for computing the diagonal entries of *Λ* is determined and computed.

Computing Diagonal Entries of Covariance Matrix Λ

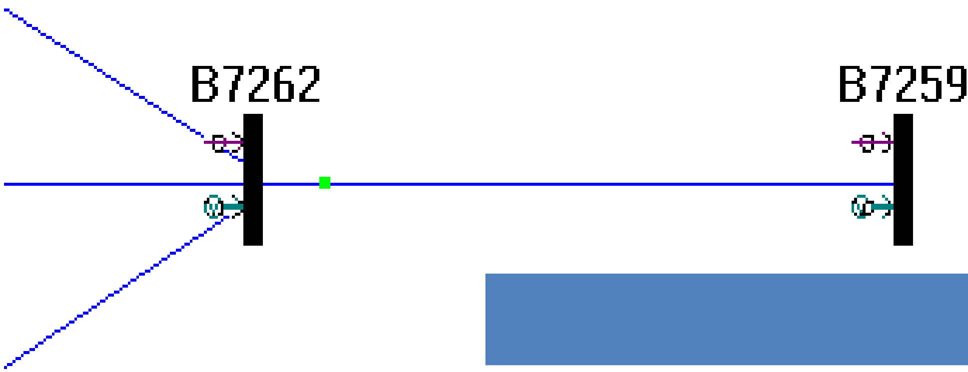




Lin, Yuzhang and Abur, A., "Highly Efficient Implementation for Parameter Error Identification Method Exploiting Sparsity," IEEE Trans. on PWRS, Vol. 32, No:1, pp.734-742, (2017).

Unidentifiable Errors

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



CANNOT BE IDENTIFIED

Errors			
$t_{(7262\text{-}7259)}$		$v_{(7259)}$	
z/p	r^N/λ^N	z/p	r^N/λ^N
$t_{(7262\text{-}7259)}$	20.68	$v_{(7259)}$	23.81
$v_{(7259)}$	20.68	$t_{(7262\text{-}7259)}$	23.81
$r_{(7262\text{-}7259)}$	20.58	$r_{(7262\text{-}7259)}$	23.74
$q_{(7262\text{-}7259)}$	6.955	$q_{(7262\text{-}7259)}$	7.705
$q_{(7259)}$	5.595	$q_{(7259)}$	5.699

Use of Multiple Scans

MIS-IDENTIFICATION OF TRANSFORMER TAP ERROR

Single Scan		Two Scans	
z/p	r^N/λ^N	z/p	r^N/λ^N
$t_{(7262-7259)}$	20.68	$t_{(7262-7259)}$	29.10
$v_{(7259)}$	20.68	$r_{t(7262-7259)}$	28.93
$r_{t(7262-7259)}$	20.58	$v_{(7259)}^{(2)}$	21.45
$q_{(7262-7259)}$	6.955	$v_{(7259)}^{(1)}$	20.68
$q_{(7259)}$	5.595	$s_{(7259)}$	7.914

Liuxi Zhang and Ali Abur, "Identifying Parameter Errors via Multiple Measurement Scans," IEEE Transactions on Power Systems, Vol. 28, No: 4, pp.3916-3923, Nov. 2013.

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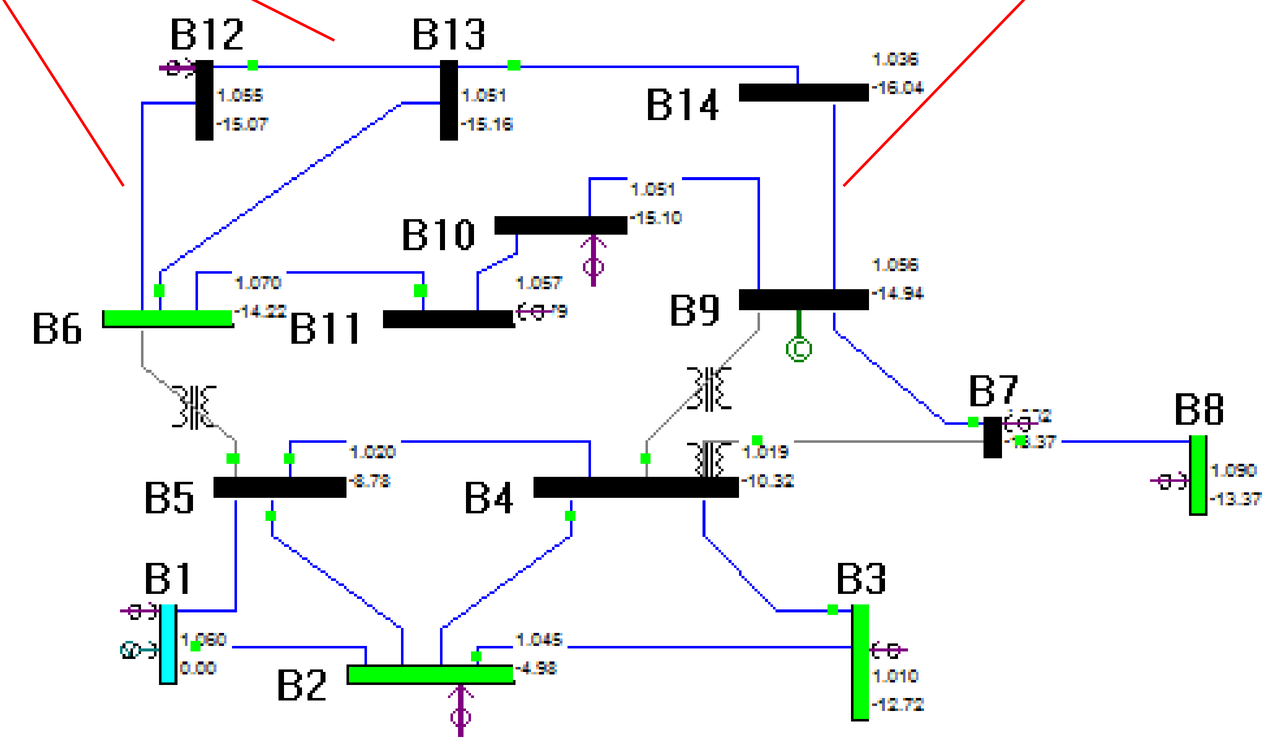
Detectability and Identifiability of Parameter and Measurement Errors

$$\lambda = \Lambda p_e + Ae$$

Critical parameter pair:
Errors detectable, but
not identifiable

Critical parameter:
Errors not detectable



Sensitivities of λ^N to p_e

$$\left|E\left(\lambda_i^N\right)\right| = \sqrt{s\Lambda_{ii}^s}\left|p_{e,i}\right|$$

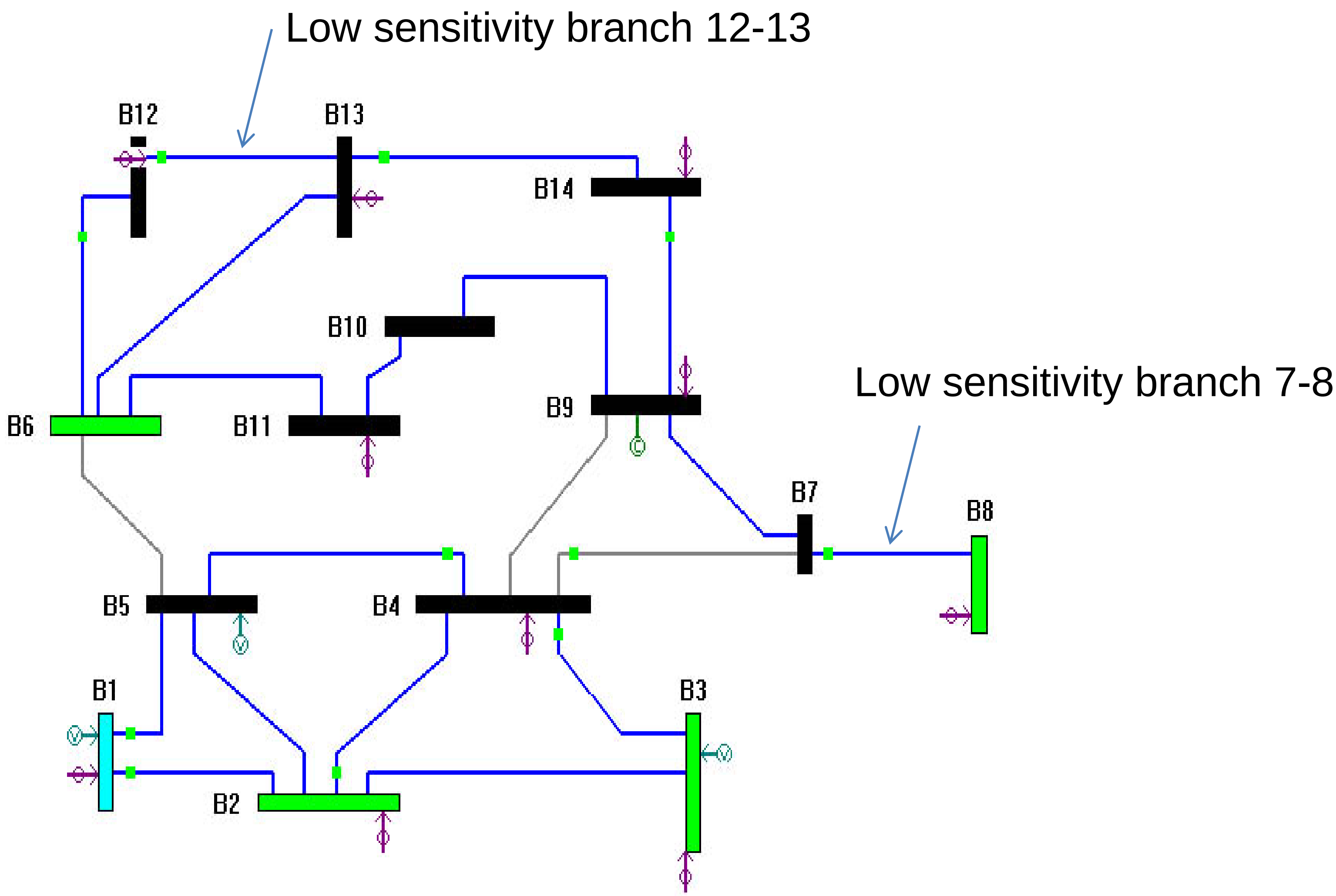
No of scans [a]

Related to the accuracy of measurements [b]

[a] Yuzhang Lin and A. Abur, “Enhancing network parameter error detection and correction via multiple measurement scans”, *IEEE Trans. Power Systems*, vol. 32, no. 3, pp. 2417-2425, May, 2017.

[b] Yuzhang Lin and A. Abur, “Strategic use of synchronized phasor measurements to improve network parameter error detection”, *IEEE Trans. Smart Grid*, doi: 10.1109/TSG.2017.2686095 (early access).

Undetectable Cases (Low Sensitivity)

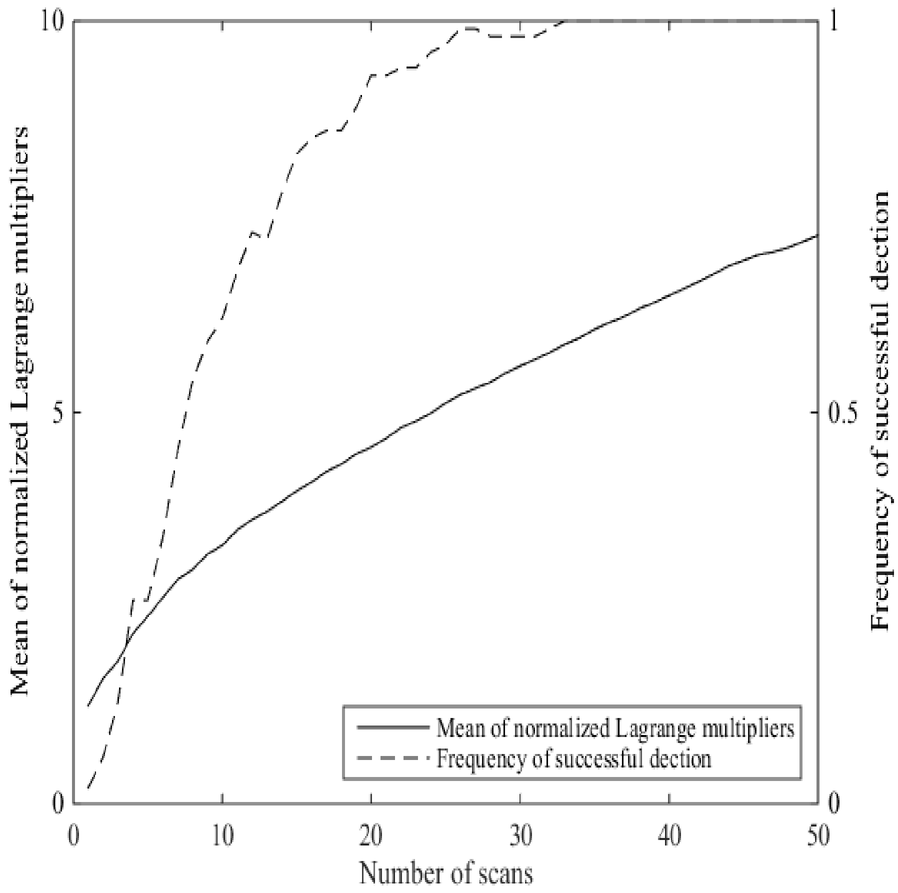


Parameter Error Sensitivities

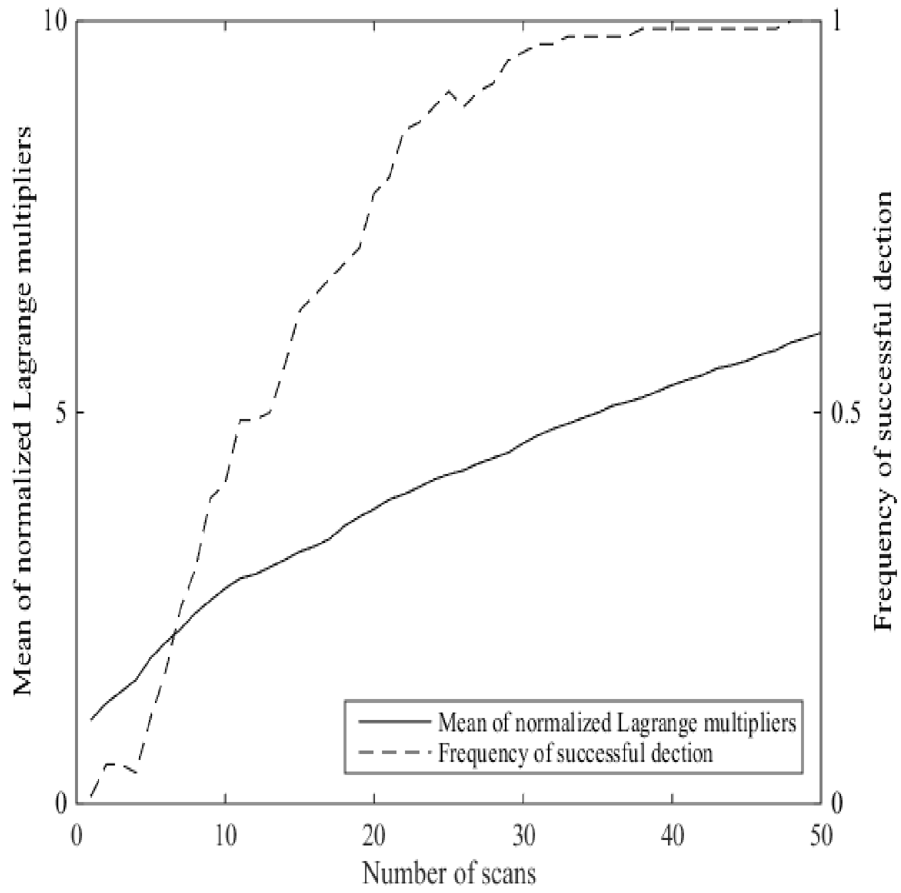
From Bus – To Bus	Λ_{ii}		From Bus – To Bus	Λ_{ii}	
	Resistance	Reactance		Resistance	Reactance
1-2	1.916×10^{7}	1.989×10^{10}	**7-8**	5.010×10^{2}	4.747×10^{2}
1-5	3.820×10^{6}	3.840×10^{6}	**7-9**	4.250×10^{5}	4.238×10^{5}
2-5	3.188×10^{6}	3.225×10^{8}	**9-10**	3.117×10^{4}	3.140×10^{4}
2-4	5.725×10^{6}	3.247×10^{8}	**9-14**	1.658×10^{4}	1.651×10^{4}
2-3	5.675×10^{6}	1.392×10^{8}	**10-11**	7.476×10^{3}	7.489×10^{3}
3-4	6.949×10^{5}	2.649×10^{8}	**6-11**	1.776×10^{4}	1.586×10^{8}
5-6	5.941×10^{5}	5.260×10^{5}	**6-12**	1.752×10^{4}	1.746×10^{4}
4-5	1.057×10^{7}	3.943×10^{9}	**6-13**	1.435×10^{5}	1.290×10^{8}
4-9	7.348×10^{7}	7.324×10^{4}	**12-13**	2.735×10^{3}	7.186×10^{7}
4-7	4.697×10^{7}	4.466×10^{5}	**13-14**	5.847×10^{3}	1.647×10^{7}

Multiple-Scans: Monte Carlo Simulations

Detection results for reactance of Branch 12-13



Detection results for reactance of Branch 7-8



Fast Correction of Parameters

$$r = Se - SH_p p_e$$

$$\lambda = \Lambda p_e - H_p^T R^{-1} Se$$

$$p_{corr,i} = p_{bad,i} - \lambda_i / \Lambda_{ii}$$

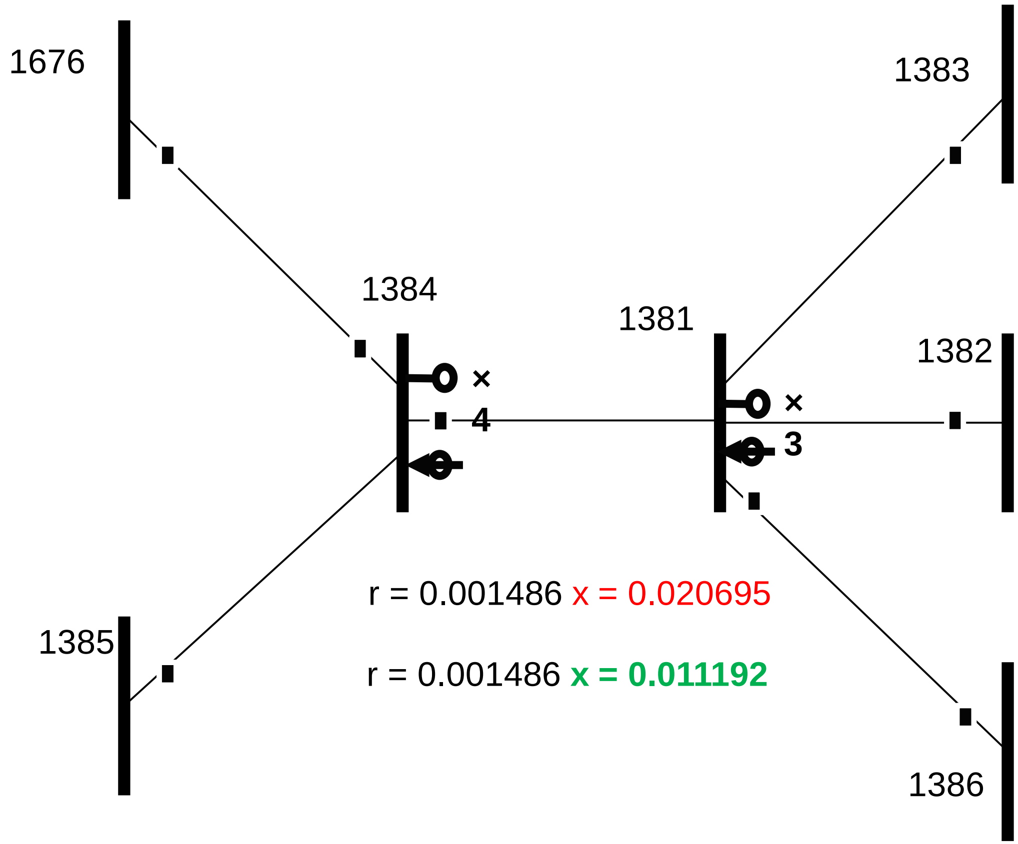
$r_{2840\text{-}2886}$, $x_{1898\text{-}1935}$, $t_{1289\text{-}1285}$, p_{2886}, $q_{287\text{-}1285}$, v_{467}

	1st cycle	2nd cycle
Identified error	$t_{1289\text{-}1285}$	$x_{1898\text{-}1935}$
λ^N / r^N	190.8	97.39
True value	1.0108	0.03704
Erroneous value	1.0158	0.04704
Estimated value	1.0108	0.03596
Estimation error	<0.01%	2.92%
	3rd cycle	4th cycle
Identified error	v_{467}	p_{2886}
λ^N / r^N	49.99	26.35
True value	1.0304	-0.04305
Erroneous value	0.9704	0.00695
Estimated value	1.0304	-0.04267
Estimation error	<0.01%	0.88%
	5th cycle	6th cycle
Identified error	$r_{2840\text{-}2886}$	$q_{287\text{-}1285}$
λ^N / r^N	26.29	19.61
True value	0.01980	0.01457
Erroneous value	0.02480	0.03457
Estimated value	0.01955	0.01441
Estimation error	1.26%	1.10%
	7th cycle	8th cycle
Identified error	$x_{1898\text{-}1935}$	None
λ^N / r^N	11.80	-
True value	0.03704	-
Erroneous value	0.03596	-
Estimated value	0.03700	-
Estimation error	0.11%	-

Samples of Actual Cases

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

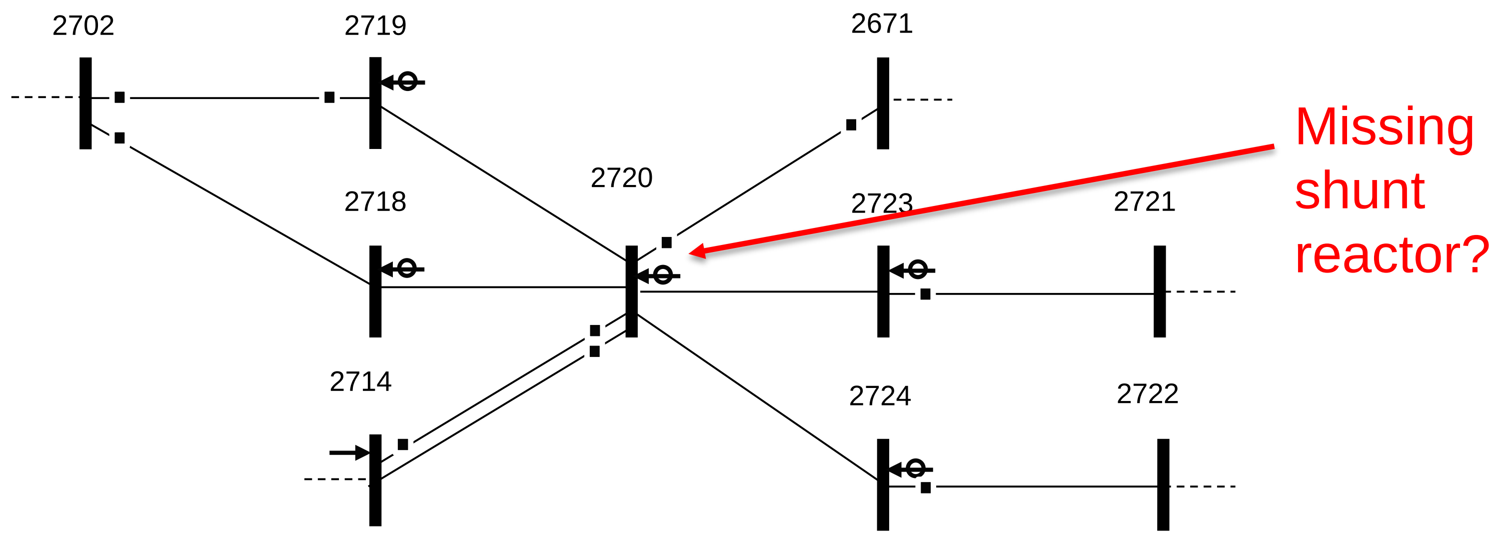
All types of measurement and parameter errors were detected



Before	After
0.460937657329165	0.289008123443830
0.269594403926207	0.0976660277362713
0.269594403926207	0.0976660277362713
0.286555371924643	0.548232003383775
0.0111368172039988	0.272815430842876
0.148316030265871	0.113363730950754
0.202480234167789	0.464157470713370
3.72719383583924	0.172400209251095
3.57662997415831	0.178522866723937
10.2149428359020	0.424435660132706
7.00998431287152	0.604911469960423
3.37988900163521	1.83936447870392
2.55415818968739	3.74037079035328
3.14912633640466	0.663251127905021
1.67961923355822	0.0701388475836307
1.71636621679793	0.0717885583858157
4.34851597108845	0.181796134065294
1.82383634029682	1.63569215634478
1.82821450856409	1.05884176923907
22.9640003606959	22.8065306842684
0.239201667925659	0.988820254404609
3.57662997415837	0.178522866723995
3.72719383583928	0.172400209251182
30.1245789635412	3.87943021959142
18.6560610719354	3.73369368975406
3.67325444350490	4.57153002106506
31.7318214586345	1.91733505819892
22.2302232306877	0.0874734903556829
21.0479351872404	1.50447458316698
18.8109980087997	3.46911839685214
1.71636621679793	0.0717885583857003
1.67961923355845	0.0701388475836307
10.3456789047939	0.142645857314481
4.59954088579938	1.93474392372585
2.52052405543636	4.60585325498197
3.39047789274865	4.35003106723479
5.10310696952164	1.85047781482126
5.61486938251085	0.177553231858535
[illegible]	[illegible]

ERROR IN 1384-1381 LINE REACTANCE→ DETECTED AND CORRECTED

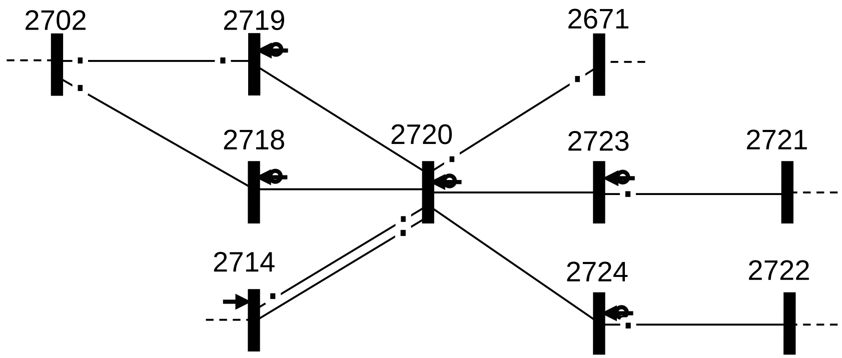
Shunt Parameter Error at 2720 : Detected / Identified



Improved metrics after correction of parameter errors

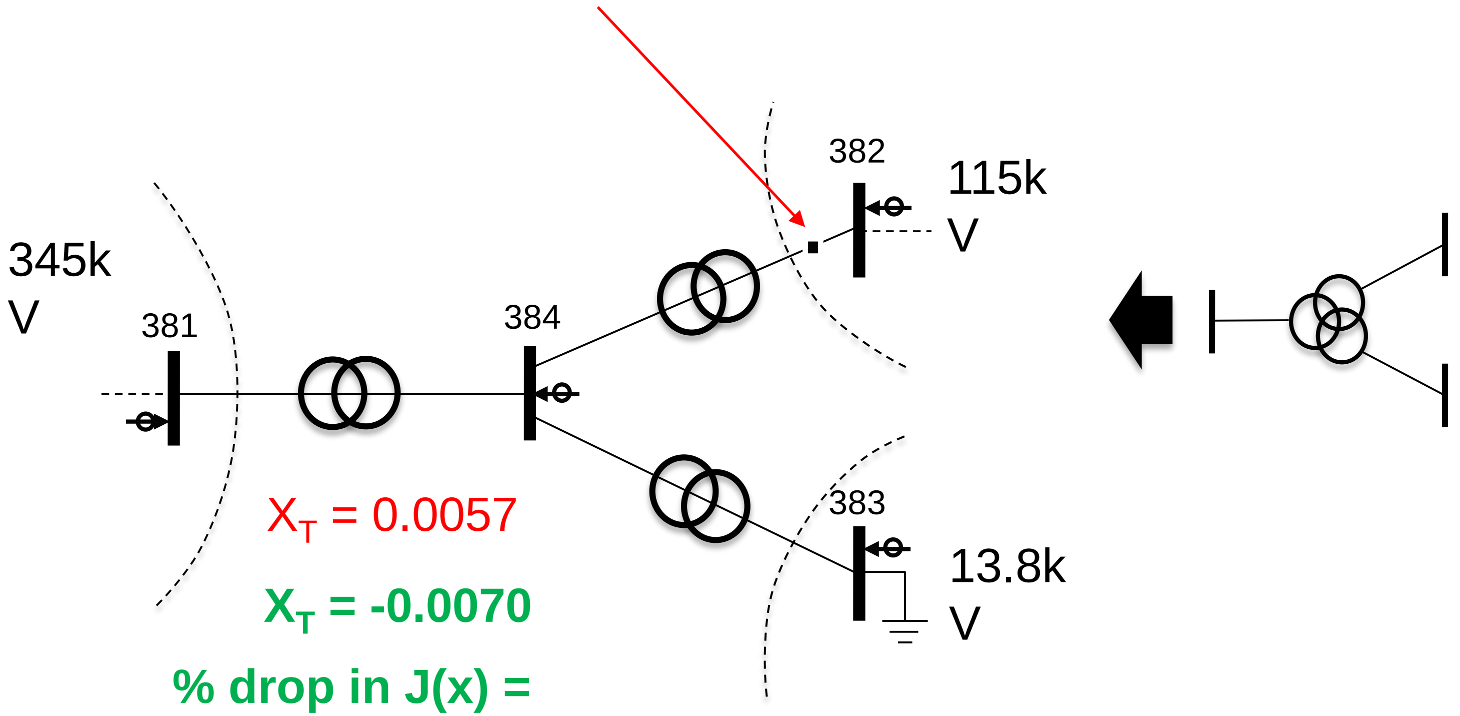
	Before Correction	After Correction
Shunt susceptance at 2720	0	-2.78 p.u. (-278 Mvar)
Objective function	3.287×10^5	3.080×10^5

Measurement	r^N/λ^N Before	r^N/λ^N After
S2720	144.05	4.595
Q2714	94.73	9.856
Q2702-2718	60.73	5.223
Q2671-2720	49.42	0.695
Q2720-2671	46.29	2.590



3-Winding Transformer Reactance Error

Company SE incorrectly flagged this as BD !



$X_T = 0.0057$

$\mathbf{X_T = -0.0070}$

% 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.

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Jun Zhu, Ph.D. 2009

Liuxi Zhang, Ph.D. 2014

Thank You

Any Questions?