Locating Faults in Large Power Grids Using a Few Strategically Placed PMU Measurements

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Outline

Sparse Estimation Problems

Formulation of Fault Location Problem

Implementation of Proposed Solution

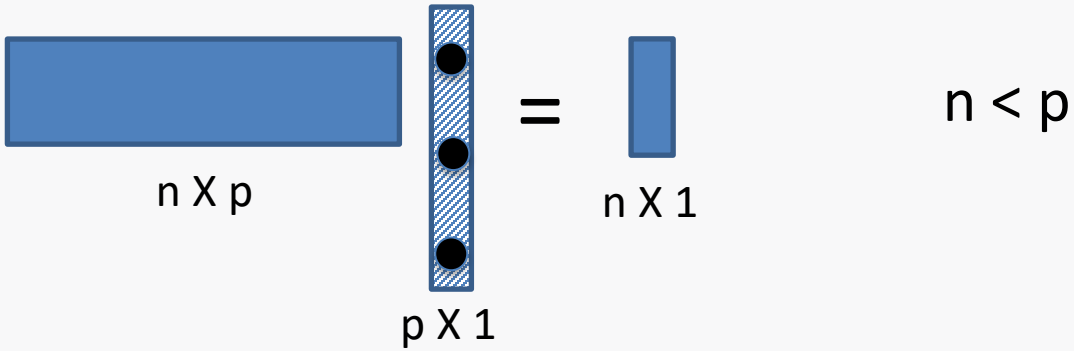
Illustrative Examples

Summary of Contributions

Sparse Estimation Problems

Underdetermined set of equations:

$$[\boldsymbol{X}][\boldsymbol{\beta}] = [\boldsymbol{y}]$$



It is known that β is "*k*" sparse, that is:

"*k*" out of "*p*" entries are known to be significantly larger than the remaining (*p*-*k*) entries,

Fault

However, it is NOT known which ones they are.

Least Angle Regression and Shrinkage (LARS)[*]

$$\hat{\beta} \in \underset{\beta \in \mathbb{R}^p}{\operatorname{argmin}} \frac{1}{2} \| \mathbf{y} - \mathbf{X}\beta \|_2^2 + \lambda \| \beta \|_1 \qquad \lambda \geq 0$$

$$\mathbf{y} \in \mathbb{R}^n \qquad \mathbf{X} \in \mathbb{R}^{n \times p} \; (p > n)$$

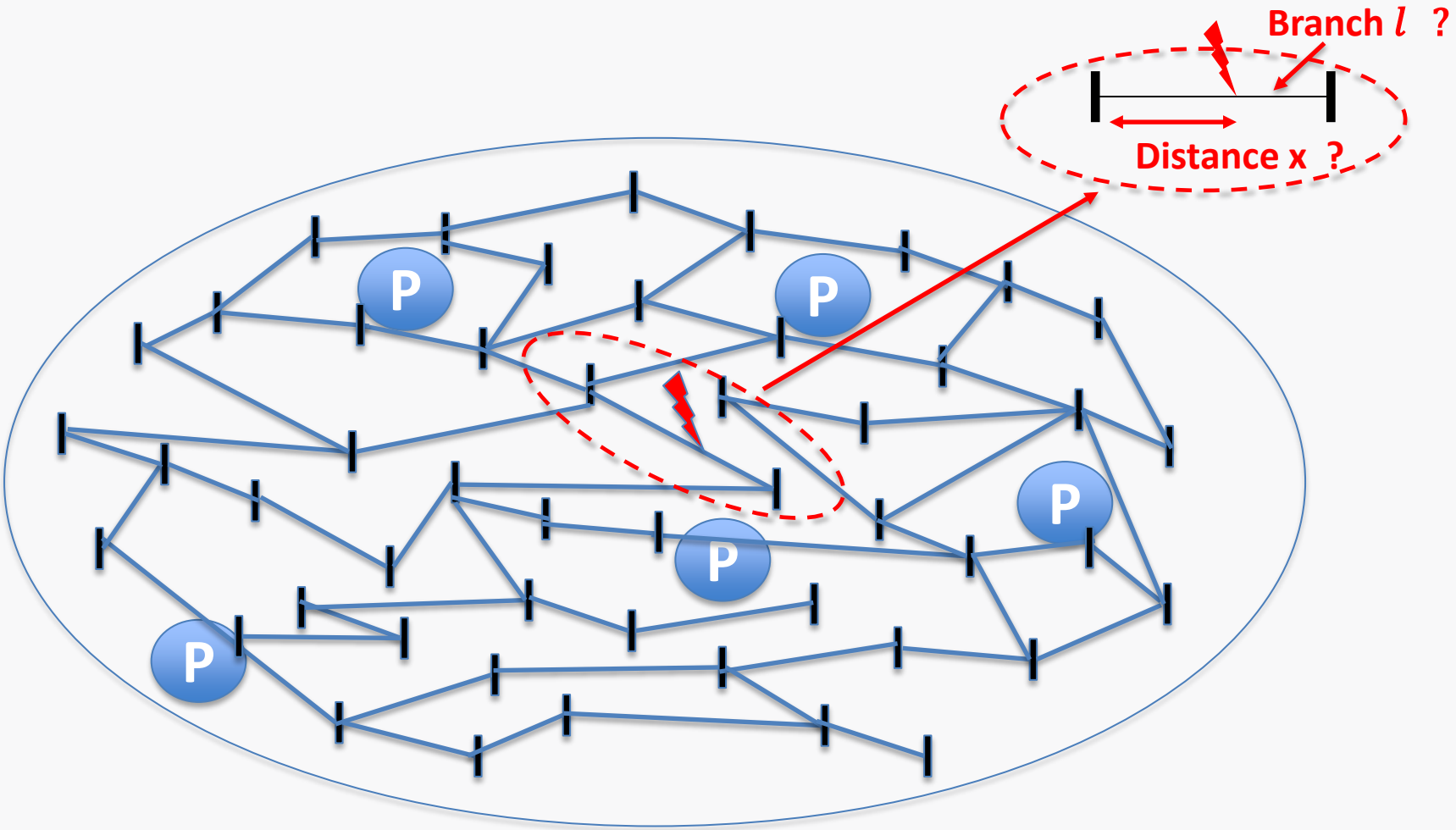
[*] R. Tibshirani, "Regression shrinkage and selection via the lasso," Journal of the Royal Statistical Society. Series B (Methodological), Vol.58,No.1, pp. 267–288, 1996.
B. Efron, T. Hastie, I. Johnstone, R. Tibshirani et al., "Least angle regression," The Annals of statistics, vol. 32, no. 2, pp. 407–499, 2004.

LASSO: Least Absolute Shrinkage and Selection Operator

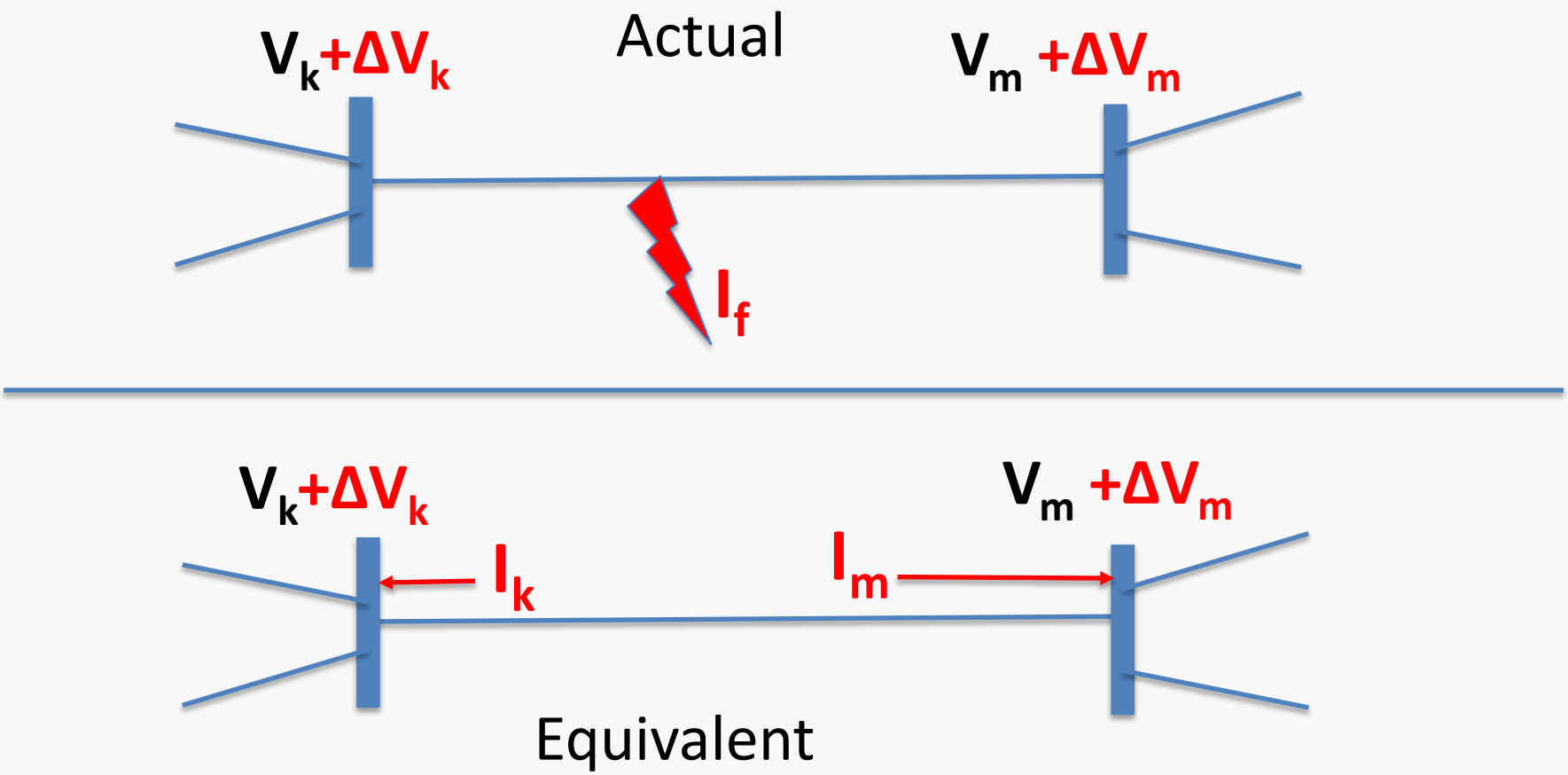
Fault location problem

Find: Faulted branch, distance x, fault type, fault current

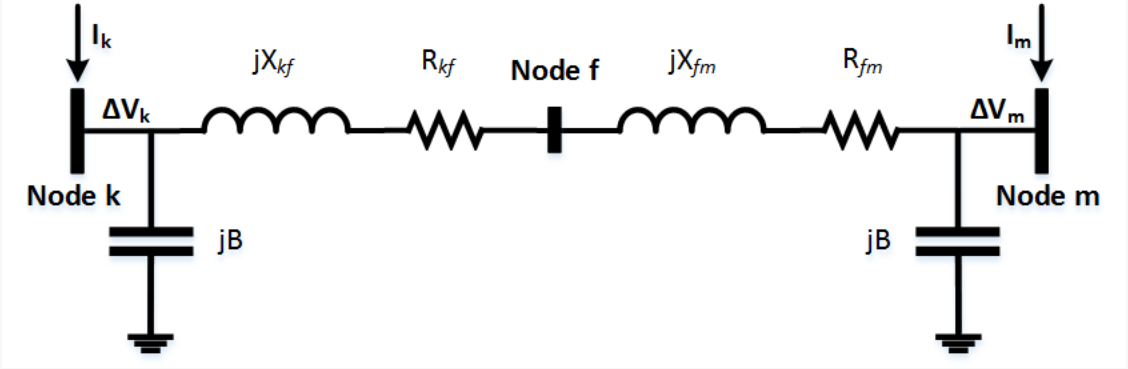
Given: Few PMU measurements



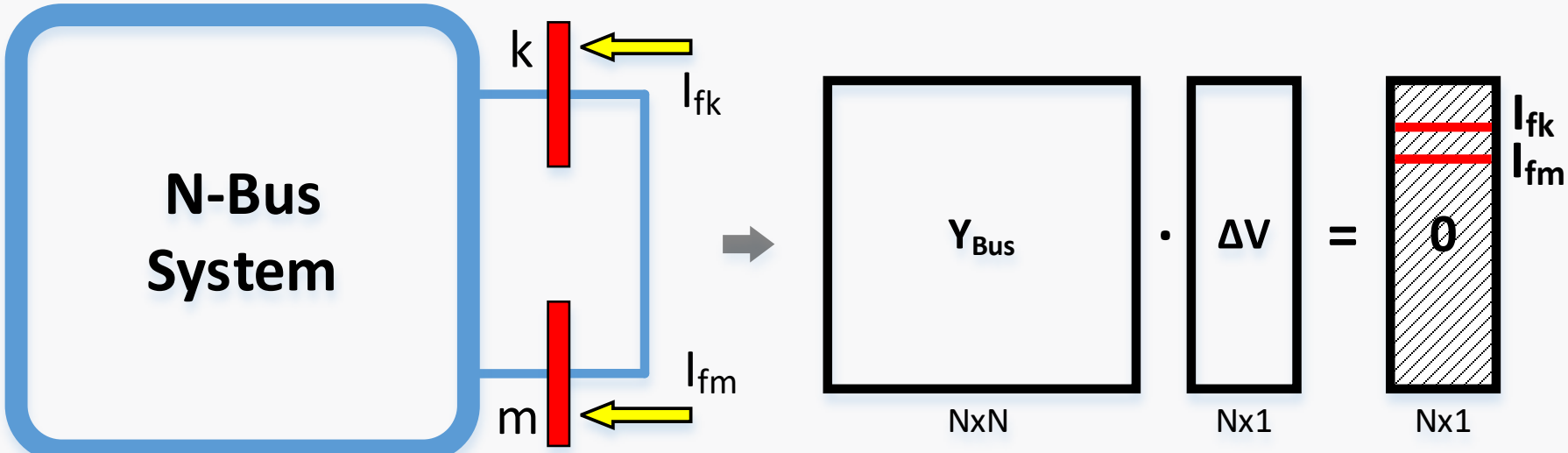
Replacing Fault Current by Bus Injections



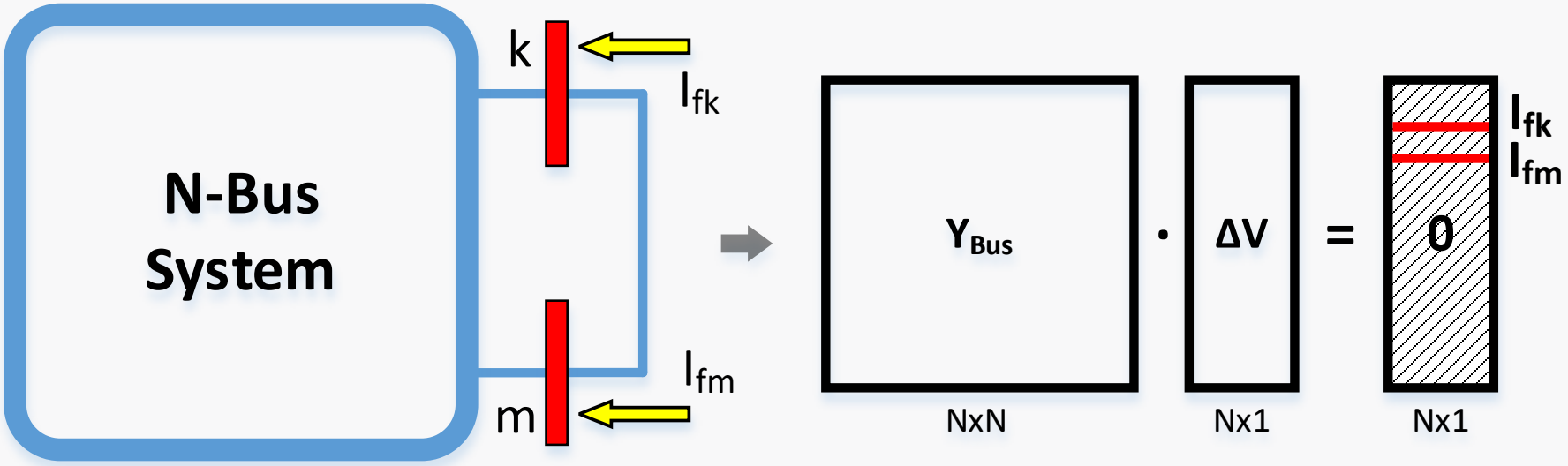
Incremental Change Network Equations



After Fault Current Replacement:



Fault Distance Calculation

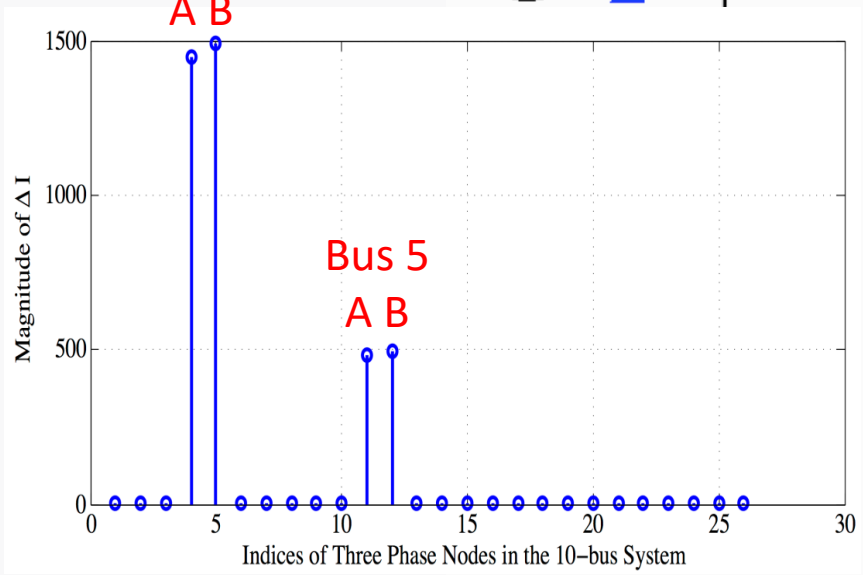


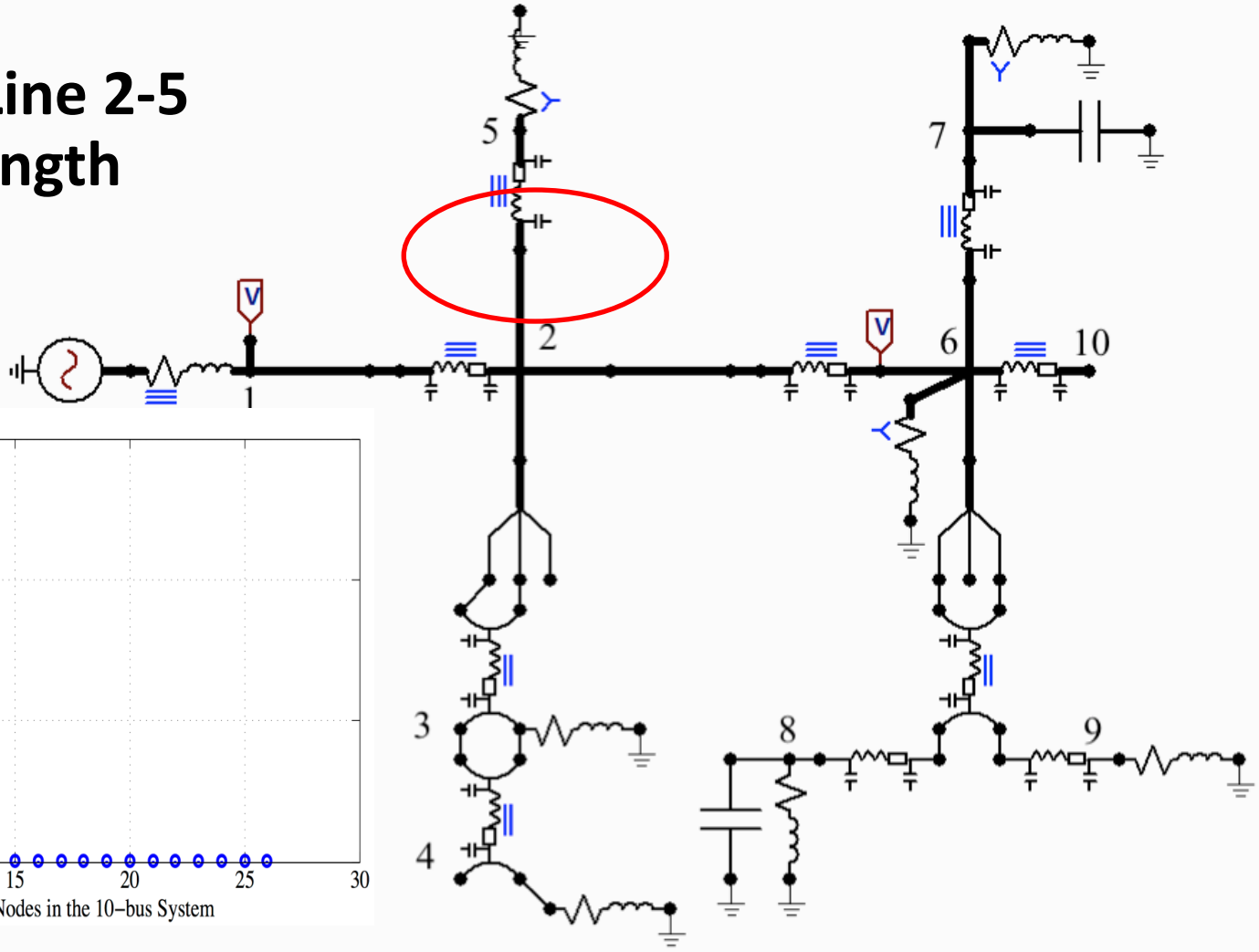
$$Fault\ Location(m) = \frac{I_{fk}}{I_{fk} + I_{fm}} * 100\%$$

$$Fault\ Location(k) = \frac{I_{fm}}{I_{fk} + I_{fm}} * 100\%$$

10-bus Mixed-Phase Unbalanced System

AB-G Fault on Line 2-5 at 1/4 line length





If every bus has a PMU:

$$[\boldsymbol{Y}][\Delta \boldsymbol{V}] = [\Delta \boldsymbol{I}]$$

Measure ΔV = (Post fault – Pre fault) Voltage

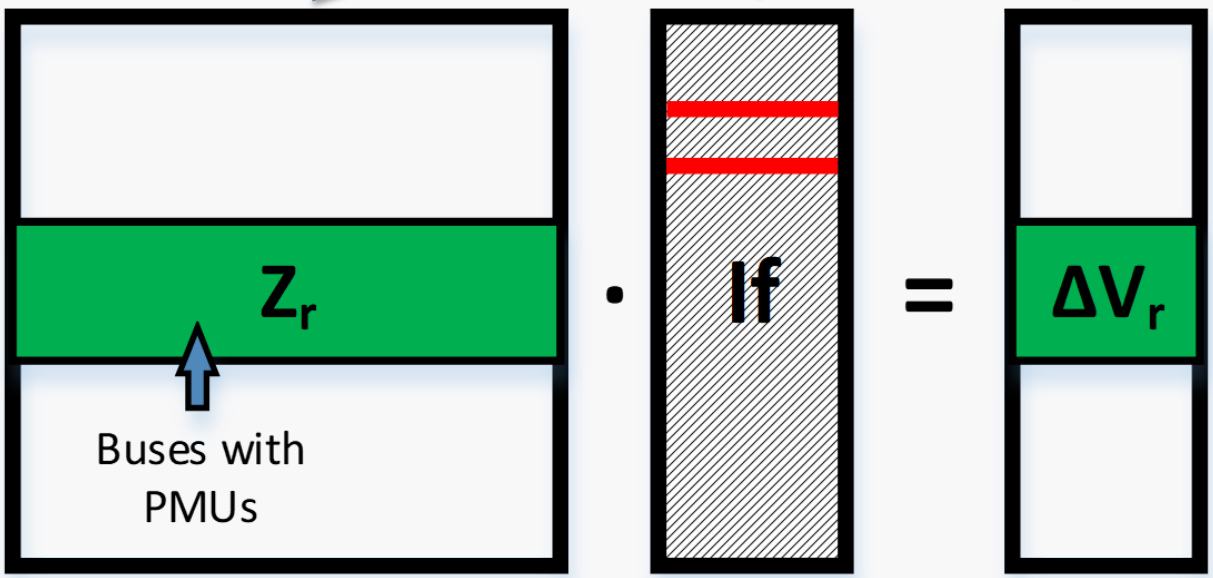
Compute ΔI

Determine:

- Distance to fault
- Fault type
- Fault current

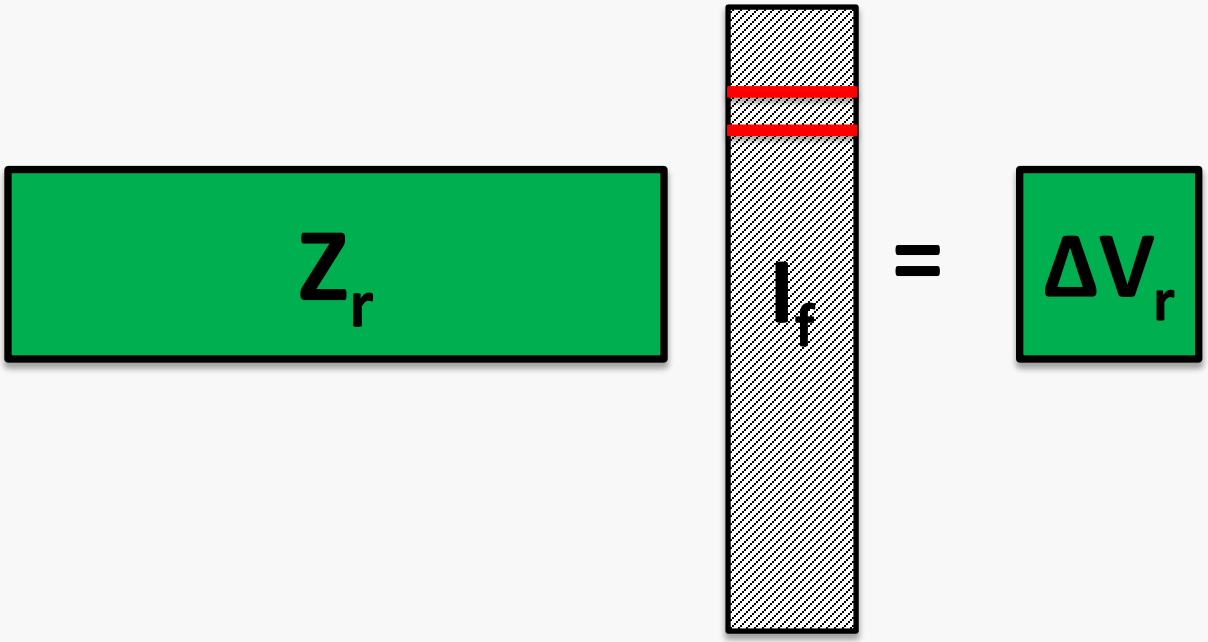
Sparse Estimation

$$[Z_{bus}][\Delta I] = [\Delta V]$$



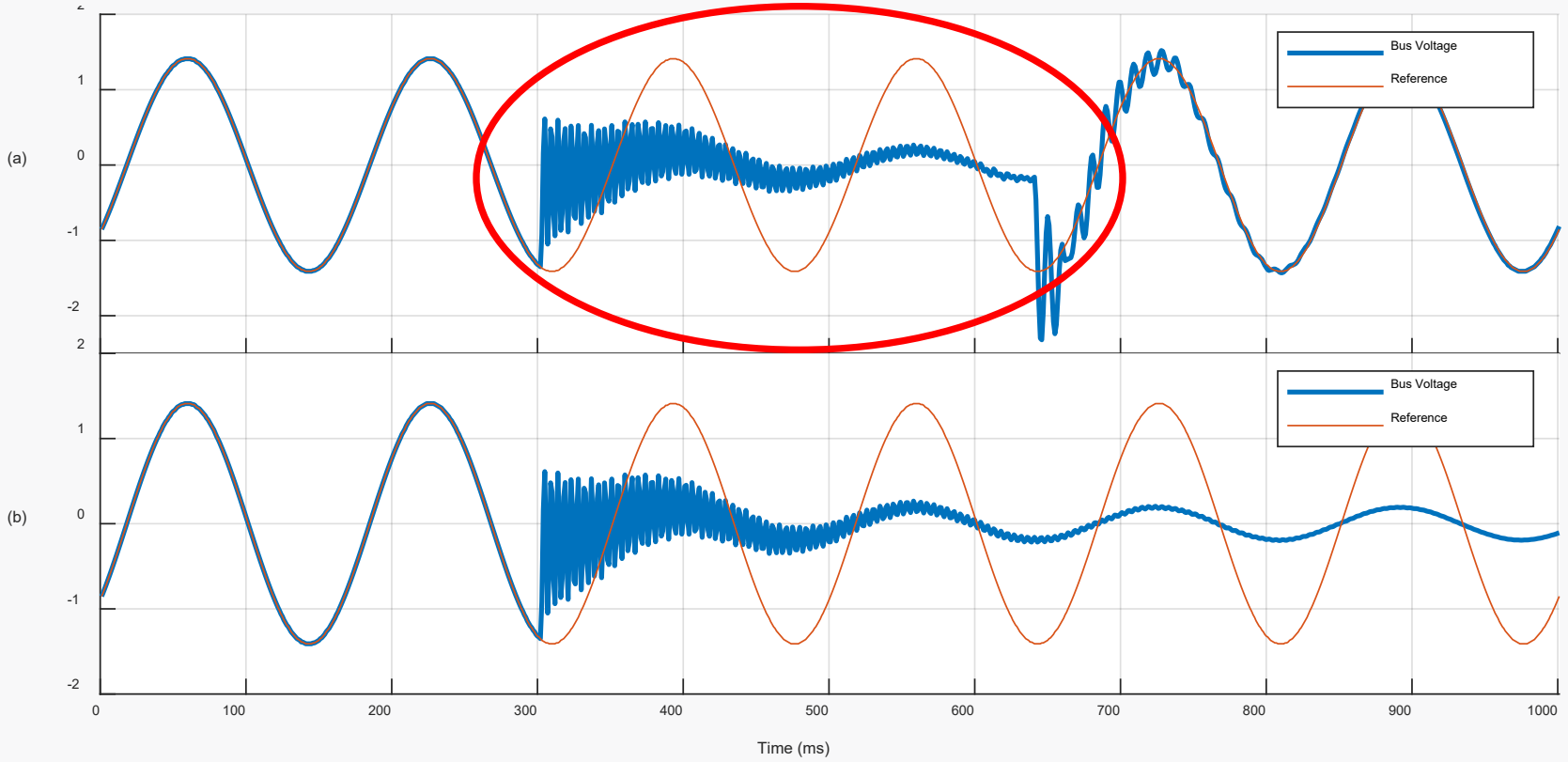
$$[Z_r][\Delta I] = [\Delta V_r]$$

Sparse Estimation



$$[Z_r].[I_f] = [\Delta V_r]$$

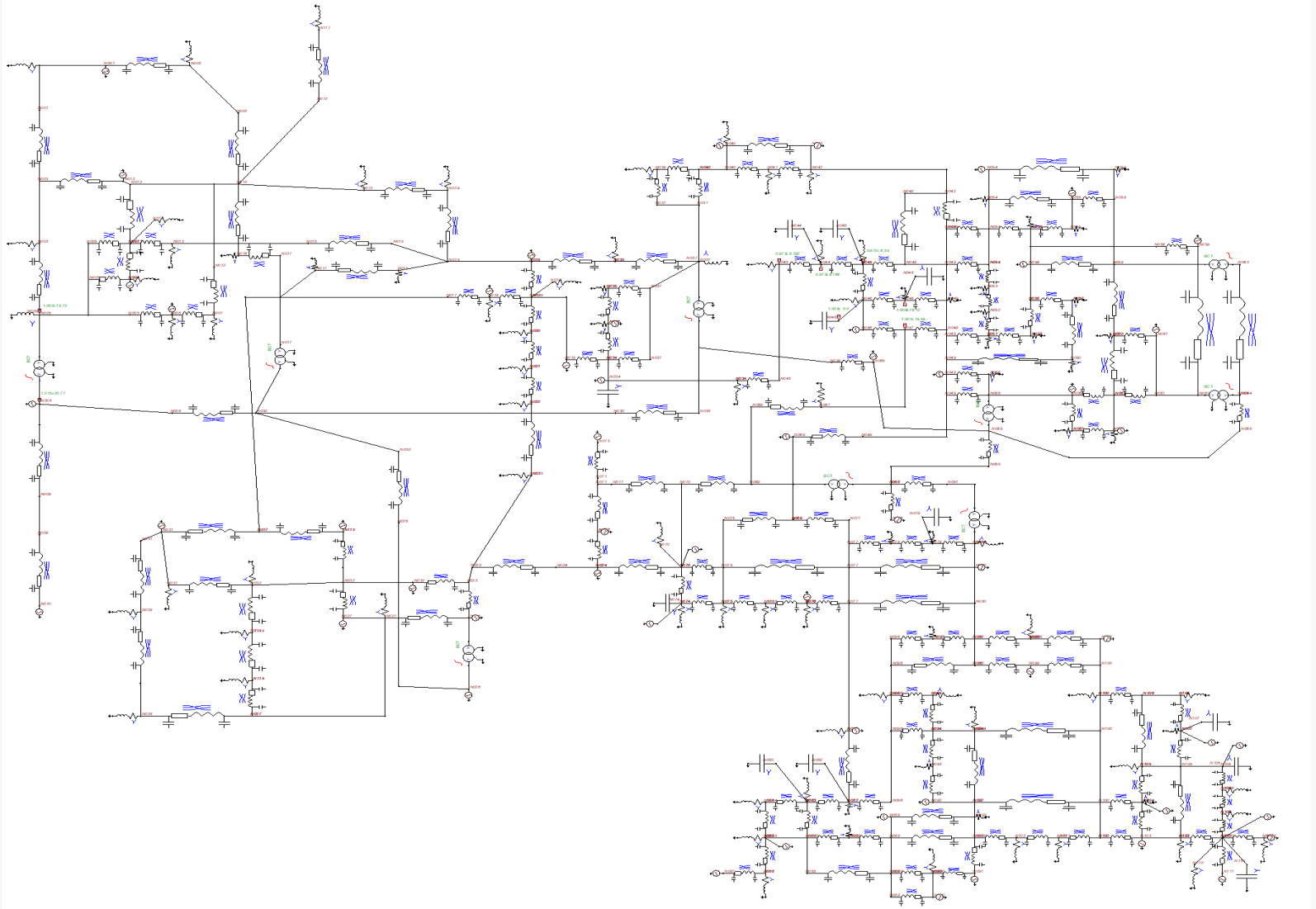
Prony Analysis



Test System

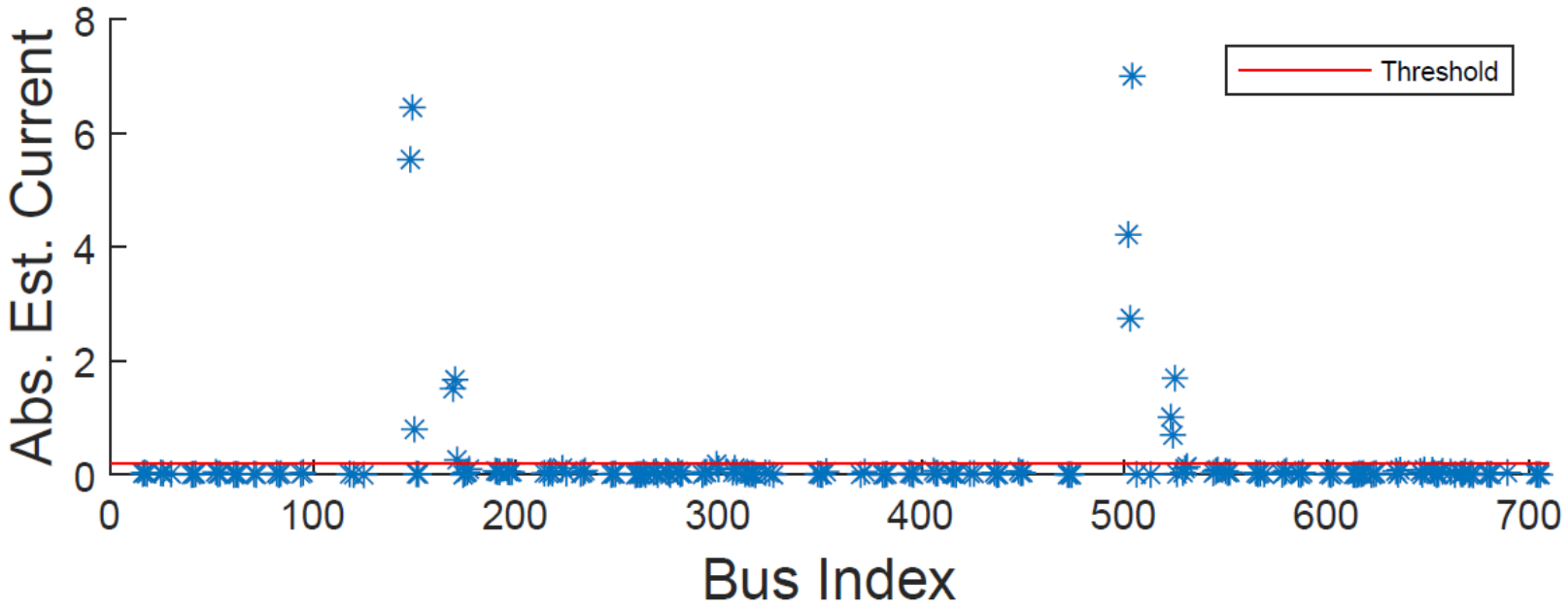
- Only 31 measured buses
- 3 cycles of fault transient data
- Several fault types tested

3-Phase Model for the IEEE 118 Bus test System



Simulation Results

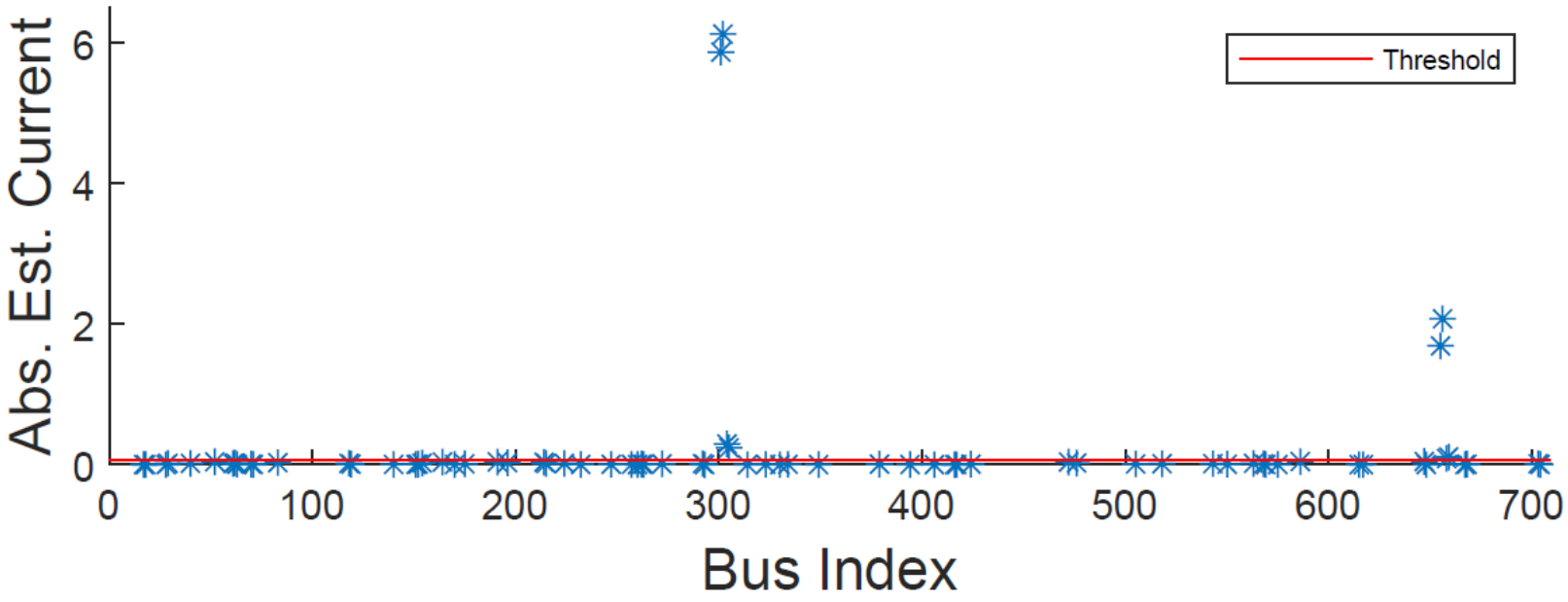
3ϕ to ground Fault at 20% of Transmission Line 50-57



Bus	Phase	Est. Current	Est. Fault Location
50	A	$5.5416 - 4.2220i$	20.74%
50	B	$-6.4571 - 2.7499i$	20.52%
50	C	$0.8004 + 7.0102i$	19.58%
57	A	$1.5136 - 1.0149i$	79.29%
57	B	$-1.6724 - 0.6971i$	79.48%
57	C	$0.2637 + 1.6973i$	80.43%

Simulation Results

ϕ to ϕ Fault at 5% of Transmission Line 101-102



Bus	Phase	Est. Current	Est. Fault Location
101	A	$5.8731 - 1.6913i$	4.80%
101	B	$-6.1302 - 2.0764i$	3.93%
102	A	$0.2956 - 0.0875i$	95.20%
102	B	$-0.2402 - 0.1105i$	96.10%

Summary of Contributions

- Faults of any type can be located on any branch in a large power grid based on very few synchronized bus voltage phasor measurements.
- PMU's internal transient sample recordings can be used to improve the post-fault steady state voltage phasor calculation.

REFERENCES:

[1] G. Feng and A. Abur, "Identification of faults using sparse optimization," *2014 52nd Annual Allerton Conference on Communication, Control, and Computing (Allerton)*, Monticello, IL, USA, **2014**, pp. 1040-1045.

[2] G. Feng and A. Abur, "Fault Location Using Wide-Area Measurements and Sparse Estimation," *IEEE Transactions on Power Systems*, vol. 31, no. 4, pp. 2938-2945, July **2016**.

[3] A. Mouco, and A. Abur, "Improvement of Fault Location Method Based on Sparse PMU Measurements," *2017 North American Power Symposium (NAPS)*, Morgantown, WV, **2017**, pp. 1-5.