UNIVERSITY OF ALBERTA
FUTURE ENERGY SYSTEMS

Estimating Distribution System Parameters Using DPMU and Smart Meter Data

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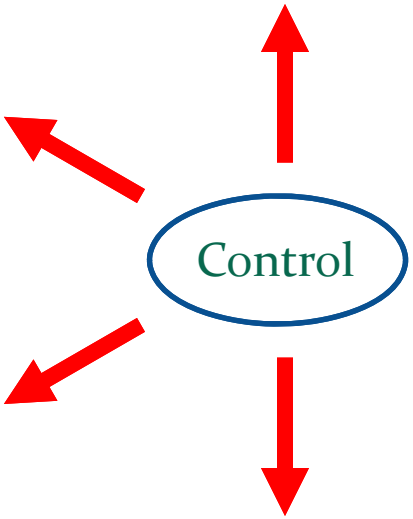
- State Estimation
- Required Data
- Bayesian Approach
- Preliminary Results
- Future Work

Motivation for State Estimation



State Estimation

State Estimation

Find system states: $x = [\theta_2, \theta_3, \dots, \theta_N, v_1, v_2, \dots, v_N]$

Given some measurements: $z = \begin{bmatrix} z_1 \\ z_2 \\ \vdots \\ z_m \end{bmatrix}$

Weighted least-squares method: $z = h(x) + e$

Network parameters

i.i.d. error

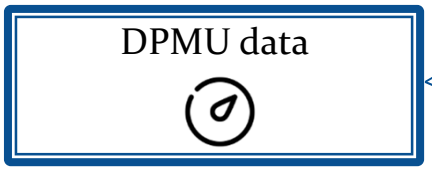
$$\text{h(x)} = \begin{bmatrix} h_1(x_1, x_2, \dots, x_n) \\ h_2(x_1, x_2, \dots, x_n) \\ \vdots \\ h_m(x_1, x_2, \dots, x_n) \end{bmatrix}, \text{e} = \begin{bmatrix} e_1 \\ e_2 \\ \vdots \\ e_m \end{bmatrix}$$

Error covariance matrix

$$J(x) = [z - h(x)]^T R^{-1} [z - h(x)]$$

Required Data

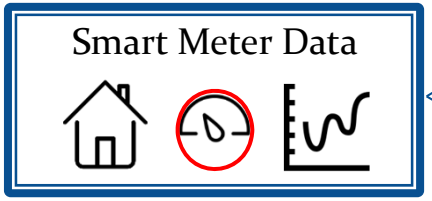
- Real time measurements
  - DSCADA
  - Distribution Automation
  - DPMU



Accuracy: 0.05%

Rate: 100/120 frame/sec

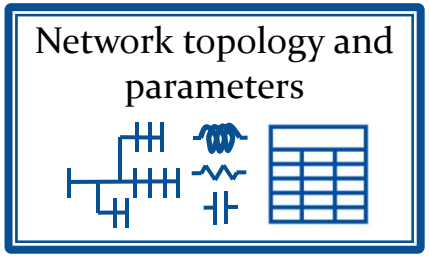
- Load demands at primary nodes
  - Pseudo measurements
  - Smart Meter



Accuracy: 0.2%

Sample rate: 1 frame/sec or slower
Report rate: Every min or slower

- Network data
  - Network topology
  - Line parameters



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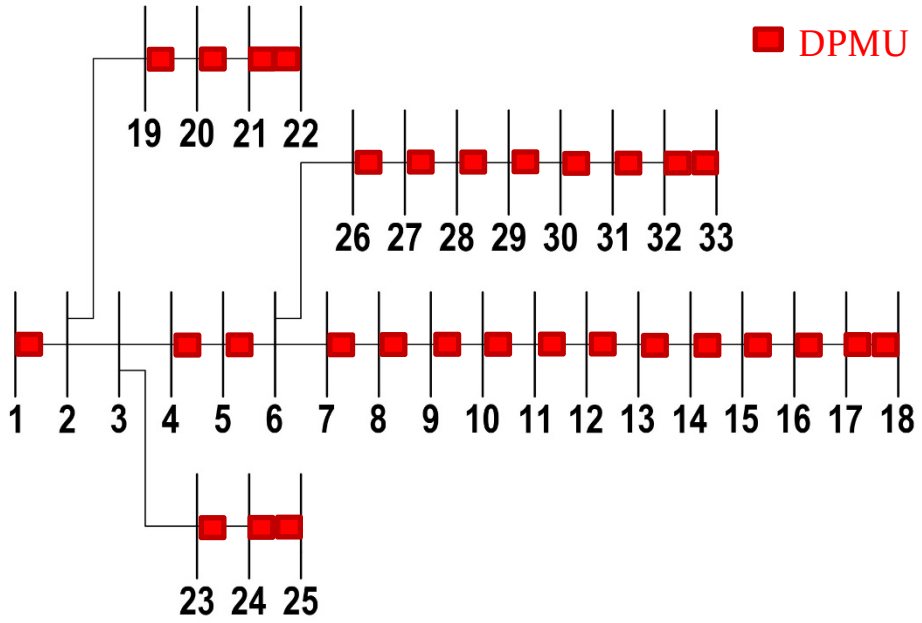
Measurement units

- Previous work: DPMUs at all nodes with order lower than 3[1]
- 33 bus test system
- 30 DPMUs needed



- Our assumptions:
  - Topology is known
  - Smart meter data is available
  - Previous estimates of the parameters might be available

[1] Ye Yuan, Omid Ardakanian, Steven Low, Claire Tomlin, "On the Inverse Power Flow Problem".

Bayesian Approach

Goal:

Find network parameters $\theta = [r_1, x_1, r_2, x_2, \ldots, r_l, x_l]$ given a training set $\mathcal{D}$

$$\underset{\theta}{argmax}\; p(\theta|\mathcal{D})$$

Likelihood function

Prior distribution

Bayes theorem:

$$p(\theta|\mathcal{D}) = \frac{p(\mathcal{D}|\theta)\, p(\theta)}{p(\mathcal{D})}$$

Marginal Distribution of Data

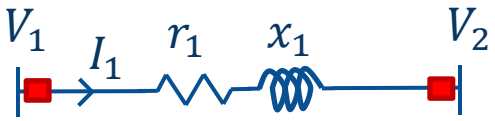
$$p(\theta|\mathcal{D}) \propto p(\mathcal{D}|\theta)\, p(\theta)$$ MAP

Uniform prior

$$p(\theta|\mathcal{D}) \propto p(\mathcal{D}|\theta)$$ MLE

Single branch, two DPMUs

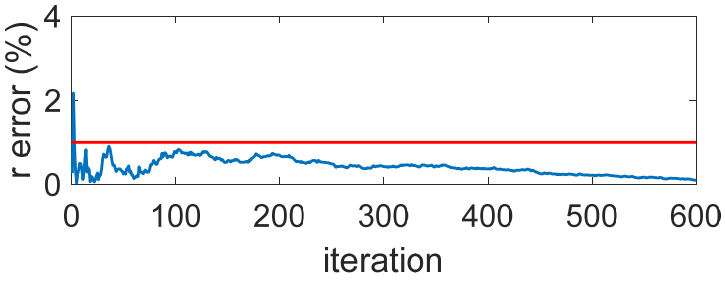
DPMU → Rate: 60 / sec
Gaussian noise with 0.05% error

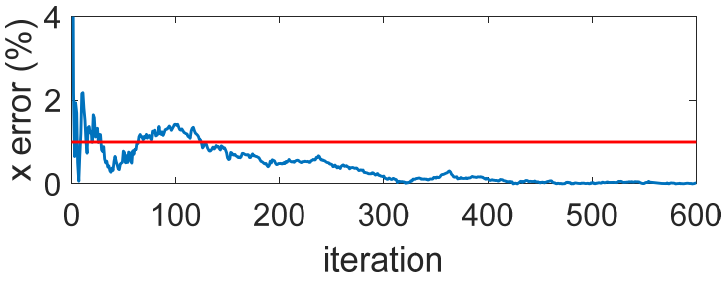


Unknowns	DPMU
r_1, x_1	V_1, I_1, V_2

$$z_1 = r_1 + jx_1 = \frac{V_1 - V_2}{I_1}$$

MLE





Single branch, two DPMUs

DPMU → Rate: 60 / sec
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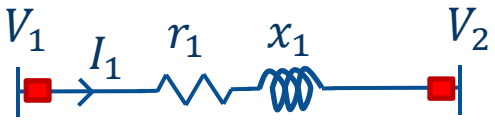

Unknowns	DPMU
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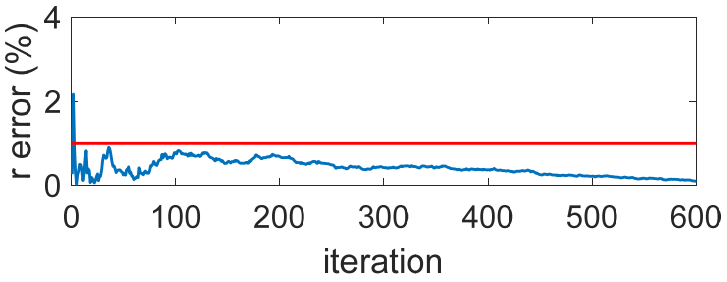
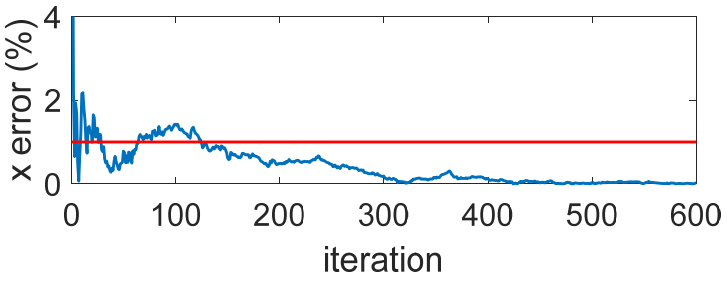
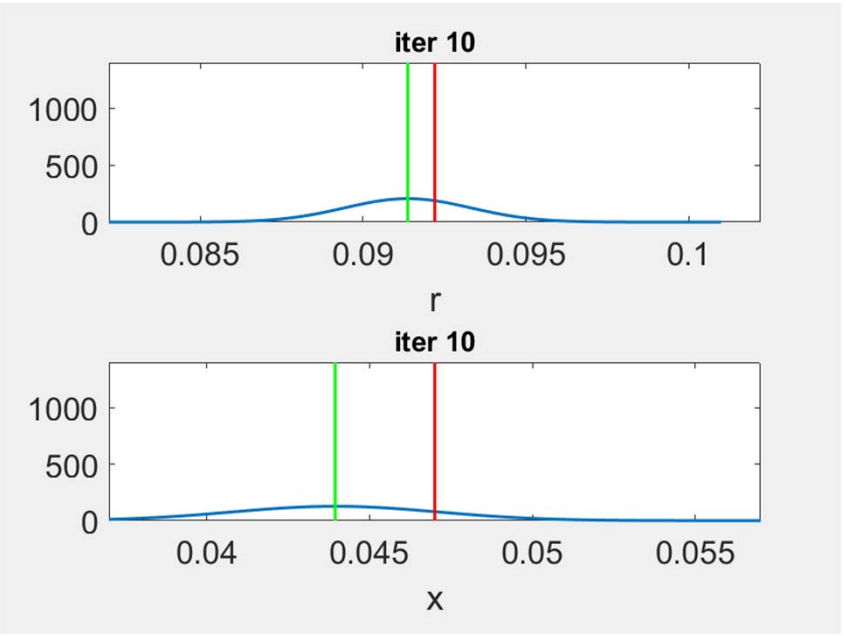
$$z_1 = r_1 + jx_1 = \frac{V_1 - V_2}{I_1}$$

MLE

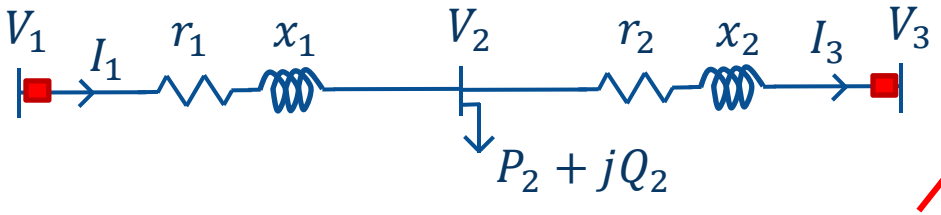




MAP



Two branches, two DPMUs



Rate: 60 / sec
Gaussian noise with 0.05% error

Rate: 1 / sec
Gaussian noise with 0.2% error

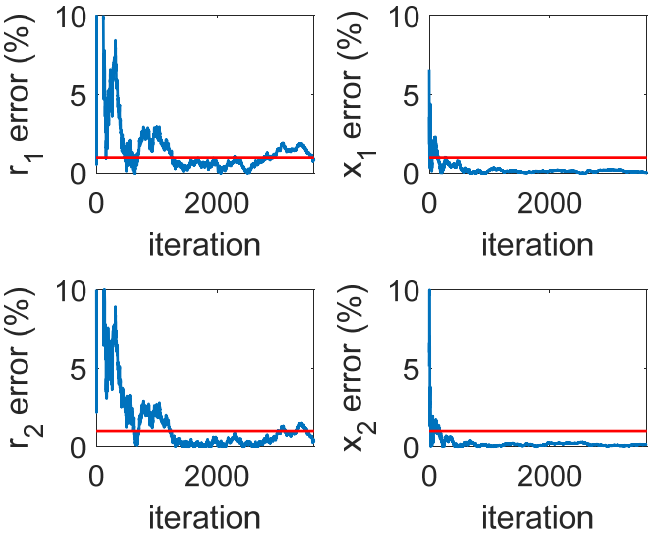
Unknowns	DPMU	Pseudo
r_1, x_1, r_2, x_2	V_1, I_1, V_3, I_3	P_2, Q_2

$$V_2 = \frac{P_2 + jQ_2}{(I_1 - I_3)^*}$$

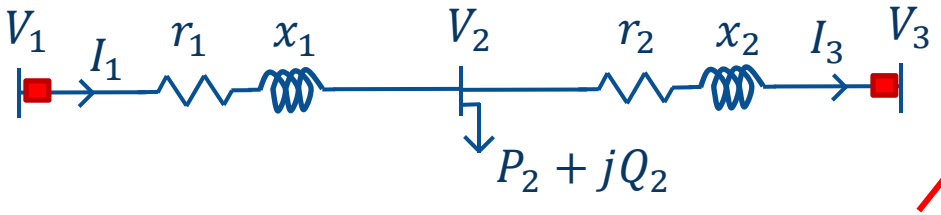
$$z_1 = r_1 + jx_1 = \frac{V_1 - V_2}{I_1}$$

$$z_2 = r_2 + jx_2 = \frac{V_2 - V_3}{I_3}$$

MLE



Two branches, two DPMUs



DPMU → Rate: 60 / sec
Gaussian noise with 0.05% error

Rate: 1 / sec
Gaussian noise with 0.2% error

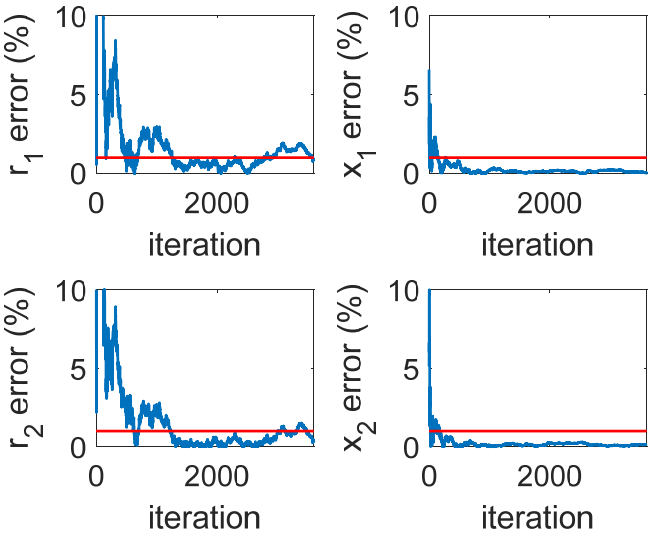
Unknowns	DPMU	Pseudo
r_1, x_1, r_2, x_2	V_1, I_1, V_3, I_3	P_2, Q_2

$$V_2 = \frac{P_2 + jQ_2}{(I_1 - I_3)^*}$$

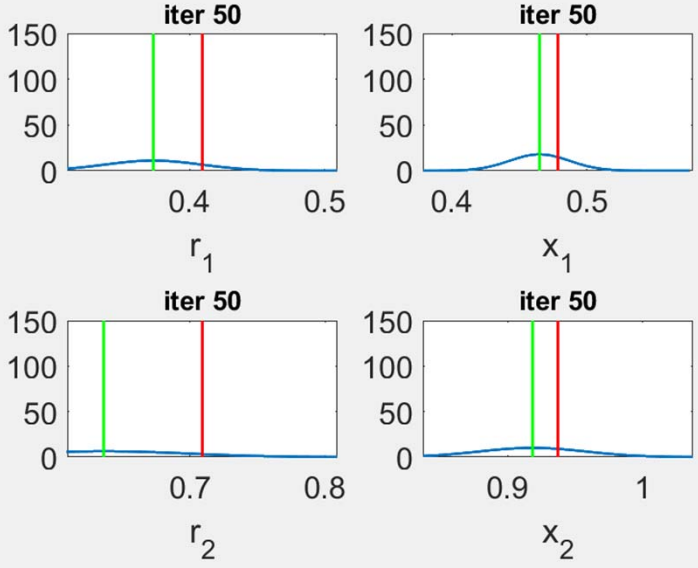
$$z_1 = r_1 + jx_1 = \frac{V_1 - V_2}{I_1}$$

$$z_2 = r_2 + jx_2 = \frac{V_2 - V_3}{I_3}$$

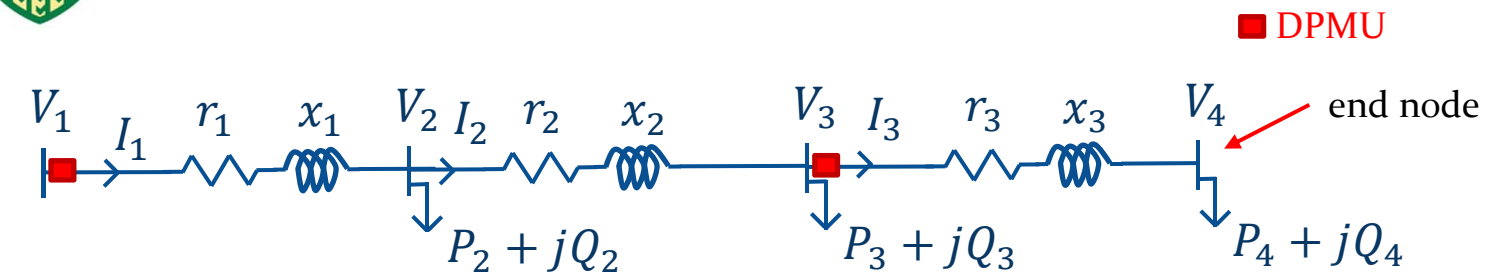
MLE



MAP



Three branches, two DPMUs



Unknowns	DPMU	Pseudo
$r_1, x_1, r_2, x_2, r_3, x_3$	V_1, I_1, V_3, I_3	$P_2, Q_2, P_3, Q_3, P_4, Q_4$

$$I_2 = I_3 + \frac{P_3 - jQ_3}{V_3^*}$$

$$V_2 = \frac{P_2 + jQ_2}{(I_1 - I_2)^*}$$

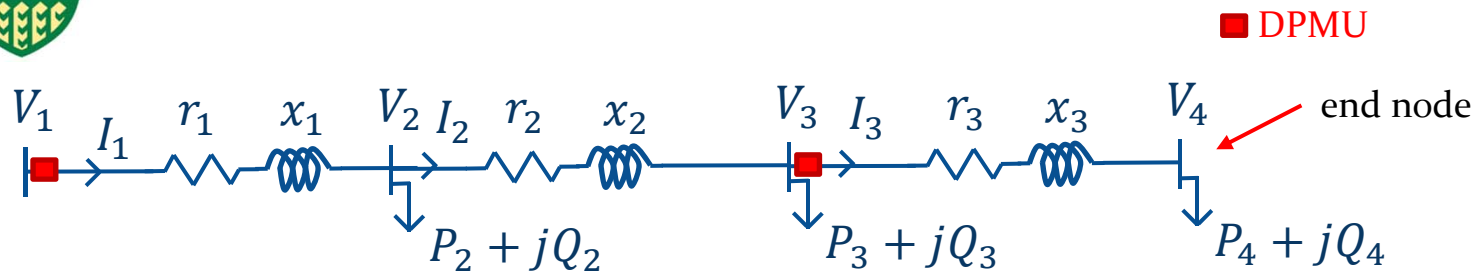
$$V_4 = \frac{P_4 + jQ_4}{I_3^*}$$

$$z_1 = r_1 + jx_1 = \frac{V_1 - V_2}{I_1}$$

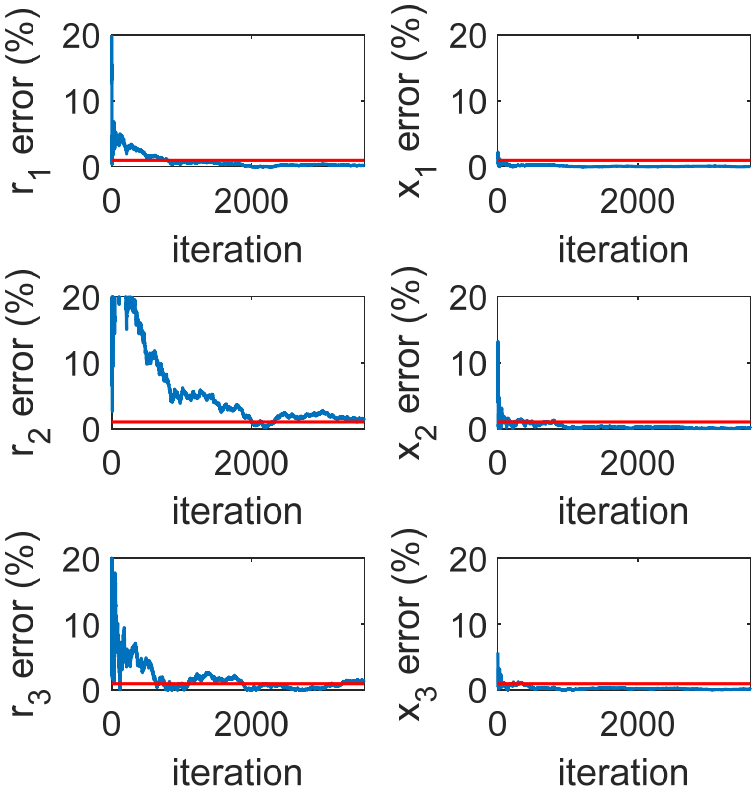
$$z_2 = r_2 + jx_2 = \frac{V_2 - V_3}{I_2}$$

$$z_3 = r_3 + jx_3 = \frac{V_3 - V_4}{I_3}$$

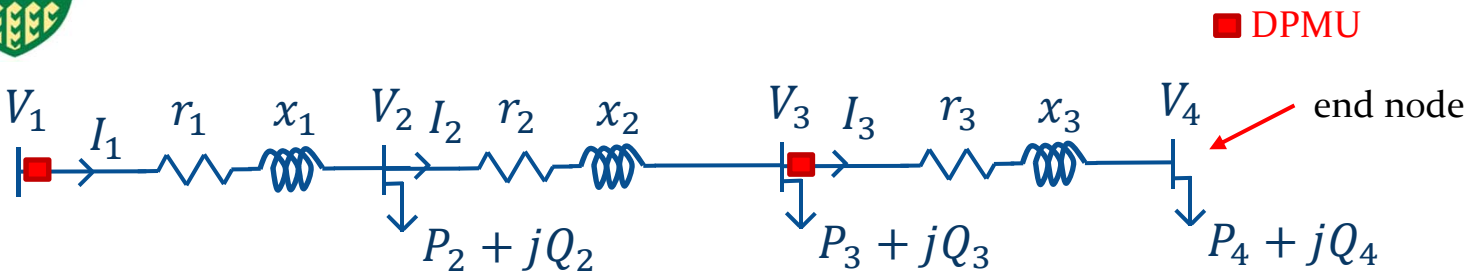
Three branches, two DPMUs



MLE



Three branches, two DPMUs



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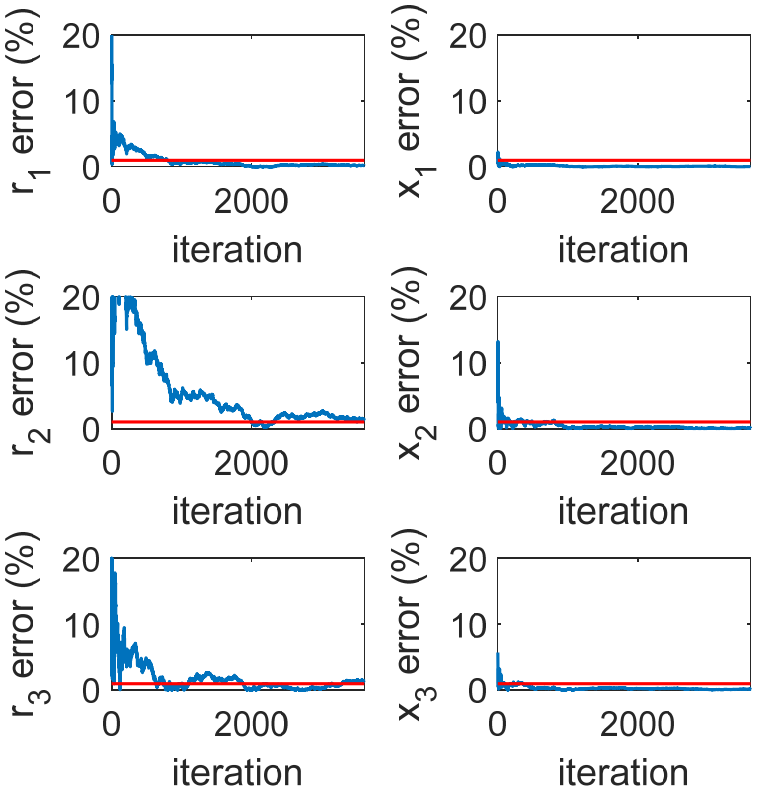
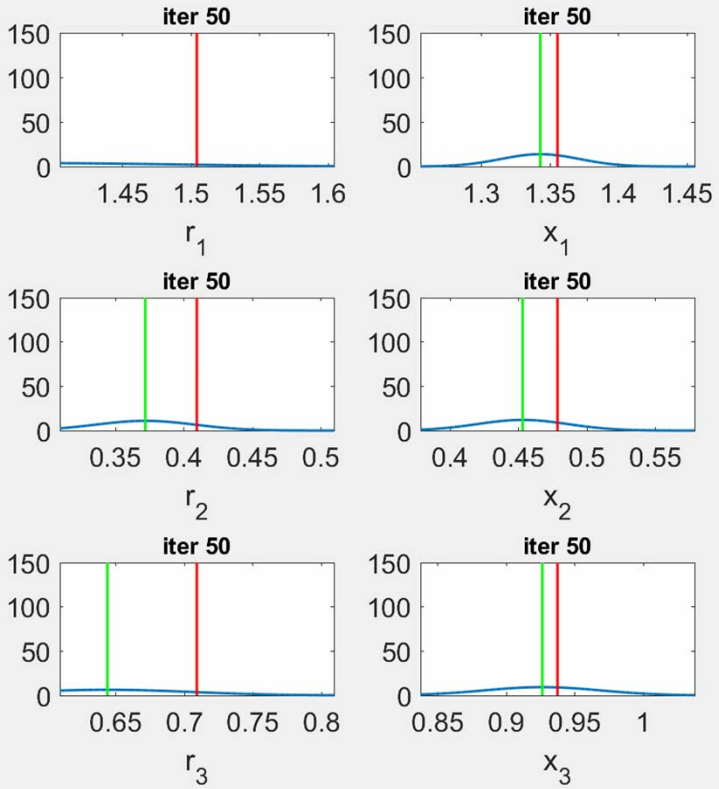
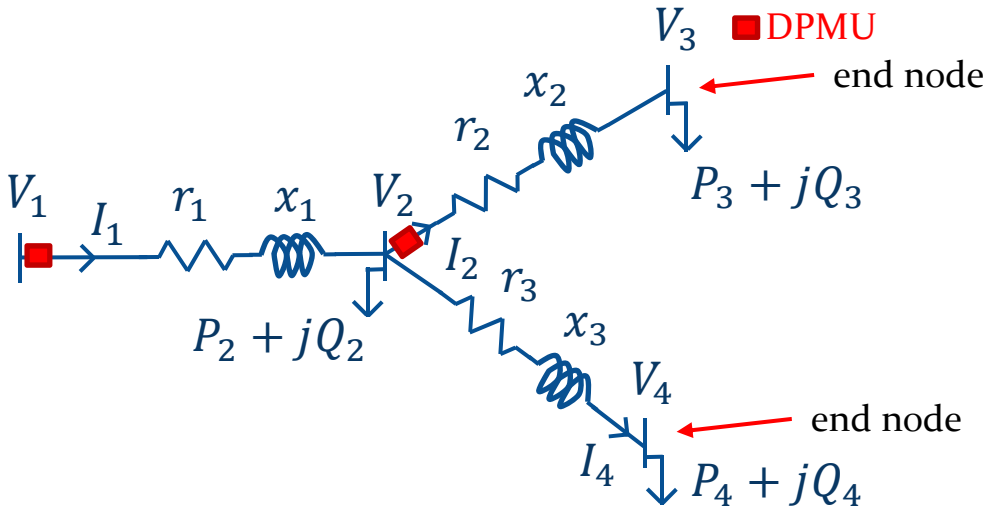


MAP



Three branches, two DPMUs



Unknowns	DPMU	Pseudo
$r_1, x_1, r_2, x_2, r_3, x_3$	V_1, I_1, V_2, I_2	$P_2, Q_2, P_3, Q_3, P_4, Q_4$

$$I_4 = I_1 - I_2 - \frac{P_2 - jQ_2}{V_2^*}$$

$$V_3 = \frac{P_3 + jQ_3}{I_2^*}$$

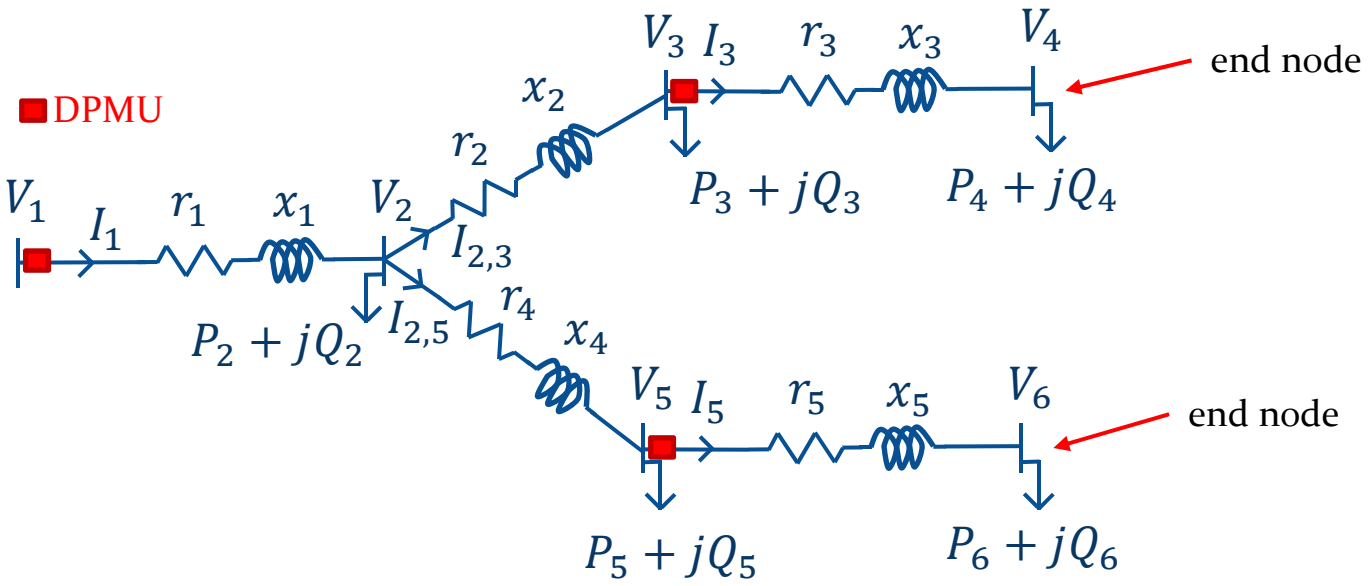
$$V_4 = \frac{P_4 + jQ_4}{I_4^*}$$

$$z_1 = r_1 + jx_1 = \frac{V_1 - V_2}{I_1}$$

$$z_2 = r_2 + jx_2 = \frac{V_2 - V_3}{I_2}$$

$$z_3 = r_3 + jx_3 = \frac{V_2 - V_4}{I_4}$$

Five branches, three DPMUs



Unknowns	DPMU	Pseudo
$r_1, x_1, r_2, x_2, \dots, r_5, x_5$	$V_1, I_1, V_3, I_3, V_5, I_5$	$P_2, Q_2, P_3, Q_3, \dots, P_6, Q_6$

$$I_{2,3} = I_3 + \frac{P_3 - jQ_3}{V_3^*} \qquad V_2 = \frac{P_2 + jQ_2}{(I_1 - I_{2,3} - I_{2,5})^*}$$

$$V_4 = \frac{P_4 + jQ_4}{I_3^*}$$

$$I_{2,5} = I_5 + \frac{P_5 - jQ_5}{V_5^*} \qquad V_6 = \frac{P_6 + jQ_6}{I_5^*}$$

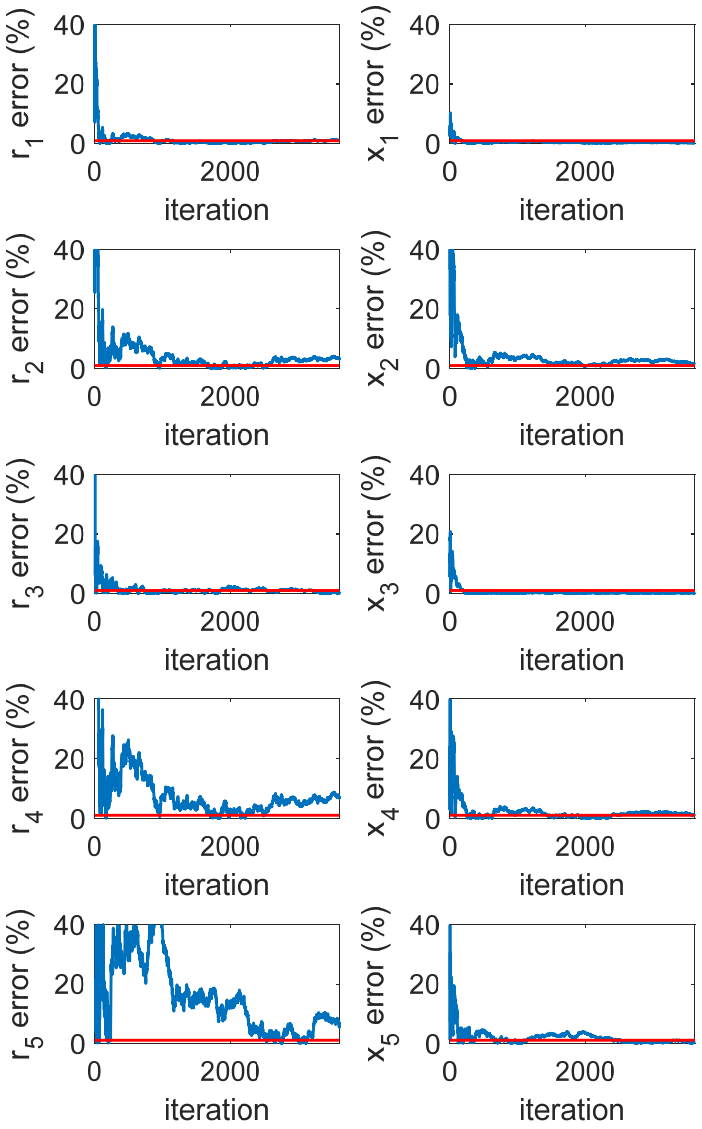
$$z_1 = r_1 + jx_1 = \frac{V_1 - V_2}{I_1}$$

$$\vdots$$

$$z_5 = r_5 + jx_5 = \frac{V_5 - V_6}{I_5}$$

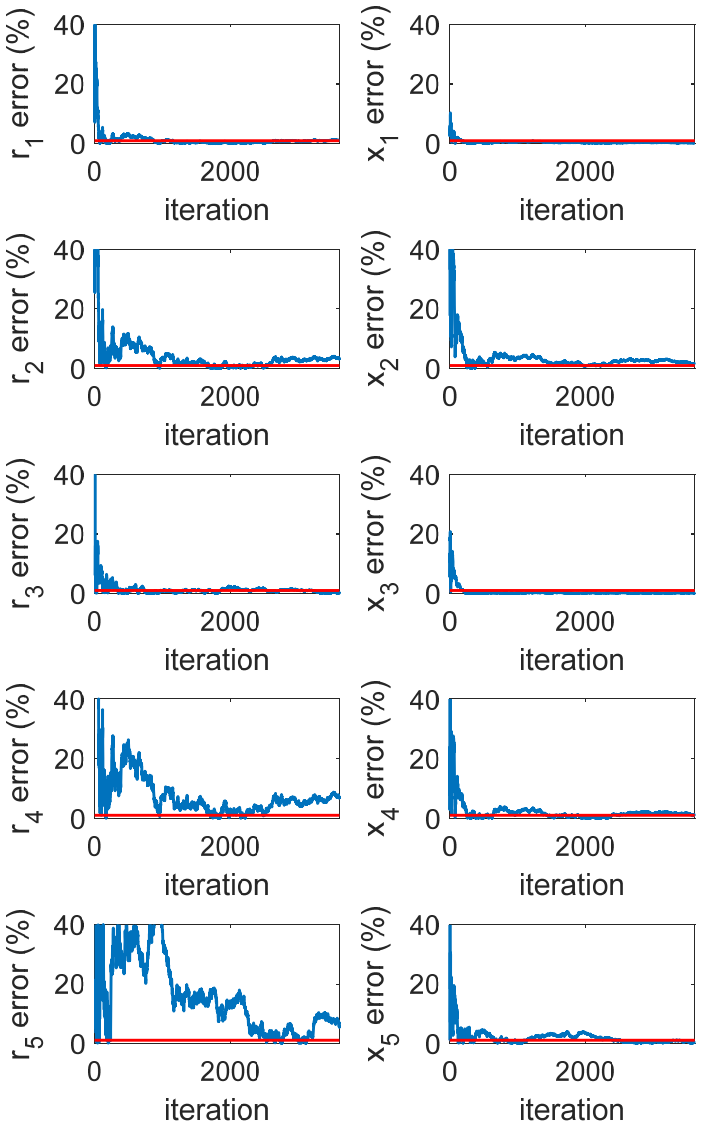
Five branches, three DPMUs

MLE

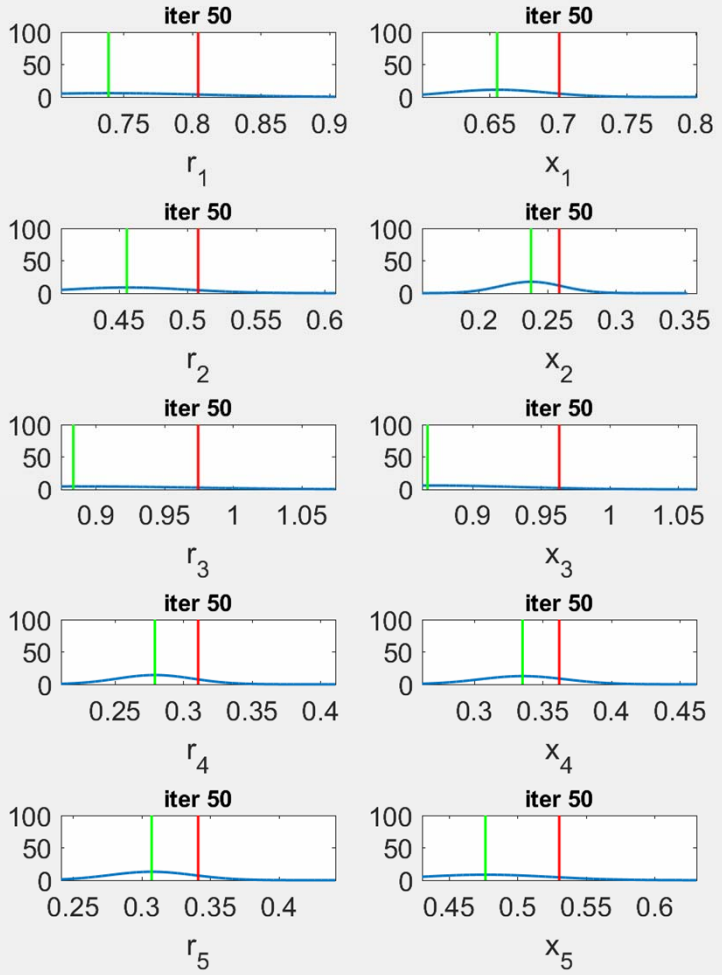


Five branches, three DPMUs

MLE

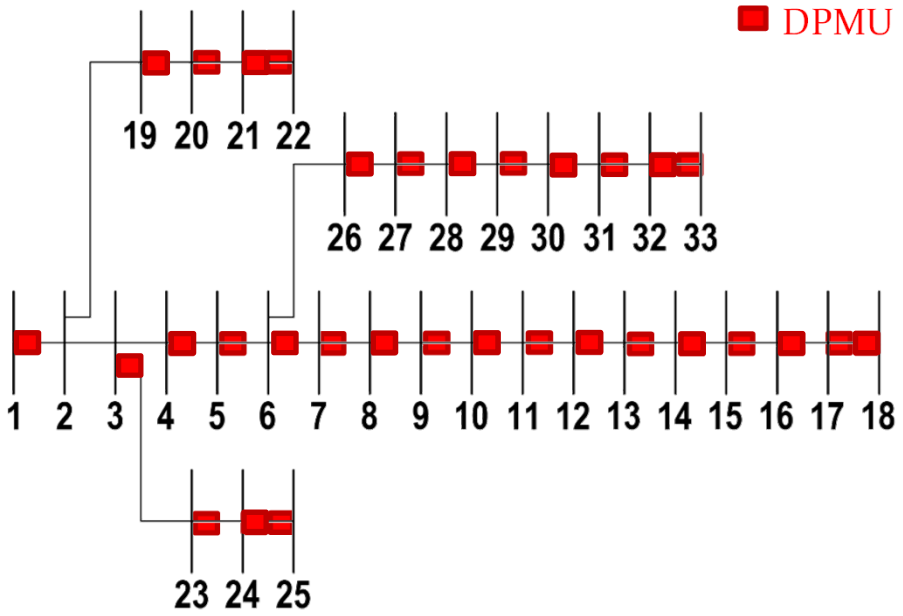


MAP



33 bus test system

- Only DPMU data: 30 DPMUs needed
- DPMU plus Smart Meter data: 17 DPMUs needed



Conclusion and Future work

- Smart Meter data can indeed be utilized for parameter estimation

but, we are not done yet!

- Considering low-voltage feeders
- Developing a model to account for loss in low-voltage feeders
- Considering non-Gaussian measurement error
- Utilizing voltage magnitude measurements from Smart Meters
- Determining the minimum number of DPMUs
- …

Thank You!

Questions?

Detailed System