State Estimation For Mega RTOs

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Traditional State Estimation

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Power System SE: Basic Assumptions

- Positive Sequence Model
- P, Q, V measurement set
- Near-Simultaneous Measurements
- Single Frequency

Implications:

- Balanced Operation
- Symmetric Power System
- Biased SE

Traditional State Estimation

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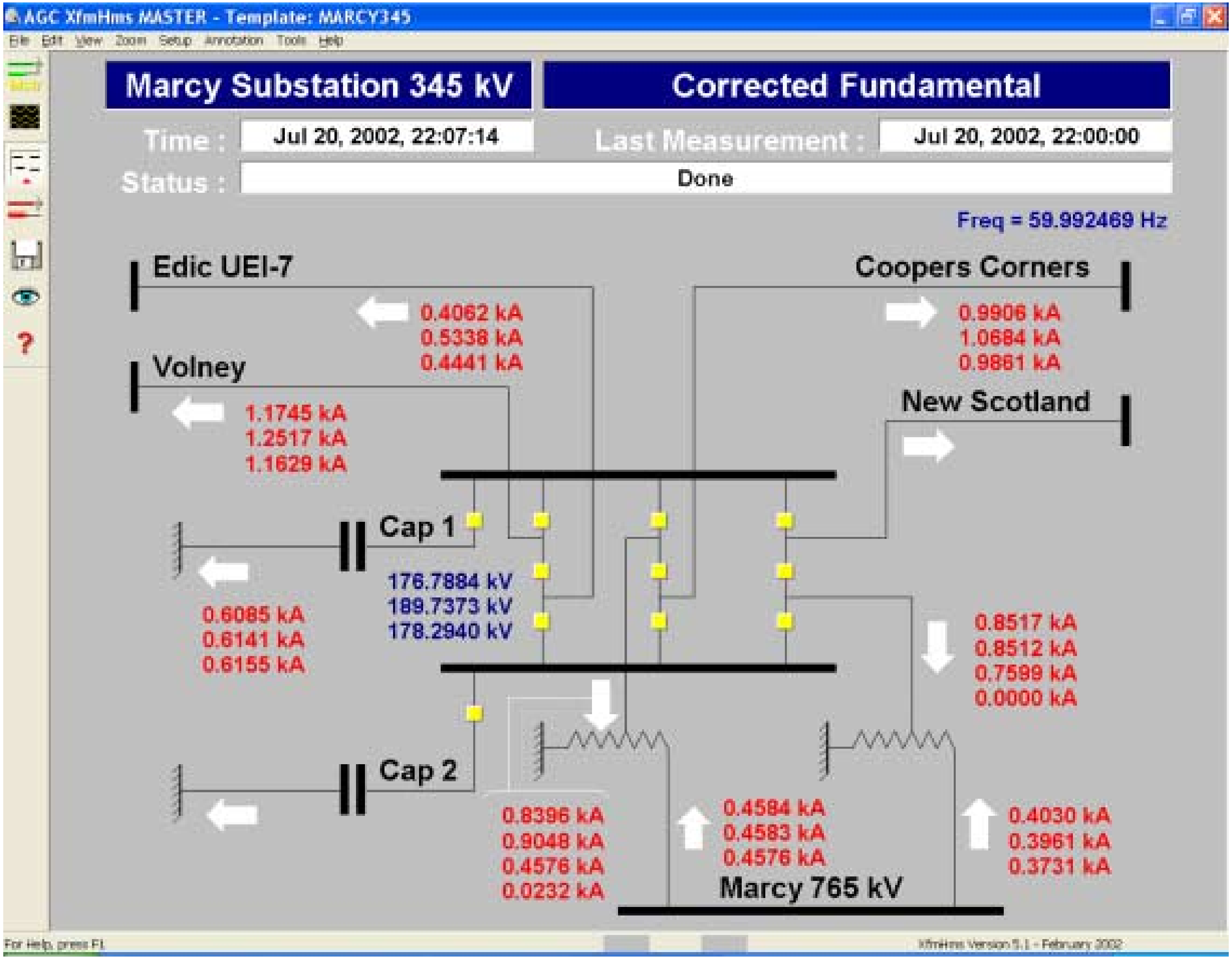
Practical Implications and Observations:

- Iterative Algorithm
- Need to Fine-Tune Algorithm
- High Percentage of NonConvergence
- Uncertainty in Bad Data Detection

This Paper Poses the Question:

Is the present SE Approach
Scalable to Mega RTOs?

Validity of Balanced Operation Assumption



Weighted Least Squares Estimation

Minimize: $\tilde{r}^H W \tilde{r}$

Subject to: $\tilde{r} = \tilde{z} - h(\tilde{x})$

Where:

W	Weighting matrix,
z	Measurement vector
x	State vector
h(.)	System model.

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Imbalance Bias

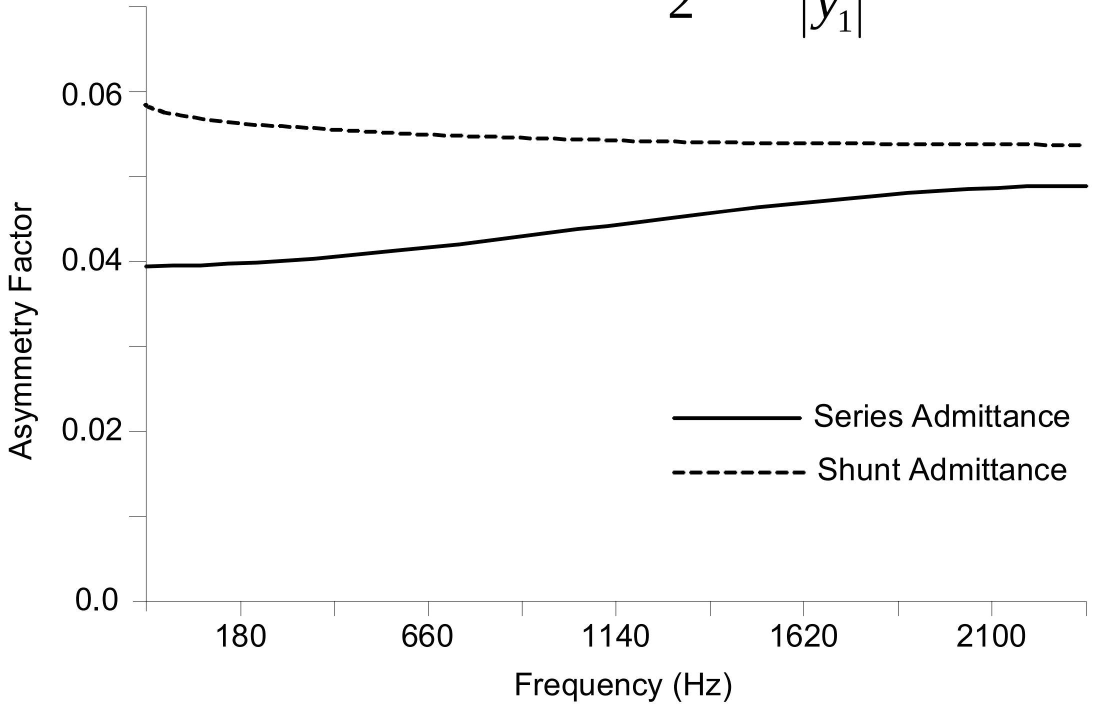
$$z = z_t + \Delta z$$

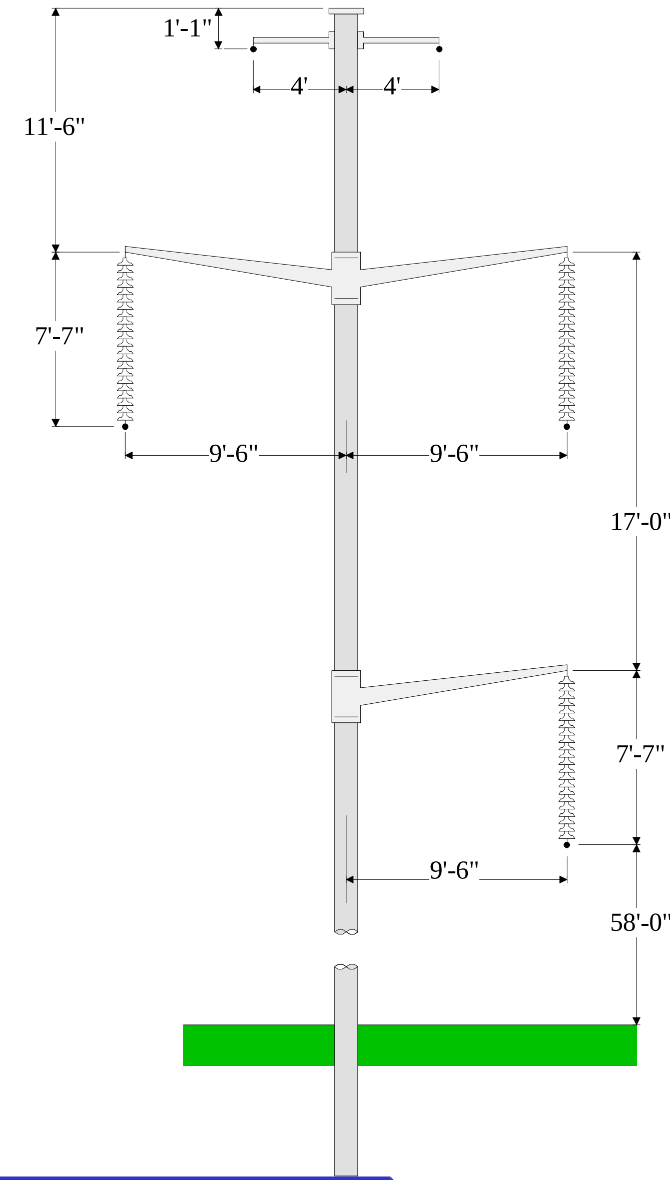
$$x = x_t + (H^T W H)^{-1} H^T W \Delta z$$

Validity of Power System Symmetry Assumption

$$S_1 = \frac{1}{2}\frac{|z_{\max} - z_{\min}|}{|z_1|}$$

$$S_2 = \frac{1}{2}\frac{|y_{\max} - y_{\min}|}{|y_1|}$$





Weighted Least Squares Estimation

Minimize: $\tilde{r}^{H} W \tilde{r}$

Subject to: $\tilde{r} = \tilde{z} - h(\tilde{x})$

Where:

W	Weighting matrix,
z	Measurement vector
x	State vector
h(.)	System model.

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Asymmetry Bias

$$z = h(x) + \Delta h(x)$$

$$x = (x_t + (H^T WH)^{-1} H^T W\Delta z)(\Delta H^T WH)^{-1}$$
$$(I + 2(\Delta H^T WH)(H^T WH)^{-1})^{-1}(\Delta H^T WH)$$

Investigation of SE Biases via Numerical Experiments

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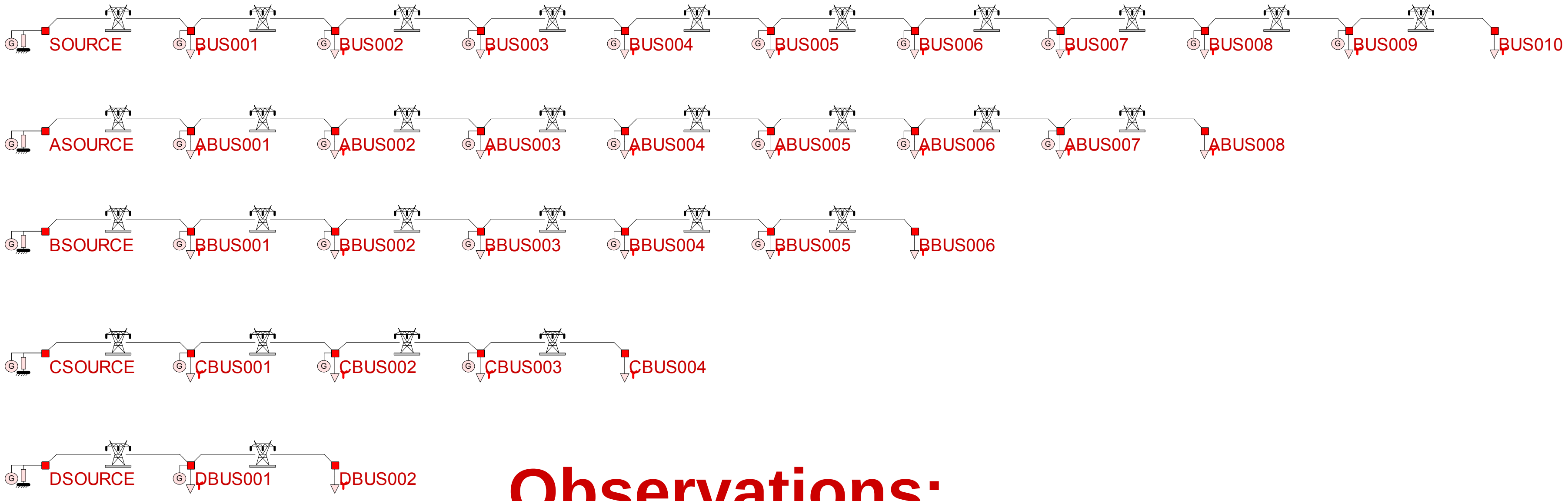
Approach: Systems of Variable Size



Observations:

System Imbalance Stabilizes

Phase with Max Voltage: Random

Effects on Mega RTO SE: Unknown

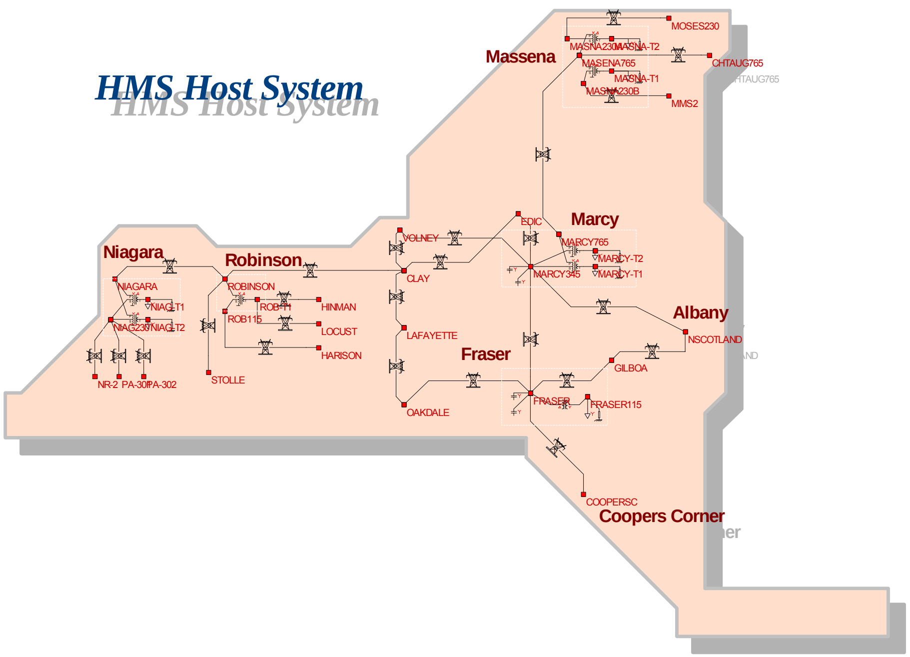
Unbiased State Estimation

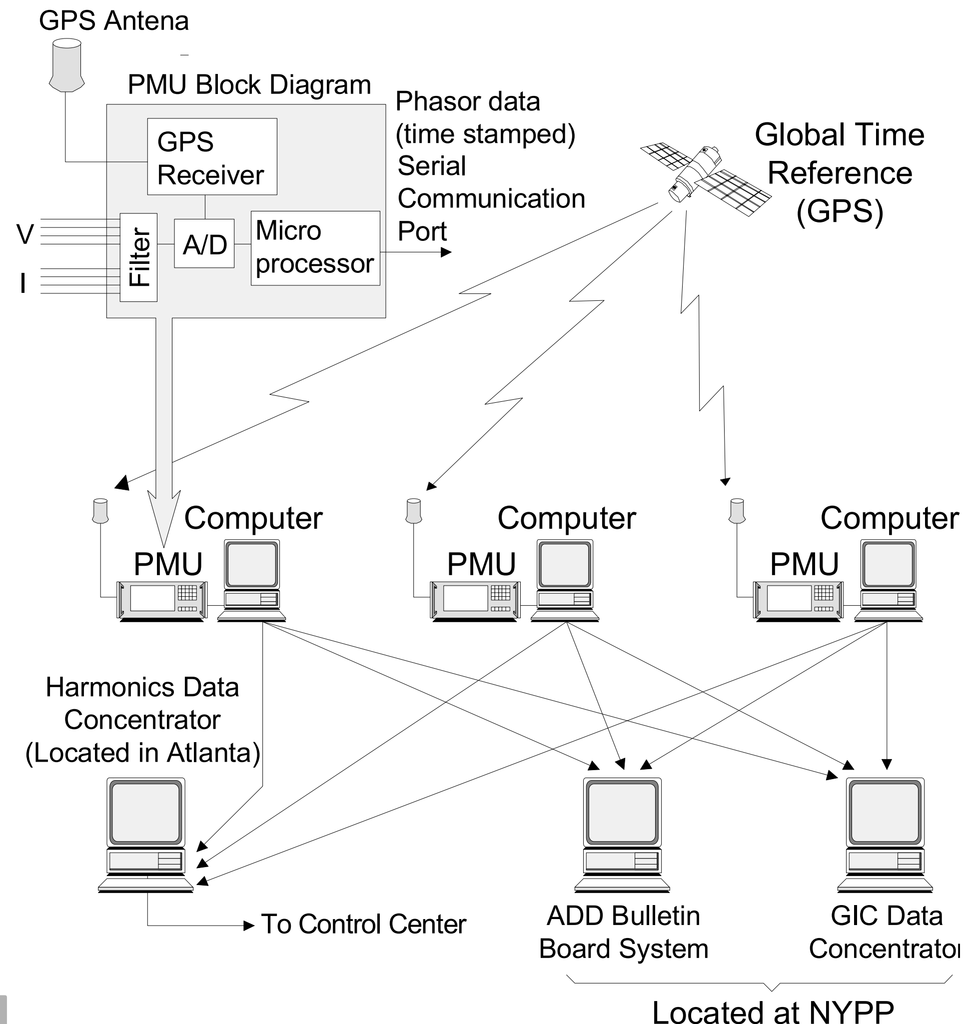
- **Three Phase Measurements**
- **Asymmetric Three Phase Model**
- **Synchronized Measurements**

Direct Solution

Asymmetric Power System Model

New York Power Authority





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SE with Synchronized Measurements

Minimize: $\tilde{r}^H W \tilde{r}$

Subject to: $\tilde{r} = \tilde{z} - \tilde{H}\tilde{x}$

Min: $r_{real}^T W r_{real} + r_{imag}^T W r_{imag}$

S.t. $r_{real} = z_{real} - (H_{real}\, x_{real} - H_{imag}\, x_{imag})$

$r_{imag} = z_{imag} - (H_{real}\, x_{imag} + H_{imag}\, x_{real})$

$$\begin{bmatrix} A & B \\ -B & A \end{bmatrix} \begin{bmatrix} x_{real} \\ x_{imag} \end{bmatrix} = \begin{bmatrix} H_{real}^T W z_{real} + H_{imag}^T W z_{imag} \\ H_{real}^T W z_{imag} - H_{imag}^T W z_{real} \end{bmatrix}$$

Direct Solution

Chi-Square Test

Step 1: Compute the state estimate x^*

Step 2: Evaluate the function: $J = \tilde{r}^H W \tilde{r} = a$

Step 3: Compute: $p = 1 - P(a, m-n)$

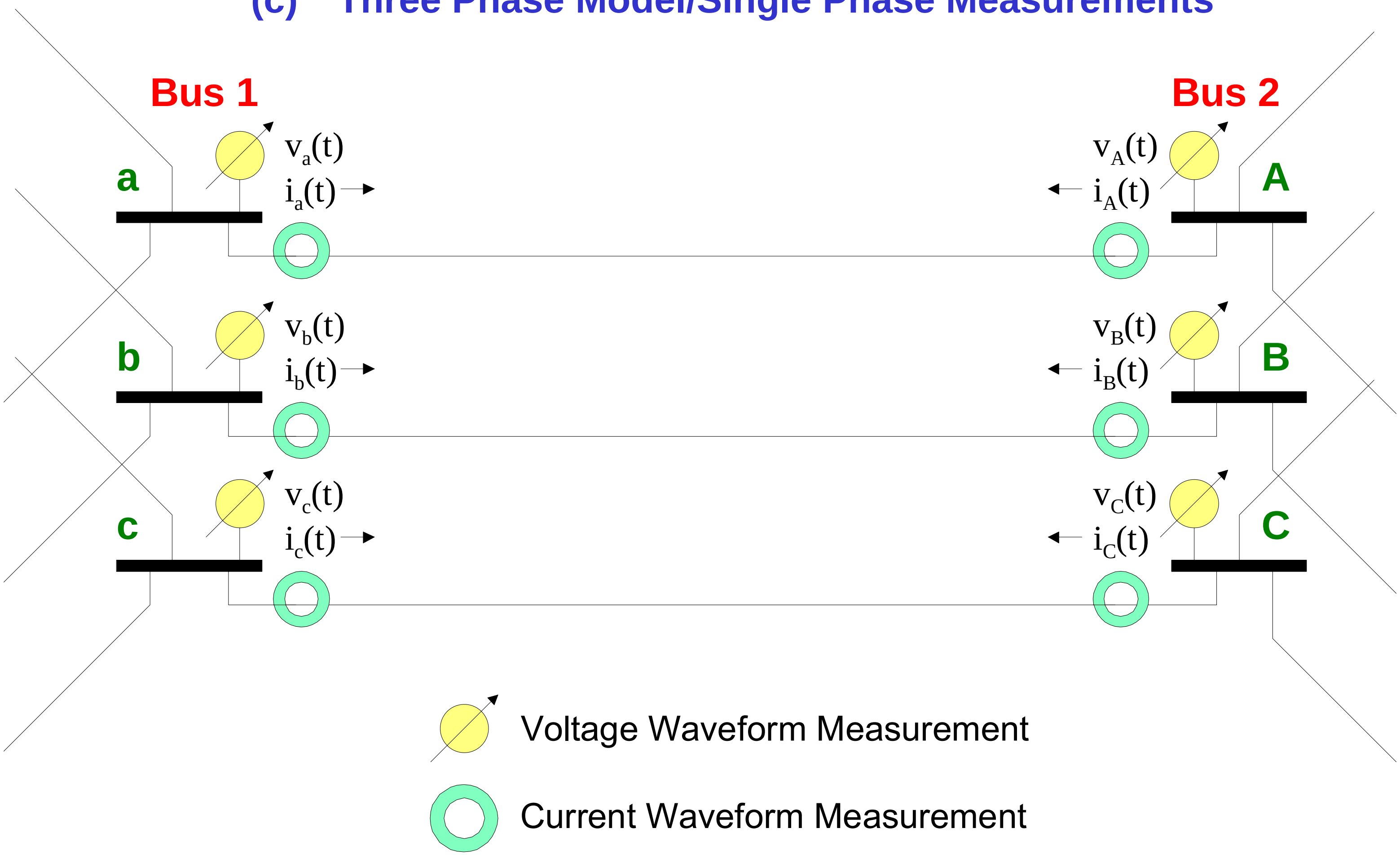
where:

$P(a,u)$ is the probability that $J \leq a$.

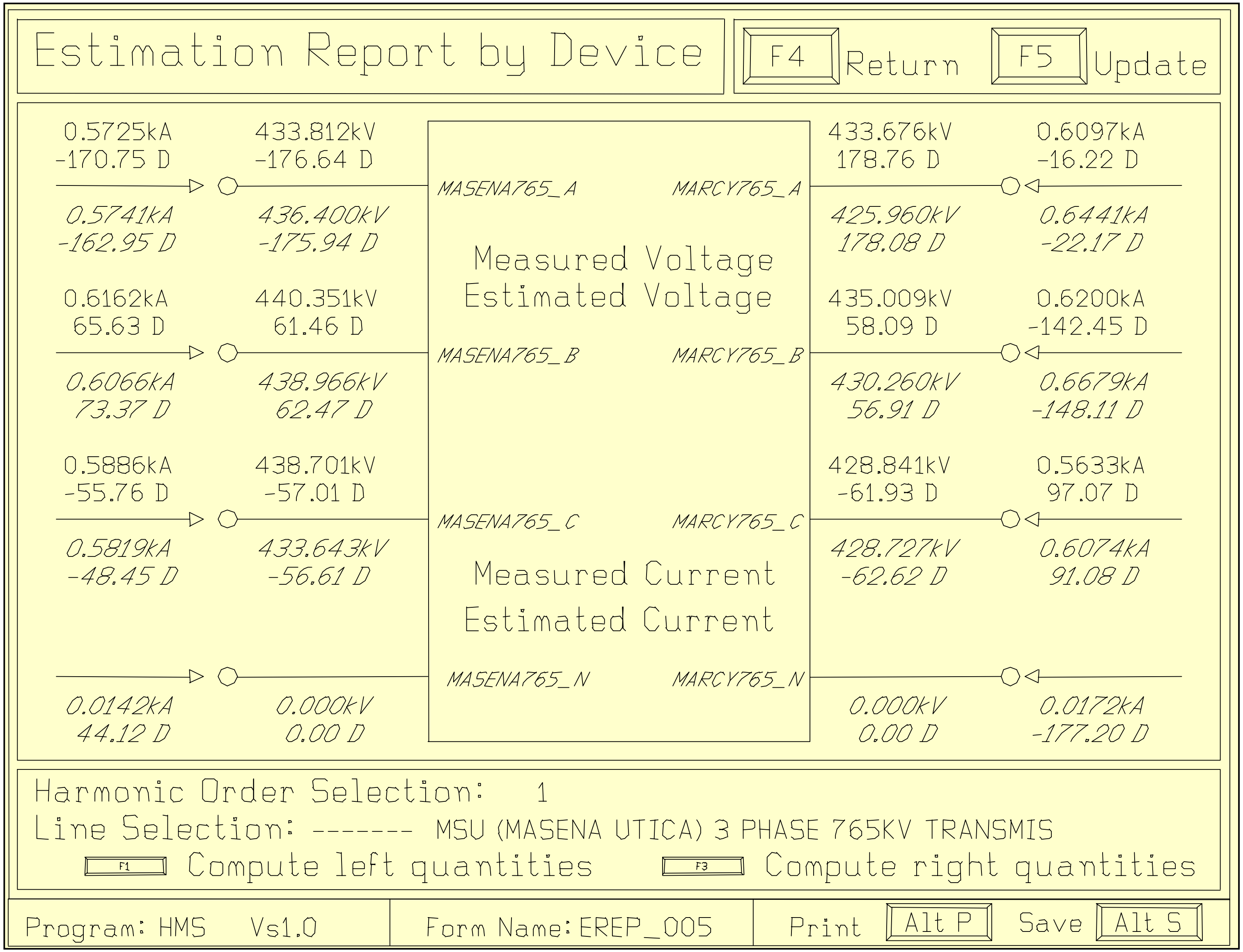
u is the degree of freedom.

Numerical Experiments

(a) Three Phase Model/Three Phase Measurements
(b) Symmetric Model/Three Phase Measurements
(c) Three Phase Model/Single Phase Measurements



Example Results



Detection of SE Bias

Numerical Experiments on the MSU-1 Line (765 kV)

Case Description	Confidence Level (Chi-Square Test)
Three Phase Asymmetric Model, Three Phase Measurements	100.00
Three Phase Symmetric Model, Three Phase Measurements	13.02
Three Phase Asymmetric Model, Single Phase (A) Measurements	0.0

Numerical Experiments

Three Phase Power Flow

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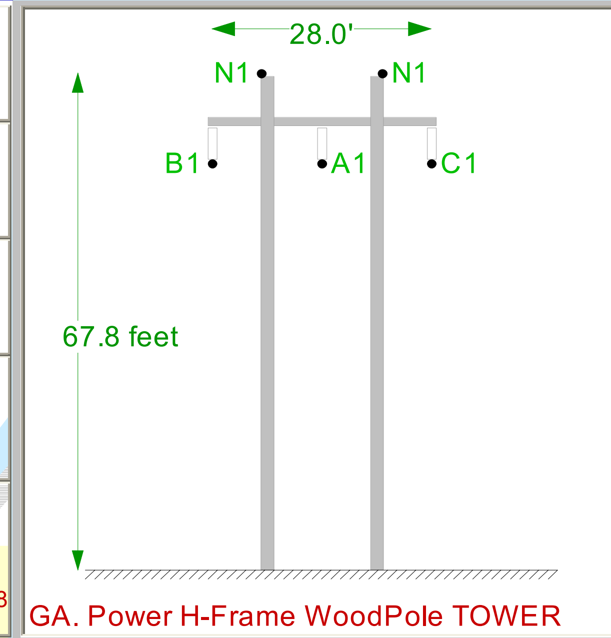
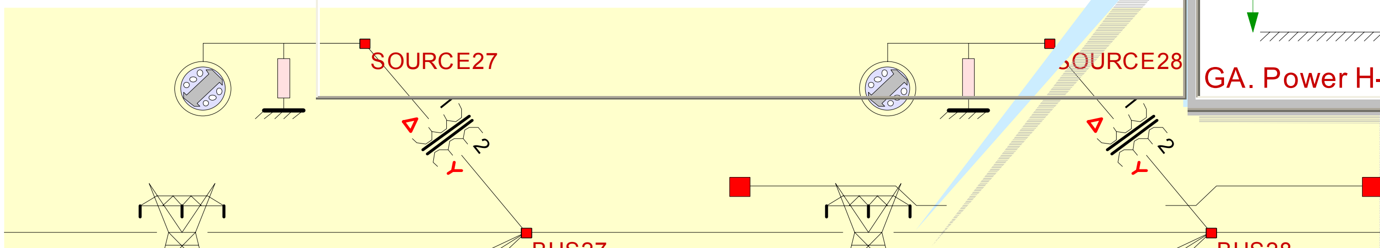
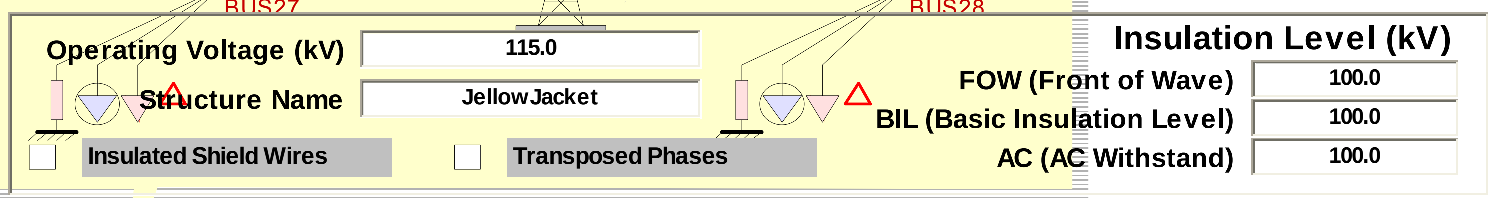
Scenario 1: Phase A Measurements

Scenario 2: Phase B Measurements

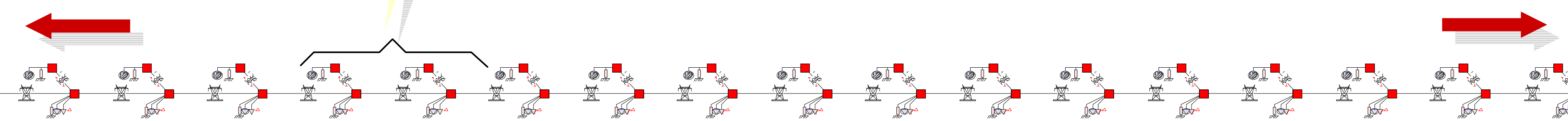
Scenario 3: Phase A Voltage and Three Phase P and Q



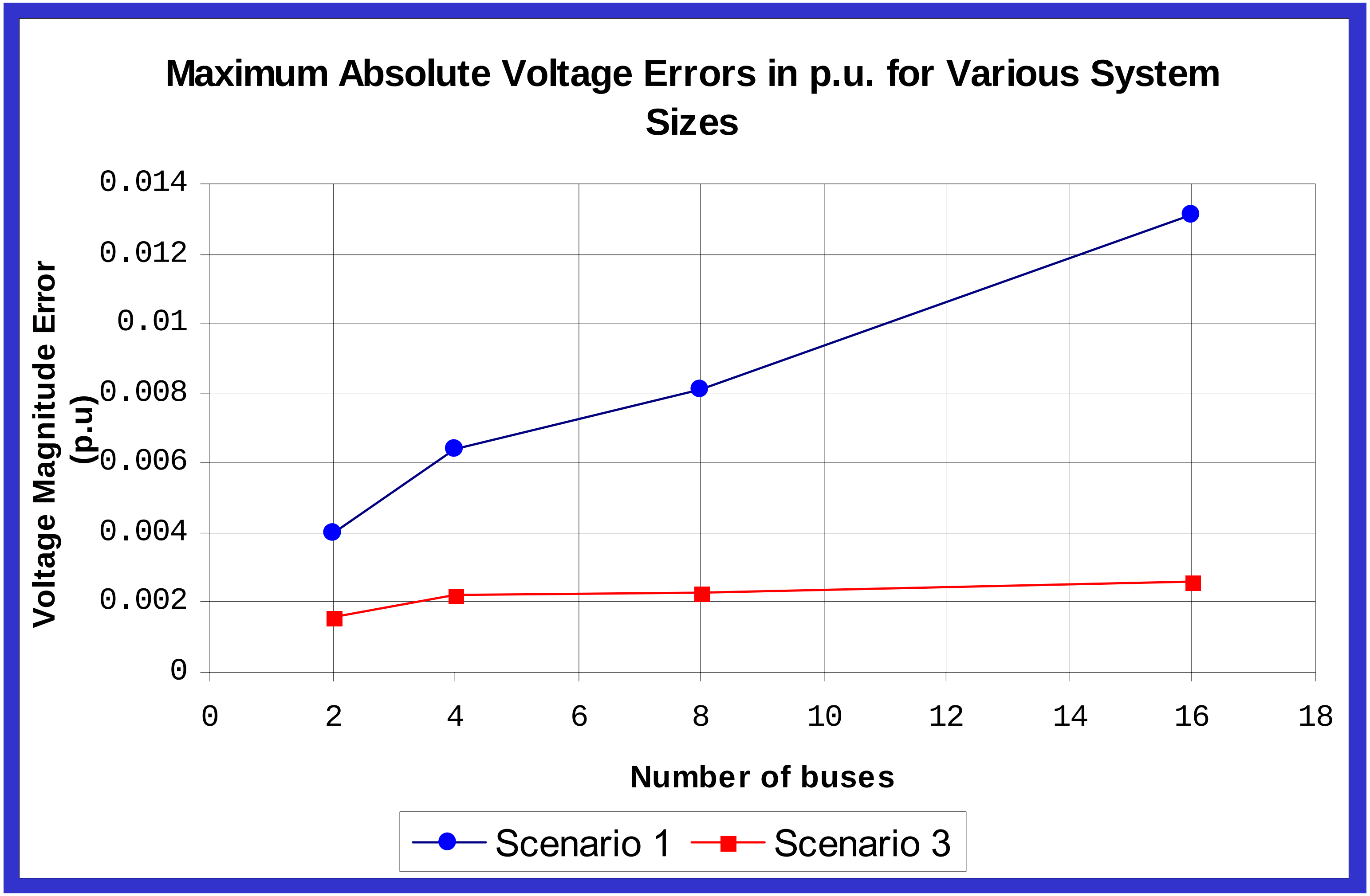




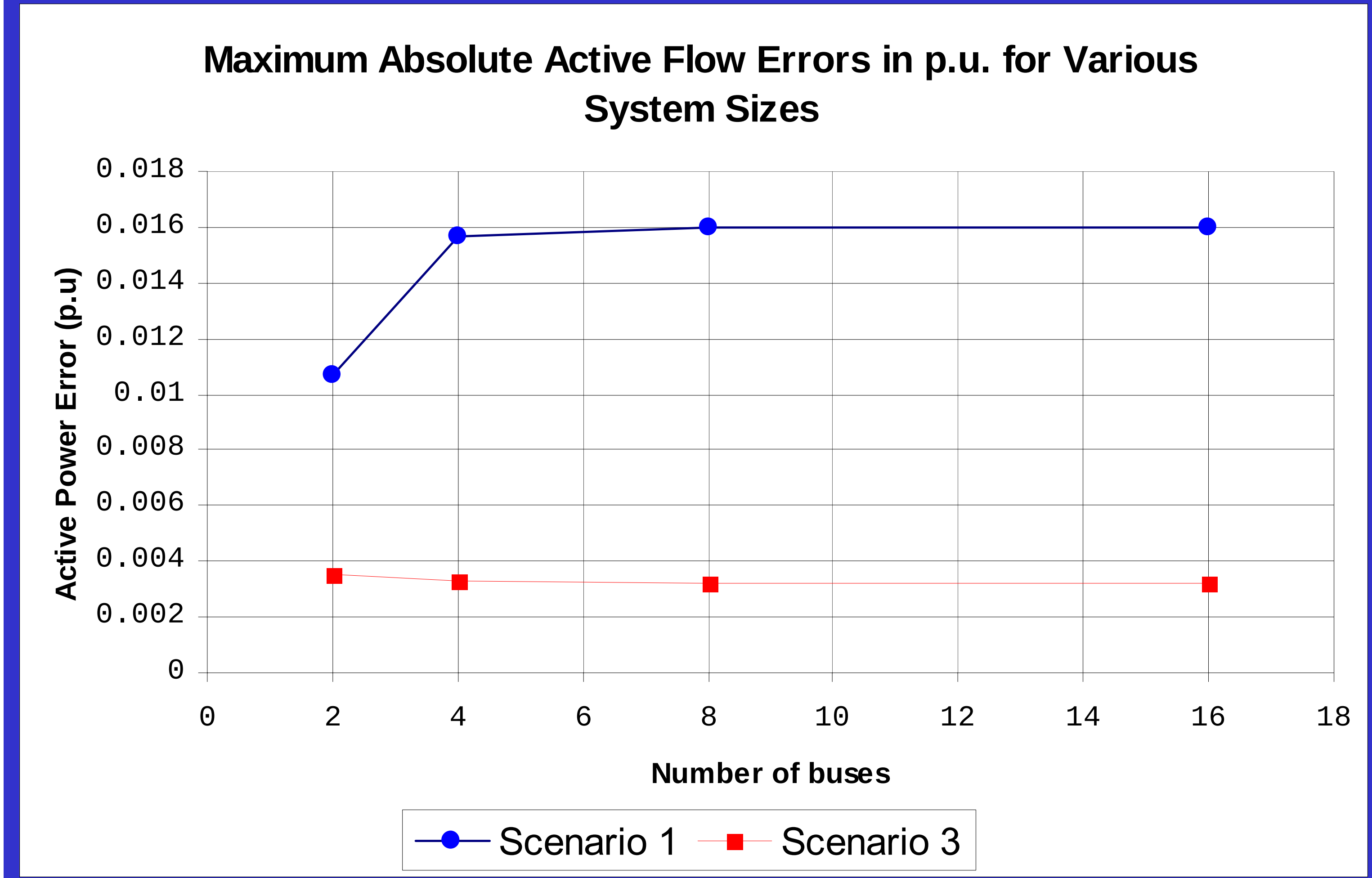
Program WinIGS - Form IGS_M102



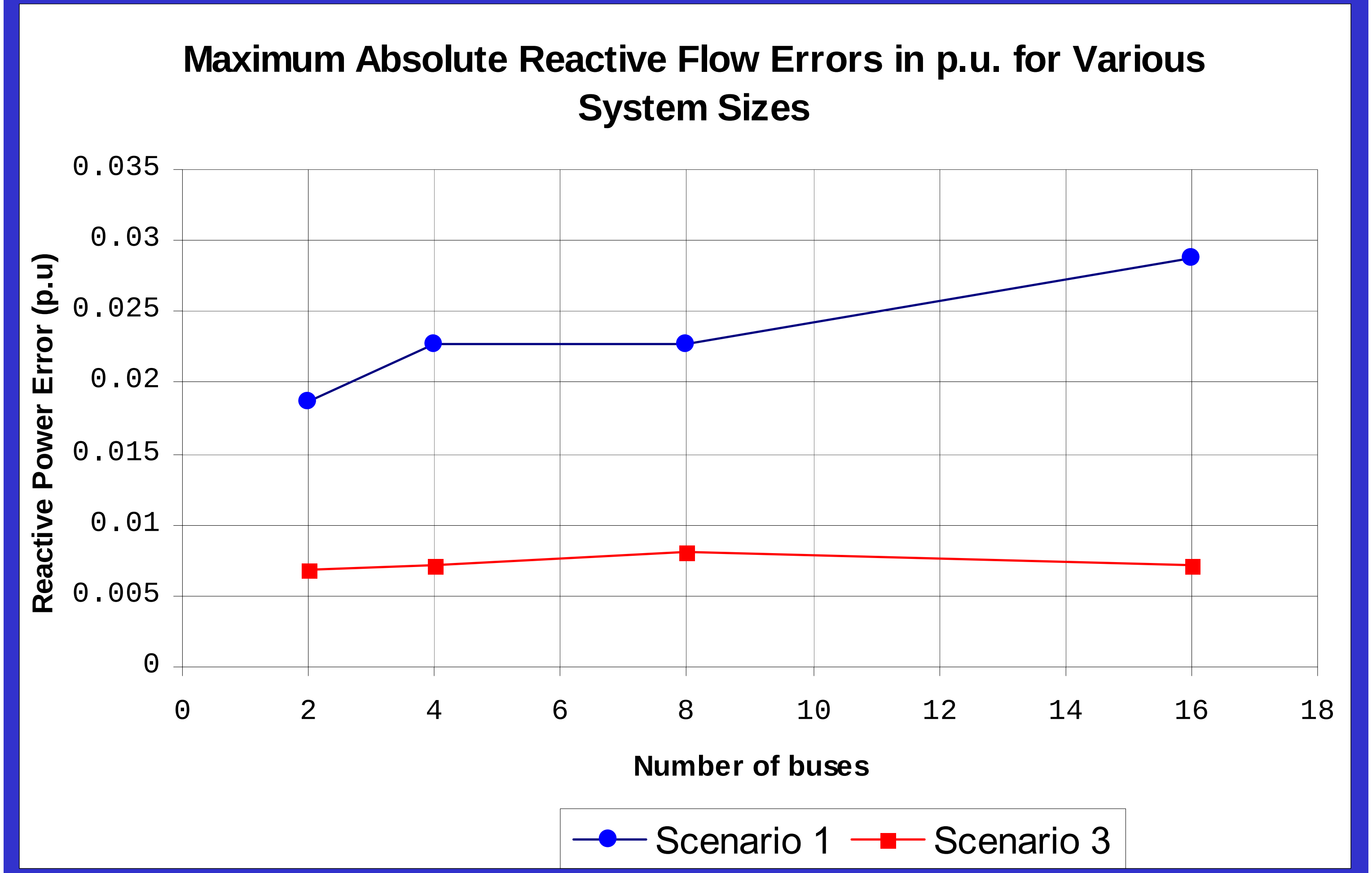
Asymmetry Errors – Voltage Magnitude



Asymmetry Errors – P Flow

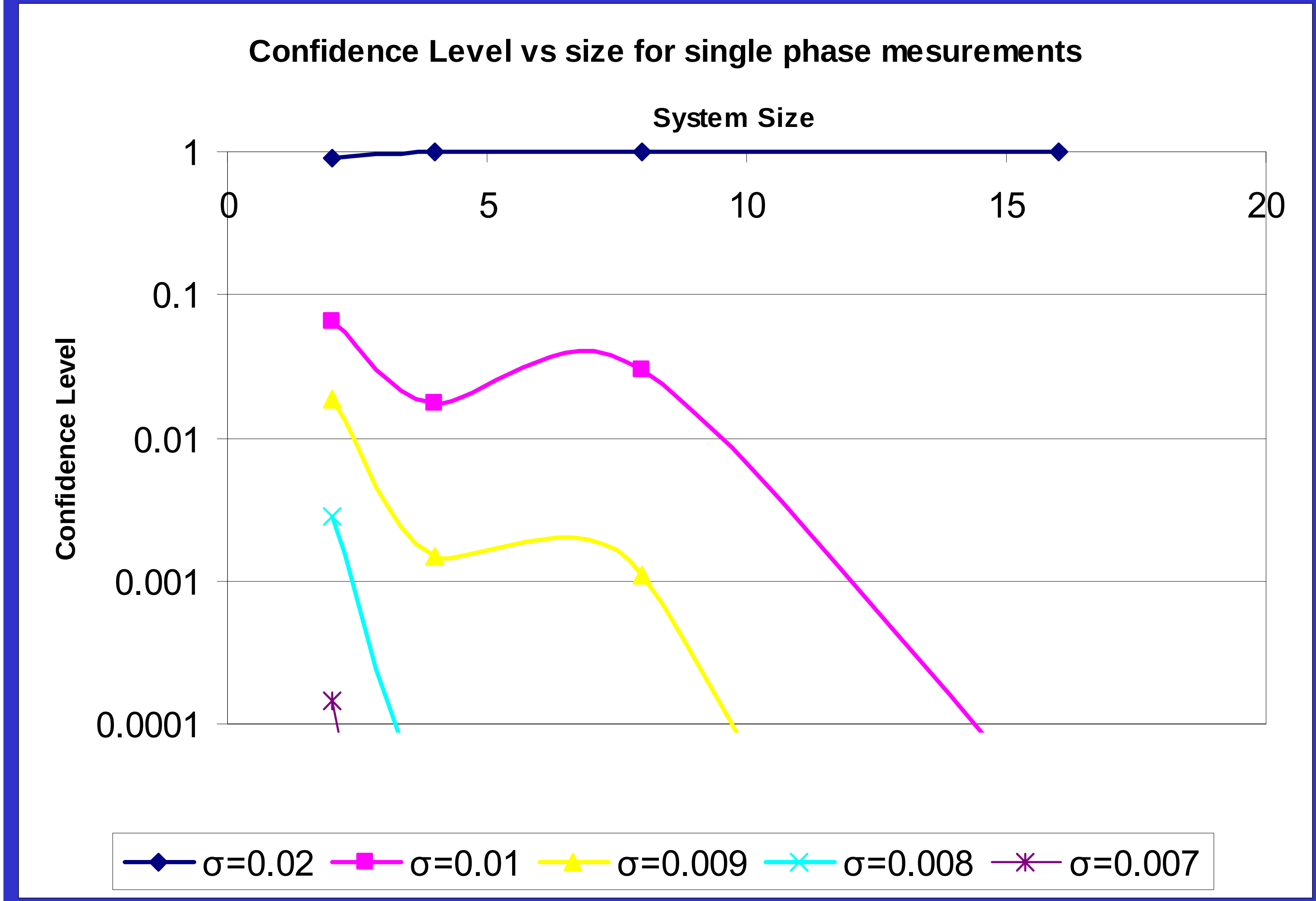


Asymmetry Errors – Q Flow



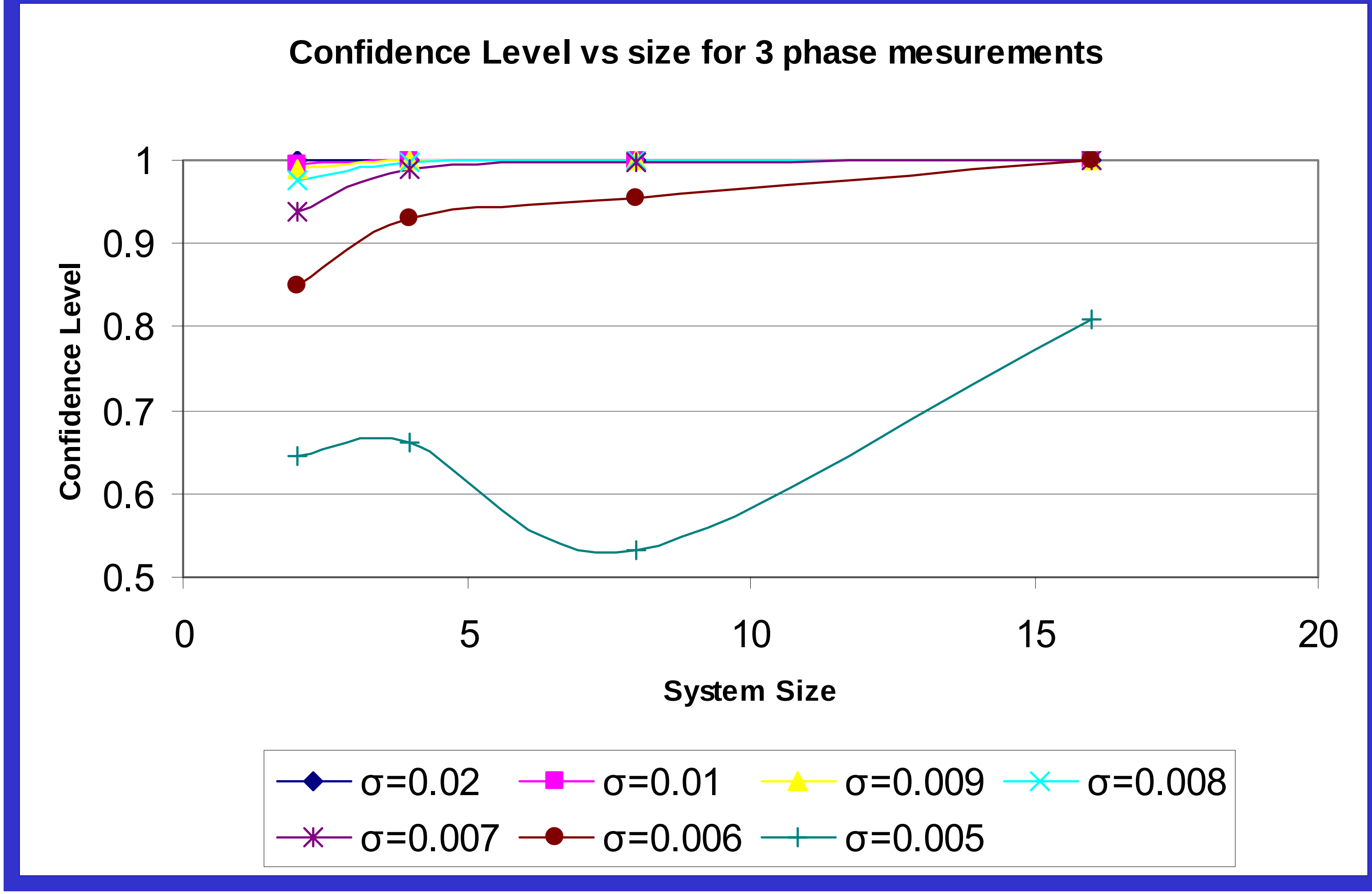
Confidence Level vs Error and System Size

Scenario 1



Confidence Level vs Error and System Size

Scenario 3



Summary and Conclusions

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Present Implementation of State Estimators

- Biased Estimator

Synchronized Measurements

- Direct State Estimation

Synchronized Measurements + Multiphase Model

- Unbiased State Estimation

Scalability of SE to Mega RTOs

Insight Can Be Obtained with:

- High Fidelity Three Phase Power Flow Models, and
- Numerical Experiments


Τελος