



State Estimation For Mega RTOs

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Traditional State Estimation

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



Practical Implications and Observations:

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

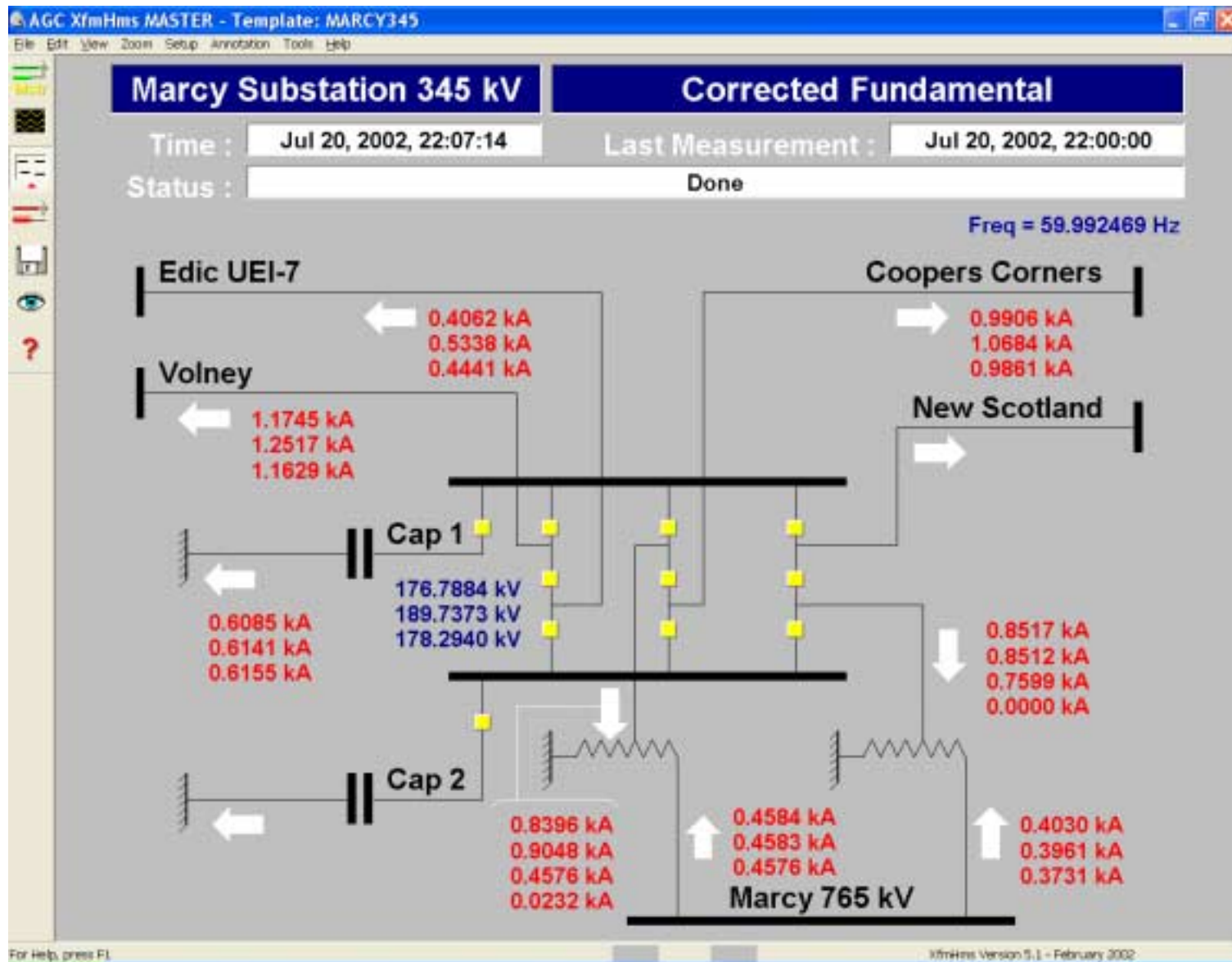
This Paper Poses the Question:

Is the present SE Approach
Scalable to Mega RTOs?



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Validity of Balanced Operation Assumption





Weighted Least Squares Estimation

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

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

Where:

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



Imbalance Bias

$$z = z_t + \Delta z$$

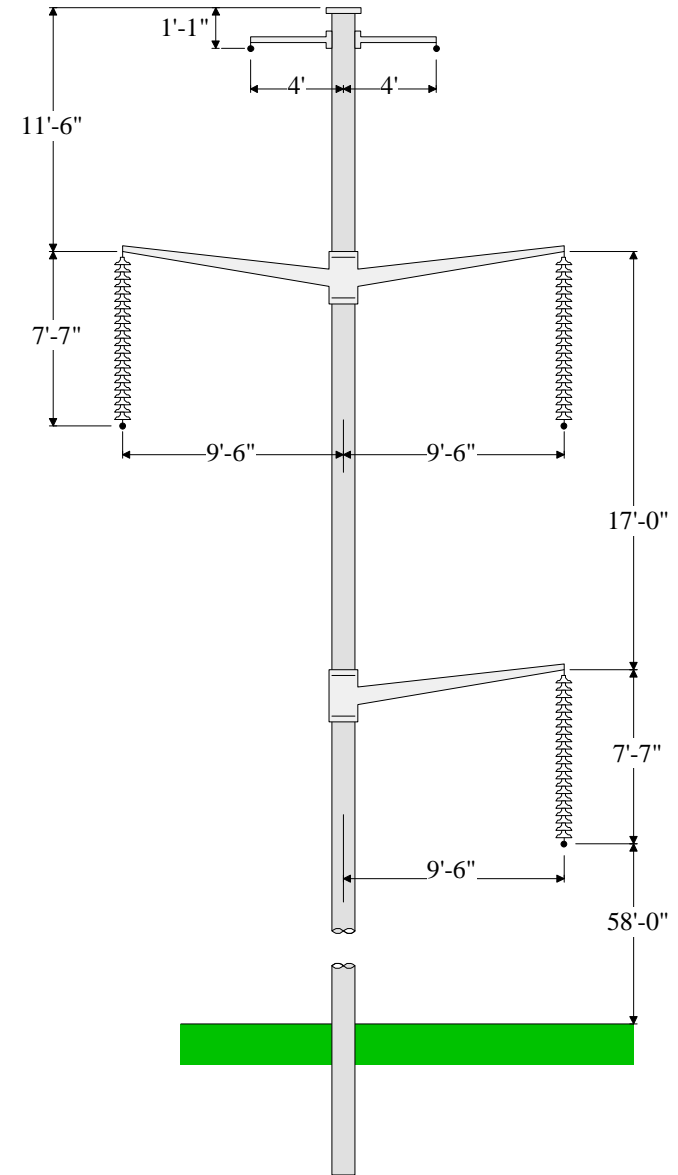
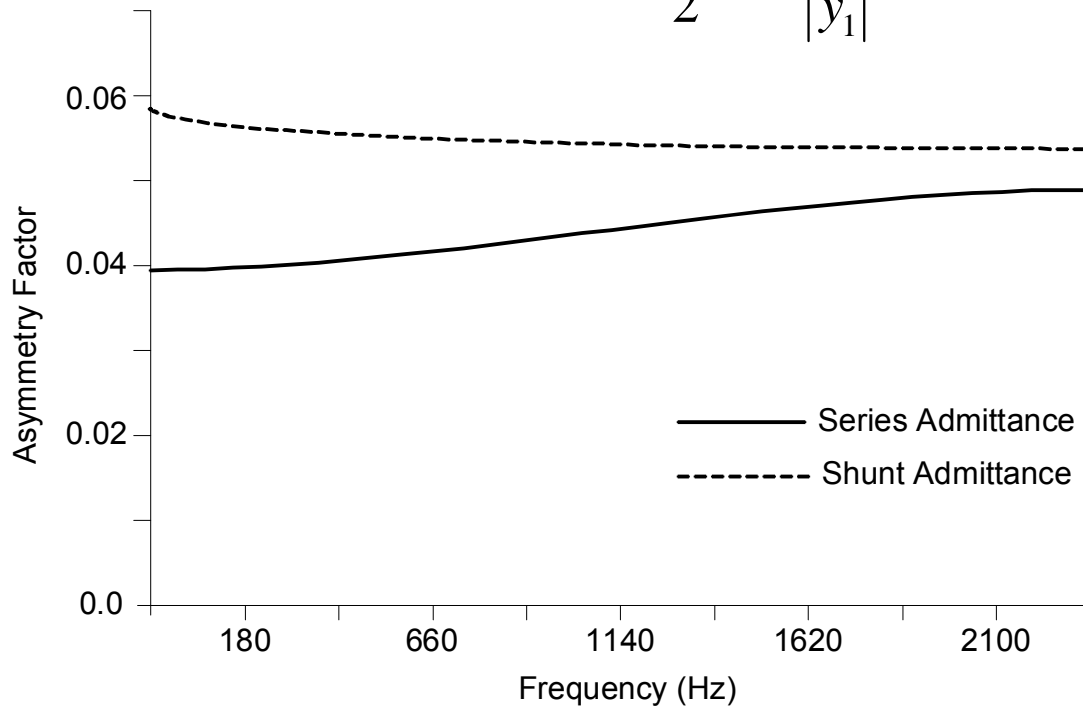
$$x = x_t + (H^T W H)^{-1} H^T W \Delta z$$



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

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

Where:

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



Asymmetry Bias

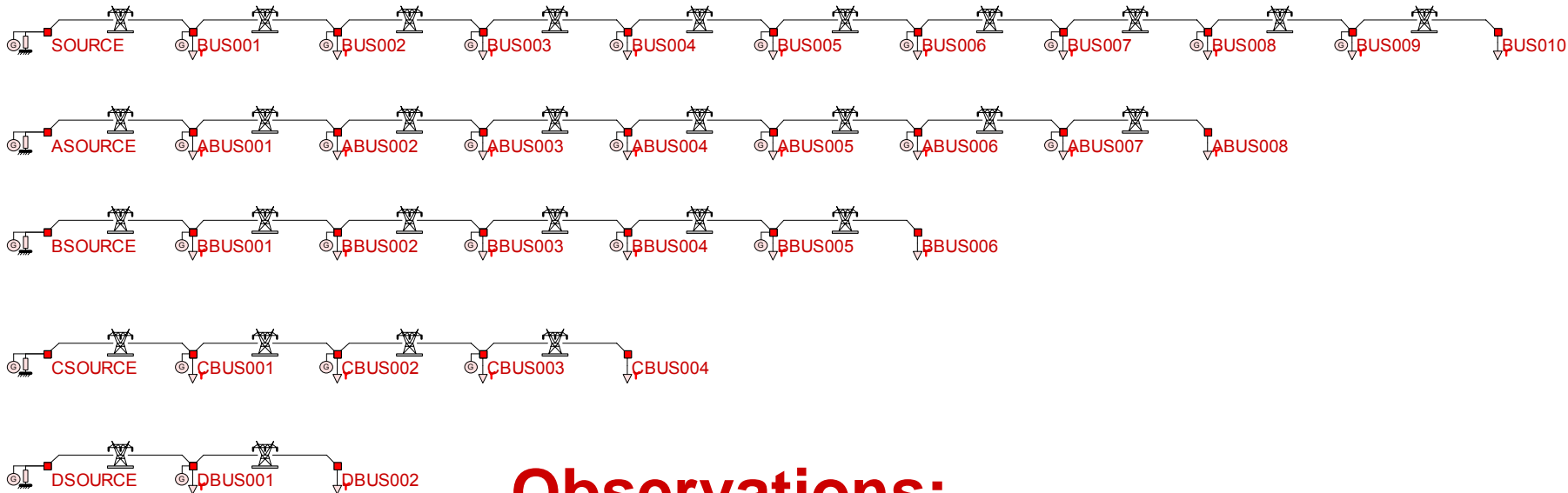
$$z = h(x) + \Delta h(x)$$

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



Investigation of SE Biases via Numerical Experiments

Approach: Systems of Variable Size



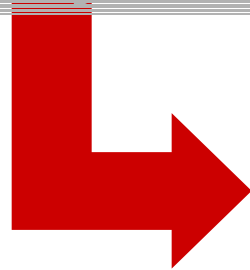
Observations:

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**

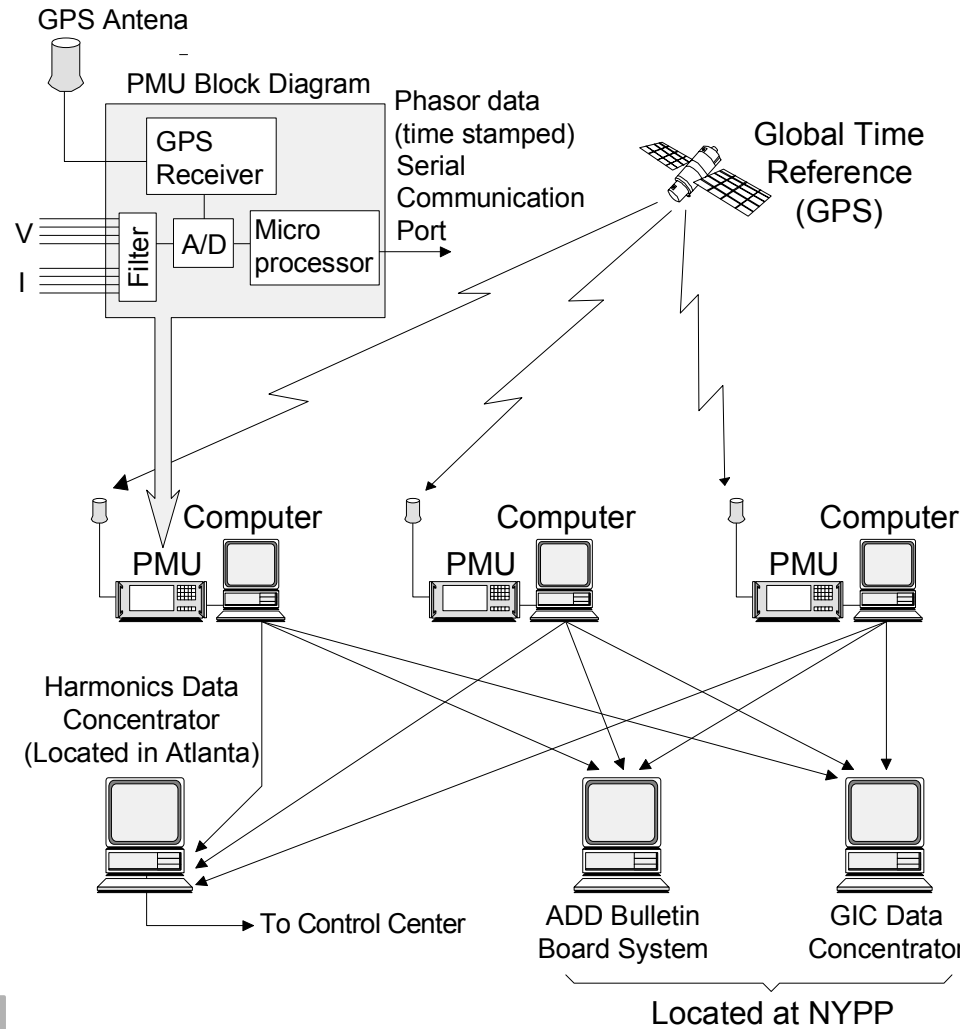
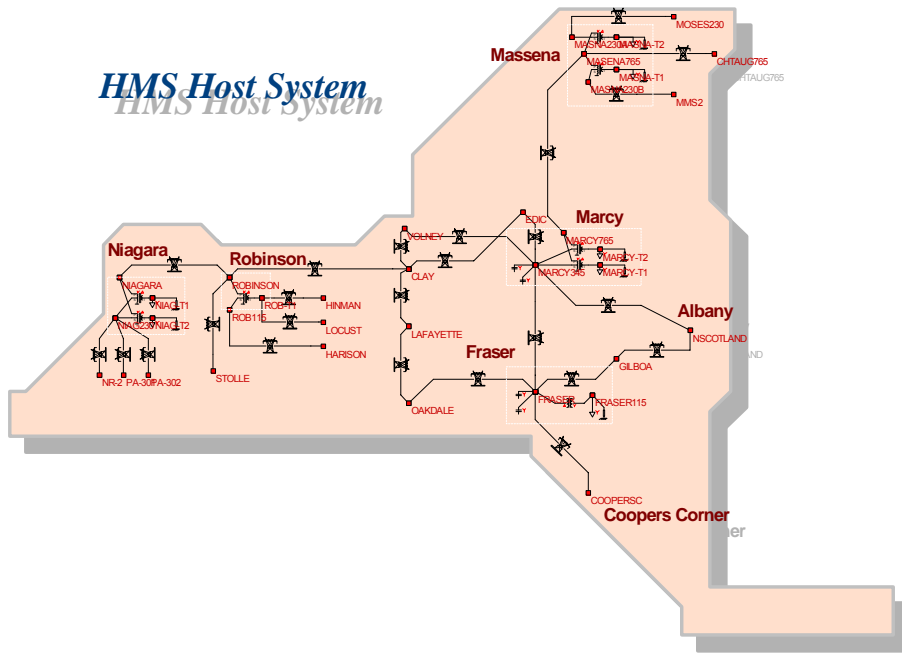


*****Direct Solution*****



Asymmetric Power System Model New York Power Authority

HMS Host System





Minimize: $\mathbf{r}^T \mathbf{W} \mathbf{r}$

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

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 $J \leq a$.

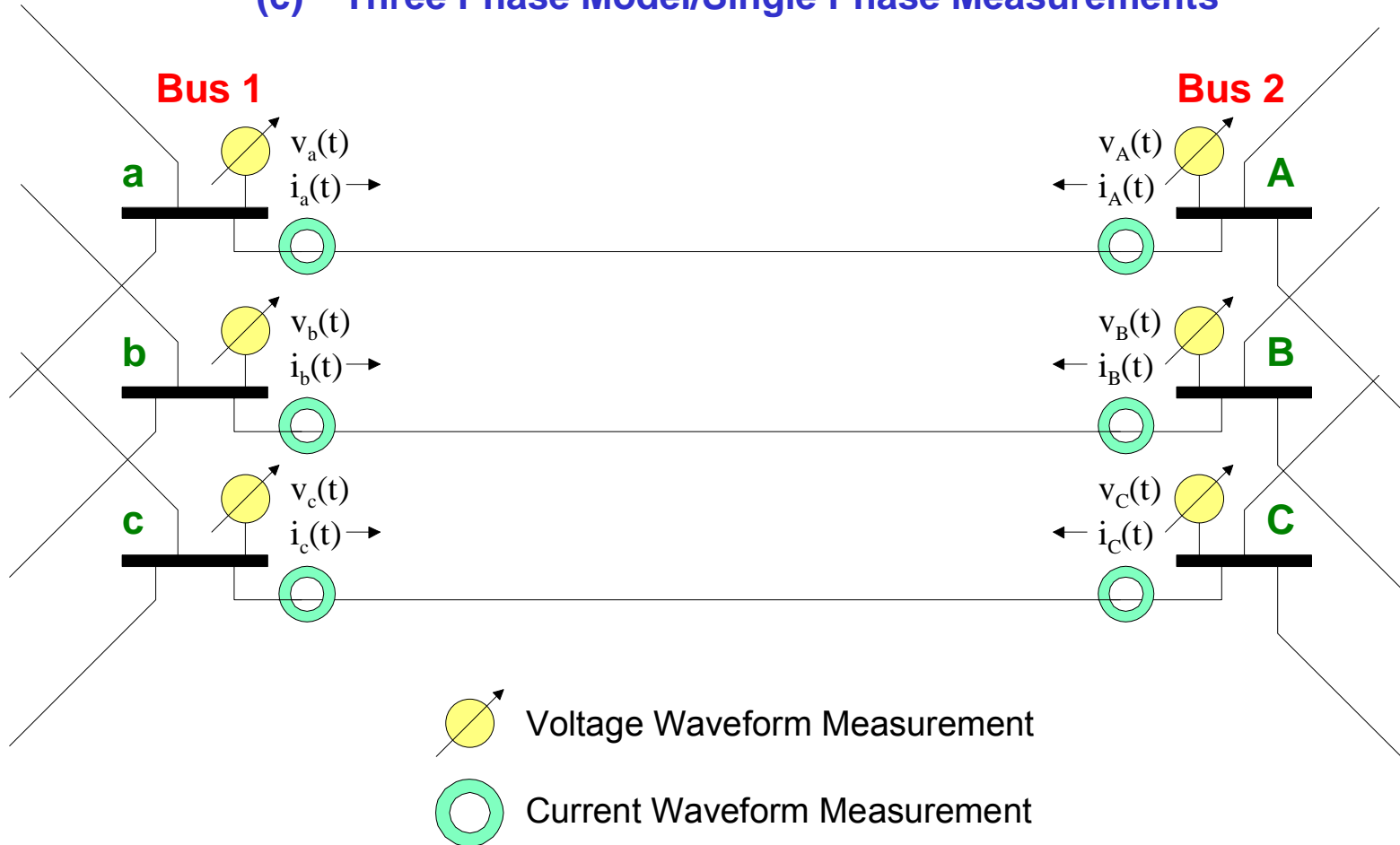
u is the degree of freedom.



Synchronized Measurement Based SE

Numerical Experiments

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





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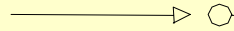
Example Results

Estimation Report by Device

Return

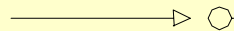
Update

0.5725kA 433.812kV
-170.75 D -176.64 D



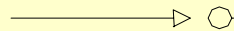
0.5741kA 436.400kV
-162.95 D -175.94 D

0.6162kA 440.351kV
65.63 D 61.46 D

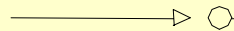


0.6066kA 438.966kV
73.37 D 62.47 D

0.5886kA 438.701kV
-55.76 D -57.01 D



0.5819kA 433.643kV
-48.45 D -56.61 D



0.0142kA 0.000kV
44.12 D 0.00 D

MASENA765_A

MARCY765_A

Measured Voltage
Estimated Voltage

MASENA765_B

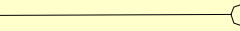
MARCY765_B

Measured Current
Estimated Current

MASENA765_N

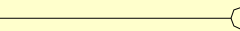
MARCY765_N

433.676kV 0.6097kA
178.76 D -16.22 D



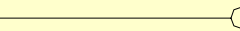
425.960kV 0.6441kA
178.08 D -22.17 D

435.009kV 0.6200kA
58.09 D -142.45 D

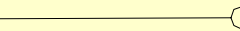


430.260kV 0.6679kA
56.91 D -148.11 D

428.841kV 0.5633kA
-61.93 D 97.07 D



428.727kV 0.6074kA
-62.62 D 91.08 D



0.000kV 0.0172kA
0.00 D -177.20 D

Harmonic Order Selection: 1

Line Selection: ----- MSU (MASENA UTICA) 3 PHASE 765KV TRANSMIS

Compute left quantities

Compute right quantities

Program: HMS Vs1.0

Form Name: EREP_005

Print

Save



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



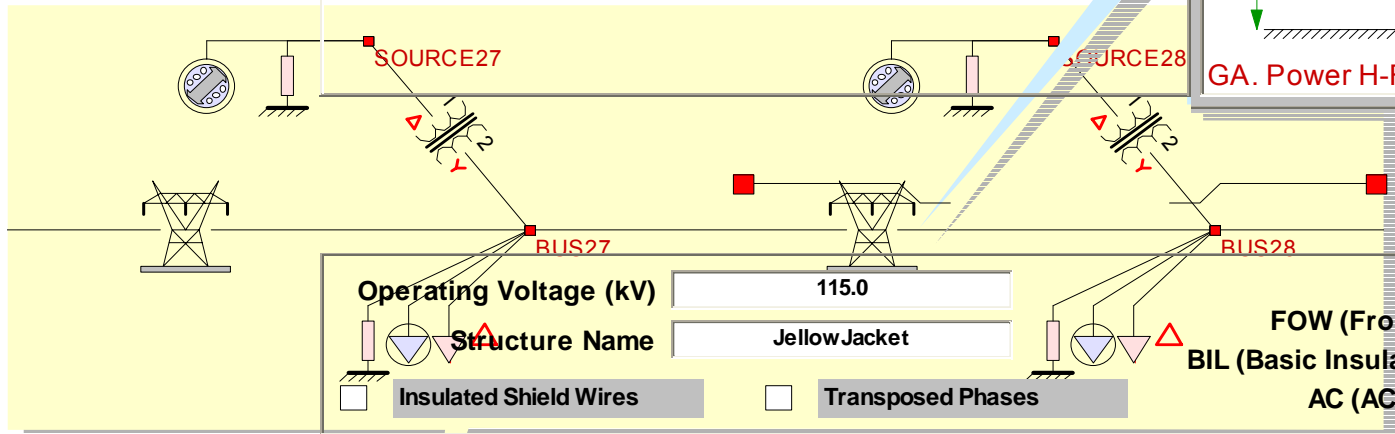
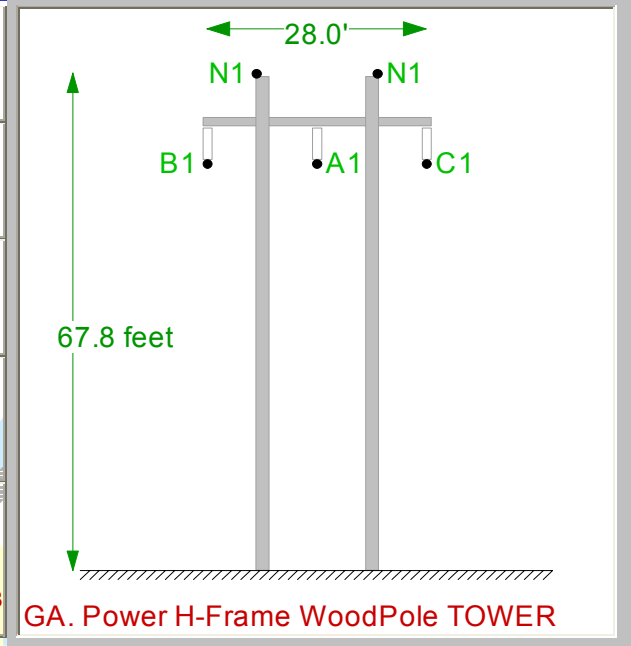
Numerical Experiments

Three Phase Power Flow

Scenario 1: Phase A Measurements Type

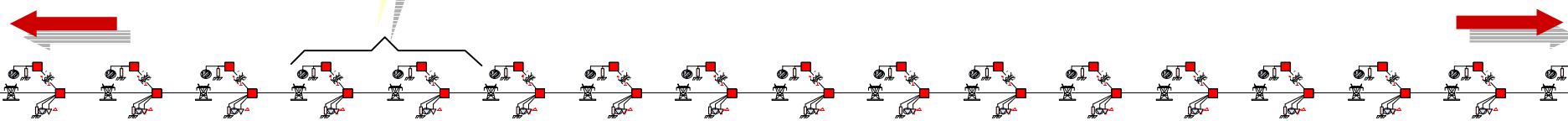
Scenario 2: Phase B Measurements Type
Size

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



Operating Voltage (kV)	115.0	Insulation Level (kV)	
Structure Name	JellowJacket	FOW (Front of Wave)	100.0
Insulated Shield Wires	<input type="checkbox"/>	BIL (Basic Insulation Level)	100.0
Transposed Phases	<input type="checkbox"/>	AC (AC Withstand)	100.0

Program WinIGS - Form IGS_M102

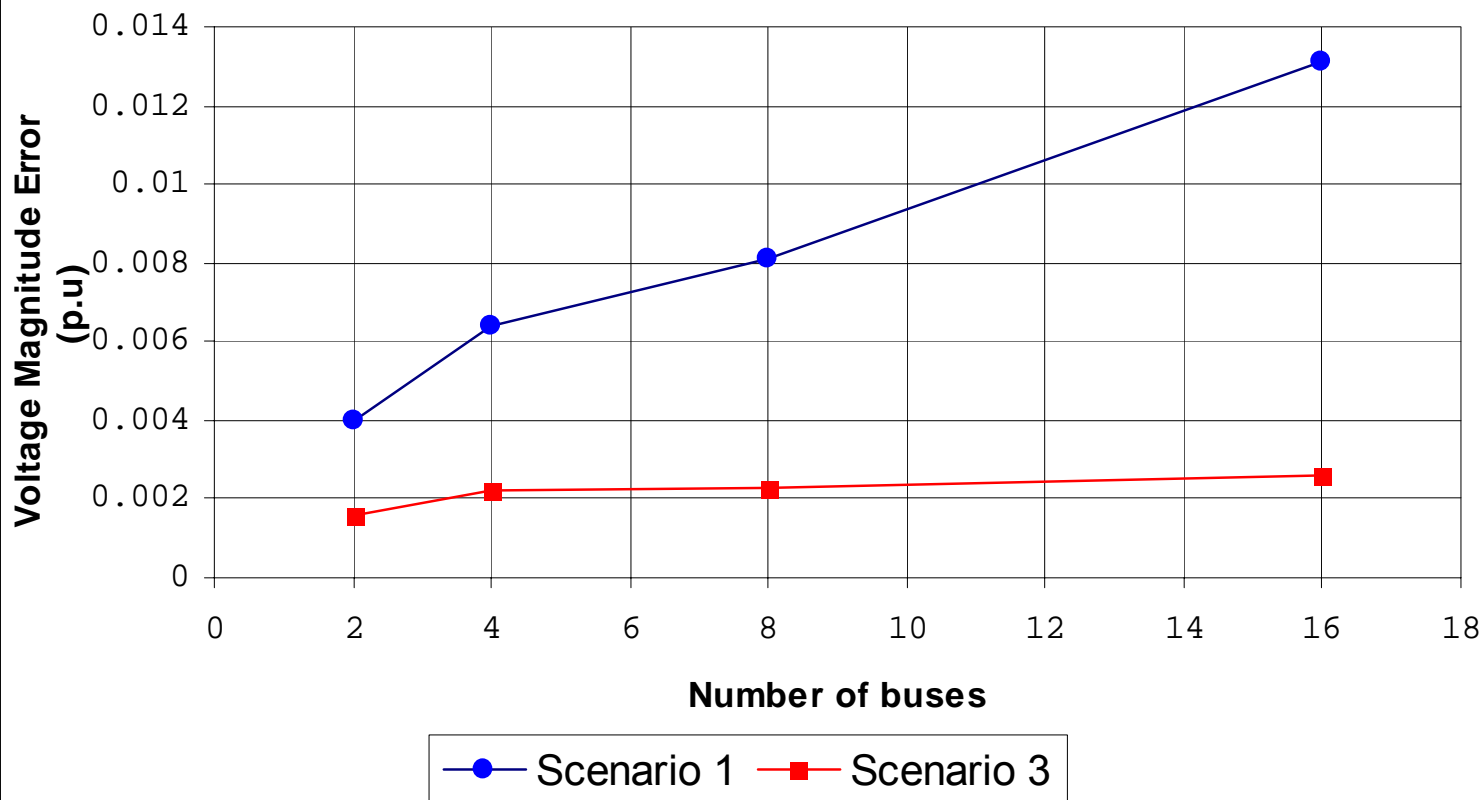


Asymmetry Errors – Voltage Magnitude



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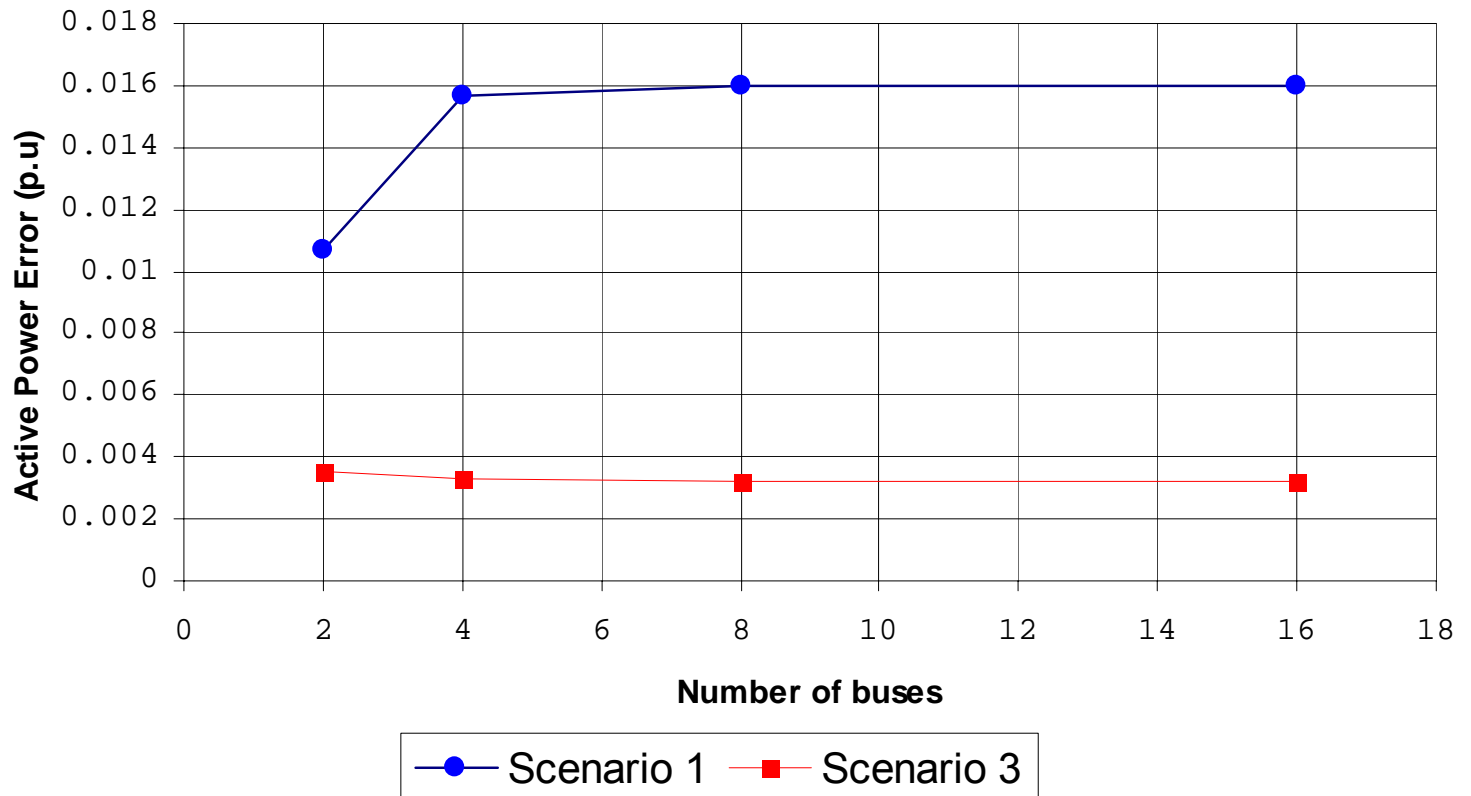
Maximum Absolute Voltage Errors in p.u. for Various System Sizes



Asymmetry Errors – P Flow



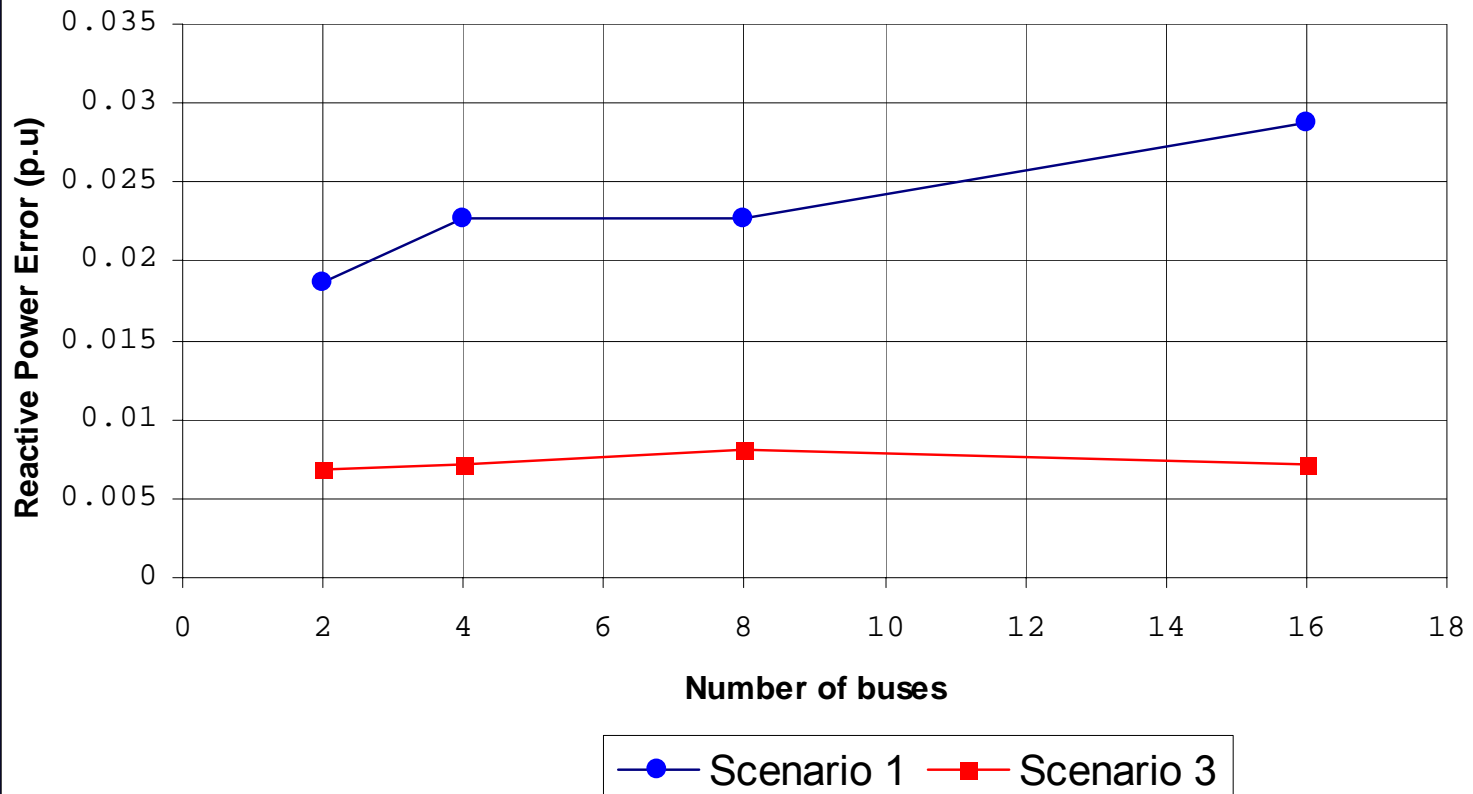
Maximum Absolute Active Flow Errors in p.u. for Various System Sizes



Asymmetry Errors – Q Flow



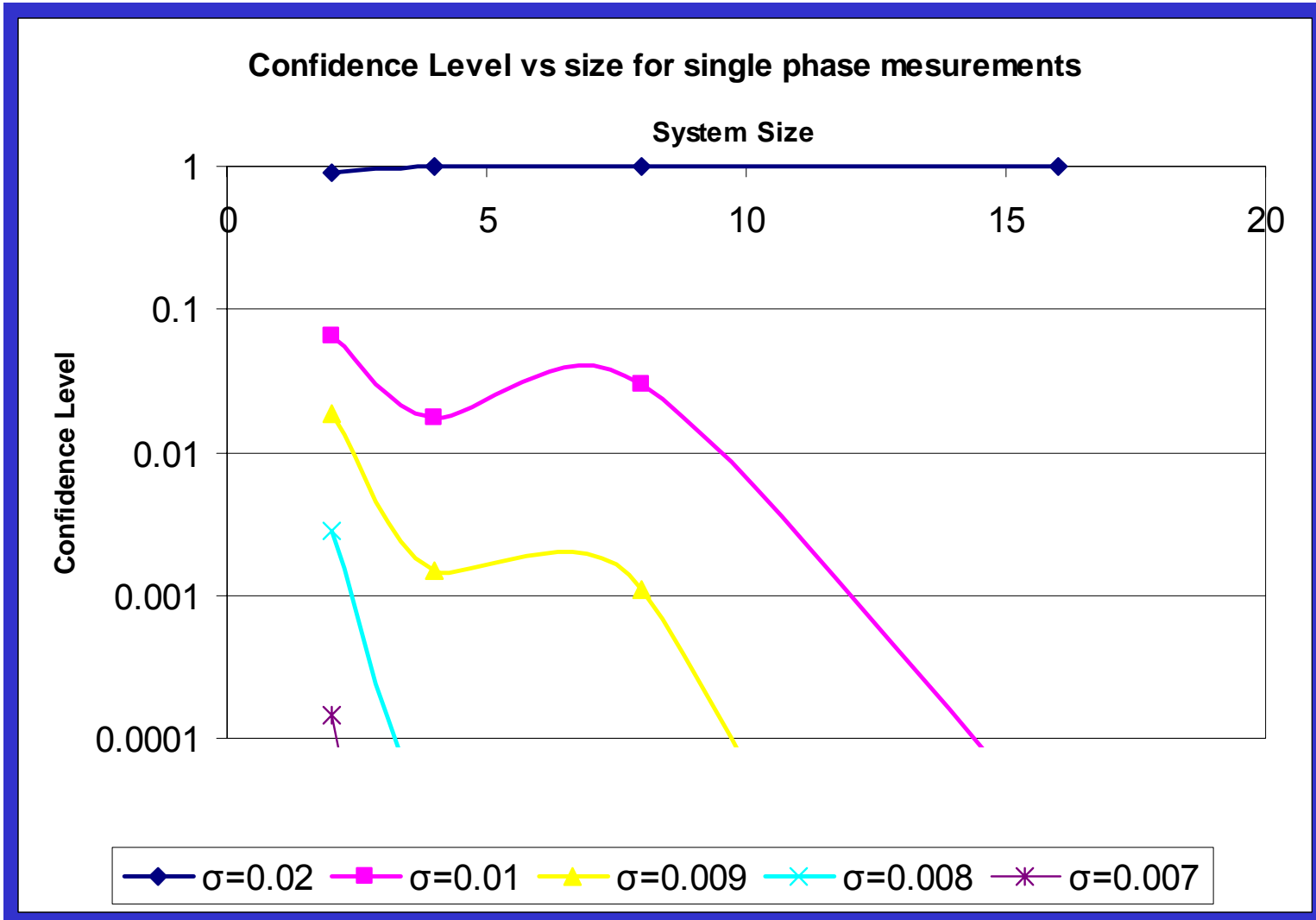
Maximum Absolute Reactive Flow Errors in p.u. for Various System Sizes





Confidence Level vs Error and System Size

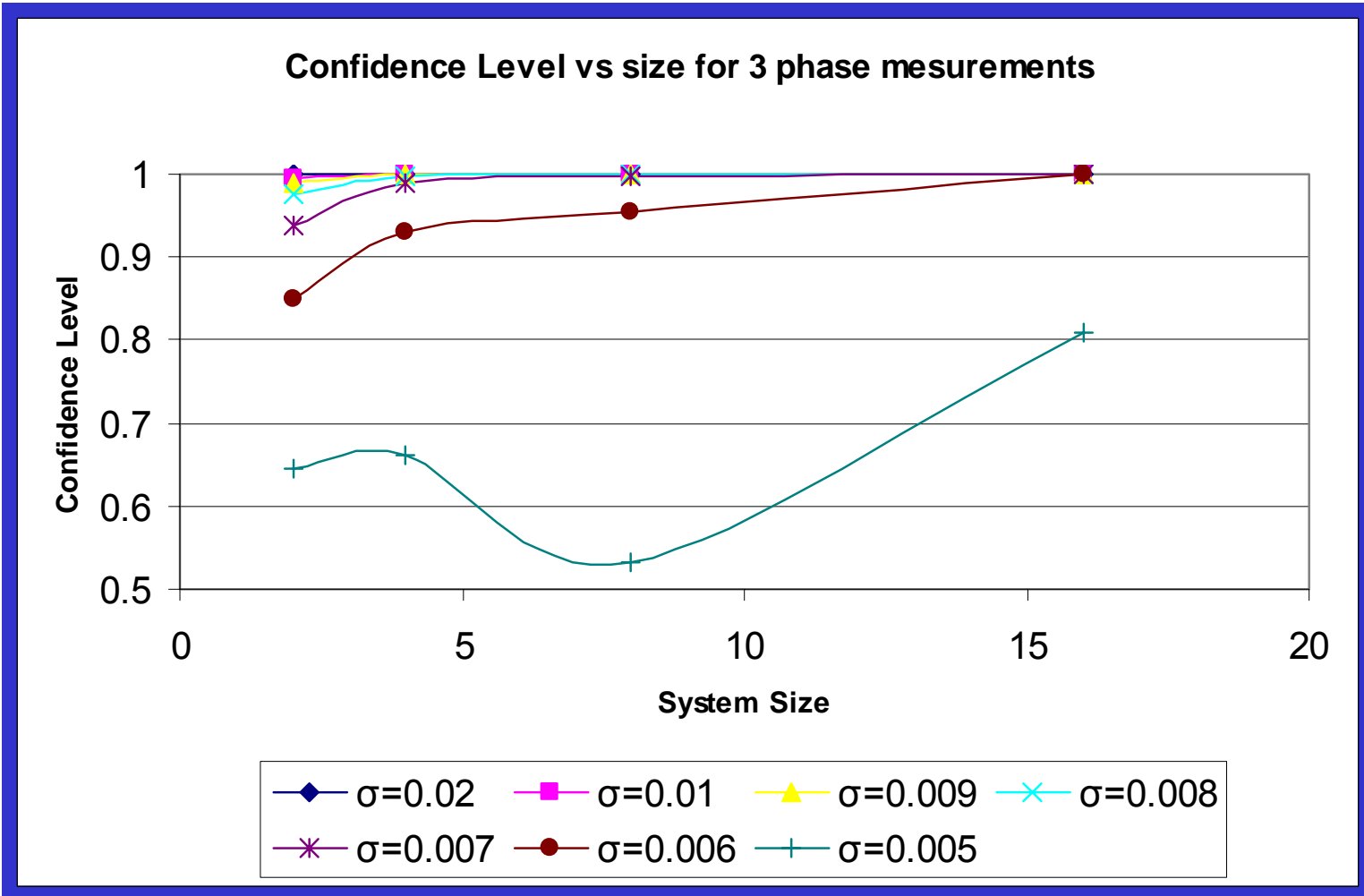
Scenario 1





Confidence Level vs Error and System Size

Scenario 3





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



Τέλος