



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



Traditional State Estimation

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?



PSERC

Validity of: Balanced Operation Assumption

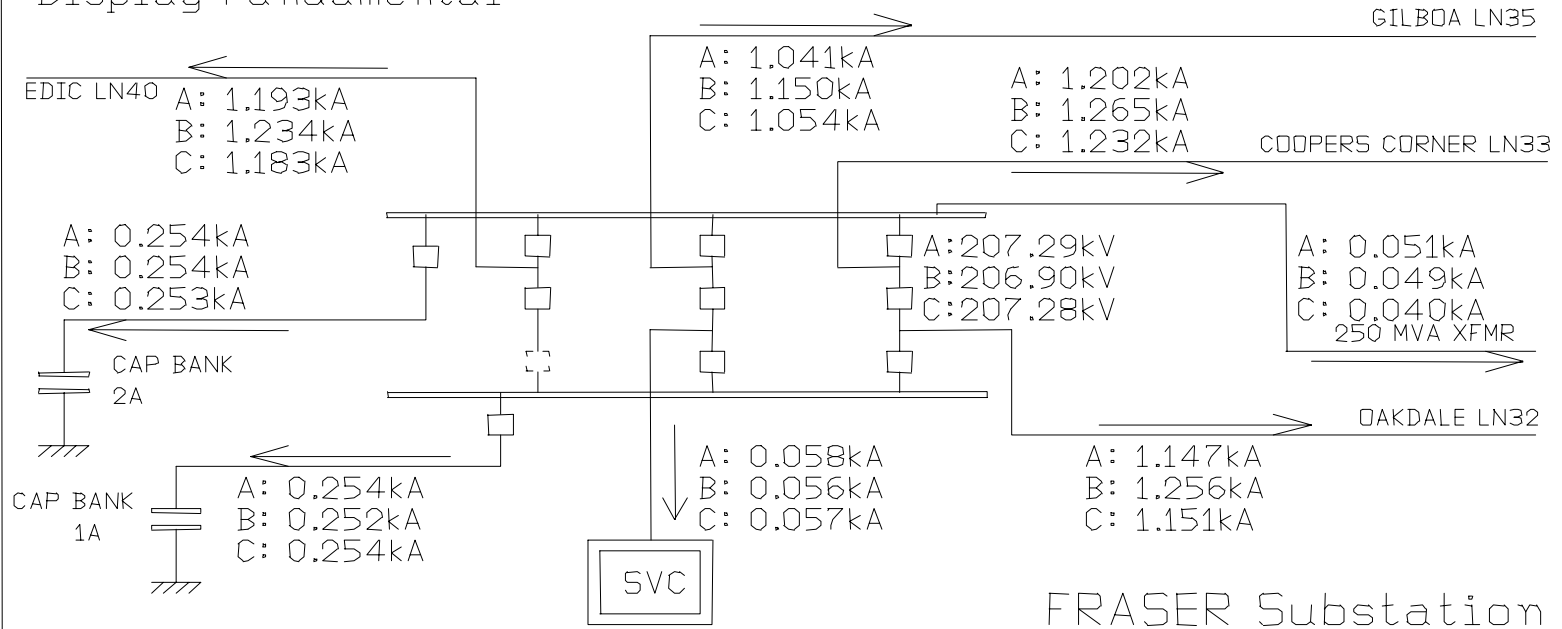
HMS Site Workstation

HMS

Date: Fri, Nov 3, 1995
Time: 07:17:37

Last Measurement: 08:30:00
Next Measurement: 07:30:00

Display: Fundamental



FRASER Substation

Program: HMS Vs1.0

Form Name: FRASER

Print

Alt P

Save

Alt S



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:

- \mathbf{W} Weighting matrix,
- \mathbf{z} Measurement vector
- \mathbf{x} State vector
- $\mathbf{h}(\cdot)$ System model.



SE: Effects of Imbalance

Imbalance Bias

$$z = z_t + \Delta z$$

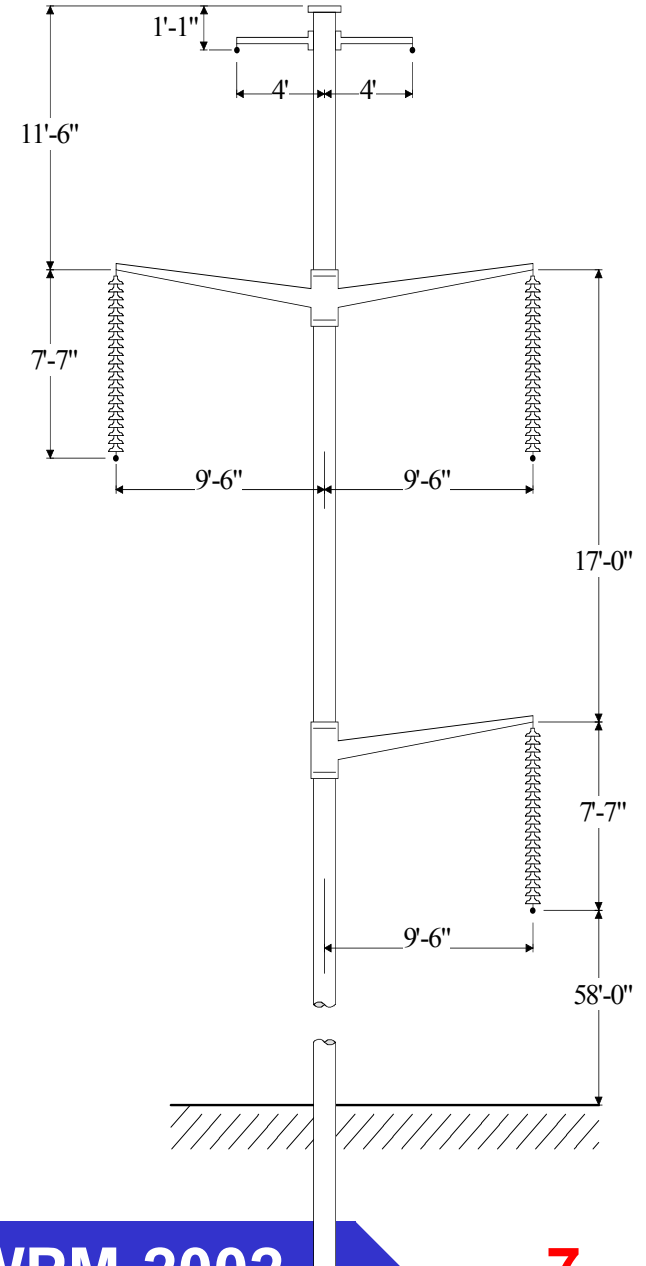
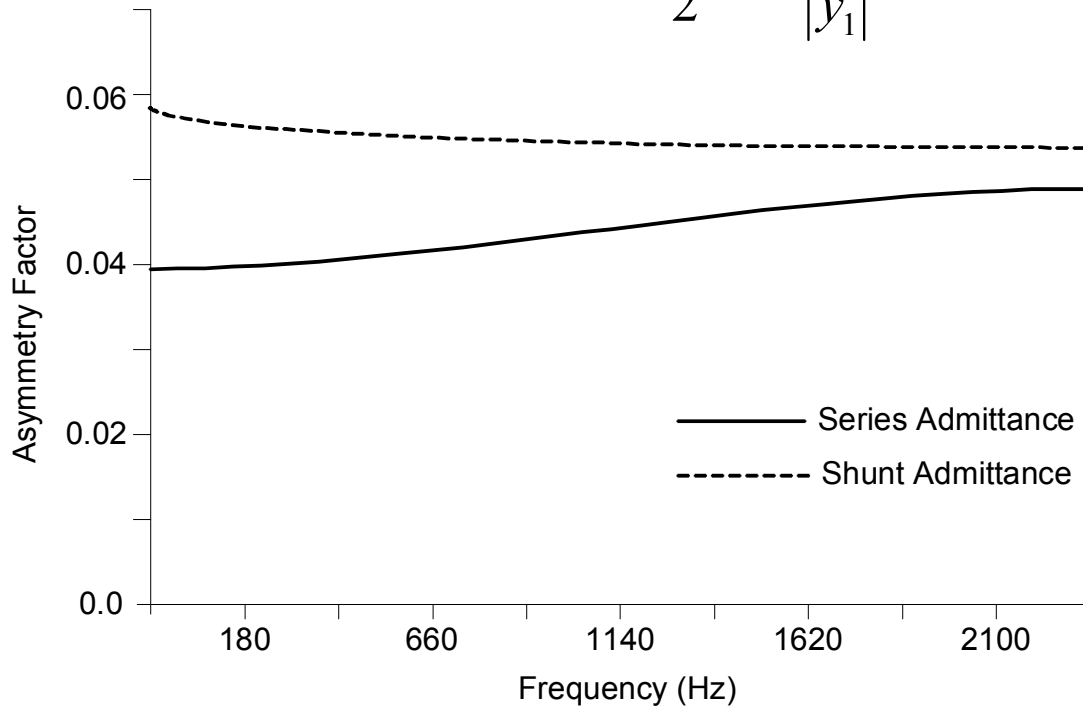
$$x = x_t + (H^T W H)^{-1} H^T W \Delta z$$



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.



SE: Effects of Asymmetry

Asymmetry Bias

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

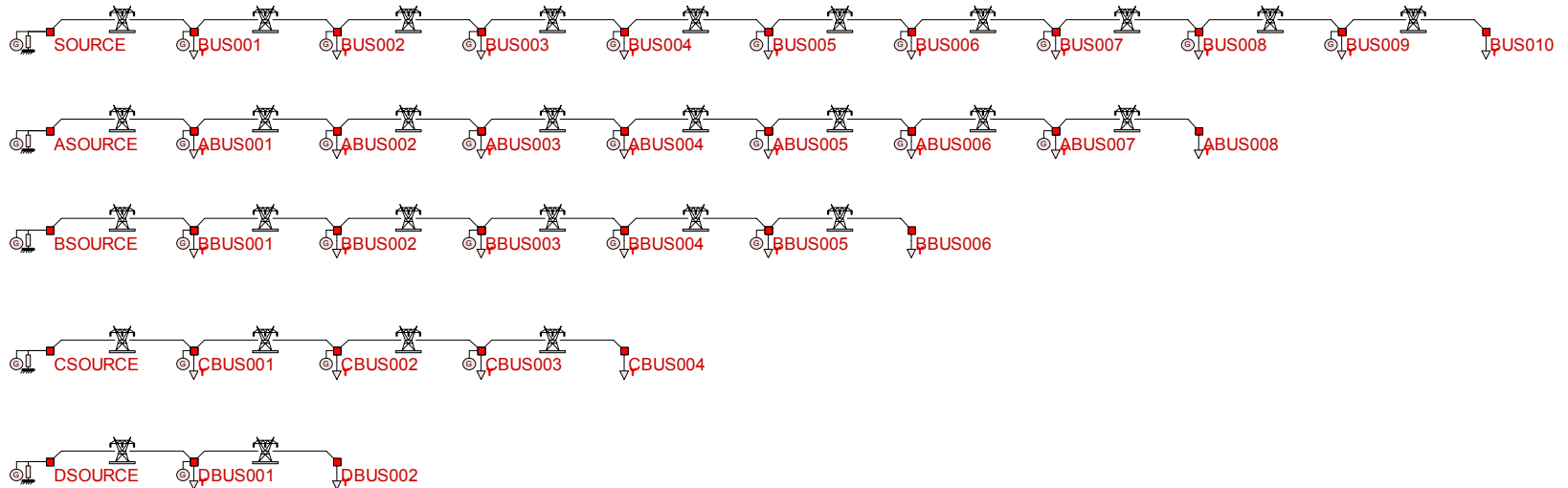
$$x = (x_t + (H^T W H)^{-1} H^T W \Delta z) (\Delta H^T W H)^{-1} (I + 2(\Delta H^T W H)(H^T W H)^{-1})^{-1} (\Delta H^T W H)$$



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

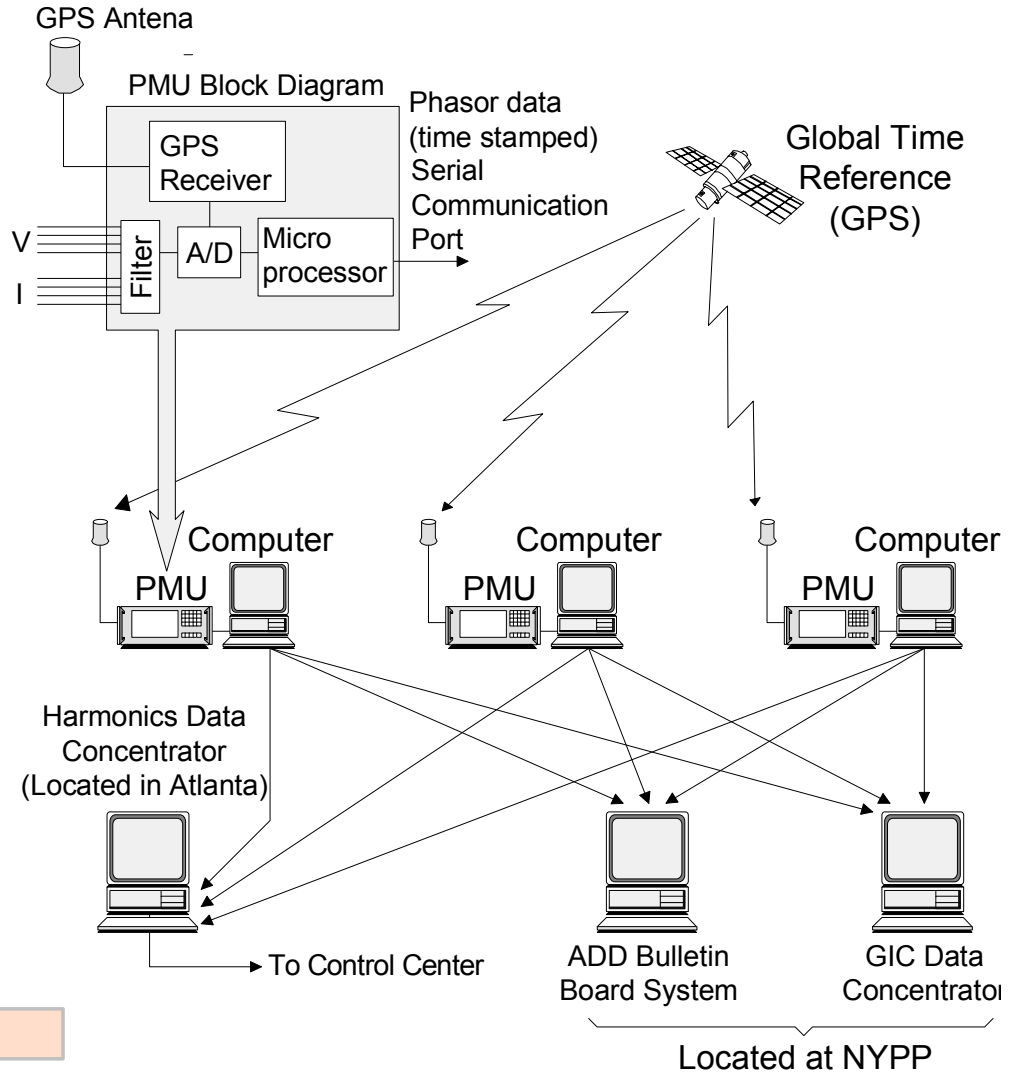
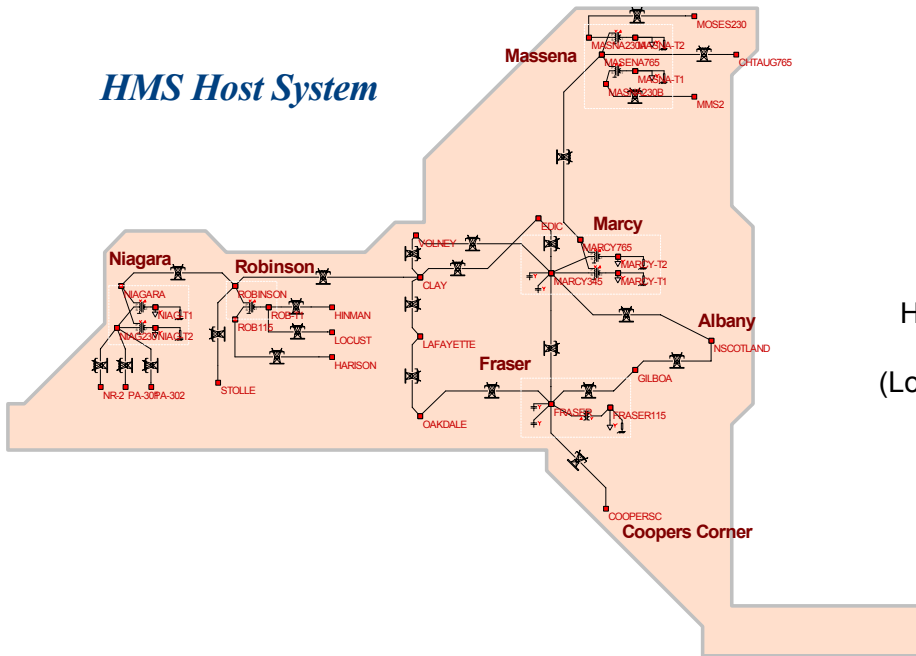
Synchronized Measurements



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



SE Using Synchronized Three Phase Measurements Asymmetric Power System Model New York Power Authority





SE with Synchronized Measurements

$$\text{Minimize:} \quad \mathbf{r}^T \mathbf{H} \mathbf{W} \mathbf{r}$$

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

$$\text{Min:} \quad r_{\text{real}}^T \mathbf{W} r_{\text{real}} + r_{\text{imag}}^T \mathbf{W} r_{\text{imag}}$$

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

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

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

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



Performance Evaluation of State Estimation

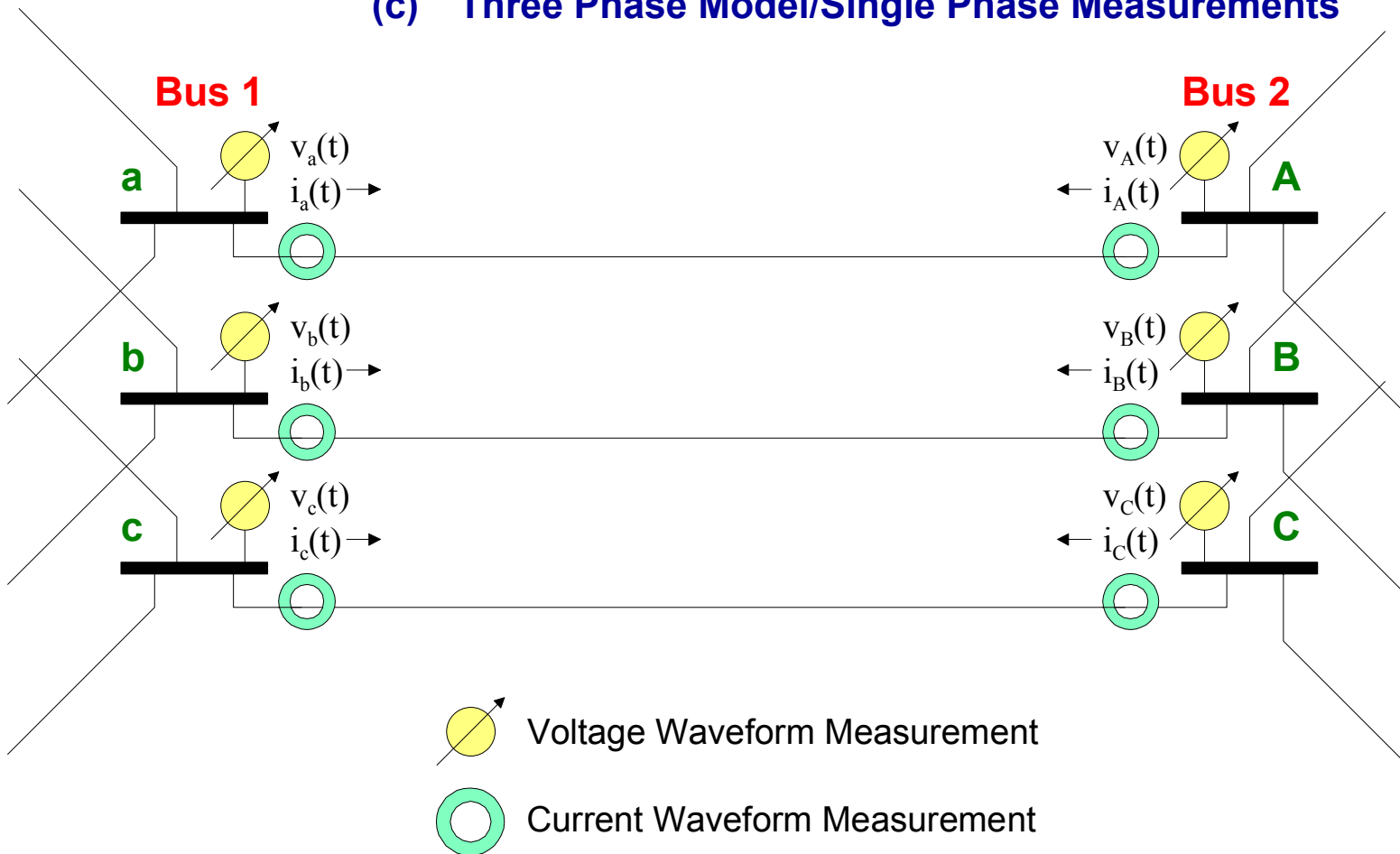
Chi-Square Test

- Step 1: Compute the state estimate \hat{x}^*
- Step 2: Evaluate the function $J^* = \tilde{r}^H W \tilde{r} = a$
- Step 3: Compute $p = 1.0 - P(a, m-n)$,
where
- $P(a, u) =$ 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





Example Results

Estimation Report by Device				F4	Return	F5	Update
0.5725kA -170.75 D 0.5741kA -162.95 D 0.6162kA 65.63 D 0.6066kA 73.37 D 0.5886kA -55.76 D 0.5819kA -48.45 D 0.0142kA 44.12 D	433.812kV -176.64 D 436.400kV -175.94 D 440.351kV 61.46 D 438.966kV 62.47 D 438.701kV -57.01 D 433.643kV -56.61 D 0.000kV 0.00 D	MASENA765_A MARCY765_A Measured Voltage Estimated Voltage MASENA765_B MARCY765_B Measured Current Estimated Current MASENA765_C MARCY765_C MASENA765_N MARCY765_N	433.676kV 178.76 D 425.960kV 178.08 D 435.009kV 58.09 D 430.260kV 56.91 D 428.841kV -61.93 D 428.727kV -62.62 D 0.000kV 0.00 D	0.6097kA -16.22 D 0.6441kA -22.17 D 0.6200kA -142.45 D 0.6679kA -148.11 D 0.5633kA 97.07 D 0.6074kA 91.08 D 0.0172kA -177.20 D			
Harmonic Order Selection: 1 Line Selection: ----- MSU (MASENA UTICA) 3 PHASE 765KV TRANSMIS <div style="display: flex; justify-content: space-around;"> F1 Compute left quantities F3 Compute right quantities </div>							
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



Summary and Conclusions

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: Unknown



FINITO