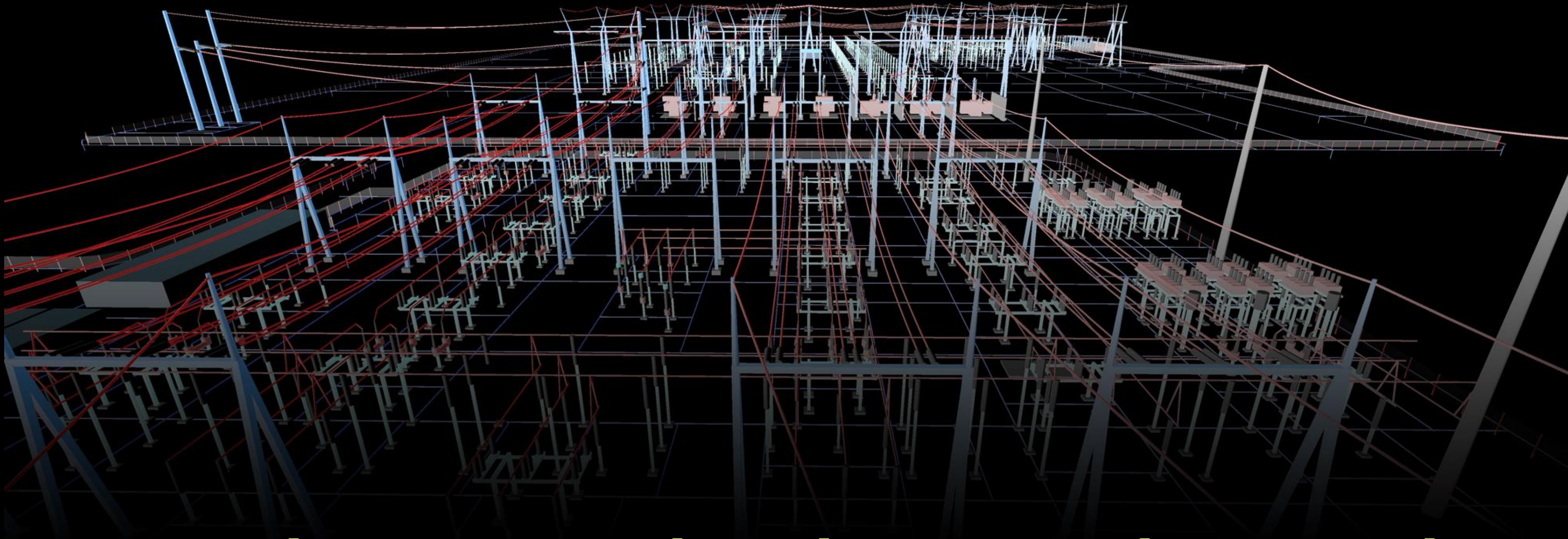
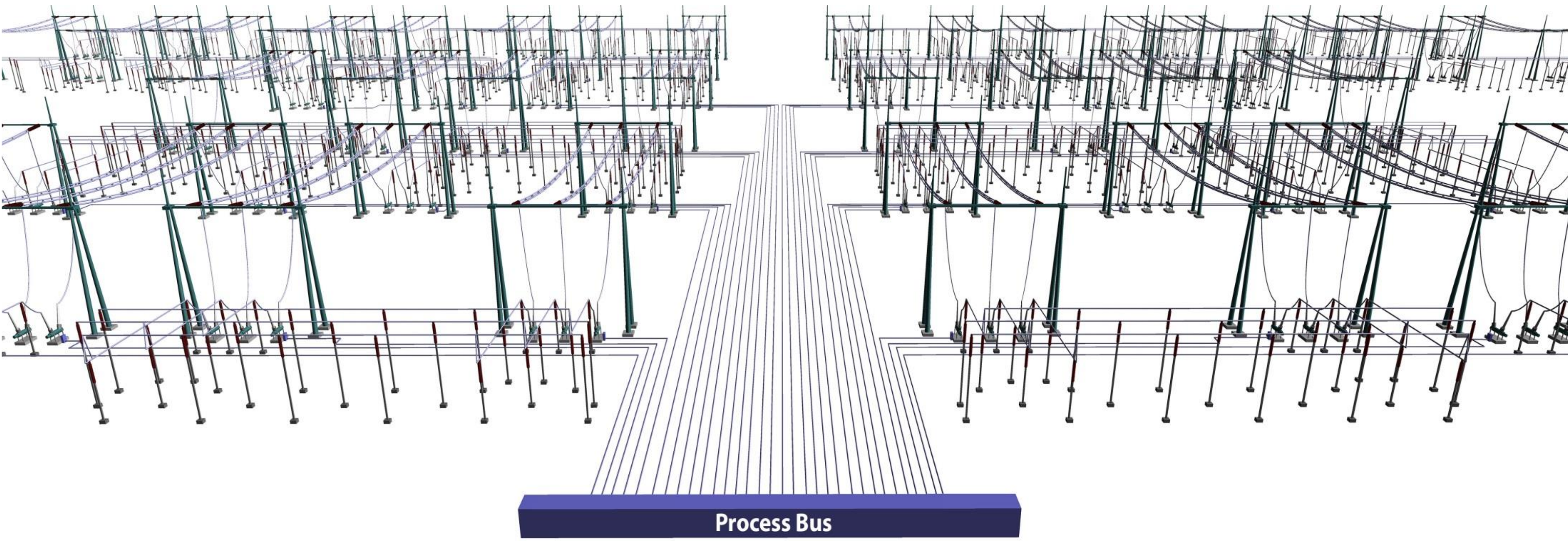


Dynamic State Estimation Based Protection (a.k.a. setting-less protection)

Sakis Meliopoulos, Ga Tech
Bruce Fardanesh & George Stefopoulos, NYPA
Paul Myrda, EPRI

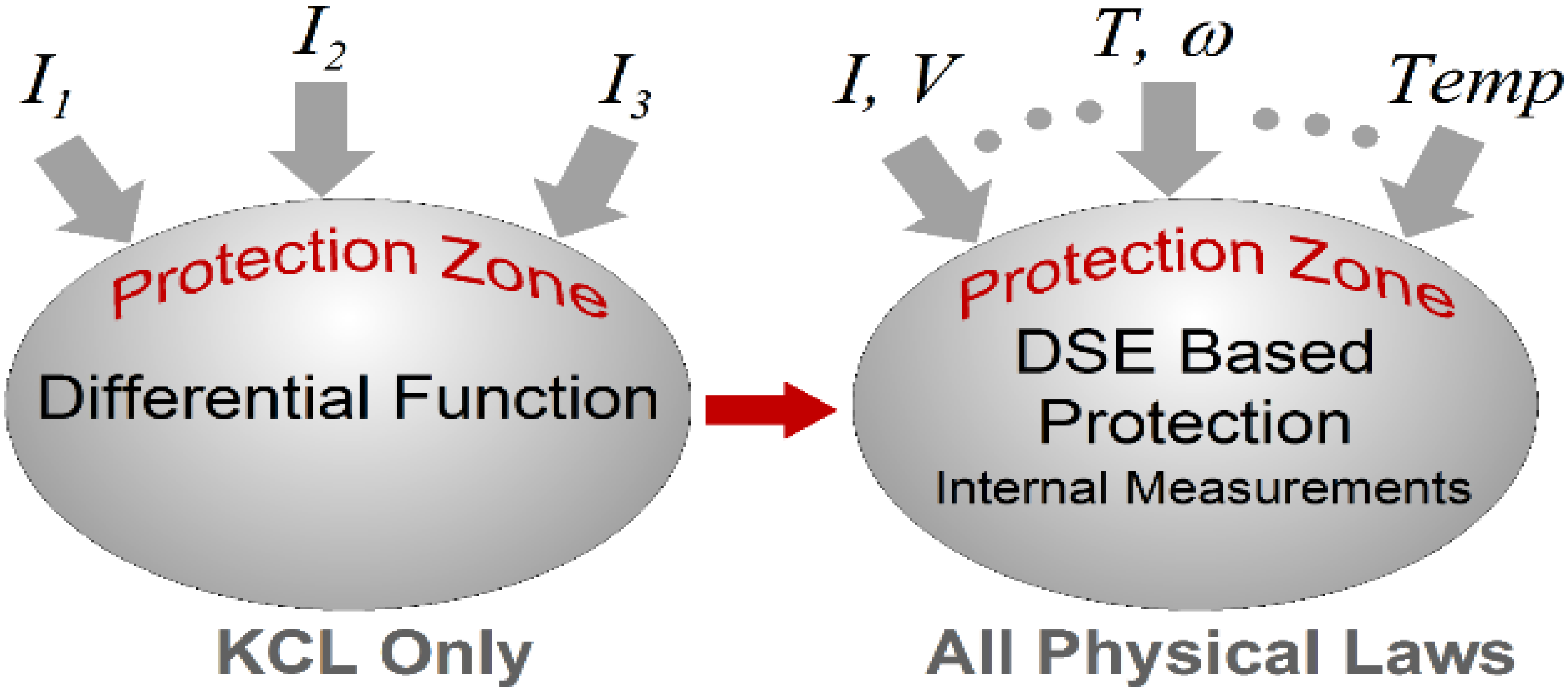
International Synchrophasor Symposium
Atlanta, Georgia, March 22-24, 2016

The Setting-Less Protection Method



DSE Motivation: In Search of Secure Protection

Setting-less Protection has been **inspired** from Differential Protection which:
(a) has minimal settings and (b) does not require coordination with other functions



Analytics: Dynamic State Estimation (systematic way to determine observance of physical laws)

Dynamic State Estimation

Given the dynamic model of a system:

$$\mathbf{i}(t) = Y_{eqx1}\mathbf{x}(t) + D_{eqxd1}\frac{d\mathbf{x}(t)}{dt} + C_{eqc1}$$
$$0 = Y_{eqx2}\mathbf{x}(t) + D_{eqxd2}\frac{d\mathbf{x}(t)}{dt} + C_{eqc2}$$
$$0 = Y_{eqx3}\mathbf{x}(t) + \begin{Bmatrix} \vdots \\ \mathbf{x}(t)^T \left\langle F_{eqxx3}^{i} \right\rangle \mathbf{x}(t) \\ \vdots \end{Bmatrix} + C_{eqc3}$$

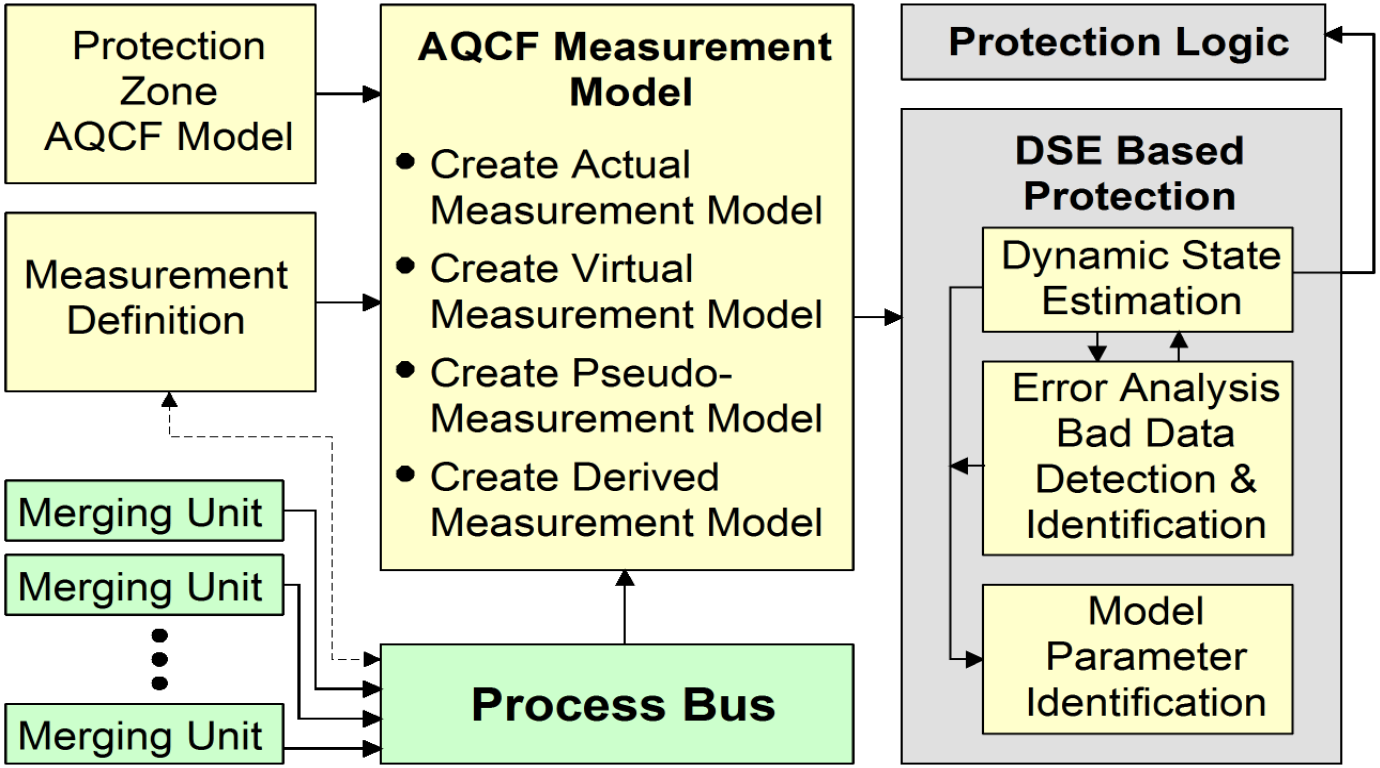
And a set of measurements at times t, t+h, t+2h, …

Compute the best Estimate of the System State at times t, t+h, t+2h, …

We have developed three algorithmic approaches which provide similar results:

- **UCWLS (Un-Constraint Weighted Least Squares)**: Treat actual measurements, virtual, derived and pseudo as data with certain uncertainty
- **CWLS (Constraint Weighted Least Squares)**: Treat virtual measurements as constraints
- **EKF (Extended Kalman Filter)**: Use Predictor-Corrector algorithm

Implementation Overview: Data Flow



- The Component is represented with a set of Differential Equations (DE). Measurements from legacy instrumentation or MUs.
- The Dynamic State Estimator fits the Streaming Data to the Dynamic Model (DE) of the Component. Protection Logic based on DSE results.
- Object Oriented Implementation

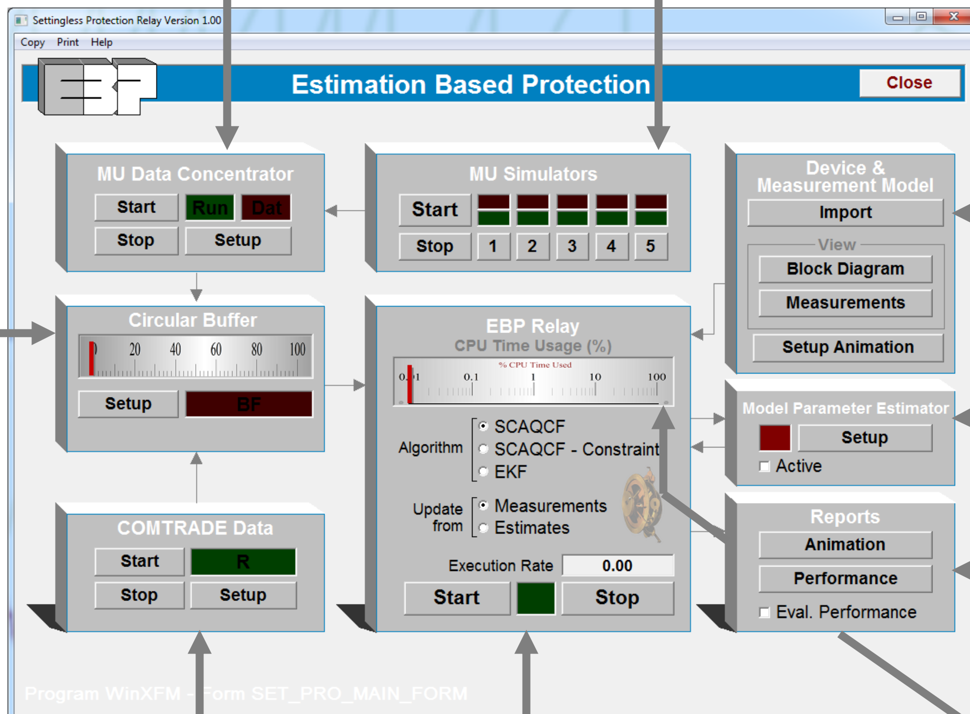
Software Implementation Overview – User Interface

MU Data Concentrator
Collects data from MU via Process Bus, Time Aligns Data and Feeds into a Circular Buffer

MU Simulator
Generates Virtual MUs

Device and Measurement Model
Enables the setting of the EBP relay. User input of the protection zone model and measurement list

Circular Buffer
With buffer utilization indicator



Model Parameter Estimation Setup

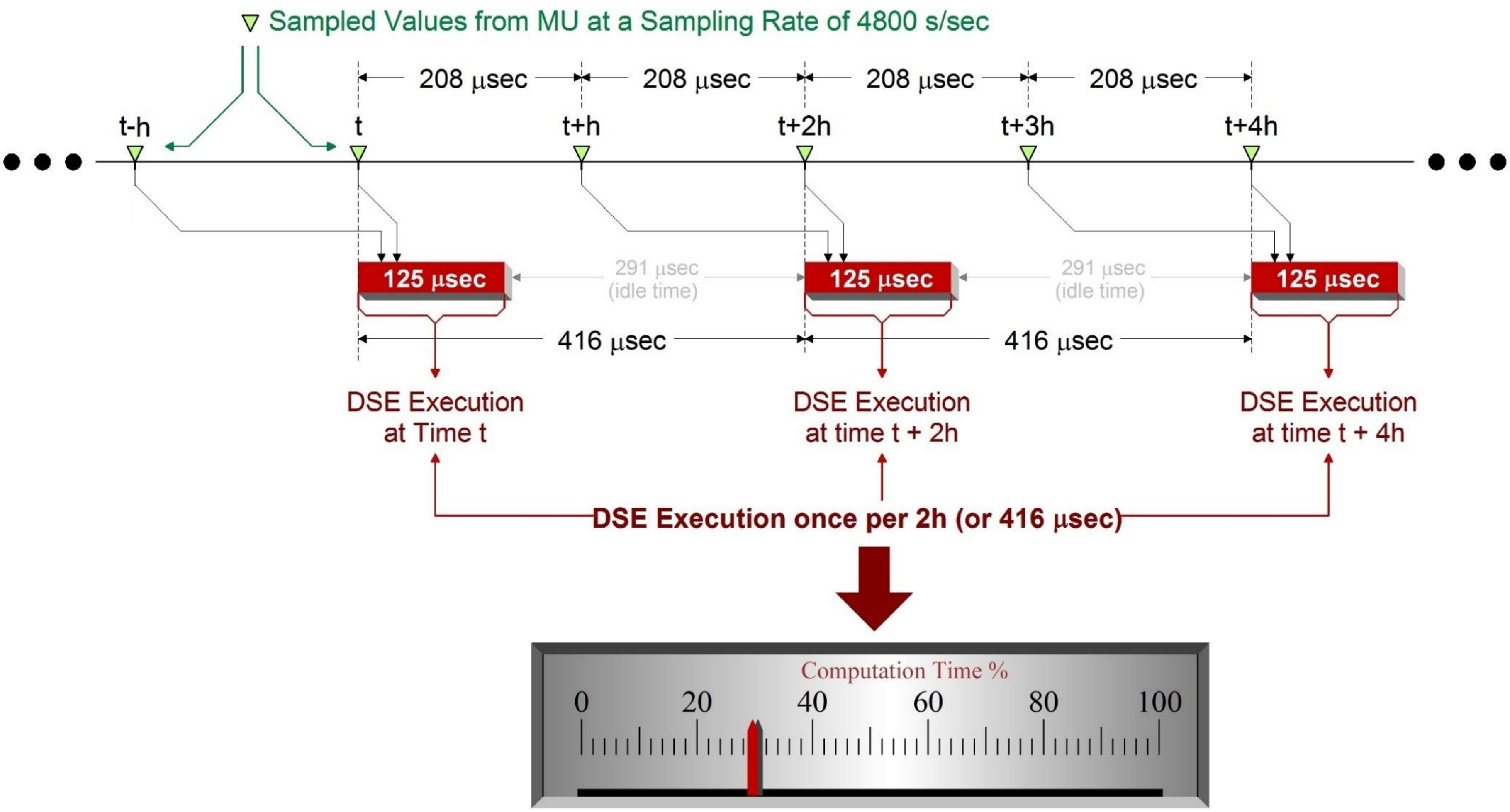
Reports
A variety of reports and visualizations

COMTRADE Data
Allows recorded data playback into the relay from a COMTRADE file

EBP Relay
Performs Dynamic State Estimation.
(3 user selected methods)

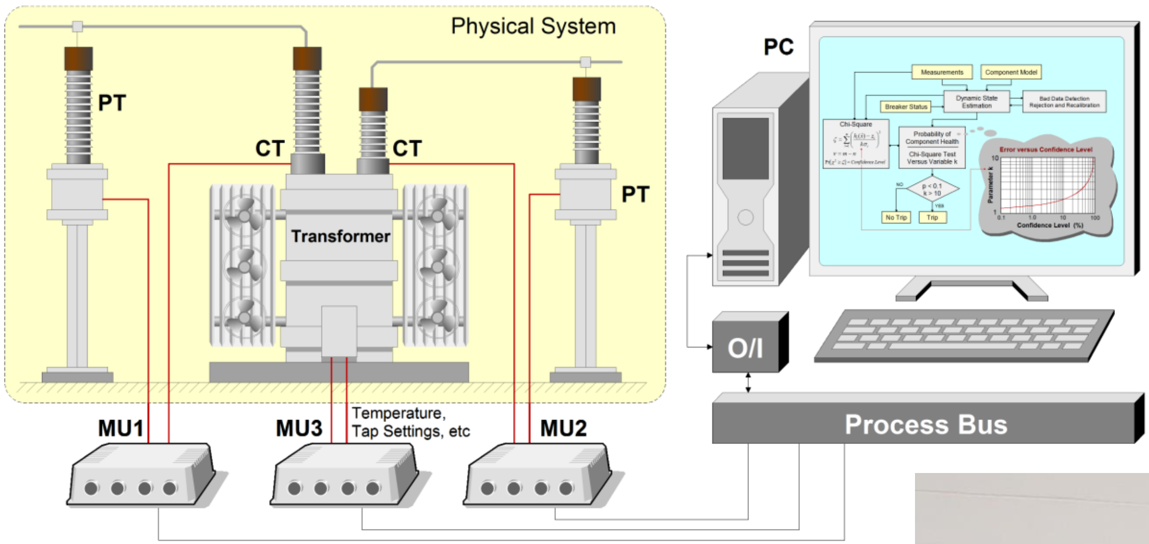
Execution Time Indicator
100% = Sampling Period

Dynamic State Estimation – Required Speed



$$\text{Computation Time} = \frac{125\ \mu\text{sec}}{416\ \mu\text{sec}} \times 100 = 30\ \%$$

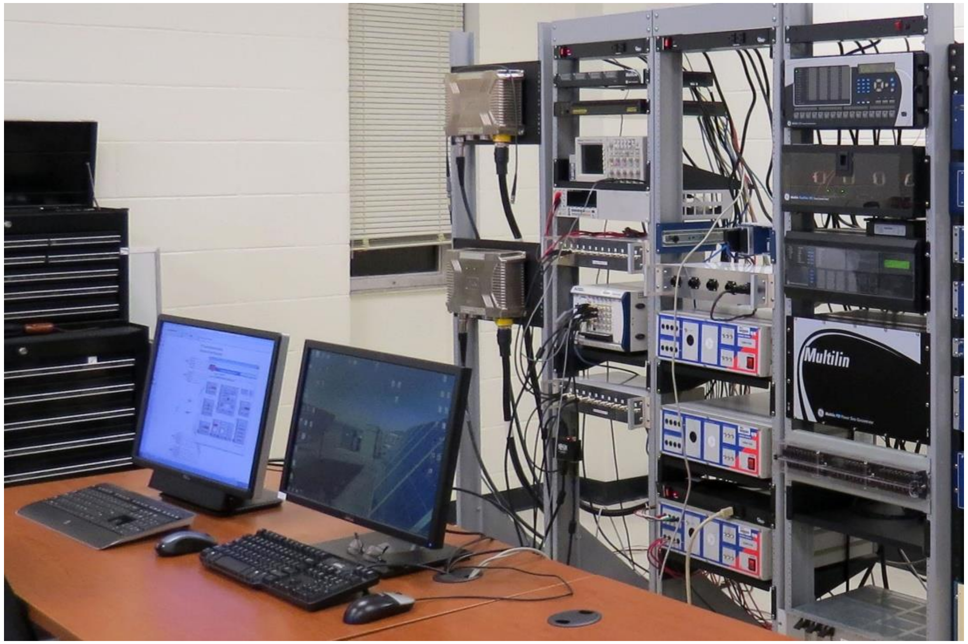
Laboratory Implementation



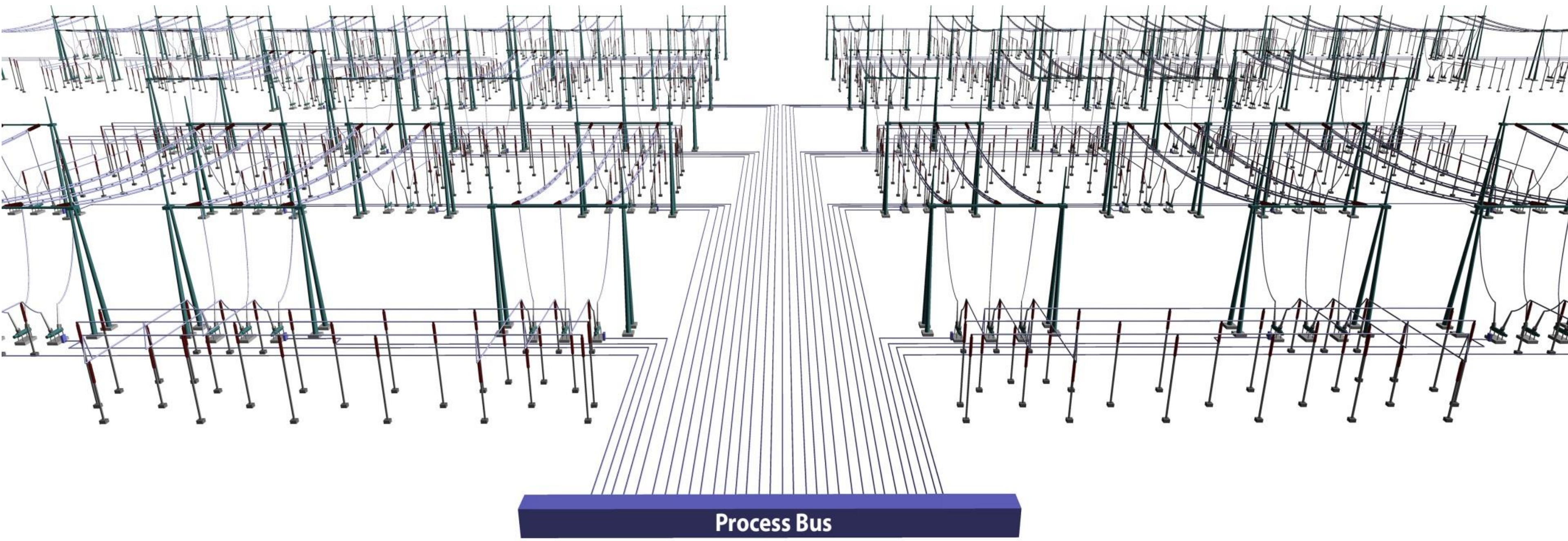
Experimental Setup Block Diagram

Experimental Setup

- Simulator / PC driven D/A Hardware (32 Chan.)
- Omicron Amplifiers (6)
- GE Hardfiber Merging Units (2)
- Reason MU (1)
- Siemens MU (2)
- Protection PC with Optical Network Interface & IRIG-B Receiver
- Arbiter GPS Clock with IRIG-B output

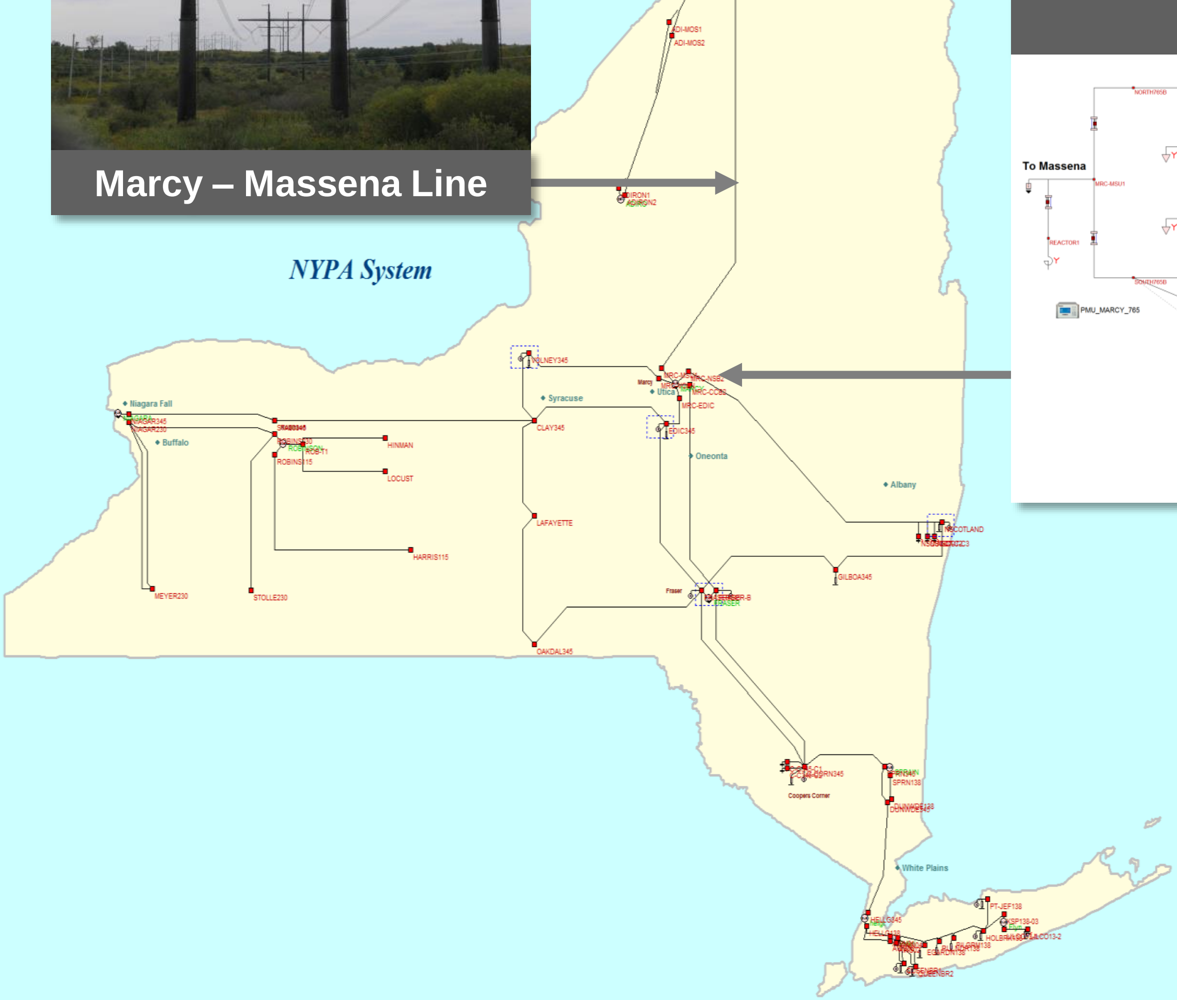


Planned Field Demonstrations

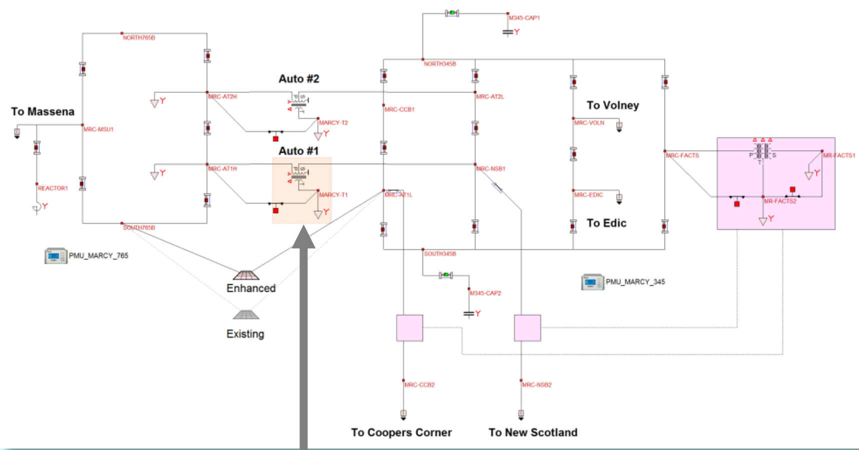


Field Demonstration on NYPA System

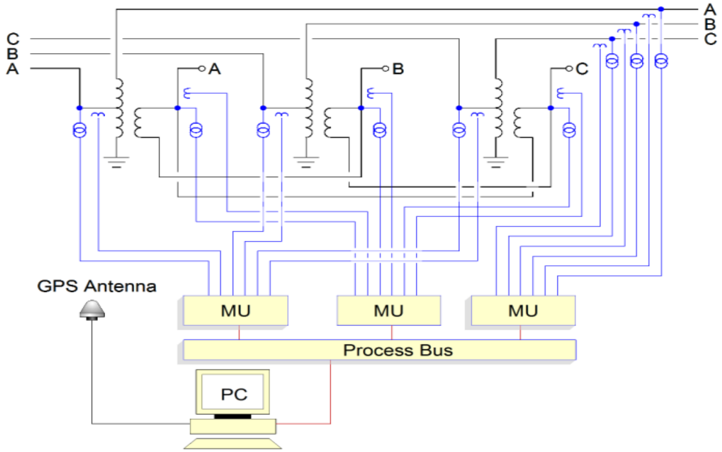
Marcy – Massena Line



Marcy Substation

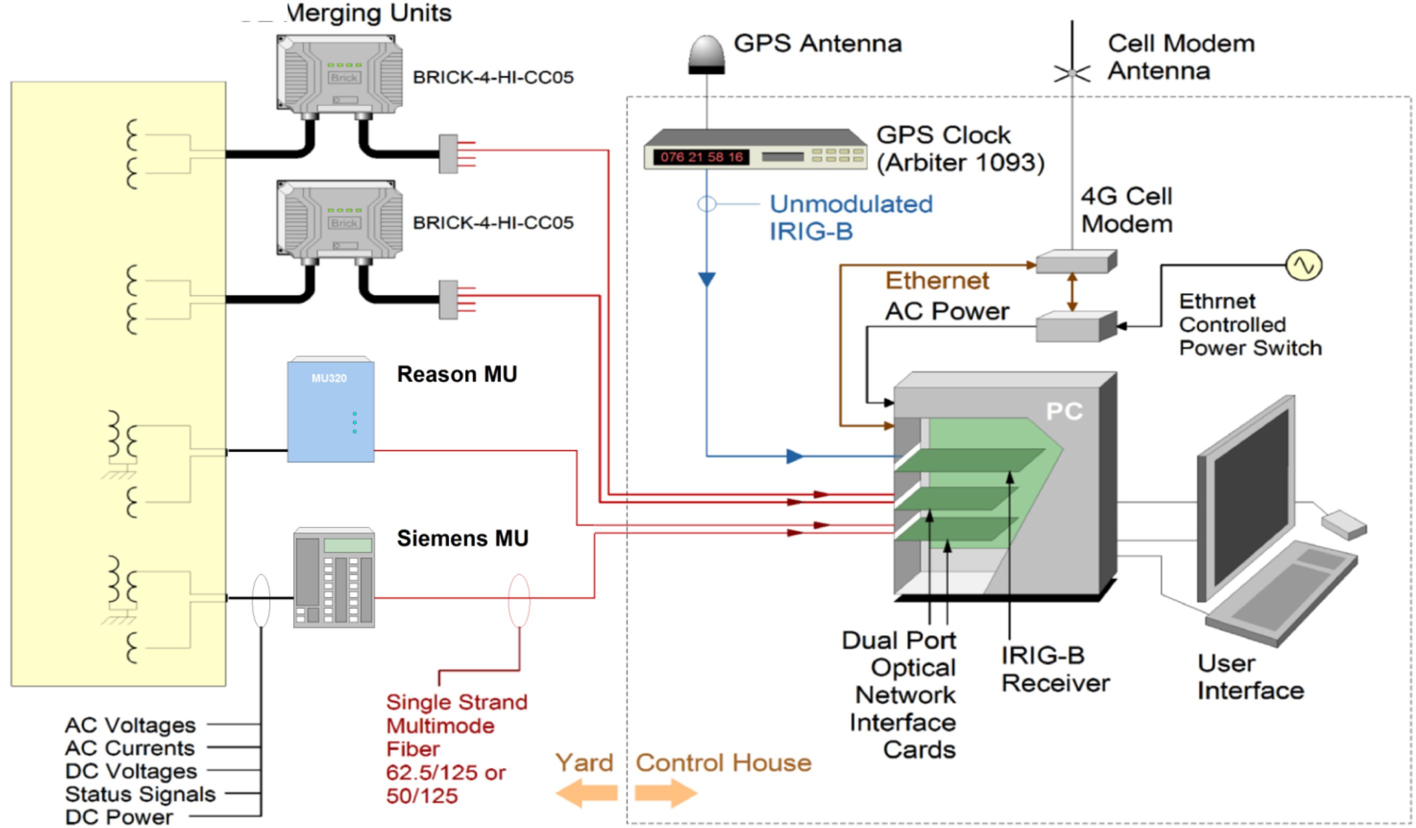


Monitored Transformer



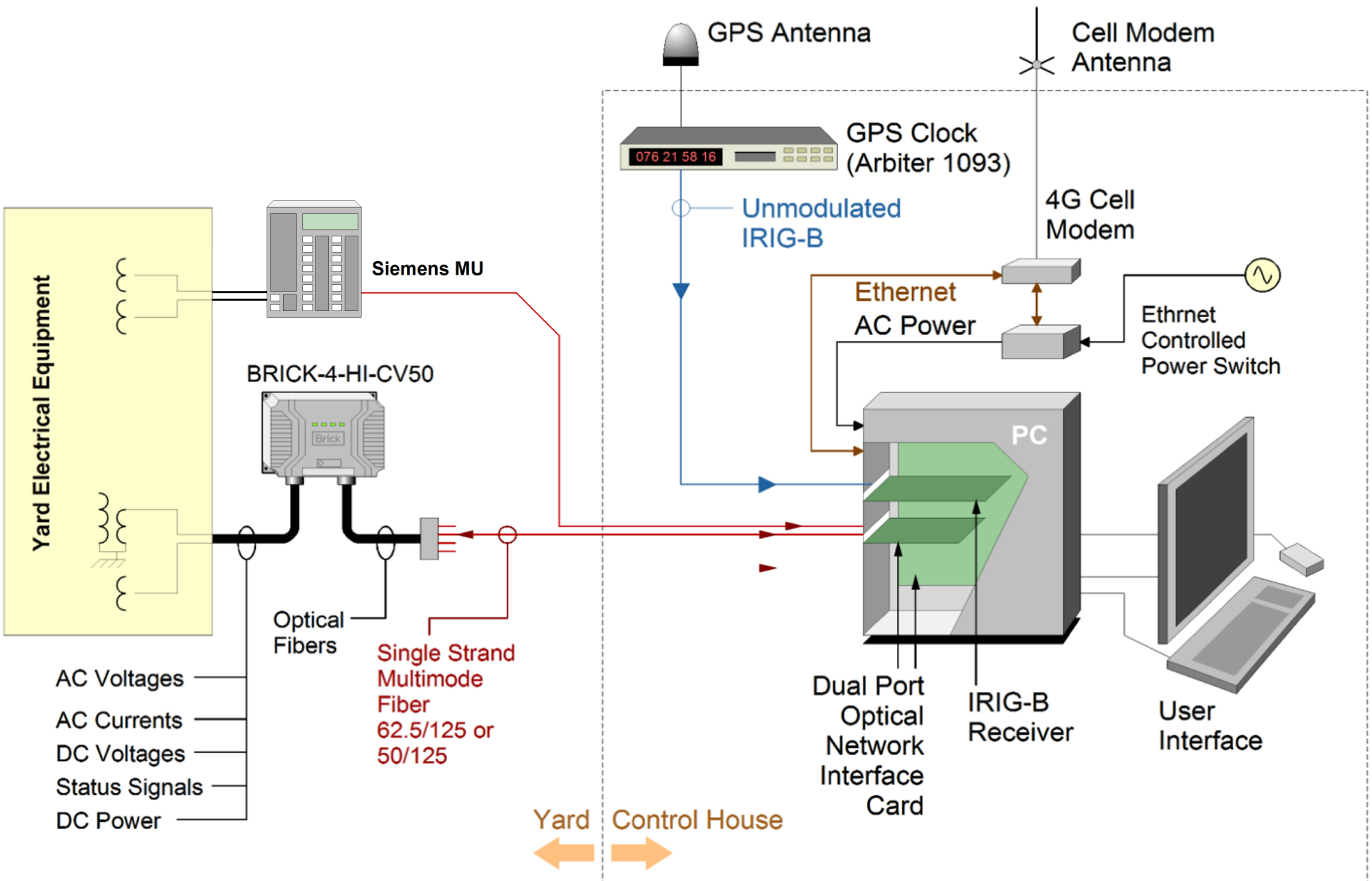
Conceptual Implementation on a 765/345/13.8 kV Autobank

Selected Hardware

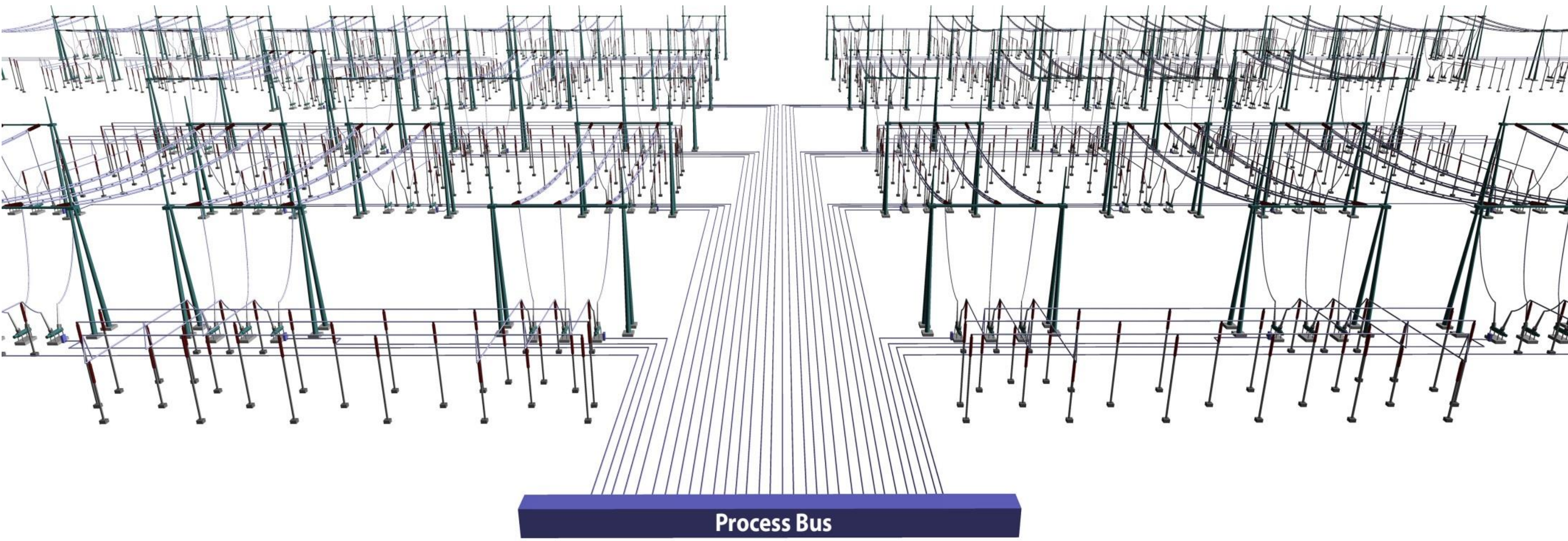


Conceptual Implementation on a 765 kV Line

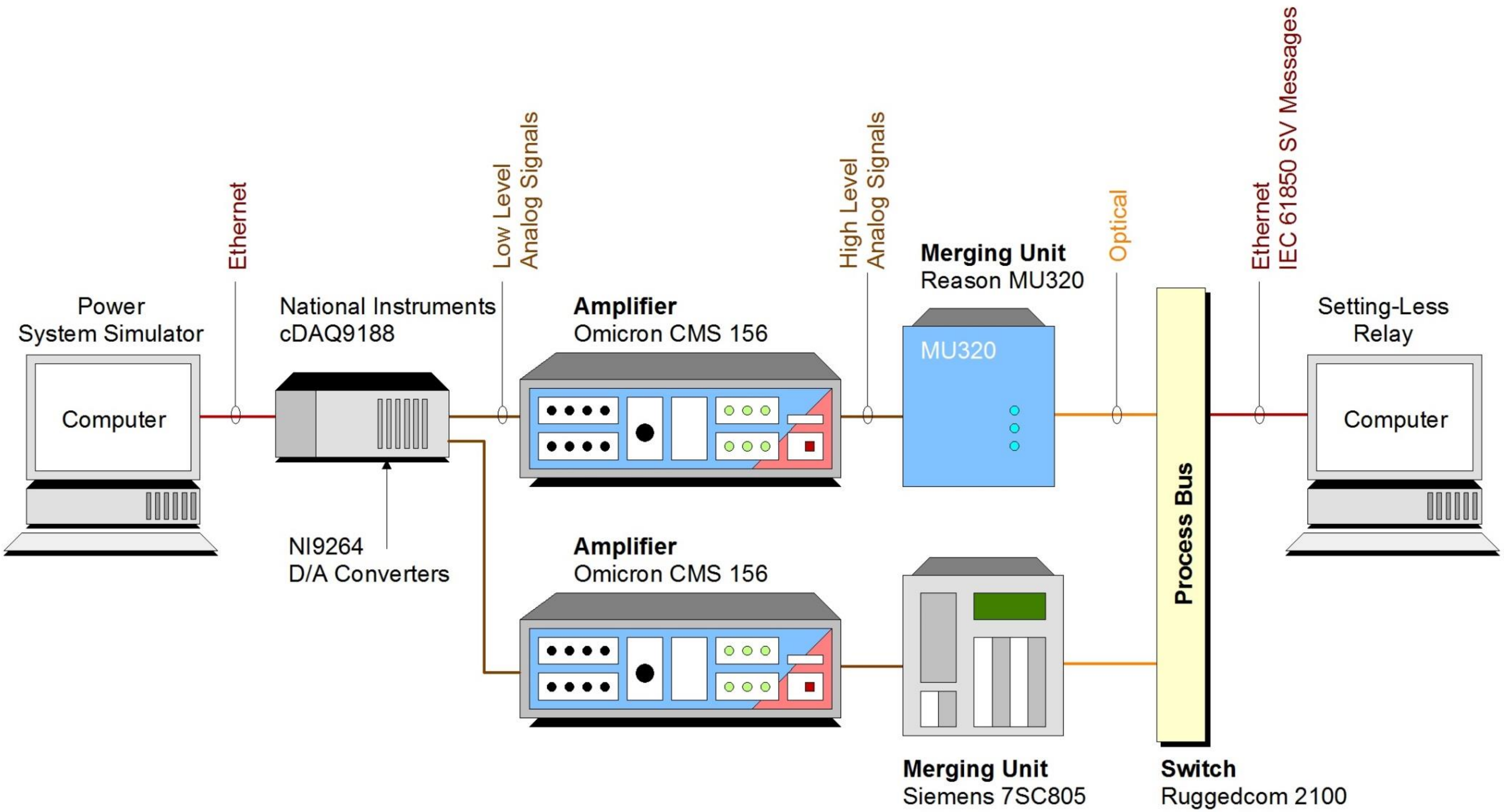
Selected Hardware



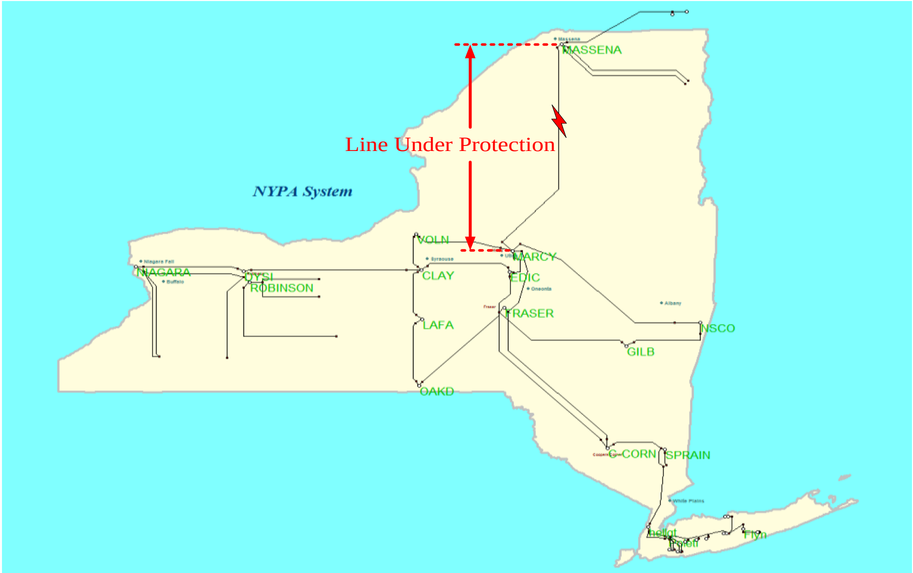
Setting-Less Protection MSU Line Testing



Laboratory Setup for Demonstration



MSU Line Internal Fault

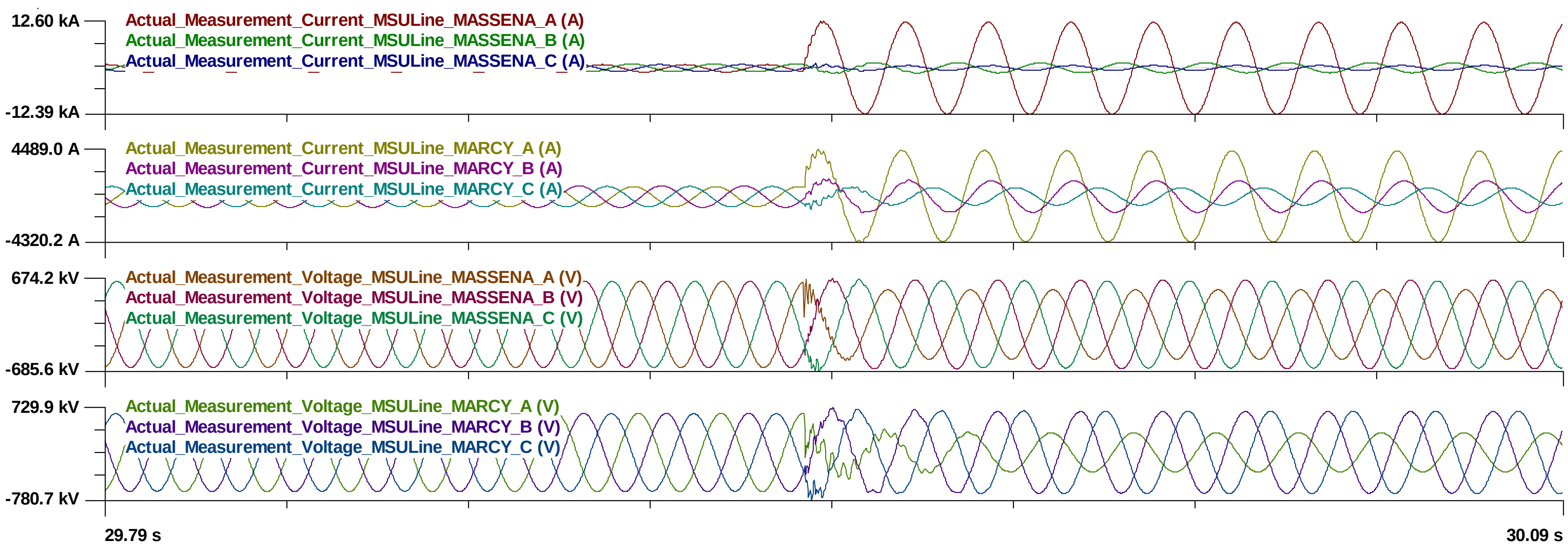


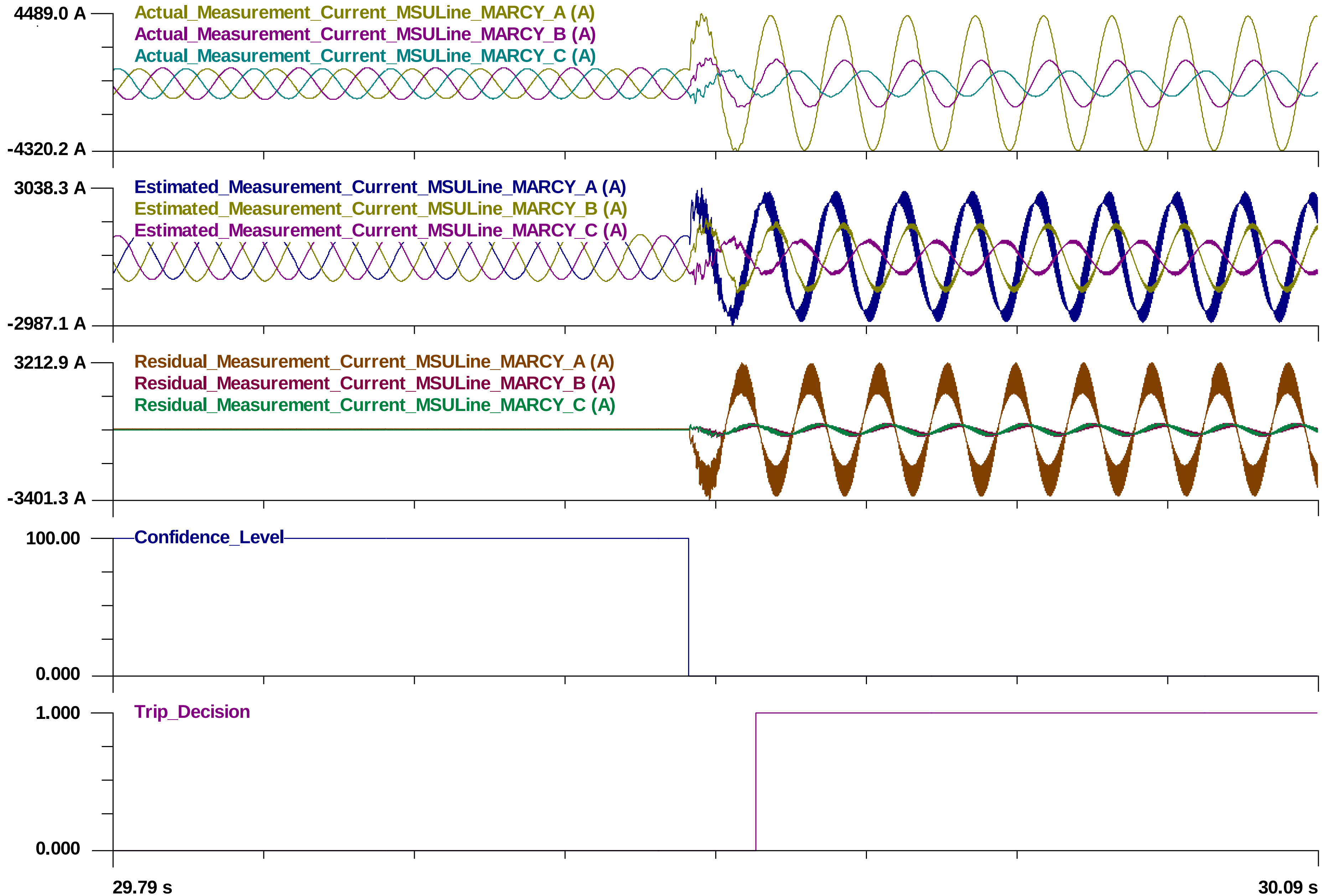
Fault Description

- Fault occurs at t = 29.94 s
- Phase A to Neutral fault
- 50 miles from MASSENA

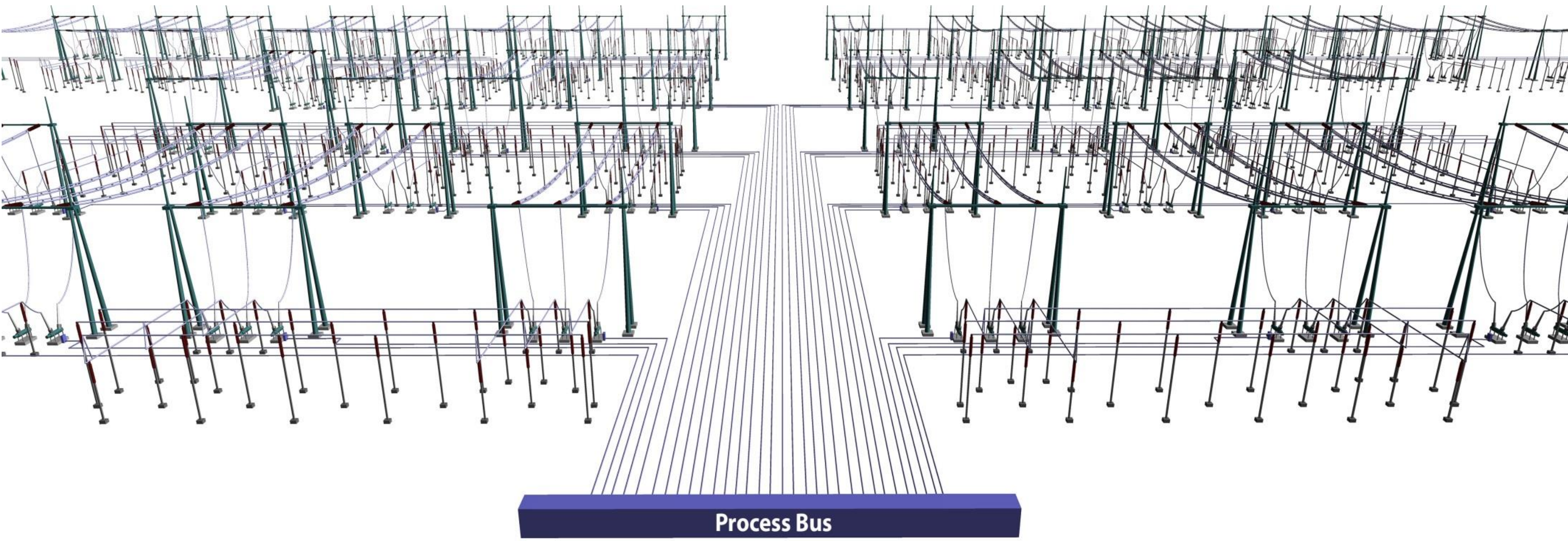
Measurements

- Three phase voltages and currents at both terminals of line

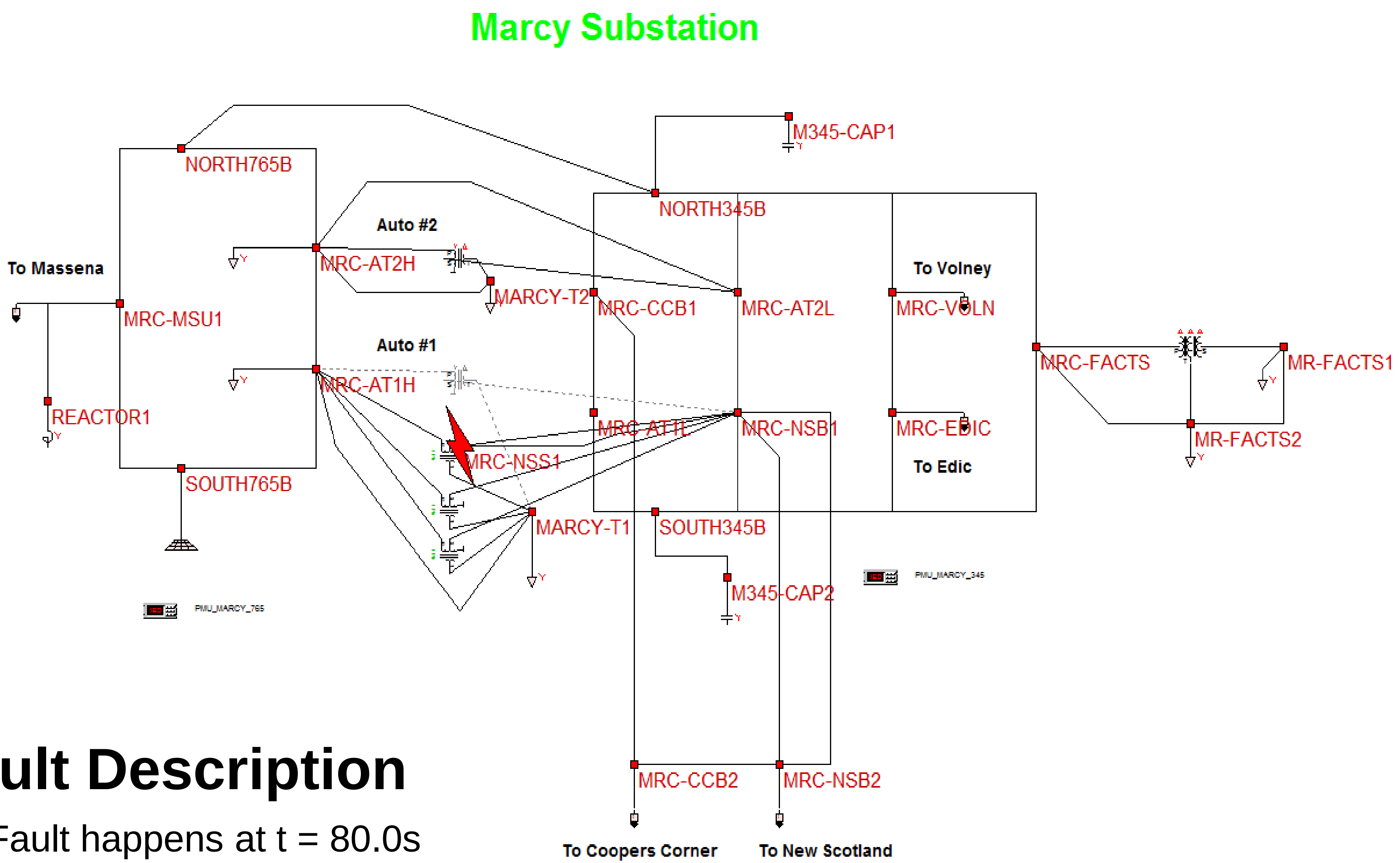



4489.0 A
-4320.2 A
Actual_Measurement_Current_MSULine_MARCY_A (A)
Actual_Measurement_Current_MSULine_MARCY_B (A)
Actual_Measurement_Current_MSULine_MARCY_C (A)
3038.3 A
-2987.1 A
Estimated_Measurement_Current_MSULine_MARCY_A (A)
Estimated_Measurement_Current_MSULine_MARCY_B (A)
Estimated_Measurement_Current_MSULine_MARCY_C (A)
3212.9 A
-3401.3 A
Residual_Measurement_Current_MSULine_MARCY_A (A)
Residual_Measurement_Current_MSULine_MARCY_B (A)
Residual_Measurement_Current_MSULine_MARCY_C (A)
100.00
0.000
Confidence_Level
1.000
0.000
Trip_Decision
29.79 s
30.09 s

Setting-Less Protection AutoBank 1 Testing



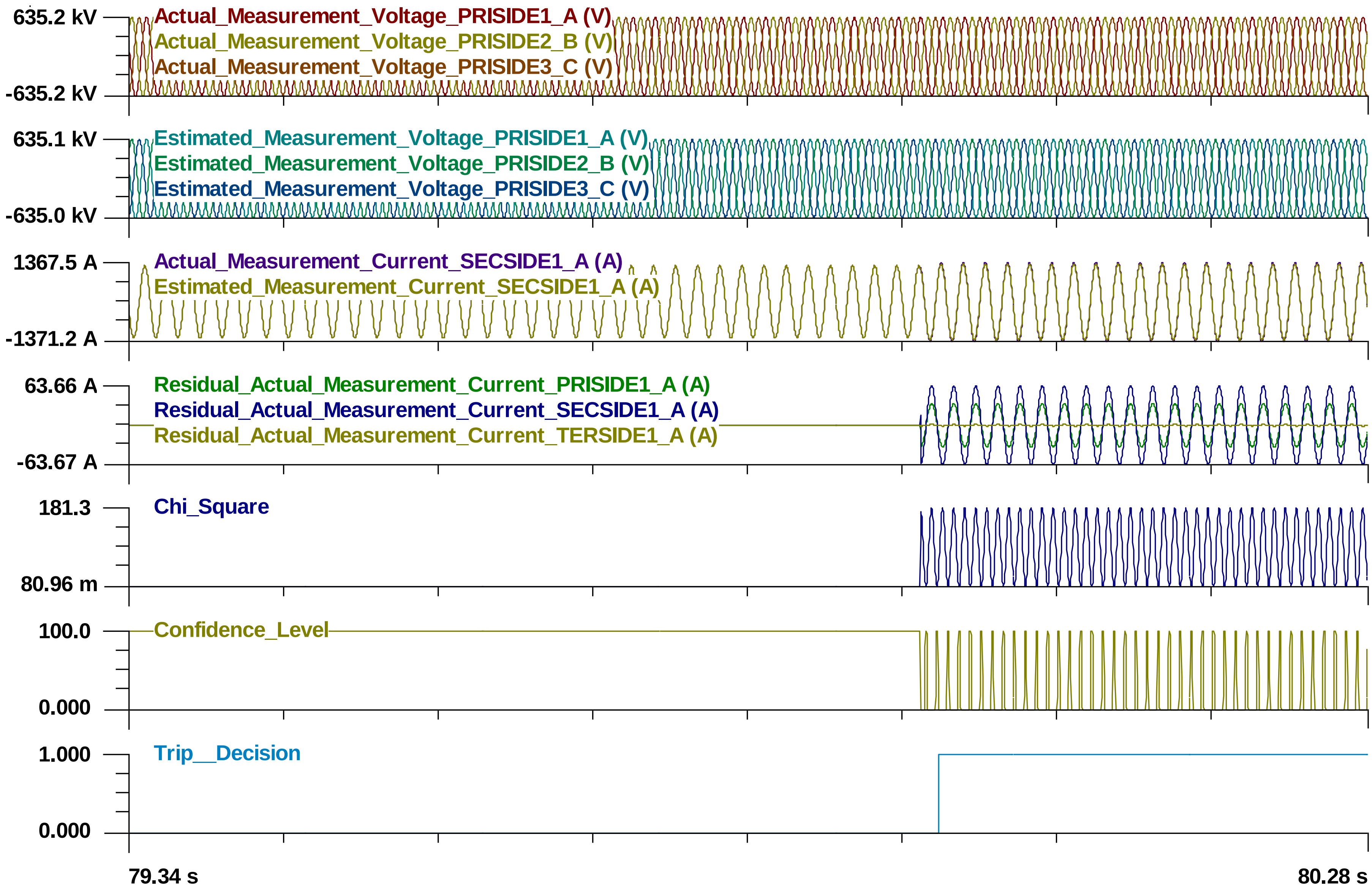
AutoBank Terminal High Impedance Fault



Fault Description

- Fault happens at t = 80.0s
- At secondary terminal phase A-N
- Fault impedance is 4k Ohms

AutoBank Terminal High Impedance Fault



Setting-Less Protection

New Method Based on Sampled Values

Sub-millisecond Fault Detection

Best Implementation with Merging Units

GPS Synchronization is a Requirement

Much more Sensitive than Legacy Methods

No Coordination Need with Other Functions

Acknowledgements

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Georgia Tech Power Systems Control & Automation Laboratory

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