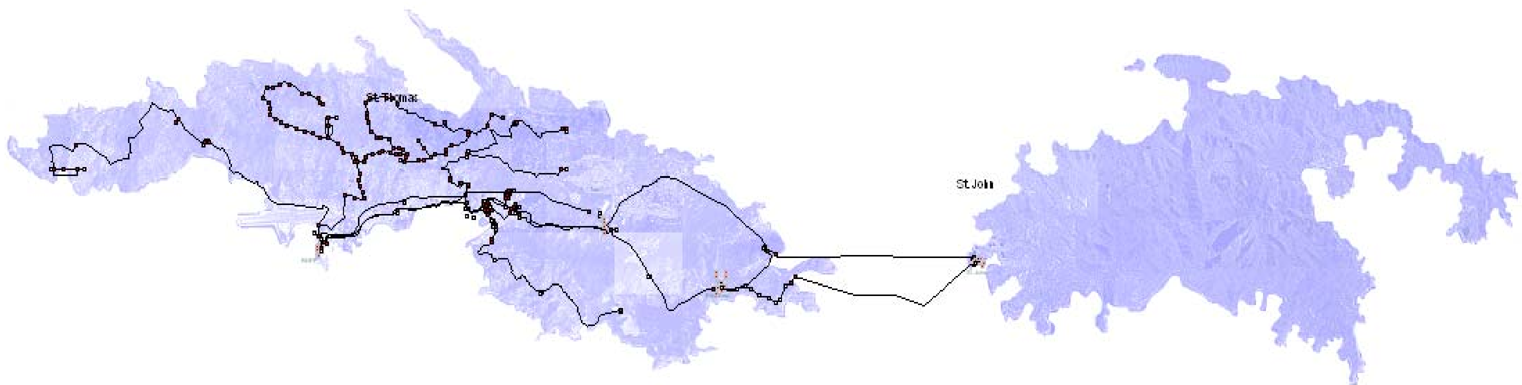
Distributed State Estimator at U.S. Virgin Islands Water and Power Authority St. Thomas and St. John



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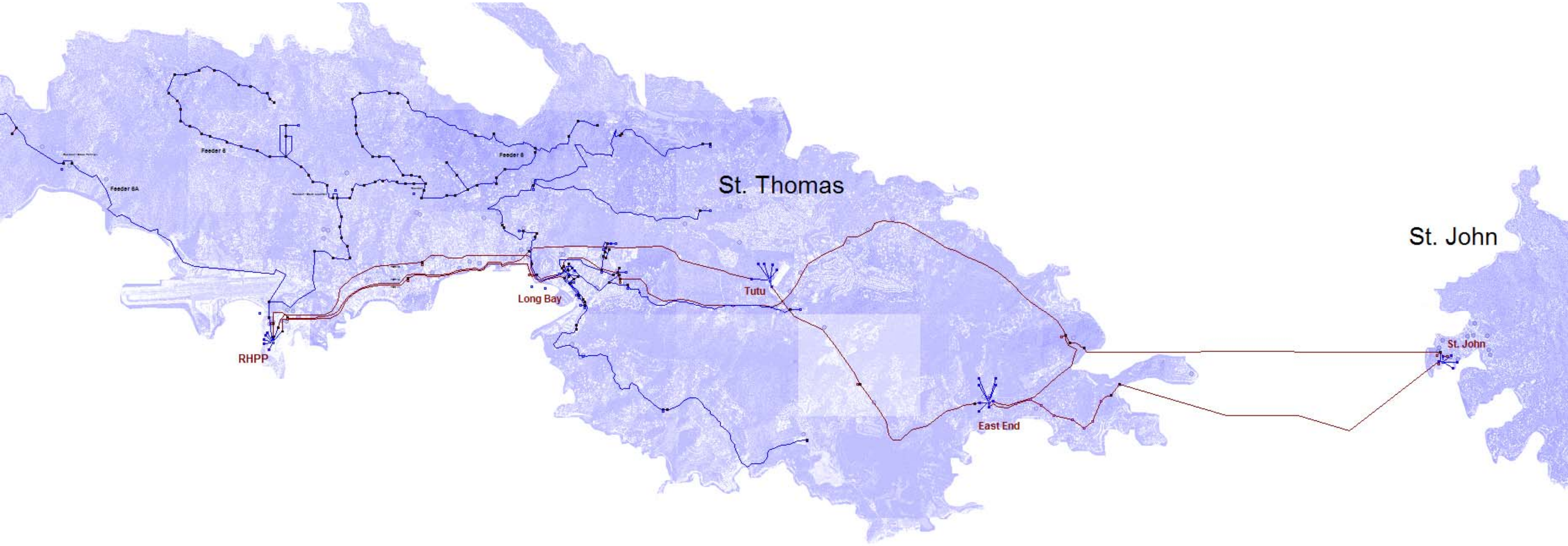
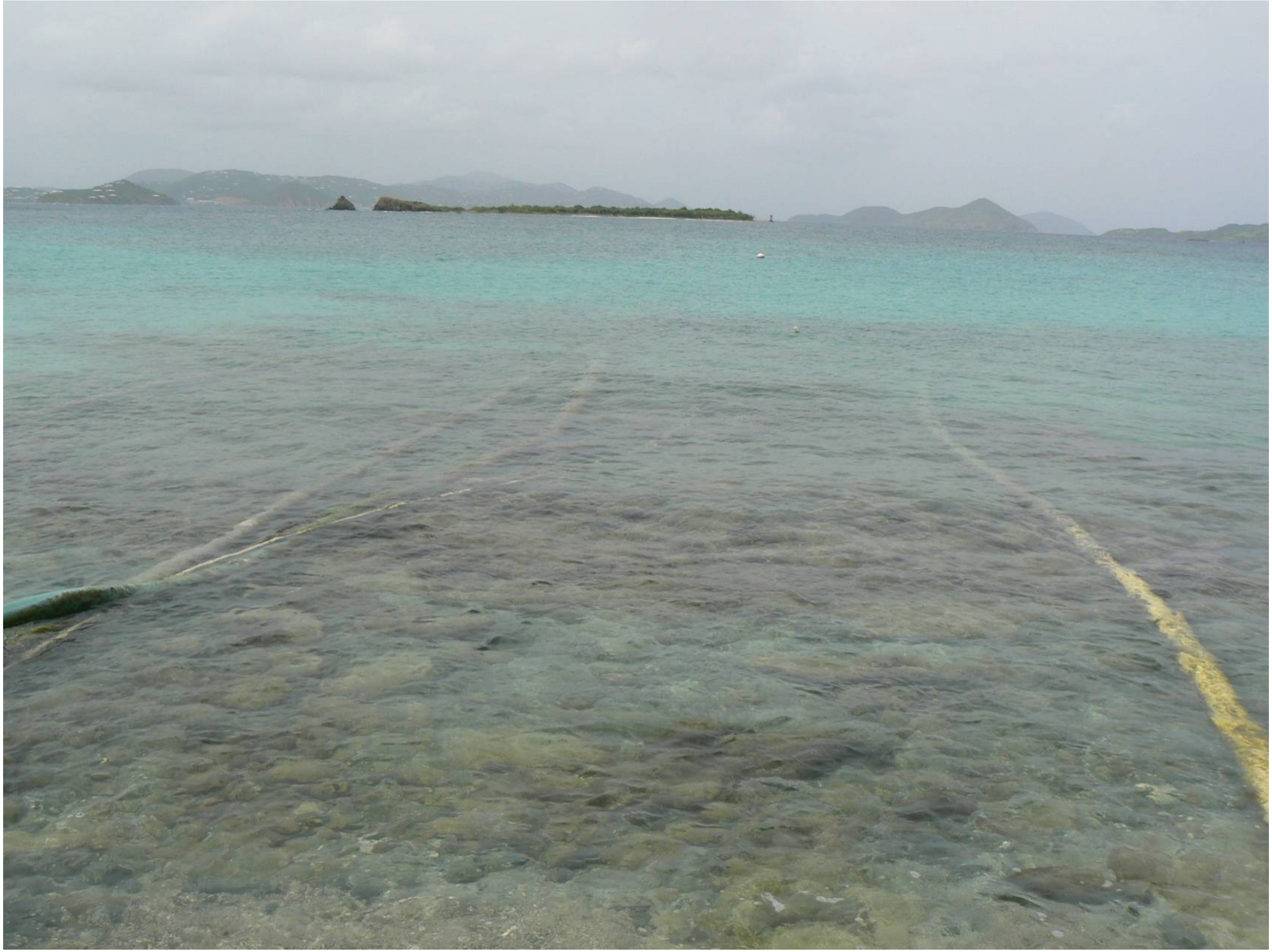
Outline

- Description of the VIWAPA System
- The SuperCalibrator Concept / Distributed State Estimation
- SuperCalibrator Implementation
- Future Plans / Demonstration
- Conclusions

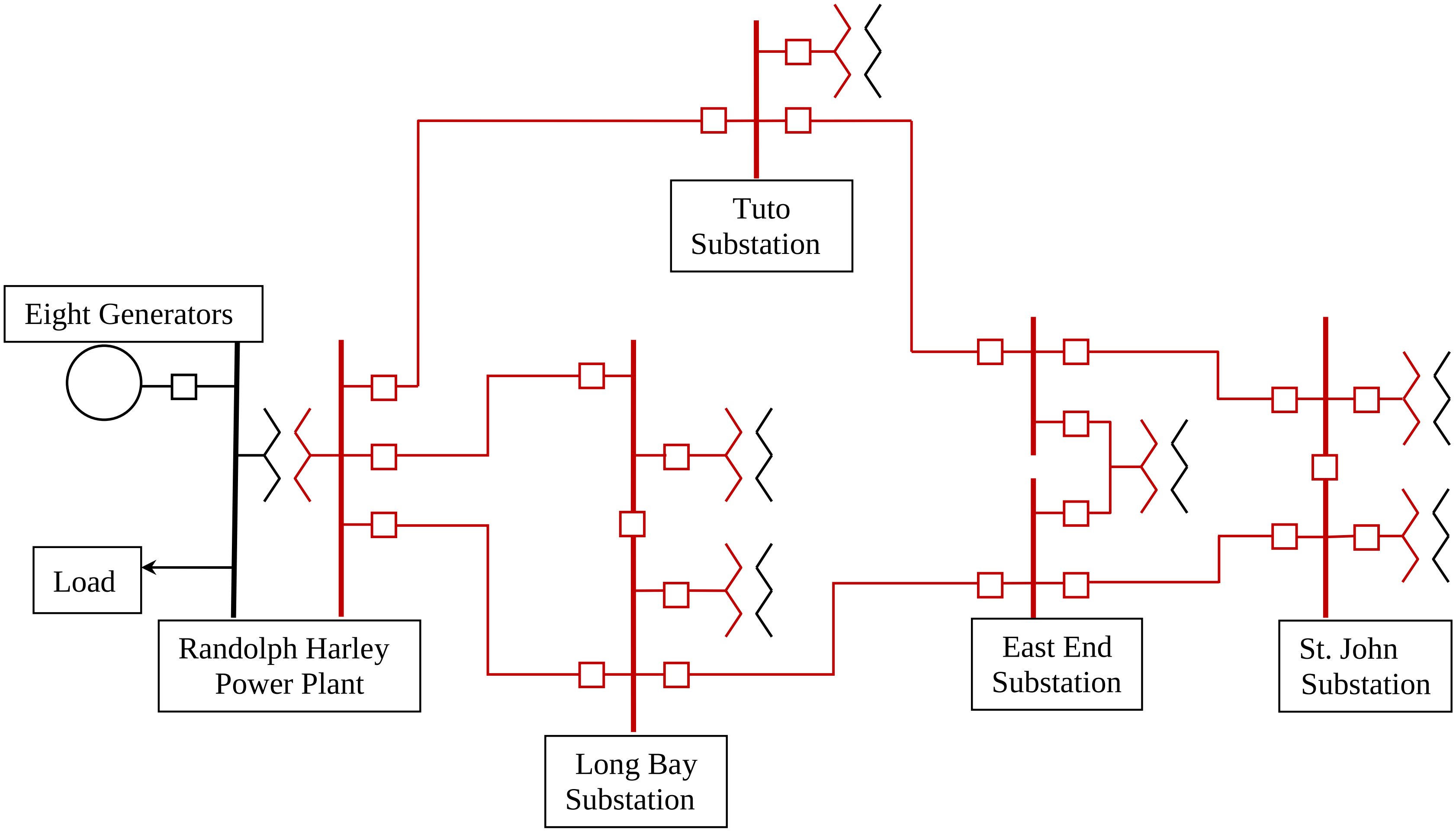
The VIWAPA System

- Single Generating Plant (Randolph Harley Power Plant)
- Five Substations (RHPPlant, Long Bay, Tutu, East End, St. John)
- 34.5 kV Transmission
- 13.8 kV Distribution





St. Thomas to St. John Water Line



Simplified VIWAPA 34.5 kV Single Line

Randolph Harley Power Plant

Randolph Harley Power Plant
Outdoor Substation

Long Bay Substation

Long Bay Substation Transformers

Long Bay Substation Switchgear Room

Long Bay Substation
Control Room

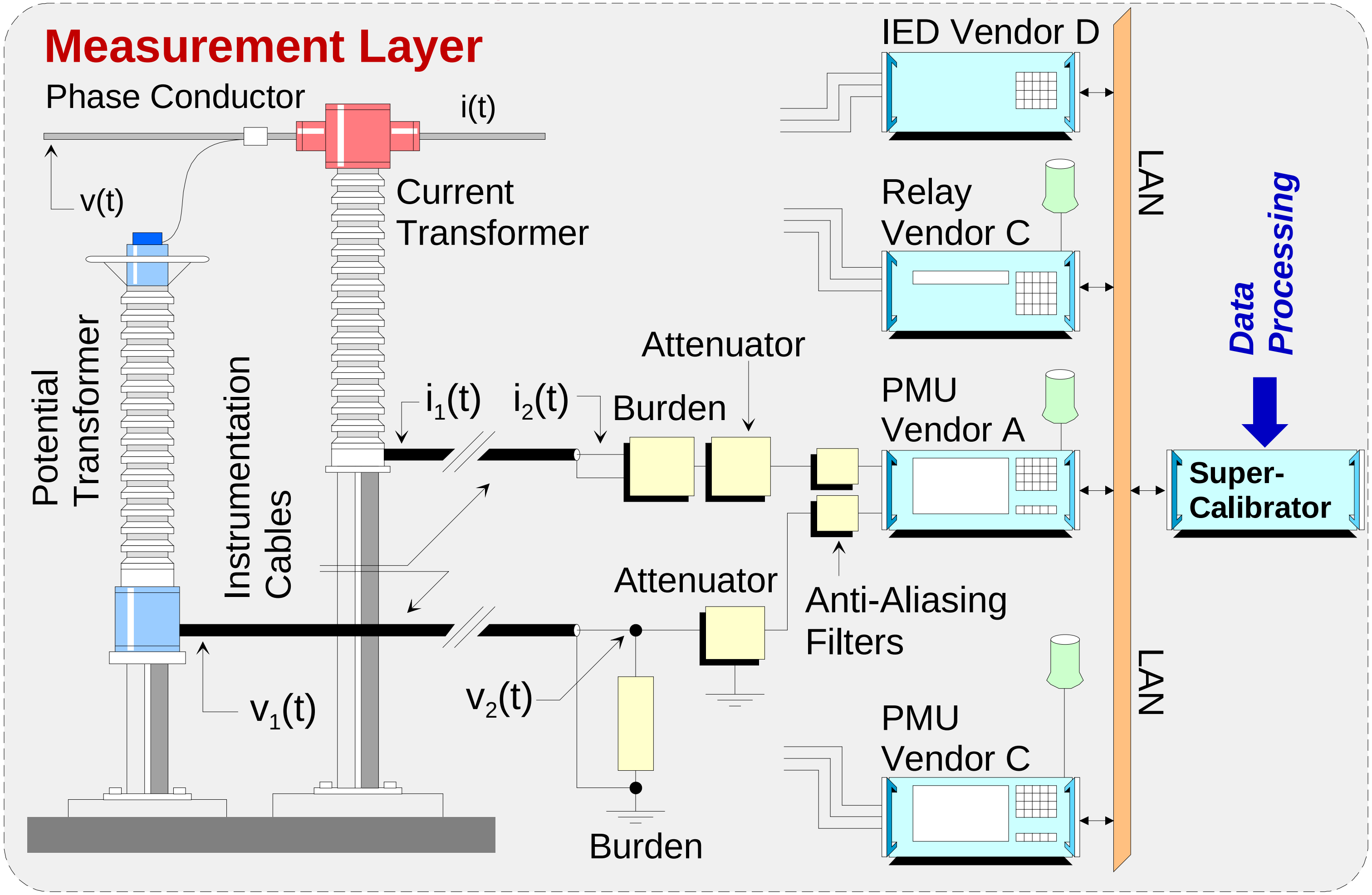
Long Bay Substation
Typical Relay Panel

The SuperCalibrator Concept

The SuperCalibrator is conceptually very simple. The basic idea is to provide a model based error correction of substation data and in particular RELAY DATA. The SuperCalibrator is facilitated by the substation automation technology that makes all substation data readily accessible at a common point. The basic idea is to utilize a detailed model of the substation, (three-phase, breaker-oriented model, instrumentation channel inclusive and data acquisition model inclusive). Then all substation data obtained with any device, PMU, meter, relay, SCADA, etc. is expressed as a function of the state of the detailed substation model. An estimation algorithm determines the best estimate of the substation model state.

GPS Synchronized Relays Make the Process Robust and the Results Globally Valid

The SuperCalibrator Concept



- Three-Phase, Breaker-Oriented, Instrumentation Channel Inclusive Model
- Utilization of All Data Available in the Substation (Relays, Meters, Tap Controller, etc.)
- Static State Estimator at the Substation Level (See Additional Slides)

SuperCalibrator Implementation

Substation Equipment

All five substation equipped with:

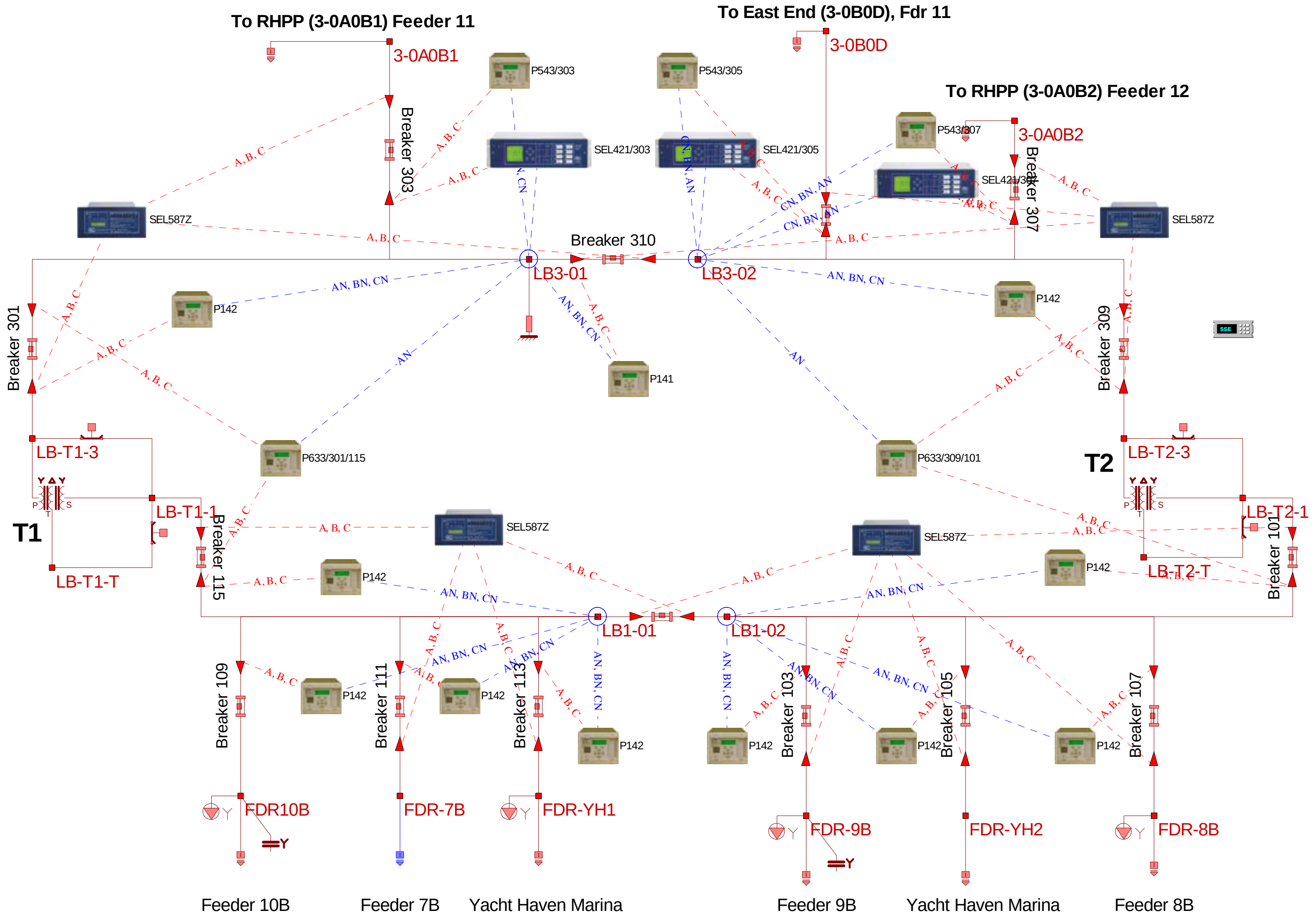
- Digital relays (SEL, Areva)
- GPS Clock
- Data Concentrator PC
- Local Area Network (Ruggedcom)

Communication Protocols Used (Relays to Data Concentrator):

- DNP3
- MODBUS/TCP
- IEEE C37.118

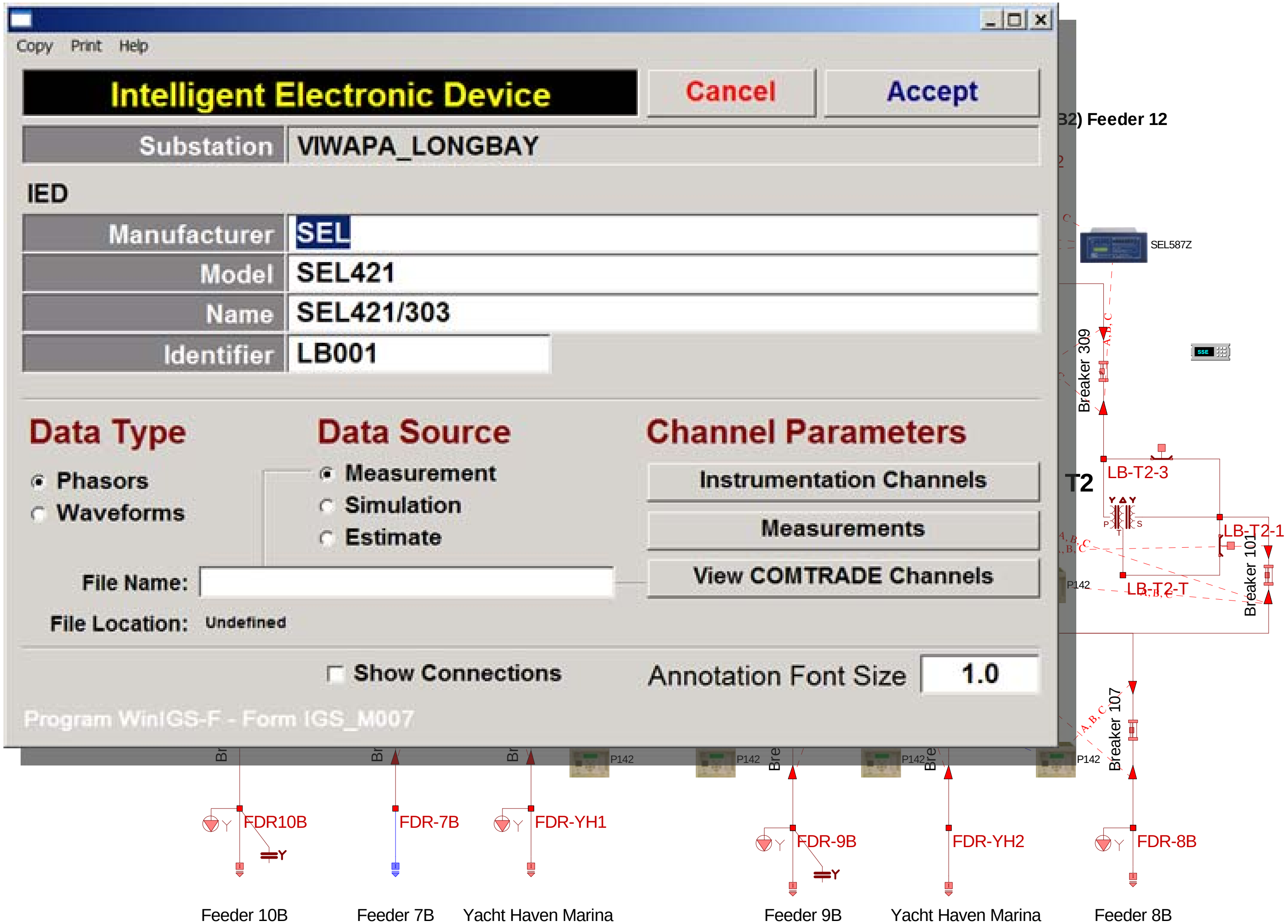
SuperCalibrator Implementation

Substation Configuration – Long Bay



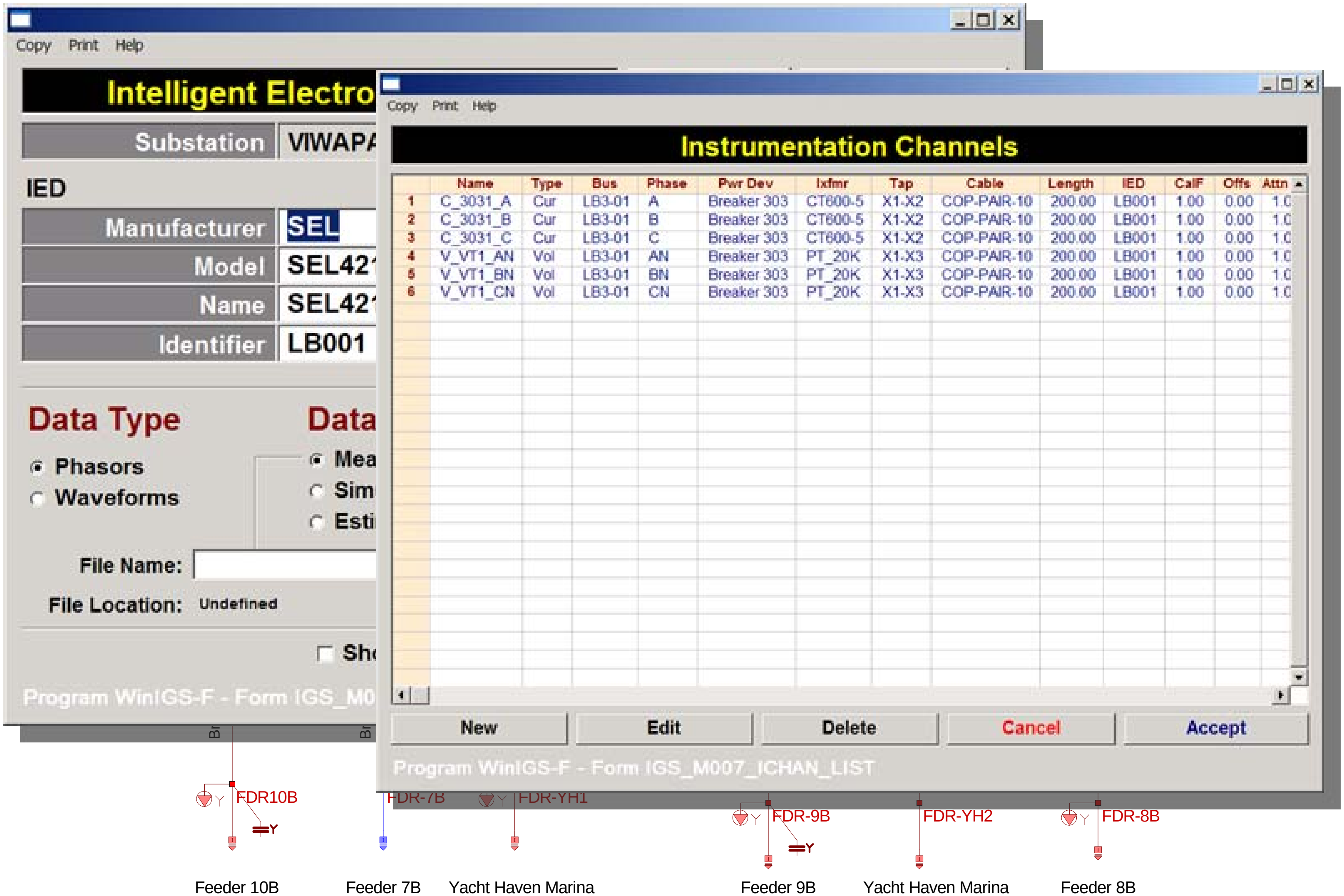
SuperCalibrator Implementation

Substation Configuration – Long Bay



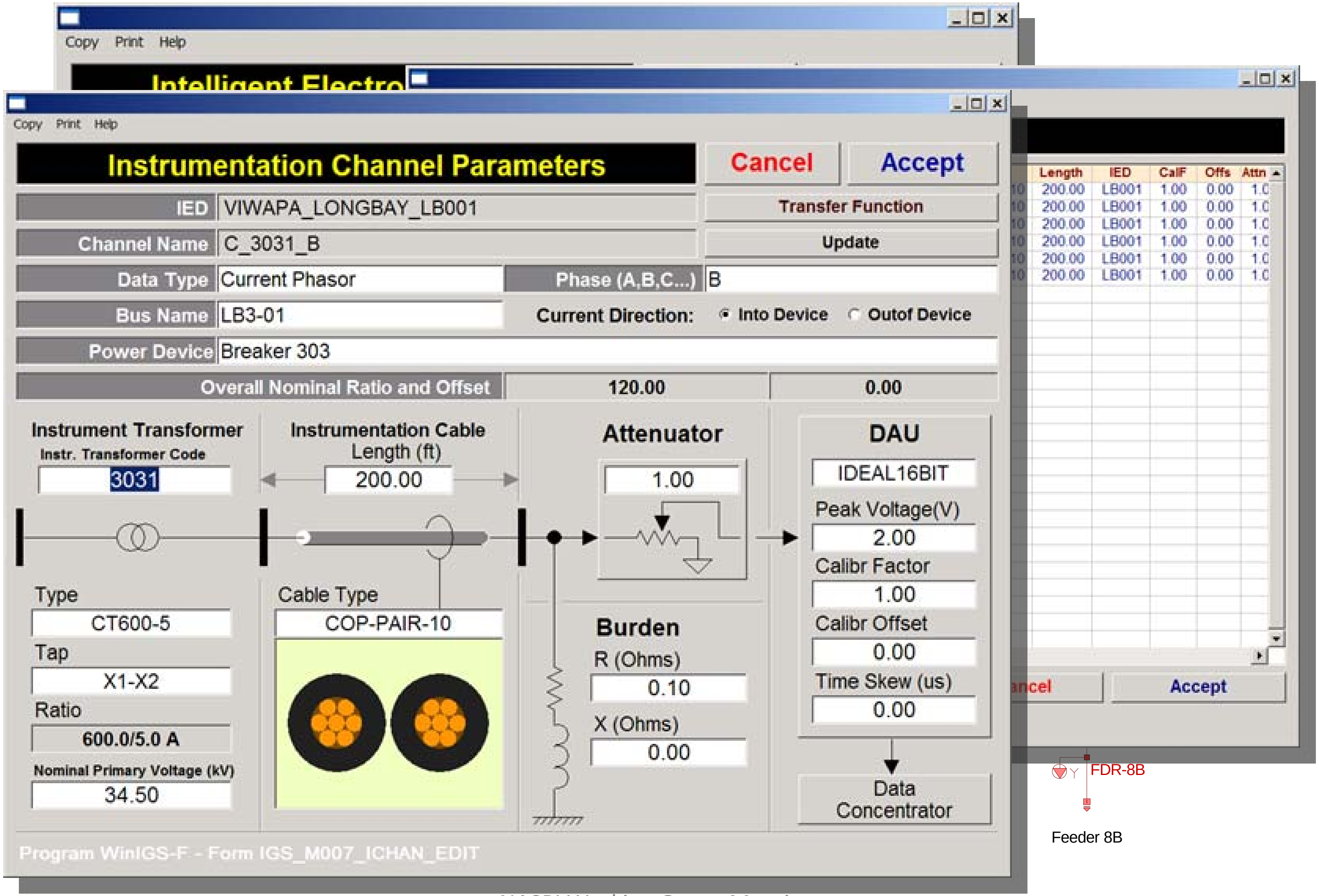
SuperCalibrator Implementation

Substation Configuration – Long Bay



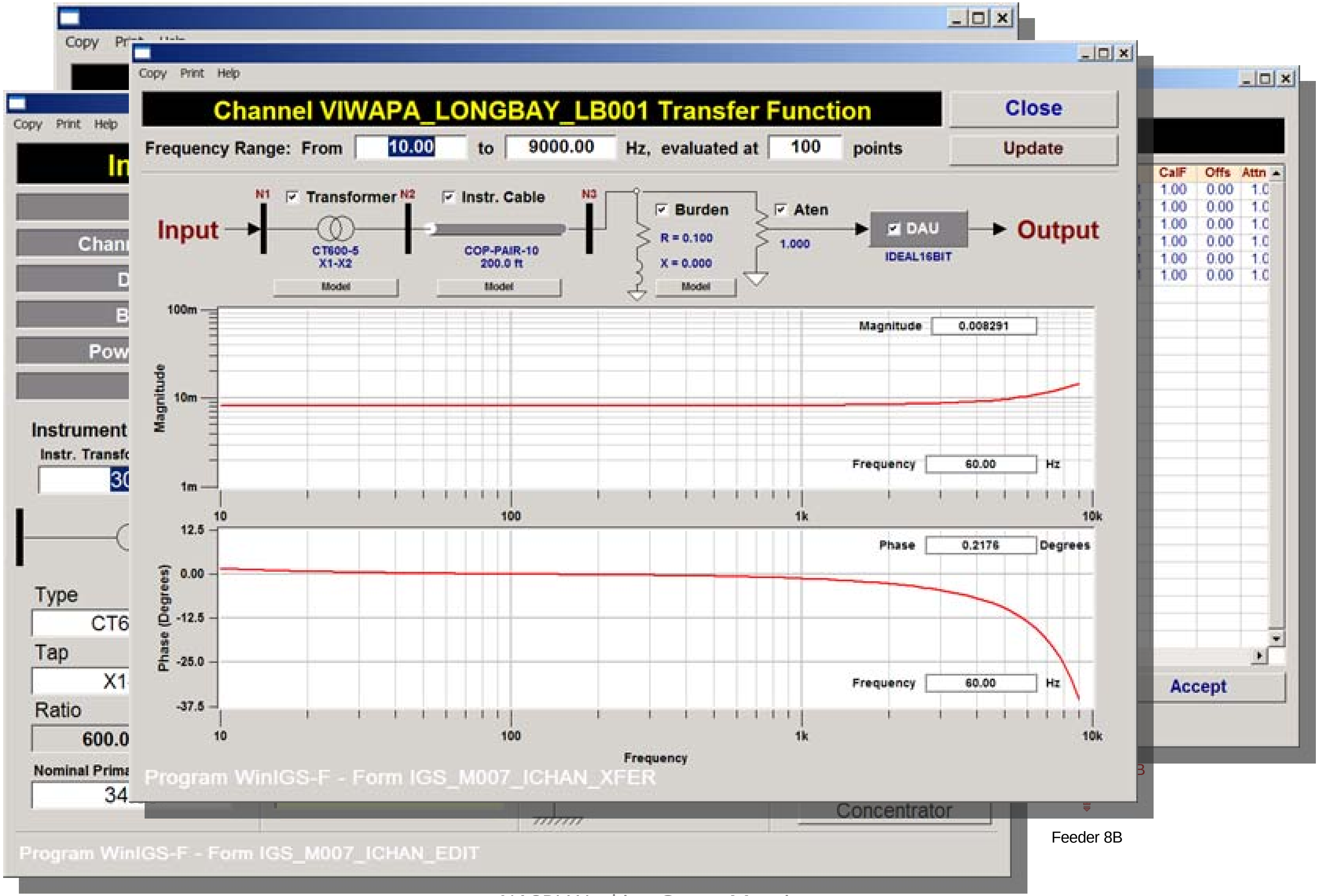
SuperCalibrator Implementation

Substation Configuration – Long Bay

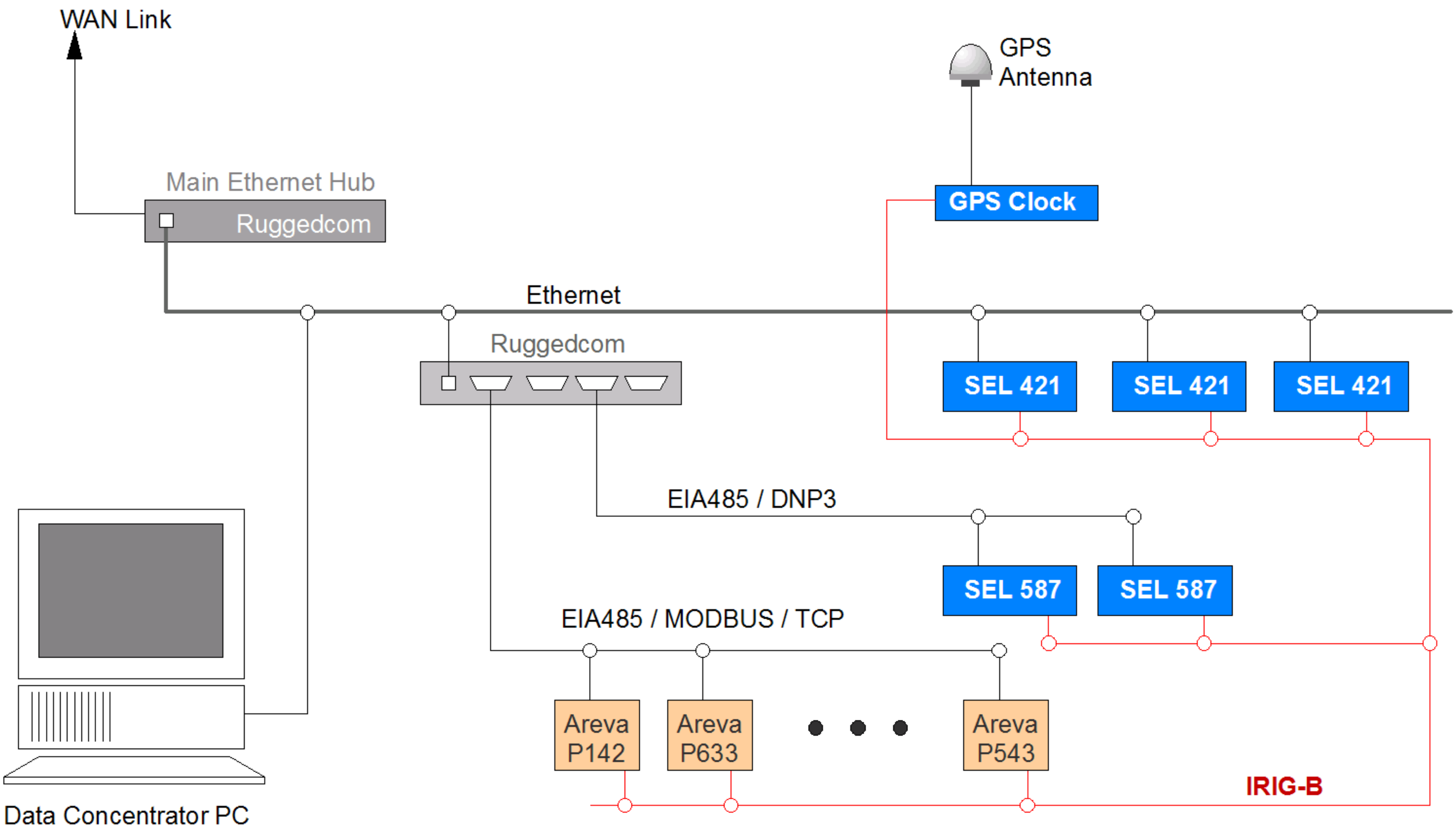


SuperCalibrator Implementation

Substation Configuration – Long Bay

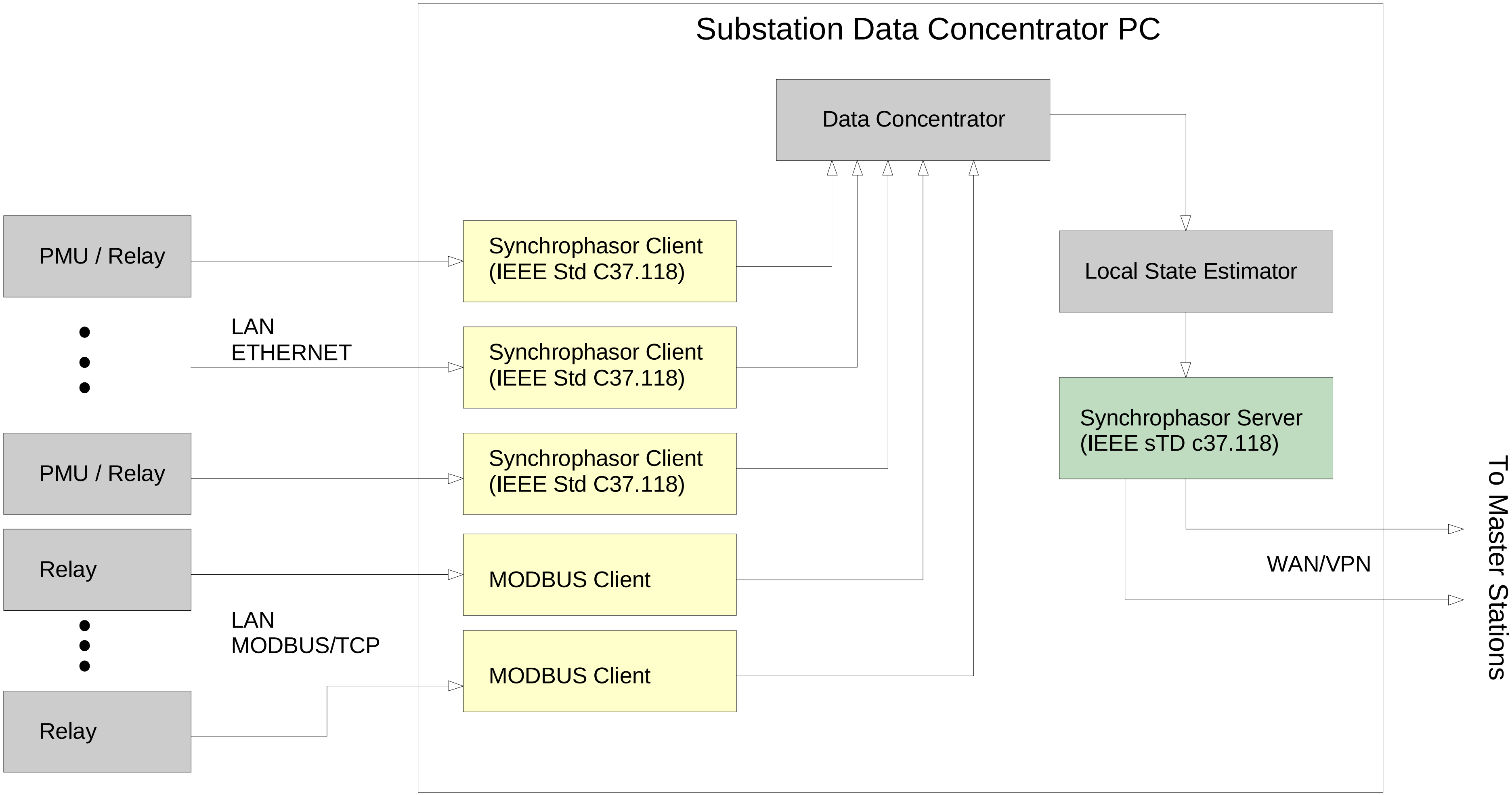


SuperCalibrator Implementation
Communications Hardware Setup – Long Bay



SuperCalibrator Implementation

Substation Data Concentrator - Organization



SuperCalibrator Approach
Static State Estimator Model

The Estimator is Defined in Terms of:

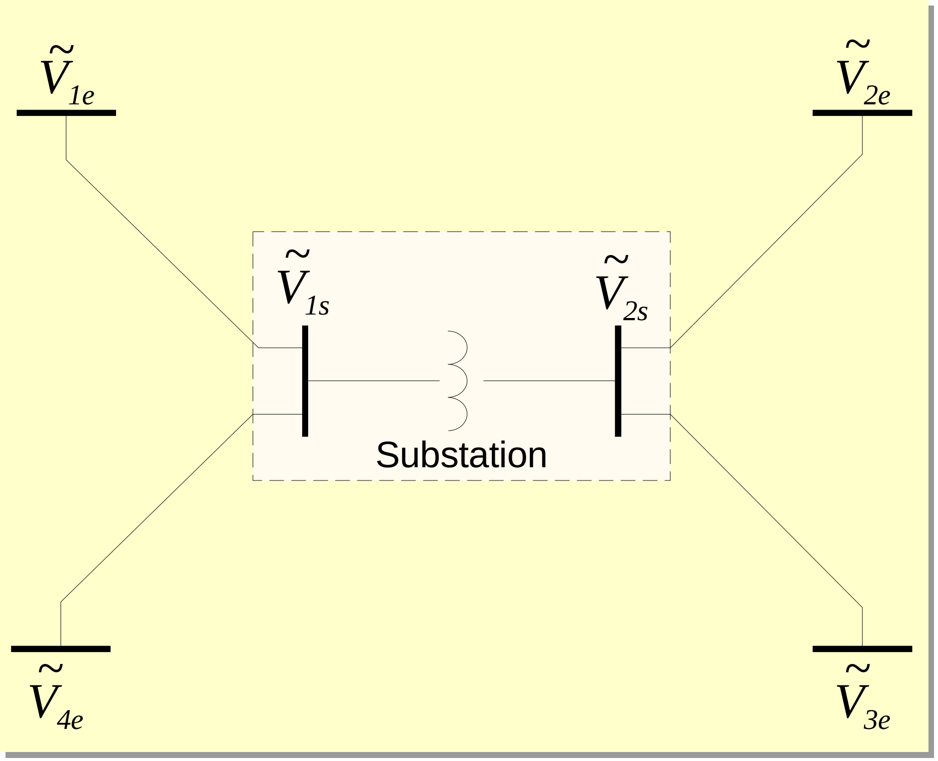
- Model (Model Fidelity Impacts SE Performance)
- State
- Measurement Set
- Estimation Method

SuperCalibrator Power System State

Definition of Substation Based System State

Substation State

$$\tilde{V}_{1s} = \begin{bmatrix} \tilde{V}_{1s,a} \\ \tilde{V}_{1s,b} \\ \tilde{V}_{1s,c} \\ \tilde{V}_{1s,n} \end{bmatrix} \qquad \tilde{V}_{2s} = \begin{bmatrix} \tilde{V}_{2s,a} \\ \tilde{V}_{2s,b} \\ \tilde{V}_{2s,c} \\ \tilde{V}_{2s,n} \end{bmatrix}$$



Extended Substation State

$$\tilde{V}_{1e} = \begin{bmatrix} \tilde{V}_{1e,a} \\ \tilde{V}_{1e,b} \\ \tilde{V}_{1e,c} \\ \tilde{V}_{1e,n} \end{bmatrix} \qquad \tilde{V}_{2e} = \begin{bmatrix} \tilde{V}_{2e,a} \\ \tilde{V}_{2e,b} \\ \tilde{V}_{2e,c} \\ \tilde{V}_{2e,n} \end{bmatrix} \qquad \tilde{V}_{3e} = \begin{bmatrix} \tilde{V}_{3e,a} \\ V_{3e,b} \\ \tilde{V}_{3e,c} \\ \tilde{V}_{3e,n} \end{bmatrix} \qquad \tilde{V}_{4e} = \begin{bmatrix} \tilde{V}_{4e,a} \\ \tilde{V}_{4e,b} \\ \tilde{V}_{4e,c} \\ \tilde{V}_{4e,n} \end{bmatrix}$$

SuperCalibrator Measurement Set

- Any Measurement at the Substation from Any IED
  (Relays, Meters, FDR, PMUs, etc.)

- Data From at Least one GPS-Synchronized Device

- Pseudo-Measurements
  Kirchoff's Current Law
  Remote End State Measurement
  Missing Phase Measurements
  Neutral/Shield Current Measurement
  Neutral Voltage

SuperCalibrator Measurement Set:
Missing Phase Measurements

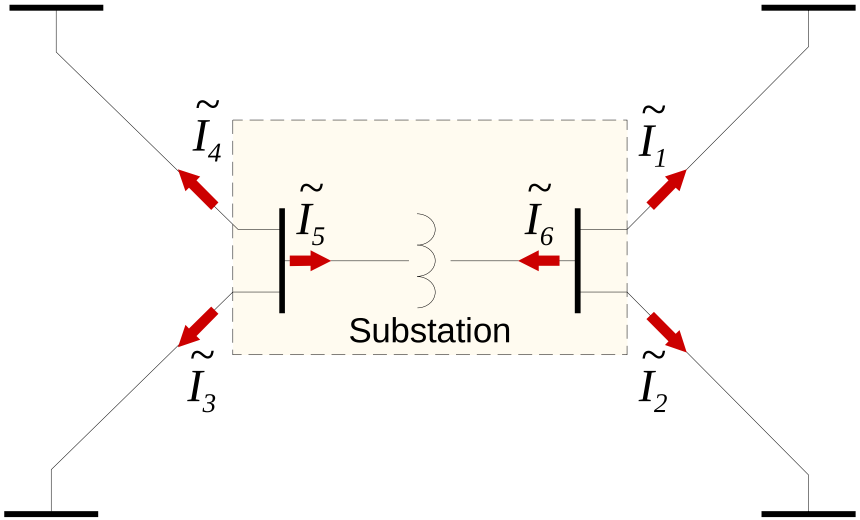
Assume There is a Phase A Voltage Phasor Measurement.
Assume there is no Phase C Measurement.

THEN:

$$\tilde{V}_{s/n}^{pseudo,m} - \tilde{V}_a e^{-j240^0} = 0$$

Expected Error: Less than 3%

SuperCalibrator Measurement Set:
Kirchoff's Current Law



$$\tilde{I}_1 + \tilde{I}_2 + \tilde{I}_6 = 0$$

Expected Error: 0.001%

$$k_1\left(\tilde{I}_3 + \tilde{I}_4\right) + k_2\left(\tilde{I}_1 + \tilde{I}_2\right) + \tilde{I}_m = 0$$

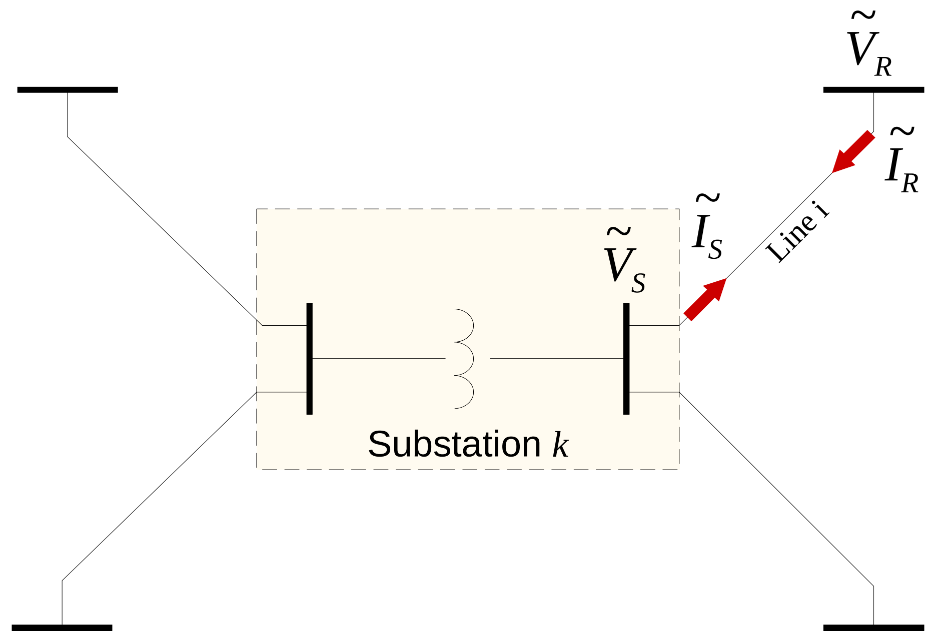
Expected Error: 0.001%

SuperCalibrator Measurement Set:

Remote End State Measurement

Line i Equations

$$\begin{bmatrix} \tilde{I}_S \\ \tilde{I}_R \end{bmatrix} = \begin{bmatrix} Y_{11} & Y_{12} \\ Y_{21} & Y_{22} \end{bmatrix} \begin{bmatrix} \tilde{V}_S \\ \tilde{V}_R \end{bmatrix}$$



Solve for V at remote end

$$\tilde{V}_R^{pseudo,m} = \left(\mathbf{I} - Z_{22}Y_{22}\right)^{-1} Z_{21}\tilde{I}_S + \left(\mathbf{I} - Z_{22}Y_{22}\right)^{-1} Z_{22}Y_{21}\tilde{V}_S$$

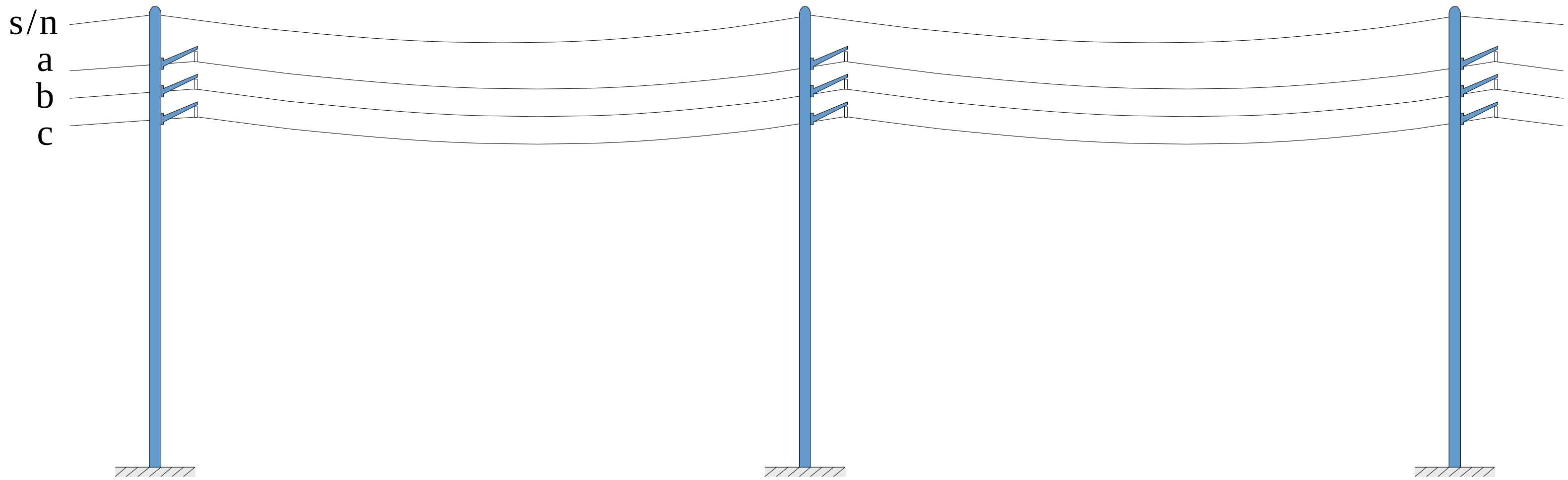
Expected Error: 0.01%

Where:

$$\begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix} = \begin{bmatrix} Y_{11} & Y_{12} \\ Y_{21} & Y_{22} \end{bmatrix}^{-1}$$

SuperCalibrator Measurement Set:

Neutral/Shield Current



$$\alpha = \frac{\tilde{I}_{s/n}}{-\left(\tilde{I}_a + \tilde{I}_b + \tilde{I}_c\right)}$$

$$\tilde{I}_{s/n}^{pseudo,m} + \alpha\left(\tilde{I}_a + \tilde{I}_b + \tilde{I}_c\right) = 0$$

Expected Error: 0.01%

Summary and Future Work

- The SuperCalibrator Provides a Fully Distributed and Scalable State Estimator. Accurately Accounts for:
  1. System Asymmetries,
  2. Voltage Imbalance,
  3. Instrumentation Channel Error.

- The SuperCalibrator Approach Requires at Least One GPS-Synchronized Device in Each Substation.

- The SuperCalibrator Is Being Implemented VIWAPA.

- Demonstration Has Been Scheduled for May 5-6, 2008.

PMU Enabled - Distributed State Estimation Demonstration

May 5-6, 2008
Virgin Islands Water and Power Authority
St. Thomas, USVI

One of the Research Projects that is Moving Towards Commercialization…

Concurrent Technologies Corporation (*CTC) through the U.S. Department of Energy's Center for Grid Modernization has sponsored a project to implement, demonstrate and validate "SuperCalibrator." This technology enables distributed state estimation by using existing relay/PMU devices in substations. "SuperCalibrator" is based on the efforts of the Power Systems Engineering Research Center (PSERC) researchers at Georgia Tech that have been searching for improved state estimation and power grid visibility approaches that use advanced data acquisition hardware. This project expanded on work that was completed in 2006-07 to prove the concept on two two-substations systems of the NYPA and ENTERGY systems. This effort was focused on implementation of this technology in a full system (the U.S. Virgin Island WAPA system). This project is being performed by Professors A. P. Meliopoulos and George Cokkinides (School of Electrical and Computer Engineering – Georgia Tech) and Terry Conrad (CTC). The fully distributed three-phase state estimator will be demonstrated in this workshop.*

Distributed State Estimator
at
U.S. Virgin Islands
Water and Power Authority
St. Thomas and St. John

Questions?

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