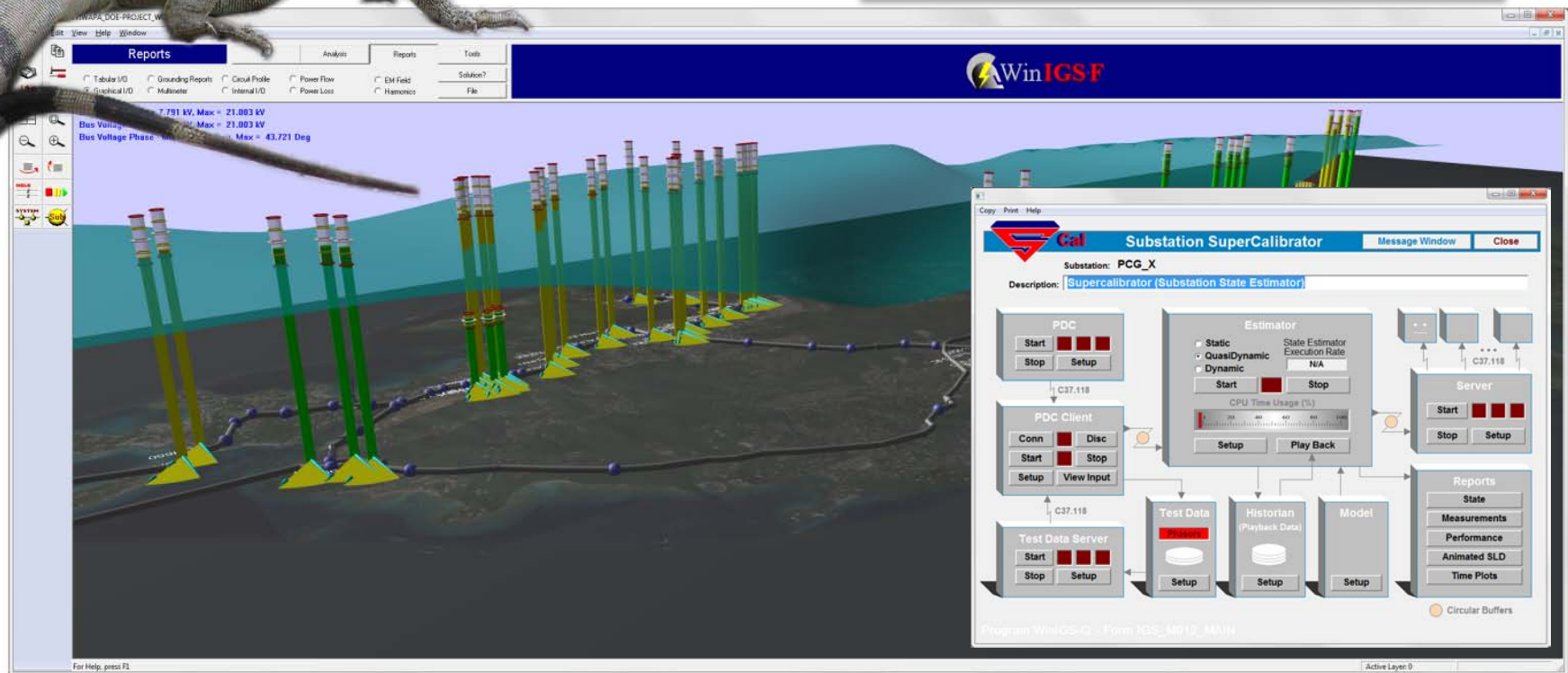
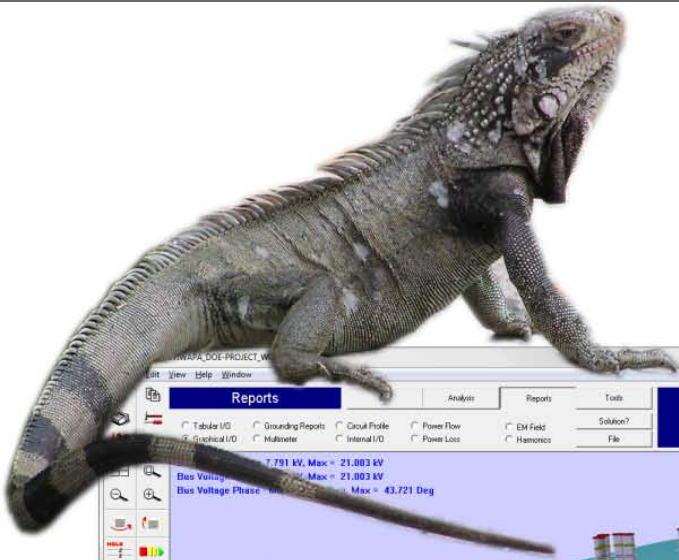


# Distributed Dynamic State Estimator, Generator Parameter Estimation and Stability Monitoring

**DoE-NETL Demonstration**  
**USVI-WAPA**  
August 1-2, 2012



# Demonstration: USVI-WAPA Project Team

## **Georgia Tech:**

Evangelos Farantatos, GRA, Renke Huang, GRA  
George Cokkinides, Faculty, Sakis Meliopoulos, Faculty

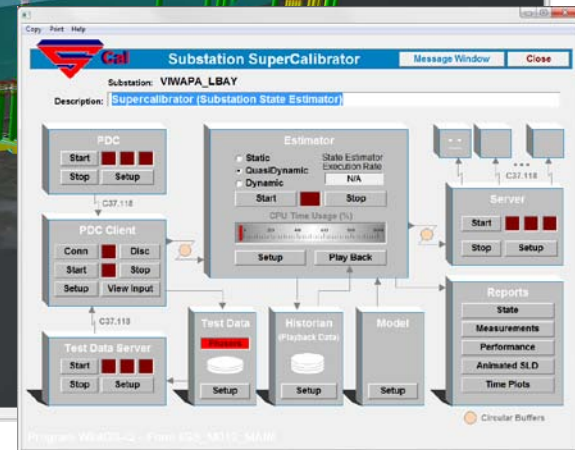
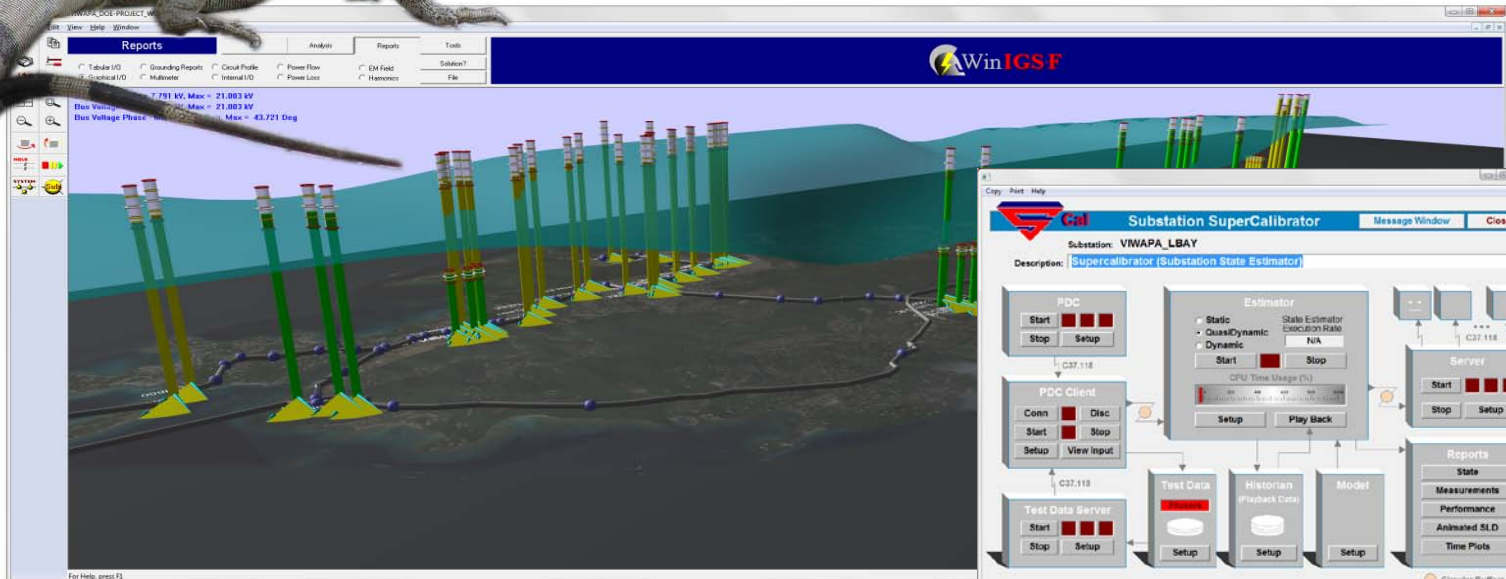
## **USVI-WAPA:**

Clinton Hedrington, Cordell Jacobs, Allison Gregory  
Niel Vanderpool

## **NYPA:**

Bruce Fardanesh, George Stefopoulos

# Demonstration: USVI-WAPA Project Overview



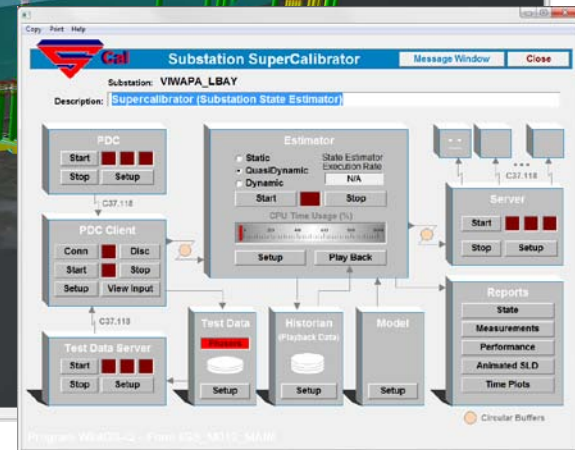
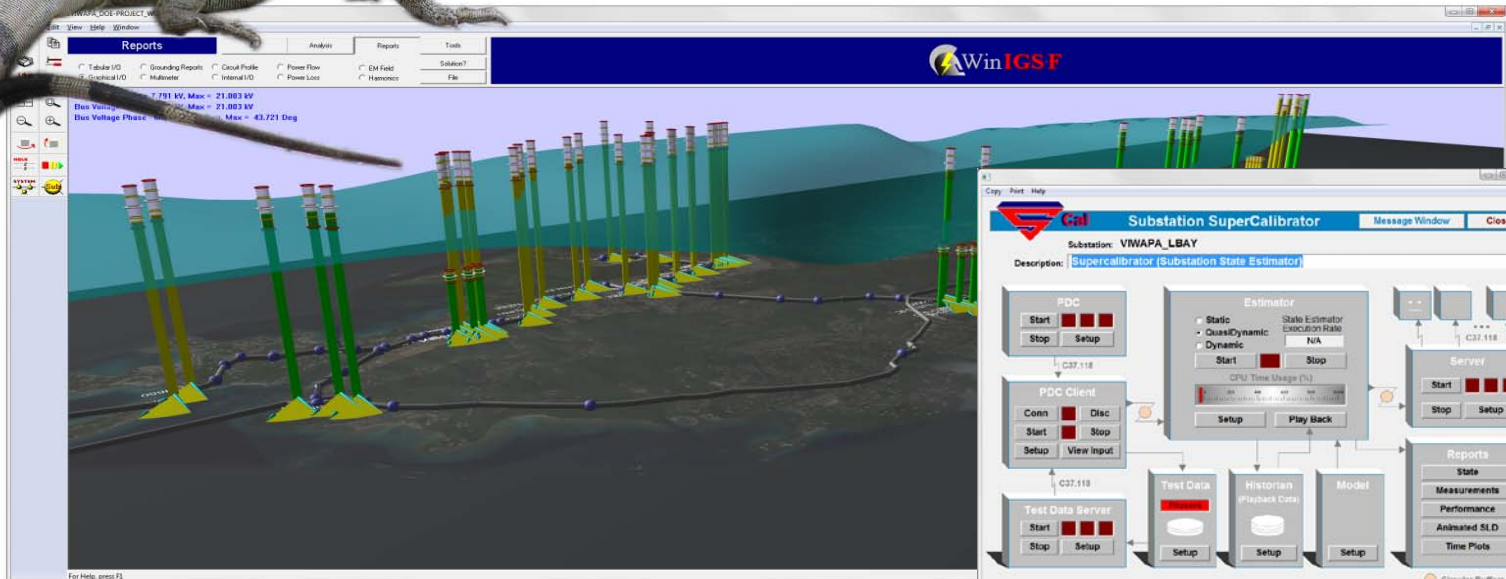
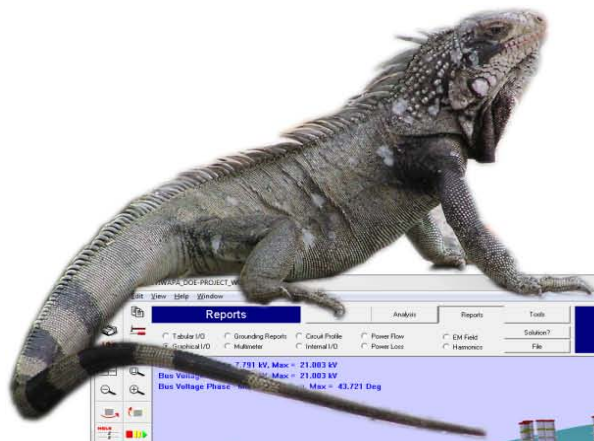
# Project Objectives and Scope

This project addresses four fundamental problems in the operation of any electric power network, let it be the national grid, a distribution circuit with distributed resources or a  $\mu$ Grid:

- (a) Real time modeling of the system via the proposed distributed dynamic state estimation using synchrophasor technology
- (b) Parameter identification of important components of the system such as generating units
- (c) Stability monitoring and prediction of eminent instabilities
- (d) Disturbance “Play Back”

**This work is fundamental for power system operations and optimization – we believe that the successful completion of the proposed work will provide a better infrastructure for power system operations and control.**

# Demonstration: USVI-WAPA Distributed State Estimator

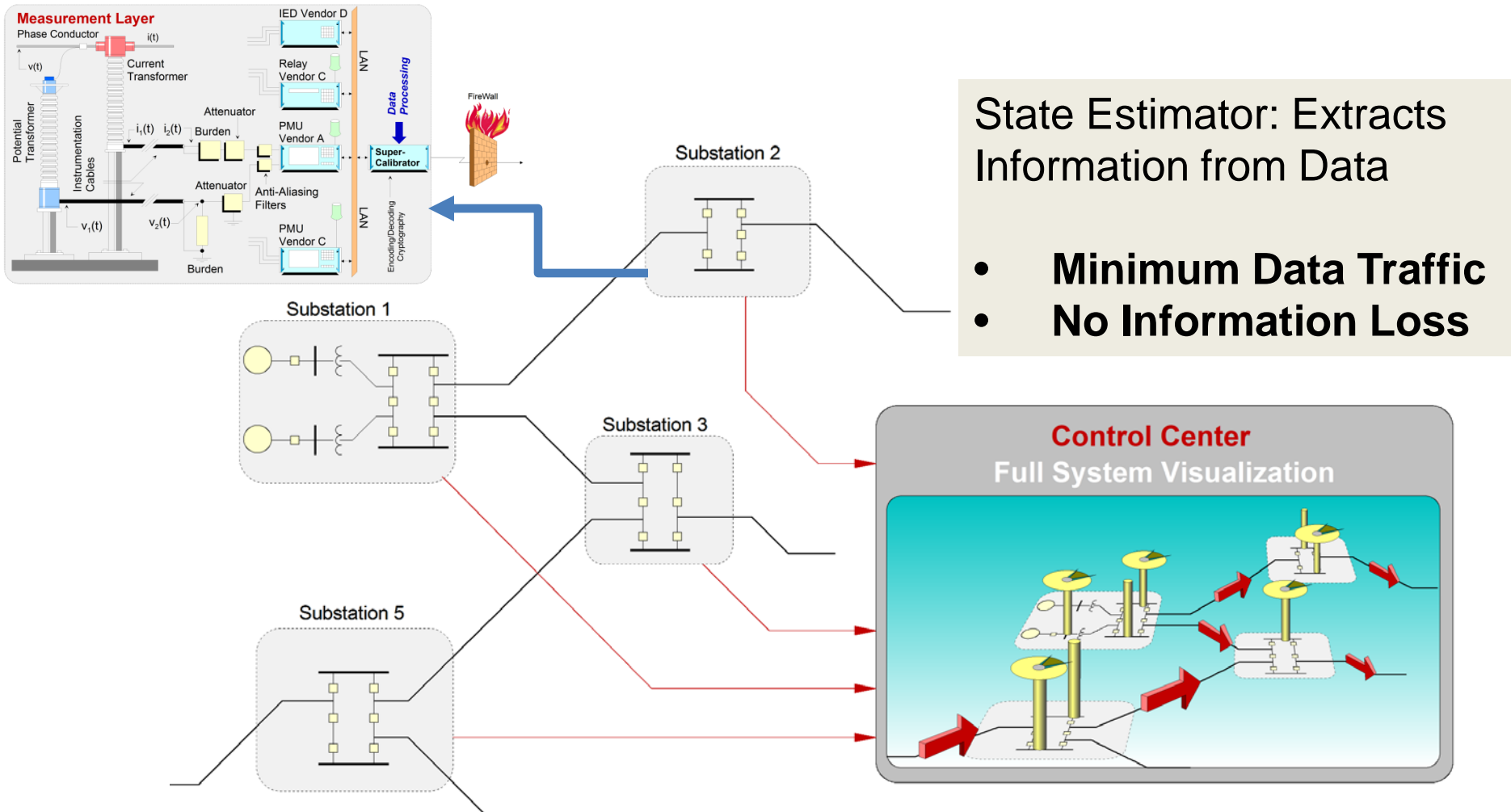




# Distributed State Estimation

Substation Level SE → Synthesis of System Wide State at the Control Center  
Enabling Technology: GPS-Synchronized Measurements

## Substation Level State Estimation



# The SuperC Concept (Distributed SE)

**The SuperC is conceptually very simple:**

1. Utilize all available data (Relays, DFRs, PMUs, Meters, etc.)
2. Utilize a detailed substation model (three-phase, breaker-oriented model, instrumentation channel inclusive and data acquisition model inclusive).
3. Use “Derived” and “Virtual” Measurements by Application of Physical Laws
4. At least one GPS synchronized device (PMU, Relay with PMU, etc.) → Results on UTC time enabling a truly decentralized State Estimator

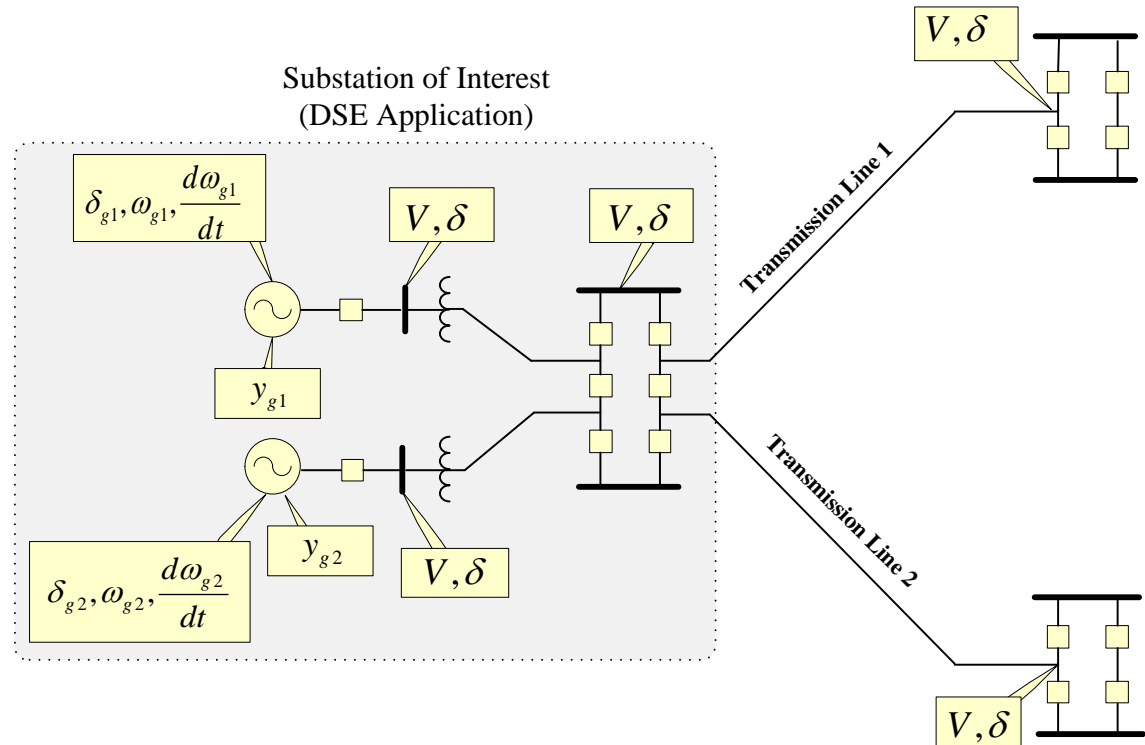
# Distributed Dynamic State Estimation Implementation

The Estimator is Defined in Terms of:

- Model
- State
- Measurement Set
- Estimation Method

Observability

Redundancy



System is Represented with a Set of Differential Equations (DE)  
The Dynamic State Estimator Fits the Streaming Data to the  
Dynamic Model (DE) of the System



# Distributed SE Measurement Set

- Any Measurement at the Substation from Any IED  
(Relays, Meters, FDR, PMUs, etc.)
- Data From at Least one GPS-Synchronized Device
- Derived Measurements  
Based on Topology
- Virtual Measurements  
Kirchoff's Current Law  
Model Equations
- Pseudo-Measurements  
Missing Phase Measurements  
Neutral/Shield Current Measurement  
Neutral Voltage

# Object Oriented Measurement Model

## Measurement Types:

- Actual Across Measurement: eg. voltage measurement
- Pseudo Across Measurement: eg. neutral voltage measurement
- Actual Through Measurement (related to a device): eg. current measurement
- Pseudo Through Measurement (related to a device)

## Power System Component Model (Dynamic Model → Integration → Algebraic Model):

$$\begin{bmatrix} i(t) \\ 0 \\ i(t_m) \\ 0 \end{bmatrix} = Y_{eq} \begin{bmatrix} v(t) \\ y(t) \\ v(t_m) \\ y(t_m) \end{bmatrix} + \begin{bmatrix} v^T(t) & y^T(t) & v^T(t_m) & y^T(t_m) \end{bmatrix} \cdot F_{eq} \cdot \begin{bmatrix} v(t) \\ y(t) \\ v(t_m) \\ y(t_m) \end{bmatrix} - b_{eq}$$

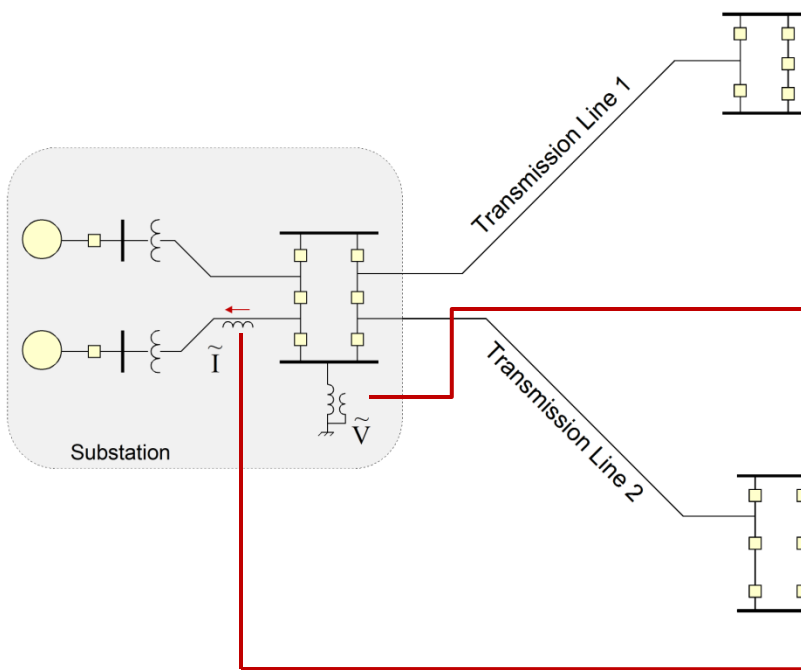
where

$$b_{eq} = \sum_i A_i \cdot \begin{bmatrix} v(t-i \cdot h) \\ y(t-i \cdot h) \end{bmatrix} + \sum_i B_i \cdot \begin{bmatrix} i(t-i \cdot h) \\ 0 \end{bmatrix} + C$$

## Each Measurement is expressed as a function of the states (at most quadratic):

$$z_k(t) = \sum_i a_{i,t}^k \cdot x_i(t) + \sum_i a_{i,t_m}^k \cdot x_i(t_m) + \sum_{i,j} b_{i,j,t}^k \cdot x_i(t) \cdot x_j(t) + \sum_{i,j} b_{i,j,t_m}^k \cdot x_i(t_m) \cdot x_j(t_m) + c_k(t) + \eta_k$$

# Object Oriented QSE



**Across (Voltage) Measurement:**

$$\tilde{z}_j(t) = \tilde{x}_j(t) + \eta_j$$

**Through (Current, Torque, etc.) Measurement:**  
Measurement  $z_j(t)$  represents a quality associated with one row of the Object oriented model

$$\tilde{z}_j(t) = \text{row k of Object Oriented Model} + \eta_j$$

**Object Oriented Model**

$$\begin{bmatrix} \tilde{I}(t) \\ 0 \\ \tilde{I}(t_m) \\ 0 \end{bmatrix} = Y_{eq} \begin{bmatrix} \tilde{V}(t) \\ \tilde{Y}(t) \\ \tilde{V}(t_m) \\ \tilde{Y}(t_m) \end{bmatrix} + \begin{bmatrix} \tilde{V}^T(t) & \tilde{Y}^T(t) & \tilde{V}^T(t_m) & \tilde{Y}^T(t_m) \end{bmatrix} \cdot F_{eq} \cdot \begin{bmatrix} \tilde{V}(t) \\ \tilde{Y}(t) \\ \tilde{V}(t_m) \\ \tilde{Y}(t_m) \end{bmatrix} - B_{eq}$$

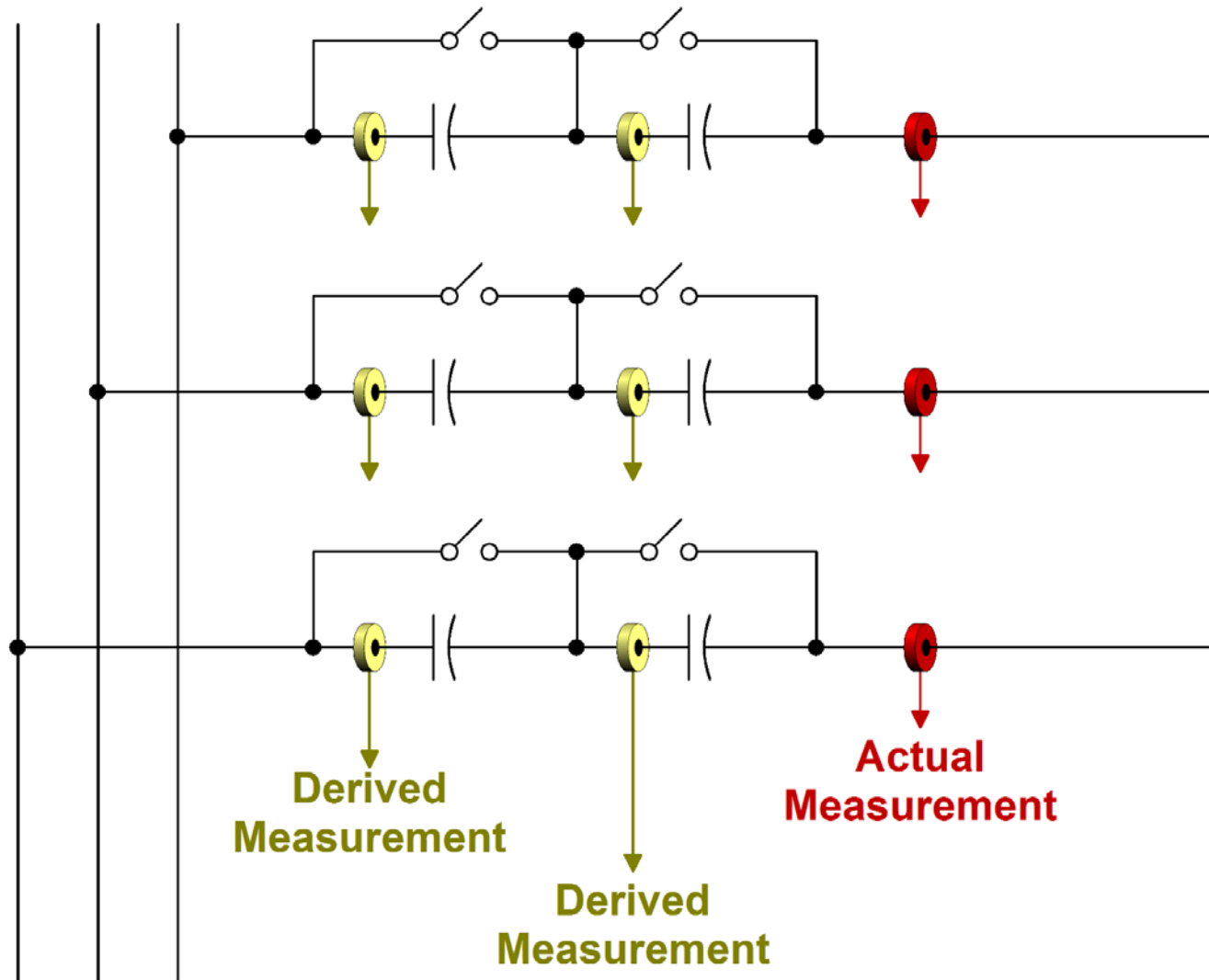
Row k

QSE states are  
***Phasors, Speed, etc***

$$\text{where } B_{eq} = \sum_i A_i \cdot \begin{bmatrix} \tilde{V}(t-i \cdot h) \\ \tilde{Y}(t-i \cdot h) \end{bmatrix} + \sum_i B_i \cdot \begin{bmatrix} \tilde{I}(t-i \cdot h) \\ 0 \end{bmatrix} + C$$

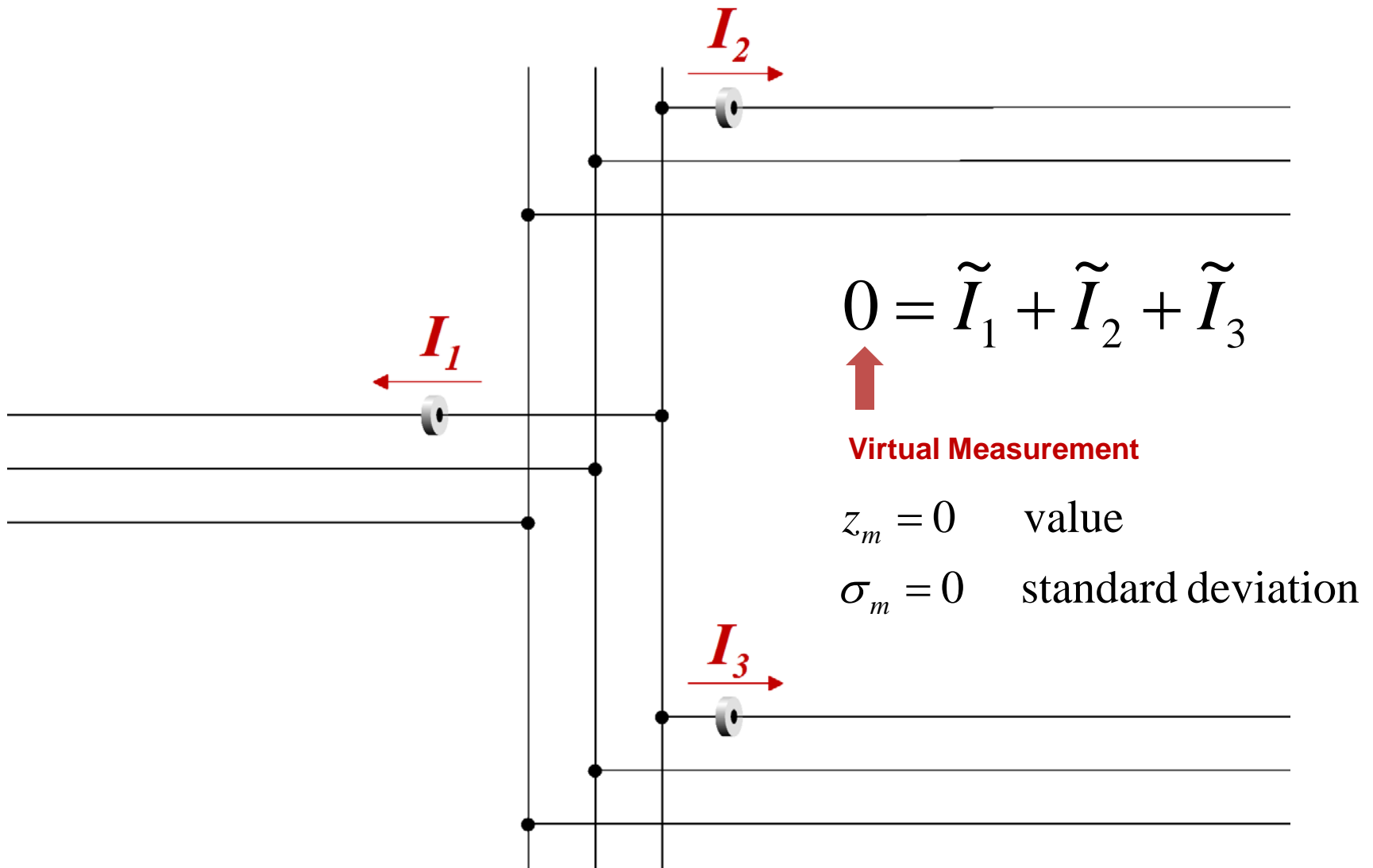
# Distributed State Estimation

## Derived Measurements - Examples



# Distributed State Estimation

## Virtual Measurements - Examples



# Distributed SE Measurement Set

## Non-Synchronized Measurements

Non-GPS Synchronized Relays provide phasors referenced on “phase A Voltage”. The phase A Voltage phase is ZERO.

The SuperC provides a reliable and accurate estimate of the phase A voltage phasor.

$$\tilde{A}_{sync} = \tilde{A}_{meas} e^{j\alpha}$$

$$\begin{aligned}\tilde{A}_{sync} &= \tilde{A}_{meas} e^{j\alpha} = \\ &A_{real} \cos \alpha - A_{imag} \sin \alpha + \\ &j(A_{real} \sin \alpha + A_{imag} \cos \alpha)\end{aligned}$$

$\alpha$  is a synchronizing unknown variable.

$\cos(\alpha)$  and  $\sin(\alpha)$  are unknown variables in the state estimation algorithm.

There is one  $\alpha$  variable for each non-synchronized relay.



# Distributed SE: Algorithm

$$\text{Min } J = \sum_{v \in \text{phasor}} \frac{\tilde{\eta}_v^* \tilde{\eta}_v}{\sigma_v^2} + \sum_{v \in \text{non-syn}} \frac{\eta_v \eta_v}{\sigma_v^2}$$

Solution:  $x^{v+1} = x^v + A[z - h(x)]$

where:  $A = [H^T W H]^{-1} [H^T W]$

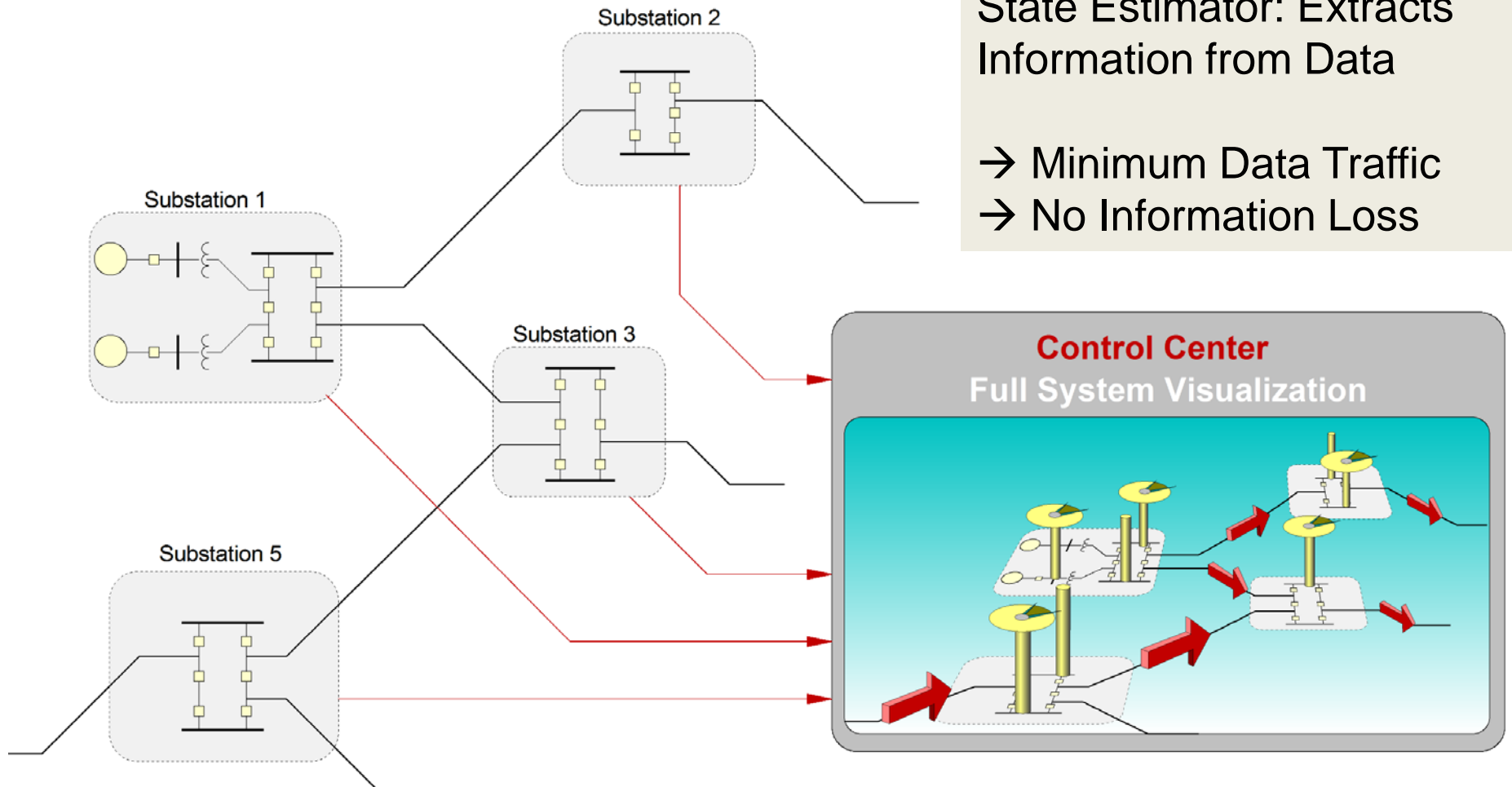
## Efficiency

Demonstrated the ability to execute the state estimator 60 times per second for substantial size substations.

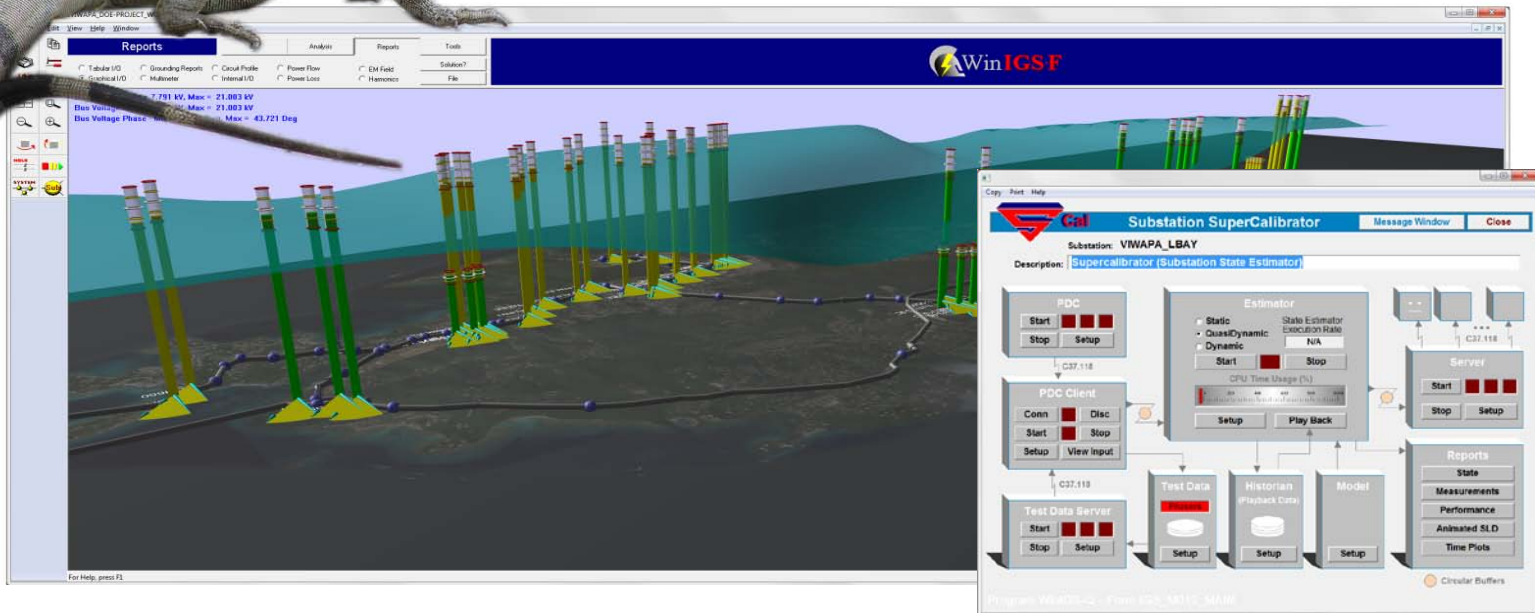
There is still space for improved computational efficiency.

# Distributed State Estimation

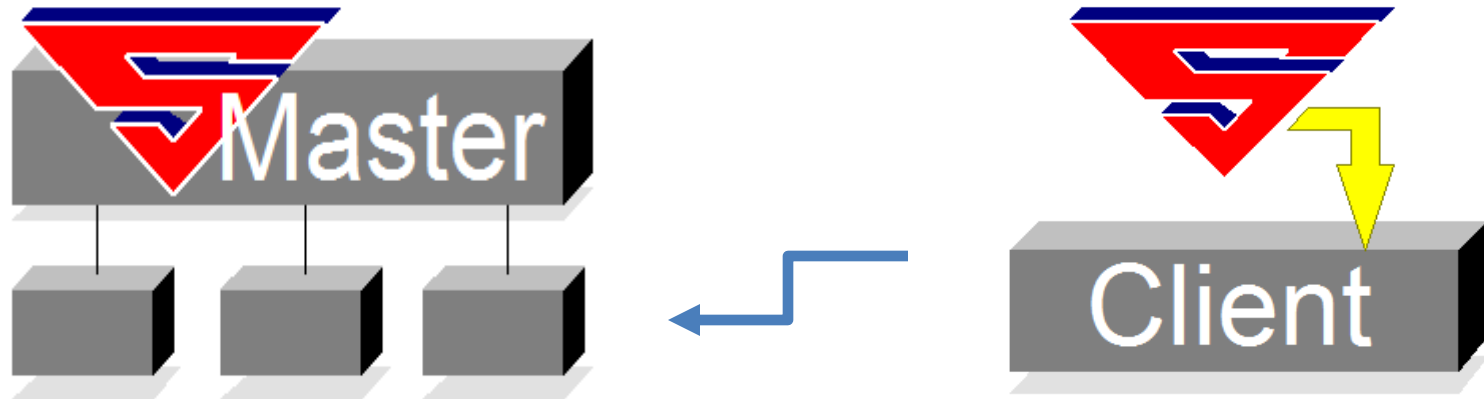
## Synthesis of System Wide State at the Control Center



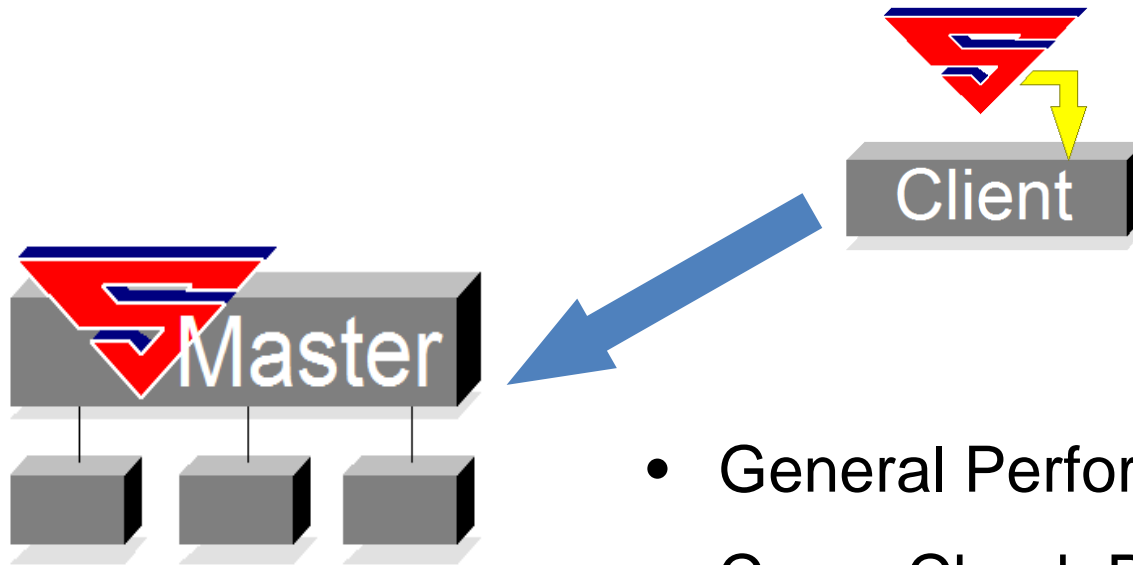
# Demonstration: USVI-WAPA Master DSE



# SuperCalibrator Master - Client

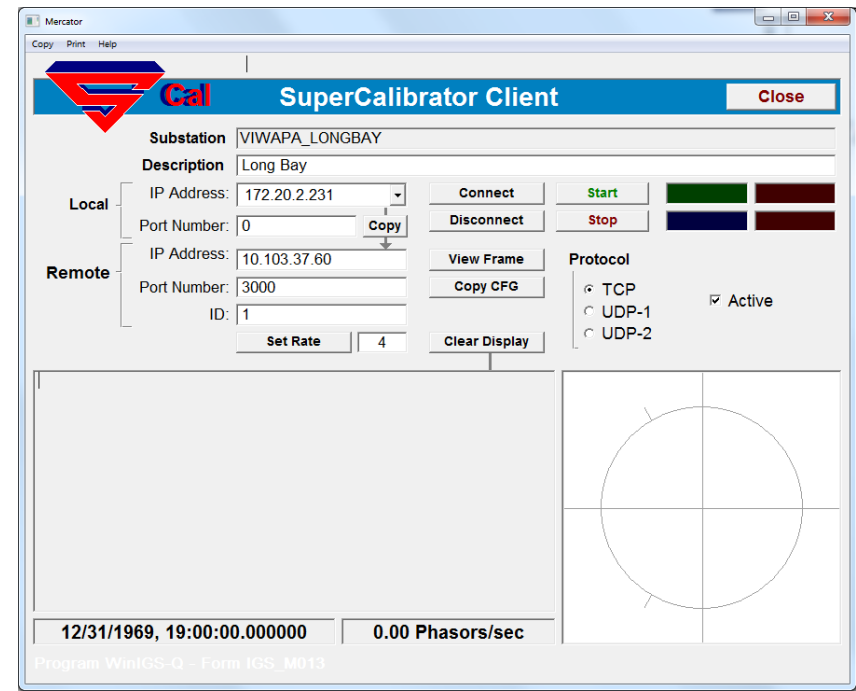
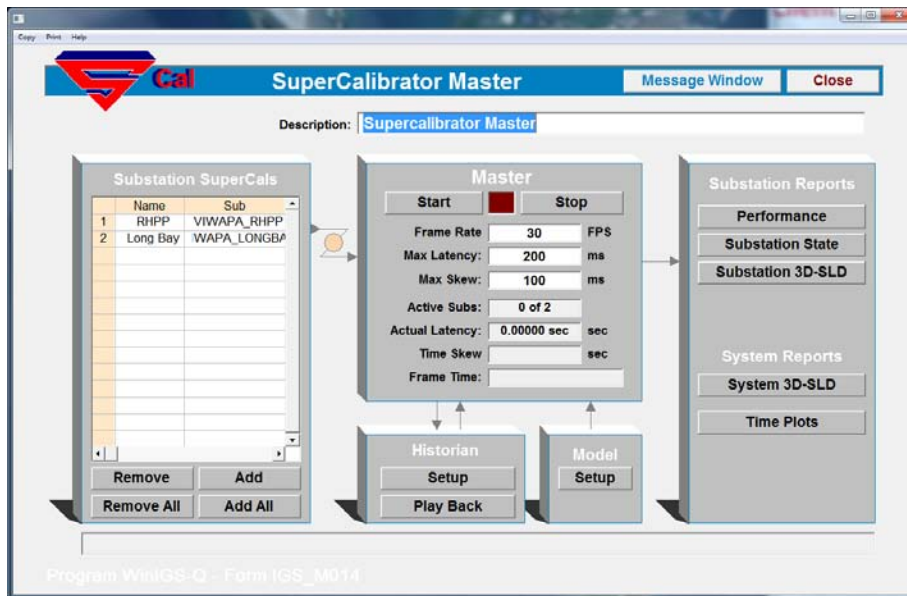
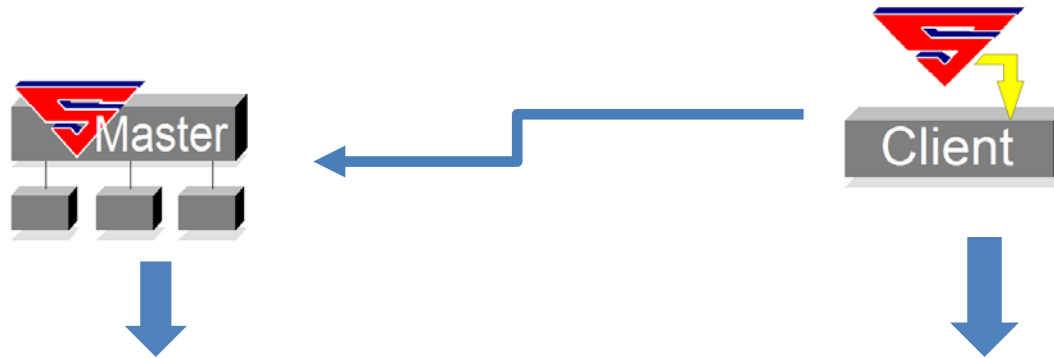


# SuperCalibrator Master Reports



- General Performance
- Cross-Check Performance
- Animated SLD's
- Etc...

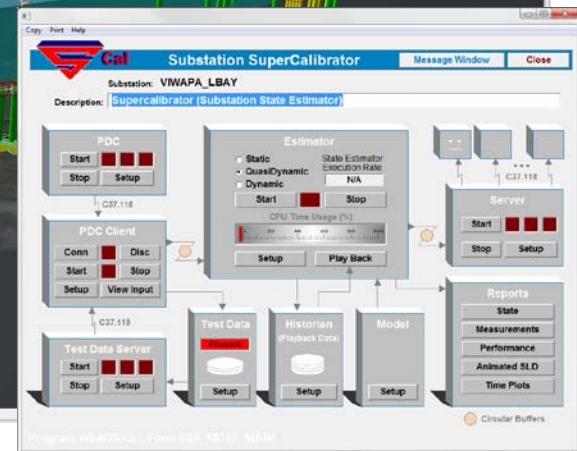
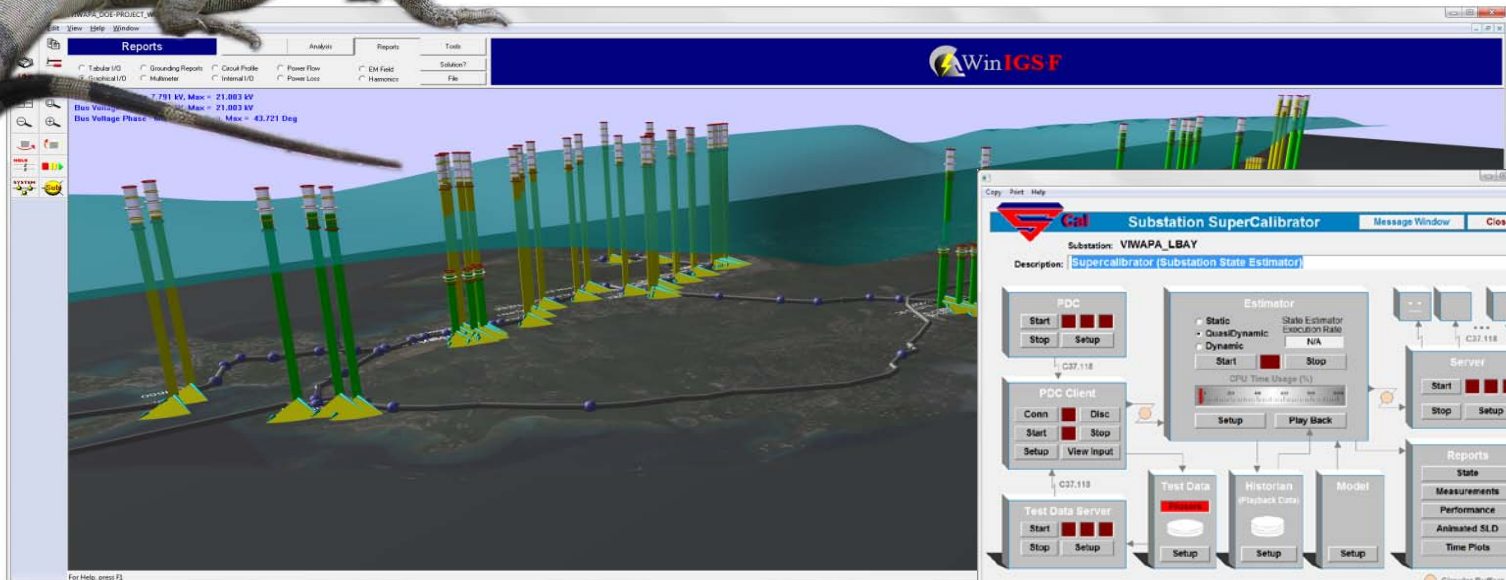
# SuperCalibrator Master & Client





# Demonstration: USVI-WAPA

## The USVI-WAPA System



# The USVI-WAPA System



# VIWAPA – LONGBAY 35 kV Substation Instrumentation

Installation of PMUs  
at Longbay:

SEL 421 (3)

Numerical Relays at  
Longbay:

SEL 587 (4)

AREVA MiCOM P543 (3)

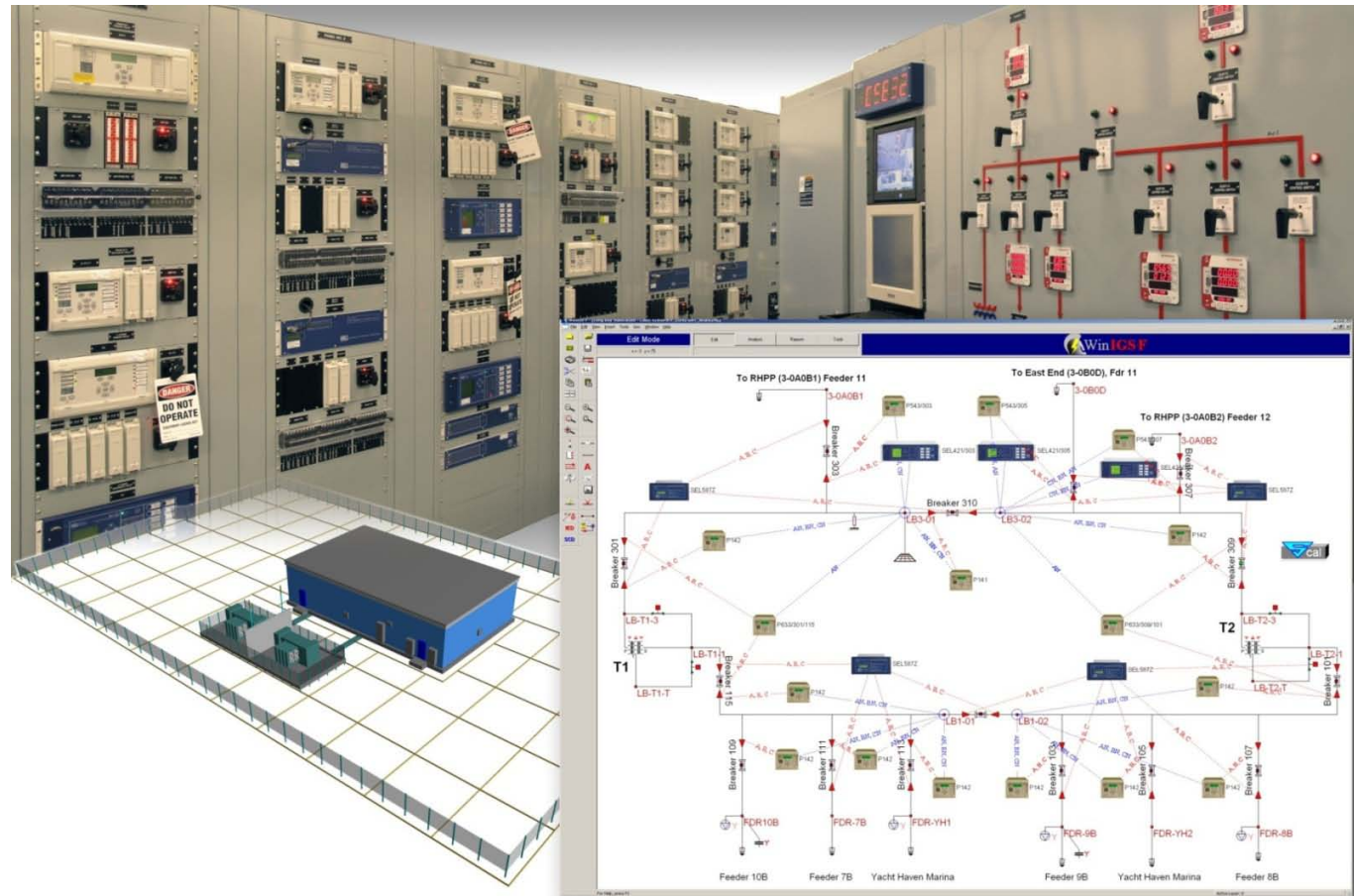
AREVA MiCOM 633 (2)

AREMA MiCOM P142 (10)

PMU Measurements: 18

Numerical Relay  
Measurements: 132

## View of WAPA's Longbay substation





# VIWAPA – RHPP 35 kV Substation Instrumentation



# **VIWAPA – RHPP 35 kV Substation Instrumentation**

## **Installation of PMUs and Relays at RPHH**

SEL 421 (3)

SEL 451 (4)

GE 60 (1)

## **Numerical Relays at RPHH**

SEL 487 (6)

AREVA MiCOM P142 (6)

AREVA MiCOM P543 (5)

AREVA MiCOM P632 (1)

AREVA MiCOM P642 (3)

AREVA MiCOM P645 (3)

**PMU Measurements: 40 (max possible 71)**

**Numerical Relay Measurements: 150**

# VIWAPA – TUTU 35 kV Substation Instrumentation

## VIWAPA's TUTU substation

### Installation of PMUs at TUTU

SEL 734 (1)

### Numerical Relays at TUTU

SEL 587 (1)

AREVA MiCOM P543 (2)

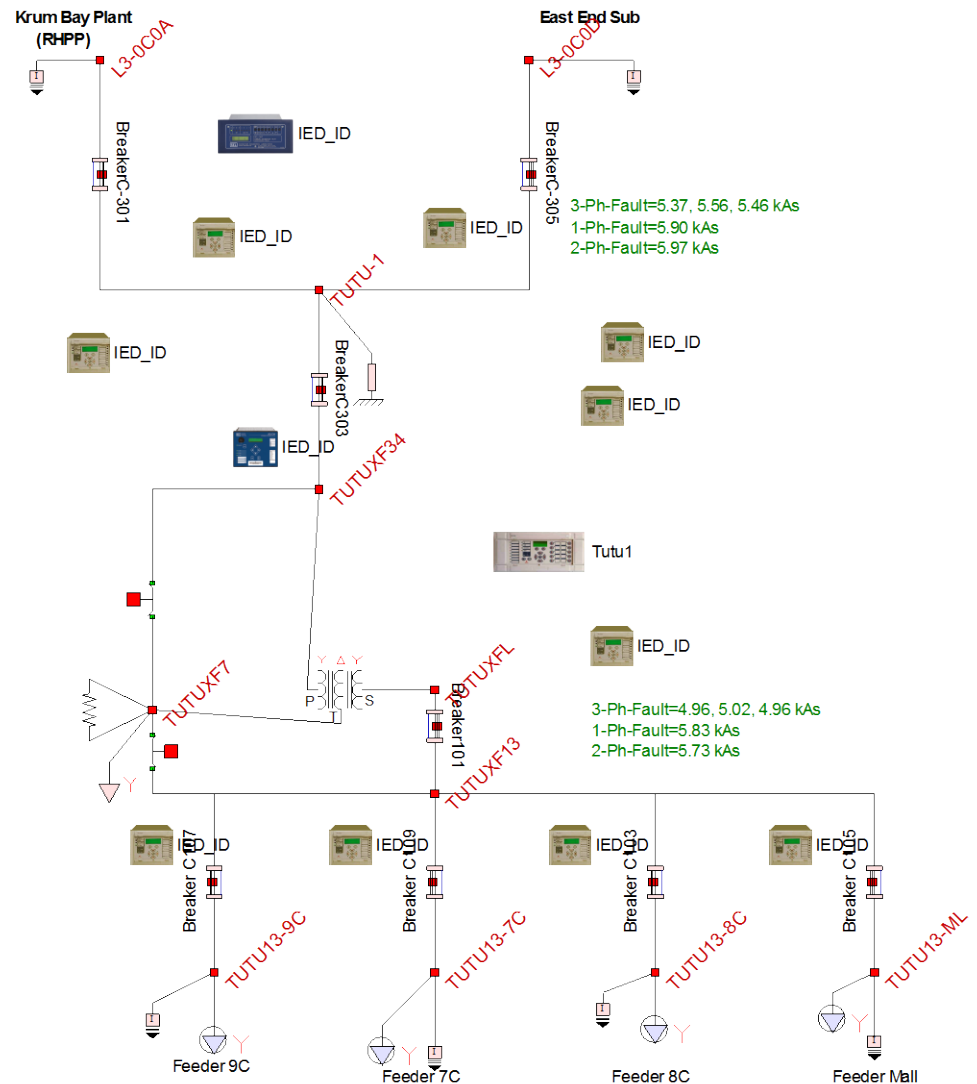
AREVA MiCOM P544 (2)

AREVA MiCOM 634 (1)

AREMA MiCOM P142 (6)

PMU Measurements: 3

Numerical Relay Measurements: 39





# VIWAPA – EAST END 35 kV Substation Instrumentation

## Installation of PMUs at EAST END

SEL 734 (1)

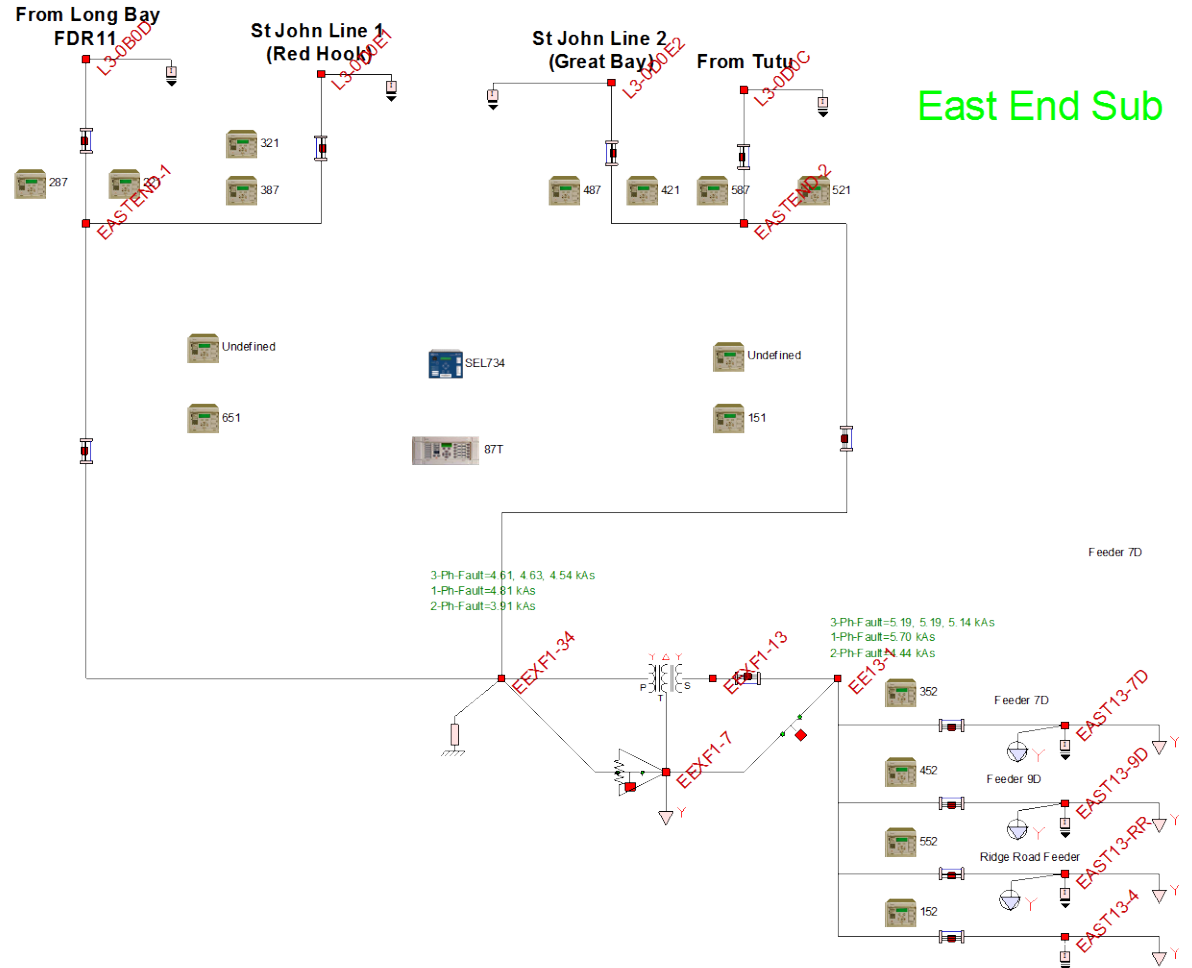
## Numerical Relays at EAST END

AREVA MiCOM P542 (4)  
AREVA MiCOM P543 (4)  
AREVA MiCOM P633 (1)  
AREMA MiCOM P141 (2)  
AREMA MiCOM P142 (4)  
AREMA MiCOM P143 (2)

PMU Measurements: 3

Numerical Relay Measurements: 51

## VIWAPA's EAST END Substation



# VIWAPA – St JOHN 35 kV Substation Instrumentation

## Installation of PMUs at St JOHN

SEL 734 (1)

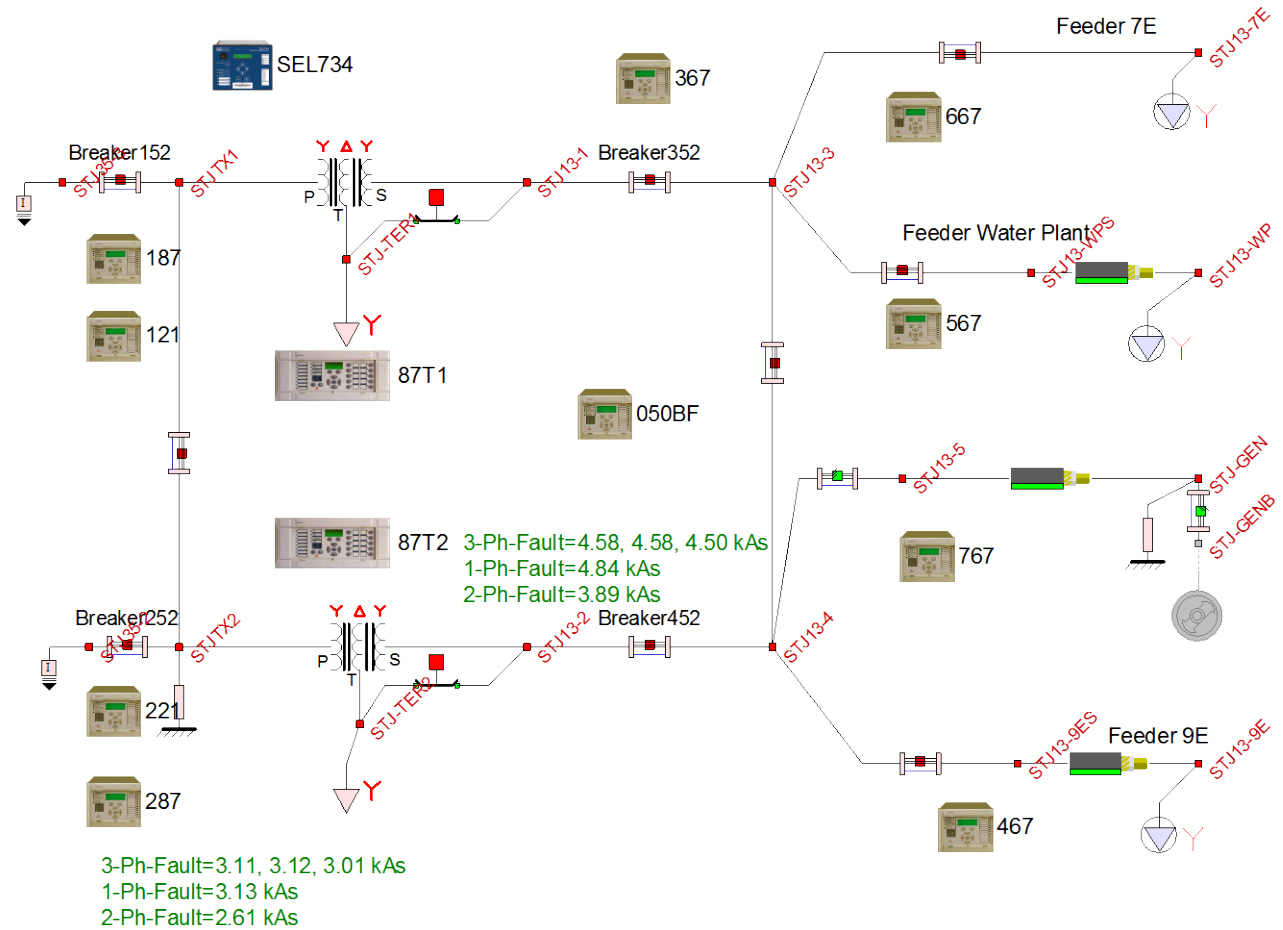
## Numerical Relays at St JOHN

AREVA MiCOM P633 (2)  
AREVA MiCOM P542 (2)  
AREVA MiCOM P543 (2)  
AREMA MiCOM P141 (1)  
AREMA MiCOM P142 (2)  
AREMA MiCOM P143 (3)

PMU Measurements: 3

Numerical Relay  
Measurements: 36

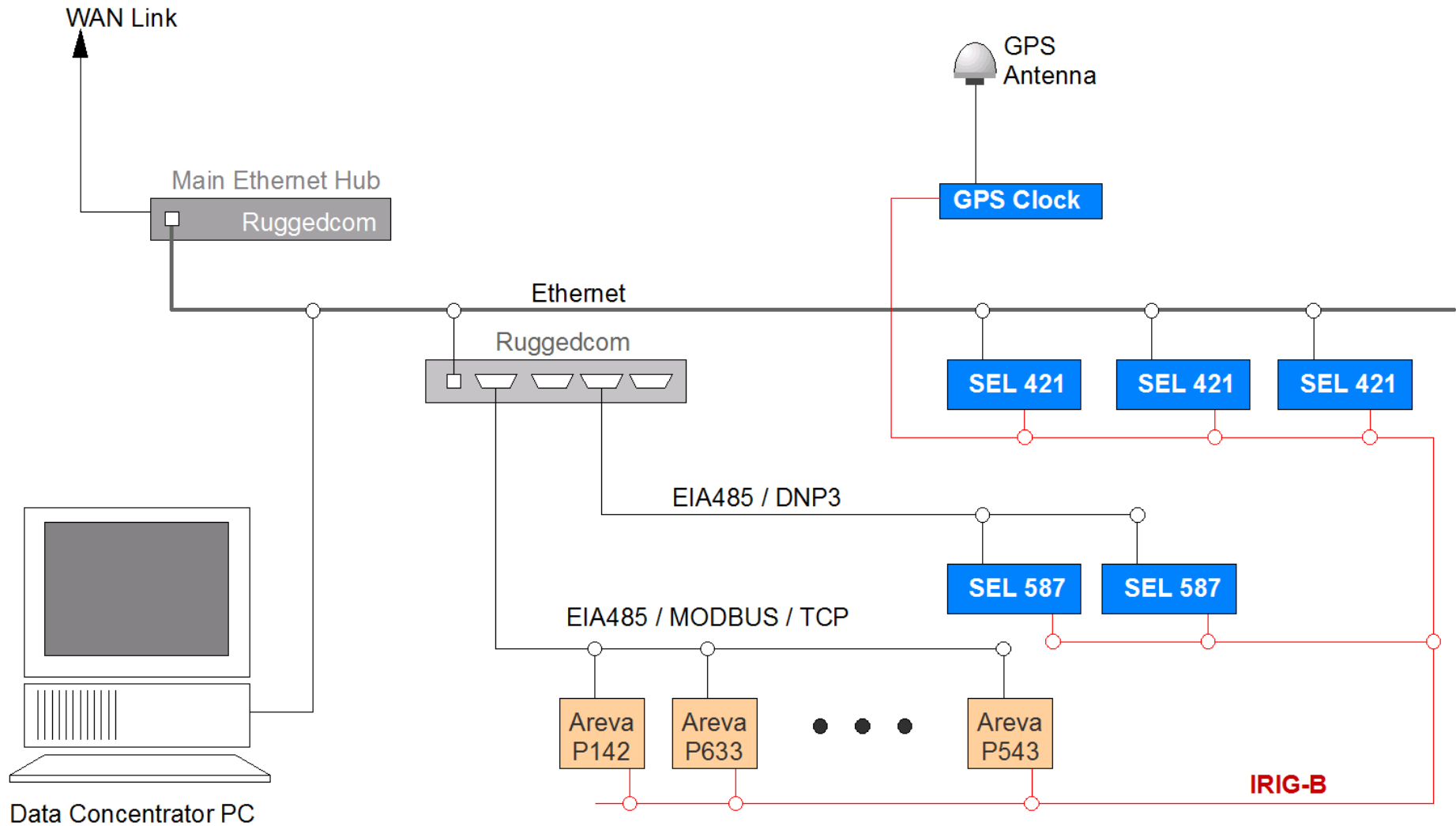
## VIWAPA's St JOHN substation



[illegible]

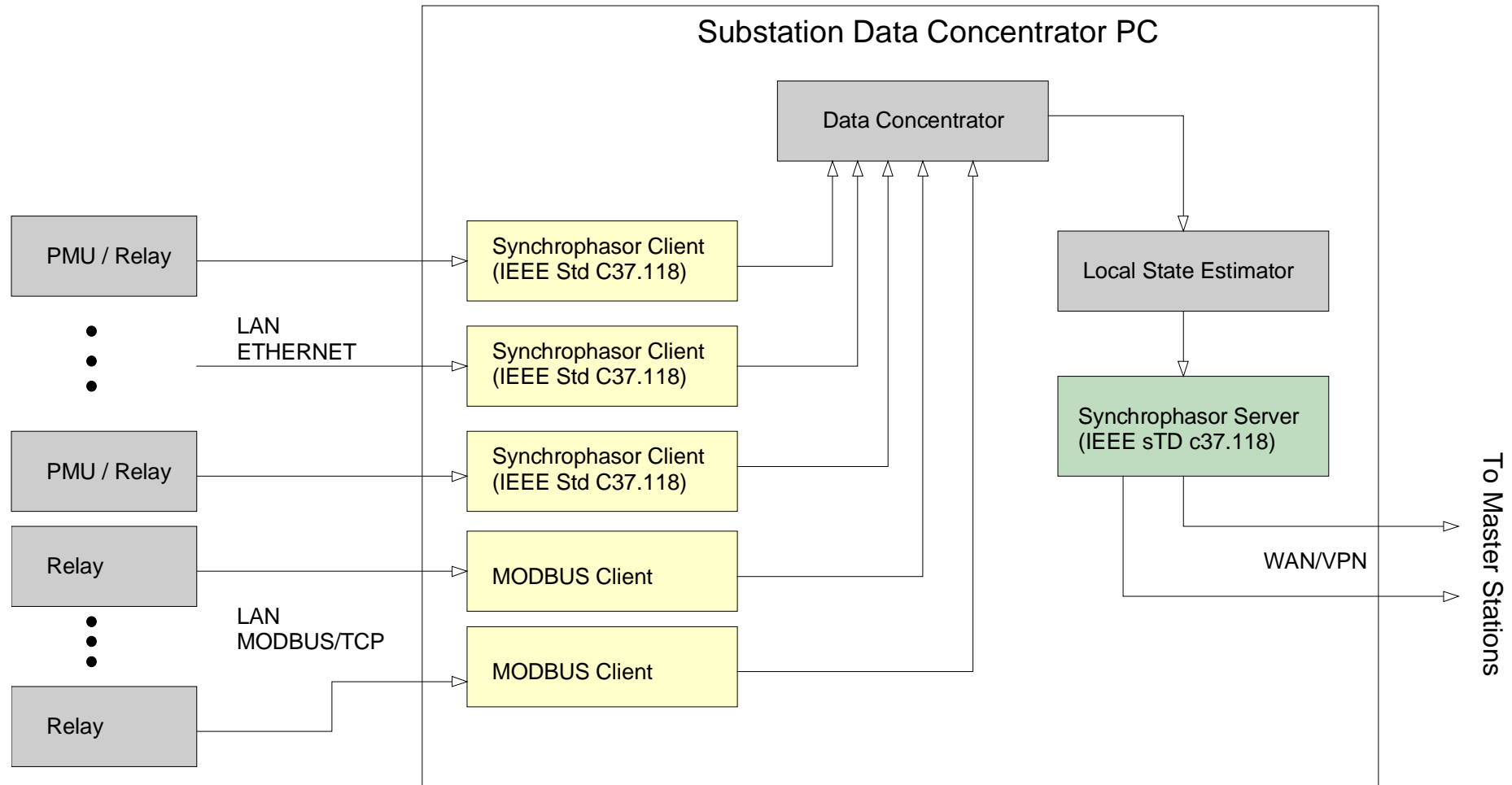
# The USVI-WAPA System

## The Communications Infrastructure

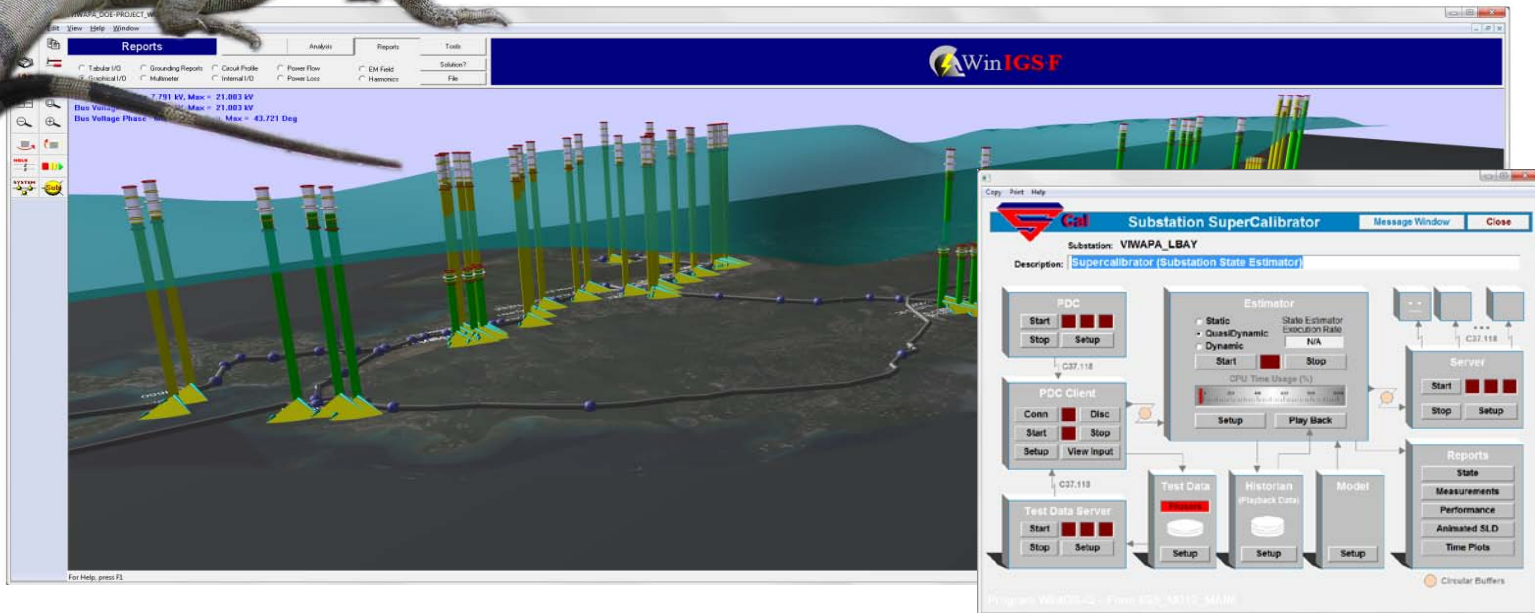


# The USVI-WAPA System

## The Communications Infrastructure



# Demonstration: USVI-WAPA Substation DSE and Master





# Demonstration: USVI-WAPA

Substation DSE and Master

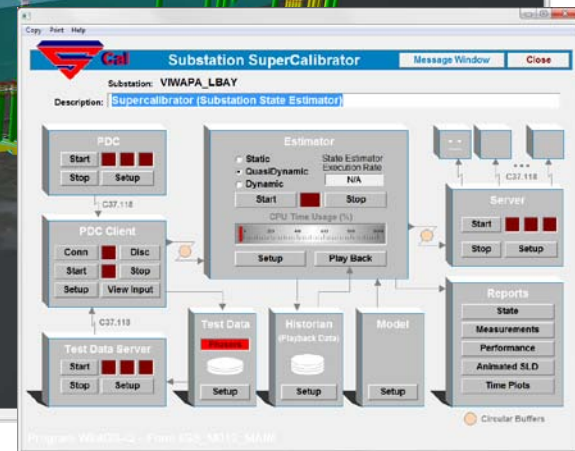
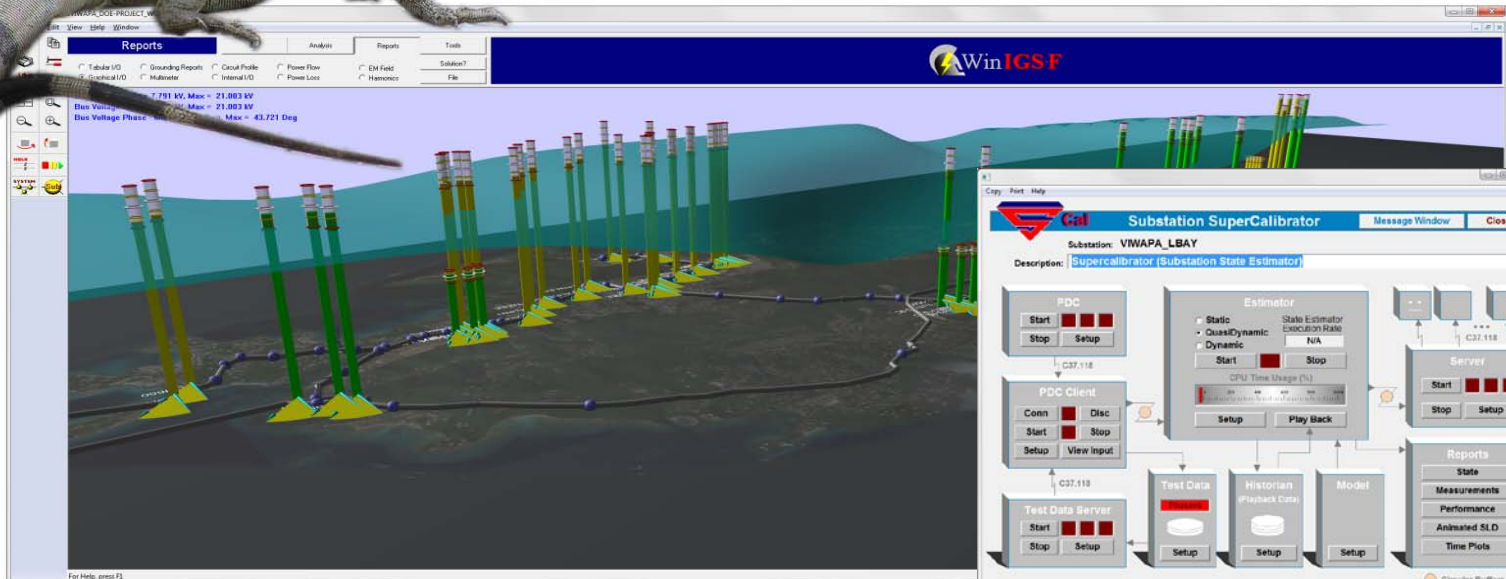


**Master**  
UI and Visualization

**Substation DSE**  
UI and Visualization



# Demonstration: USVI-WAPA Performance Evolution



# Performance Evolution: QSE: Timing Results\* - Year 1

## *NYPA Gilboa-Blenheim plant*

<b>System States</b>	<b>96</b>
<b>Actual Measurements</b>	<b>168</b>
<b>Total Measurements (Actual + Virtual)</b>	<b>744</b>
<b>Average QSE Execution Time per Time Step</b>	<b>9.5 msec</b>
<b>Variability</b>	<b>0.5 msec</b>

## *USVI LongBay Substation*

<b>System States</b>	<b>164</b>
<b>Actual Measurements</b>	<b>171</b>
<b>Total Measurements (Actual + Virtual)</b>	<b>708</b>
<b>Average QSE Execution Time per Time Step</b>	<b>13 msec</b>
<b>Variability</b>	<b>1 msec</b>

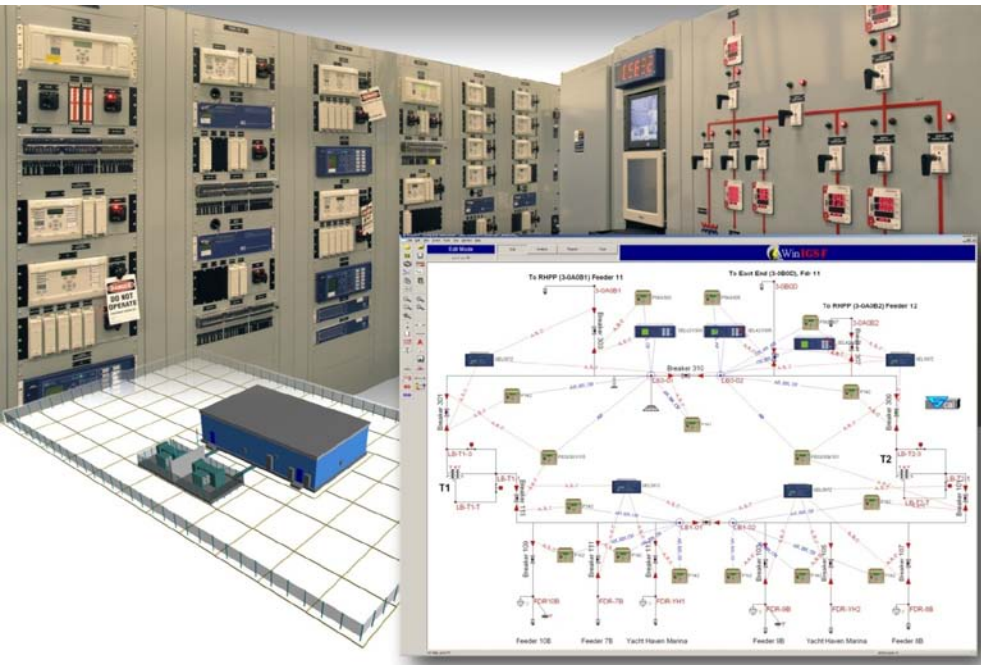
\*PC, i7-930 Processor, 2.8 Gz

## **Additional Improvements Are Possible**

- Additional Code Optimization
- Use of Multi-core Computers

# Performance Evolution: Distributed State Estimation

## Timing Results – Year 3



### Timing Experiment Summary of the QSE for Long Bay Substation

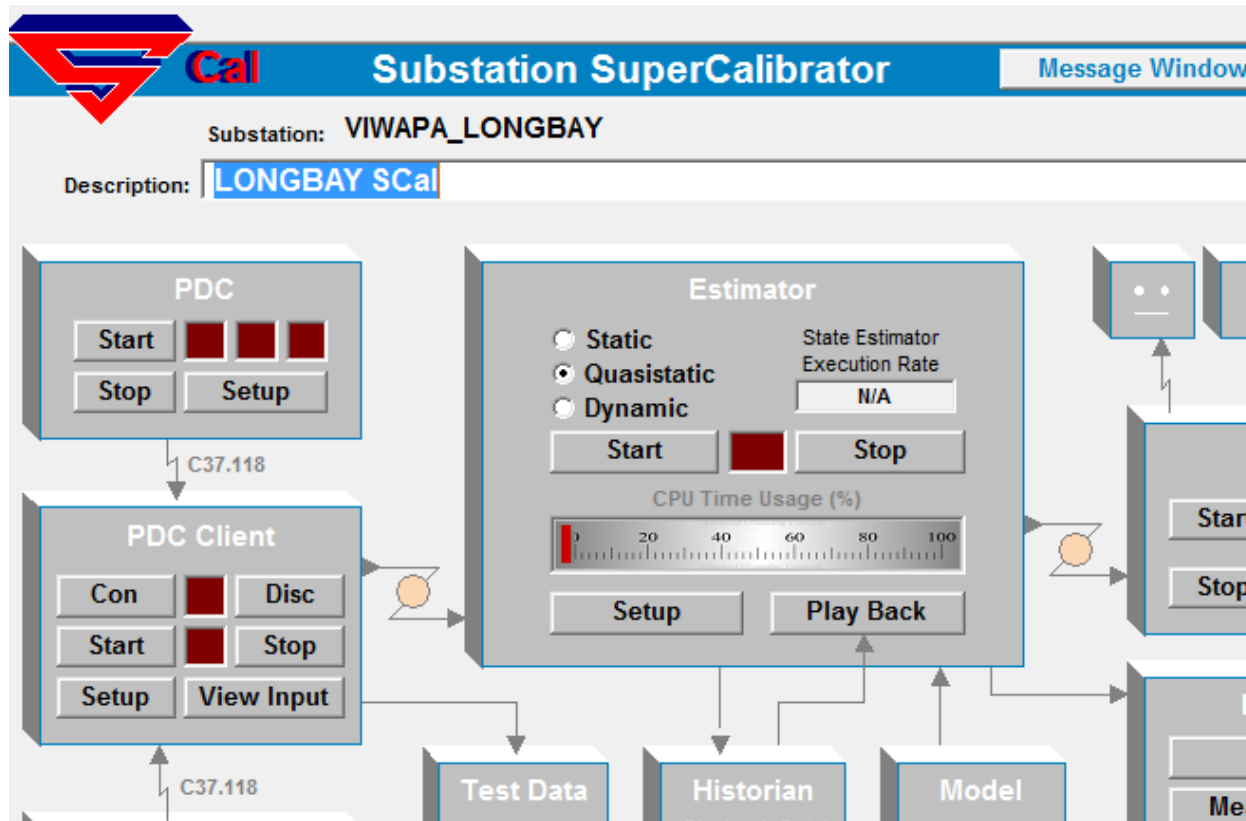
- Two kV Level Substations
- Two Transformers
- Three Transmission Lines
- Six Distribution Circuits

<b>System States</b>	<b>82</b>
<b>Actual Measurements</b>	<b>171</b>
<b>Total Measurements (Actual + Virtual)</b>	<b>784</b>
<b>Average QSE Execution Time per Time Step</b>	<b>0.42 msec</b>
<b>Variability</b>	<b>0.05 msec</b>



# Performance Evolution: Distributed State Estimation

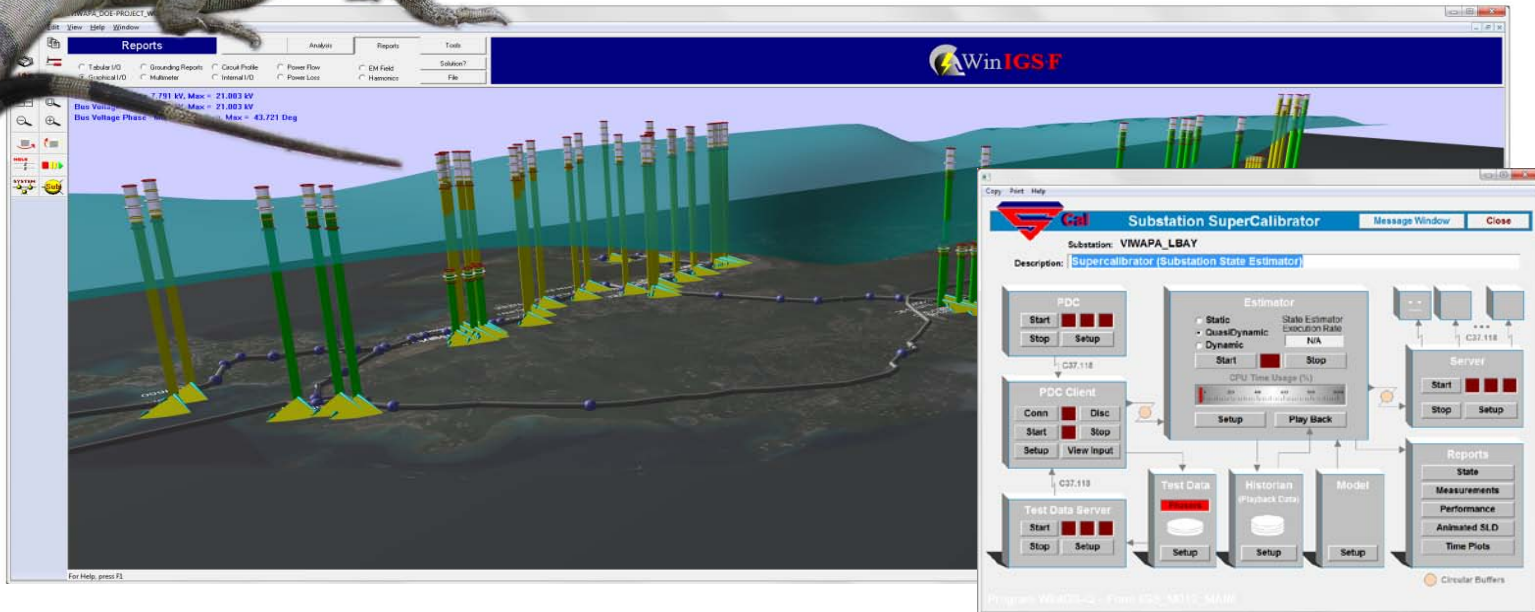
## Execution Time Monitor



CPU Time Usage Indicates in Real Time the Portion of the Time Used by the SE Calculations.

100%=Time Between Two Successive SE Computations. example: if SE is set to execute 60 times per second, then 100%=16.6 ms

# Demonstration: USVI-WAPA Disturbance Playback



# Disturbance Playback

## Via Distributed Dynamic State Estimation

**Objective:** to provide an automated playback capability of past operating conditions and disturbances.

Project objective has been accomplished.

**How:** the results of the distributed dynamic state estimation are stored in a circular buffer (months long) together with the model. Playback requires only start and end times.

# Disturbance Play-Back: User Interface

New Approach to Historian: Substation Storage Scheme  
Full Model + Model Changes + Data

System Operations Can Be “Played Back” Over a User Specified  
Time Interval (From time t1 to time t2)

Then as simple as  
pressing a button...

Playback Control

Copy Print Help

**Playback Control**

Start Pause Stop Close

Playback Delay

100 msec

From: 3/29/2011 10:41:00 0

To: 3/29/2011 10:42:00 0

All Data

Program WinIS-Q - Form OGLN\_PLAYBACK\_CTRL

X-Y Scaling

Copy Print Help

**SuperCalibrator Report Selection**

	Phase	Wall	Tube	Surf	Norm	Scale	Est/Meas/Res
V magn	A		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	0.2	<input checked="" type="radio"/> E <input type="radio"/> M <input type="radio"/> R
V angle	A		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	0.2	<input checked="" type="radio"/> E <input type="radio"/> M <input type="radio"/> R
I magn	A	<input checked="" type="checkbox"/>			<input type="checkbox"/>	0.2	<input checked="" type="radio"/> E <input type="radio"/> M <input type="radio"/> R
I angle	A	<input type="checkbox"/>			<input type="checkbox"/>	1.000	<input checked="" type="radio"/> E <input type="radio"/> M <input type="radio"/> R
P flow	A	<input type="checkbox"/>			<input type="checkbox"/>	1.000	<input checked="" type="radio"/> E <input type="radio"/> M <input type="radio"/> R
Q flow	A	<input type="checkbox"/>			<input type="checkbox"/>	1.000	<input checked="" type="radio"/> E <input type="radio"/> M <input type="radio"/> R

☒ Show Maps ☒ Colors ☒ Limits ☐ Normalized

Clear Close

Program WinIS-Q - Form OGLN\_SCAL\_REPORTS



# Important Application: Disturbance Play-Back

## Objective:

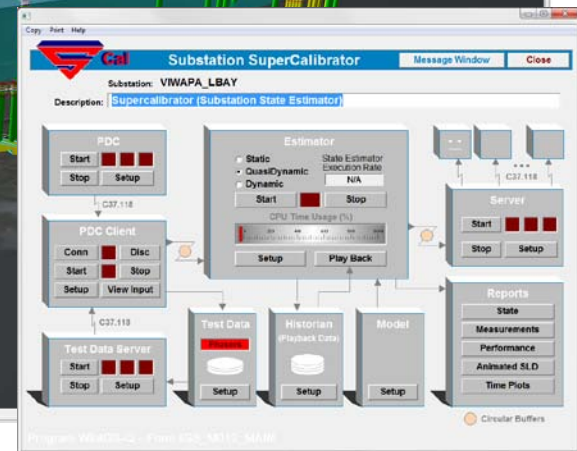
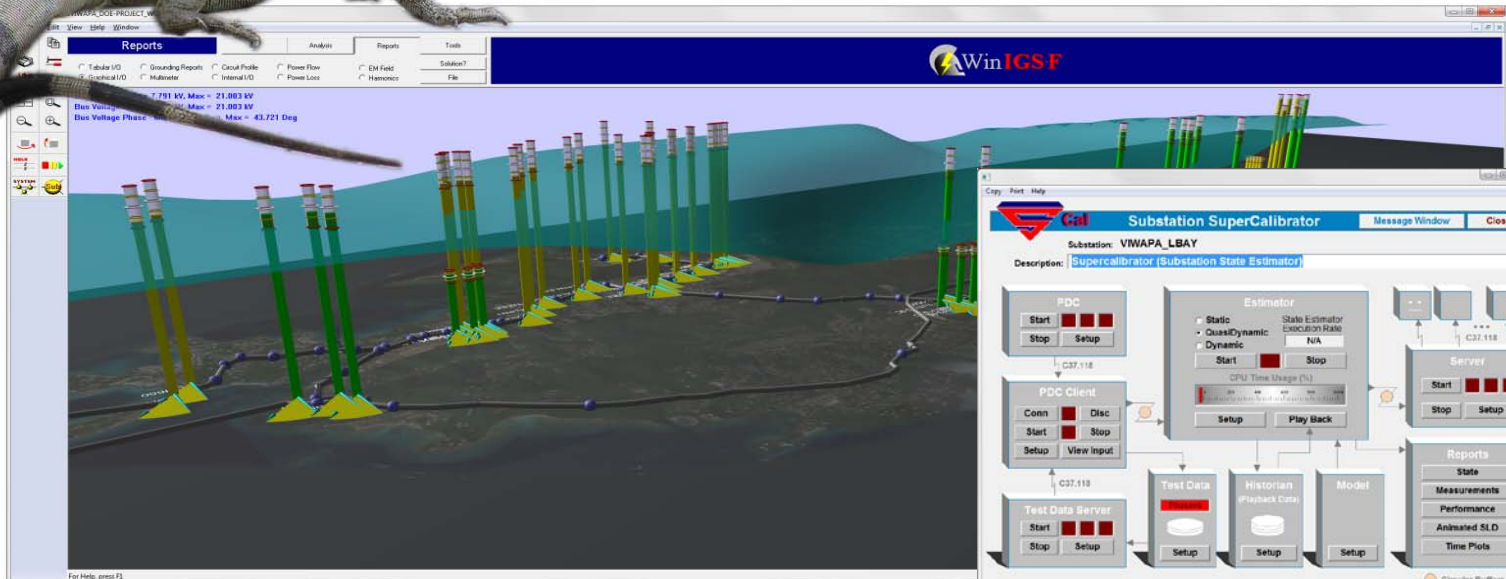
- System Operation “Play Back” over a user specified time interval (from time  $t_1$  to time  $t_2$ )
- Reconstructed state is presented via graphical visualization Techniques, ( 3-D rendering, animation etc) with multiple user options.

## Substation Storage Scheme

Full Model + Model Changes + Data

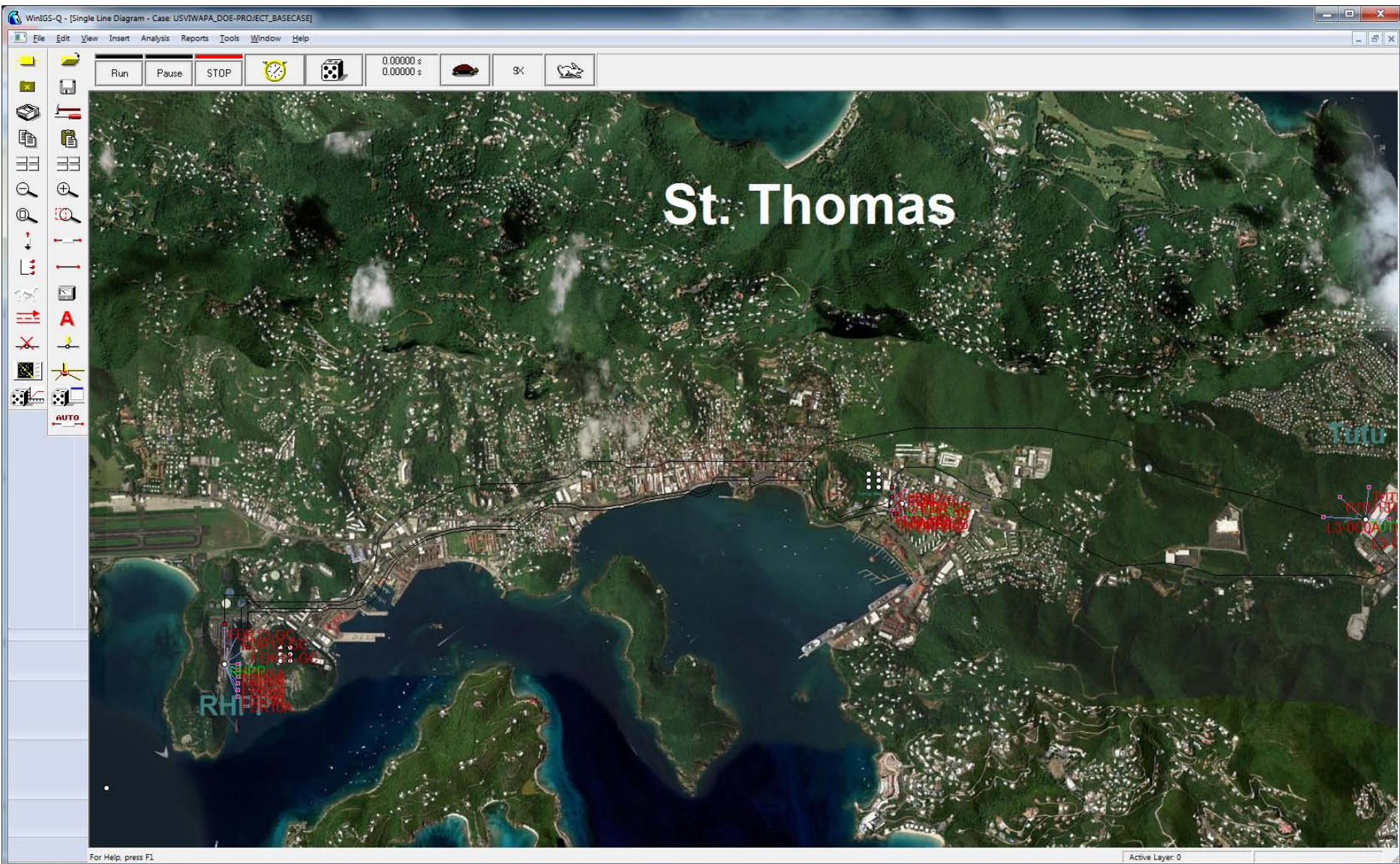
- System FULL MODEL stored once a day in WinIGS format – time of day can be arbitrarily selected, for example at 2 am. (example storage follows)
- Report system changes by exception – UTC time (example storage follows)
- Storage of state data: at each occurrence of the state estimator, the estimated states are stored in COMTRADE-like format. (example storage follows)

# Demonstration: USVI-WAPA Substation DSE



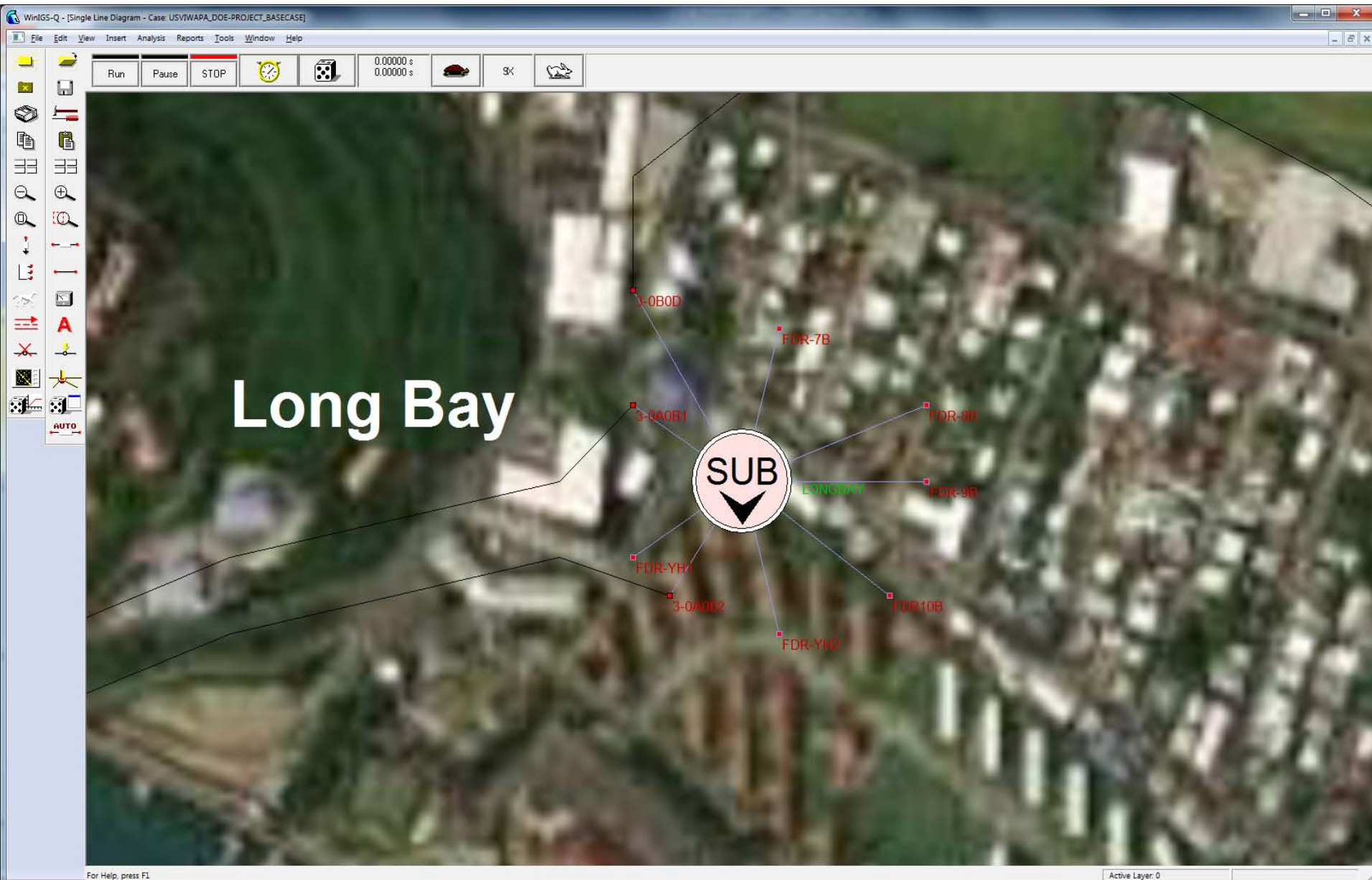


# DSE Substation Module User Interface

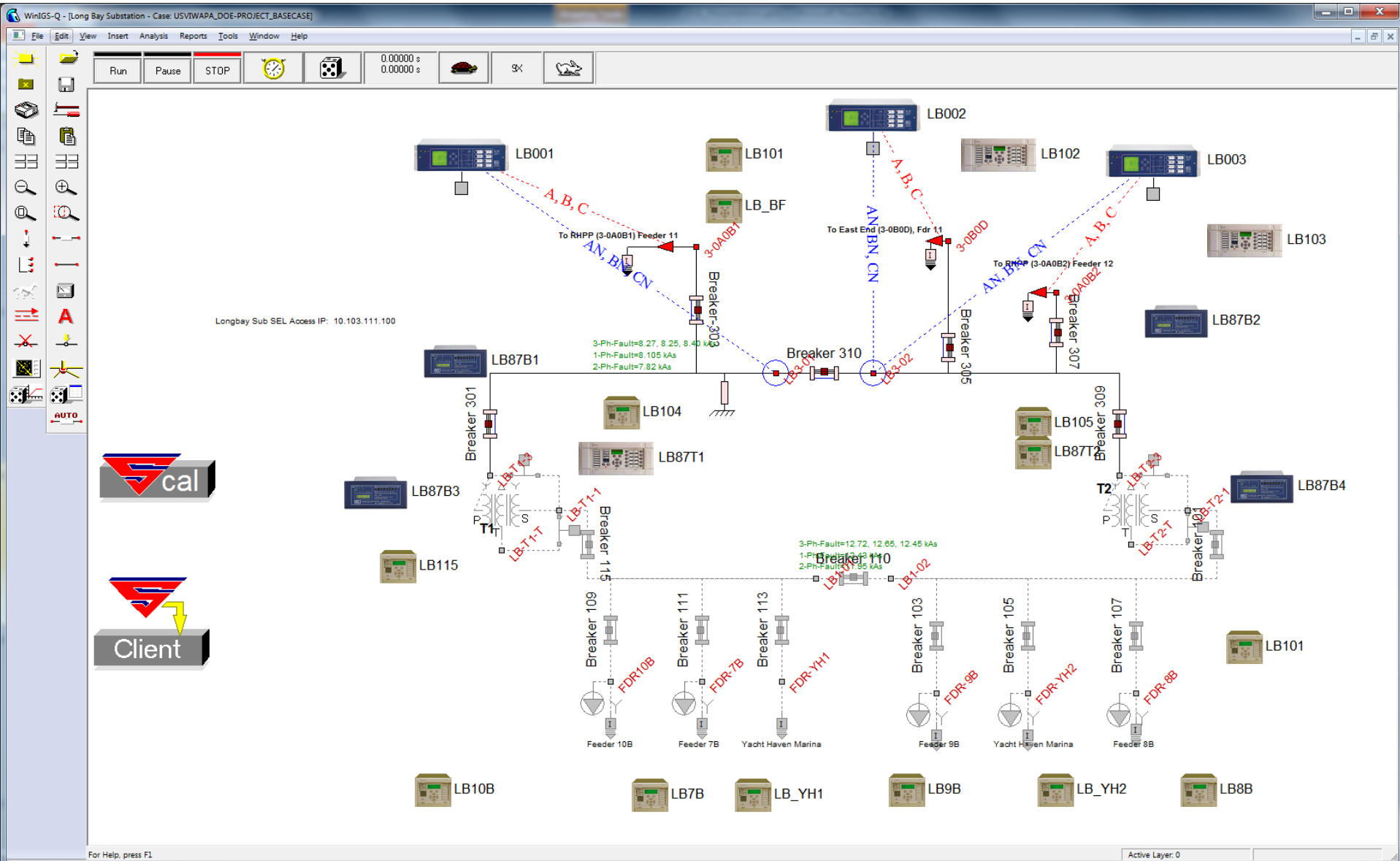




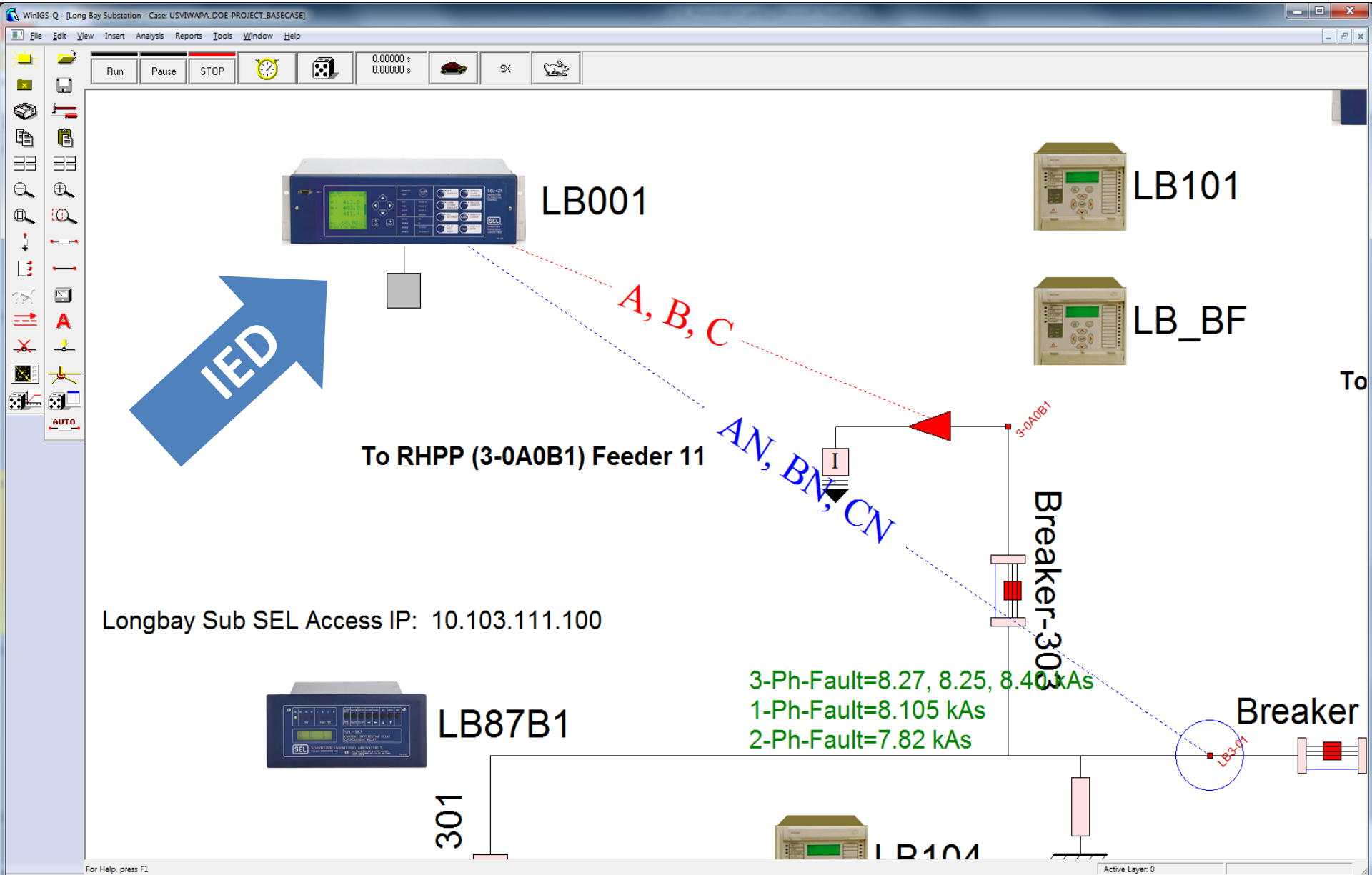
# DSE Substation Module User Interface – Long Bay



## DSE Substation Module User Interface – Long Bay



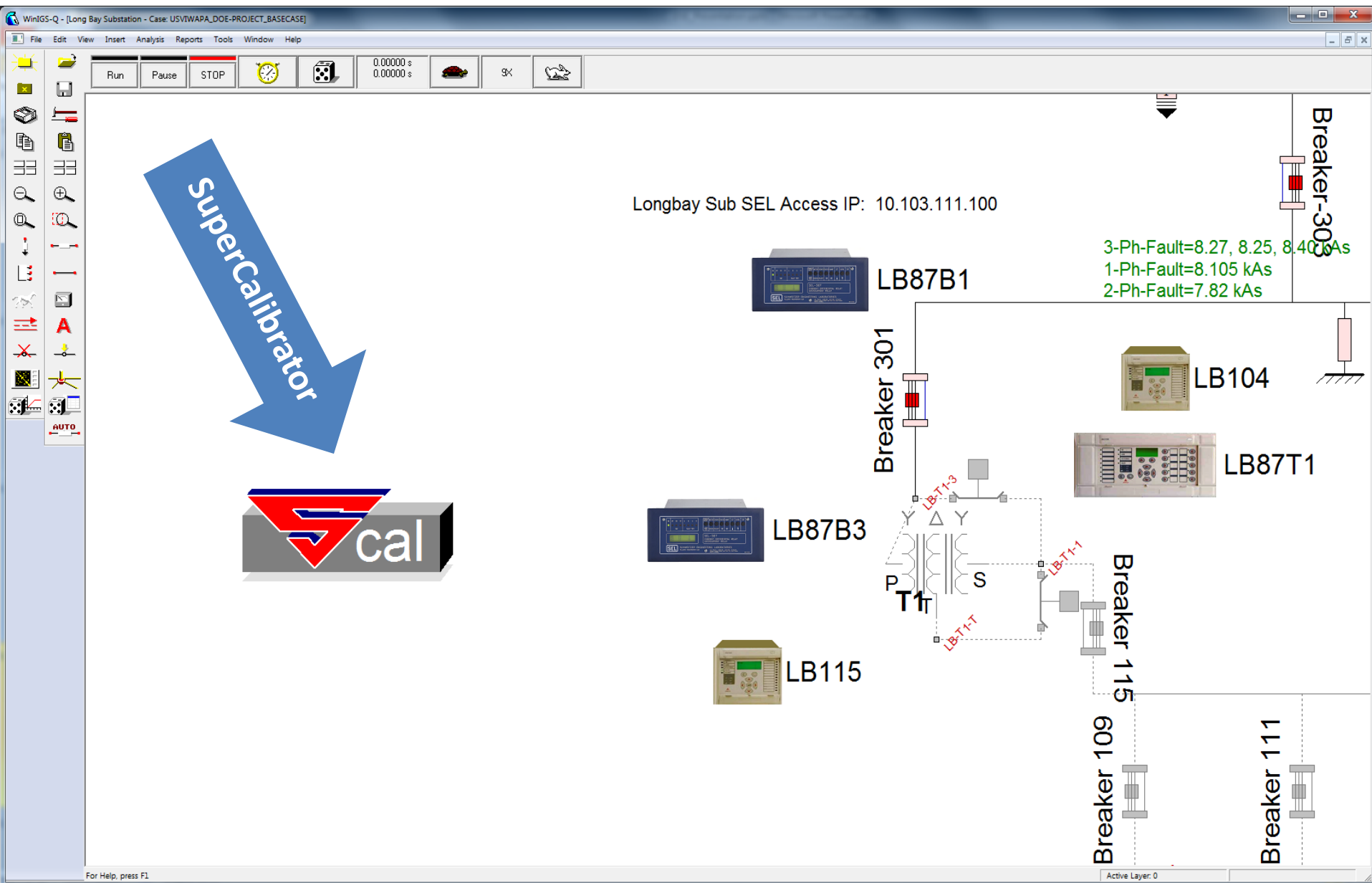
# DSE Substation Module – IED Model



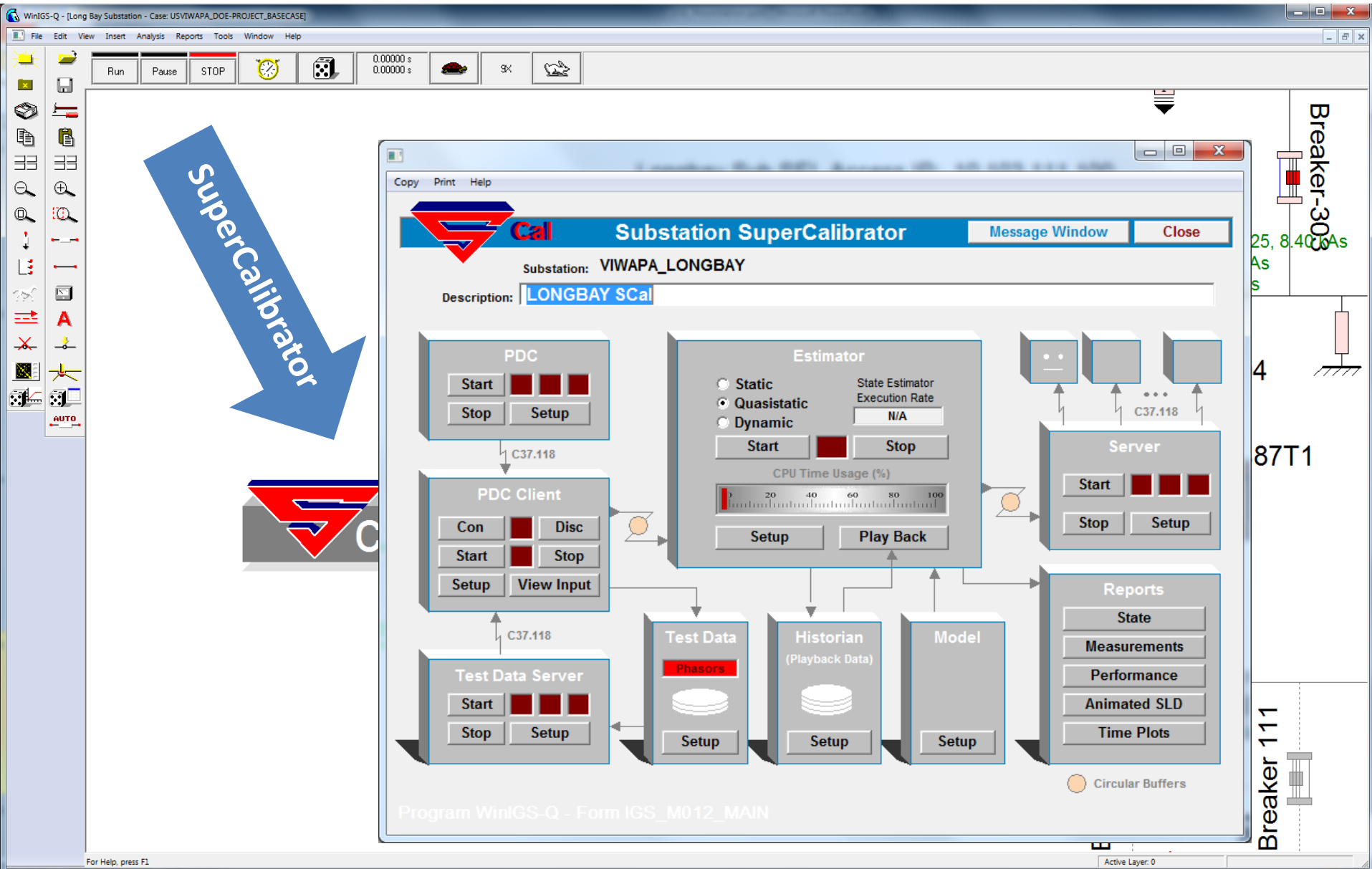
For Help, press F1

Active Layer: 0

## DSE Substation Module – The SuperCalibrator Element



# DSE Substation Module – The SuperCalibrator Element





# The SuperCalibrator SubModules

- Phasor Data Concentrator (PDC)
- PDC Client
- Test Data Server
- Historian
- Synchrophasor Server
- Reports

# The SuperCalibrator Element – PDC Component

The image displays two software windows from the WinGS-Q suite. The background window is the 'Substation SuperCalibrator' for substation 'VIWAPA\_LONGBAY'. It shows a workflow involving a PDC, PDC Client, Test Data Server, Test Data, and Historian. A large white arrow points from the PDC Client to the foreground window. The foreground window is the 'PDC host Mercator' titled 'Synchrophasor Data Concentrator'. It contains configuration fields for PDC Name, Host IP Address, Port Number, Outstation ID, Transmission Rate, Max Latency, and Max Time Skew. It also features a 'Processed IED List' table, a phasor diagram, and configuration buttons.

**Substation SuperCalibrator**

Substation: VIWAPA\_LONGBAY  
Description: LONGBAY SCAL

**PDC**  
Start Stop Setup

**PDC Client**  
Con Disc Start Stop Setup View Input

**Test Data Server**  
Start Stop Setup

**Test Data**  
Phasors Setup

**Historian (Playback Data)**  
Setup

**Estimator**  
Static Quasistatic Dynamic Start Stop  
State Estim Execution Time N/A  
CPU Time Usage (%) 20 40 60 80

Program WinGS-Q - Form IGS\_M012\_MAIN

**PDC host Mercator**

**Synchrophasor Data Concentrator** Cancel OK

PDC Name: SCAL\_PDC  
Host IP Address: 172.20.2.231  
Port Number: 2000  
Outstation ID: 1

Transmission Rate: 30 f/s  
Max Latency: 100 ms  
Max Time Skew: 5 ms  
☐ Autostart Start Stop

Server Status: RUN  
Connections: CON  
Xmit / Rcv: XMIT REC  
Max Latency:   
Buffer Usage:   
Rate = 0.0000 Hz  
Rate = 0.0000 fps

**Processed IED List**

	ID	PDC Alias	Description
1	LB002	VIW_LONGBAY_B305	SEL421/305
2	LB001	VIW_LONGBAY_B303	SEL421/303
3	LB003	VIW_LONGBAY_B307	SEL421/307

Add All Remove All Add Selected Remove Edit

Get Config Edit Config Clear

Program WinGS-Q - Form IGS\_PDATACON


# PDC Component Attributes

The screenshot shows the 'PDC host Mercator' window. At the top is a menu bar with 'Copy', 'Print', and 'Help'. Below it is a title bar with the 'Cal' logo and the text 'Synchrophasor Data Concentrator'. The main area contains configuration fields: 'PDC Name' (SCAL\_PDC), 'Host IP Address' (172.20.2.231), 'Port Number' (2000), 'Outstation ID' (1), 'Transmission Rate' (30 f/s), 'Max Latency' (100 ms), and 'Max Time Skew' (5 ms). There are 'Start' and 'Stop' buttons, and an 'Autostart' checkbox. On the right, there are status indicators for 'Server Status' (RUN), 'Connections' (CON), 'Xmit / Rcv' (XMIT / RCV), 'Max Latency', and 'Buffer Usage'. Below these is a 'Processed IED List' table with columns for ID, PDC Alias, and Description. The table contains three rows of data. To the right of the table is a circular diagram with 'F = 0.0000 Hz' and 'Rate = 0.0000 fps'. At the bottom, there are buttons for 'Add All', 'Remove All', 'Add Selected', 'Remove', and 'Edit'. On the far right, there are buttons for 'Get Config', 'Edit Config', and 'Clear'.

ID	PDC Alias	Description
1	LB002	VIW_LONGBAY_B305 SEL421/305
2	LB001	VIW_LONGBAY_B303 SEL421/303
3	LB003	VIW_LONGBAY_B307 SEL421/307

- IP Parameters
- Serviced IED List
- Desired Transmission Rate
- Max Latency
- Max Time Skew
- Test Data Server
- Historian
- Synchrophasor Server
- Reports

# PDC Automatic Configuration & Channel Mapping Validation



Cal

SuperCalibrator - PDC Measurement Mapping

Cancel

OK

Substation: Long Bay Substation

	PMU (PDC)	PMU (SCal)	PDC Channel	SCal Channel	PDC Match	Type
1	VIW_LONGBAY_B305	LB002	VALPM	V_LB3-02_AN	Yes	Voltage Phasor
2			VBLPM	V_LB3-02_BN	Yes	Voltage Phasor
3			VCLPM	V_LB3-02_CN	Yes	Voltage Phasor
4			IAWPM	C_3~0B0D_L3~0B0D_1_3~0B0D_A	Yes	Current Phasor
5			IBWPM	C_3~0B0D_L3~0B0D_1_3~0B0D_B	Yes	Current Phasor
6			ICWPM	C_3~0B0D_L3~0B0D_1_3~0B0D_C	Yes	Current Phasor
7	VIW_LONGBAY_B303	LB001	VALPM	V_LB3-01_AN	Yes	Voltage Phasor
8			VBLPM	V_LB3-01_BN	Yes	Voltage Phasor
9			VCLPM	V_LB3-01_CN	Yes	Voltage Phasor
10			IAWPM	C_FDR11~GC_3~0A0B1_1_3~0A0B1_A	Yes	Current Phasor
11			IBWPM	C_FDR11~GC_3~0A0B1_1_3~0A0B1_B	Yes	Current Phasor
12			ICWPM	C_FDR11~GC_3~0A0B1_1_3~0A0B1_C	Yes	Current Phasor
13	VIW_LONGBAY_B307	LB003	VALPM	V_LB3-02_AN	Yes	Voltage Phasor
14			VBLPM	V_LB3-02_BN	Yes	Voltage Phasor
15			VCLPM	V_LB3-02_CN	Yes	Voltage Phasor
16			IAWPM	C_FDR12~GC_3~0A0B2_1_3~0A0B2_A	Yes	Current Phasor
17			IBWPM	C_FDR12~GC_3~0A0B2_1_3~0A0B2_B	Yes	Current Phasor

Update From File

Save to File

Clear

Auto-Set

Verify PDC Mapping

All Measurements matched with PDC Channels

Program WinIGS-Q - Form IGS\_M012\_MEASMAP

# SuperCalibrator PDC Client – Setup Window

**Substation SuperCalibrator**

Substation: VIWAPA\_LONGBAY  
Description: LONGBAY SCaI

**PDC**  
Start [ ] [ ] [ ]  
Stop [ ] [ ] [ ]  
Setup [ ]

**PDC Client**  
Con [ ] Disc [ ]  
Start [ ] Stop [ ]  
Setup [ ] View Input [ ]

**Test Data Server**  
Start [ ] Stop [ ]  
Setup [ ]

**Estimator**  
Static [ ] Quasistatic [ ] Dynamic [ ]  
State Estimator Execution Rate: N/A  
CPU Time Usage (%): [ ]  
Start [ ] Stop [ ]  
Setup [ ] Play Back [ ]

**Communication Parameters**

Local IP Address: 172.20.2.231  
Local Port Number: 2000  
Outstation IP Address: 172.20.2.231  
Outstation Port Number: 2000  
Outstation ID: 10

Connect [ ] Disconnect [ ] Frame Window [ ] Set Rate [ ]  
Start [ ] Stop [ ] Copy CFG [ ]  
Buffer Usage: 0 %  
Protocol: ☒ TCP ☐ UDP-1 ☐ UDP-2  
☐ Autostart ☐ Adjust Clock

**Phasor Diagram**

F = 0.0000 Hz  
Time: 23:16:52.266666  
DF/DT = 0.0000 Hz/sec  
Rate = 60.0000 fps

☐ Save Stream to File: SynchroFile\_001  
**Edit Measurement Mapping**

Already Disconnected  
Connecting...  
Connected  
Requesting Configuration Frame  
Requesting Configuration Frame  
Received Configuration Frame

Program WinIGS-Q - Form IGS\_M012\_MAIN

Program WinIGS-Q - Form IGS\_M012\_CLIENT

# SuperCalibrator PDC Client – Input View Window

The screenshot displays the SuperCalibrator PDC Client software interface. The main window is titled "Substation SuperCalibrator" and shows the substation name "VIWAPA\_LONGBAY" and description "LONGBAY SCal". It includes a "PDC" section with "Start", "Stop", and "Setup" buttons, and a "PDC Client" section with "Con", "Disc", "Start", "Stop", "Setup", and "View Input" buttons. A "Test Data Server" section is also visible. A large white arrow points from the "View Input" button to the "PDC Incoming Data Report" window.

The "PDC Incoming Data Report" window is titled "PDC Incoming Data Report" and shows the substation name "VIWAPA\_LONGBAY". It contains a table of incoming data with columns: IED, Name, Value, and Plot. The table lists 25 entries, including PMU\_676, PMU\_677, and PMU\_679, with values for voltage, current, and phase angle.

Below the table, the "Time Stamp" is displayed as "12/31/1969, 19:00:01.000000". There are buttons for "Freeze", "Add/Remove", "Add All", and "Remove All".

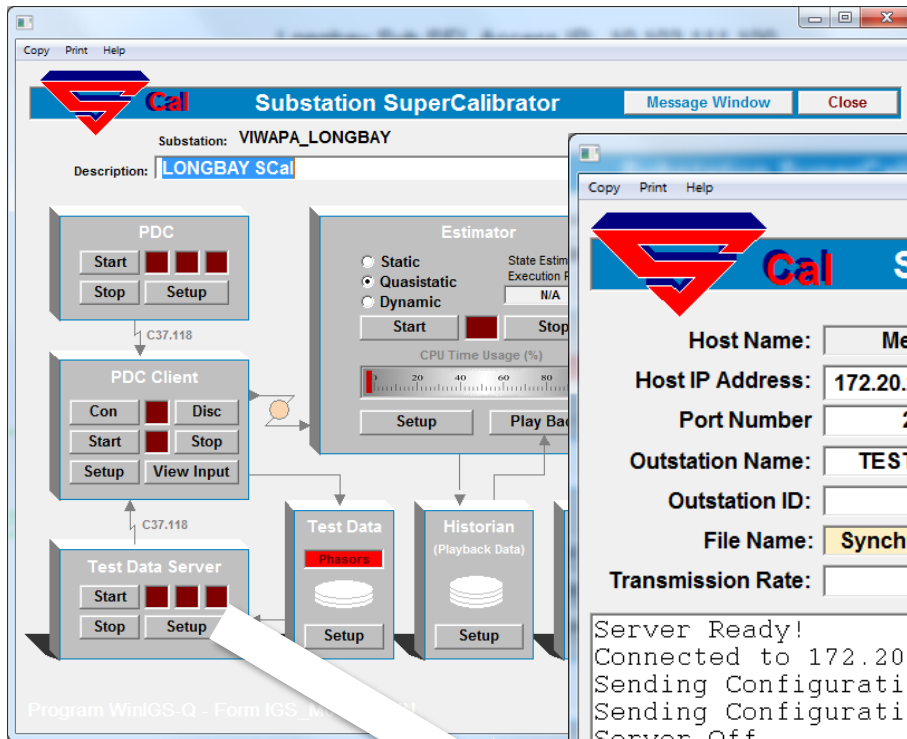
On the right side of the report window, there is a phasor diagram showing voltage and current phasors for various buses (e.g., 162, 163, 164, 165, 166, 167, 168, 169, 170, 171, 172, 173, 174, 175, 176, 177, 178, 179, 180, 181, 182, 183, 184, 185, 186, 187, 188, 189, 190, 191, 192, 193, 194, 195, 196, 197, 198, 199, 200). The frequency is indicated as  $F = 0.0000 \text{ Hz}$  and the derivative of frequency is  $DF/DT = 0.0000 \text{ Hz/sec}$ .

Program WinIGS-Q - Form IGS\_M012\_MAIN

Program WinIGS-Q - Form IGS\_M012\_CLIENT\_INCOMINGDATA

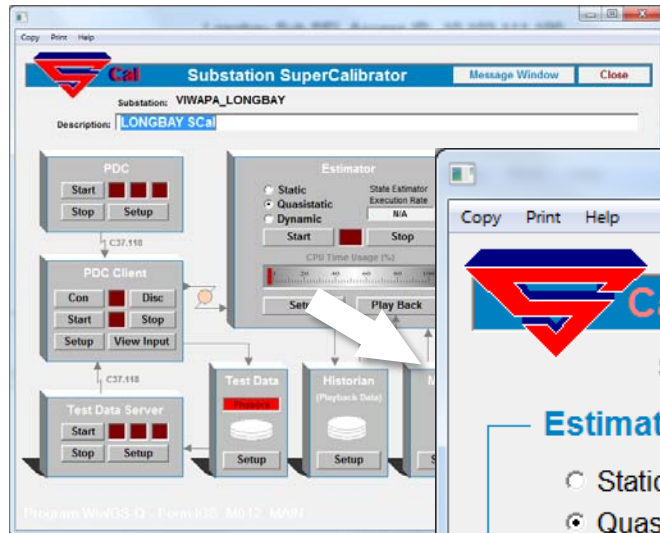


# Test Data Server – Setup Window



The screenshot shows the 'Synchrophasor Test Server' window. It has a menu bar with 'Copy', 'Print', and 'Help'. The title bar includes the 'Cal' logo and the text 'Synchrophasor Test Server'. There are 'Cancel' and 'OK' buttons in the top right. The main area contains configuration fields: 'Host Name: Mercator', 'Host IP Address: 172.20.2.231', 'Port Number: 2000', 'Outstation Name: TEST\_Server', 'Outstation ID: 10', 'File Name: SynchroFile\_002', and 'Transmission Rate: 60 f/s'. There are checkboxes for 'Autostart' and 'Infinite Loop'. A 'Data Source' section has radio buttons for 'Synchrophasor File', 'Phasor Data', and 'Time Domain Data'. On the right, there are 'Start' and 'Stop' buttons, and a status section showing 'Server Status: RUN', 'Connections: CON', 'Transmit: XMIT', 'Receive: REC', and 'Buffer Usage: 0 %'. At the bottom, there's a text area with the following log messages: 'Server Ready!', 'Connected to 172.20.2.231, Port 2000', 'Sending Configuration Frame', 'Sending Configuration Frame', 'Server Off', 'Server Ready!', 'Connected to 172.20.2.231, Port 2000', 'Sending Configuration Frame'. To the right of the text area is a phasor diagram showing a circular plot with vectors labeled 'V1', 'V2', 'V3', 'V4', 'V5', 'V6', 'V7', 'V8', 'V9', 'V10', 'V11', 'V12', 'V13', 'V14', 'V15', 'V16', 'V17', 'V18', 'V19', 'V20', 'V21', 'V22', 'V23', 'V24', 'V25', 'V26', 'V27', 'V28', 'V29', 'V30', 'V31', 'V32', 'V33', 'V34', 'V35', 'V36', 'V37', 'V38', 'V39', 'V40', 'V41', 'V42', 'V43', 'V44', 'V45', 'V46', 'V47', 'V48', 'V49', 'V50', 'V51', 'V52', 'V53', 'V54', 'V55', 'V56', 'V57', 'V58', 'V59', 'V60'. The diagram is titled 'Rate = 60.0 frames/sec' and 'Time = 31.3167 seconds'. The bottom of the window shows 'Program WinIGS-Q - Form IGS\_M012\_TESTSRV'.

# DSE - Estimator Setup Window



The 'SuperCalibrator - Estimator Setup' dialog box is shown, with the substation name 'VIWAPA\_LONGBAY'.

**Estimation Options**

- ☐ Static
- ☒ QuasiDynamic
- ☐ Dynamic
- ☐ Apply Measurement Error Correction
- Frame Skip:  Estimation Performed Once every N Frames Set to 1 for no skipped frames

**Metrics**

- ☒ K Factor Plot
- ☐ Standard Deviation

**Output**

- ☐ Measurement COMTRADE
- ☐ Store Playback Data

**Debug**

- ☐ Debug Output
- 
- 

**Bad Data Rejection**

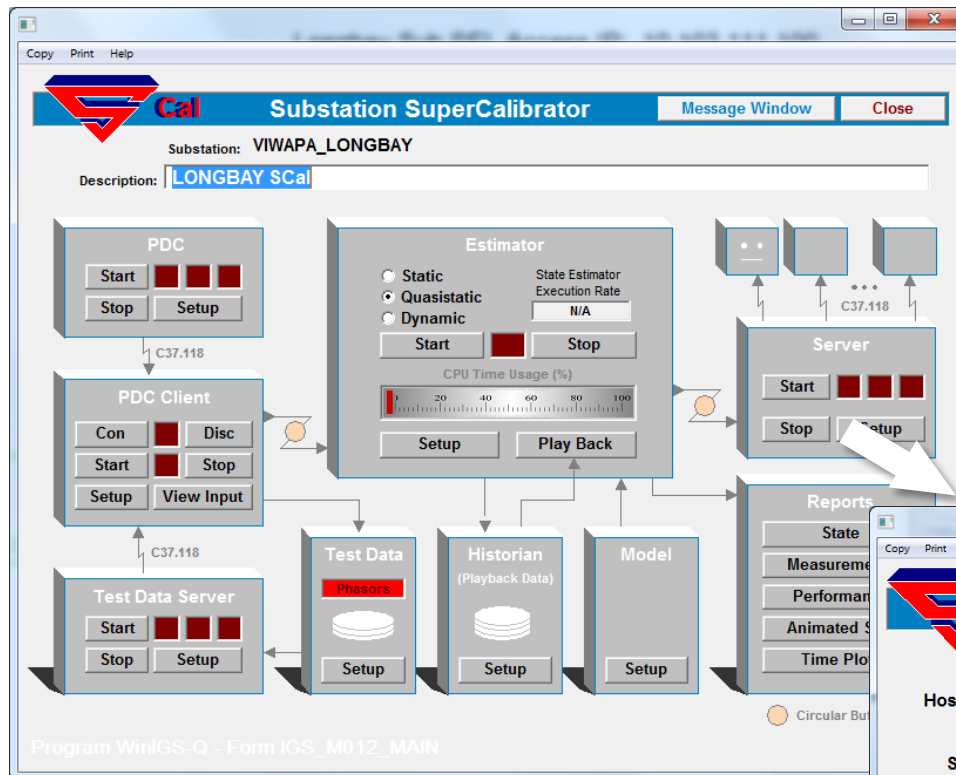
- ☐ Active
- Trigger for K >
- @ Probability
- Minimum Redundancy

**GUI Settings**

- Plot Buffer Size
- Display Refresh Rate  per second

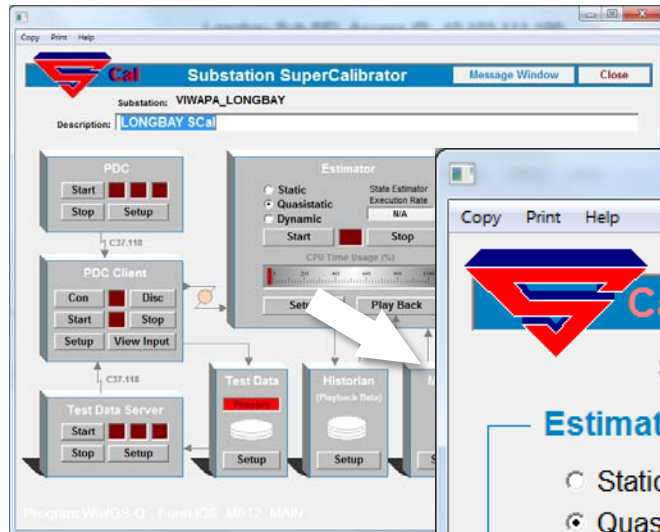
Program WinGS-Q - Form IGS\_M012\_ESTIMATORSETUP

# DSE - Synchrophasor Server – Setup Window



The screenshot shows the 'Synchrophasor Server' configuration window. It has a menu bar (Copy, Print, Help) and a title bar with the 'Cal' logo. Below the title bar, there are buttons for 'Cancel' and 'OK'. The main area contains configuration fields: 'Host Name' (Mercator), 'Host IP Address' (172.20.2.231), 'Port Number' (3000), 'Station Name' (RHPP Server), 'Station ID' (10), and 'Phasor Index' (3). On the right, there are status indicators: 'Server Status' (RUN), 'Connections' (CON), 'Transmit' (XMIT), 'Receive' (REC), and 'Buffer Usage' (0 %). Below these are 'Start', 'Stop', 'Autostart', 'Reserved', and 'Clear' buttons. At the bottom left, there is a diagram of a phasor circle with 'F = 60.0000 Hz' and 'DF/DT = 0.0000 Hz/sec'. The footer text is 'Program WinIGS-Q - Form IGS\_M012\_SERVER'.

# DSE - Estimator Setup Window



**SuperCalibrator - Estimator Setup** [Cancel] [OK]

Substation: VIWAPA\_LONGBAY

**Estimation Options**

- ☐ Static
- ☒ QuasiDynamic
- ☐ Dynamic
- ☐ Apply Measurement Error Correction

Frame Skip  Estimation Performed Once every N Frames  
Set to 1 for no skipped frames

**Metrics**

- ☒ K Factor Plot
- ☐ Standard Deviation

**Output**

- ☐ Measurement COMTRADE
- ☐ Store Playback Data

**Debug**

- ☐ Debug Output

[Init Config] [Update Config]

**Bad Data Rejection**

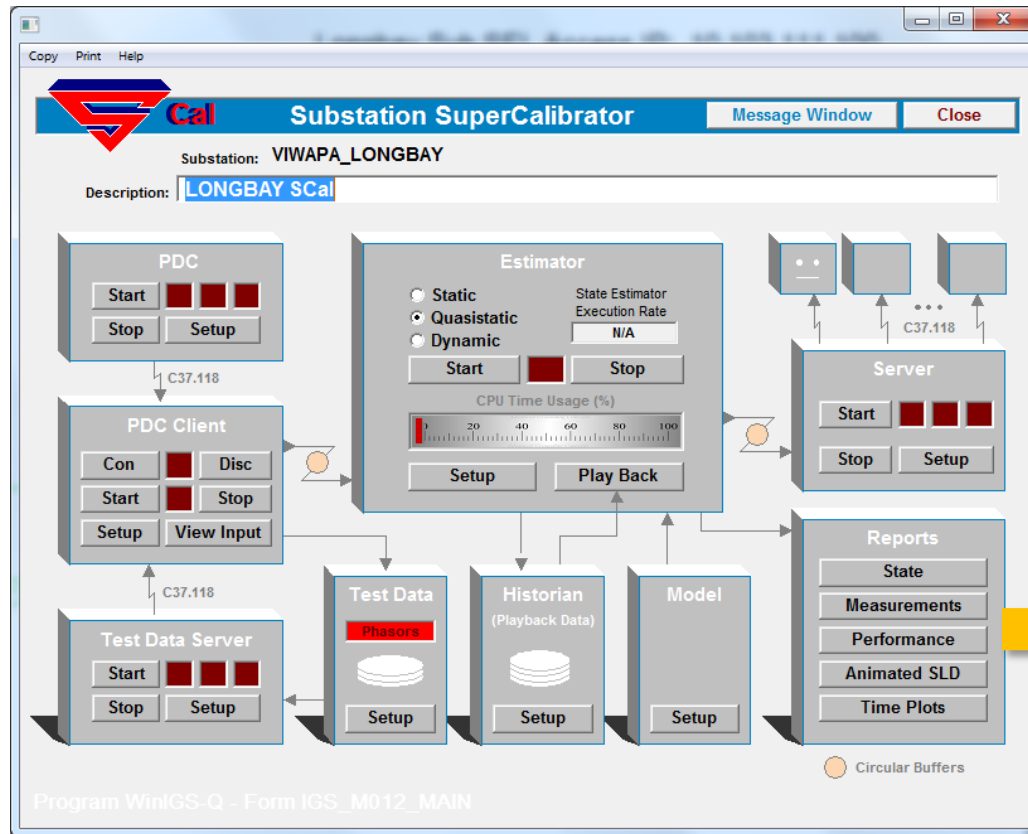
- ☐ Active
- Trigger for K >
- @ Probability
- Minimum Redundancy

**GUI Settings**

- Plot Buffer Size
- Display Refresh Rate  per second

Program WinIGS-Q - Form IGS\_M012\_ESTIMATORSETUP

# DSE - Reports



- State
- Measurements
- Performance Metrics
- Animated 3D - SLD
- Time Plots

# Summary

- Distributed State Estimation Enables State Estimation at Each Cycle (Sixty Times per Second).
- The Approach Requires a Detailed Three Phase Substation Model and at Least One PMU Device.
- Four Demonstration Projects Have Provided and Will Provide Tremendous Experience.
- The Approach Has Enabled a New Disturbance Play Back Which Has Proven to be Very Useful.