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

DoE-NETL Peer Review Meeting
October 19-20, 2010

HMS Host System

Three Phase Asymmetric Power System Model
Three Phase Harmonic State Estimation

First Wide Area Monitoring System in Eastern Interconnection
New York Power Authority
Ultimate Objective of This Project

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.
Accomplishments in FY2010

1. Completed the Distributed Dynamic State Estimator (DDSE) using synchrophasor technology

2. Demonstrate the DDSE in the laboratory

3. Performed Timing Experiments on the DDSE

4. Completed the generator parameter identification estimation

5. Completed the design of the stability monitoring and prediction of eminent instabilities

6. Completed the design of the disturbance “Play Back”
Data/Measurements from all PMUs, Relays, IEDs, Meters, FDRs, etc are collected via a Local Area Network in a data concentrator.

The data is used in a dynamic state estimator which provides the validated and high fidelity dynamic model of the system.

Bad data detection and rejection is achieved because of high level of redundant measurements at this level.
Distributed Dynamic State Estimation Implementation

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
Approach 1:
Electrical transients are neglected, Electromechanical Dynamics are Modeled – Quasi-Static Model (DQSE)

Approach 2:
Electrical transients and Electromechanical Dynamics are Modeled - Full Transient Model – (DDSE)

In both approaches we use an object oriented formulation that allows the same organization of the algorithms
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):

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

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):

\[
z_k(t) = \sum_i a_{i,t}^k \cdot x_i(t) + \sum_i a_{i,tm}^k \cdot x_i(t_m) + \sum_{i,j} b_{i,j,t}^k \cdot x_i(t) \cdot x_j(t) + \sum_{i,j} b_{i,j,tm}^k \cdot x_i(t_m) \cdot x_j(t_m) + c_k(t) + \eta_k
\]
Important Issue: Conversion of Non-Synchronized Measurements into Phasors

Data from relays that are not GPS synchronized are referenced to the phase A voltage. The phase angle of the phase A voltage is introduced as an “unknown state” that is estimated by the DSE.

\[
\tilde{A}_{\text{sync}} = \tilde{A}_{\text{meas}} e^{j\alpha}
\]

\(\alpha\) 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.
Properties of the Distributed Dynamic State Estimator

IF:
(a) All measurements are GPS synchronized (PMU Data)
(b) All models are linear (transmission lines, transformers, capacitors, reactors)

→ Linear State Estimator

Non-linear models (generators, etc.) or non-GPS synchronized data (usual relays, SCADA data, etc.)

→ Quadratic State Estimator
Numerical Experiments with Simple Systems

Numerical Experiments with NYPA’s system (Blenheim-Gilboa Plant)

Actual Implementation on Scaled System (Laboratory)
Example System: Bus 1 Voltages - Fault Scenario

Use of Local Measurements Only

Fault at Bus 3
Example System: Bus 2 Voltages - Fault Scenario

Use of Local Measurements Only

Fault at Bus 3
NYPA BLENHEIM-GILBOA PLANT MODEL
DDSE: BUS BG-UNIT1  DSE Time Step: 0.5 msec
# DDSE: State Estimation Metrics Computation

## Estimate Quality Assessment

<table>
<thead>
<tr>
<th>State Name</th>
<th>Estimated Value (kV)</th>
<th>States Standard Deviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>78 104D00821_12_tm</td>
<td>-0.029577</td>
<td>0.099916</td>
<td>Internal State of Device 821</td>
</tr>
<tr>
<td>79 104D00821_13_tm</td>
<td>-8.587795</td>
<td>0.313235</td>
<td>Internal State of Device 821</td>
</tr>
<tr>
<td>80 104D00821_14_tm</td>
<td>0.735355</td>
<td>0.027328</td>
<td>Internal State of Device 821</td>
</tr>
<tr>
<td>81 BG-UNIT3_A_t</td>
<td>13.454700</td>
<td>0.070711</td>
<td>Internal State of Device 821</td>
</tr>
<tr>
<td>82 BG-UNIT3_A_tm</td>
<td>13.454700</td>
<td>0.070711</td>
<td>Internal State of Device 821</td>
</tr>
<tr>
<td>83 BG-UNIT3_B_t</td>
<td>-3.280900</td>
<td>0.070711</td>
<td>Internal State of Device 821</td>
</tr>
<tr>
<td>84 BG-UNIT3_B_tm</td>
<td>-3.280900</td>
<td>0.070711</td>
<td>Internal State of Device 821</td>
</tr>
<tr>
<td>85 BG-UNIT3_C_t</td>
<td>-10.087800</td>
<td>0.070711</td>
<td>Internal State of Device 821</td>
</tr>
<tr>
<td>86 BG-UNIT3_C_tm</td>
<td>-10.087800</td>
<td>0.070711</td>
<td>Internal State of Device 821</td>
</tr>
<tr>
<td>87 BG-GB345_A_t</td>
<td>215.504200</td>
<td>0.050000</td>
<td>Internal State of Device 821</td>
</tr>
<tr>
<td>88 BG-GB345_B_t</td>
<td>50.850600</td>
<td>0.050000</td>
<td>Internal State of Device 821</td>
</tr>
<tr>
<td>89 BG-GB345_C_t</td>
<td>-265.631000</td>
<td>0.050000</td>
<td>Internal State of Device 821</td>
</tr>
<tr>
<td>90 BG-GB345_N_t</td>
<td>0.028700</td>
<td>0.097542</td>
<td>Internal State of Device 821</td>
</tr>
<tr>
<td>91 104D00826_00_t</td>
<td>0.025721</td>
<td></td>
<td>Internal State of Device 826</td>
</tr>
</tbody>
</table>

## Measurements Quality Assessment

<table>
<thead>
<tr>
<th>Measurement Node</th>
<th>Meas. Phase</th>
<th>IED ID</th>
<th>Measurement Type</th>
<th>Device ID</th>
<th>Measurement Std</th>
</tr>
</thead>
<tbody>
<tr>
<td>BG-UNIT1</td>
<td>A</td>
<td>012</td>
<td>Voltage Phasor</td>
<td>-1</td>
<td>0.070711</td>
</tr>
<tr>
<td>BG-UNIT1</td>
<td>A</td>
<td>012</td>
<td>Voltage Phasor</td>
<td>-1</td>
<td>0.070711</td>
</tr>
<tr>
<td>BG-UNIT1</td>
<td>B</td>
<td>012</td>
<td>Voltage Phasor</td>
<td>-1</td>
<td>0.070711</td>
</tr>
<tr>
<td>BG-UNIT1</td>
<td>B</td>
<td>012</td>
<td>Voltage Phasor</td>
<td>-1</td>
<td>0.070711</td>
</tr>
<tr>
<td>BG-UNIT1</td>
<td>C</td>
<td>012</td>
<td>Voltage Phasor</td>
<td>-1</td>
<td>0.070711</td>
</tr>
<tr>
<td>BG-UNIT1</td>
<td>C</td>
<td>012</td>
<td>Voltage Phasor</td>
<td>-1</td>
<td>0.070711</td>
</tr>
<tr>
<td>BG-UNIT1</td>
<td>A</td>
<td>012</td>
<td>Current Phasor</td>
<td>823</td>
<td>0.057716</td>
</tr>
<tr>
<td>BG-UNIT1</td>
<td>A</td>
<td>012</td>
<td>Current Phasor</td>
<td>823</td>
<td>0.057671</td>
</tr>
<tr>
<td>BG-UNIT1</td>
<td>---</td>
<td>012</td>
<td>Device Virtual Meas.</td>
<td>823</td>
<td>0.100000</td>
</tr>
<tr>
<td>BG-UNIT1</td>
<td>---</td>
<td>012</td>
<td>Device Virtual Meas.</td>
<td>823</td>
<td>0.100000</td>
</tr>
<tr>
<td>BG-UNIT1</td>
<td>---</td>
<td>012</td>
<td>Device Virtual Meas.</td>
<td>823</td>
<td>0.099937</td>
</tr>
</tbody>
</table>
DDSE: Timing Results

<table>
<thead>
<tr>
<th>System States</th>
<th>68</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual Measurements</td>
<td>168</td>
</tr>
<tr>
<td>Total Measurements</td>
<td>516</td>
</tr>
</tbody>
</table>

Total Measurements (Actual + Virtual)

Average DDSE Execution Time per Time Step: 60 msec (Variability: 2.0 msec)

- PC, i7-930 Processor, 2.8 Gz
- Code is not optimized
- We have identified a number of efficiency improvements
DQSE: BUS BG_LEEDS (Inside Substation)
Time Step: 16 msec (60 pps)
DQSE: BUS BG_UNIT1 (Inside Substation)
Time Step: 16 msec (60 pps)

**BUS BG UNIT1 Phase C Voltage Magnitude**

- Simulated Value
- Estimated Value

**BUS BG UNIT1 Phase C Voltage Angle**

- Simulated Value
- Estimated Value
DQSE: BUS LEEDS345 (Remote T-Line Side)  
Time Step: 16 msec (60pps)

**BUS LEEDS345 Phase A Voltage Magnitude**

- Simulated Value
- Estimated Value

**BUS LEEDS345 Phase A Voltage Angle**

- Simulated Value
- Estimated Value
### DQSE: State Estimation Metrics Computation

#### Estimate Quality Assessment

<table>
<thead>
<tr>
<th>Node Name</th>
<th>Estimated Value (kV)</th>
<th>Status Standard Deviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BG-GA345_B_L_t</td>
<td>-181.286702</td>
<td>0.049937</td>
<td>--</td>
</tr>
<tr>
<td>BG-GA345_C_R_t</td>
<td>-171.636803</td>
<td>0.049937</td>
<td>--</td>
</tr>
<tr>
<td>BG-GA345_C_L_t</td>
<td>60.419501</td>
<td>0.049937</td>
<td>--</td>
</tr>
<tr>
<td>BG-GA345_N_R_t</td>
<td>0.036790</td>
<td>0.049195</td>
<td>--</td>
</tr>
<tr>
<td>BG-GA345_N_L_t</td>
<td>0.016390</td>
<td>0.049195</td>
<td>--</td>
</tr>
<tr>
<td>104D00823_00_R_</td>
<td>10.476066</td>
<td>0.013720</td>
<td>Internal State of Device 823</td>
</tr>
<tr>
<td>104D00823_00_I_</td>
<td>11.719066</td>
<td>0.013720</td>
<td>Internal State of Device 823</td>
</tr>
<tr>
<td>104D00823_01_R_</td>
<td>4.648596</td>
<td>0.013720</td>
<td>Internal State of Device 823</td>
</tr>
<tr>
<td>104D00823_01_I_</td>
<td>-14.880028</td>
<td>0.013720</td>
<td>Internal State of Device 823</td>
</tr>
</tbody>
</table>

#### Measurement Node

<table>
<thead>
<tr>
<th>Measurement Node</th>
<th>Meas. Phase</th>
<th>IED ID</th>
<th>Measurement Type</th>
<th>Device ID</th>
<th>Measurement Std</th>
</tr>
</thead>
<tbody>
<tr>
<td>BG-UNIT1</td>
<td>C</td>
<td>012</td>
<td>Voltage Phasor</td>
<td>-1</td>
<td>0.041756</td>
</tr>
<tr>
<td>BG-UNIT1</td>
<td>C</td>
<td>012</td>
<td>Voltage Phasor</td>
<td>-1</td>
<td>0.041756</td>
</tr>
<tr>
<td>BG-UNIT1</td>
<td>C</td>
<td>012</td>
<td>Voltage Phasor</td>
<td>-1</td>
<td>0.041756</td>
</tr>
<tr>
<td>BG-UNIT1</td>
<td>A</td>
<td>012</td>
<td>Current Phasor</td>
<td>823</td>
<td>0.057412</td>
</tr>
<tr>
<td>BG-UNIT1</td>
<td>A</td>
<td>012</td>
<td>Current Phasor</td>
<td>823</td>
<td>0.057412</td>
</tr>
<tr>
<td>BG-UNIT1</td>
<td>A</td>
<td>012</td>
<td>Current Phasor</td>
<td>823</td>
<td>0.057412</td>
</tr>
<tr>
<td>BG-UNIT1</td>
<td>DefaultPhase</td>
<td>012</td>
<td>Pseudo Device Meas.</td>
<td>823</td>
<td>0.098834</td>
</tr>
<tr>
<td>BG-UNIT1</td>
<td>DefaultPhase</td>
<td>012</td>
<td>Pseudo Device Meas.</td>
<td>823</td>
<td>0.098834</td>
</tr>
<tr>
<td>BG-UNIT1</td>
<td>DefaultPhase</td>
<td>012</td>
<td>Pseudo Device Meas.</td>
<td>823</td>
<td>0.098834</td>
</tr>
<tr>
<td>BG-UNIT1</td>
<td>DefaultPhase</td>
<td>012</td>
<td>Pseudo Device Meas.</td>
<td>823</td>
<td>0.098834</td>
</tr>
</tbody>
</table>
### DQSE: Timing Results

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>System States</td>
<td>96</td>
</tr>
<tr>
<td>Actual Measurements</td>
<td>192</td>
</tr>
<tr>
<td>Total Measurements (Actual + Virtual)</td>
<td>880</td>
</tr>
</tbody>
</table>

Average DQSE Execution Time per Time Step: 50 msec
(Variability: 1.5 msec)

- PC, i7-930 Processor, 2.8 Gz
- Code is not optimized
- We have identified a number of efficiency improvements
Laboratory Testing of the Distributed Dynamic State Estimator Scale Model with Instrumentation, Relays and Local Area Network
Generator Parameters Are Typically Approximate
They Must Be Accurately Estimated in Field Conditions

- The model of a large generator is complex. It is defined in terms of a number of independent parameters.
- Disturbance data can be utilized to accurately estimate the parameters of the generator in field conditions. For this purpose, the dynamic state estimator is augmented to include as states the generator parameters.
- The dynamic state estimator uses a high-fidelity physically based model of the generating unit in terms of the self and mutual impedances of the various generator coils.
- The parameter estimation method also provides the expected error on the estimated parameters as well as measures of how well the model can reproduce the disturbances.
Physical Parameters of Synchronous Generators

Physically-Based Model: No Transformations

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L_s$</td>
<td>Stator self-inductance constant part due to air-gap flux and armature leakage flux</td>
</tr>
<tr>
<td>$L_{in}$</td>
<td>Amplitude of Stator’s self-inductance varying part due to rotor saliency</td>
</tr>
<tr>
<td>$L_f$</td>
<td>Field self-inductance</td>
</tr>
<tr>
<td>$L_D$</td>
<td>D damper self-inductance</td>
</tr>
<tr>
<td>$L_Q$</td>
<td>Q damper self-inductance</td>
</tr>
<tr>
<td>$M_S$</td>
<td>Stator mutual inductance</td>
</tr>
<tr>
<td>$M_R$</td>
<td>Field D damper mutual inductance</td>
</tr>
<tr>
<td>$M_F$</td>
<td>Stator field mutual inductance</td>
</tr>
<tr>
<td>$M_D$</td>
<td>Stator D damper mutual inductance</td>
</tr>
<tr>
<td>$M_Q$</td>
<td>Stator Q damper mutual inductance</td>
</tr>
</tbody>
</table>
Synchronous Machine
Physical Parameters Identification Model

Actual Measurements

Virtual Measurements

\[ \zeta(t) = A_1 v(t) + A_2 y(t) + \eta \]

\[ 0 = \frac{dx(t)}{dt} + B_1 x(t) + B_2 y(t) + \eta \]

\[ 0 = T_{wm}(t) + \left( D_{fw} + D'_{fw} \cdot \omega_m(t) + D''_{fw} \cdot \omega_m(t)^2 \right) + \eta \]

\[ 0 = P_{em}(t) - e_{abc}(t)^T i_{al,bl,cl}(t) - e_{F,DQ}(t)^T i_{FL,DQ}(t) + \eta \]

\[ 0 = P_{em}(t) + T_e(t) \omega(t) + \eta \]

\[ 0 = y_1(t) + s(t) \cdot \omega(t) + \eta \]

\[ 0 = y_2(t) - c(t) \cdot \omega(t) + \eta \]

\[ 0 = c_2(t) - c^2(t) + s^2(t) + \eta \]

\[ 0 = s_2(t) - 2c(t)s(t) + \eta \]

\[ 0 = \left[ \lambda_{abc}(t) \right] - L(t) \left[ i_{al,bl,cl}(t) \right] + \eta \]

\[ 0 = L(t) - L_1 \cdot M_F \cdot c(t) - L_2 \cdot M_D \cdot c(t) \]

\[ - L_3 \cdot M_Q \cdot c(t) - L_4 \cdot M_F \cdot s(t) \]

\[ - L_5 \cdot M_D \cdot s(t) - L_6 \cdot M_Q \cdot s(t) \]

\[ - L_7 \cdot L_m \cdot c_2(t) - L_8 \cdot L_m \cdot s_2(t) \]

\[ - L_9 \cdot L_S - L_{10} \cdot M_S - L_{11} \cdot M_R \]

\[ - L_{12} \cdot L_f - L_{13} \cdot L_D - L_{14} \cdot L_Q + \eta \]
The dynamic state estimator is utilized to predict the transient stability or instability of a generator. The dynamic state of the system provides the **center of oscillations** of the generator swing. From this information the potential energy of the generator is computed as a generalization of the basic energy function method.

The total energy of the generator can also be trivially computed once the potential energy has been computed. The total energy is compared to the potential energy of the generator – if the total energy is higher than the peak (barrier) value of the potential energy this indicates that the generator will lose its synchronism (transient instability).

It is important to note that this approach is predictive, i.e. it identifies a transient instability before it occurs.

The figures provide visualizations of generator oscillations and the trajectory of the total energy superimposed on the system potential energy.
Example Application of Transient Stability Monitoring: Out of Step Relaying

Test System: Two generating substations connected through a two section overhead transmission line

Three phase fault in Substation 2 at time= 0.9 sec, cleared in 33 cycles

Lyapunov theory used to evaluate transient stability of the system
Impedance Based “Out of Step” Relaying

- Present State of the Art in Out of Step Relaying is Based on Impedance Tracing, Timers and Blinders.
- When Relay Asserts Out of Step Condition Unit Has Slipped a Pole.
- Unit Disconnection Must Be Delayed to Avoid Breaker Overstresses

Proposed Approach

- Monitor total energy and check if it is higher than the peak (barrier) value of the potential energy. When total energy becomes higher than the barrier value, instability is detected.
- Predictive Out of Step Protection Scheme
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)
System FULL MODEL stored once a day in WinIGS format.
Time of day can be arbitrarily selected, for example at 2 am.

Example storage:

MODEL 3
DEV_TITLE Long Bay Substation
NUMERIC_ID 77
NET_LAYER 3
GEO_COORDINATES 18.339260000 -64.920927000
COORDINATES -137 2 -144 1 -137 4 -138 -1 -145 0 -145 7 -145 4 -141 6
COORDINATES -141 -2 -142 2
INTERFACES FDR-9B 3-0A0B2 FDR-8B FDR10B FDR-YH1 3-0B0D 3-0A0B1 FDR-7B
INTERFACES FDR-YH2
PARAMETERS LONGBAY VIWAPA VIWAPA
END_MODEL

MODEL 123
DEV_TITLE Feeder #11, Long Bay to East End Substation - Section 1
NUMERIC_ID 246
COORDINATES -145 7 -145 10 -141 13 -132 13 -126 10 -120 6 -114 4 -109 3
COORDINATES -107 1 -105 -2
CIRCUITS 1
INTERFACES 3-0B0D_N 3-0B0D_A 3-0B0D_N 3-0B0D_B 3-0B0D_N 3-0B0D_C 3-0B0D_N UG350_N
INTERFACES UG350_A UG350_N UG350_B UG350_N UG350_C UG350_N
PARAMETERS 5 7 14.40 3868.0 0.0 0.0 0.0 CABLE
PARAMETERS VI34KV750KCM-CU-TS -0.10802 -3.09671 CKT1 CABLE VI34KV750KCM-CU-TS -0.00119 -2.92351
PARAMETERS CKT1 CABLE VI34KV750KCM-CU-TS 0.11108 -3.09234 CKT1 CABLE CONDUIT8
PARAMETERS -0.00656 -2.93099 CKT1 COPPER 4/0 0.00667 -3.18108 CKT1
PARAMETERS 1 CKT1 5499.0 25.0000 34.5000
END_MODEL

MODEL 123
...........
Substation Storage Scheme
Full Model + MODEL CHANGES + Data

Report system changes by exception – UTC time

MODEL_CHANGE
  TIME 1267771497 450123
  TYPE XFMR_TAP
  DEVICE_ID 1265
  VALUE R12
END_MODEL_CHANGE

MODEL_CHANGE
  TIME 1267771791 609355
  TYPE BREAKER_OPERATION
  DEVICE_ID 3409
  VALUE CLOSE
END_MODEL_CHANGE

... ...

SOC + Fractional Second March 05, 01:44:57.450123

File Format – Each line begins with a keyword optionally followed by one or more arguments.
Substation Storage Scheme
Full Model + MODEL CHANGES + Data

Storage of state data: at each occurrence of the state estimator, the estimated states are stored in COMTRADE-like format. The following File Types Are Used:

**Configuration Files:** Description of State Names Types and Locations

**State Data Files:** State Values plus Model Change Information

**Triggered Event Files:** Waveform data recorded for each triggering event in COMTRADE format.
Substation Storage Scheme
Full Model + MODEL CHANGES + Data

Storage of state data: at each occurrence of the state estimator, the estimated states are stored in COMTRADE-like format.

**Configuration File – One for Each Day**

*File Naming Standard:* CompanyName_SubstationName_SOC.scf

*File Content:*

<Title or Brief Description>
<SOC> <uSec>
<Number of States>
<State Name>, <State Type>, <Bus Name>, <Phase>, <Power Device ID>
<State Name>, <State Type>, <Bus Name>, <Phase>, <Power Device ID>
...
...

*Where:*

- SOC: is the Second of Century Time Code defined as the number of seconds elapsed since midnight of January 1, 1970 (in UTC time)
- uSec is a fractional second value in microseconds.
- Above structure repeated each time the set of states changes
Storage of state data: at each occurrence of the state estimator, the estimated states are stored in COMTRADE-like format.

**State Data File – One for Each Day**

*File Naming Standard:* CompanyName_SubstationName_SOC.sdf

*File Content:*

```plaintext
STATE_VECTOR <SOC> <uSec> <State Value> <State Value> <State Value>...
STATE_VECTOR <SOC> <uSec> <State Value> <State Value> <State Value>...
...
STATE_VECTOR <SOC> <uSec> <State Value> <State Value> <State Value>...
MODEL_CHANGE
   TIME 1267771791 609355
   TYPE BREAKER_OPERATION
   DEVICE_ID 3409
   VALUE CLOSE
END_MODEL_CHANGE
STATE_VECTOR <SOC> <uSec> <State Value> <State Value> <State Value>...
STATE_VECTOR <SOC> <uSec> <State Value> <State Value> <State Value>...
...
```
Storage of state data: at each occurrence of the state estimator, the estimated states are stored in COMTRADE-like format.

**Triggered Event Files – One for Each Event**

*File Naming Standard:*

CompanyName_SubstationName_SOC.cfg
CompanyName_SubstationName_SOC.dat

*File Content:*

Standard COMTRADE Waveform File Format
**Project Deliverables**: We expect to install a Fully Distributed Dynamic State Estimator on the USVI WAPA system and on the Gilboa/Manheim Pumped Hydro plant of NYPA with several Applications (Generator Parameter Estimation and Stability Monitoring Demonstration)

![View of the proposed system for WAPA's Longbay substation](image)

Installation of PMUs is progressing nicely:

- By end of FY10:
  - 7 SEL 421
  - 4 SEL 521
  - 3 SEL 734
  - 1 GE 60
Proposed/Planned Accomplishments for FY11- Onward

Demonstration of Generator Parameter Identification and Stability Monitoring at the Gilboa Plant (NYPA)

- Four Unit Power Plant (Pumped Hydro) Attached to the 345 kV Transmission System
- Generator Parameters Have Been in the Past Computed and Verified via Other Methods