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# Use of Phasor Measurements, SCADA and IED Data to Improve State Estimation Procedures

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## Abstract

State estimators have shown a poor overall performance with an average of 5% non-convergent cases, especially when the system is heavily loaded. The theoretical basis for this behavior has been reported earlier. In the presence of a variety of IEDs and phasor measurement units and the data available from IEDs and phasor measurements, it makes sense to seek utilization of this data for the purpose of improving the performance of state estimators. The paper describes a methodology for this purpose. The available data from IEDs and phasor units are correlated to a three phase model of the system. A new state estimation method is proposed utilizing a three phase asymmetric model (hybrid state estimator). The procedure has been implemented on TVA's 500 kV transmission system. The paper describes the approach and the expected benefits from this project.

### 1. Introduction

Control and operation of electric power system is based on the ability to determine the state of the system in real time. Power system state estimation has been introduced in the 60s to achieve this objective. The initial implementation was based on single phase measurements and a power system model that is assumed to operate under single frequency, balanced conditions and symmetric system model. These assumptions are still prevalent today. The single frequency, balanced and symmetric system assumptions have simplified the implementation but have generated practical problems. The experience is that the State Estimation problem does not have 100% performance, i.e. there are cases and time periods that the SE algorithm will not converge. There are practical and theoretical reasons for this and they are explained in [7]. The state estimator can be drastically improved with GPS synchronized measurements. Specifically, recent technology of disturbance recorders introduced synchronized measurements. Synchronization is achieved via a GPS (Global Positioning System) which provides the synchronizing signal with accuracy of 1 $\mu$sec. This time precision is translated into a precision of 0.02 degrees of the US power frequency (60 Hz). Therefore, the technology provides a means to measure the phase angles with a precision of 0.02 degrees. It basically provides a direct measurement of the system state. As such, it has been greeted by some as the replacement of state estimators. This assertion however is false. GPS synchronized measurements are imperfect measurements as any other measurement. While the GPS synchronized equipment may have higher precision than conventional metering, there are sources of error from the instrumentation channel, calibration errors and systematic errors introduced by the design of the equipment (for example a constant shift of frequency). The last errors are benign in case that all equipment are of the same manufacturer but become important when equipment from various manufacturers are used on the same system.

In this paper we propose an approach that uses data from various sources for the purpose of enhancing the state estimator. The methodology is based on a three phase detailed power system model. The detailed three phase model is very important and contributes to the performance of the hybrid state estimator. The paper describes the hybrid state estimator and its implementation on the TVA system. Numerical experiments are presented that illustrate the benefits of the hybrid state estimator.

## 2. Description of the Hybrid Three-Phase State Estimator

This section presents the hybrid three-phase state estimator. This state estimator uses standard SCADA data and synchronized data together with a full three phase system model to perform state estimation.

The state of the system is defined as the phasors of the phase voltages at each bus, including the neutral node. A bus k will have three to five nodes, phases A, B and C, possibly a neutral and possibly a ground node. The state of the system at this bus is the node voltage phasors. We will use the following symbols (for a four node bus, i.e. phases A, B, C and neutral N).

$$\widetilde{V}_{k,A} = \widetilde{V}_{k,A} = V_{k,A,r} + jV_{k,A,i}$$

$$\widetilde{V}_{k,B} = \widetilde{V}_{k,B} = V_{k,B,r} + jV_{k,B,i}$$

$$\widetilde{V}_{k,C} = \widetilde{V}_{k,C} = V_{k,C,r} + jV_{k,C,i}$$

$$\widetilde{V}_{k,N} = \widetilde{V}_{k,N} = V_{k,N,r} + jV_{k,N,i}$$

The state for a four node bus k will be defined as follows:

$$\widetilde{V}_k = \begin{bmatrix} \widetilde{V}_{k,A} \\ \widetilde{V}_{k,B} \\ \widetilde{V}_{k,C} \\ \widetilde{V}_{k,N} \end{bmatrix} = \begin{bmatrix} V_{k,A,r} + jV_{k,A,i} \\ V_{k,B,r} + jV_{k,B,i} \\ V_{k,C,r} + jV_{k,C,i} \\ V_{k,N,r} + jV_{k,N,i} \end{bmatrix}$$

The voltages of all buses of the system forms the state of the system. We will refer to this as the state of the system, x.

The measurements can be GPS-synchronized measurements or usual SCADA data. A typical list of measurement data is given in Table 1. The measurements are assumed to have an error that is statistically described with the meter accuracy. Each measurement is related to the state of the system via a function.

**Table 1. List of Measurements**

| Phasor Measurements | | Non-Synchronized Measurements | |
|---|---|---|---|
| **Description** | **Type Code** | **Description** | **Type Code** |
| Voltage Phasor, $\tilde{V}$ | 1 | Voltage Magnitude, $V$ | 4 |
| Current Phasor, $\tilde{I}$ | 2 | Real Power Flow, $P_f$ | 5 |
| Current Injection Phasor, $\tilde{I}_{inj}$ | 3 | Reactive Power Flow, $Q_f$ | 6 |
| | | Real Power Injection, $P_{inj}$ | 7 |
| | | Reactive Power Injection, $Q_{inj}$ | 8 |

Given a set of measurements, the state of the system is computed via the well known least square approach. Specifically, let $z_i$ be a measurement and $h_i(x)$ be the function that relates the quantity of the measurement to the state of the system. The state is computed from the solution of the following optimization problem.

$$Min \quad J = \sum_i \left( \frac{z_i - h_i(x)}{\sigma_i} \right)^2$$

where $\sigma_i$ is the meter accuracy.

Solution methods for above problem are well known. In subsequent paragraphs, the models of the measurements and the details of the hybrid state estimator are described.

## 3. Description of the Measurement Data Set

The available data in a power system can be classified into (a) phasor measurements (GPS synchronized measurements) and (b) non-synchronized measurements. A typical list of measurements has been given in Table 1. Since at each bus the model may have a neutral node as well as a ground node, the measured phase voltages are always considered as the phase to neutral voltages. As it has been mentioned, the measurements are related to the state of the system via the "model" equations. The state of the system has been defined in the previous section. Figure 1 illustrates some typical measurements. The model equations, i.e. the equations that relate the system state to the measurement are given below. The variables that appear in these equations are defined in Figure 1.

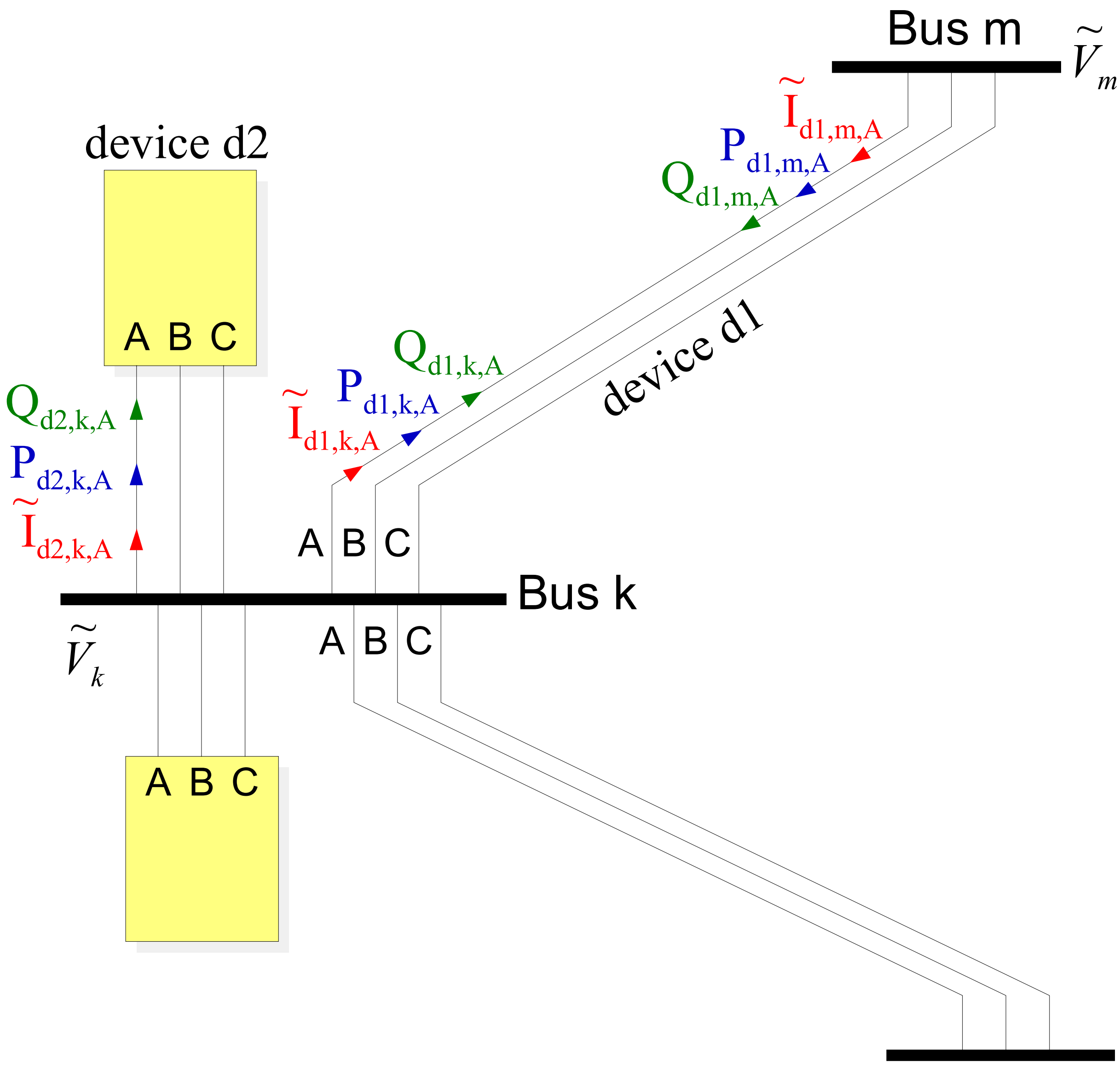


**Figure 1. Measurement Definition – Three Phase Model**

$$z_{V,k,A} = \widetilde{V}_{k,A} = \widetilde{V}_{k,A} - \widetilde{V}_{k,N}$$

$$z_{V,k,B} = \widetilde{V}_{k,B} = \widetilde{V}_{k,B} - \widetilde{V}_{k,N}$$

$$z_{V,k,C} = \widetilde{V}_{k,C} = \widetilde{V}_{k,C} - \widetilde{V}_{k,N}$$

$$\widetilde{I}_{d1,k,A} = C^{T}_{d1,k,A} \begin{bmatrix} \widetilde{V}_{k,A} \\ \widetilde{V}_{k,B} \\ \widetilde{V}_{k,C} \\ \widetilde{V}_{m,A} \\ \widetilde{V}_{m,B} \\ \widetilde{V}_{k,C} \end{bmatrix}$$ , similar equation for phases B and C.

$$V_{k,A} = \left| \widetilde{V}_{k,A} \right| = \sqrt{V^2_{k,A,r} + V^2_{k,A,i}}$$

$$P_{d1,k,A} = \mathrm{Re}\left\{ \widetilde{V}_{k,A} \left( C^{T}_{d1,k,A} \begin{bmatrix} \widetilde{V}_{k,A} \\ \widetilde{V}_{k,B} \\ \widetilde{V}_{k,C} \\ \widetilde{V}_{m,A} \\ \widetilde{V}_{m,B} \\ \widetilde{V}_{k,C} \end{bmatrix} \right)^{*} \right\}$$

$$Q_{d1,k,A} = \mathrm{Im}\left\{ \widetilde{V}_{k,A} \left( C^{T}_{d1,k,A} \begin{bmatrix} \widetilde{V}_{k,A} \\ \widetilde{V}_{k,B} \\ \widetilde{V}_{k,C} \\ \widetilde{V}_{m,A} \\ \widetilde{V}_{m,B} \\ \widetilde{V}_{k,C} \end{bmatrix} \right)^{*} \right\}$$

It is also important to note that normally measurements of neutral or ground voltages are not available. On the other hand these voltages are very small under normal operating conditions. For this reason, we introduce one pseudo-measurement of voltage phasor for each neutral and ground node in the system. The value of this measurement is exactly zero. The "meter accuracy" for this measurement is assumed to be high. Typically a value of 10% is used.

To facilitate the definition and the measurements and to devise a scheme for interfacing with the three phase quadratized power flow program, each measurement is defined with the following set:

$$S_{meas} = \{ m_{type} \quad n_{device} \quad n_{bus} \quad n_{phase} \}$$

where:

$m_{type}$ : measurement type defined as in Table 3.1

$n_{device}$ : power device ID, plus manufacturer and IED (relay, RTU, etc.) ID

$n_{bus}$ : bus name

$n_{phase}$ : measurement phase, A, B or C

The above set allows complete correspondence between measurement and system state.

## 4. Description of the Hybrid Three-Phase State Estimator

The hybrid three-phase state estimator uses standard SCADA data and synchronized data together with a full three phase system model to estimate the system state. The measurement data has been discussed in the previous section. The mathematical procedure is described next.

The measurements are assumed to have an error that is statistically described with the meter accuracy. Thus, each one of these measurements has the following mathematical model.

Phasor measurements:

$$\tilde{z}_v = \tilde{V}_{k,A} - \tilde{V}_{k,N} + \tilde{\eta}_v$$

$$\tilde{z}_v = \tilde{I}_{d1,k,A} + \eta_v = C^T_{d1,k,A} \begin{bmatrix} \tilde{V}_{k,A} \\ \tilde{V}_{k,B} \\ \tilde{V}_{k,C} \\ \tilde{V}_{m,A} \\ \tilde{V}_{m,B} \\ \tilde{V}_{k,C} \end{bmatrix} + \tilde{\eta}_v$$

Pseudo-measurements for neutrals and grounds:

$$\tilde{z}_v = 0 + j0 = \tilde{V}_{k,N} + \tilde{\eta}_v$$

Non-synchronized measurements:

$$z_v = \left|\tilde{V}_{k,A} - \tilde{V}_{k,N}\right|^2 + 2\eta_v = \left(V_{k,A,r} - V_{k,N,r}\right)^2 + \left(V_{k,A,i} - V_{k,N,i}\right)^2 + 2\eta_v$$

$$z_v = P_{d1,k,A} + \eta_v = \mathrm{Re}\left\{ \widetilde{V}_{k,A} \left( C_{d1,k,A}^T \begin{bmatrix} \widetilde{V}_{k,A} \\ \widetilde{V}_{k,B} \\ \widetilde{V}_{k,C} \\ \widetilde{V}_{m,A} \\ \widetilde{V}_{m,B} \\ \widetilde{V}_{k,C} \end{bmatrix} \right)^* \right\} + \eta_v$$

$$z_v = Q_{d1,k,A} + \eta_v = \mathrm{Im}\left\{ \widetilde{V}_{k,A} \left( C_{d1,k,A}^T \begin{bmatrix} \widetilde{V}_{k,A} \\ \widetilde{V}_{k,B} \\ \widetilde{V}_{k,C} \\ \widetilde{V}_{m,A} \\ \widetilde{V}_{m,B} \\ \widetilde{V}_{k,C} \end{bmatrix} \right)^* \right\} + \eta_v$$

The state estimation problem is formulated as follows:

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

It is noted that if all measurements are synchronized the state estimation problem becomes linear and the solution is obtained directly. In the presence of the non-synchronized measurements and in terms of above formulation, the problem is quadratic, consistent with the quadratized power flow. Specifically, using the quadratic formulation, the measurements can be separated into phasor and non-synchronized measurements with the following form:

$$z_s = H_s x + \eta_s$$

$$z_n = H_n x + \left\{ x^T Q_i x \right\} + \eta_n$$

In above equations, the subscript s indicates phasor measurements while the subscript n indicates non-synchronized measurements. The best state estimate is given by:

Case 1: Phasor measurements only.

$$\hat{x} = \left( H_s^T W H_s \right)^{-1} H_s^T W z_s$$

Case 2: Phasor and non-synchronized measurements.

$$\hat{x}^{\nu+1} = \hat{x}^{\nu} + \left(H^T W H\right)^{-1} H^T W \begin{bmatrix} z_s - H_s \hat{x}^{\nu} \\ z_n - H_n \hat{x}^{\nu} - \left\{ \hat{x}^{\nu^T} Q_i \hat{x}^{\nu} \right\} \end{bmatrix}$$

where:

$$W = \begin{bmatrix} W_s & 0 \\ 0 & W_n \end{bmatrix}, \qquad H = \begin{bmatrix} H_s \\ H_n + H_{qn} \end{bmatrix}$$

## 5. State Estimation Scenario Analysis

The state estimation scenarios are generated as follows: (a) Substation IED's are polled to collect raw measurements data – alternatively the DatAware database are used to access historical data for extracting the appropriate data sets (b) Processing of raw measurement data, (c) State Estimation Analysis, (d) Post state estimation analysis. A flow chart of this procedure is illustrated in Figure 2.

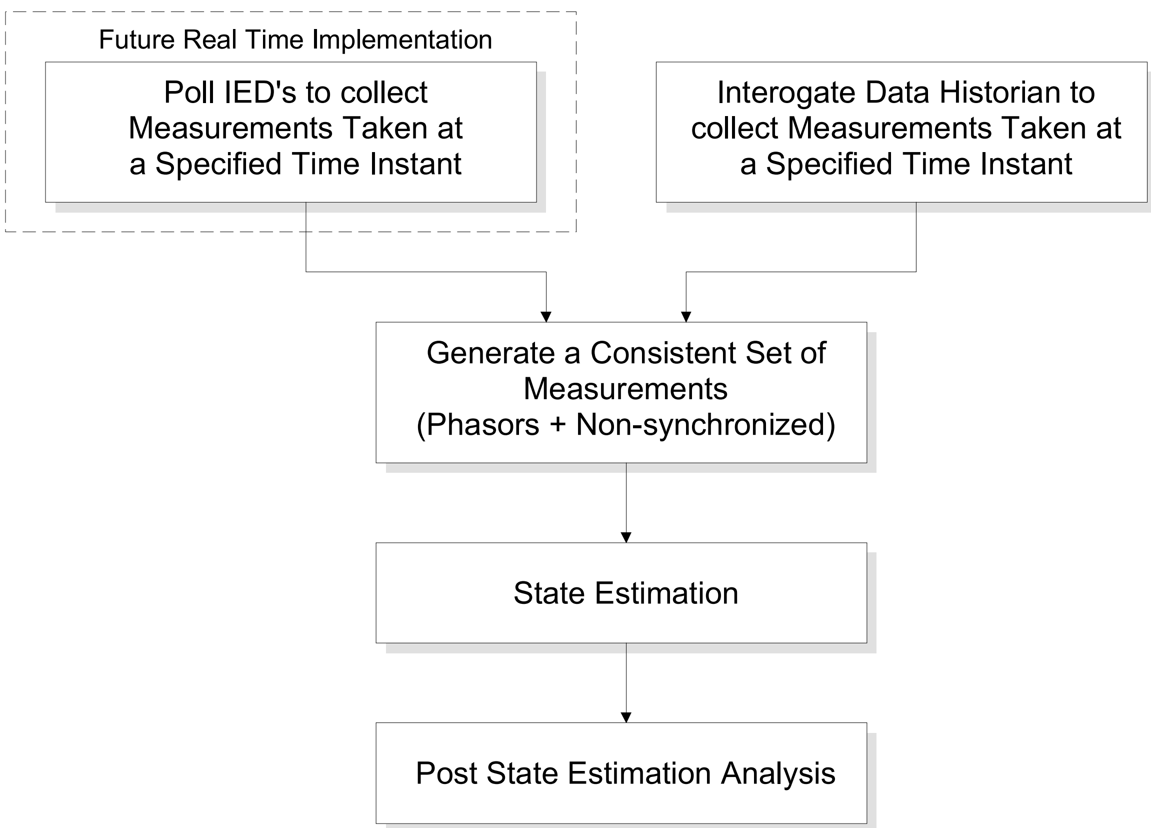


**Figure 2. State Estimation Scenario Generation and Analysis Procedure**

The raw data collection is performed by poling IED's located in the system substations. Synchronized phasor measurements or non-synchronized measurements taken at a certain time instant will be collected. The polling software utilizes the software library (DLL) developed by TVA. Alternatively, measurement data may be collected from the *DatAWare* database. The collected data from each substation is written into data files. The information written into these files includes the measurements, the IED identifier, a time tag indicating the time that the measurements were taken.

Once all data from all desired substation IED's have been collected, the data are processed to generate a consistent set of measurements. This process includes performing various consistency checks and generating pointers in order to define complete correspondence between measurements and system states.

Subsequently, the above defined consistent measurement data set are used to solve the state estimation problem. Once the system state has been estimated post estimation analysis functions allow computation of other quantities, such as circuit current and power flows.

## 5. Numerical Experiments with the Hybrid State Estimator

The hybrid state estimator has been tested with numerical experiments prior to its application in the field. This section describes the numerical experiments. The test system is the 500 kV TVA system shown in Figure 3. The model includes the entire TVA 500 kV system and the transformers and autotransformers to the lower kV levels. The remaining system (beyond the secondary of the included transformers) is represented by equivalents. The system has 53 buses. For this system the following scenarios have been studied.

**Scenario 1**: In this scenario it is assumed that the following measurements are available: (a) real and reactive power flow at the terminals of all circuits, and (b) voltage phasors of each phase at all buses.

**Scenario 2**: In this scenario it is assumed that the following measurements are available: (a) voltage magnitude of phase A at all buses, (b) total real and reactive power flow at the terminals of all circuits, and (c) positive sequence voltage phasors at all buses.

**Scenario 3**: In this scenario it is assumed that the following measurements are available: (a) voltage magnitude of phase A at all buses, (b) real and reactive power flow at the terminals of all circuits (phase A only), and (c) positive sequence voltage phasors at all buses.

The measurement data for the above scenarios were generated numerically using a load flow program and stored in data files. Note that random errors were added to the generated data to simulate typical measurement errors. The added errors were uniformly distributed with a specified range (in the order of 1.5 % of nominal values) Subsequently the estimator was executed with the numerically generated measurement data in order to evaluate its performance. In all tested scenarios the estimator converged within two to four iterations with excellent results.

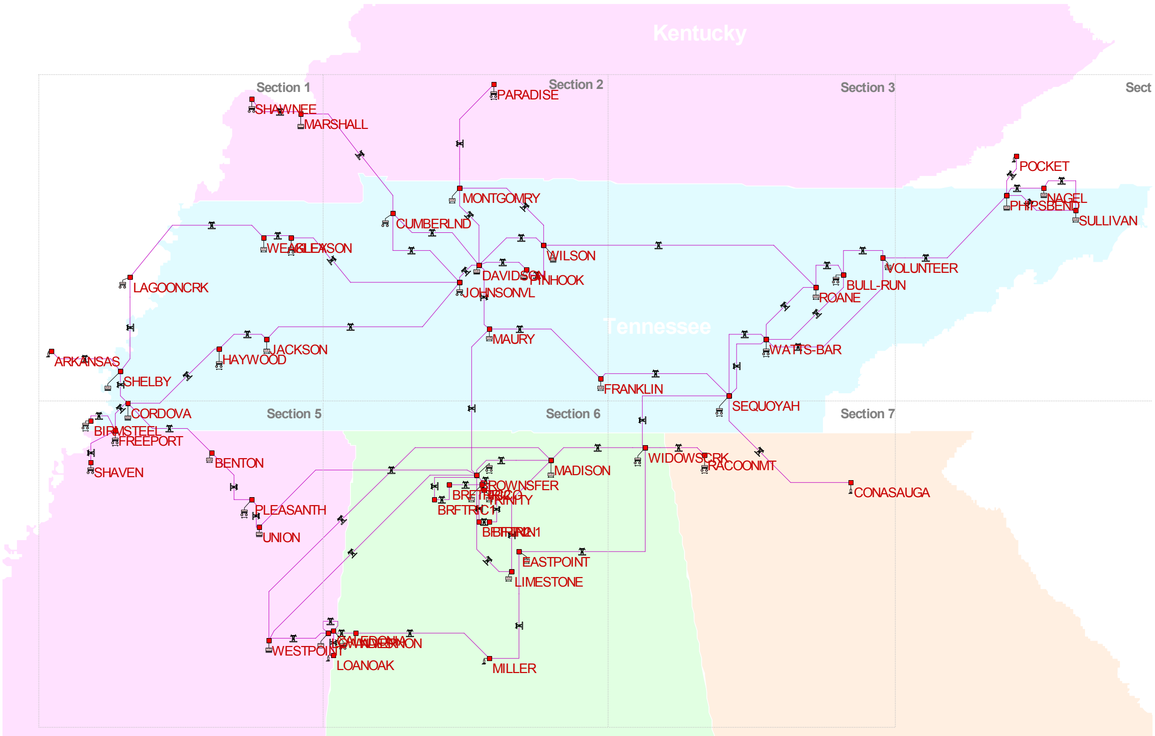


**Figure 3. TVA's 500 kV System**

In order to facilitate the evaluation of the estimator performance, a novel visualization module was developed which presents the estimator output using 3-D graphics. The visualization display shows the single line diagram of the system along with indicators of user selected quantities, such as estimated or measured values of bus voltages (magnitude and phase), circuit power and current flows, measurement errors (computed as the difference between estimated and measured values), and estimation residuals. All indicators are analog so that extreme values (large errors etc) can be easily spotted. For example, voltage magnitudes are indicated by vertical cylinders of height proportional to the voltage. Phase angles are indicated by pie charts. Circuit flows are indicated by walls along the circuit lines of height proportional to the flow, etc.

Examples of the visualization displays are illustrated in Figures 4 and 5. Figure 4 illustrates the bus voltage phase angle error, i.e. the phase angle difference between estimated and measured bus voltages (Phase A). The measurement data for this case were derived from scenario 1. The random error added to all simulated measurement data was $\pm$1.5 % of nominal values, distributed uniformly. All phase errors were below 0.15 degrees. Note that the pie-chart indicator angles have been multiplied by a factor of 200 for display clarity.

Figure 5 illustrates the estimation results for the same measurement data set, but with a large error introduced at one voltage phasor measurements. The visualization display shows both magnitude and phase errors. Phase errors are indicated by pie-graphs, while

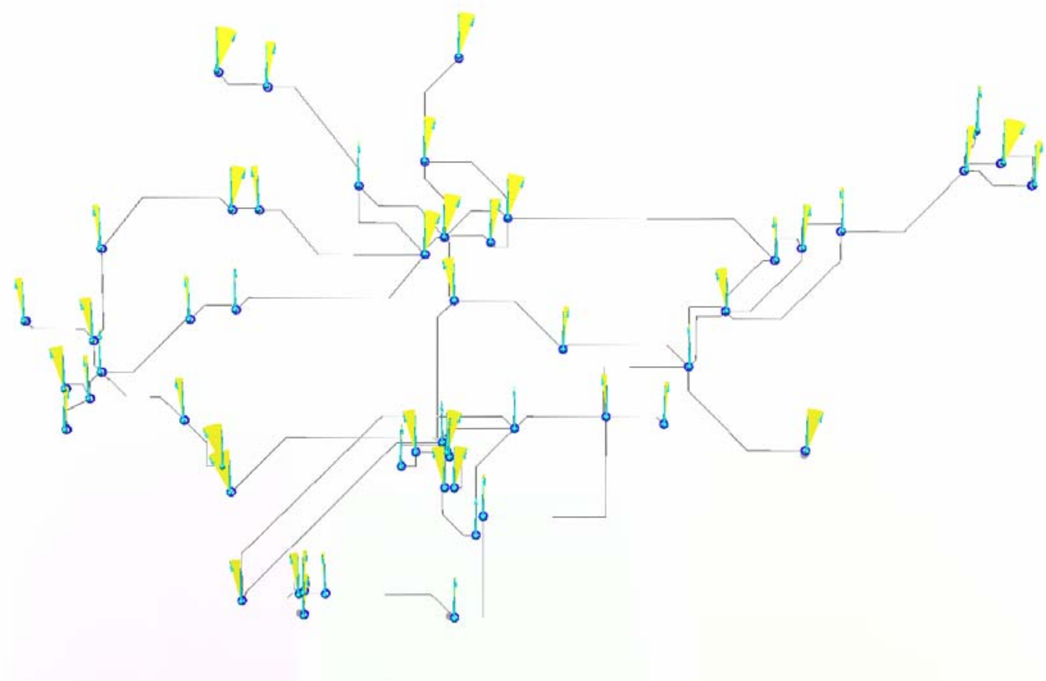

**Figure 4. Error of Bus Voltage Phase – Estimated minus Measured Value – Magnified 200 times (min error: -0.144, max error: 0.147)**

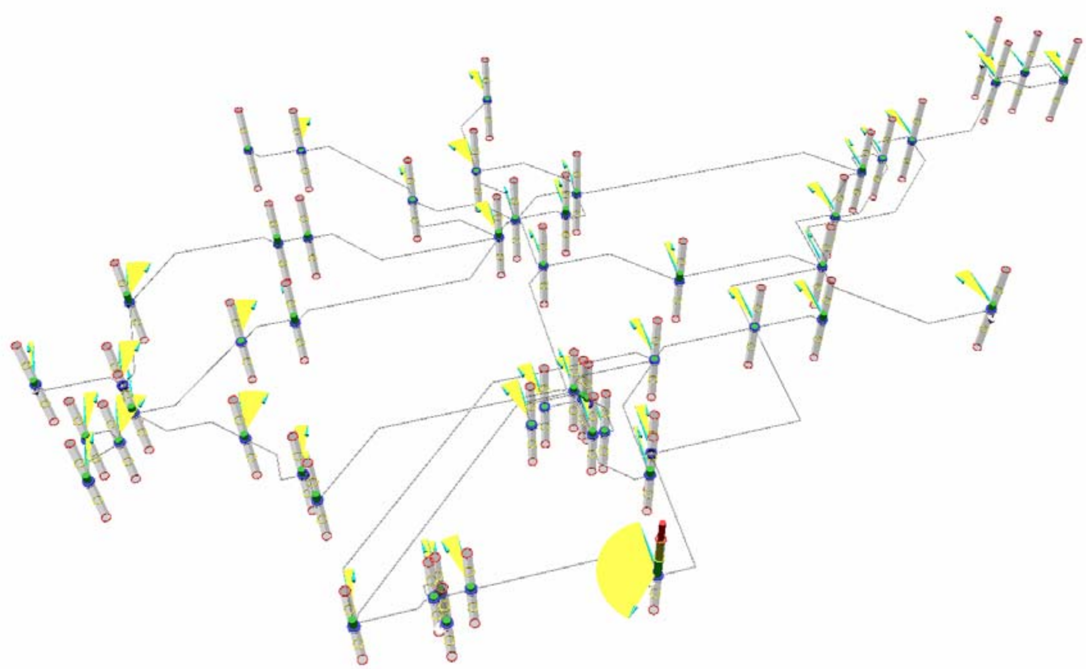

**Figure 5. Error of Bus Voltage Magnitude and Phase – Estimated minus Measured Value – Magnitude is Normalized (min magnitude error: 0, max magnitude error: 0.141), Phase is Magnified 200 times (min phase error: -0.672, max phase error: 0.165)**

magnitude errors are indicated by cylindrical indicators. The actual values are indicated by the solid cylinders, while the transparent gray cylinders and colored rings provide annotation marks. (Yellow rings are at 0.05 pu, and red rings at 0.10 pu). Note the bus voltage with the large measurement error (both in magnitude and phase) is easily identified near the bottom-center area of the diagram.

## 6. Summary and Conclusions

The conventional State Estimation (SE) has inherent biases resulting from biases in the measurements and biases in the power system model (imbalance and asymmetry of component models). The effects of these biases on SE performance increase as the size of the system increases. Many questions remain unanswered today regarding the applicability of the traditional SE to mega systems. We propose that appropriately designed numerical experiments will provide insight into these problems.

The assumptions that were adopted for the conventional State Estimation development (1-single frequency, 2-balanced and 3-symmetric system) cause estimation errors. To alleviate these sources of error, new measurement systems and estimation methods are needed. A promising SE enhancement that reduces the errors caused by assumption 1 can be achieved by the use of synchronized phasor measurements. Synchronization is achieved via GPS (Global Positioning System) which provides the synchronizing signal with accuracy of 1 μsec. Errors caused by assumption 2 (balanced system) can be met by utilizing three phase measurements. Finally assumption 3 (symmetric system) can be dropped by employing full three phase models.

Numerical examples have shown that just the use of separate power flow measurements for each phase (instead of total 3-phase flows) with the traditional estimation model results in substantial improvement in the estimation quality. It is therefore expected that if, in addition to three phase measurement sets, synchronized measurements and full three-phase models are used, the performance of the state estimation algorithm will be sufficient and reliable even for extremely large systems.

The state estimation based on these enhancements is not subject to the biases of the traditional state estimation. It can be formulated as a linear state estimation problem that has a direct solution. This takes care of the uncertainty of how many iterations will be needed for convergence in case of mega-systems. It is expected that this system, because of lack of biases, will have better bad data detection and identification. It is important, however, to add that the proposed system will need a new infrastructure that is not presently available. It is recognized that the industry is moving towards the sensor-less technology at least in new substations. The step to go from sensor-less technology to synchronized measurements is economically very short. Thus we believe that it may happen in the near future.

## 7. References


1. Fred C. Schweppe and J. Wildes, "Power system static-state estimation, Part I, II, and III" *IEEE Transactions Power App. Syst.*, vol. PAS-89, No.1, pp.120-135, January 1970.
2. S. Zelingher, G.I. Stillmann, A. P. Sakis Meliopoulos, "Transmission System Harmonic Measurement System: A Feasibility Study," *Proceedings of the Fourth International Conference on Harmonics in Power Systems (ICHPS IV)*, pp. 436-444, Budapest, Hungary. October 1990.
3. A. P. Sakis Meliopoulos, F. Zhang, and S. Zelingher, "Hardware and Software Requirements for a Transmission System Harmonic Measurement System," *Proceedings of the Fifth International Conference on Harmonics in Power Systems (ICHPS V)*, pp. 330-338, Atlanta, GA. September 1992.
4. A. P. Meliopoulos, F. Zhang, S. Zelingher, G. Stillmam, G. J. Cokkinides, L. Coffeen, R. Burnett, J. McBride, 'Transmission Level Instrument Transformers and Transient Event Recorders Characterization for Harmonic Measurements,' *IEEE Transactions on Power Delivery*, Vol 8, No. 3, pp 1507-1517, July 1993.
5. A. G. Phadke, J. S. Thorp and K. J. Karimi, "State estimation with phasor measurements," *IEEE Transactions on Power Systems*, Vol. PWRS-1, No.1, pp. 233-241, February 1986.
6. A. P. Sakis Meliopoulos, G. C. Cokkinides, and R. P. Webb, "Multiphase Power Flow Analysis," *Proceedings of Southeastcon*, Destin, Florida, pp. 270-275, April 4-7, 1982.
7. K. A. Clements, O. J. Denison, and R. J. Ringlee, "The Effects of Measurement Non-Simultaneity, Bias, and Parameter Uncertainty on Power System State Estimation", *1973 PICA Conference Proceedings*, pp. 327-331, June 1973.
8. O. Alsac, N. Vempati, B. Stott and A. Monticelli, "Generalized State Estimation", IEEE Transactions on Power Systems, Vol. 13, No. 3, pp 1069-1075, August 1998.
9. A. P. Sakis Meliopoulos, F. Zhang, and S. Zelingher, 'Power System Harmonic State Estimation,' *IEEE Transactions on Power Systems,* Vol 9, No. 3, pp 1701-1709, July 1994.
10. A. P. Sakis Meliopoulos and Fan Zhang, 'Multiphase Power Flow and State Estimation for Power Distribution Systems,' *IEEE Transactions on Power Systems*, Vol. 11, No. 2, pp. 939-946, May 1996.
11. B. Fardanesh, S. Zelingher, A. P. Sakis Meliopoulos, G. Cokkinides and Jim Ingleson, 'Multifunctional Synchronized Measurement Network', *IEEE Computer Applications in Power*, Volume 11, Number 1, pp 26-30, January 1998.
12. Sakis Meliopoulos, "State Estimation for Mega RTOs", *Proceedings of the 2002 IEEE/PES Winter Meeting*, New York, NY, Jan 28-31, 2002.

## 8. Biographies

**Michael R. Ingram**, P.E.. - is the Program Manager of Transmission Performance and Transmission Asset Utilization Technologies with Tennessee Valley Authority (TVA) in Chattanooga, Tennessee. He is responsible for the development and demonstration of new technologies which improve electrical quality and reliability, increase power flow, and reduce operating expense of the TVA transmission system.

**Sandra C. Bell** is a Project Engineer in the Power Delivery Technologies Group with the Tennessee Valley Authority in Chattanooga, Tennessee. She is responsible for supporting research, development and demonstration of new technologies which improve electrical power quality and reliability, increase power flow, and reduce operating expense of the TVA transmission system.

**Sherica A. Matthews** is currently pursuing her Master's in Electrical Engineering at the University of Tennessee, Knoxville. Her research is in the areas of Power Systems and Power Electronics. She is currently a Project Engineer in the Power Delivery Technologies group with the Tennessee Valley Authority in Chattanooga, TN. She is testing and modeling ultra-capacitors for applications in high voltage transmission systems.

**George Cokkinides** (M '85) was born in Athens, Greece, in 1955. He obtained the B.S., M.S., and Ph.D. degrees at the Georgia Institute of Technology in 1978, 1980, and 1985, respectively. From 1983 to 1985, he was a research engineer at the Georgia Tech Research Institute. From 1985 to 2000, he has been with the University of South Carolina Department of Electrical Engineering. Since 2000 he has been a visiting professor of Electrical and Computer Engineering at Georgia Tech. His research interests include power system modeling and simulation, power electronics applications, power system harmonics, and measurement instrumentation. Dr. Cokkinides is a member of the IEEE/PES, and the Sigma Xi.

**A. P. Sakis Meliopoulos** (M '76, SM '83, F '93) was born in Katerini, Greece, in 1949. He received the M.E. and E.E. diploma from the National Technical University of Athens, Greece, in 1972; the M.S.E.E. and Ph.D. degrees from the Georgia Institute of Technology in 1974 and 1976, respectively. In 1971, he worked for Western Electric in Atlanta, Georgia. In 1976, he joined the Faculty of Electrical Engineering, Georgia Institute of Technology, where he is presently a professor. He is active in teaching and research in the general areas of modeling, analysis, and control of power systems. He has made significant contributions to power system grounding, harmonics, and reliability assessment of power systems. He is the author of the books, *Power Systems Grounding and Transients*, Marcel Dekker, June 1988, *Ligthning and Overvoltage Protection*, Section 27, Standard Handbook for Electrical Engineers, McGraw Hill, 1993, and the monograph, *Numerical Solution Methods of Algebraic Equations*, EPRI monograph series. Dr. Meliopoulos is a member of the Hellenic Society of Professional Engineering and the Sigma Xi.