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Power System State Estimation using Optimally placed PMUs

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Abstract —*Power system state estimation is used to represent real time power system status. The states are defined as the voltage magnitude and the phase angle at every bus in the system, which are estimated using the measurements of electrical quantities. This paper presents a linear model of power system state estimator for IEEE-14 bus test system, using the measurements obtained from phasor measurement unit. The PMUs are optimally placed in the system such that minimum number of PMUs is required and the observability of the system is maintained.*

Keywords*-Power system, State Estimation, PMU, Optimal placement of PMU, WAMS*

I. INTRODUCTION

State Estimation is the data processing process of assigning the value to unknown states of the system using the weighted least square method[1]. The system states are the voltage magnitudes and the phase angles of each bus in the system. The state estimation process requires the measurements of electrical quantities, which are imperfect and redundant. The measurement involves real and reactive power injections, real and reactive power flows, voltage and current phasors. The estimation of the states is dependent on the statistical criteria, which estimates the true value of the states, by minimizing the weighted sum of the squares of the errors between the estimated and the true values of the quantity[2].

This article presents a view different from the conventional state estimation, by using the phasor measurements obtained from the phasor measurement units by optimally placing them in the power system. The article is divided into four parts. The article starts with the introduction to the power system state estimation, followed by the basics of the WAMS and PMU technology. The state estimation process using PMU measurements is described next, along with the simulation results for the test bus system.

II. BASICS OF WAMS AND PMU TECHNOLOGY

WAMS is defined as the wide area monitoring system. It is used in smart grid to enhance the performance and control of the conventional power system. It is a three layered architecture, as shown in figure below[3]. It consists of phasor measurement unit (PMU) at the bottom layer, which is a device measuring the voltage and current phasor, frequency and rate of change of frequency. The middle layer consists of the phasor data concentrator (PDC), which gathers the synchronized phasor data obtained via the communication link. The top layer consists of the super data concentrator (SDC) or called as the central data concentrator, which maintains the data obtained from the various regional phasor data concentrator.

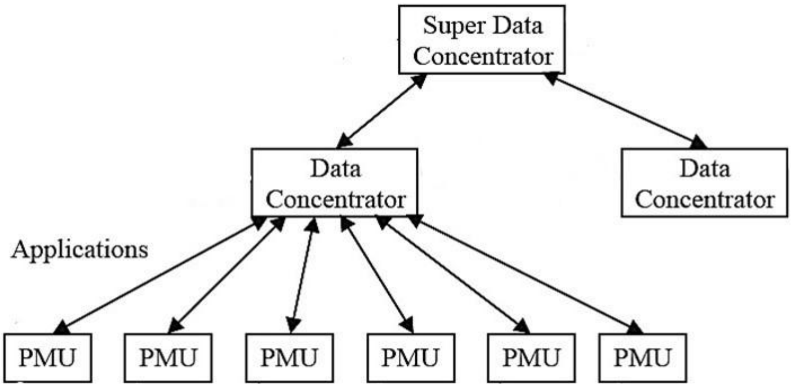

Figure 1. Three Layered structure of WAMS[3]

Phasor measurement units (PMU) are devices used to obtain the synchronized phasor measurements of the electrical quantitates[4]. Phasor measurement unit obtains the following as the outputs:

- Voltage phasor
- Current phasor
- Frequency
- Rate of change of frequency

The block diagram of the PMU is as shown in the figure, which describes the various elements of the phasor measurement unit.

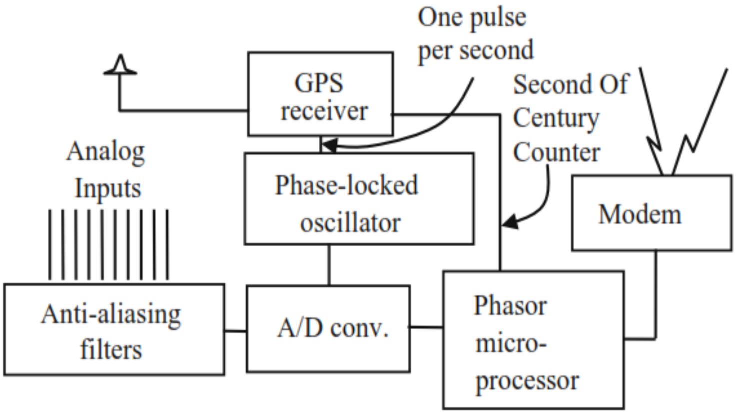

Figure 2. Block Elements of PMU[5]

PMU obtains the analog electrical quantities provided from the output of the transducers and the sensors from the electrical sub-stations. These analog signals are passed to the anti-aliasing filter which works as a low pass filter to reduce the bandwidth of the signal. The ADC converts the analog signal to the digital signal whose sampling frequency depends on the anti-aliasing filter. Global positioning system provides the pulse per second and the phase locked oscillator latches the data. These data are then fed to the phasor microprocessor, wherein various algorithms are performed on the data to provide the synchronized phasor output. These data are then provided to the phasor data concentrator via communication channel or modem.

III. STATE ESTIMATION USING PMU MEASUREMENTS

In the power system, the grid topology is meshed. So, the use of node voltages as the state variable is the optimum solution as it minimizes number of state variables used to represent the system[6]. A linear model is obtained if the state variables and the measurement vectors are expressed in rectangular co-ordinates[4]. The synchro-phasor measurements are converted into the rectangular co-ordinates.Voltage phasor measurements can be directly associated to the state variables, in rectangular co-ordinates. Current phasor measurements can be linearly associated to the rectangular voltage state. If the measuring infrastructure is fully based on PMUs, then a linear measurement model is obtained. The algorithm and the equations used in the state estimation process are described below.

- The measurement vector is represented as:

$$z = \begin{bmatrix} V_r \\ V_x \\ I_r \\ I_x \end{bmatrix}$$

Where, z represents the measurement vector, with ‘m’ number of measurements.
V_r represents the real and V_x the imaginary part of the voltage measurement.
I_r represents the real and I_x the imaginary part of the current measurement.

- The state vector is given by:

$$x = \begin{bmatrix} V_r \\ V_x \end{bmatrix}$$

Where, x represents the state vector, with ‘n’ number of state variables.

- The Jacobian matrix is given by:

$$H = \begin{bmatrix} 1 & 0 \\ 0 & 1 \\ g_{ij} & -b_{io} - b_{ij} \\ b_{io} + b_{ij} & g_{ij} \end{bmatrix}$$

Here, g_{ij} is the conductance, representing the real part of the admittance value
b_{ij} is the susceptance, representing the imaginary part of the admittance value
b_{io} represents the shunt susceptance

The Jacobian matrix is of the dimension m*n.

- The gain matrix is given by:

$$G = H' * W * H$$

The gain matrix is of the dimension n*n.

- The linear model is given by:

$$z = H * x$$

$$\begin{bmatrix} V_r \\ V_x \\ I_r \\ I_x \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \\ g_{ij} & -b_{io} - b_{ij} \\ b_{io} + b_{ij} & g_{ij} \end{bmatrix} * \begin{bmatrix} V_r \\ V_x \end{bmatrix}$$

The weighting matrix (W) is given by associating a weighting factor to each measurement depending upon the accuracy of the measurement meter and the precision of each measurement.The Jacobian matrix and Gain matrix are constant.

Linear model allows simplifying the solution of the weighted least square problem. With the help of these, the minimization of the objective function is obtained without the need of iterative algorithms by directly solving the equation:

$$x = G^{-1} * H' * W * z$$

IV. SIMULATION RESULTS

The state estimation model has been tested on IEEE 14 test bus system. There are 14 buses and 20 branches in the system. Load flow for the system has been run to obtain the true values for the system. These true values are used to validate the results obtained from the state estimation process.

To obtain the phasor measurements, PMUs are optimally placed in the system such that whole system observability is maintained. ILP (Integer Linear Programming) method is used for the optimal placement of PMU. The optimal locations obtained are bus numbers: 2, 6, 7 and 9[7]. Thus, all the buses become observable.

Table 1. System Observability

Bus Number	Observable Buses
2	1,3,4,5
6	5,11,12,13
7	4,8,9
9	4,7,10,14

Once the buses are observable, the voltage and current phasor measurements are obtained which are used as the input to the state estimator. The weighing factor is decided based on the importance and accuracy of the measurement. The voltage magnitude error and the voltage angle error are represented in figures below. The voltage magnitude is error and the voltage angle errors are representing the difference between the estimated and the true values of the states of the system.

The measurements included are the 4 numbers of voltage phasors and 15 numbers of current measurements. The PMU measures the voltage phasor of the bus on which it is placed and the current phasor of the lines connected to that bus, depending upon the number of channels of PMU. PMU measures the voltage of the adjacent bus by using the transmission line parameters and the voltage of the bus on which it is placed. Hence total numbers of measurements are 38. The state variables are 28 in number. Thus, m=38 and n=28. Here, m>n, hence there is redundancy in the measurements.

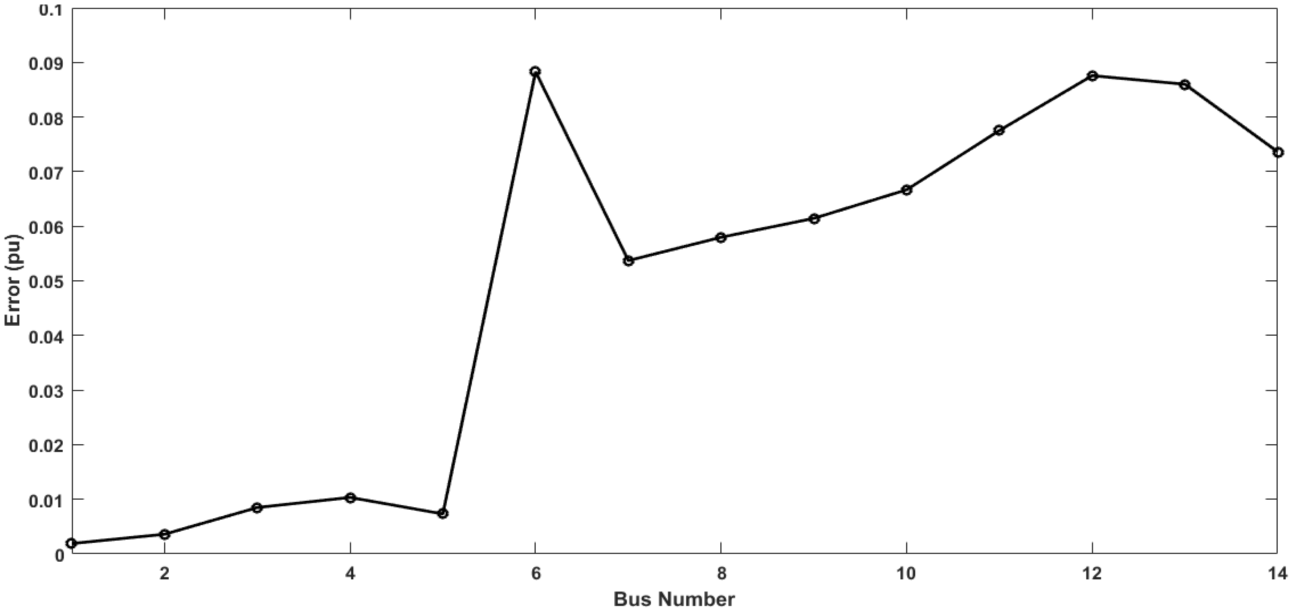

Figure 3. Voltage Magnitude Error

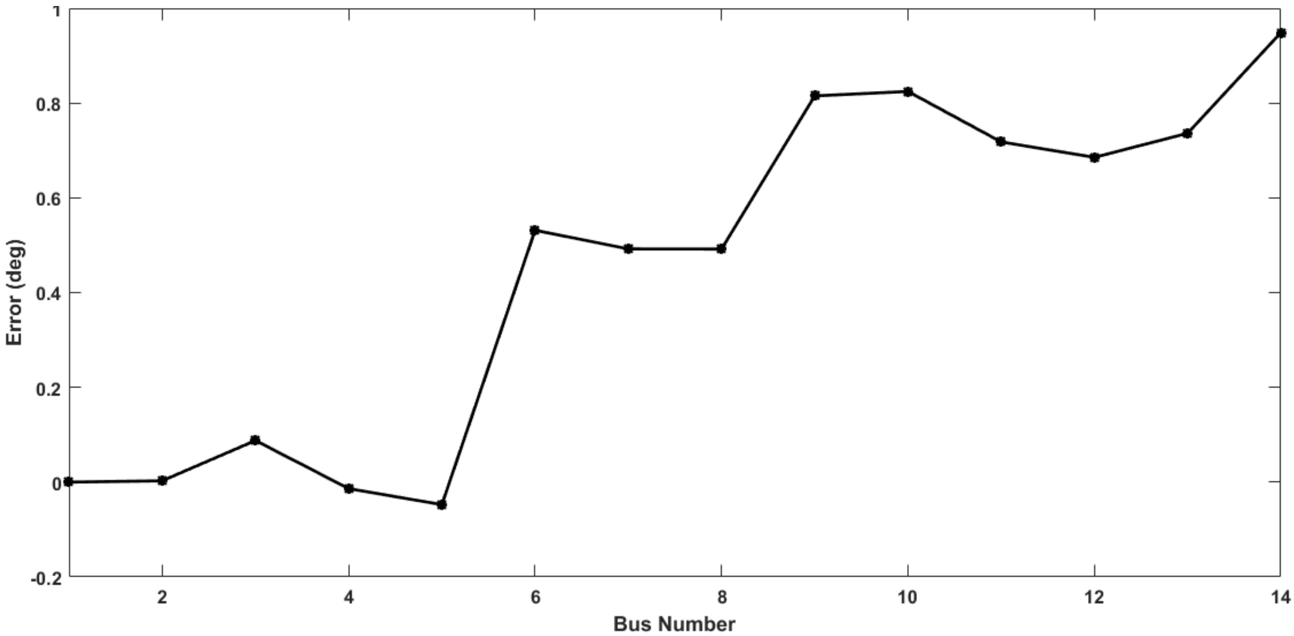

Figure 4. Voltage Angle Error

V. CONCLUSION

It can be concluded from the simulation results that, the estimated values obtained from the state estimation algorithm using the phasor measurements provided from the PMUs by optimally placing them in the system are near to the true values obtained from the load flow measurements. The estimated states are used as the base for the power system management and control purpose. The state estimator is used to detect the changes in the network configuration and also it is used to approximate the pseudo measurements.

REFERENCES

[1] A. Abur and A. Gomez-Exposito, *Power System State Estimation: Theory and Implementation*. 2004.

[2] A. J. Wood and F. Bruce, *POWER GENERATION , OPERATION , AND CONTROL*, Second. JOHN WILEY & SONS, INC., 1996.

[3] A. G. Phadke and J. S. Thorp, *Synchronized Phasor Measurements and Their Applications*, Second Edi. Springer, 2008.

[4] J. De La Ree, V. Centeno, J. S. Thorp, and A. G. Phadke, “Synchronized Phasor Measurement Applications in Power Systems,” *IEEE Trans. Smart Grid*, vol. 1, no. 1, pp. 20–27, 2010.

[5] A. Monti, C. Muscas, and F. Ponci, *Phasor Measurement Units and Wide Area Monitoring Systems: From the Sensors to the System*. 2016.

[6] A. G. Phadke, J. S. Thorp, and K. J. Karimi, “State estimation with phasor measurements,” *IEEE Trans. Power Syst.*, vol. 1, no. 1, pp. 233–238, 1986.

[7] R. Kavasseri and S. K. Srinivasan, “Joint placement of phasor and conventional power flow measurements for fault observability of power systems,” *IET Gener. Transm. Distrib.*, vol. 5, no. 10, pp. 1929–1936, 2011.

