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A compendious illustration of power system state estimation process by WLS method

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Abstract

State estimation is a computer program that helps to process the raw measurements and determine the power system state. Paper provides the commonly used state estimation method. It outlines Weighted Least Square Technique and the steps involved in the estimation. The paper describes application of the method based on IEEE 14 bus system and IEEE 30 bus system. It is predetermined system model and carried out in order to provide best estimate of what is happening in the system based on real time measurements data. The simulation program is run on the MATLAB (2013) platform.

Keywords: State estimation, transmission system network, weighted least square.

Introduction

State estimation involved in power systems is a complex procedure having the process of assigning values to unknown states of a system based on a set of measurements, it can be developed from the power system network to calculate the value of voltage magnitude and phase angle at bus.

State estimation is the process where one uses the parameters to calculate the value of one or more unknown parameter in a system and formulate a best estimation of unknown samples using the available measurements[1]. The common technique for state estimation is WLS method. Mathematical formulations of WLS for nonlinear approach are provided[2]. A state estimator is a computer program that converts telemetered analog measurements data into useful state vector. The input is taken from measurements of real and reactive power flow through SCADA and line data through topology processor and estimate the bus voltage and angle, because measurements of angle and voltage at each bus considered economically unfeasible[3]. The WLS techniques depend on Number of measurements, measurement type, measurement weight and presence of noise. Final result may affect Due to noise or error in measurements[4]. The involvement of the measurements error serves to weigh the accuracy of each of the measurement. The physical system model information and measurements are part of the equality constraints optimize[5].

To program a state vector of power system MATLAB software is used[11]. The results for 14 Bus and 30 bus system[12-14] are obtained and represented graphically, the variation of the estimates around nominal value is less in both the cases. It is also able to estimate true state of system when imperfect information is available across any Line or in case of missing data across any line. The rest of the paper is organized as follows: Section 2 is regarding procedure involved in state estimation process, section 3 delineates mathematical background along with the algorithm and in the 4th section results are discussed for both the test systems, section 5 is the concluding part. This paper addresses a concise description of steps involved in state estimation process that may be helpful in quicker grasping of the topic for a beginner in this field.

Methodology

The security consideration in power system has important part in power sector. To obtain this one it is necessary to monitor System Operating state. To study the state estimation it is required to know whether the sufficient measurements and location are available to state estimation of system state vector. If this is possible then the network is said to be observable. Transmission system measurements data are collected from RTU which is not free from errors. The errors can be in the form of noise in measurements, bad measurements. Measurements data provides Power flow/injection, voltage, current and angle. The System configuration provides line data which is almost constant but whether change affect the result.

Mathematical expression: In WLS state estimation unknown parameter is always presented as that value of the samples that gives the minimum of the sum of the squares of the difference between measured value and true value and this deviation are weighted by the variance of the meters errors.

$$J(x) = \sum_{i=1}^{m} \frac{[z_i - h_i(x)]^2}{\sigma_i^2} \quad (1)$$

n=No. of unknown parameter, m=No. of measurements, x= Estimated state vector, z_i=Measured value of measurements, $h_i(x)$=Estimated measurements, σ_i^2=Variance of the ith measurements. Equ 1 can be expressed in physical units (PU).

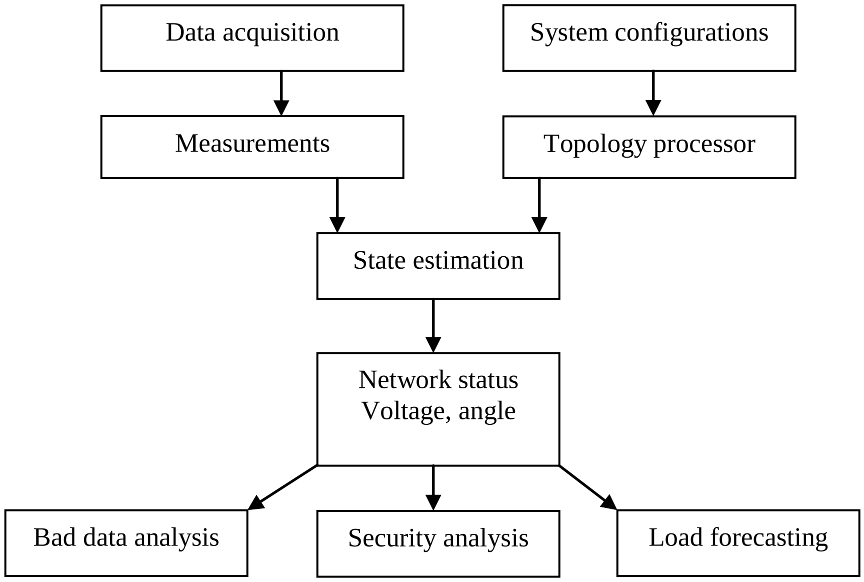

Figure-1: State estimation process.

For estimating (n) unknown parameter using (m) measurements equation (1) like this,

$$J(x_1, x_2 \dots x_n) = \sum_{i=1}^{m} \frac{[z_i - h_i(x_{1,}\, x_{2,} \dots\dots x_m)]^2}{\sigma_i^2} \quad (2)$$

The estimation calculation show is known as a weighted least square estimator. The measured error are modeled as Random numbers having Gaussian distribution.

Consider a measurement vector denoted by z containing m number of measurements and a state vector denoted by x containing n number of state variables.

Estimated measurements can be assembled in the vector form,

$$[Z] = \begin{bmatrix} z_1 \\ z_2 \\ \vdots \\ z_m \end{bmatrix} \qquad [x] = \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{bmatrix}$$

$$[h(x)] = \begin{bmatrix} h_1(x_1 & x_2 & \cdots & x_n) \\ h_1(x_1 & x_2 & \cdots & x_n) \\ \vdots & \vdots & \ddots & \vdots \\ h_n(x_1 & x_2 & \cdots & x_n) \end{bmatrix}$$

If all the measurements having some unknown [e] error in the form of column matrix then measurement matrix like,

[Z] = [h(x) + (e)]

The measurement residual J(x) can be written with error covariance.

$J(x) = [z - h(x)]^T R^{-1} [z - h(x)]$

Co variance matrix $R = \sigma^2 = G^{-1}$ (it is always a covariance matrix). Weighting matrix $W = R^{-1}$ (inverse of covariance matrix). Gain matrix calculated by $G = H^T W H$

H(x) is measurement Jacobian, it is simply the derivative of the measurement function with respect to the state vector. Voltage and phase angle are state variable. The measurement function and measurement Jacobian can be constructed using the known system model including branch parameters, network topology, and measurement locations and type.

The measurement Jacobian has the following small possible structure:

$$H = \begin{vmatrix} \frac{\partial P_m}{\partial \delta} & \frac{\partial P_m}{\partial v} \\ \frac{\partial Q_m}{\partial \delta} & \frac{\partial Q_m}{\partial v} \\ \frac{\partial P_{mk}}{\partial \delta} & \frac{\partial P_{mk}}{\partial v} \\ \frac{\partial Q_{mk}}{\partial \delta} & \frac{\partial Q_{mk}}{\partial v} \\ 0 & \frac{\partial V_m}{\partial v} \\ \frac{\partial \delta_m}{\partial \delta} & 0 \end{vmatrix}.$$

$P_{mk,}$ Q_{mk} respectively real and reactive power flow, $P_{m,}$ Q_m respectively real and reactive power injection, v_m, v_m, ∂_m, ∂_k respectively voltage and angle of corresponding bus.

Finally estimated state vector can be calculated as

$\tilde{x} = G^{-1}(H^T W Z)$

G(x) is called the gain matrix. It is sparse, positive definite and symmetric provided that the system is fully observable. The matrix G(x) is typically not inverted.

Algorithm: The final state estimation algorithm is under as following step: i. 1. Read the network topology, ii. Read the measurement data, iii. Read the bus data, line data etc. iv. Initialize the state vector x, typically as a flat start, v. Initialize all unknown variables, vi. Calculate the measurement function $h_i(x)$, vii. Construct the measurement Jacobean H(x), viii. Solve for z - $h_i(x)$, ix. Calculation of Gain matrix (G), x. Calculation of covariance matrix (R), i.e. inverse of gain matrix, xi. Solve for estimated state vector $\tilde{x} = G^{-1}(H^TWZ)$, xii. Calculate maximum $|\tilde{x}|$, xiii. Check for maximum if YES then stop, if NO then update state vector and go to step 8, iv. Stop.

Results and discussion

IEEE 14 bus system[12]: The IEEE 14-bus test system approximates the American Electric Power system (February 1962). It has 5 generators and 11 loads.

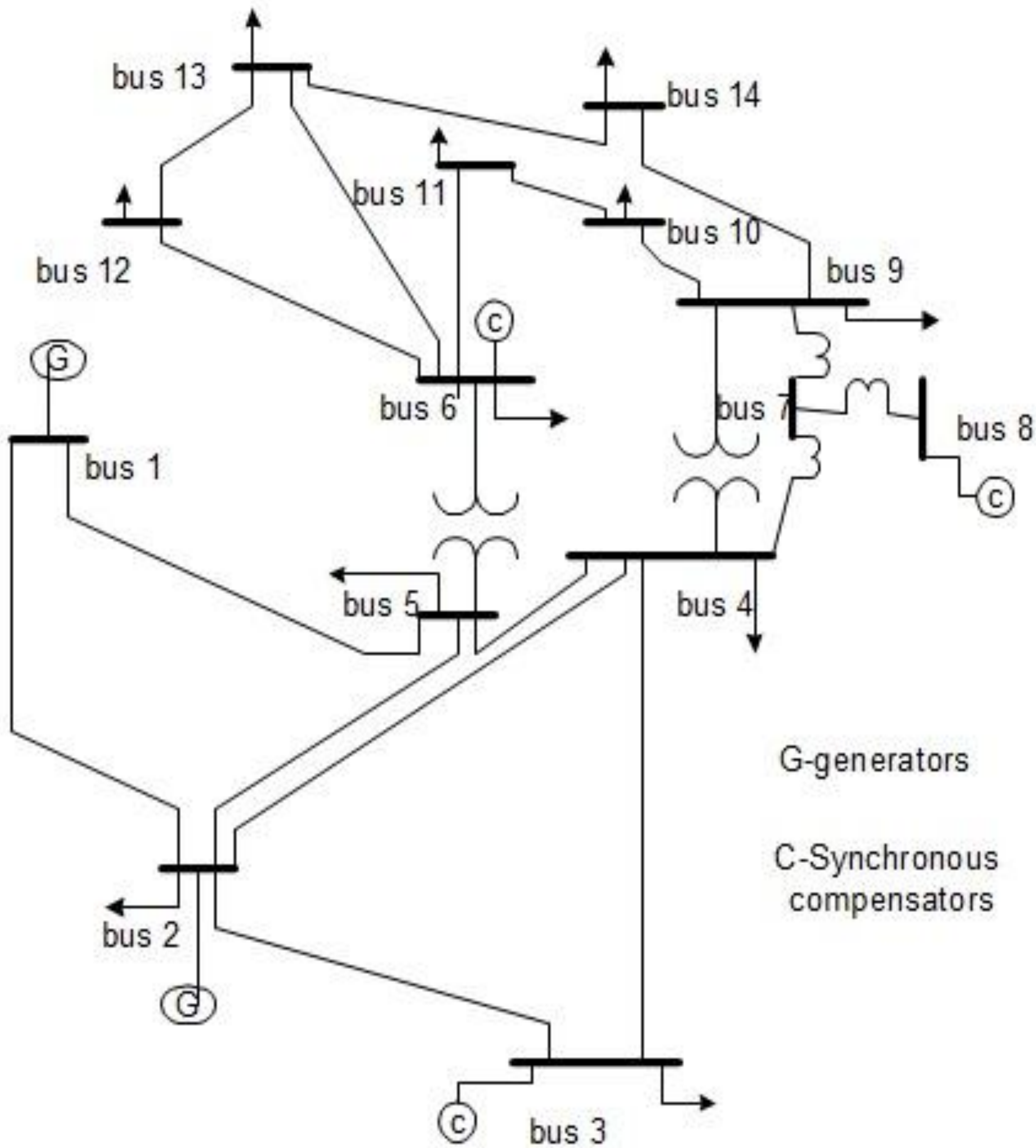

Figure-2: IEEE 14 bus system[14].

The line data, bus data are collected from and simulated using MATLAB platform. The estimated states are listed in Table-1.

Table 1: The result obtained for 14 bus System[3].

Bus No	Voltage (pu)	Angle (Degree)
1	1.0068	0.0000
2	0.9899	-5.5265
3	0.9518	-14.2039
4	0.9579	-11.4146
5	0.9615	-9.7583
6	1.0185	-16.0798
7	0.9919	-14.7510
8	1.0287	-14.7500
9	0.9763	-16.5125
10	0.9758	-16.7476
11	0.9932	-16.5397
12	1.0009	-17.0203
13	0.9940	-17.0583

The code has provision for missing data and the System matrix rebuild to ignoring those one which is missing. There is are no more effect due to missing data for rest buses result as compare to all available data.

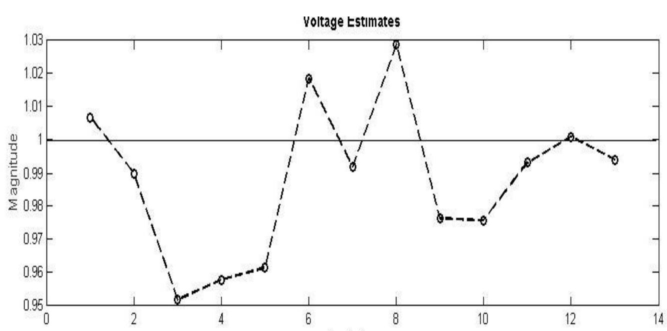

Figure-3: Voltage profile.

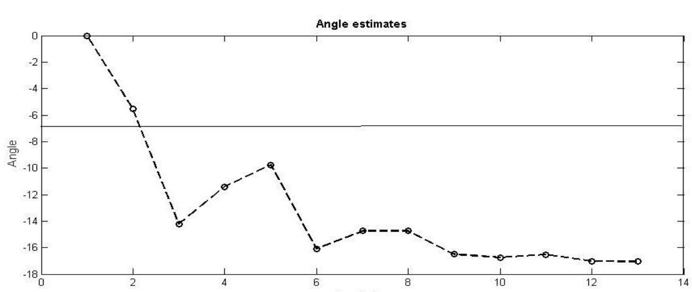

Figure-4: Phase angle.

IEEE 30 bus system[14]: The IEEE 30-bus test system approximates the American Electric Power system (Dec 1961).

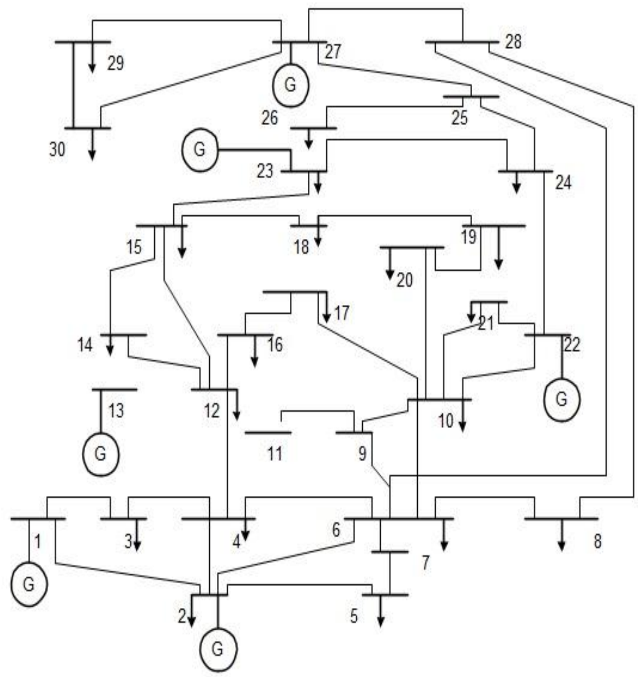

Figure-5: IEEE 30 bus system[15].

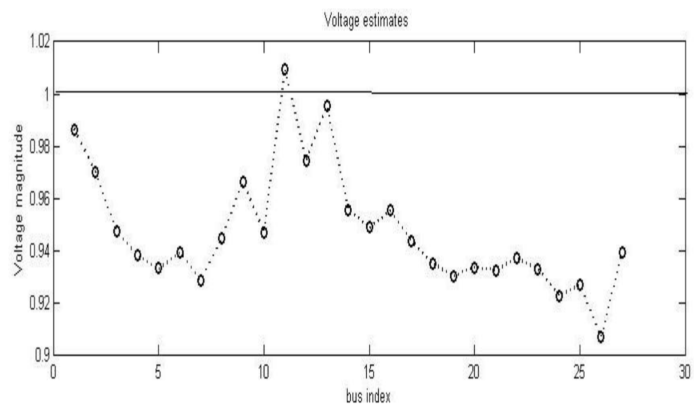

Figure-6: Voltage profile.

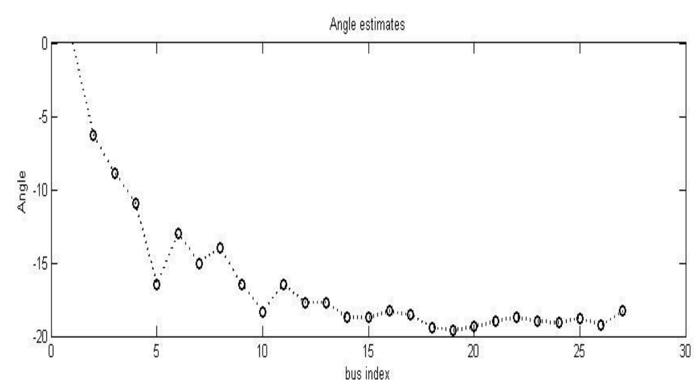

Figure-7: Phase angle.

Table-2: The result obtained for 30 bus System[11].

Bus No	Voltage (pu)	Angle (Degree)
1	0.9865	0.0
2	0.9700	-6.2635
3	0.9474	-8.8420
4	0.9384	-10.9021
5	0.9335	-16.4941
6	0.9395	-12.9975
7	0.9287	-15.0443
8	0.9449	-13.9608
9	0.9667	-16.4813
10	0.9472	-18.3445
11	1.0093	-16.4813
12	0.9746	-17.6918
13	0.9954	-17.6918
14	0.9559	-18.7137
15	0.9491	-18.7299
16	0.9555	-18.2800
17	0.9441	-18.5714
18	0.9352	-19.4195
19	0.9306	-19.6063
20	0.9339	-19.3581
21	0.9328	-18.9821
22	0.9372	-18.7111
23	0.9331	-18.9957
24	0.9231	-19.0788
25	0.9270	-18.7784
26	0.9070	-19.2593
27	0.9395	-18.2962

Conclusion

In this paper a summarized description on the topic of power system state estimation is presented. It may serve as starting point for a novice to decipher the steps involved in complex procedure of state estimation. Two standard test systems namely, IEEE 14 bus and IEEE 30 bus systems have been considered to input bus data, line data etc, required for state estimation process. The simulation of the process has been verified using MATLAB. i. The program is working properly and state estimation problem is solved with good accuracy. ii. If the size of the system increases then the accuracy of estimation by WLS decreases. iii. In case of any missing data across any bus the program is provided to calculate the result for remaining bus. iv. Load forecasting is possible by estimated Network status (voltage, angle).

References

1. Venkatesh, P., Manikandan, B. V., Raja, S. C., & Srinivasan, A. (2012). Electrical power systems: analysis, security and deregulation. PHI Learning Pvt. Ltd, India 342–374.

2. Aboonabi, A. and Saif, M. (2011). Power System State Estimation Using Contraction Mapping and Singular Value Decomposition. IFAC, 1-6.

3. Alorf, A. & Banerjee, B. (2011). State Estimation of Power Systems Using Wieghted Least Squares Optimization Technique. MA5630 Numerical Optimization Course, 1-21.

4. Meriem, M., Omar, S., Bouchera, C., Abedelaziz, B., Jmal, B., Faissal, M. and Nazha, C. (2016). Study of State Estimation Using Weighted Least Square Method. *IJAERS*, 3(8), 1-10.

5. Abur, A., & Exposito, A. G. (2004). Power system state estimation: theory and implementation. CRC press, 1-7.

6. Zamora-Cárdenas, E. A., Pizano-Martínez, A., Lozano-García, J. M., Gutiérrez-Martínez, V. J., & Cisneros-Magaña, R., (2019). Computational development of a practical educational tool for state estimation of power systems using the MATLAB optimization toolbox. *The International Journal of Electrical Engineering & Education*, 56(2), 105-123.

7. Monticelli, A. (2000). Electric power system state estimation. Proceedings of the IEEE, 262-282.

8. Liu, W. H., & Lim, S. L. (1995). Parameter error identification and estimation in power system state estimation. *IEEE Transactions on power systems*, 10(1), 200-209.

9. Jovicic, A., Jereminov, M., Pileggi, L., & Hug, G. (2018). A Linear Formulation for Power System State Estimation including RTU and PMU Measurements.

10. R. A. Jabr and B.C. Pal. (2003). Iteratively Re-weighted Least Absolute Value Method for State Estimation. IEEE Proceedings on Generation Transmission and Distribution, 150, 385-391.

11. Praviraj P.G. (2009). Power system state estimation using WLS. Access on 10 february 2020 available:

12. Ahmad F. (2019). Enhancement of the Voltage Profile for an IEEE-14 Bus System by Using FACTS Devices. In: Mishra S., Sood Y., Tomar A. (eds) Applications of Computing, Automation and Wireless Systems in Electrical Engineering. Lecture Notes in Electrical Engineering 553 Springer, Singapore. https://doi.org/10.1007/978-981-13-6772-4_109

13. Hota, P. K., and A. P. Naik. (2016). Analytical Review of Power Flow Tracing in Deregulated Power System. *American Journal of Electrical and Electronic Engineering*, 4(3), 92-101.

14. Topology for IEEE-14 bus (2020). Physical topology graph for IEEE-14 bus. https://www.researchgate.net/figure/Network-topology-for-IEEE-14-bus-system-22_fig3_261718957, Access on 10-11-2020.

15. Topology for IEEE-30 bus (2020). Physical topology graph for IEEE-30 bus. https://www.researchgate.net/figure/Physical-topology-graph-of-IEEE-30-bus-system_fig2_261111551, Access on 10-11-2020.

16. ITI Illinois (2020). IEEE-30-Bus System. https://icseg.iti.illinois.edu/ieee-30-bus-system/,Access on 11-11-2020.

17. Ajoudani M, Sheikholeslami A and Zakariazadeh A. (2020). Modified WLS method to improve active distribution system state estimation. 16(4), 559-572.

18. Marco T, Ruggero C, Luca S and Grazia B. (2020). Smart grid state estimation with PMUs time synchronization errors. 1-20.

19. A. Shau, N. Jenkins, and G. Strbac, (2005). Measurement Location for State Estimation of Distribution Networks With Generation. IEEE Proceedings on Generation Transmission and Distribution, 152(2), 240-246.

20. Jin, T., & Shen, X., (2018). A Mixed WLS Power System State Estimation Method Integrating a Wide-Area Measurement System and SCADA Technology. Energies, 11(2), 408