

Research on Weighted Least Square and Linear State Estimation Methods under Ill Condition of Power System



M.S.N.G. Sarada Devi, T.V.L.N. Pavan Phani Kumar, G.Yesuratnam

ABSTRACT---A Jacobian matrix is said to be ill-conditioned if it is very sensitive to small changes. In this paper, the performance of Weighted Least Square (WLS) and Linear State Estimation (LSE) methods under stressed condition and ill condition of power system are compared. In weighted least square method, real/ reactive power injections/flows with very few bus voltage magnitudes are used to obtain the state vector (bus voltages) for given network model. This method inclined to convergence errors when the system is in stressed state or ill condition state. In Linear State Estimation method, bus voltage and current measurements are used to obtain the state vector. Because of its linear nature, LSE method is suitable under stressed condition/ ill condition of power systems. IEEE 14 bus, 13 bus ill conditioned system and EHV 24 bus systems are used in matlab environment to examine the proposed (LSE) method and simulation results are summarized.

Keywords-State Estimation, WLS, Linear State Estimation.

I. INTRODUCTION

For protected and incessant action of power systems, system operating conditions monitoring is an unremitting course of action. In this connection, devices to measure real/ reactive power injections/flows and status (on/off) of switches are connected in different locations in entire power system. The individual values (raw data) are captured send to the energy management system. The on/off position of switches raw data is used to know the network connectivity (network model). "The process of obtaining bus voltages (state vector) for given network model and measurements is known as State Estimation". Complete information on the subject of Power System State Estimation (PSSE) is given in references [1]-[22]. Apart from these references, Forecasting aided state estimation, state estimation in grids, generalized state estimation, fast decoupled based state estimation operating state forecasting, robust dynamic state estimation and state estimation through kalman filter are also available in the literature survey. However, to the full of our cognition, weighted least square method is widely used method by state estimators to obtain the system state variables. But this

method inclined to convergence errors when the system is in stressed or ill conditioned state. This paper concentrates on this condition and compared WLS method and LSE methods under well conditioned, ill conditioned and stresses conditioned of power systems.

II. WEIGHTED LEAST SQUARE METHOD

The objective function in WLS method is given in equation (1) and estimator assumes minimizing the objective function.

$$J(x) = \frac{1}{2} [z-h(x)]^T R^{-1} [z-h(x)] \quad (1)$$

Where x is system state vector, z is available measurements vector, $h(x)$ is a vector of nonlinear functions, representing dependence of measured quantities from the state vector, R is a diagonal matrix of measurement covariances.

$$G(x^i) (x^{i+1} - x^i) = -g(x^i) \quad (2)$$

$$G(x^i) = H^T(x^i) R^{-1} H(x^i) \quad (3)$$

$$H(x) = \frac{\partial h(x)}{\partial x} \quad (4)$$

Here 'i' is number of iteration, x^i is solution vector at iteration 'i'.

$G(x)$ is gain matrix and $H(x)$ is measurement Jacobian matrix.

$$H = \begin{bmatrix} \frac{\partial(Pin_j)}{\partial\theta} & \frac{\partial(Pin_j)}{\partial V} \\ \frac{\partial(Pfl)}{\partial\theta} & \frac{\partial(Pfl)}{\partial V} \\ \frac{\partial(Qin_j)}{\partial\theta} & \frac{\partial(Qin_j)}{\partial V} \\ \frac{\partial(Qfl)}{\partial\theta} & \frac{\partial(Qfl)}{\partial V} \\ \frac{\partial(Vmag)}{\partial\theta} & \frac{\partial(Vmag)}{\partial V} \end{bmatrix} \quad (5)$$

III. ILL CONDITION OF POWER SYSTEM

A matrix is said to be ill-conditioned if it is very sensitive to small changes. The classic illustration of ill-conditioning is the following two linear equations of the form $Ax = b$:

$$\begin{bmatrix} 1 & 1 \\ 1 & 1.0001 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} 2 \\ 2 \end{bmatrix} \quad (6)$$

$$\begin{bmatrix} 1 & 1 \\ 1 & 1.0001 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} 2 \\ 2.0001 \end{bmatrix} \quad (7)$$

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The solution to equation (6) is $x_1=2$ and $x_2=0$, while the solution to equation (7) is $x_1=x_2=1$. What this shows is that a tiny change in the 4th decimal place of the vector in equation (7) can lead to relatively immense changes in the solution

vector x . As a result, inaccuracies in the data (such as rounding errors) can have large consequences when systems are ill-conditioned.

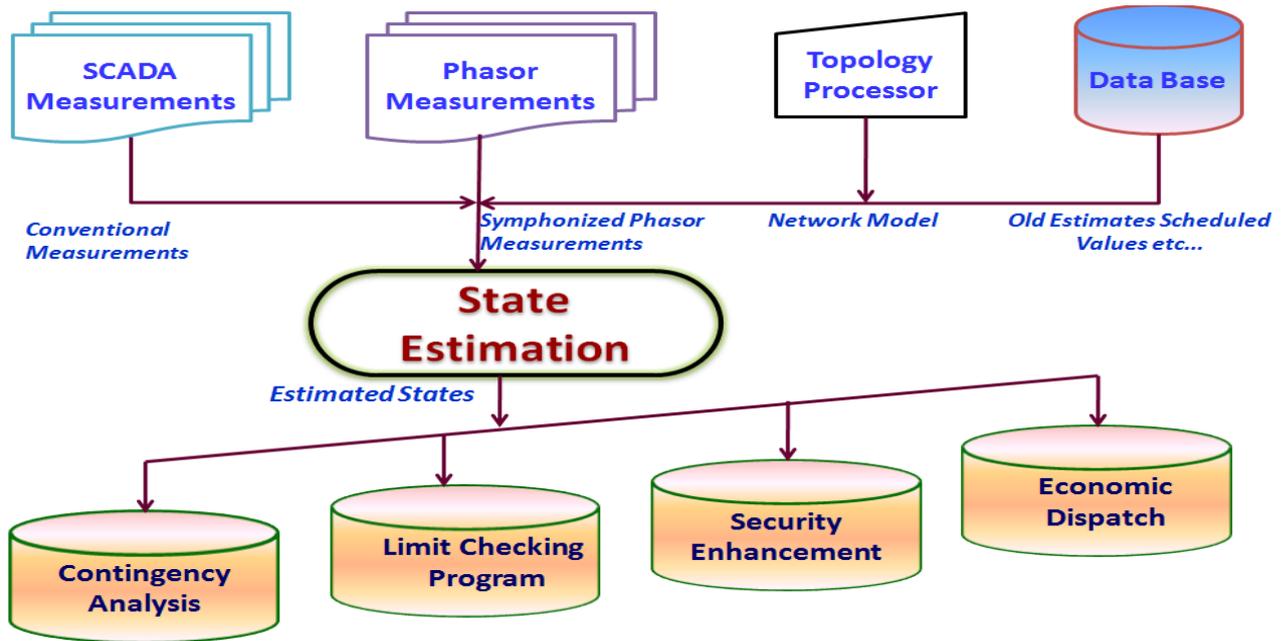


Figure 1. Importance of Power system state estimation PSSE

When the power system is heavily loaded, or when the power system is large in size with more number of radial lines, or the resistance of branch/line in the system is more than its reactance, or in a weakly meshed network if wrong bus is selected as slack bus, then the Jacobian matrix in power flow becomes ill-conditioned. The consequence decision is, the power flow problem itself is considered to be ill-conditioned.

IV. LINEAR STATE ESTIMATION

If a state estimator could function with only Phasor Measurement Unit (PMU), it is called linear state estimation.

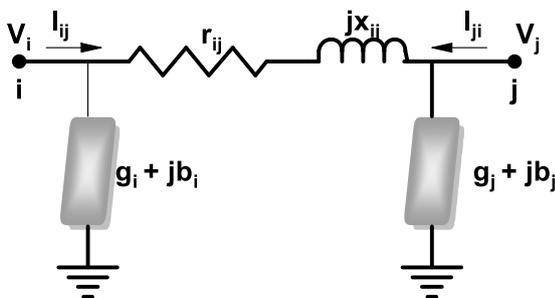


Figure 2. Pi-model of a transmission line

The system state is calculated using four matrices in LSE. Consider the following linear state equation

$$[Z] = \begin{bmatrix} E \\ I \end{bmatrix} = \begin{bmatrix} \Pi \\ yA + y_s \end{bmatrix} [X] + [e] \tag{8}$$

These matrices are called "the current measurement-bus incidence matrix (A), the voltage measurement-bus incidence matrix (II), the series admittance matrix(Y) , and the shunt susceptance matrix (Ys).

Rules to form matrices:

a). Voltage Measurement Bus Incidence Matrix (II)

In [II], a row corresponds to a voltage measurement and a column corresponds to a bus in the system which has a voltage measurement.

If measurement p (corresponding to row p) is located at bus j (corresponding to column j) then element (p, j) will be a 1. All remaining entries will be zero.

b) Current Measurement-Bus Incidence Matrix (A)

In [A], a row corresponds to current measurement and a column corresponds to a bus in the system which has a current measurement leaving the bus.

If measurement p (corresponding to row p) leaves bus j (corresponding to column j) then element (p, j) will be a 1. If measurement p (corresponding to row p) leaves bus j heading towards bus i (corresponding to column i) then the element (p, i) will be a -1. All remaining entries will be zero.

c) Shunt Admittance Matrix (Ys)

If measurement p (related to column p) leaving bus j (related to row j), then element (p, j) is the shunt admittance of the side of the branch/line where measurement p was taken.

d) Series Admittance Matrix(Y)

“It is a diagonal matrix with diagonal elements is the admittances of the branch/lines being measured”.

V. SIMULATION STUDIES& RESULTS

The linear state estimation is demonstrated in step by step on fictional 5 bus system (shown in figure 3) with assumed

network data (tabulated in table 1). Here shunt admittances are not connected to the lines.

A measurement set is formed by five voltage magnitudes followed by current measurements and is given below:

$$Z = [1 \ 0.9 \ 0.96 \ 0.9 \ 0.9 \ -0.5 \ 0.9 \ 0.8 \ -0.6 \ 0.3 \ 0.8 \ 0.4]^T$$

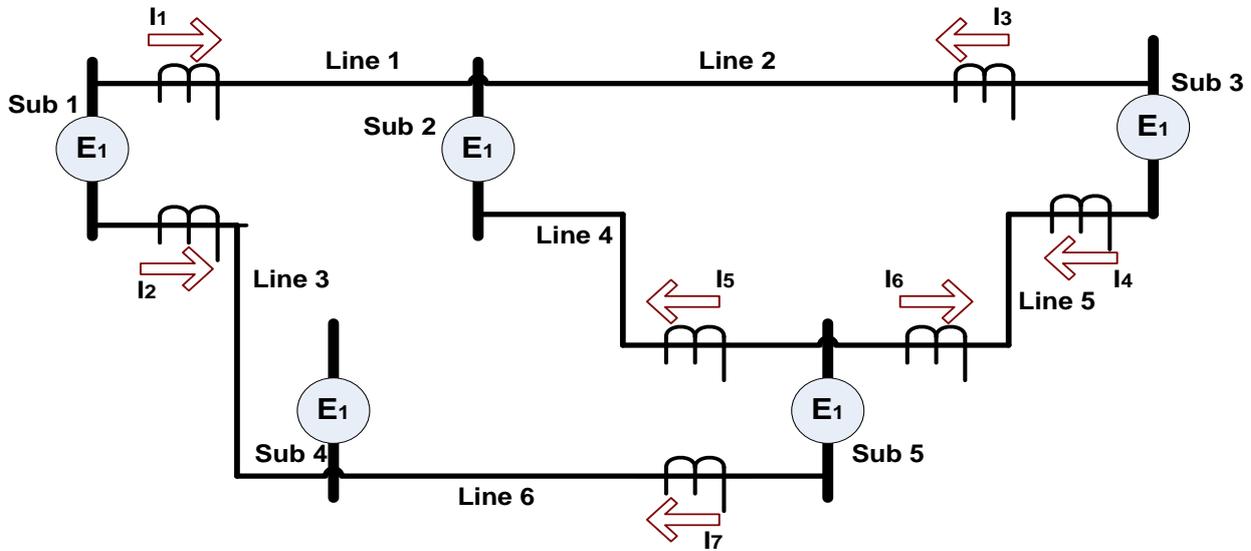


Figure 3. 5 bus System with Current Measurements

TABLE I. NETWORK DATA

From	To	R	jX	2B
1	2	0.02	0.06	0
1	4	0.01	0.08	0
2	3	0.05	0.10	0
2	5	0.02	0.07	0
3	5	0.01	0.07	0
4	5	0.03	0.09	0

$$[Y] = \begin{bmatrix} 15.81 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 12.39 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 8.94 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 14.7 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1.42 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 14.7 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 10.53 \end{bmatrix}$$

$$A = \begin{bmatrix} 1 & -1 & 0 & 0 & 0 \\ 1 & 0 & 0 & -1 & 0 \\ 0 & -1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 & -1 \\ 0 & -1 & 0 & 0 & 1 \\ 0 & 0 & -1 & 0 & 1 \\ 0 & 0 & 0 & -1 & 1 \end{bmatrix} \quad [II] = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

$$[Y_S] = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

For a error free measurements, linear state estimation method output from equation (8) is given below:

Voltage magnitudes at each bus State vector X

$$[X]_{5Bus} = \begin{pmatrix} 0.9205 \\ 0.9277 \\ 0.9452 \\ 0.8872 \\ 0.9794 \end{pmatrix}$$

Case1: Well conditioned power system:

WLS method and Linear State Estimation methods are applied on IEEE 14 bus system in mat lab soft ware. Simulation results are tabulated in table2. From the results it is clear that, LSE is more accurate than WLS method.

TABLE II. IEEE 14 BUS VOLTAGE MAGNITUDES IN P.U

TRUE VALUE	WLS VALUE	LSE VALUE
1.060	1.046	1.060
1.045	1.032	1.045
1.010	1.010	1.010
1.018	1.002	1.018
1.020	1.003	1.020
1.070	1.063	1.070
1.061	1.051	1.061
1.090	1.082	1.090
1.054	1.046	1.054
1.049	1.042	1.049
1.056	1.046	1.056
1.055	1.045	1.055
1.050	1.044	1.050
1.034	1.029	1.034

Case2: ill conditioned power system:

WLS method and Linear State Estimation methods are applied on 13 bus-ill conditioned system in matlabsoft ware. Simulation results are tabulated in table3. From the results it is clear that, LSE is more accurate than WLS method.

TABLE III. ILL CONDITION 13 BUS VOLTAGE MAGNITUDES IN P.U

TRUE VALUE	WLS VALUE	LSE VALUE
1.000	0.985	Non
1.000	0.985	Non
1.000	1.020	Non
1.000	1.014	Non
1.000	1.000	Non
0.987	1.010	Non
0.999	1.030	Non
1.060	1.100	Non
0.893	1.002	Non
1.070	1.100	Non

0.999	1.001	Non
0.999	1.100	Non
0.998	1.100	Non

*Non indicates no output

Case3: Stressed conditioned power system:

WLS method and Linear State Estimation methods are applied on EHV 24 bus system [16] in mat lab soft ware. Lines 12-14 and 17-24 are removed to create stress on system. Simulation results are tabulated in table4. From the results it is clear that, LSE is more accurate than WLS method.

TABLE IV. EHV 24 BUS VOLTAGE MAGNITUDES IN P.U

TRUE VALUE	WLS VALUE	LSE VALUE
1.0000	1.0273	Non
1.0000	0.9955	Non
1.0000	0.9928	Non
1.0000	0.9629	Non
0.9905	0.9900	Non
0.9487	0.9486	Non
0.9371	0.9370	Non
0.9585	0.9584	Non
0.9519	0.9519	Non
0.9367	0.9365	Non
1.0084	1.0082	Non
1.0004	1.0002	Non
0.9730	0.9720	Non
0.9585	0.9585	Non
1.0273	1.0273	Non
0.9905	0.9905	Non
0.9955	0.9955	Non
0.9366	0.9366	Non
0.9487	0.9487	Non
0.9371	0.9371	Non
0.9629	0.9629	Non
0.9730	0.9730	Non
0.9518	0.9518	Non
0.9928	0.9928	Non

VI. CONCLUSIONS

A Jacobian matrix is said to be ill-conditioned if it is very sensitive to small changes. In this paper, the performance of Weighted Least Square and Linear State Estimation methods under stressed condition and ill condition of power system were compared.



In weighted least square method, real/ reactive power injections/flows with very few bus voltage magnitudes are used to obtain the state vector (bus voltages) for given network model. This method inclined to convergence errors when the system is in stressed state or ill condition state. In Linear State Estimation method, bus voltage and current measurements are used to obtain the state vector. Because of its linear nature, LSE method is suitable under stressed condition/ ill condition of power systems. IEEE 14 bus, 13 bus ill conditioned system and EHV 24 bus systems are used in matlab environment to examine the proposed (LSE) method and simulation results are summarized.

From the results, it is clear that Linear State Estimation method can give very accurate solution compare to WLS method even under stressed condition and ill condition of power system. The results show the efficiency of LSE method.

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