State Estimation of Power System using weighted least sqaures method

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***Abstract*—In this Project we estimate the state of the bus of a power system. We took data from the system. it is difficult to execute it properly in the short time span because of understanding the real time time monitoring of such a dynamic system. Error comes with this analysis due to limitation in measurement. In this state estimation we actually calculate the state of a certain bus. The state of a bus defined by actually by their Voltage Magnitude and angle in the system bus. Our Data accesible b the SCADA system. It is done for IEEE 14 and 30 Bus.**

***Index Terms*—power system,bus,voltage angle, voltage magnitude**

I. Introduction

A. Objective

To estimate the accurate states of the system which results in fast tracking of system deviation in transient conditions to reduce uncertainty.

B. Introduction

State estimation is the method of assigning a value to an unknown system state variable based upon estimations from that system consistent with some criteria. Usually, the method involves imperfect measurements which are unnecessary and the way of estimating the system states relies on the statistical criterion that estimates the true value of state variables to minimize or maximize the chosen criterion. A commonly used and familiar criterion is that of minimizing the sum of squares of the differences between the calculated and true values of the function.

II. Load Flow Analysis

A. Introduction

The most common used method for power system analysis load flow (also known sometimes as the power flow)

• power flow decide how the power flows in a network.
• Also used to decide all bus voltages and currents.
• As a result of constant power models, power flow could be a nonlinear analysis.
• Load Flow Analysis is a powerful tool.

In a three phase ac power system active and reactive power flows from the generating station to the load through various system buses and branches. The flow of active and reactive power is called power flow or load flow. Power flow studies give asystematic scientific way for determination of different bus voltages, phase angles, active and reactive power flows through various branches, generators and loads under steady state condition. Power flow analysis is generally utilized by power distribution expert during the scheduling and operation of power distribution system.

Once the loads, active and reactive power injections and system parameters are characterized, load flow or power flow analysis work out the magnitudes and phase angles of load bus voltages. Hence the branch power flow can be calculated. The resulting equations in terms of power, known as the power flow equations become non-linear and should be determined by iterative procedures utilizing numerical techniques.

Moreover with the modern improvements in the society, the power system continued expanding and the dimension of load flow equation also continued expanding to several thousands. With such expands, any numerical scientific method cannot converge to a right solution. Thus power engineers need to look for more reliable techniques.The issue that faces power industry is a way to confirm that technique is most appropriate for a power system analysis. In power flow analysis, high degree accuracy and a faster time is needed to work out that technique is best to use. There have been distinctive methods utilized for load flow calculation.

B. Load flow analysis Method

The load flow methods are given as follows:

• Gauss Siedel Method
• Newton raphson method
• Fast decoupled method

There are two well known numerical methods for solving the power flow equations. These are the Gauss Seidel (G-S) and Newton Raphson (N-R) methods. The N-R method is better than the G-S method because it exhibits faster convergence characteristics.

Gauss Seidal method has the disadvantages of low rate of convergence resulting in larger number of iterations. This number of iterations increases with the number of buses. The solution for overcoming the disadvantages of Gauss seidal method is a Newton Raphson method. Its features are:

•More accurate and reliable
•Less number of iterations
•Faster computations

The Newton Raphson (NR) power flow is the most robust

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power flow algorithm used in practice but however since 1970s the load flow continues to develop in various ways and among them the best is the fast decoupled method.
Comparing the Newton method and the fast decoupled method, the latter method is faster and much simpler and needs less storage, but it may fail to converge when a portion of the basic assumptions do not hold. Because of its stability for convergence, in this project Newton-Raphson method is implemented for the calculation of actual state of power system. A comparison of the convergence of the Gauss-Seidal, Newton-Raphson and the fast decoupled method power flow algorithms is shown in figure1.

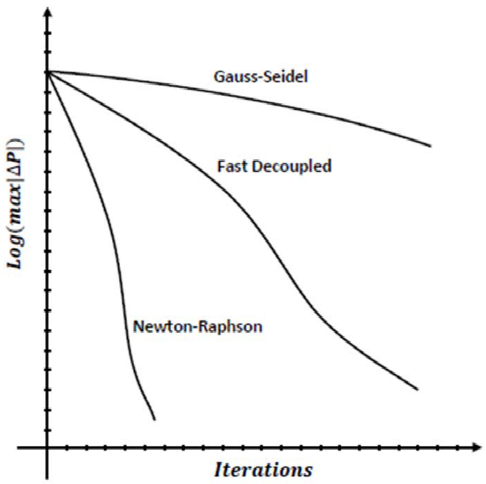

Fig. 1. Comparision of Load flow Method

C. *Newton Raphson Method*

The Newton-Raphson method is an efficient step-by-step procedure to solving non-linear equations. The network parameters, bus types and initial voltages are read from bus data. The admittance matrix is calculated by building the bus incidence matrix.
The bus admittance matrix is formed. The calculation of power mismatch vector is done. The test of convergence is calculated. If it is converged the load flow results are displayed. Otherwise the jacobian matrix and the correction vector are calculated. The voltage and angles are updated and the iterations are continued till the power mismatch vector is converged.
The bus admittance matrix Y Bus can be extracted by using the bus incidence matrix A to relate the primitive network's variables and parameters to the bus quantities of interconnected network.

$$YBus =$$

A^TY Primitive A (1)

The bus incidence matrix is singular, so Y Bus=(A^TY primitive A) is singular transformation of Y primitive. The method of singular transformations is used for forming the bus admittance matrix chosen because it performs faster simulations in MATLAB [8]simulation environment, compared to the other methods. The real and reactive power injections in polar form are given in the equation (2) and equation (3).

P$_i$=$|V_i|$ $\sum_{n=0}^{N}|V_i|$(G$_{ij}$ Cosθ_{ij}+B_{ij} sinθ_{ij}) (2)

Q$_i$=$|V_i|$ $\sum_{n=0}^{N}||V_i|$(G$_{ij}$ Cosθ_{ij}-B_{ij} sinθ_{ij}) (3)

The mismatch vector is calculated by using equation (4) and (5). Considering the first order of Taylor series expansion and neglecting the higher order terms of the nonlinear equations for active and reactive power the voltage magnitudes and angles are given in equation (6)

ΔP$_i$=$p_{sp,i}$-$|V_h|$ $\sum_{n=0}^{N}|V_i|$(G$_{ij}$ Cosθ_{ij}+B_{ij} sinθ_{ij})=0 (4)

ΔQ$_i$=$Q_{sp,i}$-$|V_h|$ $\sum_{n=0}^{N}|V_i|$(G$_{ij}$ Cosθ_{ij}+B_{ij}sinθ_{ij})=0 (5)

$$\begin{bmatrix}\Delta \mathrm{P}\\ \Delta \mathrm{Q}\end{bmatrix} = \begin{bmatrix}A = \delta\mathrm{P}/\delta\theta & B = \delta\mathrm{P}/\delta\mathrm{V}\\ C = \delta\mathrm{Q}/\delta\theta & D = \delta\mathrm{Q}/\delta\mathrm{V}\end{bmatrix}\begin{bmatrix}\Delta\theta\\ \Delta \mathrm{V}\end{bmatrix} \quad (6)$$

The ΔP and ΔQ are mismatch vector. If the mismatch vector does not converge to the specified value of the system the Jacobian matrix is calculated. The $\Delta\Theta$ and ΔV are correction vector which is to be calculated and then updating the voltage and angles. The procedure is continued till it achieves limit of the tolerance value . The power flow results will be displayed when mismatch vector converges to the specified value.

III. STATE ESTIMATION

State estimation technique has different method such as:
• Weighted least Square method
• Minimum Variance method
• Maximum likelihood method
According to these methods, it will quite important to determine how the errors in the system will affect the out coming estimates. A sensitivity analysis indicates the accuracy that can be obtained and will show which parameters have critical effect. This analysis examines the Weighted Least Squares method.
So, the common method for estimation is least square criterion which is also the maximum likelihood method in which certain assumptions are met (equal variance, gaussian error terms).

Also the maximum likelihood is more sensitive to small misspecifications.
WLS state estimation will minimize the weighted total of the squares of the measurement residuals. More accurate measurements are given more weight so that the estimation procedure influences the solution in the view of the measurements of greater accuracy. The available measurements for state estimation are power flows, voltage magnitudes, and power injections. These measurements are not free from errors. The errors can be in the form of noise in measurements, bad measurements , and wrong circuit connection information.
Consider the set of measurements [11] given by the vector z as shown in the equation (7)

$$Z = h(x) + e \tag{7}$$

Where z is the measurement vector; x is an state vector to be estimated; h(.) is a vector of nonlinear functions that relate the states to the measurements; and e is an measurement error.
The state vector includes voltage measurements and angles and hence can be taken as shown in the equation(8)

$$x = [$$

δ1,δ2,..δN....,V1,V2,...VN] (8)

Where δ1,δ1.......,δNare phase angles of buses and V1,V2,....,VN are voltage magnitudes of all the buses and N is maximum number of buses. The error vector e is assumed to be standard Gaussian with zero mean and independent covariance.The weight is the given in the equation(9). The main

$$R = \begin{bmatrix} \sigma_1^2 & 0 & \dots & 0 \\ 0 & \sigma_2^2 & 0 & 0 \\ \vdots & 0 & \ddots & 0 \\ 0 & 0 & 0 & \sigma_m^2 \end{bmatrix} \tag{9}$$

idea behind WLS estimation is the square of the measurement deviation from the initial estimate is minimized to get the best estimate.
Hence the objective function is of the form as shown in the equations (10) and (11).

$$J(X) = \sum_{i=0}^{M}($$

Z$_i$-h_i(x)^2)/(R$_{ij}$) (9)

$$j(x) = [z - h(x)]^T R^-1 * [z - h(x)] = 0 \tag{10}$$

Where R is the measurement error covariance matrix and Rij is the ith row and jth column of the matrix.
In order to solve the above equation, the first order.
The non-linear equation can be solved via an iterative Gauss-Newton method as shown below in equation

X^{K+1}=X^K-[G(X^K)]$^{-1}$ $* g$(X^k) (11)

The gain matrix is G(x). For each iteration, the gain matrix is decomposed into its triangular variables and the forward/backward substitution method is used for solving following linear set of equation.
The iterations are proceeded until and the values are updated as shown in equation

$$G(x^k)$$

Δx^{k+1}=H^T $* x^k$R^{-1}(z-h(x^k))(12)

Δx^{k+1}=x^{k+1}-x^k (13)

To provide satisfactory accuracy of the estimation process, the input data should be as measurement, but also the proper information regarding actual network topology and parameter of the network elements.
The WLS State Estimation Algorithm is as follows:

1.Initially set the iteration counter k=0, define the convergence tolerance e and the iteration limit K_{limit} values.
2.If limit K_{limit}>K terminate the iterations.
3.Calculated the measurement function h(x^k)$, the measurement Jacobian, H(x^k) and the gain matrix G(x).$
$4. Solve \Delta$x^K $using equation.$
$5. if \Delta$x^K $>\epsilon$ then the algoritm converged.

IV. RESULTS

The IEEE 14 bus system [8] is shown in Figure.2. It has 3 two winding transformers, 20 transmission lines, 4 generators and 11 loads. The residue is obtained by subtracting the base and estimated values. The true and estimated values of voltages and angles of each bus are obtained which is shown in Table III. It is found that error is high it will affect the accuracy of the system. The IEEE 30 bus system is shown in Figure.3. It has 4 two winding transformers, 41 transmission lines,6 generators and 20 loads. State Estimation Error using WLS and NR load flow Thus the states are estimated with good accuracy using weighted least square state estimation. State estimation error is calculated for 14 bus and 30 bus system. When the number of buses becomes high, the percentage of error also becomes high. This will affect the accuracy. So in order to obtain the reliable estimates bad data should be detected from the measurements.

V. CONCLUSION

The states are estimated using Weighted Least Square method with the help of true data and the actual data. The developed codes in MATLAB have been tested for IEEE 14, 30 bus systems with complete set of measurements. Thus the states are obtained with good amount of accuracy and some errors are still present due to some random measurements. So that the state estimation error is calculated between the true

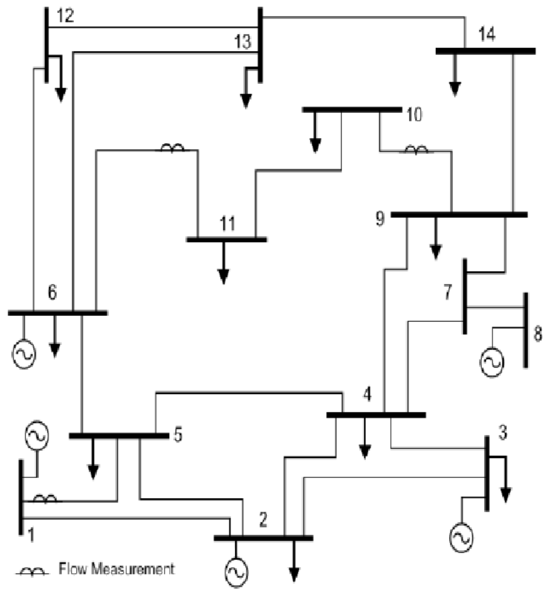

Fig. 2. IEEE 14 BUS

BUS NO.	TRUE VOLTAGE (P.U)	ESTIMATED VOLTAGE (P.U)	TRUE ANGLE (P.U)	ESTIMATED ANGLE	ERROR IN VOLTAGE (%)	ERROR IN VOLTAGE ANGLE(%)
1	1.06	1.0068	0.00000	0.0000	6.93	0.00
2	1.0450	0.9899	-4.9891	-5265	8.95	-7.22
3	1.0132	0.9518	-12.7492	-14.2039	7.27	-9.88
4	1.0166	0.9615	-10.2420	-11.4146	7.45	-12.19
5	1.0700	0.9579	-8.7601	-9.7583	6.57	-14.53
6	1.0457	0.9919	-14.4469	-16.0798	7.58	-15.22
7	1.0800	1.02	-13.2368	-14.7510	7.95	-11.86
8	1.0305	1.0287	-13.2368	-14.7500	7.53	-18.27
9	1.0299	0.9763	-14.8201	-16.5125	7.89	-16.65
10	1.0461	0.9753	-15.0360	-16.7476	9.50	-12.59
11	1.0533	0.9932	-14.8581	-16.5397	5.23	-16.58
12	1.0466	1.0009	-15.2973	-17.0203	6.35	-16.84
13	1.0193	0.9940	-15.3313	-17.0583	7.05	-13.84

Fig. 3. Output for IEEE 14 BUS

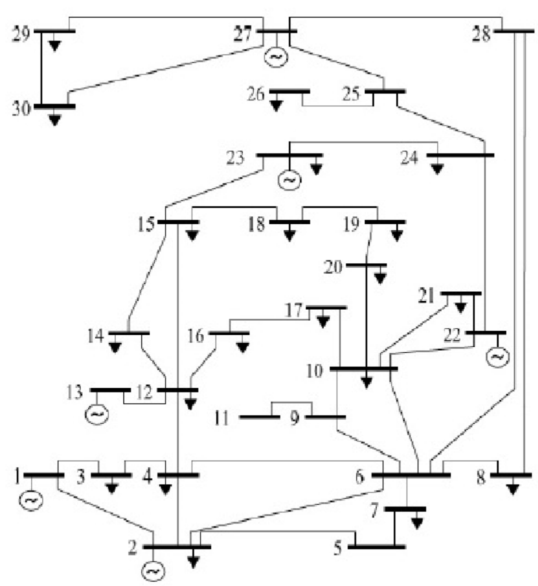

Fig. 4. IEEE 30 BUS

BUS NO.	TRUE VOLTAGE (P.U)	ESTIMATED VOLTAGE (P.U)	TRUE ANGLE (P.U)	ESTIMATED ANGLE	ERROR IN VOLTAGE (%)	ERROR IN VOLTAGE ANGLE(%)
1	1.06	0.9865	0.00000	0.0000	6.93	0.00
2	1.0430	0.9300	-5.73474	-6.2635	10.834	-9.22
3	1.0217	0.9474	-7.5448	-8.8420	7.27	-9.88
4	1.0129	0.9384	-9.2989	-10.9021	7.35	-17.19
5	1.0100	0.9335	-14.1542	-16.4941	7.57	-16.53
6	1.01210	0.9395	-11.0880	-12.9975	7.17	-17.22
7	1.0035	0.9287	-12.8734	-15.0443	7.45	-16.86
8	1.0100	0.9449	-11.8039	-13.9608	6.4	-18.27
9	1.0507	0.9667	-14.1363	-16.4913	7.99	-16.65
10	1.0438	0.9472	-15.7341	-18.3445	9.24	-16.59
11	1.0820	1.0093	-14.1363	-16.4813	6.71	-16.58
12	1.0576	0.9746	-14.9416	-17.6918	7.85	-19.84
13	1.0710	0.9954	-14.9416	-17.6918	7.05	-19.84
14	1.0429	0.9559	-15.8244	-18.3137	8.34	-15.73
15	1.0384	0.9491	-15.9101	-18.3299	8.59	-15.20
16	1.0445	0.9555	-15.5487	-18.2800	8.52	-17.56
17	1.0387	0.9441	-15.8856	-18.5714	9.10	-16.90
18	1.0282	0.9352	-16.5425	-19.4195	9.04	-17.39
19	1.0252	0.9306	-16.7273	-19.6063	9.20	-17.21
20	1.0291	0.9339	-16.5363	-19.3581	9.25	-17.06
21	1.0293	0.9320	-16.2462	-18.9321	9.45	-16.53
22	1.0353	0.9372	-16.0738	-18.7111	9.47	-16.40
23	1.0291	0.9331	-16.2528	-18.9957	9.32	-16.87
24	1.0237	0.9231	-16.4409	-19.2593	9.82	-17.14
25	1.0202	0.9270	-16.0539	-18.3364	9.13	-14.21
26	1.0025	0.9070	-16.4712	-19.2593	9.52	-14.21
27	1.0265	0.9395	-15.5558	-18.2962	8.47	-17.61

Fig. 5. IEEE 30 BUS

values which is obtained from Newton Raphson method and estimated value obtained from Weighted least Squares (WLS) method.

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