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A Review of Power System State Estimation by Weighted Least Square Technique

C.Vaishnavi
PG Student,Power System
c.vaishnavi17@gmail.com
GCET, V.V.Nagar

Prof. I.A. Sheikh
Assistant professor
ishaqsheikh@gcet.ac.in
GCET, V.V.Nagar

Abstract -- The control centers of utilities receive abundant raw measurements from power system networks. The measurements may be destroyed or lost while being transmitted to the control centers due to defects in sensors or loss of communication during a natural disaster. In such cases the raw data has to be processed before being used for analysis by various Energy Management System (EMS) applications. State estimation is a computer program that helps to process the raw measurements and determine the power system states from them. Vector consisting of bus voltage magnitudes and their respective bus phase angles are states of an electric power system. In recent years, a wide range of state estimation methods has emerged, and this paper provides an overview of the commonly used state estimation method. It outlines Weighted Least Square Technique and the steps involved in the estimation.

I. INTRODUCTION

Nowadays mechanism of data acquisition and transmission are developed. However small random errors are always present in meter readings as real time readings will not be perfect. These uncertainties are due to error in metering, communication errors, incomplete metering and error in mathematical model or unexpected system changes. Measurements are affected by errors due to bad functioning of measuring instrument in transmission lines, bad calibration of equipments. Bad data points will occur. Sometimes meter readings may be lost completely or destroyed while being transmitted to control centers due to defects in sensors or loss of communication during natural disasters.

So online control of electrical power systems demand the measurement processing to determine true state of system. The function of state estimator is shown in figure 1. The most

used are those based on the weighted least squares [2]. The exact state of the electric grid is needed to perform

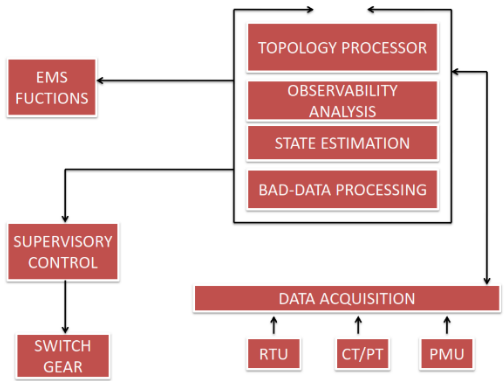

Figure 1: Functions of State Estimator

any corrective or preventive action [1]. It is possible to get a reduced set of data or corrupted data during extreme contingencies for further analysis [1]. State Estimation helps to get a better picture of the power system with an available set of measurements.

The general concepts of state estimation in power system including formulation and implementation have been discussed by the authors in [6,7]. The effect of massive data loss from a control center in a large scale power system and the type of measurements that can be included to provide a better state estimator solution was analyzed [10].

Identification of efficient state estimation algorithms at different levels of data redundancy is necessary during extreme conditions. It is also required to explore and evaluate different state estimation methods, when there are fewer amounts of data or no data from a system network.

Basically, we can define the state estimator as a calculation program carried in real time with the purpose of providing a complete, coherent and reliable database, which can describe the electrical state of the network [11]-[12].

II. OVERVIEW OF STATE ESTIMATION

Power system network is monitored by many sensors like current transformer, potential transformer, relay and Phasor Measurement Units. A conventional state estimator estimates the optimal voltage magnitudes and phase angles at the buses of the entire system [13]. The state estimation for a power network involves gathering the real time measurement data like line flows, power injections and voltage measurement through SCADA and calculating state vector using predefined specific state estimation algorithm. State estimation helps to estimate the states of the system as wells as the values of the measurements in presence of error in acquisition of measured data. The state estimation results forms the basis for other EMS functions, like security analysis, optimal load dispatch, voltage stability analysis, etc.

The application of state estimation in power system with sensors located in a substation. The data from sensors are transmitted to a control center by a communication network. In control center, the data is fed to a state estimator program for further analysis. State estimation helps to calculate the states (voltage and bus angles), as well as estimated values of the measurements in presence of error. It provides a snapshot of the power system from available data.

State Estimation is a real time mathematical methodology or procedure to process real time measurements. By using power system model and line flows and power injections and voltage measurement values, it is possible to compute an optimal estimate of the state vector.

III. LITERAURE SURVEY

Weighted Least Squares (WLS) and Iteratively Reweighted Least Squares (IRLS) algorithms are implemented on a Ward Hale 6 bus [1] test system. The measurements are obtained by performing power flow and introducing a random error in the measurements.

The implementation algorithms is shown in a brief way in figure 2.

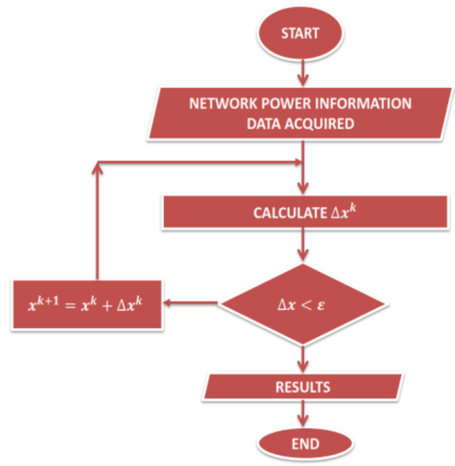

Figure 2: Flowchart of state estimation algorithm [2]

The WLS state estimation program is implemented for a 3 Bus system and convergence is checked in [3].First power flow of the 3-Bus system is run to obtain measurements for state estimation. Then real power at a bus is increased to introduce error in the system [3].

IV. POWER SYSTEM STATE ESTIMATION

Modeling Of Weighted Least Square Technique

The electric power transmission system uses wattmeter, VAR-meters, voltmeters and current meters to measure real power, reactive power, voltages and currents.

These continuous quantities are monitored by current and potential transformers on the transmission lines and on the transformers and buses of power plants and substations.

The analog quantities pass through transducers and analog-to-digital converters and the digital outputs are then telemetered to the energy control center over various communication links.
The data acquired always contains inaccuracies which are unavoidable since physical measurements cannot be entirely free of random errors or noise.

1)Measurements have certain Error associated with the true value of measured quantity

$$[\boldsymbol{Z}] = [\boldsymbol{Z_{true}}] + [\boldsymbol{e}] \quad \textbf{(1)}$$

$$[\boldsymbol{Z}] = \left[\boldsymbol{h}(\boldsymbol{x})[x]\right] + [\boldsymbol{e}] \quad \textbf{(2)}$$

$$Z = \begin{bmatrix} Z1 \\ Z2 \\ . \\ . \\ . \\ Zm \end{bmatrix} = \begin{bmatrix} h1(x1, x2, x3, \ldots, xn) \\ h2(x1, x2, x3, \ldots, xn) \\ . \\ . \\ . \\ hm(x1, x2, x3, \ldots xn)) \end{bmatrix} + \begin{bmatrix} e1 \\ e2 \\ . \\ . \\ . \\ em \end{bmatrix} \quad (3)$$

Where,

Z is measurement vector
Z_{true} is true value of measured quantity
$h(x)$ is the non linear function expressing measurements in terms of State
x is the system state vector
e is the measurement error
m is the number of measurements
n is the number of state variables

2)Error between actual measurements Z and the true (unknown) value of measured quantities:

$$[e] = [Z] - \{ [H][x] \} = [Z] - [Z\_true] \quad \textbf{(4)}$$

3)True values of state cannot be determine so we calculate estimates of states:

$$\hat{e} = [Z] - [H] * [\hat{x}] \quad \textbf{(5)}$$

$\hat{x}$ is the estimated value of state variables

$\hat{e}$ is the difference between actual measurements and their estimated values

4)Because of the errors or noise the true values of physical quantities are never known and we have to calculate the best possible estimates of the unknown quantities.

We must decide a criterion for calculating the estimates $\hat{x}$ from which error $\hat{e}$ and $\hat{Z}$ are to be computed. If algebraic sum of the errors is minimized, then positive and negative errors would offset one another. **So Sum of Squares of Error is minimized.**

To ensure that measurements from meters of known greater accuracy are treated more favorably than less accurate measurements, each term in the sum in squares is multiplied by an appropriate weighting factor W to give the objective function:

$$f = \sum_{i=1}^{n} w_i \, e_i^2 \quad \textbf{(6)}$$

5)We select the best estimates of the state variables as those values which cause objective function f to take on its minimum value.

6) For minimizing f , the estimates $\hat{x}$ are those values of x , which satisfy the equation ,

$$\left[\frac{\partial\,(\hat{e})}{\partial x}\right][W][\hat{e}] = 0 \quad (7)$$

7)Substituting $\hat{e} = Z - H\,\hat{x}$ in equation (**7**)

$$\left[\frac{\partial\,(Z - H\hat{x})}{\partial x}\right][W][Z - H\hat{x}] = 0 \quad \textbf{(8)}$$

8)Solving for $\hat{x}$

$$\Delta\,\hat{x} = (g^T\,W\,g)^{-1} \quad g^T\,W\,Z \quad \textbf{(9)}$$

The iterative approach is used to solve for the state

$$x^{k+1} = x^k + \Delta\,\hat{x} \quad \textbf{(10)}$$

Where,
g is Jacobian Matrix, $\frac{\partial h}{\partial x}$
h is Measurement Function
x are the state variables
k is iteration index

$g^T W g$ is gain matrix

x^k is value of State vector at kth itteration

x^{k+1} is the value of State vector

$\Delta\hat{x}$ is update vector of the state vector

$$g = \begin{bmatrix} 0 & \frac{\partial V_{mag}}{\partial V} \\ \frac{\partial P_{inj}}{\partial \delta} & \frac{\partial P_{inj}}{\partial V} \\ \frac{\partial Q_{inj}}{\partial \delta} & \frac{\partial\partial Q_{inj}}{\partial V} \\ \frac{\partial P_{ij}}{\partial \delta} & \frac{\partial P_{ij}}{\partial V} \\ \frac{\partial Q_{ij}}{\partial \delta} & \frac{\partial Q_{ij}}{\partial V} \end{bmatrix} \quad \textbf{(11)}$$

Where,
V_{mag} is the voltage magnitude.

P_{inj} and Q_{inj} are the real and reactive power injections respectively.

P_{ij} and Q_{ij} are the real and reactive power flow from bus i to j respectively.

V. CONCLUSION

The main focus of any power utility is the reliable and secure operation of its power system, so it can deliver an uninterrupted power supply to its customers. A reliable estimate of any power system is essential for its smooth operation. The technique that estimates the state of any power system is state estimation. Estimated state variables are then used in estimating the line power flows which are then used in system control centers in the implementation of the security-constrained dispatch and control of the power system.

Calculated Estimated Values are near to true value as error associated with estimated values reduces. WLS State estimation technique calculates accurate value of State and Measured Quantities with high confidence despite Measurements are missing, inaccurate or corrupted by Noise.

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