A survey on transmission and distribution system's State Estimation process

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ABSTRACT

State estimation is a key function (which provides creditable data from raw data supplied by measurement devices) in building adequate network models for on-line monitoring and analyses. This paper provides a survey of state estimation process on transmission network systems and on distribution network systems. This paper also focuses on measurement Jacobian matrix in both the systems.

Keywords: State Estimation, Transmission systems state estimation and Distribution systems state estimation, measurement Jacobian.

I. INTRODUCTION

Monitoring of system operation conditions is essential for secure operation of power systems. In monitoring process, system data are acquired from measurement devices, which are distributed in the entire system, and they are transmitted to the control system through communication systems. After that, received data are processed by some computer aided tools called Energy Management System (EMS). State Estimation (SE) is one of the EMS functions which have been known as basis of EMS since it provides creditable data from raw data supplied by measurement devices. Indeed, due to the fact that other EMS functions utilize obtained creditable data, SE should be considered as kernel of EMS.

SE is the process of assigning a value to an unknown system variables based on the system configuration and measurements obtained from the system.

State estimator has been widely used as an indispensable tool for online monitoring, analysis and control of power systems. It is also exploited to filter redundant data, to eliminate incorrect measurements and to produce reliable state estimates. Entire power system measurements are obtained through Remote Terminal Unit (RTU) of Supervisory Control and Data Acquisition (SCADA) systems which have both analog and logic (digital) measurements. Logic measurements are used in topology processor to determine the system configuration. Various techniques have been used to obtain an SE solution. Excellent survey on SE algorithms can be found in [1-9]. These papers focuses SE on transmission systems.

Real-time control of distribution system requires an estimate of the system states. In the past, most of the distribution systems were not monitored, therefore, there was no need for SE. Under this condition, load flow program is often used for planning purpose. Various techniques have been proposed to obtain distribution system load flow solutions [9-13]. Nowadays, the technology to automatically monitor and control a distribution system is available [14].

However, despite the growing importance of DSSE, the authors were unable to find a relevant survey paper in the literature, summarizing the current state of the art, and discussing research trends and future directions in the area of DSSE (one conference paper was found [2], but the literature survey in this paper is not comprehensive, and focuses mainly on Chinese-language publications). While there have been several survey papers and books with literature reviews in the general field of power systems SE [3]– [11], these deal primarily with techniques and methods applied to transmission systems, and there are none which focus specifically on the developments and applications of DSSE. This paper aims to fill this gap by providing a survey of the most important techniques and algorithms currently available for DSSE.

This paper provides the survey of state estimation process on transmission network systems and on distribution network systems. This paper also focuses on measurement Jacobian matrix in both the systems.

This paper is organized into following sections: section II describes power system state estimation functions. The state estimation process on transmission network system is explained in section III. The state estimation process on distribution network system is explained in section IV. The measurement Jacobian matrix changes in both the systems are explained in section V. Section VI gives conclusions and section VII ends with references.

II. POWER SYSTEMS STATE ESTIMATION FUNCTIONS

SE typically include the following functions

1. Network Topology Processor (NTP):- It gathers status data about CB and switches and configures the one line diagram of the system. The communication of NTP can be through SCADA or IEC.

2. Observability Analysis: - Observability analysis module will determine if the network state can be estimated uniquely from given measurements set. If not maximum observable sub networks has to be worked out. For unobservable networks, measurements from past history, if available, could probably be used as pseudo measurements with high variance.

Algorithm for observability analysis can be either topological or numerical (based on calculation of rank of gain matrix).

3. SE solution algorithm: - It determines the optimal estimate for the system state based on network model and the gathered measurements from the system.

4.Bad data processing: - detects the existence of gross errors in the measurement set. Identifies and eliminates bad data measurements that there is enough redundancy in the measurement configuration.

5. Parameter and structural error processing: - It estimates various network parameters errors. Detects structural errors.

III. SE PROCESS ON TRANSMISSION NETWORKS

Transmission networks are more meshed typed and over-determined (number of available measurements are more than number of state variables).

SE process on transmission networks

1. Transmission Network Topology

It gathers status data about CB and switches and configures the one line diagram of the system. The communication of NTP can be through SCADA or IEC.

2. Observability Analysis

Algorithm for observability analysis can be either topological or numerical (based on calculation of rank of gain matrix which is based on available measurement data).

3. SE solution algorithm

A power system state estimator based on the WLS method [3] - [5] is the most known. The estimator assumes minimizing the following objective function:

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

where: x – a power system state vector, z – a vector of measurements, h(x) – a vector of nonlinear functions, representing dependence of measured quantities from the state vector, R – a diagonal matrix of measurement covariances.

Solving the following normal-equation set we find out a solution of the estimation problem:

$$\mathbf{G}\left(\mathbf{x}^{k}\right) \cdot \left(\mathbf{x}^{k+1} - \mathbf{x}^{k}\right) = -\mathbf{g}(\mathbf{x}^{k}), \quad (2)$$

Where: k – a number of iteration, xk – a solution vector at the kth iteration

$$\mathbf{G}\left(\mathbf{x}^{k}\right) = \mathbf{H}^{T}\left(\mathbf{x}^{k}\right) \cdot \mathbf{R}^{-1} \cdot \mathbf{H}\left(\mathbf{x}^{k}\right), \quad (3)$$

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

G(x) is called a gain matrix. It is a sparse, positive determined and symmetric matrix for a fully observable power system.

4. Bad data processing in TSSE

The bad data analysis is usually performed using the residual analysis based on chi-square and normalized residual tests.

IV. SE PROCESS ON DISTRIBUTION NETWORKS

A. Challenges in DSSE

DSSE facing a number of new challenges, since the characteristics of distribution networks differ fundamentally from transmission networks in the following ways:

Construction: Most distribution networks have a radial construction (where as transmission networks are more meshed), often with high R/X ratios.

Redundancy: For technical and economic reasons the number of measurement points in distribution networks is much lower than in transmission networks. Systems are under-determined rather than over-determined.

Measurement types: Most of the available input data at the distribution level are measurements of power or current injections at feeders and very few branch currents. Remaining measurements are pseudo measurements.

Phase imbalances: Conventional SE techniques assume that the network is a balanced system. However, distribution systems can have significant phase imbalances, requiring the use of full three-phase system models.

B. SE process on distribution networks

1. Distribution Network Topology

Object oriented approach was proposed to process distribution network topology [37]-[38]. Due to the extent of a distribution network and its three-phase property, phase errors are frequent. Instead of treating network topology as known and fixed, a generalized SE algorithm proposed in [39] integrates the estimation of topology information with the SE process using real-time measurements by modeling parts of the distribution systems at bus/switching –device level. Autonomous network operation with SE can identify changes in the system state and automatically update the system model [40].

2. Observability Analysis

Algorithm for observability analysis can be either topological or numerical (based on calculation of rank of gain matrix which is based on available measurement data).

Measurement Data in DSSE

Real-time data

In DA, measurements of feeder bus voltages, branch currents, powers and switch status at few feeder locations are gathered. Customer smart meters report demand data is available in every 15 min or longer intervals. Synchrophasor information from IEDs is available. An issue that should be addressed in using different types of measurements is the time skew problem, i.e., the difference in the time references.

Limited real time measurement data causes unobservability problem.

Pseudo data

The use of pseudo measurements is crucial characteristic of DSSE. Pseudo power injection measurements at feeder buses can be defined as Gaussian distribution with their means at half the transformer rating, or determined based on customer billing data and typical load profiles.

The smart meter data are updated less frequently and generally involve considerable delays. Without effective implementation, data cannot be used directly as input to a measurement these profiling module to estimate the measurements for DSSE.

Virtual measurements

Virtual measurements are zero voltage drops in closed switching devices, zero power flows in open switching devices and zero bus injections that can be found at the nodes such as a switching station. The assignment of high weight to virtual measurements and low weights to pseudo measurements may cause ill-conditioned system. The use of Lagrange multipliers was proposed to handle virtual measurements [57]-[58].

3. SE solution algorithms in DSSE

A. WLS-Based Static DSSE

Weighted Least Square (WLS) estimators are the most popular and considerable efforts have been devoted to reduce the computational requirements. The main differences among proposals are basically the choice of the state variables, the simplifications to speed up the estimation, and the techniques to incorporate heterogeneous measurements. Two main categories were proposed for the choice of state variables, node-voltage and branch-current based state estimators. Both can be formulated in polar and rectangular coordinates.

Weights associated with the actual measurements are proportional to the accuracy of the measurements and nonzero mutual terms in the measurement weight matrix can be included if correlations of measurements are considered [45].

Bad data detection and identification

The capabilities of bad data and network configuration error detection and identification depend strongly on the measurement set. Since the measurement redundancy is low and load models are quite uncertain, the detection of bad data is difficult. In the WLS-based methods, it is conducted after the estimation process. The bad data analysis is usually performed using the residual analysis based on chi-square and normalized residual tests. The geometrical approach which uses composed measurement error and composed normalized error outperforms the residual analysis in detection, identification and correction of gross errors in DSSE [81]. The commonly used 3σ bad data detection threshold is inadequate when using load profile data to detect errors in feeder line flow measurements [84]. Test results indicated that gross error level would affect the bad data detection and the load models influence the gross error correction.

V. JACOBIAN MATRIX IN DSSE

When bus voltages in polar form are chosen as state variables, the entries of measurement Jacobian and gain matrix in the normal equation must be recalculated at each iteration. Similar to the ZB Gauss method [22] that uses the sparse bifactored Y_{bus} matrix and equivalent current injections to solve the distribution power flow problem, an algorithm proposed in [7] uses a bus injection current-based formulation that converts bus power injection measurements to their corresponding current injection equivalents in rectangular form. By adopting node voltage in rectangular form as the state variables, the Jacobian terms of the converted bus current

Injection measurements become constant. Bus injection power and voltage magnitude measurements can be converted into equivalent bus injection current and voltage measurements in rectangular forms based on the calculated bus voltage in the previous iteration. Actual feeder branch power and current magnitude measurements can be converted into their rectangular branch current equivalences. This rectangular form- based method requires factorization of the gain matrix only once in the solution procedure.

Power and current magnitude measurements are converted into their equivalent current measurements functions expressed in terms of branch currents to ensure that all Jacobian matrix elements are constants. Forward and back substitutions are required to obtain the estimated node voltage for measurement conversion.

VI. CONCLUSIONS

This paper is to summarize state estimation process on transmission systems and on distribution systems. This paper also focuses on measurement Jacobian matrix changes in DSSE.

Entire power system measurements are obtained through Remote Terminal Unit (RTU) of Supervisory Control and Data Acquisition (SCADA) systems which have both analog and logic (digital) measurements. Logic measurements are used in topology processor to determine the system configuration

REFERENCES

[1] F. Schweppes and E. Hands chin, "Static state estimation in electric power systems," Proc. IEEE, vol. 62, no. 7, pp. 972– 982, Aug. 1974.

[2] L. Holien, A. Gjelsvik, S. Aam, F. F. Wu, and W. E. Liu.: "Comparison of different methods for state estimation". IEEE Trans. on Power Systems, vol. 3, pp. 1798 – 1806, May 1985.

[3] SUN Guo-qiang,WEI Zhi-nong,"Power System State Estimation with Unified Power Flow Controller",DRPT2008 6-9 April 2008 Nanjing China

[4] SUN Guo-qiang,WEI Zhi-nong,PANG Bo"Power System State Estimation Containg wind generators".

[5] Dudekula Sai Babu,K Jamuna,B. Aryanandiny,"Power System State estimation-A Review",ACEEE Int.J.on Electrical and Power Engineering,Vol.5,No.1,February 2014

[6] R. Jegatheesan, and K. Duraiswamy, "AC:Multi-terminal DC Power system state estimation - a sequential approach". Elec. Machines and Power Systems, vol. 12, pp. 27-42, January 1987.

[7] A. Nabavi-Niaki, and M.R. Iravani, "Steady-state and Dynamic Models of Unified Power Flow Controller (UPFC) for Power System Studies", IEEE Trans. on Power Systems, vol. 11, pp. 1937-1943, May 1985.

[8] B. Xu, and A. Abur, "State Estimation of Systems With Embedded FACTS Devices", IEEE Powertech Conf., Bologna, Italy, pp. 1-5, 2003.

[9] B. Xu, and A. Abur, "State Estimation of Systems With Embedded UPFCs Using the Interior Point Method", IEEE Trans. on Power Systems, vol. 19, pp 1635-1641, August 2004.

[10] F. Schweppe and D. Rom, Power system static-state estimation: Parts I, II, & III, Power Apparatus & Sys. IEEE Trans., vol. 89, no. 1, p. 125–130, Jan 1970

[11] Z. Zhi, L. Min, and X. Shiyu, A survey on state estimation algorithm of distribution grid, in Proc. Spring Congress on Engineering and Technology (S-CET), 2012 IEEE, May 2012,p. 1–4.

[12] F. F. Wu, Power system state estimation: a survey, Int. Journal of Elec. Power & Energy Sys., vol. 12, no. 2, p. 80 – 87, 1990.

[13] A. Monticelli, State Estimation in Power Systems: A Generalized Approach. Norwell, MA: Kluwer, 1999. [5] A. Abur and A. G. Expsito, Power System State Estimation: Theory and Implementation. New York: Marcel Dekker, 2004

[14] W.-H. Liu and S.-L. Lim, "Parameter error identification and estimation in power system state estimation,"Power Sys., IEEE Trans., vol. 10, no. 1, pp. 200–209, 1995.