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Distribution system state estimation-A step towards smart grid

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ABSTRACT

State estimation (SE) is well-established at the transmission system level of the electricity grid, where it has been in use for the last few decades and is a most vital component of energy management systems employed in the monitoring and control centers of electric transmission systems. However, its use for the monitoring and control of power distribution systems (DSs) has not yet been widely implemented because DSs have been majorly passive with uni-directional power flows. This scenario is now changing with the advent of smart grid, which is changing the nature of electric distribution networks by embracing more dispersed generation, demand responsive loads, and measurements devices with different data rates. Thus, the development of distribution system state estimation (DSSE) tool is inevitable for the implementation of protection, optimization, and control techniques, and various other features envisioned by the smart grid concept. Due to the inherent characteristics of DS different from those of transmission systems, transmission system state estimation (TSSE) is not applicable directly to DSs. This paper is an attempt to present the state-of-the-art on DSSE as an enabler function for smart grid features. It broadly reviews the development of DSSE, challenges faced by its development, and various DSSE algorithms. Additionally, it identifies some future research lines for DSSE.

1. Introduction

SE, after it was first introduced to power systems by Fred Schweppes in 1970 [1], is nowadays an important function in the management and control of the operation of electric transmission networks all over the world. It has strengthened the SCADA systems and eventually led to the development of the EMS [2]. The state estimator obtains the system state using the SCADA measurements, measurements from PMUs [3,4], pseudo-measurements and the topology information [2,3]. After the state is known, various functions of EMS like contingency analysis, security analysis, optimal power flow and other functions can be carried out as shown in Fig. 1. Therefore, SE is the backbone function of TS EMS [5], however, its application to DS was not required. This was due to its passive nature with uni-directional power flows since there was no active generation at this level. However, due to shift towards the smart grid encompassing DG inputs and other features such as DR and DA functions, the shape of the power DS is changing and it is no longer passive due to bi-directional power flows (see, Fig. 2). This establishes a need for bringing DS into the operation circle of monitoring and control, which makes the role of DSSE more significant.

DS and TS differ from one another in many ways, such as DS have high R/X ratios than TSs, imbalances among phases and low availability of real-time measurements. This makes the use of TSSE techniques unsuitable for application to DS. This paper is an attempt to encompass various SE techniques applied to DS by reviewing the relevant literature. Many review papers on the subject can be found with the deficiency of putting various techniques together but not mentioning the adequacy of those techniques for DS. This paper attempts to address this deficiency by mentioning the adequate estimation techniques for DS. It further provides future research directions for DSSE, including intelligent load modeling techniques [6] for pseudo measurement generation [7], event-triggered SE techniques [8], incorporation of smart meter [9] data and micro-synchrophasors (μPMU) [10] data in DSSE, and finally development of advanced energy management systems [6].

This paper is divided into the following sections: Section 2 presents SE and its mathematical formulation. Section 3 discusses the need for DSSE; modification on conventional SE for DSSE; NV- DSSE; BC-DSSE; and comparison of the voltage and branch current-based DSSE. Section 4 discusses the classification of DSSE techniques, Section 5 presents multi-area or distributed DSSE techniques, future

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Nomenclature

SE	State estimation
DSSE	Distribution system state estimation
TSSE	Transmission system state estimation
DS	Distribution system
DN	Distribution network
TS	Transmission system
DER	Distributed Energy resource
SCADA	Supervisory Control and Data Acquisition
EMS	Energy management system
PMU	Phasor measurement unit
μPMU	Micro-phasor measurement unit
DG	Distributed generator
DR	Demand response
DA	Distribution automation
R/X	Resistance-to-reactance
BC-DSSE	Branch-current-based DSSE
NV-DSSE	Node-voltage-based DSSE
RTU	Remote terminal unit
PDC	Phasor data concentrator
WLS	Weighted least squares
DMS	Distribution management system
DC	Direct current
MSE	Microgrid state estimator
ACSR	Aluminum Conductor Steel-Reinforced
Y-type	Star-connected
Δ-type	Delta-connected
FA	Firefly
PCC	Point of common coupling
RMSE%	Percent-Root means square error
WLAV	Weighted-Least-Absolute-Value
SHGM	Schweppes-Huber-generalized M-estimator
IRLS	Iterative reweighted least squares
DSE	Dynamic SE
FASE	Forecast-aided state estimation
ANN	Artificial Neural Network
EKF	Extended Kalman filter
UKF	Unscented Kalman filter
LSE	Local state estimator
MASE	Multi-area state estimation
BSE	Bi-linear state estimation
ML	Machine learning
EM	Expectation maximization
RBA	Recursive Bayesian approach
SOR	Successive-over-relaxation
MV	Medium voltage
GPS	Global positioning system
AMI	Advanced metering infrastructure
ADMS	Advanced distribution management system

research directions in DSSE, outlining five areas of active research on DSSE, are briefly discussed in Section 6, and finally Section 7 concludes the paper.

2. State estimation in power systems

System state is the minimum set of variables that can be used to completely define the power system using network topology and impedance parameters, e.g. complex node voltages or branch currents could be considered as system state [3]. SE is the process of determining the system state using system measurements based on minimization of certain statistical criteria (e.g. Least Squares) [1]. The major objectives of SE are the following [11,12]:

1. Bad measurement data detection;
2. Smoothing out of small errors;
3. Detection of topology errors i.e. wrong switch statuses;
4. Provision of estimates for unmonitored parts of the system.i.e. filling in meter measurements for missing or delayed measurements;
5. Estimation of network parameters based on redundancy in measurements.

Four main processes are carried out by the TSSE present in the EMS [2,3] as depicted in Fig. 3. Topology processing uses network parameters such as circuit breaker and switch status information and updates the network topology. It makes sure that the correct topology information is used in the SE process [13,14]. Other works on topology processor can be found in [15,16]. Observability analysis determines whether the measurements are sufficient to carry out the SE. To ensure the observability, measurements based on historical load data, called

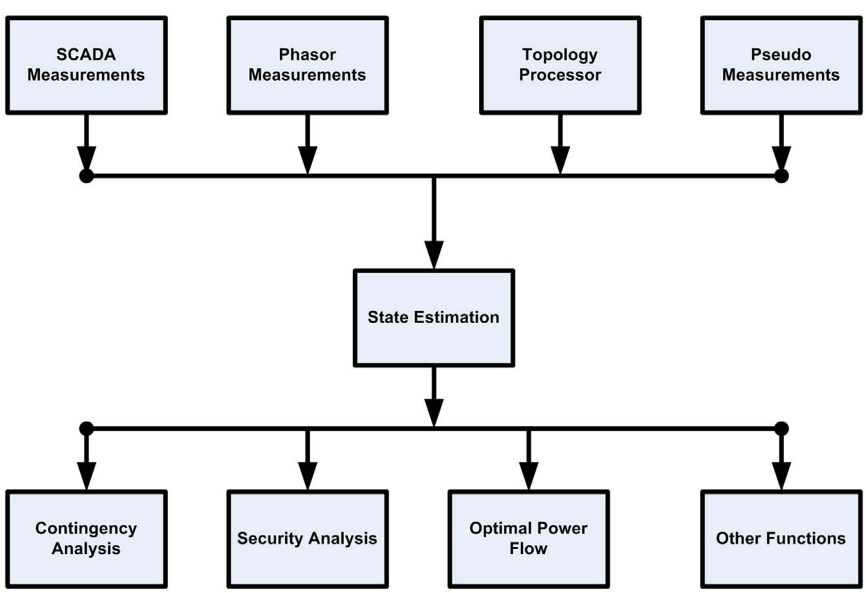

Fig. 1. Role of SE in EMS/SCADA.