PMU Placement Based on Heuristic Methods, when Solving the Problem of EPS State Estimation

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ABSTRACT

Creation of satellite communication systems gave rise to a new generation of measurement equipment – Phasor Measurement Unit (PMU). Integrated into the measurement system WAMS, the PMU sensors provide a real picture of state of energy power system (EPS). The issues of PMU placement when solving the problem of EPS state estimation (SE) are discussed in many papers. PMU placement is a complex combinatorial problem, and there is not any analytical function to optimize its variables. Therefore, this problem is often solved by the heuristic optimization methods. Depending on the chosen set of sensors (SCADA&PMU; only PMU; PMU placement based on the concept of depth of unobservability), one can obtain no less than 3 different variants of placing PMUs for one and the same system. The paper describes the PMU placement criteria suggested by the authors to solve the SE problem. Among them: improvement of bad data detection, maximum accuracy of estimates, transformation of the system graph into a tree, maximum number of measurements to be added, PMU placement during the decomposition of the power system SE problem. It is shown that the correct selection of PMU placement criteria can improve the solutions to these problems.

Keywords: Heuristic Methods, Phasor Measurement Unit (PMU), Phasor Measurement Unit (PMU) Placement, State Estimation, Supervisory Control and Data Acquisition (SCADA)

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INTRODUCTION

Heuristic methods are used for combinatorial optimization in which an optimal solution is sought over a discrete search-space. Additionally, multidimensional combinatorial problems, including most design problems in engineering such as form-finding and behavior-finding, suffer from the curse of dimensionality, which also makes them unfeasible for exhaustive search or analytical methods. Among popular heuristic methods for combinatorial problems Simulated Annealing (SA) (Kirkpatrick et al., 1983) and Genetic Algorithms (GA) (Holland et al., 1975) are well-known.

Heuristic method is a computational method that optimizes a problem by iteratively trying to improve a candidate solution with regard to a given measure of quality. Heuristics make few or no assumptions about the problem being optimized and can search very large spaces of candidate solutions. In our investigations we prefer the Simulated Annealing Method because it does guarantee the optimal solution.

Effective control of an electric power system (EPS) requires complete and accurate information on state variables which characterizes the current state of the EPS.

Until recently the measurements used for state estimation mainly included the measurements and signals received from SCADA. As a rule, SCADA measurements provided in EPSs are not sufficient to control the state of the entire system. Moreover, these measurements often have errors and gross errors. To improve the accuracy of measurements and calculations of unmeasured parameters the researchers use the methods of state estimation (Grishin et al., 1999). State estimation (SE) is an important procedure providing reliable high-quality information for the EPS control. The result of state estimation is the EPS steady state (current state) calculated on the basis of measured state variables and data on the network topology, which are then used for on-line EPS monitoring, analysis and control. SCADA systems are intended for receiving and processing information every second, and the remote control systems themselves allow delays in information delivery up to several tens of seconds. The state variables calculated on the basis of SCADA measurements are behind the current state variables of EPS and are only their approximation which can cause errors in control.

The possibility of calculating all the state variables on the basis of the set of measurements in the system is determined when analyzing the observability of EPS. To provide the observability of the calculated scheme the authors of Gamm and Golub (1990) developed special algorithms for placing measurements.

An important problem in the EPS SE is the detection of bad data in measurements (Gamm & Kolosok, 2000). When the amount of measurements is insufficient (low redundancy), they contain critical measurements and critical sets (Gamm & Golub, 1990), in which it is impossible to detect and definitely determine bad data. Reliable EPS data acquisition systems should provide such redundancy of measurements that there are no critical measurements and critical sets.

The SE methods make it possible to construct a more accurate model of the current EPS state. However, the SE of large-scale schemes encounters the problems related to the inhomogeneity of the calculated scheme, large amount of measurement data, poor data synchronization at boundaries of subsystems, necessity to transmit a lot of data to the EPS control center, etc. A serious flaw of the existing remote control systems is the absence of highly accurate synchronization of measurements with respect to astronomical time. Lack of simultaneity in receiving measurements is particularly noticeable in calculation of simultaneously operating subsystems that have their own devices for data acquisition and transfer. An effective method for solving these problems is the distributed data processing in the course of the SE problem decomposition by dividing the large-scale calculated scheme into subsystems (Gamm & Grishin, 1995).

Creation of satellite communication systems gave rise to a new generation of measurement equipment – PMU1 (Phadke, 2002). In...
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