

ABSTRACT

Today, power systems are being operated under greatly stressed conditions due to rapidly growing demand for electrical energy, penetration of renewable energy sources, large seasonal load variations and operation in competitive energy market conditions. All utilities are transferring bulk power over a longer distance. As the number of wholesale power transactions increase, the system operators are forced to monitor the operating state. Before scheduling such large scale power transactions, it is necessary to ensure that such transactions do not violate the limits of transmission line flow and bus voltage. The power system security mainly depends accurate and reliable monitoring of the system state.

The existing Supervisory Control and Data Acquisition (SCADA) system update data for every 5 seconds to bring a snapshot of a system. At present, the available SCADA measurement does not have phase angle measurements and data are not time stamped. It can only provide a steady state view of the power system and not the dynamic events. Due to this limitation, SCADA-based state estimators could not offer a real time picture of the power system. When the system operators can receive all information about the system health instantly, remedial actions can be initiated to maintain the system stability. This is practically possible by placing an optimal number of Phasor Measurement Units (PMUs).

Based on the previous experience of the major blackouts that happened around the world and especially on 14 August 2003 in United States of America (USA) and on 30 and 31 July 2012 in India, it is clear that most of the blackouts occur due to lack of situational awareness among the operators.

There is a need for real time monitoring by using PMUs in order to prevent such blackouts in future. The value of data provided by PMUs has been recognized and installation of PMUs on transmission networks has become an important current activity. India started to harness the applications of synchrophasor technology in a pilot manner on May 2010. Recently, PMUs are gradually deployed all over the world inspite of their cost due to the following main characteristics.

- ✓ Accurate phasor measurement with time stamping
- ✓ Faster sampling rates (as high as 96 or 128 samples per cycle)
- ✓ Compatible to modern communication links

A power system is said to be completely observable, when voltage phasor of every bus in a system is measured atleast once. The measurement redundancy is defined as the number of times a bus is observed more than once by PMUs. The maximizing measurement redundancy of the buses has an advantage that a larger portion of the power system remains observable, in case, one of the PMUs fails.

The main aim of Optimal Placement of PMUs (OPP) problem is to achieve complete system observability by placing a minimum number of PMUs. PMUs placement problem does not have a unique solution. Depending upon the starting point, the developed optimization scheme may yield different set of optimal solutions. The placement of PMUs can be carried out by using different criteria that depends on the objective of the investigator.

In this work, zero injection bus (node) is used to minimize the number of PMUs further or maximize the measurement redundancy of the buses (proposed rule). Firstly, the measurement redundancy of the buses is maximized randomly under normal operating condition while retaining the same minimum number of PMUs reported in the literature. The efficiency of

the proposed method is also tested under single line loss condition. It can offer a least number of PMUs required and maximum measurement redundancy of the buses, when compared to the earlier studies. Higher benefits are achieved by replacing the earlier locations of PMUs with the proposed locations.

This result shows that the required number of PMUs is minimized further or retained by the same number of PMUs presented in the earlier studies. Also, the measurement redundancy of the buses is better than the other methods.

The main part of this work involves in achieving complete system observability as well as improving voltage stability level, simultaneously by placing a minimal number of PMUs. Initially, weak buses (very sensitive to smaller reactive power variations) are identified by using Fast Voltage Stability Index (FVSI) calculation. In this work, the reliability of observing the weak buses is purposely maximized. If any sudden voltage instability problem occurs on the weak bus; PMUs can communicate to the operator immediately and prevent the outage of the weak bus, even if one of the PMUs fails. PMUs can maintain the FVSI value of the critical lines, not exceeding their maximum limit by initiating the remedial actions scheme, such as smart islanding, controlling the transformer tap settings and coordinating between automatic corrective devices, etc. In this method, PMUs placement should be preferred on the weak buses rather than other buses. The improvement of voltage stability level is possible by direct and reliable monitoring of the critical lines and weak buses. It is achieved with a little increase in numbers of PMUs than earlier results.

As above mentioned objective functions are conflicting in nature, it is imperative to use, Fuzzy logic based algorithms to solve the Multi-objective Optimal Placement of PMUs (MOPP) problem to offer a good tradeoff

solution between the competing objectives. Since swarm based optimization techniques are observed as a promising one, the best location with less computation time is a tough task within the research area.

This work verifies stability and superiority of the Fuzzified Binary Artificial Bee Colony (FBABC) and Fuzzified Binary Firefly (FBF) algorithms over Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) on IEEE test systems for solving the MOPP problem. This result shows that the required number of PMUs is less than or equal to the one third of the buses (33%) in a system under normal operating condition and half of the buses (50%) in a system under single line loss condition for achieving complete system observability and maximizing the measurement redundancy of the buses, simultaneously.