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ORIGINAL ARTICLE

Optimal PMU location in power systems using MICA

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Zero injection bus (ZIB);
Observability

Abstract This study presented a modified imperialist competitive algorithm (MICA) for optimal placement of phasor measurement units (PMUs) in normal and contingency conditions of power systems. The optimal PMU placement problem is used for full network observability with the minimum number of PMUs. For this purpose, PMUs are installed in strategic buses. Efficiency of the proposed method is shown by the simulation results of IEEE 14, 30, 57, and 118-bus test systems. Results of the numerical simulation on IEEE-test systems indicated that the proposed technique provided maximum redundancy measurement and minimum request of PMUs so that the whole system could be topologically observable by installing PMUs on the minimum system buses. To verify the proposed method, the results are compared with those of some recently reported methods. When MICA is used for solving optimal PMU placement (OPP), the number of PMUs would be usually equal to or less than those of the other existing methods. Results indicated that MICA is a very fast and accurate algorithm for OPP solution.

1. Introduction

Synchronized PMUs are rapidly populating power systems as their benefits become more and more evident in various power system applications. PMU is considered one of the most important measurement devices in future of power systems. The distinction comes from its unique ability in providing synchronized phasor measurement of voltages and currents from widely dispersed locations in an electric power grid. Synchronism among phasor measurement is achieved by same-time sampling of voltage and current waveforms using a common synchronizing signal from global positioning satellite (GPS) [1–4]. PMU, a newer intelligent electronic device, offers to more frequently provide accurate measurements of the states for power system. However, due to its relatively high costs, practically, PMUs are usually only installed on some selected buses of a power system. By utilizing PMUs, reliability and stability in the power system are expected to be improved. Conventionally, an optimal PMU placement is considered to use the least number of units to make the entire system completely observable.

Strategic placement of few PMUs in the system can significantly increase measurement redundancy, which in turn can improve capability of the state estimator to detect and identify bad data, even during loss of measurement. Meanwhile,

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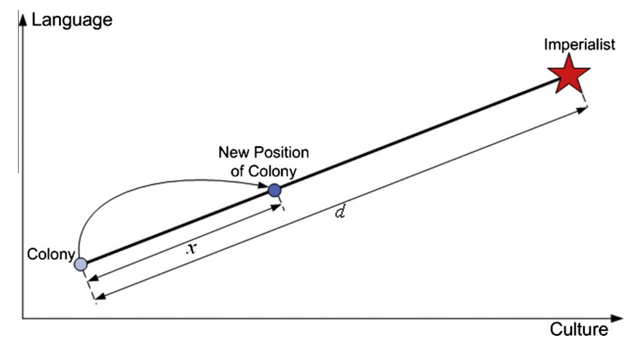

Figure 1 Moving colonies toward their relevant imperialist.

strategic placement of traditional and phasor measurements can also improve the state estimation's topology error detection and identification capability, stability and control, remedial actions and outage monitoring [5–8].

A power system is considered completely observable when all of the states in the system can either be directly or indirectly observable. In recent years, there has been significant research activity on the problem of finding minimum number of PMUs and their optimal locations. The initial work on PMU placement is based on the assumption that PMUs will have an infinite number of channels to monitor phasor currents of all branches that are incident at the bus where a PMU will be installed [9,10]. In [11], an optimal PMU placement method based on the non-dominated sorting genetic algorithm (GA) is proposed. The problem is to find placement of set of minimum PMUs so that the system is still observable during its normal operation and any single-branch contingency. Each optimal solution of objective functions is estimated by the graph theory and simple GA. Then, the best trade-off between competing objectives is searched using no dominated sorting GA. Since this method required more complexity computation, it is limited by size of the problem. A topology method considering only single-branch outage is presented in [12]. However, its topological observability did not guarantee that the state estimation can be solved [13]. A sequential selection process based on performance indices measurement sensitivities and measurement failures is presented in [14].

In this paper, modified imperialist competitive algorithm (MICA) based method was used for solving optimal PMU placement and maximum redundancy in normal and contingency conditions (PMU or line outage). By the proposed method, optimal PMU placement (OPP) was solved and power network became observable.

2. OPP formulation

PMUs are devices which can measure voltage and current sinusoidal waveforms on transmission lines and transmit data to the utility for monitoring and control purposes. Data consist of phase angles, frequency, and electrical parameters (voltage, current, real power, and reactive power). Therefore, a suitable methodology is needed to determine optimal locations of synchrophasors so that the number of PMUs should be minimized to make the system completely observable. When a PMU is located at a certain bus, this bus is directly observable, the neighboring buses that they connected to this bus, they are indirectly observable, and other buses are unobservable.

0	1	1	0	1	0	0	0	0	1	1	0	0	1

(a)

0	1	0	0	1	0	0	0	1	1	1	0	0	1

(b)

Figure 2 Positions of 3 and 9 are mutated: (a) before and (b) after mutation.

If for any possible sequence of state and control vectors, the current state can be determined in finite time using only the outputs, in that case, the system is dynamically observable. In this paper, static (topological) observability is used. Topological observability analysis of a system is mainly found on the basis of the following three rules [15]:

Rule 1: When a PMU is installed at a bus, this bus and other buses are incident to the bus are observable.
Rule 2: If only one bus is unobservable among a ZIB and its entire incident buses, the unobservable bus will be identified as observable bus by applying the Kirchhoff's current law (KCL).
Rule 3: If are observable and related buses that connect to unobservable ZIBs, ZIBs can be observability applying KCL.

For an N-bus system, the OPP problem is formulated as follows:

$$\text{Min} \sum_{\mathrm{i}=1}^{N} (c_i \times x_i) \qquad \text{s.t. } \mathrm{A} \times \mathrm{X} \geqslant \mathrm{b} \tag{1}$$

where c_i is weighting factor representing the cost of installed PMU at bus i, b is a vector whose entries are all one, and N and i are the number of buses, and the ith row of c matrix, respectively. Also, x_i and A_{ij} are defined as follows:

$$x_i = \begin{cases} 1 & \text{if PMU is installed at bus } i \\ 0 & \text{otherwise} \end{cases} \tag{2}$$

$$A_{ij} = \begin{cases} 1 & \textit{if } \mathrm{i} = j \\ 1 & \text{if the } i\text{th bus is connected to bus } j \\ 0 & \text{otherwise} \end{cases} \tag{3}$$

1	0	0	0	1	1	0	1	0	1	0	0	1	1

(a)

1	1	0	0	1	1	0	1	0	0	0	0	1	1

(b)

Figure 3 Positions of 2 and 10 are replaced with each other: (a) before and (b) after replacement.