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A new smart approach for state estimation of distribution grids considering renewable energy sources

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ABSTRACT

The idea of smart grids has created new opportunities in the electrical networks for monitoring the system status. One of the valuable and significant techniques for monitoring the smart grids is state estimation. In this way, this paper proposes a sufficient state estimation algorithm for inclusive monitoring of the distribution systems in the presence of RESs (renewable energy sources). The proposed method is a hybrid technique using WLS (weighted least square) method and FA (firefly algorithm) to reach more reliable and accurate state estimation of the network. FA is equipped with new optimization operators that make it possible to solve the multi-modal problems using an automatic sub-division feature. In order to improve the overall search ability of the algorithm, a new two-phase modification method is proposed. The proposed hybrid method can estimate the voltage angle using the WLS method. The simulation results show more optimal cost function value with faster response with escaping from the several local optima of the problem.

1. Introduction

In the last years, a rapid progress from the conventional electrical grids toward the new smart grids has happened to deal with the increasing requirements of customers. In this regard, some of the available and significant techniques that have been considered for this evolutionary movement are fast reconfiguration [1], intellectualization of the system [2], decentralization of power system [3] and fast monitoring devices. In the first stages of creating new smart grids, monitoring of the system status is a necessary task which without it the whole idea is devastated. One of the most precious and useful strategies for monitoring the system is state estimation [4]. Power system state estimation is defined as the process of estimating the state of the electrical system from the redundant telemetry measurements located in different positions of the grid [5]. Technically, state estimation is considered as the solution of finding the voltage phasors of all buses at certain time. Generally, a direct solution is to install accurate measurement on all buses of the system to obtain the synchronized voltage phasor of these buses. However, such a solution is exposed to communication failures or measurement errors. In order to overcome this issue, redundant measurements can be employed to reduce the measurement errors and find the optimal estimation which is discussed in the state estimation problem. Some of the parameters that can be used for accurate state estimation can be named as real and reactive power injection, voltage magnitude or current. In this regard, iterative WLS (weighted least square) algorithm is a usual and widely used technique which uses a sequence of measurement samples to estimate the system and offer static or quasi-static state information [6]. The conventional state estimator function performs centrally in a control center and takes the desirable data, real time and static, to solve the TP (topology processor), SE (state estimation), and the BD (bad data) detection-identification sequentially [7–9]. Therefore, one of the main useful outcomes of optimal state estimation is safe and efficient operation of power systems in both normal and contingency situations [10–12].

One of the new technologies that has affected the optimal state estimation problem is DG (distributed generation). The idea of DG was devised to bring generation near the consumers and thus reducing the power losses, improving the voltage of profile and providing more reliable electrical services [13]. Some the researches have also suggested to install DGs in the same building as

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Nomenclature

$\tilde{z}$	the measurements vector
$\tilde{r}$	error vector
$\tilde{W}$	weight factor matrix
$\tilde{H}$	functional measurement matrix
$f(\tilde{X})$	cost function
δ	weighting factor
h	state equation
n_{gen}	number of DGs
n_{load}	number of loads
V_{Pgj}	the voltage of the *jth* DG
V_{Load_j}	voltage the *jth* load
$P^j_{Gen,\min}$	minimum value of active power produced by *j*th DGs
$P^{Be,line}_{ij}$	the perfect power flowing between buses *i*–*j*
$P^{Be,line}_{ij,\max}$	maximum value of transmission power between buses *i*–*j*
$P^j_{Load,max}$	maximum value of the *j*th load
Q^j_c	reactive power value of *j*th bus
I_s	source intensity
r_{ij}	distance between *i*th and *j*th fireflies
X^{Iter}_{Best}	worst solution of the population
Δ	random number laying in the range of [0,1]
$N_{equality}$	number of equality
$J_i(\tilde{X})$	equality constraint
α_1	constant penalty factors
$X_{estimated\ value}$	estimated value

consumers [14–16]. Along with these benefits, the high penetration of DGs can increase the complexity of system planning, operation and communication which will affect the optimal state estimation too. In response to these complexities, new methods especially based on evolutionary algorithms have been proposed in the literature. In Ref. [17], authors proposed ant colony optimization for distribution state estimation. A hybrid method based on PSO (particle swarm optimization) was proposed in Refs. [18,19] for distribution state estimation with DGs. In Ref. [20], a new state estimation technique was devised to estimate the magnitude and phase angle of current in three phase distribution system. Here Takagi–Sugeno fuzzy system is used to estimate the system states in the unbalanced condition of the feeders. A two-stage approach based on WLS technique was proposed in Ref. [21] for state estimation of feeders' current. Here first the WLS sub-system is presented and then each sub-system is solved individually. In Ref. [22], state estimation of power system is done using a probabilistic load flow approach. In Ref. [23], a synchronized method was proposed for state estimation of three-phase systems. Here a new method based on HBMO (honey bee mating optimization) algorithm was suggested to increase the accuracy of state estimation in the presence of DGs. Here, the idea was to use HBMO for searching the problem space in the three-phase systems.

According to the above discussions, this paper tries to address the state estimation problem in the distribution systems considering DGs. In this way, a hybrid WLS and evolutionary algorithm is used to increase the accuracy of estimation effectively. According to the high complexity of the problem and its nonlinear search space, FA (firefly algorithm) is employed. FA is a meta-heuristic optimization method that is equipped with an automatic sub-division feature to escape from the several local optima of the problem [24]. In order to increase the diversity of the firefly population, a new two-phase modification method is proposed. The feasibility and satisfying performance of the proposed method are examined on a standard distribution system.

2. State estimation in smart distribution networks

Generally, the power industry tries to deliver electric power to the consumers with the highest reliability and quality and least cost and emission productions. Smart grids are new solutions for reaching these targets. In a smart grid, the producers are managed to control their production when consumers are also managed to obey a smart loading pattern with intelligent consumption pattern and cost. In order to reach these goals, the necessary of having full monitoring of the system and attaining the required information from all buses is quite obvious. Technically, the smart grid design is done in three areas of consumers, equipment and communication. As the direct result, smart grid technology is reflected in three parts of generation, transmission and distribution which can bring useful features in all parts from the electrical service point of view. The vital issue for reaching the idea of smart grids is the proper access to the required data in the network which is called shortly as state estimation. The use of appropriate state estimation will bring the below advantages:

a. Peak shaving: The use of smart network can affect both the generation and consumptions sides which a direct result is peak load shaving.
b. Fossil fuel reduction: By reducing the loss of energy in the feeders as well as possibility of altering the topology through some useful techniques such as reconfiguration will result in notable fossil fuel reduction.
c. Interruption reduction: Reducing the outage time, the number of interruptions and unwanted shut downs.
d. Reducing investment costs: The main reason for new investments in the current electric grids is the load growth which is mainly caused at peak load hours. By the use of idea of smart grid and intelligent management techniques, the load growth can be controlled which will reduce the investment costs.
e. Reducing switching cost: Decreasing costs associated with the switching of remote subscribers.

Fig. 1 shows a typical smart grid. In this figure, PMU (phasor measurement unit) will measure and synchronize data of the network. It is worth noting that there is less than one millisecond difference in the data acquisition of the voltage angles of buses. During the state estimation process, bad data and fake measurements are removed from the data set. It is obvious that the observability of the system should be preserved before and after data clearing process. The significant issue is that a smart grid requires adequate number of data processing devices including measuring devices and control devices. This can increase the complexity of the new smart grids greatly when the total cost of the network is increased too. Nevertheless, the use of appropriate state estimation method can help for using less hardware in the system. This paper tries to address this issue using the idea of FA and WLS technique.

2.1. WLS (weighted least square) estimator

It is demonstrated in the literatures [7] that if the analog devices were synchronized for current and voltage data, then the state