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Decentralized economic dispatch of an isolated distributed generator network

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ABSTRACT

A novel decentralized method for optimal load distribution in an isolated power system is proposed. In contrast to the traditional centralized method, the load economic dispatch is distributed to every smart distributed generator (DG) without the need for a monitoring host. Similar to the structure, mechanism and characteristics of biological communities, a smart DG node can communicate with adjacent nodes and operate collaboratively to complete the optimal operation of an isolated power system. The task is formulated as a decentralized optimization with a number of local constraints and is solved by a penalty function method. With the economic dispatch algorithm computed in all of the DG nodes in parallel, a new, fully distributed flat control network is established. The convergence property of the novel method is analysed theoretically. Simulation results on an illustrative system provide support for the validity of the proposed method.

1. Introduction

An isolated power system is commonly adopted to supply energy for critical systems, such as national defence projects in emergency cases [1]. Therefore, the reliability and stability of isolated power systems are vital to the normal operation of defence projects. Currently, each power station services only a determined subarea in a defence project; that is, different stations cannot work collaboratively. In the present study, to improve the robustness of isolated power systems in national defence projects, power stations are connected as an organic and flat entity according to the installation layout, which learns from the hybrid wind/PV/diesel microgrid. In this set up, it becomes a total system consisting of distributed generators (DGs).

An isolated microgrid system is quite different from bulk power systems with respect to programme, design, operation and maintenance processes. In fact, the operational condition of a microgrid is much poorer than that of a host grid. In response to these challenges, hierarchical control is proposed as the basic control strategy for microgrids [2], which includes primary control, secondary control and tertiary control. The primary control maintains the voltage and frequency stability of the microgrid, like the droop control method. The secondary control compensates for the voltage and frequency deviations caused by the operation of the primary controls. For example, a distributed secondary control is designed by using a multi-agent approach in [3]. The distributed secondary voltage and frequency control with uncertain communication links are studied in [4]. Furthermore, to extend the support time of the power station in the national defence projects, the tertiary control of DGs, which mainly facilitates an economically optimal operation, is also important.

Numerous researchers of microgrid (MG) concentrate on dynamically allocating power loads among DGs in order to achieve a reliable and economical operation [5,6]. The current economic dispatch approaches can be divided into centralized and decentralized styles. In the centralized methods, a monitor centre is needed to calculate the power output reference for each generator. Many different centralized methods have been developed to solve the economic dispatch (ED) problem [7].

Olivares D E et al proposed a centralized energy management system (EMS) for optimal operation of an isolated MG using the model predictive control technique in [8]. Besides, a genetic algorithm was also presented to solve the problem in [9]. And an approach considering two market policies for demand-side bidding options was developed by [10]. The authors in [11] introduced an optimization method for cooperative multi-microgrids with sequentially coordinated operations. Baghaee et al. formulated the MG operation as a multi-objective function to find the optimal size and location of flexible alternating current transmission system (FACTS) devices in [12]. The multi-objective optimization method was also applied for hybrid wind/PV/

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diesel systems in [13].

However, due to the distributed characteristic of isolated power systems with DGs, the traditional centralized ED method may not be the best option. Specifically, under the centralized hierarchical style, the process of network construction is complex and time consuming because a considerable amount of secondary development work, such as configuring and commissioning, is necessary onsite. And, the key procedure is to write the control model and algorithm into the monitoring centre, which must be reprogrammed as the system configuration or device type changes. Therefore, the development further incurs high maintenance and labour costs. This necessity conflicts with the plug-and-play concept required by an isolated DGs system.

Moreover, traditional centralized methods require information transmission to the supervising computer during operations, which can cause severe link congestion and operational lag. Finally, the entire system develops chain breaks if the central point breaks down; thus, this type of system is vulnerable to disturbance threats.

The decentralized concept can provide more robust, more economic and more efficient control to the isolated power systems. A number of decentralized optimization methods for isolated power systems have been described in the literature.

The major approaches are solved by a distributed consensus algorithm based on the equivalent incremental principle [14–17]. In [18], a distributed constrained consensus optimization is applied to an optimal load-sharing control problem. However, the method requires a global power flow network calculation. In addition, a state-based potential game is utilized to obtain a fully decoupling approach for the power system [19]. Unfortunately, the solution only converges to the stationary Nash equilibrium, which may be suboptimal. A replicator equation model is proposed for the power system in [20]. However, this method is impractical in actual applications because it requires the supply-demand balance constraint to be satisfied in the initialization. Du et al. formulated and solved the ED problem with practical operation constraints using potential games. And two learning algorithms with guaranteed convergence to Nash equilibria and/or optima are applied [21]. However, this approach neglects the power limit on the electrical line and the transmission congestion. A diffusion strategy has also been presented in recent studies [22,23]. However, the non-dispatchable demand must be calculated in a global style in the method. In addition, the method of coupled oscillators is proposed in [24], where the global variable is computed in a multi-agent consensus algorithm, but it requires the generator number. Other distributed methods require all-to-all connection among each DG, which is not decentralized in our sense of the term [25,26].

Motivated by this observation, a novel decentralized optimization method for ED of isolated distributed generation systems in defence projects is proposed in this paper. The contributions of this paper are listed as follows:

- A new fully distributed flat DG control network structure with advantages, such as easy extension, convenient implementation, and plug-and-play operation, is proposed for a power station in a defence project.
- This paper proposes a novel decentralized ED model for an islanded power system, which can improve the effectiveness of the distributed method in the presence of an islanded power system.
- A decentralized optimization mechanism based on a varying penalty function is designed such that a decentralized load distribution can yield a global optimum solution approaching a centralized manner via only local interactions between each updated smart DG.

The remainder of this paper is outlined as follows: In Section 2, the decentralized system model and optimal load distribution problem are formulated. Then, a decentralized algorithm is derived to solve the abstracted mathematical problem in Section 3. Section 4 focuses on a performance assessment through simulations and experiments. Conclusions are drawn in Section 5.

2. System model and problem formulation

2.1. System model

For simplicity, the following assumptions are made:

(1) Each DG unit is fitted with a microcontroller chip such that it becomes an updated smart unit in this paper. Each smart DG can communicate with other nodes and operate collaboratively.
(2) Demand and generation capacities of DGs remain almost stable in the defence project.
(3) The system is equipped with diesel generators (considered DGs); the cost function of each generation source is convex, and the overall cost in the system is a linear combination of individual costs.

Without loss of generality, the generation cost function of generator i ($i = 1, 2, \ldots, n$) can be approximated with a quadratic function [27] as

$$f_i(p_i) = \frac{1}{2}a_i(p_i)^2 + b_i p_i + c_i \, (p_i^{\min} < p_i < p_i^{\max}) \tag{1}$$

where a_i, b_i and c_i are cost parameters and determined by experiment or designed by manufacturer [28]. $p_i^{\min}$ and $p_i^{\max}$ are the lower and upper bound generation power of each DG i, respectively. The configuration of a typical isolated power system is shown in Fig. 1. Therefore, DGs at different buses are connected using network cables according to the spatial layout and electrical connection as shown by the red dotted line in Fig. 1. Then, these scattered DGs are correlated as an organic and flat entirety according to physical relations. The information flow is identical to the electrical flow as far as possible; that is, the physical network of the power system and the cyber network of control network are identical.

Thus, considering a network of connected units composed of n smart DGs that are responsible for multiple load demand. The corresponding communication network can be modelled as an undirected connected graph $\boldsymbol{G} = (\boldsymbol{V}, \boldsymbol{E})$, where $\boldsymbol{V}$ denotes the nodes set of DGs, and $\boldsymbol{E}$ denotes the set of communication links among DGs. The edge l (??, ??) $\in \boldsymbol{E}$ indicates that node ?? and node ??, $i, j \in \boldsymbol{V}$, can establish a communication link with each other. The neighbourhood of a given smart unit i ($i = 1, 2,\ldots, n$) is defined as $N_i = \{j | i$-th smart DG has a network cables connected with the j-th smart DG$\}$ to provide a clear expression.

2.2. Optimal load distribution

Optimal dispatch plays an important role to ensure safe and stable

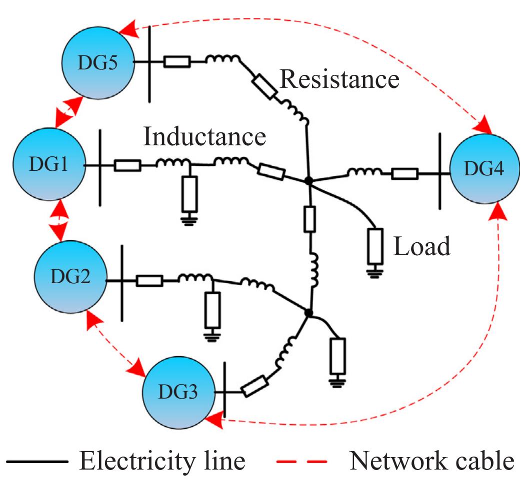

Fig. 1. Distributed generation system topology and its decentralized flat control network.