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Optimal operation of autonomous microgrid including wind turbines

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ABSTRACT

This paper gives a novel hybrid optimization method to find optimal sitting and operation of an autonomous MG at the same time. The operation is optimized via finding the optimal droop gain parameters of DGs. The optimization problem is formulated as a multi-objective problem where the objectives are applied to minimize the fuel consumption of DGs and to improve the voltage profile and stability of MG subject to operational and security constraints. A hybrid algorithm, named HS-GA, is developed to solve the paper optimization problem. A new formulation of power flow is derived to run the proposed algorithm where the steady state frequency of system, reference frequency, reference voltage and droop coefficients of DGs, based on a droop controller, are considered as optimization variables. The performance of the paper approach is compared with other optimization and non-optimization methods in MG with 33and 69 buses using MATLAB. The performance of the proposed method is compared with a method that the parameters of DGs are pre-determined without conducting any optimization process. The results show, which optimized droop parameters improves the operation of the MG.

1. Introduction

Distributed generations (DG) emerge from the utilization of renewable energy resources (RES) in distribution networks. DGs come in different types, controllable such as diesel generators, fuel cells and micro-turbines, and uncontrollable such as wind turbines and photovoltaic systems. DGs along with energy storages, controllers, loads, and communication systems make a small low-voltage system, known as a Micro-grid (MG), which is a significant and essential part of distribution networks development [1]. MGs operate in two different modes, namely connected where MG is connected to a grid via the point of common coupling (PCC), and autonomous, also known as islanded mode. Among different factors influencing the behavior of MGs, finding optimal sizing, siting and operation of DGs are of particular interests in the power grid optimization literature [2–7]. To find the optimal operation of the autonomous MG with and without droop control the use of central controller is vital. A number of methods exist concerning the improvement of the operation of the autonomous MG with central controller (MGCC). In Ref. [8] optimum scheduling techniques for autonomous MGs are discussed focusing on economic profits. In Refs. [9] and [10], MGCC is utilized to optimize the total fuel cost of islanded MG where DGs are modeled based on droop control and a combined heat and power (CHP) unit as well as a heat load in the MG are used. The research of [11] looks at the power dispatch among DGs using an evolutionary algorithm. In Refs. [12] and [13], different techniques are proposed to reduce fuel cost of islanded MGs. In Refs. [14] and [15], an analytical programming method is given for sharing reactive power among DGs using DGs droop control and considering uncertainty of small wind plants. An optimum combination of DG is developed in Refs. [16], [17] and [18]. In Refs. [23], [32–35] operation of DGs is optimized subject to environmental constraints. In the authors, previous studies [24] and [25] optimal sizing and operational strategy of DGs in MGs was proposed using a hybrid evolutionary algorithm by considering the grid-connected mode of MGs [29].

Despite the great contribution of the above studies in the area of power grid optimization, a review of the literature reveals that few studies have looked at both optimal operation and location of DGs. This paper addresses this shortfall. It gives a novel optimization approach to find the optimal location and operation of an autonomous MG at the same time. The operation is optimized via finding the optimal droop gain parameters of DGs. The optimization

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problem is formulated in terms of a multi-objective problem to minimize the fuel consumption of DGs and to improve the voltage profile and stability of MG subject to operational and security constraints. To propose the paper optimization method, the harmonic search, HS, algorithm is adopted. Although HS is regarded as one popular optimization approach it has some deficiency due to its low speed divergence and sticking in local optimal solutions. To cope with such deficiency HS is combined genetic algorithm, GA, to provide a new optimization algorithm. A new load flow formulation is derived to run the proposed algorithm where the steady state frequency of system, reference frequency, reference voltage and droop coefficients of DGs, based on a droop controller, are the optimization variables. In the paper proposed approach, first the Pareto front of non-dominated results is provided then, the best solution of non-dominated results is obtained by employing a fuzzy method.

The paper is structured as follows. First, a background to the paper is discussed. Then the problem formulation is developed and its corresponding solution is given. This is followed by providing numerical results and discussion.

2. Background

In order to give some background on the paper three issues are argued here. Two modes of operation can be considered for MGs, namely the grid-connected mode and the autonomous mode. In a grid-connected mode, voltage and frequency of MG are dictated by grid where MG controls the electrical power interchange with grid [19].

In the autonomous mode where there is no link between MG and the main grid, the MG control is responsible for frequency and voltage regulation. Also, the power generated by MG needs to meet its local demand. To share power among DGs a proper control method is required to manage the supply of MG's load. There are two control methods: centralized and decentralized control. Centralized control methods require remarkable data transfer capacity and reliable communication link to swap power division signals among DGs [20] and [21]. Though, such methods are costly due to the use of high bandwidth and reliable communication links. The centralized control method is appropriate for small-scale MGs where DG units are close together. With a decentralized method, load demand is shared between DGs using droop controller characteristics and local measurement (frequency and voltage variations). The decentralized method provides a proper voltage regulation in PCC, though there are some drawbacks regarding decentralized methods such as voltage drop in some buses, lack of minimizing power generation costs of MG and lack of dispatching reactive power generation among DGs (based on DG characteristics) [22]. To cope with these drawbacks, tuning of DGS droop parameters becomes of particular importance. In practice MGCC might be employed to make such parameters tuning.

In this paper, a combination of MGCC and a decentralized control method is developed to solve the optimal power sharing problem of DGs. MGCC is employed to provide optimum DGs droop parameters while the decentralized controller is used to operate with optimal droop parameters. The merit of this combination is that MG acts based on the decentralized control in the environment where the likelihood of having problems related to MGCC or communication link is high. Accordingly, any MG defeat is prevented and all DGs can keep operating though such operation is not optimal. Another merit is reliability and low cost of decentralized methods with droop control compared with conventional methods due to reducing communication bandwidth and making the control system robust against any communication link defect.

3. Problem formulation

The problem here is to find DGs location and static characteristics of DGs to optimize three objective functions comprising fuel cost reduction of DG units (f_1); voltage stability improvement (f_2); and reducing the total voltage variation (f_3). These three objective functions are mathematically formulated as a minimization problem as follow,

$$Min\ \{f_1(i,k),\ f_2(i,k),\ f_3(i,k)\} \tag{1}$$

where i is the bus number, representing DGs location; and k represents static characteristics, including frequency, voltage references and static droop gains,

$$k=\left\{\omega_i^*,\ \left|V_i^*\right|,\ s_{pi},\ s_{qi}\right\}\quad i\in N_{dr} \tag{2}$$

A. Fuel cost of DG units

Fuel consumption cost can mathematically be given by

$$f_1=\sum_{i=1}^{n_{DG}}P_{DG_i}{*}C_i(P_{DGi}) \tag{3}$$

$C_i\ (P_{DGi})$ is the fuel consumption of the ith DG unit as a function of its active power generation. It should be noted that the DG units based on gas turbines and synchronous generators.

B. Voltage Stability Index (VSI)

This index can mathematically be given by, [25],

$$VSI(i+1)=V_i^4-4\left[\hat{P}_{i+1}X_i-\hat{Q}_{i+1}R_i\right]^2-4\left[\hat{P}_{i+1}R_i+\hat{Q}_{i+1}X_i\right]^2V_i^2. \tag{4}$$

VSI is utilized to compute the stability of a MG line as illustrated in Fig. 1. For the stable action of MG, the VSI should be positive in microgrid buses. Then, to locate DG units the bus with the lowest VSI must be chosen as the voltage of such bus is more probable to be instable. The second objective function is to improve VSI which is equivalent to maximizing (4) or minimizing f_2 as given by,

$$f_2=\frac{1}{VSI(i+1)}\quad i=1,2,\ldots,NB\ . \tag{5}$$

C. Total Voltage Variation (TVV)

Total voltage variation (TVV) is used as the third objective function. This can be mathematically expressed by Ref. [31]

$$f_3=\frac{\sum_{i=1}^{NB}|1-V_i|}{NB} \tag{6}$$

By minimizing (6), a flatter voltage profile can be obtained leading

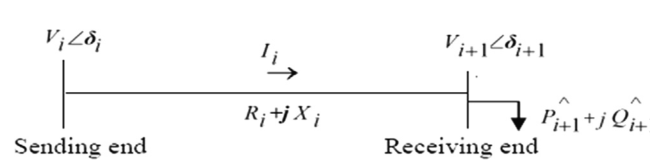

Fig. 1. One-line diagram of the MG line.