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Optimum islanded microgrid reconfiguration based on maximization of system loadability and minimization of power losses

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ABSTRACT

Distribution grids are being transformed from passive to active networks. The active distribution systems are constructed through the implementation of microgrids (MGs) which are characterized as the "building blocks of smart grids". This type of network eases the integration of distributed generation into power networks and makes it possible to define a new index for voltage stability, power flow development and a development reconfiguration method. In this paper, an improved indicator is proposed to estimate the voltage stability margin of a two-bus system based on both saddle node and limited induced bifurcations. A new concept named reduced islanded MG network (RIN), is used for generalization of the proposed index to n-bus islanded MGs and a development power flow algorithm by splitting these networks. The increasing loadability index of microgrids in the islanding mode is more important than the index of the grid-connected mode due to its operational limitations such as reactive power generation. In this process, islanded microgrid reconfiguration (IMGR) is proposed as an operational tool for improving loadability as well as decreasing power losses using an Adaptive Multi Objective Harmony Search Algorithm. The performance and effectiveness of the proposed method are demonstrated on 33- and 69-bus test systems.

Introduction

Motivation and approach

The configuration and limitation of active and reactive power generation of islanded microgrid (IMGs) have resulted in voltage stability boundaries and active power losses of these networks. There are two possible ways of improving the operation of IMGs: voltage stability boundaries and active power losses. The first one is based on increasing investment for the better operation of IMGs, while the second one attempts to incorporate innovative solutions and technologies to change the technical specification of IMG. A significant amount of investment will be required to develop and to renew the old infrastructures, while the most efficient way to meet social demands is to incorporate innovative solutions, technologies and grid architectures. Therefore, if IMGs managed efficiently, distinct benefits can be provided. For this purpose, powerful toolboxes are developed to access the voltage stability index, power loss calculation by considering IMG modeling and its limitation especially active and reactive generation limit and frequency deviation. These toolboxes can be used in islanded microgrid reconfiguration (IMGR), as specific tools, for efficient management of IMG operation and delay in renewing MG's infrastructures. In order to solve the proposed problem, an Adaptive Multi Objective Harmony Search Algorithm (AMOHSA) is used for finding the best configuration of IMG and for maximizing the voltage stability index as well as minimizing the active power losses.

Literature review and contributions

The literature review of microgrid concept, control strategies of distributed generations (DGs), voltage stability, reconfiguration, and multi objective harmony search algorithm are briefly studied in this section.

A microgrid (MG) can be recognized as an integrated system, which can operate in both grid-connected and islanded operation modes at the point of common coupling (PCC) [1]. This paper

Abbreviations: MGs, microgrids; RIN, reduced islanded MG network; IMG, islanded microgrid; IMGR, islanded microgrid reconfiguration; MGR, microgrid reconfiguration; AMOHSA, Adaptive Multi Objective Harmony Search Algorithm; DG, distributed generations; SNB, saddle node bifurcation; LIB, limited induced bifurcation; ***BIBC***, bus current injections and the branch current; ***BCBV***, branch currents and the bus voltage; ***ILF***, IMG load flow.

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focuses exclusively on the islanded mode operation and therefore control strategies of distributed generations (DGs) is discussed briefly in the following.

There are several strategies for control DGs in islanded microgrids (IMGs), among them, the droop control has been widely used for sharing power between distributed generations [2,3]. In this strategy, the power sharing is acquired by mimicking the behavior of synchronous generators operating in parallel [4]. To do that, the frequency and the voltage of DG units are drooped by increasing the active and reactive power, respectively [5,6].

With the development of national economies and the improvement of people's lives, load demands are sharply increased and the operating conditions of the active distribution systems are closer to the system boundaries. MG as a part of these systems does not exclude from this concept and is more tangible in IMG owing to absence of main grid and its operational limits, especially as the maximum generation capacity of DGs. MGs experience a distinct change from low to high load levels in islanded mode. Under certain critical loading conditions, IMGs may experience a voltage collapse. Hence, voltage stability is considered to be one of the keen interest of industry and research sectors around the world.

Over the last several years, a lot of attention has been devoted to MGs in technical, environmental and economic fields [7]. Although voltage stability is related to a technical issue, but it might affect the economic aspect of MGs. Therefore, it is important to consider this issue in MG studies. Voltage stability is the ability of a system to maintain voltage, which is closely associated with power delivering capability of power system [8]. The voltage instability is not a new phenomenon for power system practicing engineers and researchers, but a few researchers have focused onthe effect of these phenomena on the MGs, especially the islanded ones. The decline of the voltage stability level is one of the important factors that restricts the increase of loads served by IMGs. Hence, it is necessary to consider voltage stability constraints in the planning and operation of IMGs. Some studies in this field are reviewed here. In [9], the stability issue in MGs is divided into three categories, i.e. small signal, transient and voltage stability. In the mentioned paper, the small signal stability is analyzed with a linearized model of micro sources and loads. In addition, the transient stability of a MG is assessed with a nonlinear model. This paper also describes that P–V and Q–V curves have useful information in the voltage stability study. The P-V curve indicates the maximum loadability while Q–V curve shows the necessary amount of reactive power at the load end for desired voltage. In order to analyze the dynamic voltage stability of MGs,the dynamic model of autonomous MGs was used in [10]. The dynamic voltage stability index is evaluated by the conventional continuation power flow (CPF). In [11], the maximum static loadability is considered in the operation of droop-controlled IMG. The optimal power flow (OPF) solution has been used for calculating maximum loadability in this system. The final aim was to solve bi-objective OPF problem for loadability maximization and generation cost minimization as a techno-economic problem.

Microgrid reconfiguration (MGR) like radial network reconfiguration is an instrument for configuration of MG to improve the technical operation of MGs under normal and abnormal conditions. In the stand-alone or islanded microgrid reconfiguration (IMGR), it is important to consider their special specifications.

Authors in [12] analyzes the network reconfiguration of MG by conventional manner on the basis of the mathematical model. MGR is established in order to improve the reliability parameters of the MGs. In [13], MGR is used to restore service to a section or to meet some operational requirements of dropping minimum loads of MG. It offers novel real-time implementation of intelligent algorithm for MGR. Shariatzadeh et al. used a genetic algorithm (GA) and graph theory for reconfiguration of 8-bus shipboard power system and modified CERTS microgrids with consideration of distributed generation and islanding operation mode [14]. In [15] Shao et al., presented a multi-agent system based approach for microgrid reconfiguration in order to minimize the loss of load under system and unit constraints. Ding et al., presented a hierarchical decentralized agent-based network reconfiguration methodology to minimize power losses for smart distribution systems [16,17]. In these researches, a two-stage method is defined for coordinating the reconfigurations of decomposed subsystems.

As seen, the past researches contained useful methods for the distribution systems and grid connected microgrids reconfiguration. Therefore, it is necessary to pay attention to the islanded microgrid reconfiguration. Inspired by the past studies, we use an Adaptive Multi Objective Harmony Search Algorithm (AMOHSA) for IMGR that maximize the voltage stability index as well as minimize the power losses. This algorithm has emerged as a useful tool for engineering optimization that has been used in complex optimization problems in different categories such as electrical engineering fields. For instance, this algorithm is used in optimal placement of DGs in distribution systems [18], in optimal power flow problem [19], and in environmental/economic dispatch [20]. In this research, the 33- and 69-bus MG test systems are used to illustrate the performance of the proposed methodology.

IMG model

MG as the building blocks of smart grids is a new network structure. Therefore, it is necessary to establish a new model considering the characteristics of the IMG such as the operating modes of DGs in IMGs. In grid-connected mode, the main grid specifies the frequency of the whole network. However, in the islanded mode, the frequency is determined through the sharing power between DGs by the droop control strategy.

By considering above notification, a brief view of IMG components is given in this section in order to present the problem formulation.

Branches

The branch is modeled as an impedance series $z_{ij} = r_{ij} + jx_{ij}$, in which $x_{ij} = w \times L_{ij} = 2 \times \pi \times f \times L_{ij}$. Where r_{ij}, x_{ij} and L_{ij} are the $i - j$ line resistance, reactance and inductance, respectively. f is also the operational frequency of IMG.

Distributed generators

In grid-connected mode, the upstream power network which supplies the MG is substituted with an equivalent generator and it is treated as slack bus. Similar to traditional power flow studies, here, DGs can be treated as PV and/or PQ buses. Adversely, in islanded mode, there is no slack bus anymore and DGs operation is governed by droop characteristics. This characteristic can be represented as:

$$P_{Gi} = (w_i^* - |w_i|)/m_{p_i} \tag{1}$$

$$Q_{Gi} = (V_i^* - |V_i|)/n_{p_i} \tag{2}$$

Droop-controlled DG is a control strategy in controllable DGs in IMGs. The droop-controlled inverter curves determine the frequency of IMG and the voltage magnitudes of the DGs. The relation between DG active power, P_{Gi}, and the output voltage frequency, w, can be given as:

$$w = w_i^* - m_{pi} \times P_{Gi} \tag{3}$$