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Optimal operation of autonomous microgrid using HS–GA

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Identifying location and operation of DGs are vital in effective performance of autonomous MGs. This paper gives a novel optimization method for finding the optimal operation and location of DGs. The optimal operation is obtained via setting DGs economic droop parameters which operate based on droop control. A multi-objective function is developed to provide a new problem formulation for finding the optimal operation of DG units. The objectives include the fuel consumption cost, voltage stability index and the total voltage variation of MG. A hybrid optimization algorithm is proposed to solve the problem by combing the harmony algorithm (HS) and mutation and crossover operators of the genetic algorithm (GA). To find the best solution of non-dominated results a fuzzy method is employed. The performance of the paper approach is compared with other optimization and non-optimization methods in MG with 33 and 69 buses using MATLAB. The results support a good performance for the paper approach.

Introduction

Distributed generations (DG) emerge from 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 Micro-grid (MG), which is a significant and essential part of development of distribution networks [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. Theproblem of DG sizing and sitting is significant. Different methods offered to solve type of optimization problems, as detecting the Pareto front answers or finding a single multi-objective function solution calculated by a weighted sum of the objective functions. Methods such as analytical [2–5], meta-heuristic [6–8] and combination [9–11] techniques are promising and still evolving in the issues of optimal kinds, capacities, and locations of DG in a MG. In [12,13], the authors improved the optimal strategy of MGs consisting of a fuel cell, storages and DGs under hybrid electricity market to maximize the net present value utilizing Genetic algorithm (GA). In [14,15], optimum scheduling techniques for autonomous MGs on the islands are studied, that only their economic profits are considered. Variety methods have been shown in the papers to optimize the autonomous MG operation the use of MG central controller (MGCC). In [16,17] a MGCC is utilized to optimize the total islanded MG fuel cost. This idea investigates the DGs based on droop control and the use of a combined heat and power (CHP) unit as well as a heat load in the MG. The major disadvantages of the plan offered in [16], is that it did not study the reactive power demands and the system losses in the MG optimization as well as it did not investigate the MG operational limits. In [18] proposed a method to plan the operation of a MG that including CHP. Optimal sitting, sizing, and kind of DGs are identified to minimize MG losses as the main objective function. Then the power division among DGs is studied utilizing evolutionary algorithms until satisfied all the limits. In [19,20,34] different techniques are shown to reduce fuel cost of islanded MGs. In [21] proposed a new analytical programming method for sharing reactive power among DGs using the DGs droop control and the uncertainty of small wind plants is studied. In [22] used of a Niching evolutionary algorithm to solve optimal power flow (OPF) problem in an autonomous MG considering two control levels that one of them is droop control and other minimizing cost of the MG. Vallem et al. [23] used a dynamic programming method on a small MG for solving optimally combine of DGs between photovoltaic, micro-turbine, and energy storage system to supply both thermal and electrical demand. In [24] improved an optimum combine of DG utilizing linear programming with gas emission as one of the limits. In [25], proposed multi-agent system construction for MG management to optimize operation of the system using some agent to extract generation scheduling molds from MG information.

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Nomenclature

i, j	bus indices
P_{gi}	active power delivered to bus i
Q_{gi}	reactive power delivered to bus i
P_i	demand active power of bus i
Q_i	demand reactive power of bus i (MVAr)
P_{DGi}	active power of DG_i (MW)
$Y_{ij}(\omega)$	the ijth element of admittance matrix Y (Ω)
θij	phase angle (degree)
V_i	bus i voltage (kV)
$V_{\min}$	minimum bus voltage (kV)
$V_{\max}$	maximum bus voltage (kV)
NB	number of buses
N_{DG}	number of DGs
M	a random number
BW	the distance bandwidth
N_{obj}	number of objective functions
N_{rep}	number of solutions in repository
N_{dr}	number of droop buses
κ_i	the decision maker preference for all objective functions
δ_i	phase angle of voltage at bus i (degree)
$I_i, I_i^{\max}$	current and rated current of branch I (KA)
$S_{gi}^{\max}$	maximum apparent power of DG_i (MVA)
$P_{gi}^{\max}$	maximum active power of DG_i (MW)
$Q_{gi}^{\max}$	maximum reactive power of DG_i (MVAr)
$P_{loss_{ij}}$	active power loss between buses i and j (MW)
$Q_{loss_{ij}}$	reactive power loss between buses i and j (MVAr)
k_p	active power static droop gain
k_q	reactive power static droop gain
ω_i^*	angular frequency of DG_i at no load (Hz)
$\lvert V_i^* \rvert$	voltage magnitude of DG_i at no load (kV)
P_j	injected active power to bus j (MW)
Q_j	injected reactive power to bus j (MVAr)
P_l	active power demand (MW)
Q_l	reactive power demand (MVAr)
P_s	the total active power (MW)
Q_s	total reactive power (MVAr)
$C_m(P_{DGi})$	fuel consumption of DG_i
τ	number of parameters (control variables)
$P_{i+1}^{\wedge}, Q_{i+1}^{\wedge}$	active and reactive power of load at bus $i+1$ (MW and MVAr)

In [31], operation of DGs is optimized subject to environmental constraints. In the authors previous study [32] optimal sizing and operational strategy of DGs in MGs was proposed using a hybrid PSO and fuzzy algorithm. In another authors previous study [33], optimal location and capacity of DGs were given as a multi-objective problem in a competitive market where a combination of evolutionary algorithm and game theory are used to solve that multi-objective problem.

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.

This paper proposed a novel hybrid optimization method to plan operation of an autonomous MG. In autonomous operation mode, there is not slack bus therefore all DG sources together should supply active and reactive loads of MG. Thus, a modeling strategy of DGs based on decentralized droop control in autonomous operation of the MG with a MGCC is offered. Also, HS–GA algorithm has been offered to find the optimal sitting, maximum capacity and droop parameters of DGs in the autonomous MG. The optimization problem is done by applying multi-objective functions. These functions are minimizing the fuel consumption of DGs, improving the voltage profile and stability of MG within the framework of operation and security constraints in autonomous MG. In this case alternating measurements of the loads and generated powers in MG are sent to the MGCC. The MGCC utilizes the received information to find the answers of autonomous MG optimization problem by proposed method and optimize power dispatch among DGs in the autonomous MG.

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 giving. This is followed by providing numerical results and discussion.

Background

In order to give some background on the paper three issues are argued here.

MG control in autonomous mode

Microgrids can operate in grid-connected and islanded modes. In the grid-connected mode of operation, the DG units in the microgrid are operated to supply a pre-specified amount of active and/or reactive power to fulfill a predetermined system requirement. The difference between the active and reactive power produced by the microgrid DG units and the microgrid total load demand are either supplied or absorbed by the main grid and thus the frequency and voltage regulation are maintained at the different microgrid buses [26,27].

In the islanded 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. The centralized control approach, as its name implies, depends on having a central controller controlling the operation of all the DG units in the islanded microgrid. The centralized control approach does not offer the required redundant operation. Further, having a single point of failure in the islanded system can counteract the positive reliability boost anticipated from the implementation of the islanded microgrid concept. Also, as the DG units forming the microgrid might be dispersed from one another; achieving high bandwidth communication to share the dynamic current and voltage signals among these DG units or between the different DG units and a central controller can be both expensive and impractical [28,29].

The decentralized control approach depends on local controllers located at the different DG units in the islanded microgrid and uses the system frequency as a means of communication among these controllers. This approach is mainly based on the droop control technique first proposed in [28] to be used in an isolated UPS system.

In this paper, a combination of MGCC with a decentralized control method is developed to solve the optimal power sharing problem of DG units. MGCC is employed to provide optimum DG units and 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