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Optimal operation of microgrid using four different optimization techniques

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ABSTRACT

In this paper, an economic dispatch (ED) problem of a microgrid (MG) is formulated and solved using four different optimization techniques – lambda iteration, lambda logic, direct search method (DSM), and particle swarm optimization (PSO). The objective is to minimize the fuel cost of the dispatchable DGs present in the microgrid. Variation in load demands, variation in the output powers of non-dispatchable DGs, and requirements of stable grid connected and islanded operations impose additional operational constraints in a microgrid. In this paper, all these constraints have been considered while formulating the ED problem. The effects of these constraints on the daily fuel cost of dispatchable DGs are then inspected on two test systems. The first test system is a synthesized three control – area MG system. Each control area in the test MG system comprises dispatchable DGs, loads, and non-dispatchable (wind and solar power based) DGs. The second test system is a two control area thirty-three node microgrid comprising dispatchable and non-dispatchable DGs and loads.

Introduction

Concerns about environmental compliance, energy conservation needs, requirements of reduced emissions from power generation activities, and depleting natural fuel resources have led to a change in the electrical power system [1]. Use of distributed energy resources (DERs) addresses all these issues, and therefore, they are fast emerging as an alternative to conventional power generation technologies.

Distributed generation (DG) [2] includes a variety of prime mover technologies including but not limited to either dispatchable sources like internal combustion (IC) engines, gas turbines, microturbines and fuel cells or non-dispatchable renewable sources like photovoltaic and wind power [3–6]. Despite multiple benefits of introducing DGs in distribution network [1,3–6], increased penetration of DGs, especially that of intermittent, renewable based sources like photovoltaic and wind generators causes multiple technical, operational and safety related problems [1,6–9].

To solve the problems that may arise due to indiscriminate connections of individual DGs with the main grid, a system approach of integrating DGs with the existing network has evolved, leading to the concept of microgrid [3,4,9,10]. In literature, many definitions of microgrid (MG) are available. However, we can define microgrid as a medium voltage or low voltage distribution network comprising a cluster of loads and micro sources (MS), operating as a single controllable system, that provides both power and heat to its local area [3,4,9,10]. MGs can operate in grid-connected, islanded or transition modes.

Microgrid and DERs have become a major thrust area of contemporary research work. Numerous industrial and academic projects [9–12] have been undertaken in the recent past to find suitable control, operational and islanding strategies for various inverter-interfaced MGs. While some schools of thoughts suggest the development of a plug and play (PNP) and Peer to Peer (P2P) models for microgrids [3,9,10]; others advocate the use of a microgrid central controller (MGCC) at low voltage or medium voltage substation for economic and control functionalities [13].

For obtaining maximum benefit and better DG usage from the operation of a microgrid, different controllers, and energy management systems (EMS) have been proposed [11,14–17]. EMS calculates and sets voltage and power reference points for the controller of each DG. This ensures that the microgrid operates stably and optimally while meeting all the operational and contractual constraints. EMS also provides signals for quick and stable islanding of the microgrid during grid faults [2,3,12,14–17]. To perform these tasks, EMS uses information like local electrical load demand, electricity prices, costs of fuel, and power quality require-

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Nomenclature

f_j	Fuel cost of jth dispatchable DG
Pg_j	Power output of jth dispatchable DG
Pg_j^{min}, Pg_j^{max}	Minimum and maximum limits of power of jth dispatchable DG
P_{0_1}	Power flow from main grid to Microgrid (MG)
P_{i-1_i}	Inter-area power flow from area 'i − 1' to area 'i' in MG
PL_k	kth load power
NG	Total number of dispatchable DGs in MG
NL	Total number of loads in MG
NI_s	Total number of non-dispatchable DGs in MG
PIs_{mm}	Power output of mmth non-dispatchable DGs
N	Numbers of areas in MG
Rg_j	Droop constant of generator 'j'
ΔPa_m	Total change in power generation of all dispatchable DGs in area 'm' after mode transition
ΔPg_j	Change in power generation of jth dispatchable DG after mode transition
PL_{am}	Sum of all loads in area 'm'
Pa_m^{min}, Pa_m^{max}	Sum of minimum and maximum power limits of all generators in area 'm'
$PIsa_m$	Total power output from all non-dispatchable DGs in area 'm'

ments [8,15]. EMS is mainly responsible for the economic and reliable operation of a microgrid.

Considerable amount of research has been carried out for optimal power scheduling of DGs in a MG. In [17], the authors have minimized the fuel consumption in an islanded MG. In [18], the authors have determined the output power of DGs for the optimal grid connected operation of a microgrid considering reserve requirement for the load variability, and reserve requirement for a stable transition of the microgrid from the grid-connected mode to islanded mode. However, the constraints developed in [18] do not explicitly include the terms arising from the presence of non-dispatchable DGs. Further, in [18], the authors have not considered the economic operation of an islanded microgrid with reserve requirement for a stable transition of the microgrid to grid-connected mode.

In this paper, the ED problem (fuel cost minimization) of a microgrid (comprising dispatchable and non-dispatchable DGs) is formulated with various operational constraints. The constraints arise due to the following:

a) Reserve requirement for load variation.
b) Reserve requirement for non-dispatchable DG power output variation.
c) Reserve requirement for stable transition of the MG from grid-connected mode to islanded mode.
d) Reserve requirement for stable transition of the MG from islanded mode to grid-connected mode.

Presence of non-dispatchable DGs is also explicitly considered in this paper. For simulation, we have considered two test systems. The first test system is a balanced three control- area microgrid. Each area consists of six dispatchable DGs, renewable based non-dispatchable DGs (solar PV cells, and wind power) and loads. For the analysis of this test system, typical seasonal loads have been considered. The second test system is a balanced two control-area thirty-three node microgrid system. The optimization problem has been solved using four optimization techniques, namely direct search method (DSM), particle swarm optimization (PSO), lambda iteration method and lambda logic based iteration less technique.

Technical factors of ED problem of microgrid

In a microgrid, a dispatchable DG can operate either in feeder flow control (FFC) mode or in unit power output control (UPC) mode [10]. The output power of a feeder flow controlled DG is controlled to keep the real power flow in a feeder constant. On the other hand, a unit power output controlled mode DG generates constant real power as per the power set point. In this work, the references for the feeder flow (for FFC mode DG) and output power (for a UPC mode DG) are obtained by solving the economic dispatch problem for the microgrid using various optimization techniques stated earlier.

In an islanded microgrid, the sum of the power outputs of all the DGs must match the total load demand. Many researchers have adopted droop control for dynamic balancing of the real load by the DG power outputs [3,4,10,11]. Generally, droop constant of a DG is a constant value. Droop constants are chosen in such a way so that the DGs share the total load in the ratio of their ratings. A DG with a constant value of droop is called a fixed droop DG. In [19,20], the authors have proposed a new method of power sharing among the DGs. In the proposed method, the droop constants of the DGs are modified periodically according to their operating points. Such a DG is called a variable/adjustable droop DG. The output power of DGs with renewable sources such as wind turbine generators and PV cells are dependent on weather conditions [5]. These intermittent sources are non-dispatchable. In this work, such sources are also considered.

Microgrid configuration and the associated constraints

Fig. 1(a) shows the configuration of a microgrid with many control areas. We assume that the dispatchable DGs of each area take care of the load and renewable power variations of the concerned area. Hence, the inter-control area power flows remain constant. To perform this task, in each area, the first DG operates in FFC mode, while the rest operate in UPC mode. Fig. 1(b) shows the configuration within a control area. With this configuration, variations in load and/or non-dispatchable DG power output in an area are met by the FFC mode DG of that area. This ensures constant inter-area real power flow [19,20].

Economic dispatch (ED) problem of a microgrid

The objective function of an ED problem can be written as:

$$\text{Minimize } Ft = \sum_{j=1}^{NG} f_j(Pg_j) \tag{1}$$

Subject to:

$$\sum_{j=1}^{NG} Pg_j = \sum_{k=1}^{NL} PL_k \tag{2}$$

$$Pg_j^{min} \leqslant Pg_j \leqslant Pg_j^{max} \tag{3}$$