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Microgrids: Planning of fuel energy management by strategic deployment of CHP-based DERs – An evolutionary algorithm approach

Ashoke Kumar Basu *

Department of Electrical Engineering, C.I.E.M., 20/2 Khanpur Road, Kolkata 700 047, India

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ABSTRACT

Planning of fuel energy management of a CHP-based microgrid requires strategic deployment of DERs. Strategic deployment of DERs is meant to select their optimal locations, optimal sizes and optimal technologies. Optimal locations and sizes, which are independent of types of CHP-based DERs used, are selected, here, by loss sensitivity index (LSI) and by loss minimization using differential evolution (DE) algorithm respectively. In the context of planning of a 14-bus radial microgrid present paper incorporates originality in ideas in the analysis technique based on differential evolution (DE) algorithm to evaluate how different optimal output sets of a group of four DERs, while operating within their respective capacity limits as well as tracking an electrical demand without grid participation, could satisfy a range of heat demands, each representing a specific solution of optimal fuel consumption. For investment decision in the perspective of the owner of the microgrid the author performs the analysis with two separate groups of 4-DER each of various sizes – one group with all diesel generators (i.e. All-Dg) and other with mix of diesel generators (Dgs) and microturbines (Mts) (i.e. Mix-DER). As the present microgrid is intended to cater both heat and electric demands, as per profiles, to its all-commercial customers, a boiler is considered as need-based back-up source to meet the deficit of daily heat generation, if any, for balancing the daily heat demand. At the best result of optimal fuel cost of each group obtained from above analysis, an economic comparison is done between the two groups with the help of pay back period (*PP*), internal rate of return (*IRR*) and net present value (*NPV*) of the microgrid to decide better investment option of the two. Results of DE are confirmed and compared with particle swarm optimization (PSO) technique.

1. Introduction

Due to several reasons, like environmental awareness, requirement of improved supply of different PQR to critical customers in the present digital era (i.e. heterogeneous PQR), scarce resources of fossil fuels, escalation of cost of construction of central power plants, ratification of the Kyoto protocol, competitive deregulated electricity market, etc., distributed generators (DGs) at the MV/LV distribution level are gaining more and more importance presently. But with higher non-coordinated penetration of such DGs, some technical problems, like excessive voltage rise, and increase of fault level to name a few, appear in the network operation. To overcome these problems a new concept in the form of a microgrid is adopted as a novel energy management system to provide both heat and electricity reliably to its customers. A microgrid utilizes local DERs, which encompasses DGs, energy storages, boilers, etc. [1–4].

Fuel energy management in a microgrid is important to study its economic feasibility. It is governed, mainly, by economic issues of power sharing among CHP-based DERs. In the present paper microturbines (Mts) and diesel generators (Dgs) have been used as the two types of CHP-based DERs. Mts run on natural gas and Dgs on diesel oil. Both these fuels are depleted resources and will reach their maximum consumption level in the foreseeable future. So, the future of these fuel markets indicates a high pricing period. Therefore, to obtain maximum benefits from the energy resources available in a microgrid, an appropriate power sharing strategy must be scheduled for DERs to supply the required demands plus network losses at minimum generation (i.e. fuel) cost, usually termed as "Economic Load Dispatch (ELD)" in conventional power system [5,6]. Hernandez-Aramburo et al. [7] aimed at developing a unit commitment operation in a microgrid on optimal fuel consumption with constraints of both local heat and electricity demand balance as well as provision for certain minimum reserve power. Authors of Ref. [7] imposed penalty on excess heat generation and finally, claimed their solution strongly supporting the communication infrastructure. Pipattanasomporn et al. [8] developed an optimal mix of DG model using mixed-integer linear program with NO_x emission as one of the constraints. Hawkes and Leach [9] developed a linear programming based unit commitment for a microgrid with an object to minimization of equivalent

* Tel.: +91 (0) 9903620062.
E-mail address: ashokekumarbasu@gmail.com

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Nomenclature

CHP	combined heat and power
DER	distributed energy resources
Mt	microturbine
Dg	diesel generator
DG	distributed generator/generation
DE	differential evolution
P_L	system electric losses in kW
PG_i, PG_{imax}, PG_{imin}	active power generation of ith bus DER, its upper and lower limits in kW respectively
P_i	active power injection at ith bus in kW
δ_i	phase angle of ith bus
U_i, U_{imax}, U_{imin}	voltage of ith bus, its upper and lower bounds in p.u. respectively
QG_i, QG_{imax}, QG_{imin}	reactive power generation of ith bus DER, its upper and lower bounds in kVAR respectively
P_D	total electric demand in kW
S_{ij}	line flow from ith to jth bus in kW
N	total nos. of DERs
C	total cost of fuel from DERs including boiler in \$/h
a_i, b_i, c_i	fuel cost coefficients of ith bus DER
η_{ith}	thermal efficiency of ith bus DER
η_{hex}	efficiency of heat exchanger
H_D	heat demand in kW h
H_R	useful heat in kW h
H_0	waste heat in kW h
LSI	loss sensitivity index
H_s	quantity of heat stored in kW h
PQR	power quality and reliability
ELD	economic load dispatch
O&M	operation and maintenance
PVF	present value factor
f_1	fuel consumption costs of DERs in \$/h
f_2	fuel consumption costs of Boiler in \$/h

annual cost of meeting a given energy (electricity and heat) demand profile. Hatziargyriou et al. [10] addressed the unit commitment problem assuming linear continuous and convex bid functions for DG as well as loads along with market price. But the economic dispatches of regulated DGs were handled using monthly 24-h typical emission curve to incorporate environment impact. Vahedi et al. [11] presented a DE-based optimization method to seek an optimal operating strategy and cost optimization for a microgrid taken into account both costs of the emissions and (O&M) expenditure of DERs as cost function. Piperagkas et al. [12] studied the IEEE 30-bus system, using multiobjective PSO technique, at various percentage of CO_2 reduction. Authors of Ref. [12] have compared the cost of CO_2 reduction achieved by extended use of cogeneration units and wind power penetration for various wind power prices, while satisfying heat and electricity deviations limits and considering security. Siting and sizing of DGs in the network are supplementary, or supporting, work in the present paper but their relevance on system loss are very high. So, a few research works on these topics have been surveyed. Optimal location of DGs in the microgrid have been selected using loss-sensitivity indices based on Newton–Raphson (N–R) load flow method [13], state based reliability modeling [14], dynamic programming [15], etc. Whereas Genetic Algorithm (GA) [16] and a simple conventional iterative search technique along with N–R method of load flow [17] are found to be suitable for finding both optimal siting and sizing of DGs.

In the present paper, the author conducts a comparative study on a 14-bus radial microgrid between two groups of 4-DERs each of different sizes – one group with all Dgs (i.e. All-Dg) and other with mix of Dgs and Mts (i.e., Mix-DER) – to evaluate an economic choice of deployment of technologies from an owner's investment point of view with an object to minimize fuel cost. Minimization of fuel cost in the above two deployment strategies is done using differential evaluation (DE) technique under constraints of electric and heat balance, capacity limits of DERs, etc. Originality in the analysis technique is to obtain an array of optimal solutions in each group while tracking a particular electric demand. Each solution indicates a distinct scheduling of DERs and their corresponding heat output, fuel cost and system loss. From these ranges of solutions the best optimal fuel cost is searched out, at which the economic choice between the two groups is done with the help of pay back period (*PP*), internal rate of return (*IRR*) and net present value (*NPV*) of the microgrid. Results of DE are compared with particle swarm optimization (PSO) technique. DE is one of the most prominent new generation evolution algorithms, proposed by Storn and Price in 1995. It is found to yield consistently better and faster reliable solution, satisfying all the constraints, both for uni-modal as well as multi-modal ELD systems, using its different crossover strategies. Its advantages over other evolutionary algorithms (EAs) are, mainly, finding the true global optima regardless of the initial parameter values, fast convergence and few control parameters. These advantages have made it a popular stochastic optimizer compared to other EAs. DE is an improved version of GA (Genetic Algorithms). The main difference between the GA and DE is the mutation scheme that makes DE self-adaptive selection process. In DE, all solutions have the same chance of being selected as parents without dependence of their fitness value. DE employs a greedy selection process: the better one of new solution and its parent wins the competition providing significant advantage of converging performance over GA. Empirical studies have shown that DE can outperform many other well known (EAs) and also PSO. PSO is attractive as there are only a few parameters to adjust. The main advantages of PSO algorithm are summarized as simple concept, easy implementation, robustness to control parameters and conceptually efficient when compared with mathematical algorithm or other heuristic optimization techniques [18–24].

The contents of this paper are organized into six sections. Section 1 contains Introduction and Nomenclature, Section 2 provides detailed formulation of the problem. Section 3 gives a brief overview of 'Differential Evolution (DE)' technique. Section 4 details the DE algorithms in the context of present ELD problem. Section 5 includes necessary figures, results and discussions of the study cases. The conclusion is drawn in Section 6. References are appended last.

2. Problem formulation

Present paper addresses, firstly, the ELD based scheduling of DERs for proper energy management planning in a microgrid and secondly, the economic feasibility of the microgrid under ELD. As sitings and sizings of DERs are relevant in the present context for the determination of B-coefficients, so their formulation are added additionally with ELD.

2.1. Bus-location selection of DERs using LSI [13,25–27]

Loss sensitivity Eq. (1) based on Newton–Raphson load flow method is used to find out the optimal placement of DERs in a microgrid