Applied Energy 128 (2014) 164–174

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Experimental validation of a real-time energy management system using multi-period gravitational search algorithm for microgrids in islanded mode

Mousa Marzband [a,b,*], Majid Ghadimi [b], Andreas Sumper [c,d,e], José Luis Domínguez-García [c]

[a] The University of Manchester, School of Electrical and Electronic Engineering, Ferranti Building, Manchester M13 9PL, UK
[b] Department of Electrical Engineering, Lahijan Branch, Islamic Azad University, Lahijan, Guilan, Iran
[c] Catalonia Institute for Energy Research (IREC), Jardins de les Dones de Negre 1, 08930 Sant Adrià de Besòs, Barcelona, Spain
[d] Departament d' Enginyeria Eléctrica, EU d' Enginyeria Técnica Industrial de Barcelona (CITCEA-UPC), Universitat Politècnica de Catalunya (UPC), C. Comte d'Urgell 187, Pl. 2. 08036 Barcelona, Spain
[e] Centre d'Innovació Tecnològica en Convertidors Estàtics i Accionaments (CITCEA-UPC), Departament d'Enginyeria Elèctrica, Universitat Politècnica de Catalunya, ETS d'Enginyeria Industrial de Barcelona, Av. Diagonal 647, Pl. 2. 08028 Barcelona, Spain

HIGHLIGHTS

- An algorithm coded in C environment is developed to enhance the performance of the IREC's microgrid system.
- Local energy market cost model is proposed to obtain the best buying price in a day-ahead energy market.
- Several real technical and market scenarios incorporating demand response, price sorting, etc., are considered in the study.
- Simulation results demonstrate a significant reduction in the overall plant cost of the system.

ARTICLE INFO

Article history:
Received 10 December 2013
Received in revised form 29 March 2014
Accepted 20 April 2014
Available online 14 May 2014

Keywords:
Day ahead scheduling
Demand response
Energy management system
Microgrid
Optimal operation and scheduling
Gravitational search algorithm

ABSTRACT

Both performance optimization and scheduling of the distributed generation (DG) are relevant implementing an energy management system (EMS) within Microgrid (MG). Furthermore, optimization methods need to be applied to achieve maximum efficiency, improve economic dispatch as well as acquiring the best performance. This paper proposes an optimization method based on gravitational search algorithm to solve such problem in a MG including different types of DG units with particular attention to the technical constraints. This algorithm includes the implementation of some variation in load consumption model considering accessibility to the energy storage (ES) and demand response (DR). The proposed method is validated experimentally. Obtained results show the improved performance of the proposed algorithm in the isolated MG, in comparison with conventional EMS. Moreover, this algorithm which is feasible from computational viewpoint, has many advantages as peak consumption reduction, electricity generation cost minimization among other.

1. Introduction

Distributed generation can become integrated into distribution power systems through a controllable platform called Microgrid (MG) which includes converter-based systems [1]. In the MGs, if energy generation sources are not enough to feed the requested load, the system is not able to match supply demand. To apply a proper energy management system (EMS) is crucial to avoid this problem. An EMS makes possible the optimum implement and use of distributed energy sources. Failing of these systems in load feeding is possible if the total demand is more than the maximum capacity of the generation sources.

Applying either supporting systems such as diesel generators, distributed storages (DS) or implementing demand side management (DSM), may be useful to reduce a supply–demand mismatch [2–4].

Special attention is considered in using support systems as DSM and storage systems in this paper. The main objectives of DSM program is minimizing mismatch between feed power and load during

* Corresponding author at: The University of Manchester, School of Electrical and Electronic Engineering, Ferranti Building, Manchester, M13 9PL, UK. Tel.: +44 (0) 1613064654; fax: +44 (0) 1613064820.
E-mail address: mousa.marzband@manchester.ac.uk (M. Marzband).

http://dx.doi.org/10.1016/j.apenergy.2014.04.056
0306-2619/

Nomenclature

Acronyms	
DR	demand response
DS	distributed storages
DSM	demand side management
EGP	excess generated power
EMS	energy management system
EMS-MGSA	EMS based on MGSA
ES	energy storage
ES+	ES during charging mode
ES−	ES during discharging mode
EWH	electric water heater
MG	Microgrid
GSA	gravitational search algorithm
LEM	local energy market
MCEMS	modified conventional EMS
MCP	market clearing price
MGSA	multi-period GSA
MT	micro-turbine
NRL	non-responsive load
PV	photovoltaic
RLD	responsive load demand
SOC	state-of-charge
UP	undelivered power
WT	wind turbine
Variables	
π^A	the supply bids by A (€/kW h) $A \in \{WT, PV, MT, ES-, ES+, UP, EGP, \text{and } EWH\}$
λ_t^{MCP}	MCP at each time t in MCEMS (€/kW h)
$\lambda_t'^{MCP}$	MCP at each time t in EMS-MGSA (€/kW h)
P_t^A	available power of A in MCEMS (kW)
$P_t'^A$	available power of A in EMS-MGSA (kW)
$\widetilde{P}_t^A$	real power set-points of A in MCEMS (kW)
$\widetilde{P}_t'^A$	real power set-points of A in EMS-MGSA (kW)
$\hat{P}_t^A$	available power of A (kW)
P_t^n	non-responsive load (NRL) demand (kW)
SOC_t	battery SOC in MCEMS (%)
SOC_t'	battery SOC in EMS-MGSA (%)
$\overline{P}$, $\underline{P}$	limit of power (kW)
$\overline{E}$, $\underline{E}$	limit of energy (kW h)
$\overline{SOC}$	maximum SOC (%)
$\underline{SOC}$	minimum SOC (%)
Δt	time step

consumption peak by changing the system load curve. The variation of system load curve can be done through both the distribution system facilities and end-use customers [5–7]. Demand response (DR) is a mechanism in which consumers participate voluntarily in reducing consumption peak by changing the consumption model. Consumers participating in DR receive some energy cost benefit [8]. Large scale participation in DR into distribution systems can be managed by applying aggregators. The role of an aggregator is gathering all the DRs requested by the end users, to present them in wholesale electricity market [9,10]. One of the key goals of DR management plans is shift power demand to non-peak hours [8]. The combined operation of DS and DR brings more reliability into distribution system operation [11]. DS may include some constant storage systems (e.g. battery energy storage) and mobile storage (e.g. plug-in electric vehicle). On the other hand, the DR can also be treated as a load shaping tool in distribution grids with high penetration of plug-in loads, such as electric vehicle [12]. Applying DR in smart distribution networks with several micro sources requires a complex and fast EMS [13–15]. Thus, optimal techniques are required to fulfill the aforementioned cases.

The use of deterministic methods is not complex and time consuming to solve optimum problems with large dimensions. Hence, these problems can be solved with the non-deterministic polynomial-hard (NP-hard) problem [16]. There is increased tendency for using population algorithms in recent years. These are inspired by social and natural behaviors. Several research is done over these algorithms dealing with solving complex numerical problems. Various innovative methods are introduced for solving optimization problems like genetic algorithm (GA) [17,18], simulated annealing (SA) [19], ant colony optimization (ACO) [20] and particle swarm optimization (PSO) [21–23].

For that reason, a swarm intelligence method called multi-period gravitational search algorithm (MGSA) is applied in this paper. Its main benefits include exploration operation can be started in several working point at the same time [24], without memory and evaluation of the masses can be done in each interval [25], multi-agent considering an agent can be evaluated by noting the total force obtained by all of the other agents [26], update results applying the quality of solving the problem with attention to fitness function [27]. Because of this, it is implemented for EMS.

This paper aims to introduce and validate experimentally an EMS based on MGSA within MG. The main contribution are as follows:

1. The implementation of MGSA algorithm for using in MG applications with the following characteristic:
   (a) Presented method for solving problems with K spaces N dimensional; It is useful for calculation of each interval.
   (b) Modification of the relationship of velocity, displacement and force for compatibility with MG applications.
2. Experimental implementation of the MGSA for EMS which demonstrates that it is fast, extendible and flexible.

2. Problem formulation

The system under analysis encompasses a stand-alone wind turbine (WT), photovoltaic (PV), microturbine (MT), and energy storage (ES) system.

2.1. The mathematical implementation of MGSA units

The following assumptions will be considered for the optimization problem:

– The voltage level in all of the points of MG is the same.
– The power loss is neglected.
– The reactive power flow is neglected.

The optimization problem is defined according to the following objective function:

$$min\sum_{t=1}^{m}(\mathbb{C}_t^g + \mathbb{C}_t'^g + \mathbb{C}_t^{ES-} - \mathbb{C}_t^\ell - \mathbb{C}_t^{ES+} + \Omega_t) \times \Delta t \quad (1)$$

where m is the number of time periods in the scheduling time horizon T, $\mathbb{C}_t^g$, $\mathbb{C}_t'^g$ depict to the cost of energy produced by renewable and non-renewable generation units in period t, $\mathbb{C}_t^{ES+}$, $\mathbb{C}_t^{ES-}$ present the cost of energy produced by ES units during charging and discharging operation mode in period t, $\mathbb{C}_t^\ell$ is the cost of energy consumed by responsive load demand (RLD) and Ω_t is the penalty