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Real time experimental implementation of optimum energy management system in standalone Microgrid by using multi-layer ant colony optimization

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ABSTRACT

In this paper, an algorithm for energy management system (EMS) based on multi-layer ant colony optimization (EMS-MACO) is presented to find energy scheduling in Microgrid (MG). The aim of study is to figure out the optimum operation of micro-sources for decreasing the electricity production cost by hourly day-ahead and real time scheduling. The proposed algorithm is based on ant colony optimization (ACO) method and is able to analyze the technical and economic time dependent constraints. This algorithm attempts to meet the required load demand with minimum energy cost in a local energy market (LEM) structure. Performance of MACO is compared with modified conventional EMS (MCEMS) and particle swarm optimization (PSO) based EMS. Analysis of obtained results demonstrates that the system performance is improved also the energy cost is reduced about 20% and 5% by applying MACO in comparison with MCEMS and PSO, respectively. Furthermore, the plug and play capability in real time applications is investigated by using different scenarios and the system adequate performance is validated experimentally too.

Introduction

The increase of distributed generation (DG) penetration in power systems and the introduction of energy markets in recent years have caused numerous challenges in design and planning of power systems based on DG [1]. In the future, consumers would have an isolated MG that includes micro generation systems and their consumption management can be done by EMS according to real time electricity cost.

The main constraints related to renewable energy sources are reliability and dispatchability issues associated with their performance [2]. Since the output power of renewable sources changes with weather conditions, power balance between producers and consumers is considered as a key problem in EMS design. Complex constraints and the impossibility of complete accordance of all DG generation sources with the paradigms of power system has led to the presentation of Microgrid (MG) concept. The main specifications of a MG are as follows:

1. Capability of executing programs such as DR management for controlling the shiftable loads [3].
2. Error tolerance, this tolerance must also be considered for confronting the transient faults [3].
3. Load curtailment ability when the MG cannot feed its load completely or when the electricity prices are high [3].
4. High reliability, power quality, security and system efficiency [3].
5. Self revival which means that the system can revive itself after the occurrence of error in it [3].
6. Plug and play capability of all the devices that are added to the system as microsources with any capacity or are put out of the system is provided automatically by EMS.

For obtaining the characteristics mentioned for MGs, it is necessary to consider short term scheduling (STS) and very short term

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Nomenclature

Acronyms

ACO	ant colony optimization
CCU	central control unit
DAM	day-ahead market
DER	distributed energy resources
DG	distributed generation
DR	demand response
EGP	excess generated power
ES	energy storage
EMS	energy management systems
EWH	electric water heater
FMRTS	five minute real time scheduling
HDAS	hourly day ahead scheduling
LEM	local energy market
MACO	multi-layer ant colony optimization
MCP	market clearing price
MCEMS	modified conventional EMS
MG	Microgrid
MT	micro-turbine
NRL	non-responsive load
PSO	particle swarm optimization
PV	photovoltaic
ES+	ES during charging mode
ES−	ES during discharging mode
SOC	state-of-charge
TCP	total consumed power
UP	undelivered power
WT	wind turbine

Variables

π^A	the supply bids by A (€/kWh) $A \in \{WT, PV, MT, ES-, ES+, UP, DR, EGP, \& EWH\}$
λ_t^{MCP}	MCP at t in MCEMS (€/kWh)
$\lambda_t'^{MCP}$	MCP at t in EMS-PSO (€/kWh)
$\lambda_t''^{MCP}$	MCP at t in EMS-MACO (€/kWh)
P_t^A	available power of A in MCEMS (kW)
$P_t'^A$	available power of A in EMS-PSO (kW)
$P_t''^A$	available power of A in EMS-MACO (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-PSO (kW)
$\widetilde{P}_t''^A$	real power set-points of A in EMS-MACO (kW)
P_t^n	uncontrollable load demand at t (kW)
SOC_t	battery SOC in MCEMS (%)
SOC_t'	battery SOC in EMS-PSO (%)
SOC_t''	battery SOC in EMS-MACO (%)
Δt	time step (h)

scheduling (VSTS). Very short and short term economic dispatch are a very important choice in the modern EMS to reduce the operational cost [4–6].

In addition, demand response (DR) is recognized as a very important energy source for cost optimization [3]. Distributed energy resources (DER) significantly increase the number of variables that must enter the economic dispatch problem. STS and VSTS are a large scale, non-convex, nonlinear and time consuming [6]. Therefore, it is necessary to present alternative methodologies for improving the efficiency of these methods against the new paradigms of power system such as heuristic methods [7]. This methodology peresents very fast and adequate response and must be considered for the optimization problems with a lot of variables [8–10].

Ant colony optimization (ACO) algorithm is implemented based on the behavior of real ants that can find the shortest route from the nest to a food source [11,12]. This method is one of the common methods for optimizing different problems [7]. It presents some advantages in comparison with gravitational search algorithm, artificial bee colony and imperialist competition including usefulness in dynamic applications [13], positive feedback which leads algorithm to rapid discovery of good solutions [14] and distributed computation in order to avoid premature convergence [15]. In this paper, the efficiency of this algorithm in solving problems related to performance optimization, DER scheduling improvement and also the cost reduction of system performance is shown in an MG. This method does not have any special algorithm thus, a proper design should be done. As a result, the algorithm designer has an open hand for increasing its efficiency [16–18].

The algorithm presented in this paper has flexibility and adequate fast response to any incident in the system. In the methodology presented, the sources timing schedule with the time intervals day ahead, hour ahead and 5 min ahead are considered. STS of energy sources considering intensive penetration of DERs, load curtailment by using DR and plug and play capability are some specific objectives of this paper. The proposed algorithm is implemented and tested experimentally over the IREC's MG system and the experimental results state the proper performance of this algorithm in handling different scenarios occurred in the system. Moreover, the comparison of it with other EMS algorithms shows its better performance.

Problem formulation

The mathematical implementation of EMS optimization problem

The following assumptions will be considered for the optimization problem within a small MG [7]:

– The voltage level in all of the points of MG is the same.
– The power loss is neglected because of short cabling distance between generation and loads.
– The reactive power flow is neglected.

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

$$z = min\,(\mathbb{C}_{Tot}) \tag{1}$$

where

$$\mathbb{C}_{Tot} = \sum_{t=1}^{m} (\mathbb{C}_t^g + \mathbb{C}_t'^g + \mathbb{C}_t^{ES-} - \mathbb{C}_t^{\ell} - \mathbb{C}_t^{ES+} + \Omega_t) \times \Delta t \tag{2}$$

where m represent the number of time periods in the scheduling time horizon T; $\mathbb{C}_t^g$ and $\mathbb{C}_t'^g$ are respectively the cost of energy produced by dispatchable and non-dispatchable generation units in period t; $\mathbb{C}_t^{ES+}$ and $\mathbb{C}_t^{ES-}$ are also cost of energy produced by ES units respectively during charging and discharging operation mode in period t; $\mathbb{C}_t^{\ell}$ state cost of energy consumed by responsive load demand (RLD) and Ω_t justify to depict the penalty cost resulting from undelivered power (UP) during the time period t.