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Experimental evaluation of a real time energy management system for stand-alone microgrids in day-ahead markets

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HIGHLIGHTS

- An energy management system software has been proposed in experimental Microgrid.
- Local Energy Market has been presented for islanded Microgrids in Day Ahead Market.
- Simulation and experimental results demonstrate a reduction in generated power cost.

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ABSTRACT

A Microgrid (MG) Energy Management System (EMS) is a vital supervisory control to make decisions regarding the best use of the electric power generation resources and storage devices within this MG. This paper presents an operational architecture for Real Time Operation (RTO) of an islanded MG. This architecture considers two different parts including Central Control Unit (CCU) and MG Testbed. CCU implements an EMS based on Local Energy Market (LEM) to control a MG. In order to reach this objective, this unit executes Day Ahead Scheduling (DAS) and Real Time Scheduling (RTS). Regarding DAS, a Modified Conventional EMS (MCEMS) based on LEM ($MCEMS_{-LEM}$) algorithm has been proposed to find out hourly power set-points of Distributed Energy Resources (DERs) and customers. LEM is also presented in $MCEMS_{-LEM}$ to obtain the best purchasing price in Day-Ahead Market (DAM), as well as to maximize the utilization of existing DER. With regard to RTS, it must update and feedback the power set-points of DER by considering the results of DAS. The presented architecture is flexible and could be used for different configurations of MGs also in different scenarios. Simulations and experimental evaluations have been carried out using real data to test the performance and accuracy of the MG testbed. This paper aims to operate the MG in islanded mode, ensuring uninterruptable power supply services and reducing the global cost of generated power. Results demonstrate the effectiveness of the proposed algorithm and show a reduction in the generated power cost by almost 8.5%.

1. Introduction

MG can significantly improve the efficiency of energy production to maintain the balance between power generation and load demand mostly at the distribution level. It is also desired to obtain measurable reduction in environmental emissions and increased power quality through MGs. EMS helps to coordinate such functions. Various configurations for EMS with different algorithms and different MG structures have been presented in literature [1,2].

Effective energy management can provide the necessary optimal and sustainable energy supply with the maximum ability. Furthermore, given the intermittent nature of renewable energy resources, EMS should be able to find the best solution to supply consumers quickly and continuously, i.e., every minute or few minutes. In general, gradient-based optimal EMSs are slow to be used for real-time energy management problem. As a result, recent research in this area has been focused on the off-line application of intelligent methods for energy utilization in the hybrid energy

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Nomenclature

Acronyms

DAM	Day-Ahead Market
DER	Distributed Energy Resources
DSP	Digital Signal Processing
EGP	Excess Generated Power
ES	Energy Storage
EMS	Energy Management Systems
EWH	Electric Water Heater
IREC	Catalonia Institute for Energy Research
LEM	Local Energy Market
MCP	Market Clearing Price
MCEMS	Modified Conventional EMS
MG	Microgrid
MT	Microturbine
PV	Photovoltaic
ES,c	ES during Charging Mode
ES,d	ES during Discharging Mode
SOC	State-of-Charge
SSA	Single-Sided Auction
TRP	Total required power
TGP	Total generation power
WT	Wind Turbine

Variables

π^A	the supply bids by A (€/kW h) $A \in \{WT, PV, ESd$ and $MT\}$
λ_t^{MCP}	MCP at each time t using MCEMS algorithm (€/kW h)
$\lambda_t^{\prime MCP}$	MCP if MT always on during a day (€/kW h)
P_t^C	available power of C in $MCEMS_{-LEM}$ (kW)
$\widetilde{P}_t^C$	active power from C emulator (kW) $C \in \{WT, PV, MT, ES, ESc, ESd, EWH, TRP, TGP$ and $EGP\}$
P_t^n	uncontrollable load demand at each time step (kW)
$\widetilde{P}_t^n$	active power from Load demand emulator (kW)
P_t^{Req}	difference between the produced power by renewable resources and the consumed power by load demand (kW)
$Q_t^{j,b}$	the quantity produced by generation unit j in step b at time t, in (kW h)
Q_t^{TRE}	the total required energy by costumers (kW h)
Q_t^{TGE}	the total generated energy by micro-sources (kW h)
SOC_t	battery SOC (%)
Δt	energy management time step

systems, e.g. [3,4]. Only few other studies have been reported with limited simulation evaluations for real-time management in specific applications [5,6]. This paper has focused on real time implementation of EMS with additional constraints for battery operation and its life time extension. Real time operation have been investigated in literature [7,5,8] but these algorithms have never been tested in real experimental MGs.

In this work, an MCEMS for a low voltage stand-alone MG is proposed to determine the best dispatch of an aggregated group of DGs with the ultimate goal to obtain MCP under various scenarios for ES. This algorithm has been intended to significantly improve the efficiency of energy production and delivery as well as to maintain the balance between power generation and load demand, to optimize the energy utilization and to enhance energy sustainability. Furthermore, generator owners keeps the right on generation and consumption pattern and try to maximize its economical profit. Under this assumption, LEM is proposed in order to obtain the best purchasing price as well as to maximize the use of the existing DER. Furthermore, the well-established LEM structure has also been compared the results obtained using this algorithm to another one. It is also applied for real time application using a proposed architecture which can achieve EMS objectives in a few seconds. The proposed architecture can be easily applied to any configuration of MG system with various characteristics. Then, it has been validated in IREC's MG testbed. Primary frequency control is not addressed in this paper.

As reported in literature, some MG test systems have been implemented around the world [9–13]. These systems allow testing different components [14–17], control strategies [18–24], topologies for communication between micro-sources [25], storage technologies [26] and the used standards in MGs [27]. IREC's MG testbed has also been developed at IREC which has been justified and utilized in different studies at this center. The effectiveness of the performance of this testbed is also verified in different projects [28–32].

The novelties and contributions of this paper are listed as follows:

- To propose fast, flexible and extendable RTO architecture to coordinate DAS and RTS; Moreover, to improve ES operation considering two extra operation modes for the ES including Over Charging Protection Mode and Over Discharging Protection Mode.
- Experimental testing and validation of proposed algorithm in a real MG based on power emulators.

The paper is organized as follows. Section 2 describes the problem formulation, which covers EMS and LEM mathematical implementation. The proposed real time operational architecture for both simulation and experimental evaluations is presented in Section 3 which divided to different subsections to explain about the proposed algorithms and Testbed configuration. Application of this architecture to test systems is demonstrated in Section 4. Section 5 presents simulation and experimental results and discusses about it. Finally, the paper is concluded in Section 6.

2. Problem formulation

2.1. MCEMS unit mathematical implementation

In this paper, an MCEMS unit is proposed to dispatch power set points in a MG comprises PV, WT, MT and ES systems. The proposed unit is illustrated by a Pseudo-code in Algorithm 1. In this unit, when the sum of the produced power by the PV and WT is more than the load demand, and the battery is not in Fully Charged Mode, the battery bank can be operated in two operation modes (i.e. Charging and Over Charging Protection Modes). Likewise, the discharge process can be used in the case when the power generated by the hybrid system does not meet the load demand completely. In this case, ES can also work in two operation modes namely Discharging and Over Discharging Protection Modes during Discharging Mode. The highlighted areas in Algorithm 1 are one of the novelties of this paper. Each of operation modes have been presented in detail in [33].