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An advanced real time energy management system for microgrids

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ABSTRACT

This paper presents an advanced Real-Time Energy Management System (RT-EMS) for Microgrid (MG) systems. The proposed strategy of RT-EMS capitalizes on the power of Genetic Algorithms (GAs) to minimize the energy cost and carbon dioxide emissions while maximizing the power of the available renewable energy resources. MATLAB-dSPACE Real-Time Interface Libraries (MLIB/MTRACE) are used as new tools to run the optimization code in Real-Time Operation (RTO). The communication system is developed based on ZigBee communication network which is designed to work in harsh radio environment where the control system is developed based on Advanced Lead-Lag Compensator (ALLC) which its parameters are tuned online to achieve fast convergence and good tracking response. The proposed RT-EMS along with its control and communication systems is experimentally tested to validate the results obtained from the optimization algorithm in a real MG testbed. The simulation and experimental results using real-world data highlight the effectiveness of the proposed RT-EMS for MGs applications.

1. Introduction

The concept of MGs has received an increasing interest from the scientific community. This is mainly due to their flexible and intelligent characteristics bringing a significant potential to promote and integrate renewable energy resources. Moreover, MGs are regarded as a way to improve overall system reliability, efficiency, and resiliency. They can be used as an autonomous power source (islanding mode) in parallel with a main grid (grid connected mode), as well as during transition to islanding mode (on/off grid mode) [1–3].

The power electronics interface circuits (PEICs) bridge different MG components making them into two main configurations: AC and DC microgrids [4,5]. AC microgrids (ACMGs) are gaining in popularity due to their variety of applications. On the other hand, DC microgrids (DCMGs) provide DC power and are usually connected to a DC bus line [6]. In this case, an inverter (DC/AC) and a rectifier (AC/DC) are both required for bidirectional connection with ACMGs.

ACMGs and DCMGs along with their respective PEICs still face numerous challenges such as efficient energy control and management [7–11]. Therefore, a Microgrid Energy Management System (MG-EMS) is required to identify operation costs and emission limits while taking into account the consumer power demand for each Distributed Energy Resource (DER) and Energy storage system (ESS) unit.

As such, efficient algorithms are developed to optimize the use of individual DERs by minimizing an objective function while considering the system constraints such as load power balance, fuel cost, performance, specifications, limitations due to safety, fuel supply limitation, restrictions on noise/pollutant emissions, and so on [12–17].

Various optimization algorithms have been considered for this problem. In Refs. [18], the evolutionary optimization algorithm is proposed to minimize the sum of the total capital, operational and maintenance cost of DERs subject to constraints such as energy and emission limits of each DER and Loss of Power Supply Probability (LPSP) of the microgrid. Ant Colony Optimization (ACO) is used in Ref. [19] to solve the economic and environmental dispatch of MGs containing different types of generation systems. Other than that, an advanced EMS in a typical MG working in grid and island operating mode is introduced in Ref. [20] based on Advanced Integrated Multidimensional Modeling Software (AIMMS) to

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determine the optimal operating strategies to minimize the energy costs and pollutant emissions hence maximizing the output of the available renewable energy resources. However, these methods are often used offline, which restrict their use for real-time applications. Real-Time Energy Management Systems (RT-EMSs) is described as one which controls an environment by receiving data, processing them, and returning the results sufficiently quickly to affect the environment at that time [21,22].

To improve the performance of RT-EMSs, a robust and reliable communication network is required to exchange the information and decision commands between the EMS, DERs, ESSs, local controllers, and PEIC in real time. The communication network should be flexible and expandable to provide a link with all the nodes within the MG location. For customer privacy and system security, a strong encryption algorithm should be used to secure the communication between different nodes and MG-EMS [23,24].

An advanced RE-EMS is proposed for MG application based on wired communication network in Ref. [25]. Wired communication systems do not have interference problems and their functions are not dependent on batteries, as wireless solutions often do. On the other hand, wireless communications have some advantages over wired technologies, such as low-cost infrastructure and ease of connection to difficult or unreachable areas. However, the nature of the transmission path may cause the signal to attenuate.

Recently, different wireless communication technologies are available and utilized for smart MGs to meet certain requirements such as low cost, simple deployment, working in noisy and harsh environment and support large number of nodes to accommodate for all smart appliances, distributed energy resources and controllers [26]. Among these technologies, ZigBee communication is widely accepted as the most suitable standards for MGs residential network domain by the U.S. National Institute for Standards and Technology (NIST) [27]. ZigBee is an ultra-low power wireless networking technology which makes it suitable to embed in wide range of devices and application. ZigBee is chosen as a good option for MGs implementations according to its simplicity, mobility, robustness, low bandwidth requirements, low cost of deployment and easy network implementation. In addition, it has the ability to operate within an unlicensed spectrum [28].

In this regard, this paper presents an advanced RT-EMS suitable for MGs applications. The optimization problem is solved using GA to satisfy the load demand requirements during 24 h operation with the lowest utility cost by finding an hourly optimal allocation for each DER unit. In order to improve the performance of RT-EMS, the communication network is designed based on ZigBee technology which has the ability to work in harsh radio environment. The proposed RT-EMS along with its communication system is experimentally tested to validate results obtained from the optimization algorithm on a real-time MG testbed. The simulation and experimental results highlight the effectiveness of the proposed RT-EMS for MGs.

The paper is organized as follows: firstly, the MG system description is illustrated in Section 2. In Section 3, the optimization model and its algorithm are introduced and analyzed. In Section 4, the experimental setup using the proposed RT-EMS with its communication system are presented and discussed. Finally, the experimental results are discussed in Section 5.

2. MG system description

The schematic diagram of the MG-EMS under consideration is depicted in Fig. 1. There are three DERs: Micro-turbine (MT), wind,

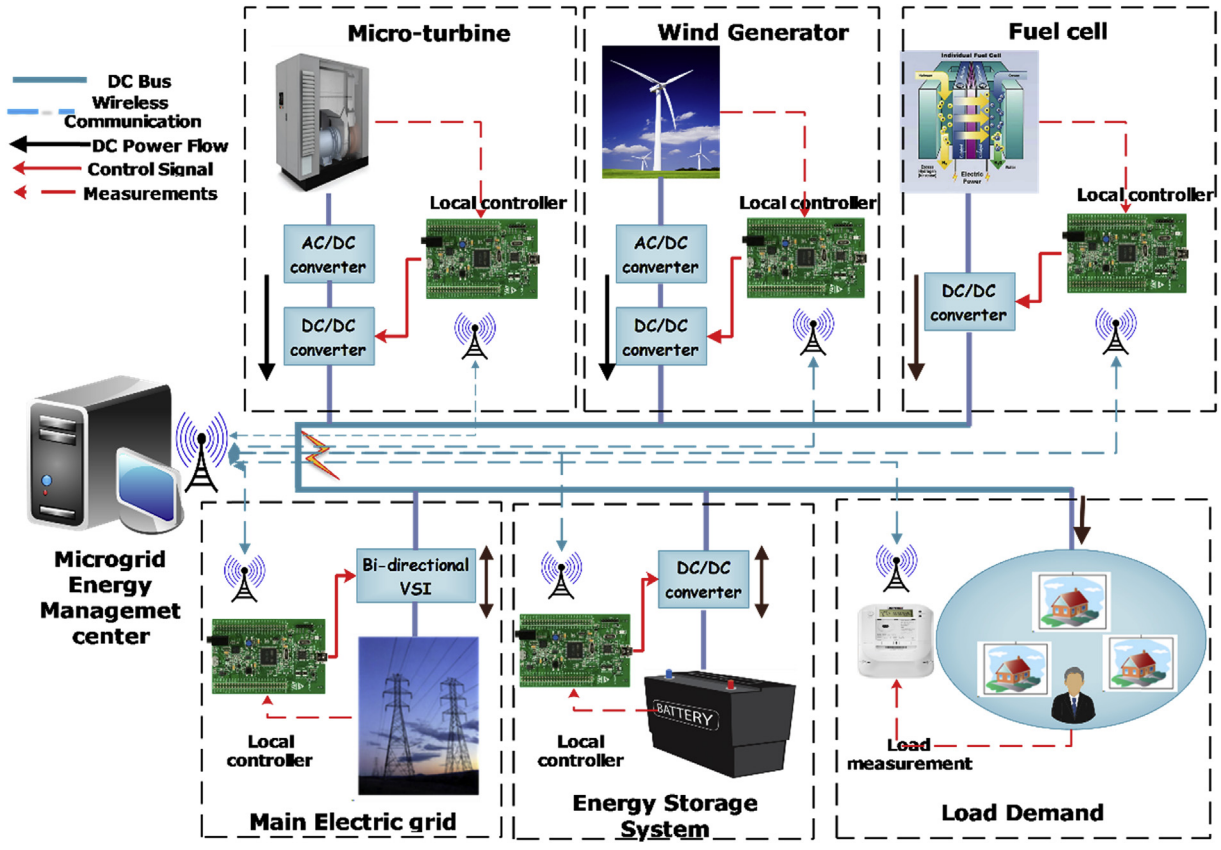

Fig. 1. The schematic diagram of the MGEMS under consideration.