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Microgrid energy management system for smart home using multi-agent system

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ABSTRACT

This paper proposes a multi-agent system for energy management in a microgrid for smart home applications, the microgrid comprises a photovoltaic source, battery energy storage, electrical loads, and an energy management system (EMS) based on smart agents. The microgrid can be connected to the grid or operating in island mode. All distributed sources are implemented using MATLAB/Simulink to simulate a dynamic model of each electrical component. The agent proposed can interact with each other to find the best strategy for energy management using the java agent development framework (JADE) simulator. Furthermore, the proposed agent framework is also validated through a different case study, the efficiency of the proposed approach to schedule local resources and energy management for microgrid is analyzed. The simulation results verify the efficacy of the proposed approach using Simulink/JADE co-simulation.

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1. INTRODUCTION

The electrical system should be produced to offer new technologies behind the global dependency on renewable powers. This renewables sources have a large influence on the power grid system quality and balance. The electrical grid traditional is growing to be the intelligent electrical network (smart grid) to making the power production more durable, sustainable, and low economy. The notion of a smart grid is the integration of the electrical power and the information and communication technology for data transmission between all electrical components (sources, loads, and transformers) to ensure the real-time balance between supply and demand and to increase the power grid stability [1].

Microgrids are small-scale power grids produced to provide a stable power supply to a small number of consumers. The microgrid combines various local and distributed generation facilities (wind generators, fuel cells, small diesel generators, photovoltaic generators, and small hydropower), consumption equipment, storage system, and supervision and monitoring center. The balance between consumption and production is necessary to manage the energy and to ensure the reliability of microgrid (MG). A microgrid is a medium or low-voltage hybrid power generation system that integrates small-scale energy producers renewable as primary resources to produce high-quality energy to a few consumers. The microgrid can run in mode connected to the main grid high or medium voltage by the common coupling point (PCC) or can also operate totally in an isolated mode [2], [3]. The power grid structure of MG is defined by the application and user specifications. The MG can be divided into three main groups: alternating current (AC) microgrids, direct current (DC) microgrids, and hybrid microgrids. One of the principal goals of the energy management system (EMS) is to attain a very important level of suppleness and also the system must be able to adapt to most of the variations in the structure of microgrids. The MG operation is controlled using microgrid central controller (MGCC) and local controllers [4]. In this paper, a microgrid is available is considered to provide local energy to the smart home.

The energy management of some complex systems such as microgrids requires a distributed intelligence system. A multi-agent system (MAS) is a multilayer and complex system based on smart agents enable to communicate between them for achieving a general objective at decentralized management of electrical energy system. Various applications of MAS, particularly in MG energy management have several functionalities in electrical power such as identified MG optimization method carried out by increasing the renewable sources and monitoring electrical power exchange with the main power grid [5]. MAS application in microgrid energy management has been proposed by many authors, some of which are presented here.

Power management is implemented out by MASs to satisfy the consumer’s load request from the grid and to enhance electrical power according to the deficiency or surplus power information in [6]. The surveillance of MG systems based on the cooperative capacity of agents probably offers optimal results and a suitable dynamic director for the MG activities [7]. The implementation of a MAS for the high-level microgrid control and demand-side supervision of a solar microgrid for a smart home is introduced in [8]. A MAS for power flow control in the microgrid connected to the main power grid is proposed in [9]. The MG component-based on wind and photovoltaic sources, diesel generators, energy storage systems, and EMS. Liang *et al.* [10] proposed a combination control technique for an autonomous MG that is composed of energy control using MAS. Logenthiran *et al.* [11] offers a multi-agent method for energy source scheduling of power systems with renewable energies for many microgrids with lumped loads. It manages each microgrid alone first and then the microgrids are rescheduled to satisfy the total demand. MAS with supervisory control and data acquisition system was considered in [12] to efficiently run and control a distributed energy sources inside a micro-grid system using Java agent development framework (JADE).

This paper proposed a new system based on a MAS for energy management in the MG. The smart technique is developed using a co-simulation (combine MATLAB/Simulink and JADE) platform for a real-time simulation. The electrical components are modeled using MATLAB/Simulink, and the MAS interaction performed using JADE.

The rest of the paper is organized as follows. The multi-agent system technique is discussed in section. 2. The microgrid architecture is given in section 3. The energy management approach is proposed in section 4. Simulation and discussion are given in section 5. The conclusion of this paper is given in section 6.

2. MULTI-AGENT SYSTEM TECHNIQUE

All distributed system with many continuing cooperation and communications is practically infeasible. These challenges have increased the development of approaches to a distributed system (power grid) based on agents, which present techniques for correspondence and continuous interaction. A MAS is a distributed method based on different agents, to run concurrently to solve challenges that are continuously from their capacities or knowledge of individual agent (node) [13].

MAS is among the methods of distributed artificial intelligence (DAI). Multi-agents cover a method to develop new decentralized systems first than centralized, developing rather than intended, and cooperative rather than consecutive, with many benefits. MAS has inherent advantages such as flexibility, autonomy, and a decrease in problem complexity. Each agent has some behaviors and techniques to satisfy specific goals using their sources, experiences, and co-operations [14].

Agents run commonly simultaneously to update system data based on any change in the microgrid. In this paper, the electrical elements of the microgrid and the proposed multi-agent system are simulated on two separate simulators. The MATLAB/Simulink platform is applied to design and simulate the elements of the microgrid and the JADE tool is applied to estimate the efficiency of the multi-agent algorithm proposed. A communication interface between MATLAB/Simulink and JADE is provided via the MACSimJX Middleware [15]. The results of agent actions are control signals sent back to Simulink through the Windows pipe server [16].

3. MICROGRID ARCHITECTURE

Microgrids are small power grids created to produce stable and better-quality electricity provide to a few consumers. They mixed various energy sources such as (wind generator, fuel cells, small diesel generators, photovoltaic sources, and small hydropower), storages systems as a backup energy system, and

AC/DC load for the energy consumption [17]. Analysis of microgrids in the literature largely centers on constant voltage (DC) and variable voltage (AC) type microgrids [18]. This is determined by the quality of the voltage at the bus used. In the DC type microgrid, the elements of the DC microgrid are connected to the DC_Bus.

The microgrid used in this paper joins many distributed power sources and home loads. Two sources are considered in this microgrid and two types of loads (AC load and DC load). The photovoltaic (PV) and battery energy systems are used to supply the load demand as shown in Figure 1.

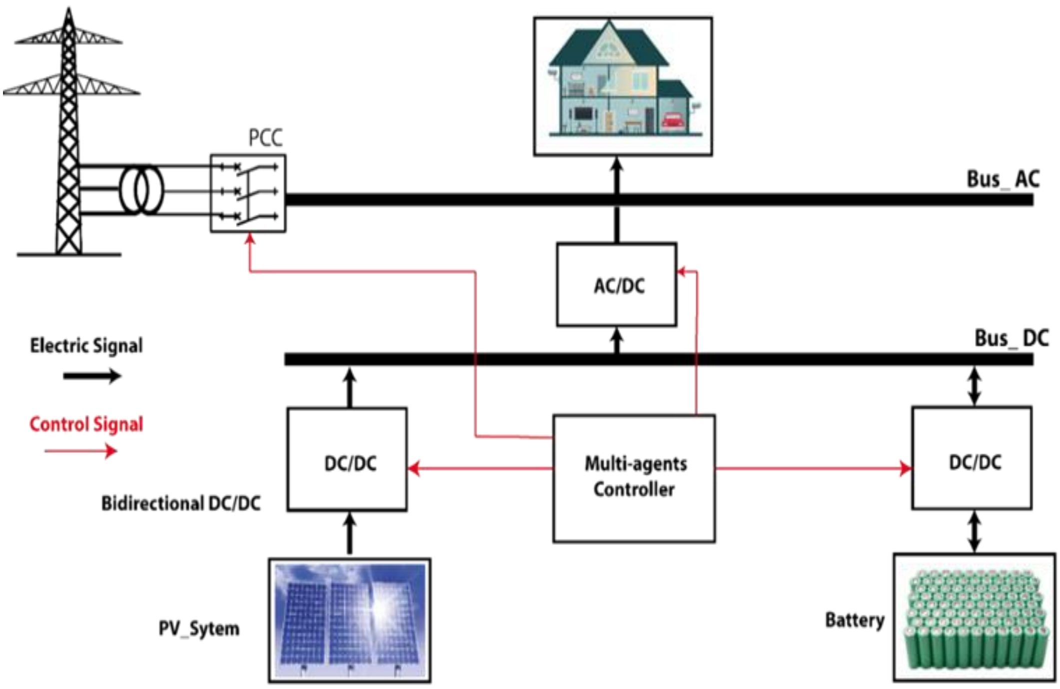

Figure 1. Microgrid control by MAS

3.1. PV model

A photovoltaic cell can be modelled with the equivalent electric circuit. The latter consists of a current generator and a parallel diode with a standard resistor (shunt) R_s to take account of the following dissipative phenomena at the cellular level. The diode current can be written as:

$$I_d = I_0\left(exp^{\frac{V_{pv}+R_S I}{V_T}} - 1\right) \tag{1}$$

and PV generator output current of the of the N_s series of cells can be written as:

$$I_{PV} = I_{ph} - I_0\left(exp^{\frac{V_{pv}+R_S I}{V_T}} - 1\right) - \frac{V_{pv} + R_s I}{R_{sh}} \tag{2}$$

$$V_T = \frac{N_s\, n\, k\, T}{q}$$

with, VT: the thermal voltage, N_s: cells connected in series, n: the diode ideality constant, q: is the electron charge, k: is the Boltzmann constant, T: is the temperature of the p-n junction, I_{ph}: the photo-current, and I_0: reverse saturation currents of the diode.

To obtain the maximum power generated by the PV generator to transfer it to the load, a static converter (DC/DC power converter) is used as an adapter between the PV generator and the load. An maximum power point tracking (MPPT) controller is used to control the Boost converter to provide the maximum power efficiency at any time [19]. Various MPPT algorithms are able of discovering the MPP based on the evolution of the power supplied by the PV generator, such as the perturb and observe algorithm (P&O) [20] and the incremental conductance method, the P&O method is generally the most used one due to its simplicity and ease of use and realization [21].

3.2. Energy storage system for microgrid

Lithium batteries are the preferred battery type for many storage system due to their advantages compared with the other battery types. Furthermore, unlike other battery types, Li-ion battery electrolyte is a volatile, highly flammable liquid that burns rapidly and readily [22]. Therefore, the state of charge (SOC) is considered in the energy management strategy to protect the battery against the overcharging and over discharging. The SOC of battery charged is defined by the (3):

$$\mathrm{SOC}(\%) = 100\left[1-\left(\frac{1}{Q_{bat}}.\int_0^t i_{bat}(t)\,dt\right)\right] \quad (3)$$

where:
Q_{bat} : Battery capacity (Ah)
i_{bat} : Battery current (A)

Lithium-ion batteries have been considered in previous years due to their advantage (high energy density, long life cycle, and no memory effect) compared with the other type of battery storage system. In this work, the battery storage system will be used as a power source when renewable sources are insufficient to meet load demand and as a load when they have enough power to keep the system balanced [23]. A bidirectional DC/DC converter connected the lithium-ion battery to the microgrid [24].

The bidirectional DC/DC converter allows power to be transferred in either direction between the battery and the DC Bus. They are increasingly being employed as a connection between the battery and microgrid system to control battery charging and discharging because of their capacity to reverse the direction of current flow, and power, while keeping the voltage polarity at either end unchanged [25].

The battery storage system consists of a Li-ion battery and a bidirectional DC-DC converter. This converter controlled by an agent, and it' responsible for maintaining and stabilizing the DC bus voltage through the controller as shown in Figure 2. The converter employed in this research is a half-bridge insulated-gate bipolar transistor (IGBT). The converter can operate in boost mode to discharge the battery or in buck mode to store the excess energy on the DC bus as shown in the Figure 2.

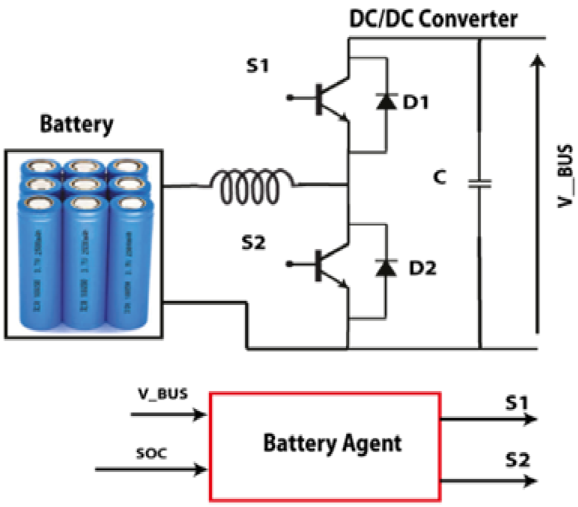

Figure 2. Battery storage system with agent controller

4. THE MAS APPROACH FOR ENERGY MANAGEMENT

The multi-agent systems proposed for the management of the microgrid consist of four intelligent agents: control agent (CA), battery agent (BA), load agent (LA), and PV agent.

- Control agent (CA): it is in charge of managing the energy exchange between the microgrid's various units, as well as confirming the shortage or excess of energy in the bus. It is also in charge of microgrid control when connected to the grid.

- Battery agent (BA): it plays a key role in the management of microgrid by providing energy requested by consumers when production is insufficient. He receives the order from the CA to absorb the excess energy or to provide it when there is a deficit. The storage agent is based on the SOC value to accept or reject the CA proposal.
- Load agent (LA): is largely responsible for the control and management of consumer status. The la collects load data such as power, current, and voltage to be sent to the control agent to meet expected consumer demand.
- PV agent: Primarily responsible for monitoring power generator, able to perform tasks based on generator capacity and collect data such as real-time power output and the availability of sources. The ability of each agent to interact with and communicate with other agents distinguishes it. The primary goal of the proposed energy management is to maintain a balance between production and consumption.

5. SIMULATION AND RESULTS

To validate our energy management approach, we have considered some simulation scenarios that the micro-grid is brought to face in real operation. The studied small hybrid solar battery technical details are described in Table 1. Because renewable energies are intermittent, the electricity generated from them is not stable over time. As a result, there are two distinct modes of processing at the DC BUS: surplus or absence of energy. MATLAB/Simulink is used to simulate the proposed single-phase hybrid energy system. I n this simulation, the solar energy source is linked to a boost converter to extract the maximum power from it. As a result, the P&O MPPT technique is used to monitor the maximum power of the PV panel.

The simulation runs for 3 seconds with 1e-5 sampling time to display the voltage at the DC Bus for various solar irradiation values. To demonstrate the robustness of our management strategy in the face of harsh changes in meteorological conditions, we have chosen a scenario with multiple irradiation changes to represent all possible scenarios. The Figure 3 and Figure 4 shown the proposed solar irradiation scenario and the power produced during this scenario.

Table 1. Technical details of the proposed microgrid system

System	Characteristic
DC_BUS	V_{DC}=220 V, V_{AC}=220 V
Battery	Type: Li-ION, V=48 V; Q_{batt}=250 AH
PV System	N_s: 6, N_p=10
Load (AC+DC)	P_{LDC}=5 KW, P_{LAC}=5 KW

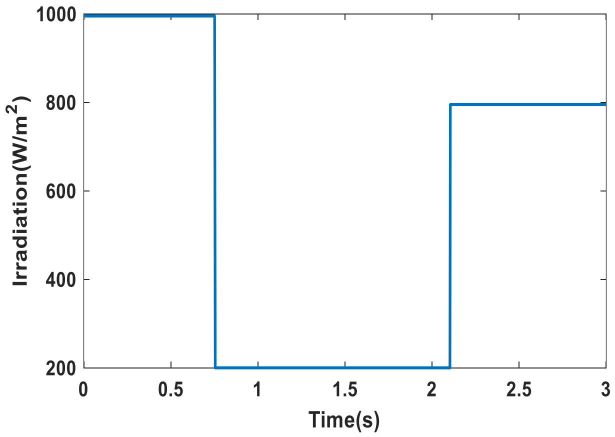

Figure 3. Solar irradiation scenario (W/m²)

As we can see from the Figure 4, the power produced using the solar panel is not stable o the time, which mean another source for stability is needed. The Figure 5 shows the battery state of charge variation, as we discussed before the main role of the battery is to grantee the energy stability on the bus using charging in case of energy surplus in the bus, as show between [0 to 0.7] and [2.1 to 3]. In addition, to provide the stored energy in case of needed energy at the bus [0.7 to 2.1]. The Figure 6 and Figure 7 show the variation of the bus DC and AC voltage during the simulation respectively, we can see the effectiveness of the energy management strategy in the stabilization of voltage in the both buses.

Figure 8 depicts the signal sinusoidal 220 V of the voltage at the AC Bus over a small interval between 1.5 and 1.8. Based on multi-agent system communication, the proposed technique ensures a quick return of the real powers to their steady-state conditions in order to maintain the balance between generation and demand. The simulation results presented above demonstrate the advancement and efficiency of the multi-agent approach strategy proposed using co-simulation in the Simulink and JADE environments.

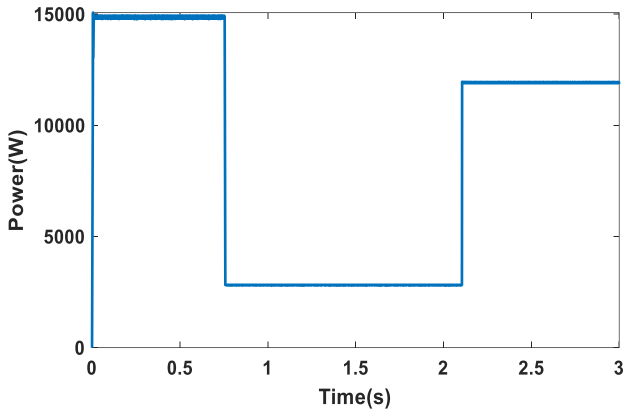

Figure 4. Solar power (W)

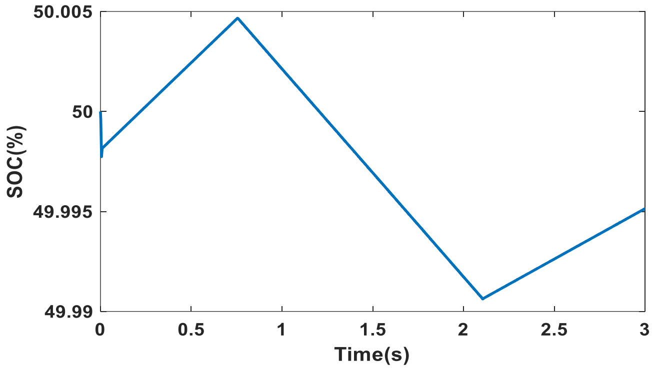

Figure 5. Battery state of charge (%)

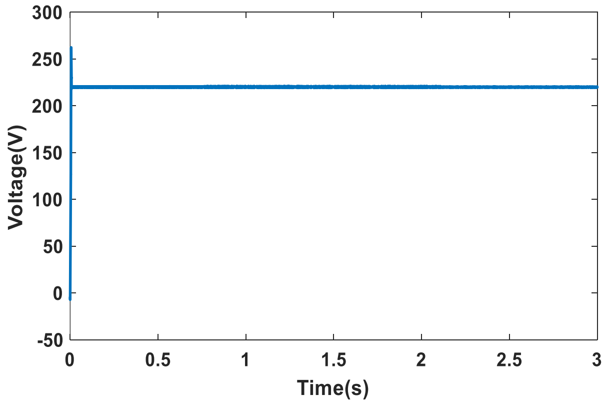

Figure 6. Voltage at the Bus_DC

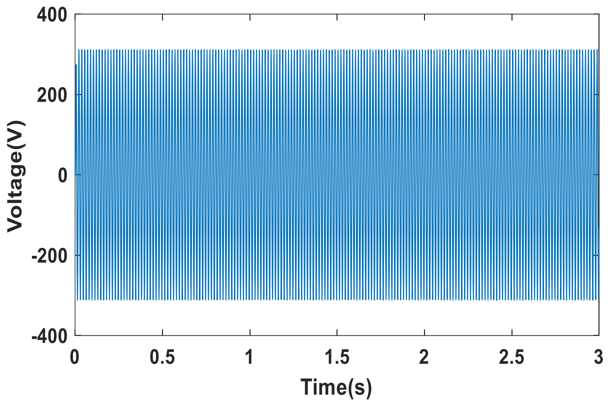

Figure 7. Voltage at the Bus_AC

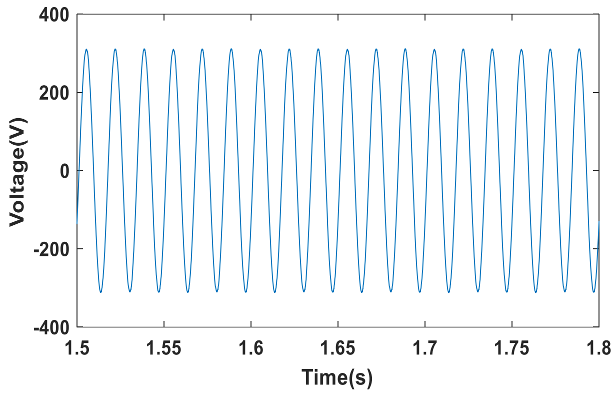

Figure 8. Voltage at the Bus_AC

6. CONCLUSION

In this study, a decentralized multiagents system for energy management in microgrid connected to the main grid for smart home application has been proposed. The proposed MAS can be controlled the dynamic loads of smart home according to the available PV source and the SOC of the battery. Based on the MAS algorithm, the agents communicated with each other in a distributed for best energy management. According to the simulation results, the agents are able to dynamically adapt to changes in the system configuration for environmental events such as changes in solar irradiation and battery state of charge. The simulation of the proposed technique guarantees faster efficiency and also guarantees the safety of the energy supply based on the data transfer between the agents.

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