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Research Paper

IoT Based Load Management of a Micro-Grid Using Arduino and HMAS

M. Mozaffari Legha* and E. Farjah*(C.A.)

Abstract: This paper aims to establish an Arduino and IoT-based Hierarchical Multi-Agent System (HMAS) for management of loads' side with incentive approach in a micro-grid. In this study, the performance of the proposed algorithm in a micro-grid has been verified. The micro-grid contains a battery energy storage system (BESS) and different types of loads known as residential consumer (RC), commercial consumer (CC), and industrial consumer (IC). The user interface on a smartphone directly communicates with the load management system via an integrated Ethernet Shield server which uses Wi-Fi communication protocol. Also, the communication between the Ethernet Shield and the Arduino microcontroller is based on Wi-Fi communication. A simulation model is developed in Java Agent Development Environment (JADE) for dynamic and effective energy administration, which takes an informed decision and chooses the most feasible action to stabilize, sustain, and enhance the micro-grid. Further, the environment variable is sensed through the Arduino microcontroller and sensors, and then given to the MAS agents in the IoT environment. The test results indicated that the system was able to effectively control and regulate the energy in the micro-grid.

Keywords: Load Management, Arduino, Micro-Grid, Wi-Fi, Hierarchical Multi-Agent Systems.

1 Introduction

THE concept of load management started with the advanced metering infrastructure (AMI) to improve the demand side management. However, with the emergence of the Internet of Things (IoT) and advancement in communication technologies, energy management solutions have gained renewed interests to provide more flexibility for the user as well as to offer intelligent services. A micro-grid is an independent, controllable, and single energy system which includes different load types, energy storages system (ESS), and control devices, in which DG and ESS are connected directly parallel to the user's side. The smart network tries to prepare advanced control technology for electrical power systems at different levels of production, transmission, and consumption.

By applying the information technology concepts, conventional electrical power systems would be transformed into far safer, more flexible, and highly efficient networks.

A home energy management system design focusing on the use of IEEE 802.15.2 and Zigbee for user load response and load management was investigated in [1]. Further, [2] proposed a hardware design system for home energy management using sensing technology and machine learning algorithm, to enable users to achieve real-time price response control over residential loads. A new approach was investigated in [3] which dealt with the integration of DG units in distribution networks in order to reduce the consumers' peak demand.

The operation scheme of an industrial load was tested in [4], which participates in DR, considering the electricity price where the labor costs are reviewed. Further, [5] explored an intelligent load management system by combining renewable energy for smart homes. In this paper, the demand-side management (DSM) model is based on evolutionary and

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* The authors are with the Department of Electrical Engineering, Shiraz University, Shiraz, Iran.
E-mails: mozaffari.m@shirazu.ac.ir and farjah@shirazu.ac.ir.
Corresponding Author: E. Farjah.

genetic algorithms for timing of residential users' tools. The model is priced at using time for three items are simulated: 1) Traditional houses 2) Smart houses 3) Smart houses with renewable energy sources. In DR programs, the integration of renewable energy in residential units is growing more reliable, efficient, and attractive. This can reduce the cost of electricity in residential units and properly manage power in residential units. The work presented in [6] and [7] uses different types of battery storage systems to reduce the cost of power while enhancing network stability. The effect of uncertainty in the production of renewable energy at the market price of the forecasted market has been presented in [8]. Some authors have designed automatic control devices for planning the power management of residential units to create an optimal cost for users. On the other hand, some others have used artificial intelligence (AI) techniques for automatic scheduling [9]. Also, [10] tested the design and implementation of home energy management and the power control system. This paper proposed the load management using the multiagent systems with an incentive approach based on IoT. The proposed method enables users to monitor, adjust, and manage response loads using a mobile application dynamically. At the heart of the power management system is an embedded microcontroller encoded with monitoring, management, scheduling, and control programs. The user interface (UI) on the mobile device is directly used by the integrated Raspberry Pi server which uses the Wi-Fi connection protocol [11].

Internet of things is a conceptual and universal pattern that is applicable in all areas of energy, transportation, health, production, etc. for creating a smart world. With the use of the current and growing compatible information and communication technologies, this technology can contribute to realization of advanced services. With the advent of IoT and progress in information technology, energy management solutions have generated new profits in order to bring more flexibility for the user and offer smart services as well [12, 13]. This paper aims to establish an Arduino and IoT-based Hierarchical Multi-Agent System (HMAS) for management of loads side in a micro-grid.

The superiority of this work compared to other studies is that in this work different loads including residential, commercial, and industrial consumers that are able to take part in load response programs are managed with an incentive approach and with multi-agent systems with the help of IoT [14].

The second part introduces load management based on a hierarchical multi-agent system. Section 3 examines the method of load management and implementation of the system design in the micro-grid. The formulation is also described in this section. The simulation and flowchart of the strategy is described in Section 4. The results and discussions of the scenarios of the proposed method are presented in the final section.

2 Load Management Based on Hierarchical Multi-Agent System

In this section, the recommended micro-grid structure is presented, after which the agents, as well as their tasks and interrelationships to each other, are determined. Then, the algorithm and strategy of micro-grid energy management are presented by the hierarchical multi-agent system based on the JADE platform [15].

The micro-grid considered in this paper, as presented in Fig. 1, is the recommended micro-grid including a battery energy storage system (BESS) plus different types of loads known as residential consumer (RC), commercial consumer (CC), and industrial consumer (IC) [10]. The micro-grid is connected to the upstream grid and exchanges energy with that. The micro-grid manager has the task of the utilization of micro-grid, with an agent considered for each of the units, with the responsibility of local controlling of the unit under its supervision. The manager of micro-grid (MMG) has information and interactions with the upstream grid manager and is responsible for the coordination of the units with each other. The micro-grid's manager, after processing and optimizing the plan, determines the amount of charge and discharge of the storage within the next 24 hours. It also determines the extent of reductions of loads' use in the next 24 hours. It further determines the amount of power required for exchange with the upstream grid and announces it to the related agent.

The load management system of the micro-grid is a device composed of software and hardware. The purpose of such a system is to manage different kinds of loads based on hierarchical multi-agent systems and Arduino. The overall purposes of such devices include:

1. Determining the optimal amount of charge/ discharge of battery of energy storage system;
2. Determining the optimal amount of loads' power reduction.

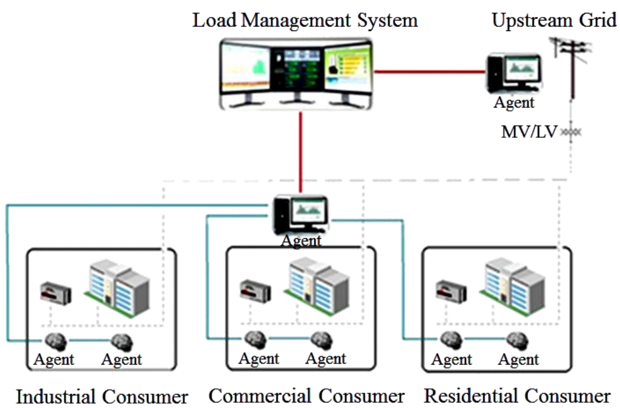


Fig. 1 Micro-grid structure based on agents.

3 Implementation Development Process

3.1 Hardware System Design

To acquire information on energy consumption in the micro-grid [16], voltage and current sensors were designed. The voltage sensor allows the system to read the voltage data. The acquired voltage signals were scaled down to the range of 0–5V and sent to the analog-to-digital converter unit on the Arduino micro-controller device for processing. The sensed voltage and current readings were transferred to the Arduino micro-controller device for computation of the energy consumption by appliances on the circuits. Also, the computed information was transferred to the Ethernet Shield server.

The hardware consisted of sensors, data loggers, and modules which obtain the information from the upstream grids and micro-grid in the load management system. The entire information of agents would be transmitted to the Ethernet Shield server, then the agent of the upstream grid sent the average value of the power of load responses based on the IoT to the user agent for each hour. Finally, the agent of loads and BESS, optimal determined the power reduction and power charge/discharge, respectively.

```
void getACS712() {  // for AC
     ACSVoltage = getVPP();
     VRMS = (ACSVoltage/2.0) *0.707;
     VRMS = VRMS - (calibration / 10000.0); //calibtrate to zero with slider
     AmpsRMS = (VRMS * 1000)/mVperAmp;
     if((AmpsRMS > -0.015) && (AmpsRMS < 0.008)){//remove low end chatter
     AmpsRMS = 0.0;
  }
  Serial.print(String(AmpsRMS, 3));
  Serial.print(" Amps RMS");
  Serial.print("\tPower: ");
  WH = (inputV * AmpsRMS) * (pF / 100.0);
  Serial.print(String(WH, 3));
  Serial.print(" WH");
  Blynk.virtualWrite(V0, String(AmpsRMS, 3));
  Blynk.virtualWrite(V1, String(WH, 3));
  Blynk.virtualWrite(V3, int(WH + 0.5));  // gauge
  energyCostpermonth = 24.0 * 30.0 * (WH / 1000.0)*(energyTariff / 10000.0);
  Serial.print("  Approx cost per month: £");
  Serial.println(String(energyCostpermonth, 2));
  Blynk.virtualWrite(V6, String(energyCostpermonth, 2));
}
```

Fig. 2 Pseudo code of the load management algorithm.

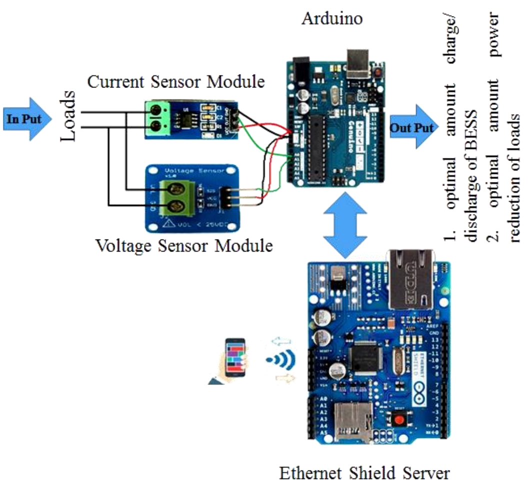


Fig. 3 The proposed implementation of the load management system for each of the consumers.

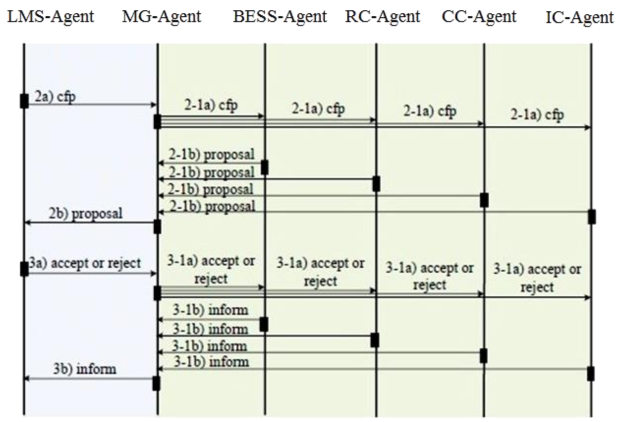
These concepts have led to a decision process for which the pseudo-code is shown in Fig. 2. Fig. 3 illustrates the architecture of implementation of the load management system for each consumer.

3.2 Software System Design

The user application on the smartphone was designed using the Android platform. Also, the server application on the designed method used the JADE platform. The software was designed to establish connections between the electrical servers. The server application system interfaces were available to determine the optimal extent of production of BESS and reduction of types of load. The mobile application system three interfaces available to energy monitor, energy control, energy planning management [17].

The interaction between different developed agents in the proposed operation strategy is shown in Fig. 4. According to this figure, the manager of micro-grid (MMG) has information and interactions with the upstream grid manager and is responsible for coordination of the units with each other. The agent BESS, after calculation of the cost of its generated power, announces the cost and the range of generated power to the micro-grid manager during the next 24 hours. Using hierarchical multiagent systems, there are direct interactions which are mutual interactions between the agent of central control for the load management system and agent of the micro-grid as well as the agent of all types of loads and battery.

In this paper, the user interface directly interacts with the Ethernet Shield server stability for all data required for displaying real-time and historical energy plus power consumption data. The Ethernet Shield also saves data for persistence and provides asynchronous access to the various services the application requests for. A charting library was used to render live data flow and monthly usage data as graphs [18].



LMS: Load Management System
MG: Micro Grid
BESS: Battery Energy Storage System
RC: Residential Consumer
CC: Commercial Consumer
IC: Industrial Consumer

Fig. 4 Interaction between agents in micro-grids.

3.3 Objective Function

In the recommended method [19], MMG tries to minimize the total costs of micro-grids, taking into account the technical constraints of the micro-grid. Indeed, micro-grid utilization management can be defined as an optimization that results in that the efficient generation points and the units being or not being in the circuit is determined such that the total reduced cost and equal and unequal constraints will be observed.

$$F(x)=\sum_{t=1}^{24}\Big[P_{grid}^{t}\times B_{grid}^{t}+P_{BESS}^{t}\times C_{BESS}^{t}$$
$$+\sum_{k}RP(k,t)+\sum_{b}CP(b,t)+\sum_{j}IP(j,t)\Big] \quad (1)$$

In this equation, P^t_{BESS} and P^t_{grid} are the power of charge and discharge of BESS (kWh) and the power exchanged with the upstream grid (kWh) in t time, respectively. B^t_{grid} and C^t_{BESS} are the price of power exchange with the upstream grid, (Rials/kWh) and the cost of BESS, (Rials/kWh), respectively. $IP(j,\ t)$, $CP(b,\ t)$, and $RP(k,\ t)$ are the rewards paid to the loads (Rials).

4 Simulation Studies

4.1 Test System and Main Assumptions

In this section, the proposed approach is implemented on a micro-grid as shown in Fig. 1. Micro-grids are assumed to have, different types of loads, as reported in Table 1. The micro-grids structure consists of a 27kW residential, a 36kW commercial, and 33kW industrial loads. The storage device contains 30 batteries with a maximum charging and discharging power of 30kW as reported in Table 2. Note that these data are just illustrative and are arbitrarily assumed for demonstrating the performance of the proposed framework [20].

4.2 Method

In this paper, a hierarchical multi-agent system (HMAS) is proposed for load management systems with an incentive approach in the micro-grid.

Table 1 Loads characteristics.

Unit	Type	Daily peak	Max capacity in an hour
1	Industrial	610 kW	33 kW
2	Commercial	607 kW	36 kW
3	Residential	457 kW	27 kW

Table 2 Energy storage unit characteristics.

Unit	Min-Max SOC [%]	Max charge/ discharge power [kW]	Charge/Discharge efficiency
1	5-100	-30 / +30	0.9

The proposed strategy is implemented based on hierarchical multi-agent systems in the JADE software environment for the server application, as well as in the Android environment for mobile application. Many studies have been conducted on managing and reducing peak demand. Some of the approaches include load change algorithms and proper DG's control [20].

The aims of this paper included determining the optimal amount of charge/discharge of BESS and reducing the power of loads in the proposed method. After determining the power for each of the loads and the charge/discharge power of the battery, information using agents would be sent to the upstream grid agent associated with the server. The agent of the upstream grid calculated the average optimal value of the power of load and BESS based on the genetic algorithm and sent based on the IoT to user agents for each hour. Finally, the agent of loads and BESS optimally determined the power reduction with incentive approach and power charge/discharge, respectively. Fig. 5 illustrates the flowchart of the strategy of load management systems in the micro-grid based on Arduino and HMAS.

4.3 JADE

In order to validate the method of energy management of the micro-grid based on the multi-agent systems recommended in this section, a micro-grid has been modeled in the JADE software environment. The reason for using JADE is that it conforms to the FIPA standards and creates a space where the programmer can

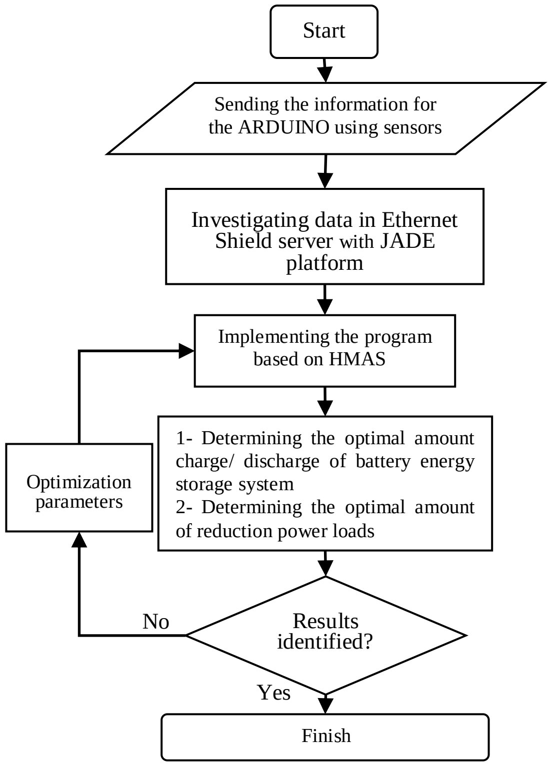


Fig. 5 Flowchart of the strategy of energy management systems.

directly focus on the design of the operating system. The platform created by JADE allows users to easily focus on controlling and monitoring the power balance in a micro-grid. JADE is a platform to facilitate the implementation of multi-agent systems including:

– A runtime environment where JADE agents are enabled.
– A library of programming classes used to develop agents.
– A collection of graphical tools that can display the activity of the agents at run-time [21-23].

4.4 Results and Discussions

The numerical simulation of the design in Fig. 3 together with a model of the micro-controller device was implemented using Arduino simulation software [24]. To simulate the system's ability for measuring different current values on the circuit, each current sensor was connected to a variable resistor. The voltage sensor's ability to measure the voltages was simulated by connecting it to a nominal supply of 220 Vrms. To validate the proposed method, a micro-grid was simulated based on Fig. 1 which managed the loads and DERs based on the multi-agent system. Hierarchical multiagent system is a method that has different agents, working together, which can recognize the surrounding environment.

In order to examine the method proposed in this paper, two scenarios were tested on the micro-grid. In the first and second scenarios, the micro-grid was connected to the upstream grid. The micro-grid contained a battery energy storage system (BESS) plus residential consumer, commercial consumer, and industrial consumer. However, the consumption pattern of different types of loads of each scenario has been different from each other.

The manager of the upstream grid is responsible to efficiently use all agents. Further, some agents will be assigned to different sections that are responsible to control their sections. The hierarchical multi-agent system includes agents of load types and agent of BESS. The performance of load management in micro-grid was simulated for 24 hours whose results are as follows. After implementation of the program, the power of BESS and power of consumers from scenarios 1 and 2 observed per each hour are presented in Figs. 6 and 7, respectively. This section provides the results of the evaluation of the proposed design on the micro-grid under study. In the following, some of the outputs are analyzed. In this regard, Figs. 6 and 7 demonstrate reduction of the power consumption of each of the loads as well as charge and discharge power of the battery in a 24-hours period for the two scenarios.

In this paper, the proposed rebate based on the incentive approach is a function of both reduction power and utilization improvement due to load management. Customer participation based on the incentive approach is usually through a detailed survey at the beginning of the load management program. Also, Load Priority Index (LPI) is a user-defined value where the user (i.e., the agent of the customer) has the authority to reduction loads that should be operated per the priority of the duties.

After determining the optimum power for each type of load and the charge/discharge power of the battery, the agent of power distribution network sends the average power of the type of responsive load on the Internet to the user agent each time. Then, the agent of each load, based on the incentive approach, first covers the charge/discharge power of its battery. In the next step, each agent will reduce the load per hour, if appropriate, and reduce the amount of power consumed the basis for the freight charge and the special incentive factor for the attendant loads will be rewarded .It can be observed that each factor supplies its need, primarily from the battery and then at its discretion starts to reduce the load in each hour, only if the attendant loads in the incentive-based program have a demand level lower than the average total hourly power level.

According to the results, the reduction of power customer based on the incentive approach is through load priority index and discretion of load agents.

Fig. 8 indicates the diagram related to the power exchanged with the overhead electricity distribution network within a 24-hour interval for each of the various scenarios.

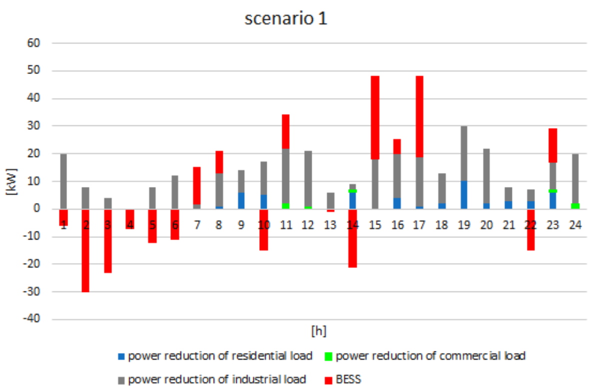


Fig. 6 Power of BESS and power of the consumers in scenario 1.

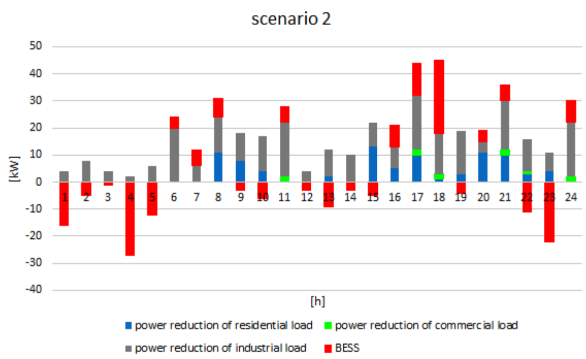


Fig. 7 Power of BESS and power of the consumers in scenario 2.

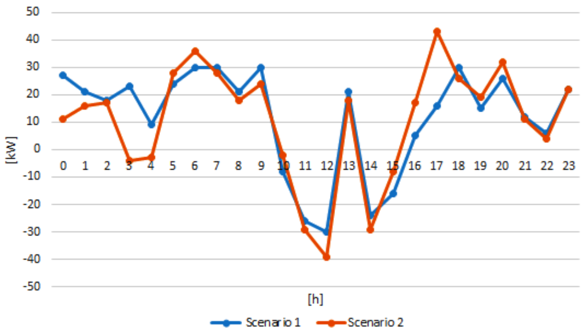


Fig. 8 Power exchanged in scenarios 1 and 2.

As can be seen, the information of the loads and BESS existing in the micro-grid is sent to the server by the data sensors. Then, different proposed loads and BESS will be applied to the proposed program separately. The output of the program determines the optimal extent of production of BESS and reduction of different consumers. Accordingly, the production of BESS and the amount of load reduction will be sent to the smartphone of the users for load management.

In this paper, the optimum determination of battery charge and discharge, as well as the optimum determination of the amount of reduced power consumption of different loads, are based on an incentive approach. After identifying the optimum results via the server through the internet, the power distribution network manager agent sends the results to all manager factors in the program based on the incentive approach and the manager factor applies the results according to the conditions and according to its discretion.

5 Conclusion

In this paper, a hierarchical multi-agent system (HMAS) was proposed for load management with an incentive approach in the micro-grid. The load management system was implemented in the JADE software environment on multiagent systems for server application as well as in the Android environment for mobile application. The aim of this paper was to determine the optimal amount of production of BESS and reduction of different types of load.

The results of the simulation of processing different possible states of the recommended model were presented further. It can be observed that the recommended method has been able to accomplish the energy management of distributed and storage energy resources in the micro-grid with the minimum possible cost.

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M. Mozaffarilegha was born in Kerman, Iran, in 1987. He received his B.Sc. from Islamic Azad University Yazd Branch in 2009 and received the M.Sc. degrees from Islamic Azad University Saveh Branch in 2011. He is a Ph.D. student of Power Engineering from Shiraz University and Faculty Member of Power Electrical Engineering at from Islamic Azad University Kahnooj Branch. He is interested in the power system probabilistic analysis and electrical distribution systems, energy management and micro-grids.

E. Farjah (M’04) received the B.Sc. and M.Sc. degrees in Electrical and Electronics Engineering in 1987 and 1989, respectively, and the Ph.D. degree in Electrical Engineering from INPG, Grenoble, France. Currently, he is an Associate Professor in the School of Electrical and Computer Engineering, Shiraz University, Shiraz, Iran. His research interests include energy, power electronics, power quality, and micro-grids.