Aryu_Proceeding_2019-1.pdf

by

Proceedings of 2019 IEEE
International Conference on Mechatronics and Automation
August 4 - 7, Tianjin, China

Intelligent Multi Agent System for Energy Management in the Classrooms with Grid Connected PV

Aryuanto Soetedjo, Yusuf Ismail Nakhoda and Choirul Saleh

Department of Electrical Engineering
National Institute of Technology (ITN) Malang
Jalan Raya Karanglo KM 2 Malang, Indonesia
aryuanto@gmail.com

***Abstract* - This paper presents an application of the Multi Agent System (MAS) in the Building Energy Management System, more specifically to manage the energy in the classrooms of a university. The grid connected photovoltaic (PV) is used as the electrical generation system to supply the loads in the classrooms. The objective is to minimize the electricity cost while maintaining user comfort. The MAS consists of the PV Agent, the Utility Agent, the Load Agent and the Central Control Agent. In addition, the Course Scheduler Unit is employed to inform the utilization or occupancy of the classrooms. The proposed system provides a new method to manage the energy usage from the PV by changing the temperature set-point of the air conditioner system using the Fuzzy Logic Controller. The simulation results show that the proposed system provides the highest performance index of 0.9902 in the optimization of the electricity cost and temperature comfort compared to the conventional method using a fixed temperature set-point.**

Index Terms* – *Multi agent, energy management, grid connected PV.

I. INTRODUCTION

An Intelligent Multi Agent System (MAS) is widely adopted in the distributed control systems [1]. An intelligent agent (or agent) is an autonomous system that acts in the environment to achieve its goal. An agent receives the information from the environment and takes a decision to response the changes according to the goal. In the MAS, several agents collaborate with each other to meet the global objective.

Nowadays, the development of electrical power system increases rapidly in the framework of smart grid technology. The distributed generation becomes popular due to the high penetration of renewable energy resources. Another aspect in the smart grid that attracts the attention is the energy management system. The MAS is adopted in both applications, such as for the microgrid operations [2,3], the renewable energy generation [4], the energy management in smart homes [5-7] and the buildings [8-13].

The MAS was employed to schedule smart devices in multiple smart homes [5]. The objective is to minimize the cost and peak load. In [6], the MAS was proposed to optimize energy usage in a smart home. The multi agents consist of the Management Agents, the Electrical Supply System Agents, and the Home Appliance Agents. There are three agents in the Management Agents, i.e. the Supply Side Management Agent, which is used to manage the power from the supply systems; the Demand Side Management Agent, which is used to manage the power to the loads; and the Home Energy Management Agent, which is used to manage both Supply Side Management Agent and Demand Side Management Agent. The MAS in [7] used the Fuzzy Logic Controller (FLC) which is embedded in each agent of the home appliance. The system was developed to minimize the electricity cost while maintaining the user comfort level.

A four-layer agent consisted of the Switch Agent, the Central Coordinator Agent, the Local Controller Agent, and the Load Agent was proposed in [8] to manage energy in the commercial building. The Local Controller Agent controls the lighting and temperature of the rooms using the FLC. The Central Coordinator Agent coordinates the Switch Agent, the Local Controller Agent, and the Load Agent.

In [11] the MAS was employed in the Building Energy Management System (BEMS). The building is divided into several zones which are controlled by the agents. The agents consist of the Local Zone Agent, the Zone Agent, the On-site Generation Agent, and the Building Agent. The Local Zone Agent controls the environment at the local zone (room), which is composed of the H-agent (heating system), the V-agent (ventilation system), the C-agent (cooling system), the E-agent (lighting and electrical systems) and the U-agent (occupancy level).

Three agents namely the Generation Agent, the Load Agent, and the Storage Agent were proposed to manage the energy operation in the self-sustainable building [12]. The Generation Agent performs the following tasks: analyze and acquire the historical and weather data, control the electrical output, and power conditioning. The Load Agent optimizes the usage of loads of building by performing several tasks, such as load forecasting, appliance management, metering, and load scheduling. The Storage Agent controls the charging/discharging of the battery storage based on the state of charge (SOC) and the charging/discharging rate.

As discussed previously, the MAS in the BEMS is usually divided into the generation agents (and the storage agents), the load agents and the control agents. The loads discussed previously are the general loads in the common building such as the air conditioner, the lighting, etc. In this paper, we deal with the BEMS in a university building, more specifically the lecture rooms or the classrooms. The building is powered by the grid connected PV system. One unique characteristic of our proposed system is that the occupancy of the classroom is well defined by the course schedule. The main contribution of our paper is in the application of MAS to optimize the energy consumed by the classrooms by maximizing the energy from the PV resources while satisfying the temperature comfort in the classrooms. It is conducted by employing the FLC to set the temperature set-point of the classroom according to the power availability of the PV system and the outdoor temperature.

The rest of paper is organized as follows. Section 2 presents the proposed system. Section 3 discusses the simulation results. The conclusion is covered in Section 4.

II. Proposed System

A. System Overview

The configuration of the electrical system is depicted in Fig. 1, where the arrow indicates the electrical flow. As shown in the figure, the electrical power to the loads in the classrooms is supplied by the PV system and the electric utility.

In this research, to simplify the discussion, only five classrooms are considered. However, the proposed system could be extended to cope with a large number of classrooms accordingly. In each classroom, there are three kinds of loads, i.e. the air conditioner (AC), the LCD projector, and the lamps. The LCD projector and the lamps are controlled by on/off mode according to the class utilization. While the AC is a thermostat controlled, in which the temperature set-point is determined by the MAS as described in the next section.

The configuration of MAS to manage the energy consumption in the classroom is depicted in Fig. 2. The Load Agent (LA) is used to control the loads in a classroom. It sets the temperature set-point for operating the AC and switches on/off the lamps and the LCD projector based on the information from the Central Control Agent (CCA) and the Course Scheduler (CSCH). The CCA sends information about the available power of renewable resources. The Course Scheduler (CSCH) is an information system that manages the utilization of classrooms, i.e. the time schedule of the course.

The PV Agent (PVA) is an agent that is responsible to manage the power from the PV. The PVA sends the information about its power to the CCA and gets the control signal related to its power flow from the CCA. The UA is basically a simple agent to control the connection of the utility to the grid according to the signal control sent by the CCA.

CCA is the main control of the whole system. It manages the operation of the loads, the PV system and the utility. The CCA employs the FLC to generate the signal controls to the respective agents. The main objective is to maximize the power while maintaining the user comfort.

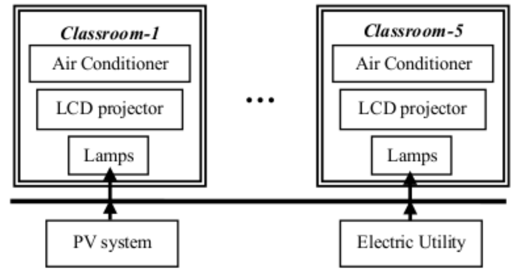

Fig. 1 Configuration of electrical system.

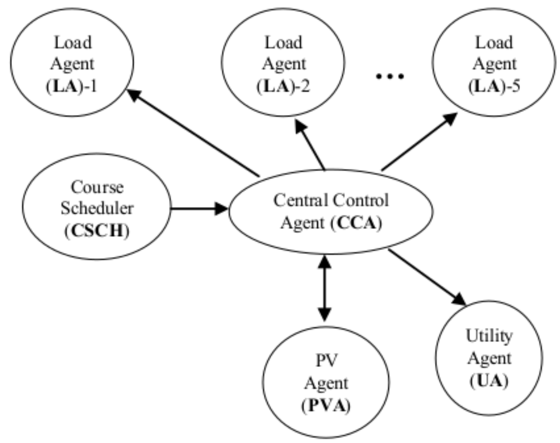

Fig. 2 Configuration of MAS.

B. Multi Agent System

The configuration of the Load Agent (LA) is depicted in Fig. 3. All three loads (AC, lamps, LCD projector) are operated when the classroom is occupied, i.e. there is a course conducted in the classroom. The occupancy information is obtained from the CSCH.

In the current research, the operation of the Lamps and the LCD projector is just switched on/off. While the AC is operated using the thermostat control, i.e. the temperature of the classroom should follow the temperature set-point of AC. By varying the temperature set-point, the energy consumed by the AC could be managed respectively.

As shown in the figure, the agent controls the operation of the loads based on the occupancy of the classroom, the outdoor temperature and the level of renewable energy resources (RES_LEV). The RES_LEV data is sent by the CCA. The RES_LEV is a value that indicates the level of availability of renewable energy resources. This value will be used by the FLC in the LA to set the temperature set-point as discussed in the next section.

The configuration of the PV Agent (PVA) is depicted in Fig. 4. PVA has two main tasks. The first task is to read the weather information and send the predicted PV power to the CCA. The second task is to read the control signal from the CCA and generate a switching signal to the power switch.

The switching signal is used to select the power flow from the PV as follows:

- Grid connection: the PV is connected to the grid
- Disconnected: the PV is disconnected from the system.

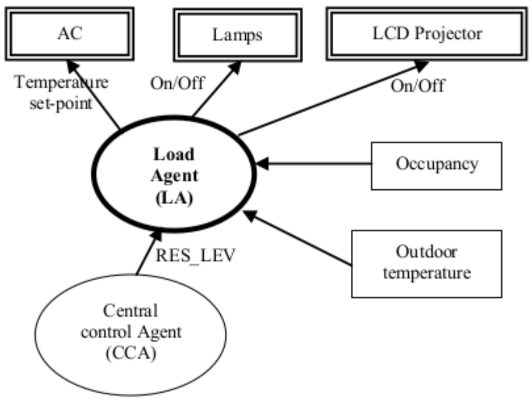

Fig. 3 Configuration of the Load Agent.

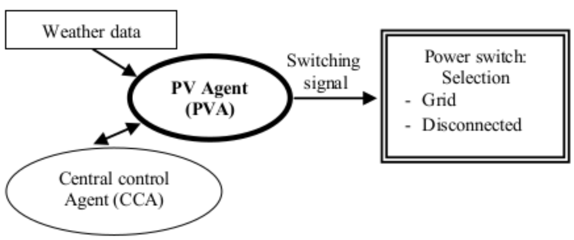

Fig. 4 Configuration of the PV Agent.

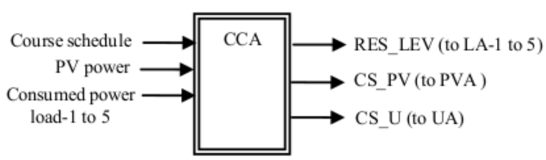

Fig. 5.The input and output of the Central Control Agent.

The CCA generates the control signals to the other agents as depicted in Fig. 5. The control signal to PVA and UA are CS_PV and CS_U, which are used to connect or connect the PV and the utility to the grid.

The control signal to the LA is RES_LEV which is determined by the FLC as described in the following section.

C. FLC in the Central Control Agent

As described previously, the CCA employs the FLC (later on is called as the FLC-CCA) to generate the control signal to the LA, the PVA, and the UA. The architecture of FLC-CCA is depicted in Fig. 6. As shown in the figure, the FLC-CCA has two inputs and one output. The inputs are the available power from the renewable energy resources (RES_PWR=PV power) and the power consumed by the loads (CONS_PWR=Consumed power load-1 to 5). While the output is the level of available power from renewable energy resources (RES_LEV).

The fuzzy membership functions of RES_PWR, CONS_PWR, and RES_LEV are depicted in Fig. 7. Each variable has three linguistic values, i.e. LOW, MED, and HIGH.

Since the objective of MAS is to minimize the electricity cost by maximizing the energy usage from the RES, thus the fuzzy rules are developed in such a way to fulfill that objective. The main idea is to provide information about the availability of RES to the LA. Then the LA uses this information to determine the temperature set-point.

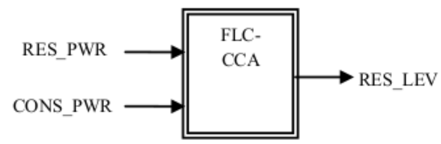

Fig. 6 FLC-CCA architecture.

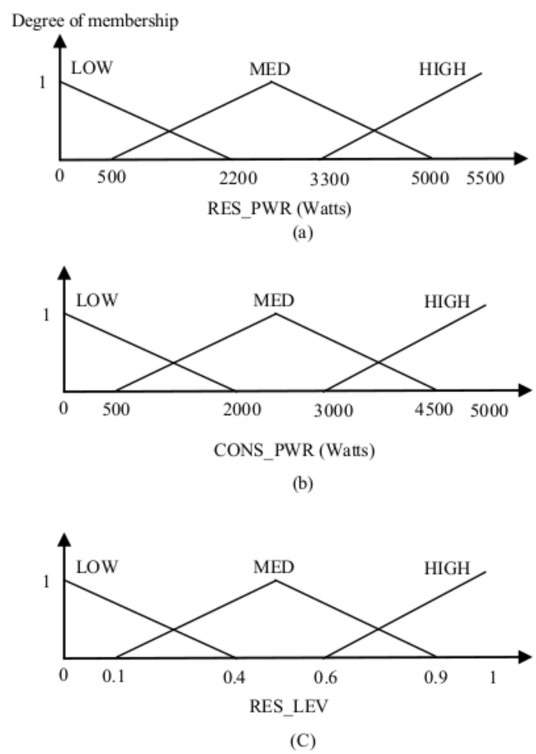

Fig. 7 Membership functions of FLC-CCA: (a) RES_PWR; (b) CONS_PWR; (c) RES_LEV.

TABLE I
FUZZY RULES OF FLC-CCA

CONS_PWR \ RES_PWR	LOW	MED	HIGH
LOW	*MED*	*MED*	*HIGH*
MED	*LOW*	*MED*	*HIGH*
HIGH	*LOW*	*MED*	*MED*

TABLE II
FUZZY RULES OF FLC-LA

OUT_TEMP \ RES_LEV	LOW	MED	HIGH
LOW	*VERY HIGH*	*MED*	*VERY LOW*
MED	*HIGH*	*MED*	*LOW*
HIGH	*HIGH*	*MED*	*LOW*

The information about the availability of RES is then called as the RES_LEV and determined based on the RES_PWR and CONS_PWR. The fuzzy rules are listed in Table 1. Several rules from the table could be explained as follows:

- IF RES_PWR is HIGH AND CONS_PWR is LOW THEN RES_LEV is HIGH: There is surplus power from RES, thus the RES_LEV is set to a high level.
- IF RES_PWR is LOW AND CONS_PWR is HIGH THEN RES_LEV is LOW: There is not enough power from RES, thus the RES_LEV is set to a low level.
- IF RES_PWR is MED AND CONS_PWR is MED THEN RES_LEV is MED: The availability of power from RES is medium, thus the RES_LEV is set to medium level.

D. FLC in the Load Agent

The FLC in the LA (later on is called FLC-LA) is used to set the temperature set-point of the AC in the classroom as depicted in Fig. 8. This set-point is determined to satisfy two conditions: a) the temperature set-point is in the range of comfortable level; b) the availability power from RES should be extracted as much as possible.

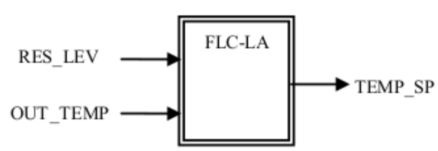

Fig. 8 FLC-LA architecture.

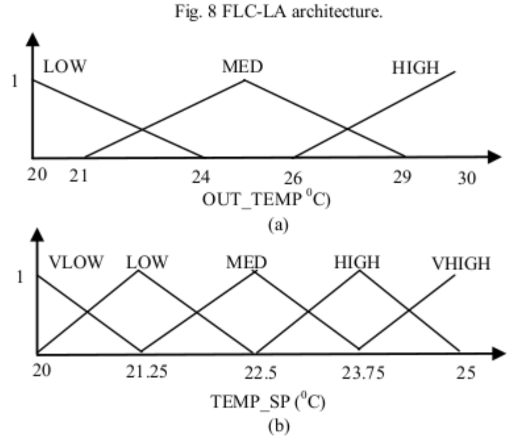

Fig. 9 Membership functions of FLC-LA: (a) OUT_TEMP; (b) TEMP_SP.

As shown in Fig. 8, the inputs of FLC-LA are the RES_LEV and the outdoor temperature (OUT_TEMP). While the output is the temperature set-point (TEMP_SP). The fuzzy membership function of RES_LEV is the one in the FLC-CCA which is shown in Fig. 7(c). The fuzzy membership functions of OUT_TEMP and TEMP_SP are depicted in Fig. 9. It is noted here that the value of TEMP_SP falls in the range of user comfortable, i.e. from 20 ^{0}C to 25 ^{0}C.

To achieve the goal of minimizing the electricity cost while allowing the temperature comfort, the fuzzy rules are defined as listed in Table 2. The rules are determined based on the idea that by increasing the temperature set-point, the energy consumed by the AC will decrease. Thus when the RES power is low, it is better to increase the temperature set-point and vice versa.

From the fuzzy rules listed in Table 2, several rules are explained as follows:

- IF RES_LEV is LOW AND OUT_TEMP is LOW THEN TEMP_SP is VERY HIGH: There is a small amount power from RES, and the outdoor temperature is low, thus it is a better to set the temperature set-point to very high value for decreasing the energy consumption.
- IF RES_LEV is HIGH AND OUT_TEMP is HIGH THEN TEMP_SP is VERY LOW: There is surplus power from RES, and the outdoor temperature is low, thus it suggests that the temperature set-point could be set to a very low value.

III. SIMULATION RESULTS

To verify our proposed system, we model the system using MATLAB-SIMULINK [14]. The PV generator is simulated using the model developed in [15]. The AC and thermal system of the room are modeled based on the example given in the SIMULINK software [14]. The electrical power rating of the PV and the loads in the classroom are given in Table 3. The data for irradiation, outdoor temperature, course schedule (occupancy of the classroom) are given in Table 4.

The simulation results are depicted in Fig. 10 and Fig. 11. In Fig. 10, the profiles of RES_LEV, outdoor temperature, temperature set-point, classroom temperature of classroom-1 are shown. For convenience, the profiles are shown from 06:00 h to 17:00 h when the classrooms are occupied. From the figure, we can see that at 07:00 h, the classroom-1 is occupied and the PV produces a small power.

Therefore the RES_LEV is low and forces the system to set the temperature set-point to the higher value, i.e. 23 ^{0}C. At 12:00 h, when there is enough power from the PV and the consumed power is also high, then the RES_LEV will have a medium value, i.e. 0.5. It will set the temperature set-point to the medium value, i.e. 22.5 ^{0}C.

Fig. 11 shows the profiles of consumed power of classroom-1 to classroom-5 from 06:00 h to 17:00 h. By observing the top figure, i.e. the consumed power of classroom-1, it is obtained that the consumed power in the morning is lower than the one in the afternoon. This result could be understood by examining Fig. 10 as follows. In the afternoon, the outside temperature is higher than the one in the morning. Since the temperature set-point is about 22.5 ^{0}C, the AC will consume more power in the afternoon to reach the set-point.

TABLE III

POWER RATINGS OF GENERATOR AND LOADS

Generator and Loads	Power rating
PV	3000 W
AC	450 W (per room)
LCD projector	310 W (per room)
Lamps	240 W (per room)

TABLE IV

IRRADIATION, OUTDOOR TEMPERATURE, OCCUPANCY OF CLASSROOM-1 TO 5

Time (hour)	Irradiation (W/m^2)	Outdoor temperature (^{0}C)	Classroom (O=occupied; X=empty)				
			1	2	3	4	5
00:00	0	21	X	X	X	X	X
01:00	0	21	X	X	X	X	X
02:00	0	21	X	X	X	X	X
03:00	0	21	X	X	X	X	X
04:00	0	21	X	X	X	X	X
05:00	0	21	X	X	X	X	X
06:00	0	22	X	X	X	X	O
07:00	200	22	O	X	X	O	O
08:00	300	24	O	O	X	O	O
09:00	500	25	O	O	X	O	O
10:00	700	26	X	O	O	X	O
11:00	900	26	X	O	O	X	O
12:00	900	26	O	O	O	X	X
13:00	800	26	O	X	O	X	O
14:00	600	27	O	X	O	O	O
15:00	400	27	X	X	O	O	O
16:00	300	24	X	X	X	O	X
17:00	0	24	X	X	X	X	X
18:00	0	24	X	X	X	X	X
19:00	0	24	X	X	X	X	X
20:00	0	23	X	X	X	X	X
21:00	0	23	X	X	X	X	X
22:00	0	23	X	X	X	X	X
23:00	0	22	X	X	X	X	X

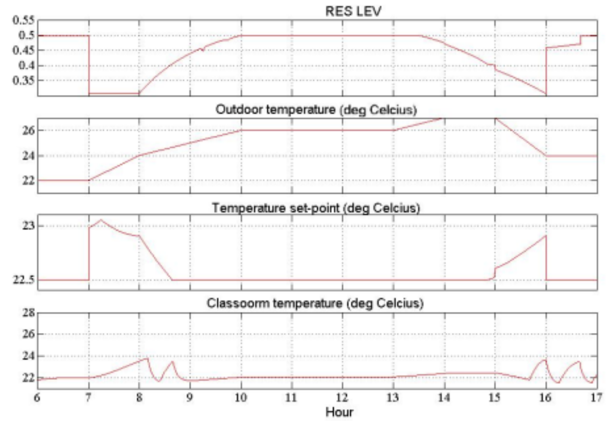

Fig. 10 Profiles of RES_LEV, outdoor temperature, temperature set-point, classroom temperature of classroom-1.

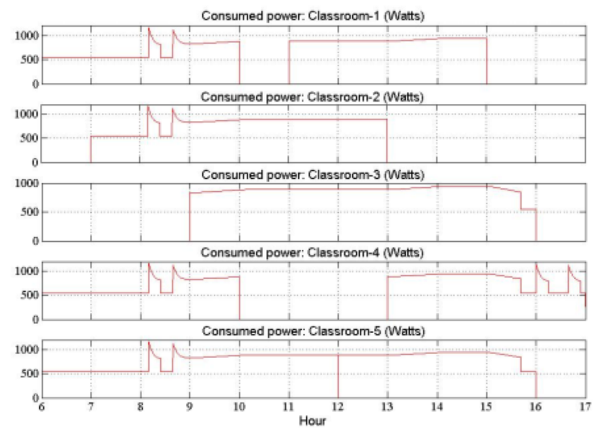

Fig. 11 Profiles of consumed power of classroom-1 to classroom-5.

TABLE V

COMPARISON RESULTS OF PERFORMANCE INDEX

Method		*en_lev*	*cf_lev*	*pi*
Fixed temperature set-point	21 ^{0}C	0.0039	0.8480	0.8519
	22 ^{0}C	0.0498	0.9124	0.9622
	23 ^{0}C	0.1475	0.8276	0.9751
	24 ^{0}C	0.4317	0.3541	0.7858
	25 ^{0}C	0.6358	0.0077	0.6435
Proposed system		0.0989	0.8913	0.9902

To measure the effectiveness of the proposed system in the optimization of the electricity cost and the comfort level, we define the performance index (*pi*) as follows:

$$pi = en\_lev + cf\_lev \quad (1)$$

$$en\_lev = 1 - \sum_h (c - p)/\beta) \quad (2)$$

$$cf\_lev = 1 - \sum_h |st - rt| / \gamma) \quad (3)$$

where *en_lev* and *cf_lev* represent the level of electricity cost and the temperature comfort respectively, *c* and *p* are consumed power by the loads and the PV power respectively, *st* and *rt* are the reference temperature and the classroom temperature respectively, β and γ are the constants for normalization, and *h* represents the hour.

In the simulation, we compare our proposed system, i.e. varying the temperature set-point, with the fixed temperature set-point. The comparison results are given in Table 5. It is clearly shown that the proposed method provides the highest value of the performance index (*pi*). It means that our proposed system achieves the highest performance among the other methods (fixed temperature set-point). The table suggests that our proposed system achieves the high index of the temperature level. It conforms with the idea of the proposed algorithm that determining the temperature set-point according to the availability of power from the PV and the outdoor temperature.

In addition, we test our proposed MAS on the embedded system, especially dealing with the execution time, the implementation cost, and the communication interface. The embedded platform is similar to our previous work [16], i.e. using the low cost WeMos module [17]. The main algorithm of each agent is implemented on the WeMos module, which is communicated with other agents via the WiFi communication. From the experiments, the execution time of the FLC is 13 ms and the transfer time between each agent is 332 ms. The results show that our proposed method is suitable for the real-time implementation, in which the update time of building energy management system is usually on hourly basis.

IV. CONCLUSION

The MAS is proposed to manage the energy in the classrooms by varying the temperature set-point according to the PV power and the outdoor temperature. The FLC is adopted in the agents to find the optimal temperature set-point. The performance index representing the measurement of the level of electricity saving cost and the user comfortable level is developed which is used to compare the proposed system with the fixed temperature set-point. Using the developed performance index, the proposed system achieves the highest value of 0.9902. Further, the possible implementation in the real-time system is verified by a small embedded platform and shows the promising results, in terms of the fast execution time, i.e. less than one minute, and the low cost implementation of the embedded system.

In future, the system will be extended to cope with more complex building. The advanced algorithms will be adopted accordingly. Further the system will be implemented in the hardware prototype.

ACKNOWLEDGMENT

This work is supported by the Research Grant, Excellent Basic Research on Higher Institution scheme (PDUPT) from Directorate General of Higher Education, Ministry of Research and Technology and Higher Education, Republic of Indonesia, 2019.

REFERENCES

[1] J. Xie and C.-C. Liu, “Multi-agent systems and their applications,“ *Journal of International Council on Electrical Engineering*, vol.7, no. 1, pp. 188-197, July 2017.

[2] H.-M. Kim, Y. Lim and T. Kinoshita,“An Intelligent Multiagent system for Autonomous Microgrid Operation, “ *Energies*, vol 2012, no. 5, pp. 3347-3362, Sep. 2012.

[3] D.O. Elamine, E.H. Nfaoui and J. Boumhidi,“Intelligent multi-agent system for smart microgrid energy management,“ *International Journal of Intelligent Engineering Informatics*, vol. 4, no. 3/4, pp. 245 – 266, Nov. 2016.

[4] R.G. Ramirez and M. Borunda,“An intelligent multi-agent based improved approach for conventional and renewable power generation operation and control, “ *Journal of Renewable and Sustainable Energy*, vol. 9, issue 1, Jan. 2017.

[5] F. Fioretto, W. Yeoh and E. Pontelli, “A Multiagent System Approach to Scheduling Devices in Smart Homes,” in *Proc. of the International Conference on Autonomous Agents and Multiagent Systems* Sao Paulo, 2017, pp. 981–989.

[6] W. Li, T. Logenthiran and W. L. Woo, "Intelligent multi-agent system for smart home energy management," in *Proc. 2015 IEEE Innovative Smart Grid Technologies - Asia* (*ISGT ASIA*), Bangkok, 2015, pp. 1-6.

[7] A. Garrab, A. Bouallegue and R. Bouallegue,”An Agent Based Fuzzy Control for Smart Home Energy Management in Smart Grid Environment,” *International Journal of Renewable Energy Research*, vol. 7, no. 2, pp. 599-612, June 2017.

[8] S. D. Smitha and F. M. Chacko, "Intelligent energy management in smart and sustainable buildings with multi-agent control system," in *Proc. 2013 International Mutli-Conference on Automation, Computing, Communication, Control and Compressed Sensing* (*iMac4s*), Kottayam, 2013, pp. 190-195.

[9] P. Zhao, S. Suryanarayanan and M. G. Simoes, "An Energy Management System for Building Structures Using a Multi-Agent Decision-Making Control Methodology," in *Proc. 2010 IEEE Industry Applications Society Annual Meeting*, Houston, TX, 2010, pp. 1-8.

[10] V. Sutedy, P. Wang, L.H. Koh and F.H. Choo,”Intelligent Eco-Building Management System,” *in Proc. the 5th Annual IEEE International Conference on Cyber Technology in Automation, Control and Intelligent Systems,* Shenyang, 2015, pp. 229-233.

[11] L. A. Hurtado, P. H. Nguyen, W. L. Kling and W. Zeiler, "Building Energy Management Systems — Optimization of comfort and energy use," *2013 48th International Universities' Power Engineering Conference* (*UPEC*), Dublin, 2013, pp. 1-6.

[12] S. Sharma, B. K. Panigrahi and A. Verma, "A Smarter Method for Self Sustainable Buildings: Using Multiagent Systems as an Effective Iterative for Managing Energy Operations," *IEEE Consumer Electronics Magazine*, vol. 7, no. 2, pp. 32-41, March 2018.

[13] S. D. Smitha, J. S. Savier and F. Mary Chacko, "Intelligent control system for efficient energy management in commercial buildings," in *Proc. 2013 Annual International Conference on Emerging Research Areas and 2013 International Conference on Microelectronics, Communications and Renewable Energy*, Kanjirapally, 2013, pp. 1-6.

[14] Thermal Model of a House. [Online]. Available: https://ww2.mathworks.cn /help/simulink/shef/thermal-model-of-a-house.html (Date accessed: 26 May 2019)

[15] PV Array Simulink Block. [Online]. Available: https://ww2.mathworks.cn/ matlabcentral/fileexchange/30326-pv-array-simulink-block (Date accessed: 26 May 2019)

[16] A. Soetedjo, Y.I. Nakhoda and C. Saleh, “Embedded Fuzzy Logic Controller and Wireless Communication for Home Energy Management Systems,” *Electronics*, vol. 7, issue 9, pp. 1-21, Sep. 2018.

[17] An Arduino UNO Compatible WiFi board on ESP8266EX [Online]. Available: https://wiki.wemos.cc/products:d1:d1 (Date accessed: 26 May 2019)

Aryu_Proceeding_2019-1.pdf

ORIGINALITY REPORT

2%	3%	2%	%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	Aryuanto Soetedjo, Yusuf Ismail Nakhoda, Choirul Saleh. "Simulation of Fuzzy Logic Based Energy Management for the Home with Grid Connected PV-Battery System", 2018 2nd International Conference on Smart Grid and Smart Cities (ICSGSC), 2018 Publication	2%

Exclude quotes	On	Exclude matches	< 2%
Exclude bibliography	On		