Development of an Automated Building Energy Management System with IoT (aBEMS-IoT) for Supporting the Demand Response

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ABSTRACT

This paper presents the development of demand-side management technology for managing the load supporting the demand response which is the solution for the coming future because of the limitation of fossil fuels and the environmental problems. An Automated Building Energy Management System with the Internet of Thing (IoT)so-called aBEMS-IoT was developed for the reservation of the DR program to stabilize the power quality and stability of the grid network. The aBEMS-IoT consisted of hardware part, which consisted of controlling devices, IoT gateway communication devices, data analytic devices, and the communication part which able to use both, communication cable or wireless solution. The communication of aBEMS-IoT which was implemented in the building of the Post Engineering office using the loRaWan (all devices communicated by the wireless system). After aBEMS-IoT was developed and implemented, it will be tested to find the technical capability of the developed system, the test was classified into two groups, laboratory test for finding the response time, and the actual building integrated with aBEMS-IoT. The analyzed results of the test indicated that aBEMS-IoT could effectively manage the load following assumed the DR program. The response time from the control to the end devices until the process finish, it took about 650 ms so this value is lower than 1 second and the load power which was controlled by aBEMS-IoT in case of the actual system, it was able to connect (load building) and to disconnect (Load clipping) the load following assumed DR program. Fourteen air-conditioners and about forty lighting bulbs and some motors were controlled, and the capability of the actual building integrated with aBEMS-IoT was about 45 kW. The aBEMS-IoT is the technology for balancing supply and demand by managing the demand side, and it will be the solution for Smart Grid or Microgrid which will take the grid stability, power quality, resiliency, and finally reliability.

1. INTRODUCTION

At present, it requires the traditional generation to ramp up quickly for covering the demand. When the load pattern is quickly changed some of the traditional generations cannot respond, it may affect power quality and stability of the grid. Not only in the evening time but also in the daytime when the PV system is high power production, this case may negatively impact on the power quality of the grid network. In the case of high-power production in the daytime and low generation in the evening, this creates the duck curve. The duck curve problem occurs in the countries that generate much electricity from solar energy because solar power plants can produce electricity only in the daytime when having solar irradiation. According to the problem mentioned above, many countries find the solution to flatten the Duck Cure by making the grid more advance called Smart Grid and Microgrid. [1] – [2] The advance gird can balance the supply and demand for system stability. Demand Response (DR) is significant for the future grid [3] – [5], also known as demand-side management. DR is to change in load demand by the customer or users from a normal load demand profile in response to changes for incentive electricity price, or maintaining the grid power quality. The benefits from the DR program also depend on the level of customer’s feedback or gratification with the DR program. However, profits from applying are on both, utility and customers reactions. Many utilities apply DR programs for controlling the power quality, stability, and reliability of the grid instead of build fossil power plants [6] – [9]. Price-based program is the tools for international demand response program such as TOU which is time of use pricing, CPP which is critical peak pricing, and RTP which is dynamic

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real-time pricing, and also DAP which is day-ahead pricing [10] – [12]. For supporting the DR programs, the buildings are upgraded to smart building these building can be managed the load by internet known as the Internet of Thing (IoT). Also, Big Data analysis can help to manage the load demand better in all sectors [12] – [13].

This work concentrated on development of the automated building energy management system using IoT which is aBEMS-IoT. The aBEMS-IoT components are consisted of two parts as following. The first is controlling devices or hardware that can control the load turn on and turn off to increase or decrease the load pattern's power demand. The second is a data processing device which is analyzing the collecting data from users or utility after that all data is analyzed and sending the signal to the controlling devices for the upcoming process. The third is the monitoring system which is showing the important data and also presents the analyzed results of the DR process. After aBEMS-IoT is developed and implemented in the commercial building, this building becomes a smart building. The performance of the aBEMS-IoT will be tested under the assumed DR program. The response time and firmware stability will be investigated. The working principle will also be analyzed under the assumption of demand response and this will be referenced from other countries where have been using.

2. THE aBEMS-IoT

The automated building energy management system using IoT (aBEMS-IoT) will be developed for the demand response program [14] – [18]. The automated demand response (ADR) or load management is an automatic response to the requirement of an aggregator or an emergency [19] – [22]. The concept of the aBEMS-IoT can be divided into four levels; the first is sensing devices and load, the second is a control level which controls the purposive load, the third is operation level and the management level. The detail of a BEMS-IoT can be presented in Figure (1).

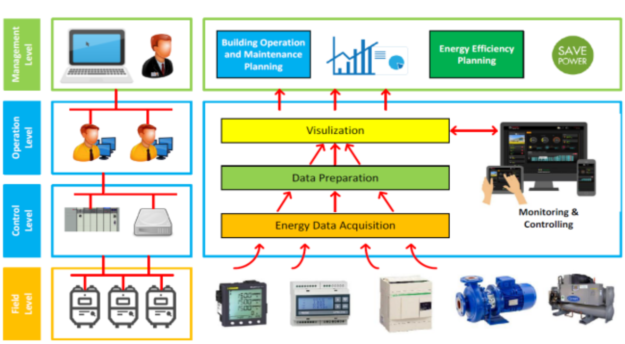

Fig.1. The concept of aBEMS-IoT.

The concept of aBEMS-IoT is to accomplish for management of the load profile in the smart building by BEMS' components, it is exchanging the data by sending and receiving the controlling signal through the IoT gateway device. The two-way communication between the IoT Gateway devices and electricity appliances can be the cable or wireless, this may concern with implementing building.

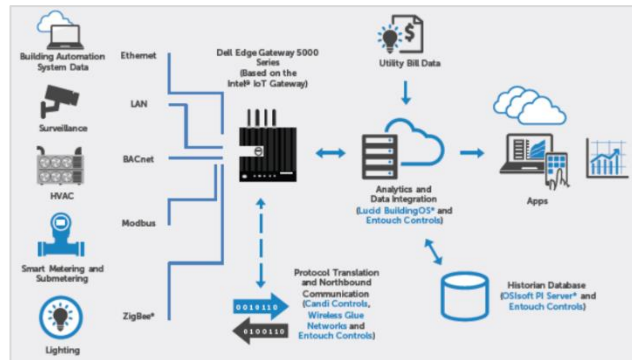

Fig. 2. The components of the aBEMS-IoT.

The aBEMS-IoT system are three main parts as shown in Figure (2); the first is controlling devices (Hardware), and the second is data processing and monitoring system (Software), finally, the third is communication.

2.1 The Control System (Hardware)

The hardware of the aBEMS-IoT which can control the electricity appliances on and off for increasing and decreasing the load demand. The power consumption which are managed by the aBEMS-IoT consisting of the air conditioner, lighting, and plug for electric appliances. These components of this part consist of MicroController, automatic on and off switch or breaker, and the controller for the air conditioner system. The control system can control on and off switch or breaker, and it enables to decrease and increase power in the air conditioner system. The control system for aBEMS-IoT is shown in Figure (3).

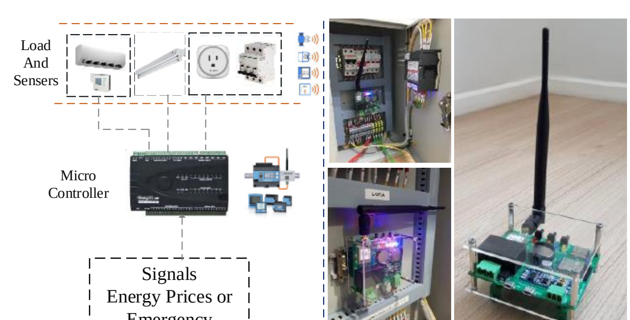

Fig 3. The Hardware of the aBEMS-IoT.

2.2 The data analytics and monitoring system

The firmware will be developed for managing the load demand in the implementing building under the demand response project. This firmware can control the load as following the requirements of utility, load aggregators or customers. The data analytics and monitoring system is developed for smart load management response to any situation. The electrical appliances such as air conditioners, lighting, plug, and beakers can be controlled by smart devices. the gateway devices can connect to smaller sensor networks and non-Ethernet/IP-based devices to a network such as data center or cloud. In case of a gateway measuring electrical power with a wired current and voltage clamps at the main load panel of the building can also collect data from nearby wireless sensors for measuring voltage and current of the load. Data analytics enable to be a centralized in a data center or cloud but decentralized measuring devices can be installing at the local. Centralized data analytics center is easy to implement and maintain for software operation in one place. Backhauling all of important data and other information to comprehensive centralized data analytics also needs a substantial capacity of storage. The gateway communication and data analytics of aBEMS-IoT is shown in Figure (4).

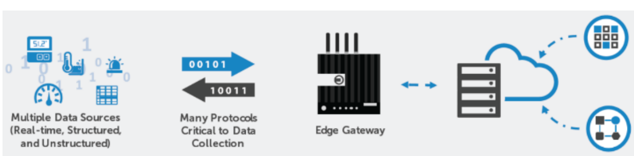

Fig. 4 The data analytics and gateway of aBEMS-IoT.

The data sources such as real-time, structured, and unstructured data are recorded and send via the data gateway to the analytics device. After that, the control signal which is form the decision process will be sent to control the load via the IoT gateways. The result of the process is reported to the customer via the monitoring system which enable to accessed via internet by (mobile, dashboard, and other internet devices). The data analytics and monitoring system of the aBEMS-IoT is presented in Figure(5) and Figure(6).

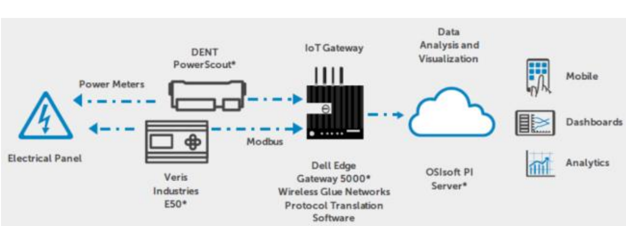

Fig. 5. IoT gateway and data analytic devices of aBEMS-IoT.

Fig. 6. The monitoring system of the aBEMS-IoT.

2.3 The communication of aBEMS-IoT

The communication of aBEMS-IoT can use both cable and wireless that depends on the working area of the building [23] – [26]. The communication via the wireless is popular because easy to install and it doesn't need to wiring the cable. For the wireless solution, aBEMS-IoT uses LoRaWan which is a low power, wide-area networking protocol. The wireless communication takes advantage of the long-range characteristics, allowing a single-hoplink between the end-device and one or many gateways. All modes are capable of bi-directional communication, end-to-end security, mobility, and localization. The wireless solution of aBEMS-IoT is shown in Figure (7).

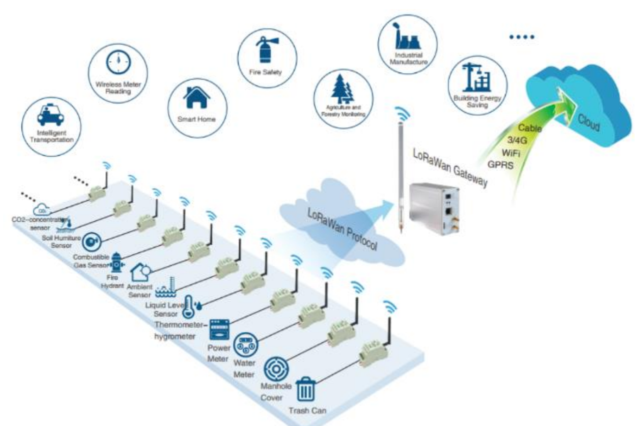

Fig. 7. The wireless solution of aBEMS-IoT.

aBEMS has been implemented in the purposive building for testing the technical performance for controlling the target load under the demand response program. Some example of the building integrated with aBEMS-IoT is in the hospital and the Post Engineer Department.

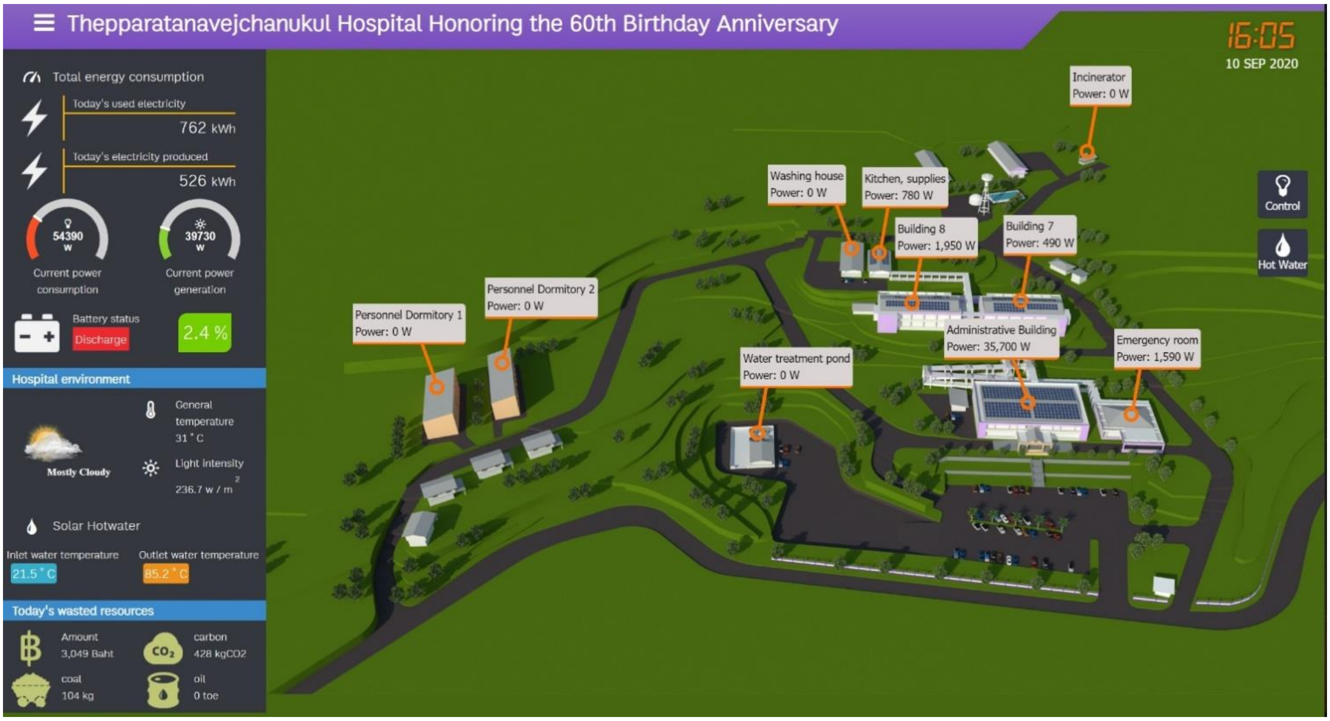

Fig. 8. The implementation of aBEMS-IoT in the actual building.

3. THE CAPABILITY TEST OF ABEMS-IOT

After aBEMS-IoT was developed and implemented in the commercial building as shown in Figure(8), this building becomes a smart building. The performance test of the aBEMS-IoT can be divided into two parts; the fist is a laboratory test and the second is an actual system test. The laboratory test is a controlling test in the laboratory for finding the response time (turn-on or turn-off the load). An actual system test is a test of the building that is integrated with aBEMS-IoT, and it will be tested under the assumed DR program. The response time and firmware stability will be investigated. The working principle will also be analyzed under the assumption of demand response.

3.1 The assumed DR program

The demand response program in this research was assumed as the signal for testing aBEMS-IoT. The signal is the electricity prices which can be classified into low, fair, and high as shown in Figure (9).

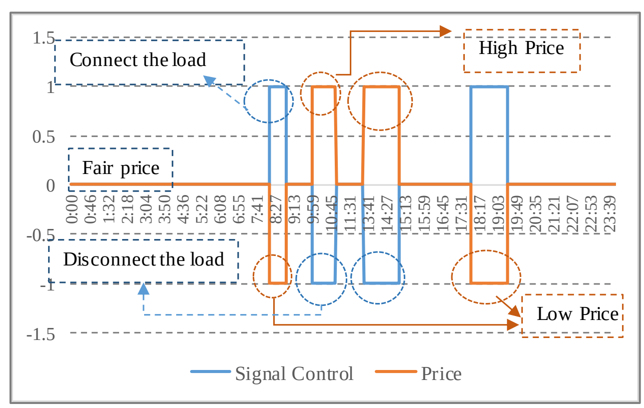

Fig. 9. The assumed electricity price and signal control of the DR program for this research only.

Table 1. The basic algorithm of the a BEMS-IoT

Event	Price	Signal Control	aBEMS-IoT operation
1	-1	1	aBEBS-IoT connect the load which consist of air conditioner, motors and lighting (called load building)
2	1	-1	aBEBS-IoT disconnect the load which consist of air conditioner, motors, and lighting (called load building)
3	0	0	aBEBS-IoT is standby

Figure (9) presented that the assumed DR program for testing aBEMS-IoT in case of an actual system test. The price stands for electricity price which consisted of Fair price, low Price, and High price. The signal control is the signal which controls the load from the control device thought the IoT gateway. The value -1 of the price is low price, 0 is fair and 1 is the high price but the signal control is opposite, - 1 is a disconnection of the load (load clipping), 0 is standby and 1 is a connect the load (load building). The algorithm of the aBEMS-IoT can be presented in Table 1.

4. THE RESULTS OF THE CAPABILITY TEST OF aBEMS-IoT

The results of this research can be classified into two groups; the first is the result of a laboratory test and the second is an actual system test as the detail below.

4.1 The result of a laboratory test

The aBEMS-IoT was tested in the laboratory for finding the response time when it controlled the load. The control signal sent from the control device through the IoT gateway to the end device for switching on and off (open and close contact). When the target loads were controlled following the signal control then load power can be managed for balancing supply and demand. The result of a laboratory test is shown in Figure (10).

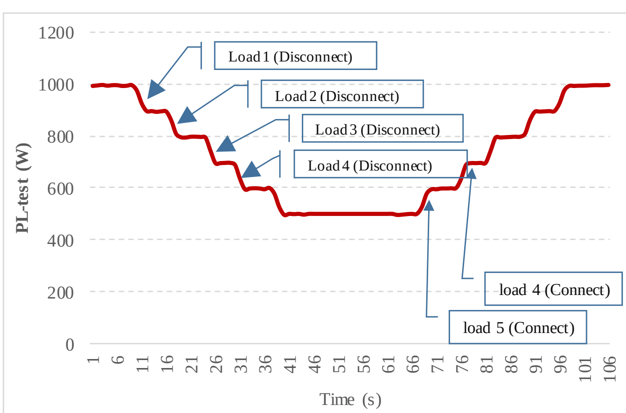

Fig.10. The result of a laboratory test for controlling the load of aBEMS-IoT.

Figure (11) presented the load management of the aBEMS-IoT in the laboratory test, the test loads consisted of baseload, load 1, load 2, load 3, load 4, and load 5. The total capacity of the test load is about 1,000 W. This test will control the test load for five-steps on load clipping management, which decreased the power demand and on the load building management, which increased the power demand. The average response time for controlling the test load is about 650 ms, this value is very fast for load management and can maintain the balance of supply and demand. This test can control the test load by about 50 % of the total capacity which means the baseload was about 50 %, which could not control.

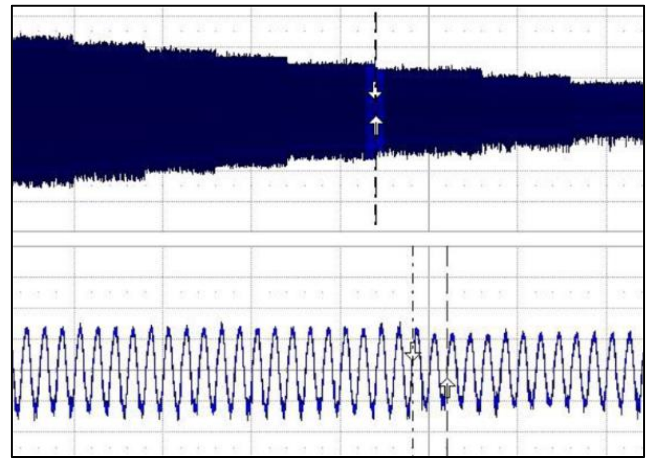

Fig. 11. The response time for controlling the load measured by the oscilloscope.

4.2 The result of the actual aBEMS-IoT system test

An actual system test is a test of the building that is integrated with aBEMS-IoT, and it has been implemented in the Post Engineer Department. This case was tested under the demand response program as mentioned above, the original load profile of the buildings without demand side management is shown in Figure (12).

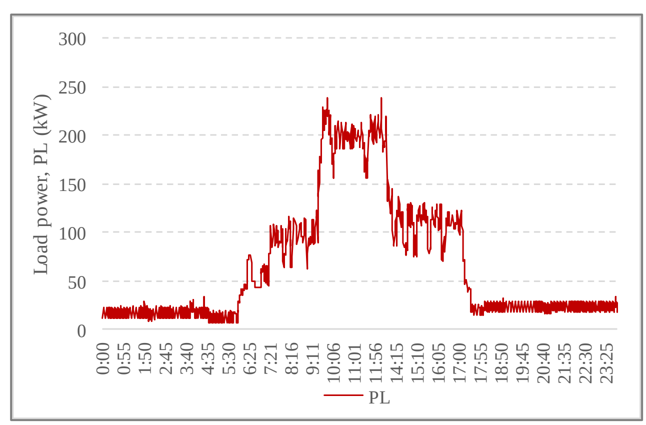

Fig. 12. the original load profile of the tested buildings.

The peak load was about 240 kW from 9.10 a.m. – 14.15 p.m., the load power was fluctuation because 65 % of the load demand is an air conditioner, the rest is an office devices, and lighting. After implemented aBEMS-IoT, these buildings became the smart buildings, which are fully controlled and monitored by aBEMS-IoT, more than 60 % of electrical devices are controlled by mobile applications via the internet access system. The buildings integrated with aBEMS-IoT was tested for controlling the target load under the assumed a DR program as presented in figure(13).

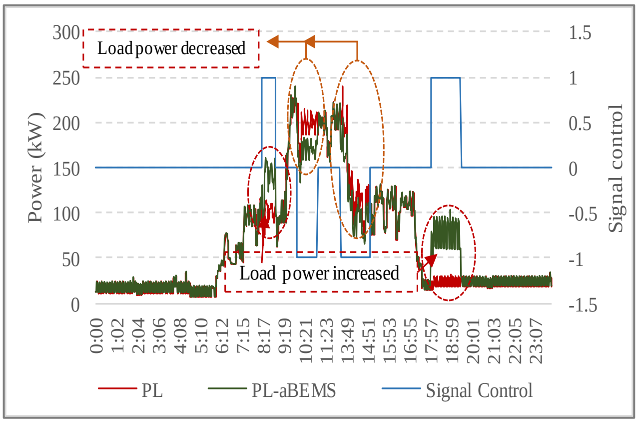

Fig. 13. The relationship between load profile and signal control.

The operation of aBEMS-IoT was only followed the assumed DR program to perform the technical performance and to manage the load in the actual buildings. The target loads were managed following the signal control as presented in figure(13). Considering, when the signal equaled to 1 the loads, air conditioners about 16 units and lighting lamp 40 bulbs were controlled for load building (connect the load), this process affected to increase the load power about 50 kW. On the other hand, when the signal control became -1, the load air conditioners (14 units) and lighting bulbs (10 units) were managed for load clipping (disconnect the load), it directly decreased the power demand about 35 kW. From the results can be concluded that aBEMS-IoT can manage the loads, able to increase the power consumption when signal control equal to 1 and to decrease the load demand when signal control -1 as clearly presented in Figure (14).

The load power in the buildings that integrated with aBEMS-IoT could be managed following the signal control, this signal control in the actual demand response program, may come from the load aggregator or grid operator. The aBEMS-IoT operates following the signal control which may be the signal for electricity price or can be the signal for the emergency. In the case of price, this signal can be the price of electricity which reserves the customers who have the ability to manage the load. In case of emergency signal, the BEMS of the customers who involve in the DR program can manage load for the power quality and stability of the grid by managing the load for balancing the demand. The aBEMS-IoT is developed for supporting any demand respond scenarios and can control the load with effective response time which presented in the figure(14). when the signal comes the aBEMS-IoT can immediately manage the load. This kind of technology for control the demand side or demand-side manage will be mutual in the near future because the electricity consumption of the country is growing rapidly but the generation is limited due to fossil supply and environmental problems. The aBEMS-IoT is the solution for the stabilize grid and can also be an important part of Microgrid and Smart grid in the near coming future.

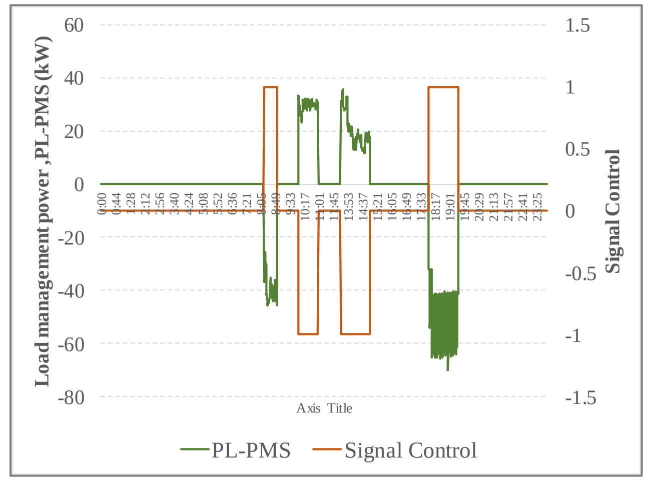

Fig. 14. The demand power which was controlled by aBEMS-IoT and signal control.

5. CONCLUSION

This research developed the automated building energy management system using internet of thing so-called aBEMS-IoT, this system consisted of three parts, the first is hardware which consists of controlling, analytic and communication devices, the second is software which consists of aBEMs-IoT firmware and mobile application, and the third is a communication system which can be communication cable or wireless solution. After the aBEMS-IoT was developed, it was tested in the laboratory and was implemented in the buildings of Post Engineering Office where was used to test the technical capability of a developed system. The analyzed results indicated that a BEMS-IoT could effectively manage the test loads following the assumed demand response program. The response time for controlling the load was very fast less than 1 s, then aBEMS-IoT can be the solution for the coming future of the Smart grid because the limitation of fossil fuels and environmental problems then the demand side management will be the essential key to maintain the power quality and stability of the grid network.

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