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Development of Battery Monitoring System in Smart Microgrid Based on Internet of Things (IoT)

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Abstract

In this paper, battery monitoring system based on internet of things (IoT) has been developed to monitor the operational and performance of batteries in a smart microgrid system. This smart microgrid includes a battery pack, PV system, Intelligent Electronic Device (IED) hybrid inverter, grid connection and electricity load. The IoT developed in this work consists of a communication channel from and to IED, data acquisition algorithm, cloud system and Human Machine Interface (HMI). Data acquisition was scheduled to execute every minute as mentioned in IEC61724. The battery monitoring system information as part of battery management system (BMS) is displayed on a Human Machine Interface (HMI) using ExtJS / HTML5 framework which can be accessed using desktop or mobile devices. From analytical results, the average execution time for overall BMS-IoT based data acquisition to the cloud server is 19.54 ± 18.00 seconds. The result of availability monitored data in the cloud database server is 92.92 ± 6.00 percent, which shows satisfactory result for the reliability of BMS-IoT system data acquisition.

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Keywords: battery monitoring system; smart microgrid; communication protocol; battery system; internet of things;

1. Introduction

A lot of research focuses on renewable energy as future potential resources, such as wind, geothermal, hydro, and solar energy, yet some renewable energy has disadvantages in producing energy. For example, solar cells can only produce energy during the scorching sun and wind energy is just as an intermittent energy. In order to overcome the limitation, all energy generating sources have been integrated into a system which is called smart microgrid. Smart microgrid also needs battery system as a backup energy that will deliver its stored energy when the main energy producer does not produce energy.

Battery Management System (BMS) needs to be enhanced in order to provide a better performance. Battery monitoring system (BMoS) is a part of BMS that is required in order to monitor the operational system, performance and battery life such as charge and discharge process. Battery monitoring system consists of measuring devices to measure parameters such as battery voltage, current, and temperature. These parameters can be processed to estimate the state of charge (SOC) and state of health (SOH) of the battery [1,2].

The Internet of Things (IoT) enables smart microgrid to share information for more users and it enhances connectivity throughout many infrastructures [3]. Internet of Things (IoT) is the fourth generation of supervisory control and data acquisition (SCADA), a system to monitor and control which communicates through an internet gateway. Cloud system is the best partner for data storage for IoT. Cloud system is a third party for database which transfers data over internet gateway. The advantages of cloud system are large data storage, high reliability, low cost, and excellent scalability that can handle growing amount of work

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[4]. Cloud system benefits to the industries because it reduces the cost of data storage facilities and extra maintenance to keep or maintain the data. With the data in the cloud, users can process and analyze the data accurately anywhere – because of large data stored in the Cloud – and make faster decisions.

Many studies have developed IoT for various areas and it has been implemented in various domains, for example in transportation and logistics, environment (home, office, and plant), personal and public, biomedical, and energy [3,4,5]. Energy domain based on IoT allows users to visualize energy consumption in real time. One of application from energy domain is smart grid. Application of smart grid based on IoT has been developed for contingency management using smart loads [6].

In the previous research [1], a battery monitoring and protection system has been developed; it consists of two main parts: the local module as a data acquisition component and central module which collects all data from the local module. Central module can be connected directly to HDMI display and also has remote desktop access via the user interface as the communication protocol. In this work, a battery monitoring system was developed as central module to monitor operational and performance of batteries in smart microgrid system based on IoT.

2. Battery Monitoring System in Smart Microgrid

In this work, a battery monitoring system has been developed to monitor operational and performance of batteries in smart microgrid system based on IoT. The smart microgrid consists of a battery pack, PV system, hybrid controller, grid connection and electricity load (See **Fig. 1**). The battery pack consists of eight valve regulated lead acid batteries with nominal voltage of 12V and 100Ah which is configured as 4 batteries connected in series and then the two strings are connected in parallel such that it generates nominal voltage of 48V and nominal capacity of 200Ah or 9600Wh. The PV system consists of 20 modules of 50Wp and operational voltage of 12Volt which is connected to grid-tie inverter SB-2000 as 10 modules in series and a parallel set of 2 strings with total capacity of 1000Wp.

The hybrid controller is a bidirectional inverter SI-5048 with total capacity of 5000Wp and it is an Intelligent Electronic Device (IED) which measures battery system voltage, temperature and current. The IED provides SMA-COM which proprietary serial communication to communicate from/to the IED, and also provides TCP/IP communication with JSON format as an open communication protocol.

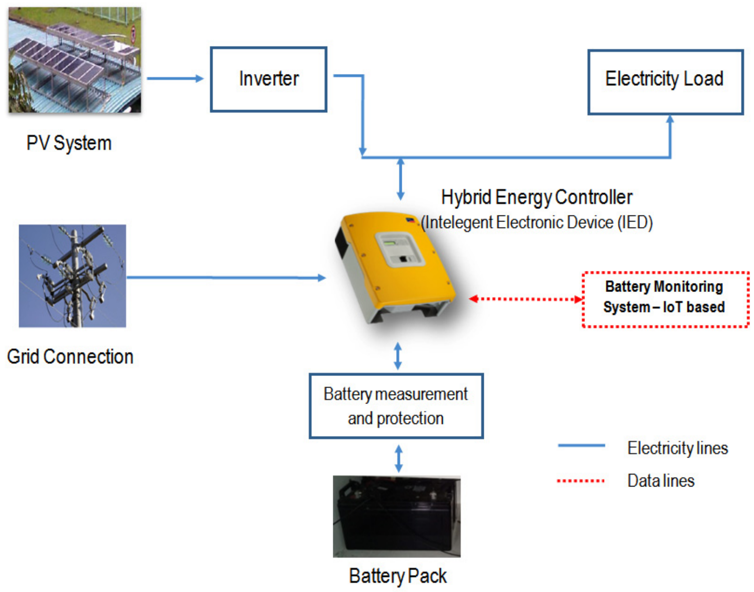

Fig. 1. Configuration of battery monitoring system in smart microgrid based on Internet of Things (IoT)

3. Battery Monitoring System based on Internet of Things (IoT)

The IoT based Battery Monitoring System which is developed in this work consists of a communication channel from and to the IED, data acquisition, cloud system and Human Machine Interface (HMI). An embedded system has been developed as an IoT to provide communication from and to the IED, as a data acquisition and as an internet gateway for all battery system parameters such that it enables to store, process and access all the parameters through the cloud system.

The IoT based battery monitoring system utilizes digital communication TCP/IP with JSON format as a data acquisition to retrieve battery measurement parameter from the IED (See **Fig. 2**). Data is sent to the database and web server on the cloud system via the Internet gateway. The data in the cloud system is processed and analyzed to produce information which can be understood easily by users as it is displayed in Human Machine Interface (HMI) using ExtJS / HTML5 framework which can be accessed using desktop or mobile devices as per **Fig.3**.

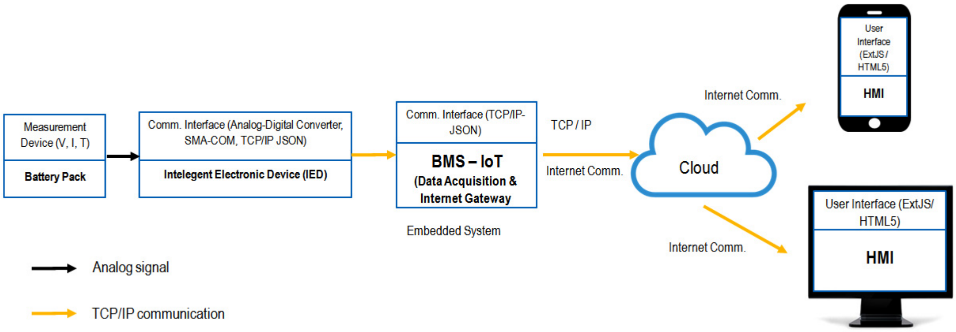

Fig. 2. Battery monitoringsystem based on IoT diagram

3.1. Internet of Things

The embedded system utilized as an IoT in this work is a Raspberry Pi Model 2, where its primary function is to execute data acquisition, and as an internet gateway to the cloud server. The data acquisition algorithm in the embedded system shown in **Fig.4**, is implemented using PHP server side programming that executes two main programs, which is for battery monitoring system and photo voltaic monitoring system.

The PHP executes the data acquisition program that retrieves battery measurement parameters from the IED with JSON format, where all of the data is processed and converted according to the structured query language so that the data could be stored in a cloud database. The data acquisition that is written in PHP programming is scheduled to execute every minute using cronjob in raspbian linux operation system for Raspberry Pi 2, as mentioned in the International Electro-technical Commission (IEC) Standard 61724 per monitored data between 1 – 10 minutes [7].

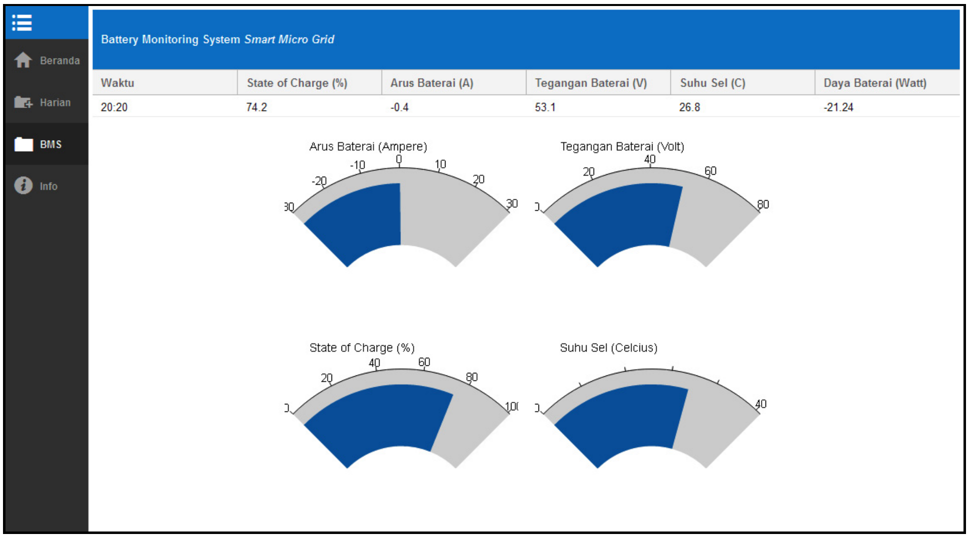

Fig. 3. Human Machine Interface (HMI) display for battery monitoring system

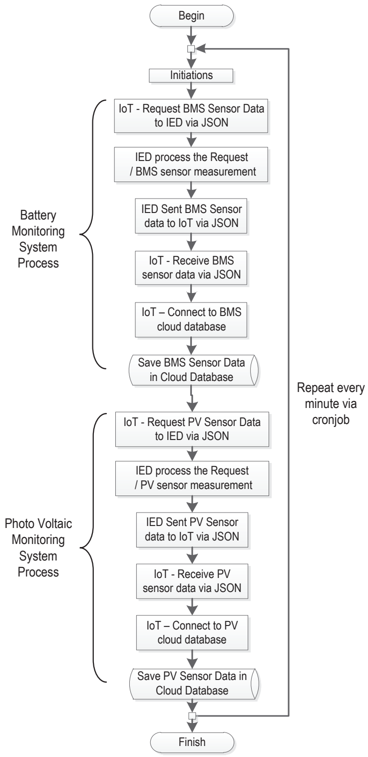

Fig. 4. Data acquisition algorithm of battery monitoring system in IoT

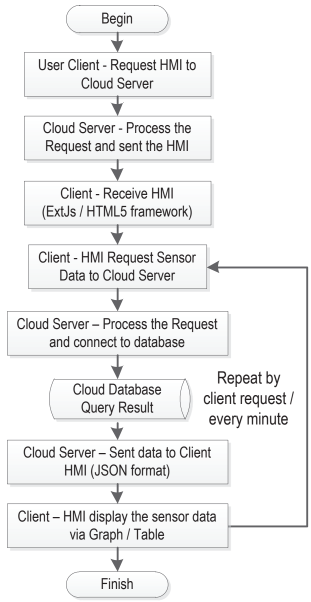

Fig. 5. Human Machine Interface (HMI) client server Algorithm

The embedded system will restart for every 3 hours in order to optimize the system execution. As for the IoT internet gateway, asymmetric digital subscriber line (ADSL) provider with download speed 1024 kbps and upload speed 384 kbps is utilized to send BMS-IoT data to the cloud server. A web and database application server is implemented in the cloud system to provide Human Machine Interface (HMI) for client as in Fig.3. The application servers consist of apache web server, MySQL database server, PHP server side programming, and the HMI program that uses ExtJs/HTML framework with the algorithm shown in **Fig.5**.

3.2. Experimental Methods

The IoT application for battery monitoring system in this work has been tested to verify the performance and availability of the system. Performance testing were done as in Fig.3 to know the speed and delay time of IoT to collect data from the IED and delay time to send BMS sensor battery parameters to cloud database. The experiments has been performed for 120 times at intervals of 1 minute. The measured data in this test consists of data transmission speed, number of bytes sent/received from or to IoT and IED, execution time from IoT to cloud server and the total data acquisition execution time.

$$A_{MD} = \frac{\tau_{MA}}{\tau} \times 100\% \qquad (1)$$

where :

A_{MD} = Availability of Monitored Data

τ_{MA} = total duration of monitoring activity / total monitoring data recorded in database

τ = reporting period (day, month, year)

The availability of the system is measured in the form of availability of monitored data (See Eq. 1), that describes the percentage of measured data recorded in the database system compared to the reporting period of monitoring system [7]. The experiments are done in this work by taking historical data from the cloud database in a span of 15 days, and then the data were analyzed per one day. The target availability in this work is above 80% which represents the satisfactory value for system reliability.

4. Results and Discussion

Fig 6. shows the total execution time of data acquisition performed by IoT from collecting data from the IED and sending all of battery monitoring system parameters to cloud server. These are not only to collect battery monitoring system parameters but also to include the photovoltaic monitoring system in the smart microgrid as per **Fig 3**. The average execution time for overall data acquisition to the cloud server is 19.54 ± 18.00seconds.

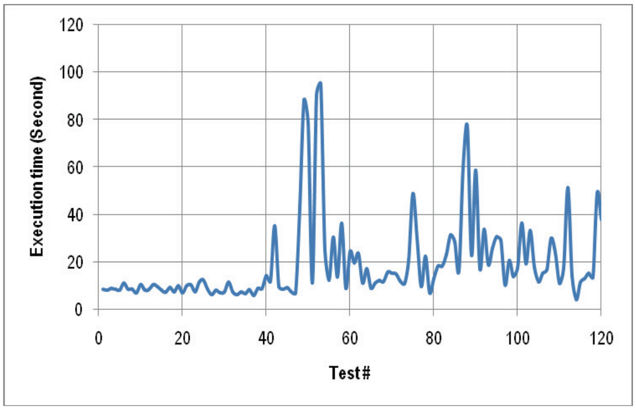

Fig. 6. Total data acquisition execution time

In the first 40 test data, the average execution time takes about 10 seconds but after that, the execution time is quite dynamic and it needs to be analyzed. From **Fig 7,** it can be seen that the IoT interaction to the cloud system causes delay in the data acquisition execution time. There are two points of value where the execution time are over 60 seconds, which means that the connection from the IoT to the cloud database exceeds the data acquisition sampling time. The average value of IoT connection from / to IED is 1.04± 0.66 seconds and IoT to Cloud database 8.71± 12.12 seconds. **Table 1** shows the result for every average value of performance testing for the IoT based battery monitoring system.

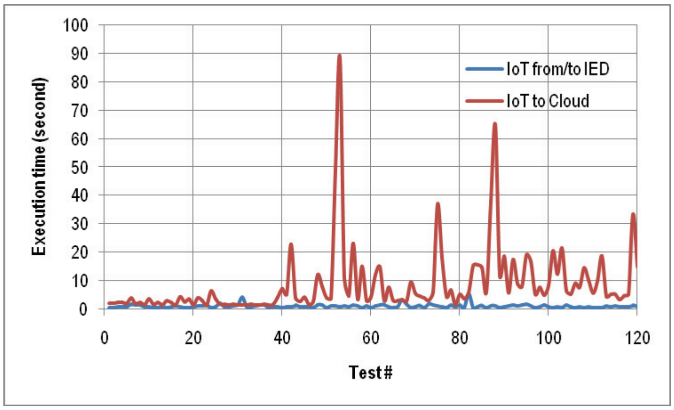

Fig. 6. Execution time of BMS-IoT to other system

Table 1. Experiment result

Average Parameter Result of BMS-IoT	Value
Total number of bytes uploaded to IED	1328.00 bytes
Total number of bytes downloaded from IED	3033.73 bytes
Total number of bytes upload + download from/to IED	4361.73 bytes
Upload speedto IED	3746.02 bytes/second
Download speed from IED from IED	7328.35 bytes/second
Data transfer speed (upload + download) from/to IED	11230.93 bytes/second
Total execution time BMS-IoT to IED	1.04 ± 0.66 seconds
Total execution time BMS-IoT to cloud database	8.71 ± 12.12 seconds
Total of all data acquisition program execution time	19.54 ± 18.00 seconds

Based on the monitoring data stored in the MySQL cloud database, **Fig. 8** shows the result of availability of monitored data of IoT based battery monitoring system in cloud database server, as it is calculated using **Eq. 1.** From the span of 15 days from 16-07-2016 to 30-07-2016 which represents half a month's worth of data, the average value of availability of monitored data in cloud database server is 92.92±6.00 percent, which means that the value is above the target value and the result is satisfactory.

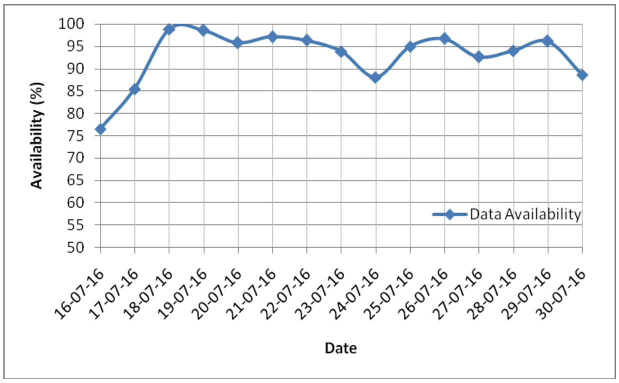

Fig. 7. Availability of monitored data of IoT based battery monitoring system in cloud database server.

For future work, battery monitoring system with cell monitoring feature is needed to monitor every battery cell performance which will show the unbalance voltage or capacity of battery cells. Furthermore, to increase the speed of data transfer and the reliability of cloud connection, other IoT communication protocol such as MQTT could be implemented.

5. Conclusion

A battery monitoring system has been developed to monitor operational and performance of batteries in smart microgrid system based on IoT. The IoT which is developed in this work consists of communication channel from and to the IED, data acquisition algorithm, cloud system and Human Machine Interface (HMI). The IoT utilizes digital communication TCP/IP with JSON format as data acquisition to retrieve battery parameters, such as voltage, current, and temperature dynamics from the IED. A data acquisition algorithm is implemented in an embedded sytem using PHP server side programming, and all of data is processed and converted according to the structured query language so that the data could be stored in a cloud database. The data acquisition is scheduled to execute every minute as mentioned in the International Electro-technical Commission (IEC) Standard 61724. The data stored in the cloud system database is processed and analyzed to produce information that can be understood easily by users as it is displayed in HMI using ExtJS/HTML5 framework which can be accessed using a desktop or mobile device. From analytical results, the average execution time for overall BMS-IoT based data acquisition to the cloud server is 19.54 ± 18.00 seconds, the average value of connection from and to IED is 1.04 ± 0.66 seconds and the average value of connection to cloud database is 8.71 ± 12.12 seconds. The availability of monitored data is 92.92 ± 6.00 percent, which shows satisfactory result for the reliability of the BMS-IoT system data acquisition. For future work, battery monitoring system with cell monitoring feature is needed to monitor every battery cell performance, and other IoT communication protocol could be implemented to increase the speed of data transfer and reliability of cloud connection.

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