Hardware Development of the Energy Management System with Smart Monitoring and Control and the Battery Lifetime Estimation based on Data Logging

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Abstract: In this paper, we implement hardware of energy management system (EMS) for power monitoring and control, and also develop battery life prediction based on data logging. Nowadays, Power management is an essential tool for microgrid (MG) safe and economic operation, particularly in the islanded operation mode. The lifetime of the batteryis a huge part of the performance and price of the EMS. Therefore, it is effectivefor the battery lifetime to observe and manage the electric power all the time. This method enables to control the daily power consumption and the battery life is also able to be monitored to ensure the performance of the independent power system.The test proves the effectiveness of the operation and demonstrates the operation stability of the proposed smart monitoring and control (SMC) function and the data logging function for the battery life prediction.

Keywords: EMS, SMC, battery, data logging, lifetime estimation

1. Introduction

Standalone microgrids with renewable sources andbattery storage play an important role in solving power supplyproblems in remote areas such as islands. To achieve reliable andeconomic operations of a standalone microgrid, in addition to theconsideration of utilization of renewable resources, the lifetimecharacteristics of a battery energy storage system also need to befully investigated.

According to the 3020 renewable energy plan of the Ministry of Commerce, Industry in Korea, 20% of renewable energy generation will be targeted by 2030, and the cumulative renewable energy capacity will be increased to 63.8GW. In addition, the world is spreading the micro grid as one of the means to improve stability and efficiency in the past large-scale plant-based power supply system. The microgrid is classified into grid-connected type and stand-alone type depending on the grid connection. The grid-connected type supplies electric power in connection with the power system normally, but separates the system from the grid in case of emergency and supplies power to the uninterrupted power, and the stand-alone power supply is appropriately combined with an isolated area (island, desert, etc.) [1].

In general, real-time MG management is classified into energy and power management. The energy management algorithms deal with monitoring and operation of a complex system of electrical, thermal, and mechanical components with emphasis on desired and longer term outcomes. However, the objective of power management is to affect the instantaneous operational conditions toward certain desired performance [2]-[9]. From a general perspective, both power and energy management refer to control actions that are based on particular objectives.

In this paper, we implement hardware of energy management system for power monitoring and control, and also develop battery life prediction based on data logging. Data needed to improve smart monitoring and control (SMC) function, daily power consumption setting, and battery life prediction may vary depending on the user. And also data logging system is required for continuous monitoring. To do this, a real time clock (RTC) module is required to display the time, and a wireless setting module is required to reset the system after confirming such data. In addition, a buzzer and a lamp are installed to inform the user of the warning by the battery life prediction algorithm and also the LCD is mounted as a display device so that necessary information can be outputted. The test proves the effectiveness of the operation and demonstrates the operation stability of the proposed SMC function and battery life prediction data logging function.

2. EMS with SMC

In the prototype, SMC has newly designed and manufactured a PCB board, and the whole prototype system through commercialization is shown in Figure 1.

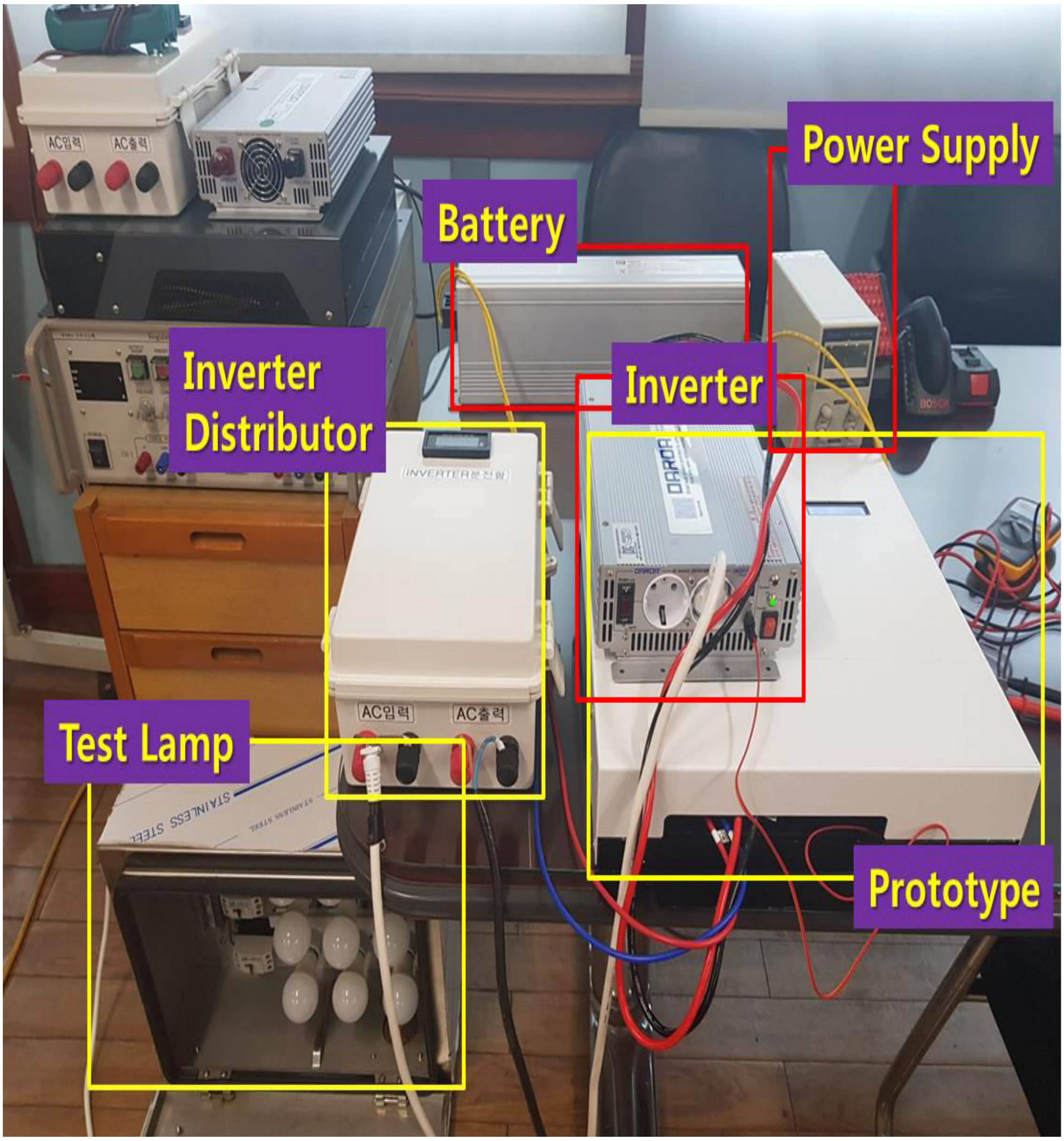

Figure 1. Prototype of the EMS with SMC

The prototype with the SMC controller and other modules is on the bottom right and the inverter distributor box is to distribute the power supplied by the battery. The power supply of these inverters is performed by the SMC controller in the prototype according to the statedecided by the power setting control algorithm.

The inside of the prototype is shown in Figure 2, which includes a charge controller that charges the battery with the power supplied by the solar cell, a circuit breaker to protect the system during various power surges, a terminal box to connect various parts of the system, And an SMC controller that plays a pivotal role in the SMC algorithm.

If you look closely at the SMC controller, it can be seen that the modules used in the test system are uniformly arranged on the PCB board faithfully manufactured. Each part is composed of a modular structure so that it can be easily replaced respectively only when the part fails. The SMC controller consists of a sensor part for power measurement of various voltages and currents, an inverter control part that will control power through it, a data monitoring part for monitoring battery life prediction and daily power consumption,and a communication part for setting up the control value through the wireless connection with the SMC controller, and finally, an embedded system for supervising all of them.

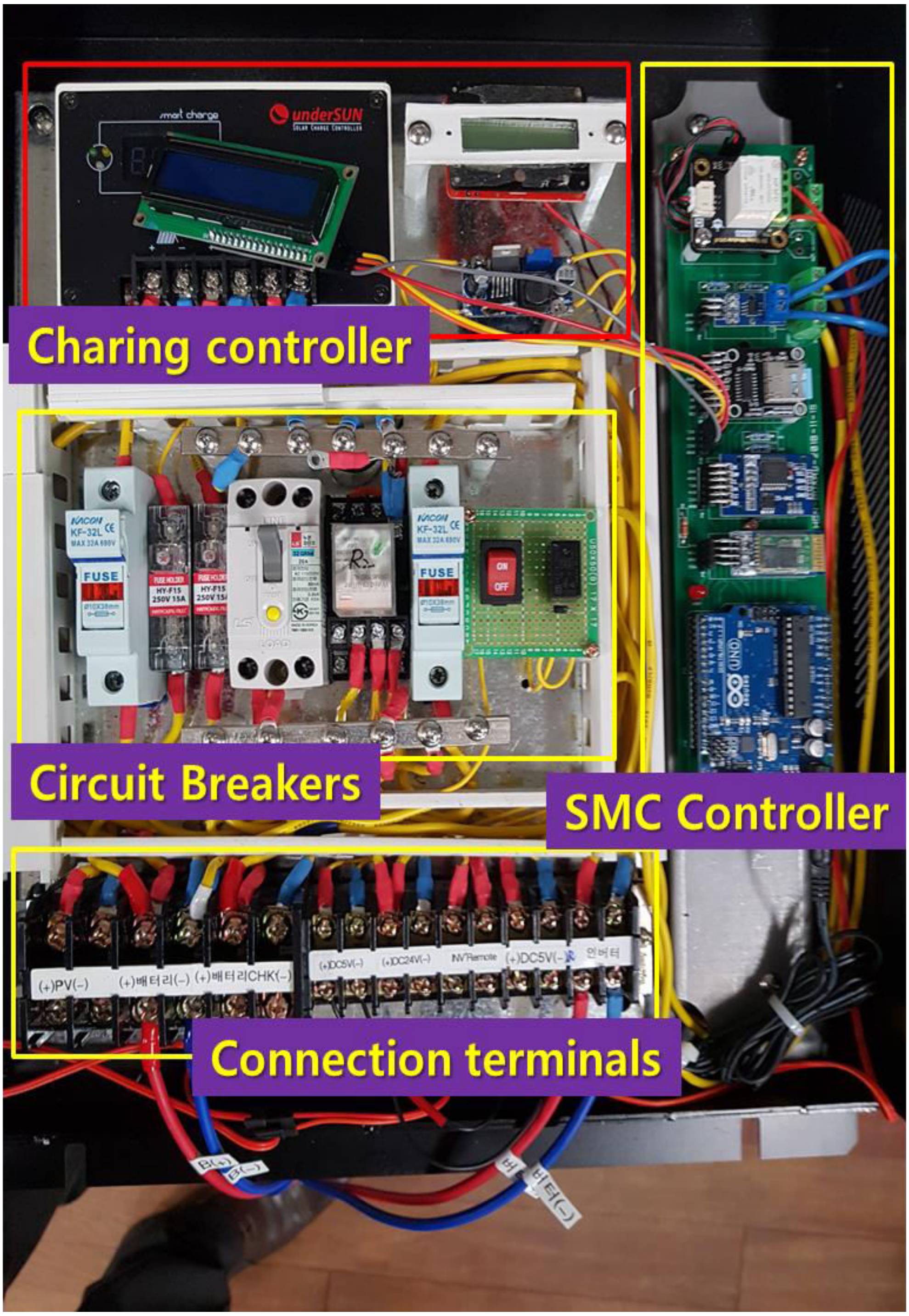

Figure 2. Prototype inside

As shown in Figure 3, the sensor parts are equipped with voltage and current sensors to measure the DC voltage and DC current supplied from the battery, and the inverter control module use a relay element to control the ON / OFF switch of the inverter. As a data monitoring part, a voltage (V), a current (I), a power (P), an energy (E) are recorded by using a secure digital (SD) memory card as a data logging module and used as raw data for battery lifetime prediction, But there is no information about time in the embedded system. So a real time clock (RTC) module is added. Furthermore, a communication part (Comm. Module) is added for wireless communication with the embedded system in order to set the data of daily use or battery life prediction. Finally an embedded controller performs all automatic controland battery life prediction function.

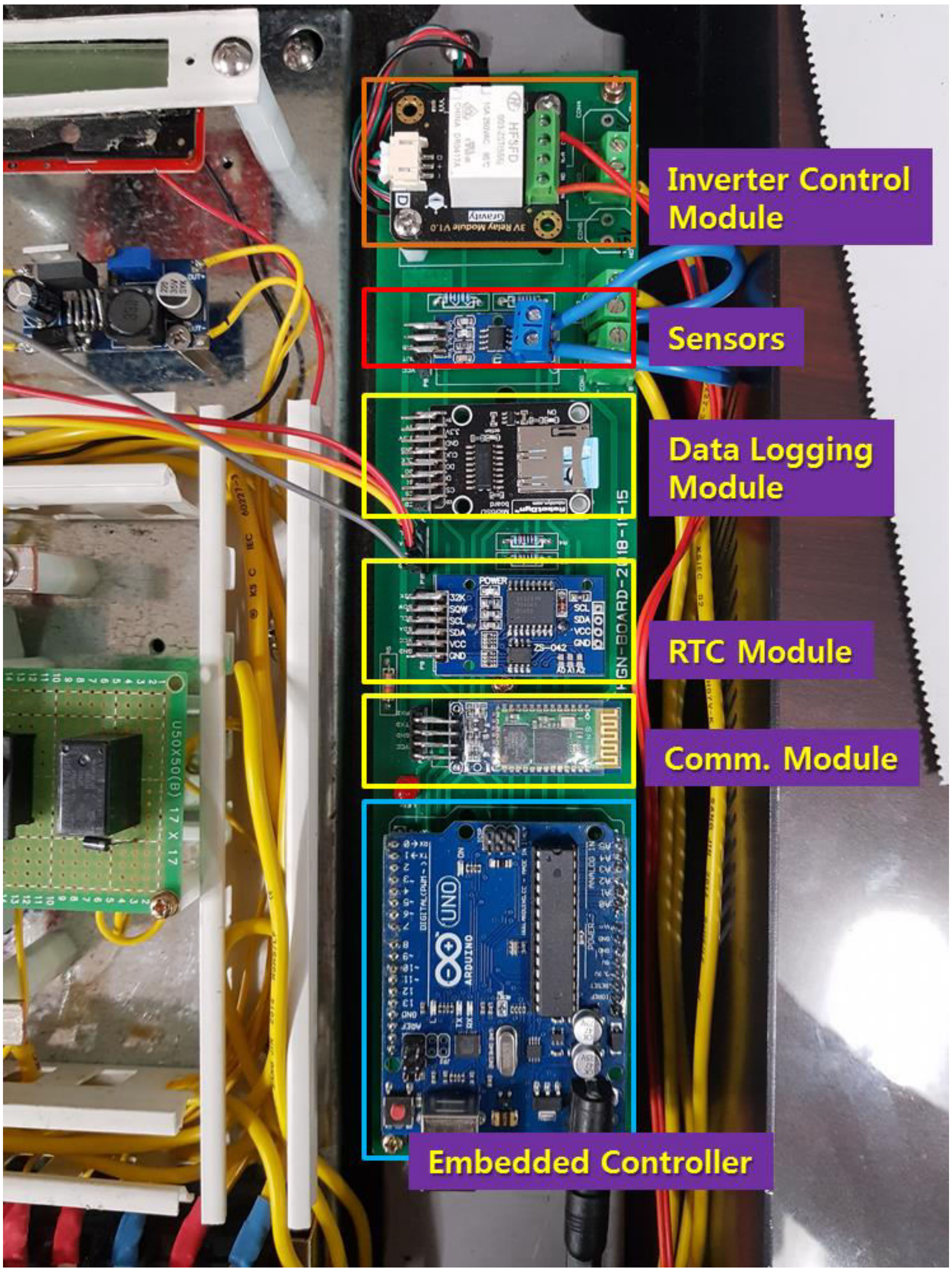

Figure 3.SMC controller

The communication used in the system is Bluetooth and Inter Integrated Circuit (I2C) communication. Bluetooth communication is used for commands such as system initialization, setup and confirmation when necessary, and I2C is applied as one of the solutions to solve the limit of the number of I / O connections of embedded system.I2C is used for communication of sensors and other attached devices.

Bluetooth communication must be synchronized between the devices, and it is connected to the master-slave configuration. A maximum of 7 slave devices can be connected to one master device, and communication between slave devices is impossible.Only communication between master device and slave device is possible. However, since the master and slave roles are not fixed, if users change their roles according to the situation, they can communicate in the opposite direction.

In case of (a) in Figure 4, one slave is connected to the master. (b)is a case where three slaves are connected to one master, and in the case of (c), a complex Bluetooth network is shown with many masters and slaves.

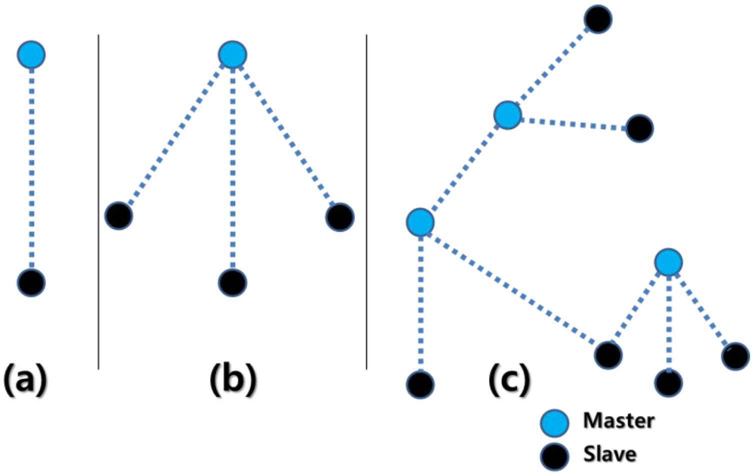

Figure 4. Bluetooth network

In this paper, we can stop the system operation, set the daily power consumption, predicted battery life, and set the system time by using Bluetooth communication. Also, by applying the sequential and numerical name to the Bluetooth device of the developed system, it is possible to distinguish the commanded system in many products.

Various sensors and data storage devices are used in this system. So, it is difficult to mount them due to the limitation of the number of I / O pins. In order to connect many of these devices to this system, I2C communication is used.

I2C communication consists of a line (SDA) for sending and receiving data and a clock line (SCL) for timing synchronization of sending and receiving. It consists of one master and one or more slaves. Up to 127 slaves can be connected. Figure 5 shows an example in which several devices are connected via I2C communication.

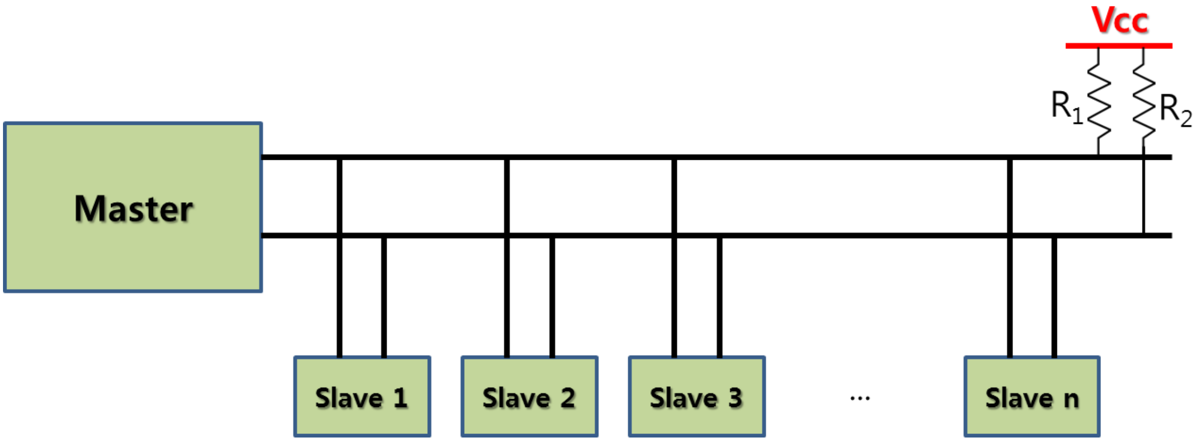

Figure 5.I2C connection with multiple devices

In Figure 5, one of the devices becomes the master device and the others become the slaves. Note that "R1" and "R2" are resistors. In order to communicate, it is important to make HIGH state with pull-up resistor because both SDA line and SCL line must be basic HIGH state.

Remark 1)There may be more than one master on one line in I2C communication. However, only one master and one slave can communicate at a time.

Remark 2)SDA line is used for both INPUT and OUTPUT,because all the operations of transmitting and receiving data in both master and slave are accomplished only by the SDA line. So it is necessary to use pull-up resistorsfor preventing the floating.

Data transmission / reception is mainly used in short data communication rather than long data communication because it is dominated by the master and communication must be started after specifying the slave address before transmitting or reading data.

Compared to serial (UART) communication, the advantage of I2C communication is that it is a synchronous communication method. The synchronous communication method is a method of synchronizing the transmission timing of data by using a clock signal. Therefore, there is an advantage that the communication speed does not have to be determined as much as serial communication.

3. Battery Lifetime Estimation

Data needed to improve SMC function, daily power consumption setting, and battery life prediction may vary depending on the user. So a data logging system is required for continuous monitoring and to do this, a real time clock (RTC) module is also required to keep time tracking, and a wireless setting module is required to command the system when the system restarts after acquiring the data. To implement all of these functions, additional modulesareconsidered and installed in the test system as shown in Figure 3

The Micro SD card adapter modules allow you to read and write files to a micro SD card. Since the input values of various sensors can be stored in the SD card, which is a very large storage space, for example, if you create a system for weather observation, you can record the data independently on the SD card. So if you want to save the saved data in CSV format, you can read it in Excel or database management system (DBMS) and draw a graph or do various analyses.

To use SD card, usually serial peripheral interconnect (SPI) is applied. The SPI bus is a synchronous communication standard developed by Motorola that enables full duplex communication. Like I2C, it operates in master-slave mode and the master outputs the clock for synchronization. Each SPI slave device has a chip enable (/CE) input and operates only when this input is enabled. Thus, the master can drive more than one slave device by connecting multiple slave select (SS) lines to slaves' /CEs and selecting only one slave at a time. SPI's communication speed is up to 70 MHz, which is much faster than I2C.

The following figure shows a situation where multiple slaves are connected to the master through the SPI bus. The signals in the Figure 6 are:

- SCLK : Serial Clock. Synchronizing clock output from master
- MOSI : Master Output Slave Input
- MISO : Master Input Slave Output
- SS : Slave Select. master output signal for selecting slave. active when the signal is zero.

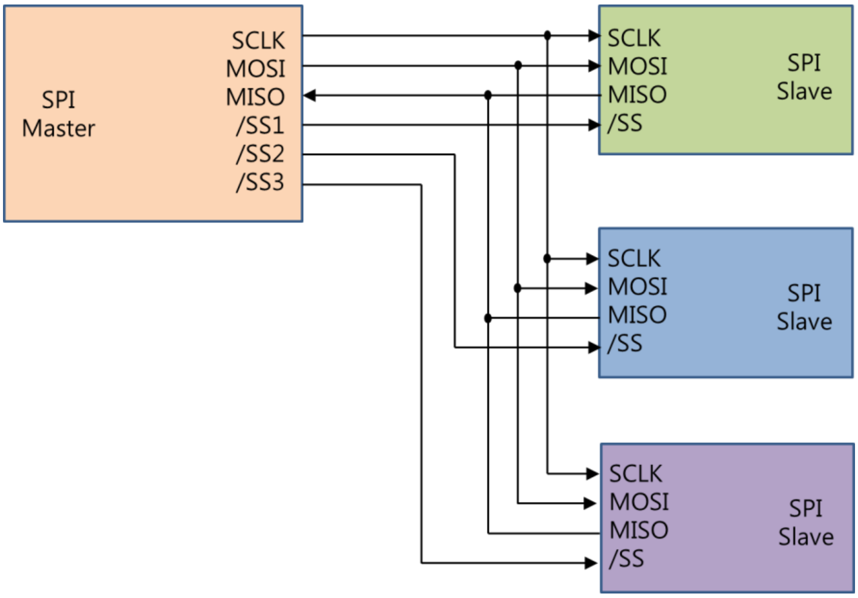

Figure 6. Typical SPI bus: master and three independent slaves

The embedded system used in this paperdoes not have its own RTC, so the DS1302 RTC module in the Figure 7 is used for the RTC function. The DS3231 chip in the RTC module has the following advantages: time error less than 2 minutes per year, combined with 5V / 3.3V, two alarm functions, periodic interrupts can be generated, and the internal oscillation function eliminates the need for external crystal parts. For this reason, the DS3231 chip is more suitable for projects that require more precise time. In addition, temperature measurement is also possible for DS1302 RTC module.

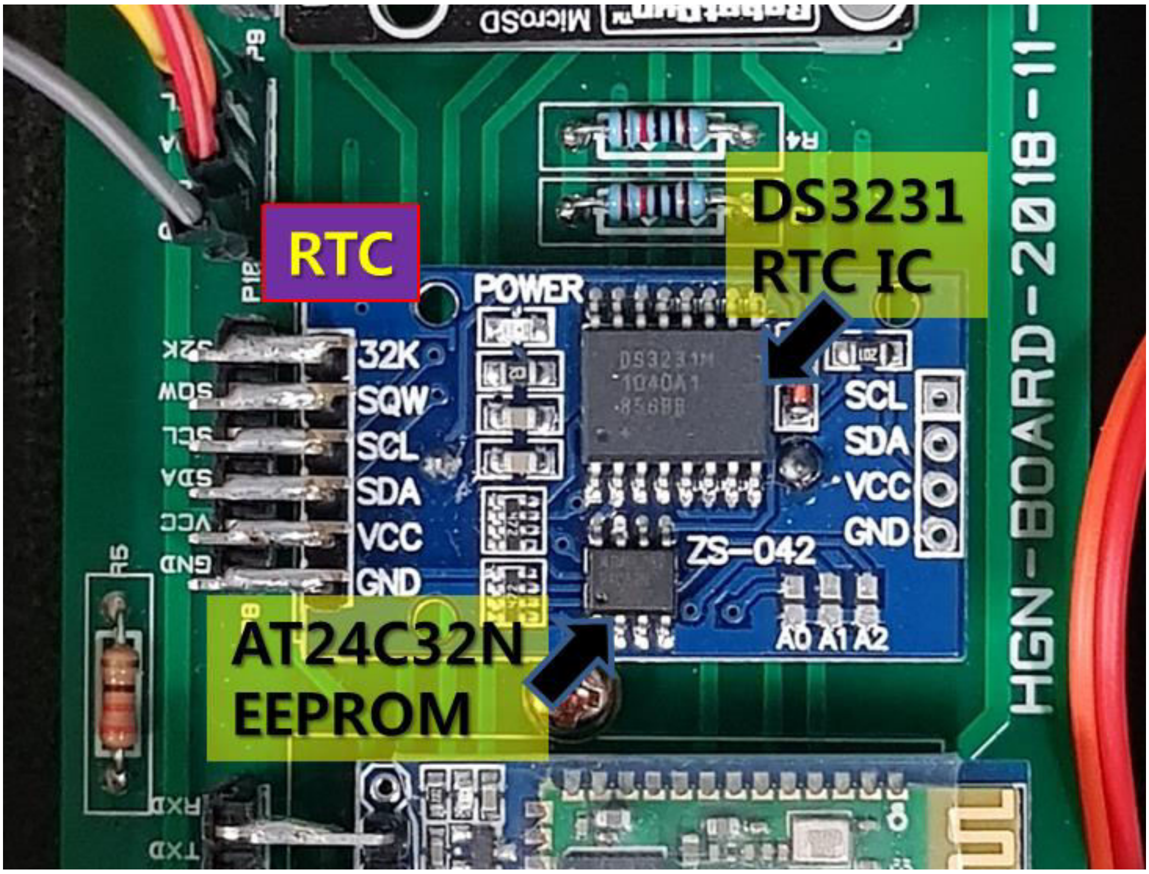

Figure 7.RTC module

The structure of the RTC module is as above. DS3231 chip with all RTC functions are located at the top and AT24C32N, which is an EEPROM chip that can store 32KB of data at the bottom. Therefore it is possible to record voltage continuously by using a data logging system based on RTC.

As an algorithm for implementing the SMC function, the daily power consumption monitoring control is as follows. At first, the SMC checks whether the current power consumption is exceeded based on the daily set power amount, and if it exceeds, the power supply stops. If not, the SMC continuously performs power supply. Although the SMC stops the power supply, when the next day starts, the power supply is resumed and the power supply is monitored and controlled again based on the daily power consumption. The flow chart of this algorithm is in the Figure 8.

To predict battery life time based on the Data logging and RTC functions, we consider the voltage after the battery is discharged as a way to find when the battery has reached the end of its life. A normal battery does not significantly differ in voltage value after a day's power consumption is supplied to the initial voltage, whereas as the battery reaches its end of life, the voltage value that appears after supplying the same power usage varies significantly. Based on the data logging data, the moment of such a sudden voltage difference is the moment when the battery has reached the end of its life and needs to be replaced. If the battery is used beyond this life time, it may cause instability in the power supply and it is difficult to expect a normal power system performance.

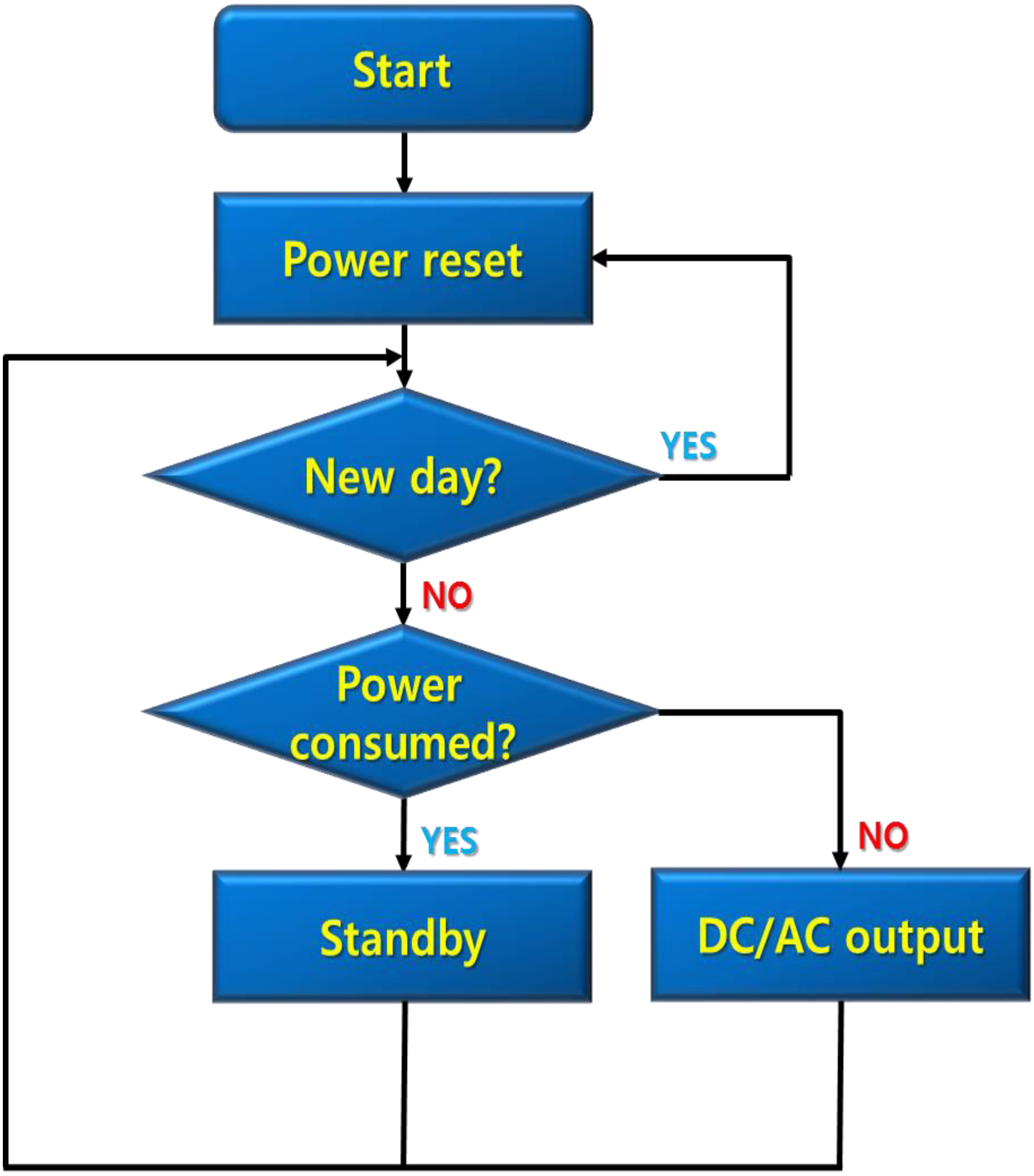

Figure 8. Everyday power management algorithm

By measuring the discharge time of the battery, it is possible to verify the change of the battery voltage according to the amount of power used. So the battery life time can be estimatedfrom both the discharging time and the amount of power consumed, which are compared to the initial time. Thereby the load usage time of the battery can be controlled by estimating the battery life time from the discharging time and the amount of power consumed.

Compared with the discharge voltage of the battery at the initial installation and the discharge voltage of the battery according to the power consumption, the voltage difference shows the change by the long-term battery use compared to the initial installation. Therefore, it is possible to plan the maintenance and management of the battery by presenting a voltage change range and it can be determined whether the battery has shortened the discharge time compared to the initial stage. As a result, it is developed as a system that supports to predict the replacement time or inspection time according to the use after installation.

The flow chart of the battery life time estimation and control algorithm is in the Figure 9.

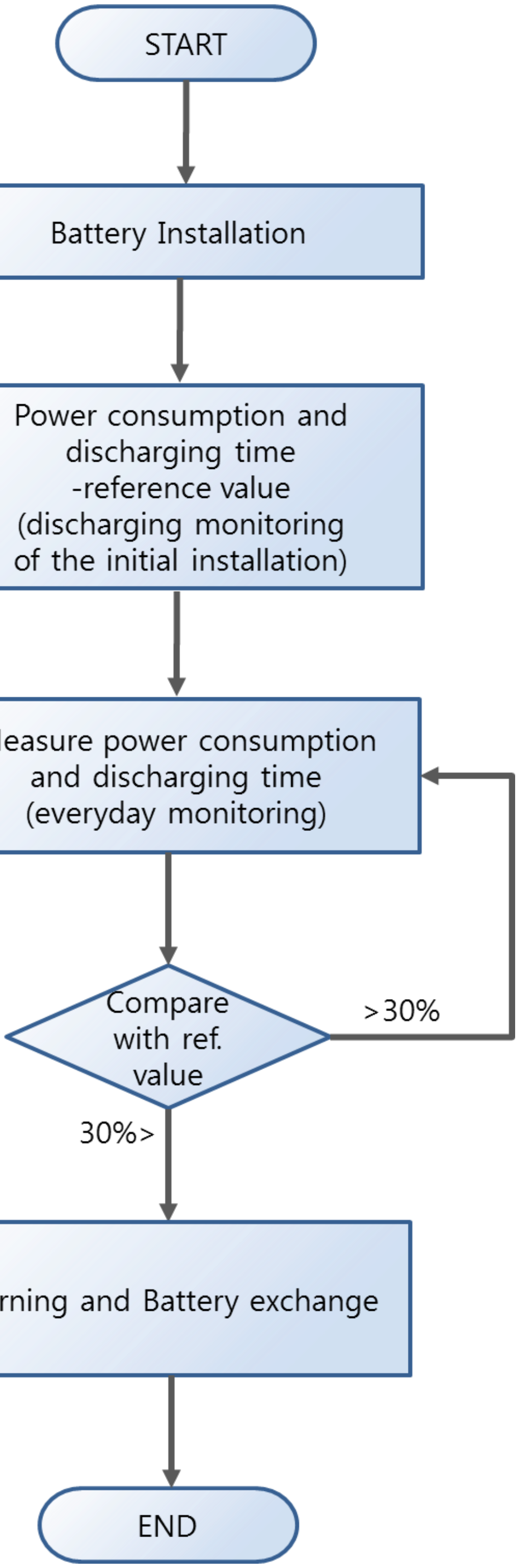

Figure 9. Battery lifetime estimation and control algorithm

4. Test and Validation

To verify the proposed battery life time estimation algorithm, two types of batteries were used. Lithium batteries that were purchased less than one year ago and lead-acid batteries that were purchased more than four years ago were used. The experiment of life time estimation through actual battery use takes a long time, so two types of batteries, one with good life time (new battery) and one with the bad life time (old battery), are prepared.To determine the battery life expectancy that is measured by taking a long time due to charging and discharging of the battery, an old battery and a battery less than one year are applied to compare the battery with the reference value to derive the result.

In order to use it as a reference value for battery life time estimation, the discharge time and the amount of the power consumption of the battery were measured during the initial installation and the battery voltage fluctuation width and usage time were measured over time to apply the battery life time estimation algorithm. Tests were done by step 1) and 2) and step 1) is measurement of reference value and step 2) is daily inspection test.

1) Initial power consumption and battery voltage fluctuation-**measurement of reference value**
    a. Setting the reference value: Voltage for a certain period when using the initial battery
    b. Comparison of reference values during discharge: battery voltage fluctuation, power consumption
    c. Calculation of battery voltage fluctuation range and usage time according to power consumption
2) Battery voltage fluctuations over time-**daily inspection**
    a. Setting the reference value: Voltage for a certain period when using the initial battery
    b. Comparison of reference values during discharge: battery voltage fluctuation, power consumption
    c. Calculation of battery voltage fluctuation range and usage time according to power consumption

The reference batteries and loads used are as follows.

Reference battery: Set the battery reference value as the initial battery voltage 24.5V at the initial installation

Loads: 10W x 9 = 90W (LED Lamps)

The test results of step 1) are Table 1 and the discharge time/ΔV and the power consumption/ ΔV are the reference values, which mean 100%. Now when the battery discharges, we measure same values every day and if the value shows 30% of the reference value, we assume the battery life time is done.

Table 1. Reference values

Battery	V fluctuation	Discharge time	Power consumption	Discharge time/ ΔV	Power/ ΔV	Remark
Reference Battery	3.91V	13,200 sec	323W	3,375sec/1V	82.7W/1V	100% load
				100%	100%	Random charging
Life expectancy (replacement, inspection criteria): 30% or less of the reference values						
If discharge time/ΔV and power/ΔV are less than 30%, notify the battery replacement and inspection.						

The test batteries and test conditions used are as follows.

Test batteries)

Battery A, B: Lithium battery within one year of purchase

OLD 1,2 battery: Lead-acid battery more than 4 years after purchase

Experimental condition:

A. Apply load 100% or 33%

B. Random charging, full charging, battery low voltage

The test results of step 2) are Table 2 and when the battery discharges, we measure the discharge time and the power consumption every day and if the value shows 30% of the reference value, we assume the battery life time is done.

Table 2. Every day inspection

Battery	V fluctuation	Discharge time	Power consumption	Discharge time/ ΔV	Power/ ΔV	Remark
Battery A	0.16V	300 sec	9.85W	1,875sec/1V	61.56W/1V	100% load
	Result: Sustained use			55.60%	74.40%	Random charging
Battery A	4.52V	9,600 sec	325W	2,123sec/1V	50.49W/1V	100% load
	Result: Sustained use			62.90%	61.10%	Random charging
Battery A	2.96V	3,600 sec	86.35W	1,216sec/1V	86.35W/1V	100% load
	Result: Sustained use (battery low voltage discharging)			36.00%	36.20%	No charging
Old 1 Battery	3.23V	2,100 sec	43W	650sec/1V	13.50W/1V	100% load
	Result: replacement, inspection required			19.30%	16.30%	Random charging
Old 2 Battery	2.91V	1,200 sec	19.82W	412sec/1V	6.81W/1V	100% load
	Result: replacement, inspection required			12.20%	8.20%	Random charging
Old 2 Battery	2.43V	480 sec	12.34W	197sec/1V	5.08W/1V	100% load
	Result: replacement, inspection required			5.80%	6.10%	Part charging
Old 2 Battery	3.13V	2,160 sec	15.68W	690sec/1V	5.01W/1V	33% load
	Result: replacement, inspection required			20.40%	6.10%	Part charging
Battery B	1.56V	6,000 sec	141.88W	3,846sec/1V	90.90W/1V	100% load
	Result: Sustained use			114.00%	109.90%	Random charging
Battery B	0.10V	1,140 sec	13.09W	11,400sec/1V	130.9W/1V	33% load
	Result: Sustained use (full charge and load 33%)			337.00%	157.00%	Full charging
Battery B	0.11V	2,580 sec	28.92W	23,454sec/1V	262.91W/1V	33% load
	Result: Sustained use (full charge and load 33%)			694.90%	317.00%	Full charging
Battery B	0.05V	1,140 sec	12.95W	22,800sec/1V	259W/1V	33% load
	Result: Sustained use (full charge and load 33%)			694.90%	313.00%	Full charging

Battery life time estimation test result shows that

-For products purchased within one year of lithium batteries, all the batteries (measured three or more times each) are checked with a reference value of 30% or more.

-In the case of an old battery that has passed 4 years or more of lead-acid battery, it is checked that the replacement time and inspection are required because of less than 30%.

Remarks)

-The level of the initial reference value is determined according to the battery capacity and manufacturing date.

-The predicted value may vary depending on the amount of load used, but it is assumed that the conditions applied to the TEST are constant during the initial design. Normally, since the battery capacity is determined by setting the load amount used, it is expected that the fluctuation of the load usage will not be large in actual conditions.(Although the load change test also affected the voltage change amount, it is displayed as a condition that requires constant inspection even in old batteries)

-Depending on the repeated use of charging and discharging, and the state of charge, the battery discharge voltage and start voltage were affected, but the use of the aged battery was checked poorly even during full charge.

4. Conclusion

In this paper, we implement hardware of energy management system for power monitoring and control, and also develop battery life prediction based on data logging. Data logging system is required for continuous monitoring. In order to use it as a reference value for battery life time estimation, the discharge time and the amount of the power consumption of the battery were measured during the initial installation and the battery voltage fluctuation width and usage time were measured over time to apply the battery life time estimation algorithm.The test proves the effectiveness of the operation and battery life time estimation data logging function. In the future study, if the battery voltage is divided and set for each section when setting the reference value due to the influence of the charge/discharge voltage of the battery, it is expected that the result of the battery life time estimation will contribute to improving accuracy.

ACKNOWLEDGMENT

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