Development of an Ultra-small and Cost-effectiveness Outdoor Setting Type Solar Power Generation Remote Monitoring System with a Linux Microcomputer Operation and Related Application to Education in Electrical Engineering

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ABSTRACT

In this study, the authors constructed the system to acquire real time and time-series data of the power status in detail in sensor-remote locations where solar power generation equipment was installed trough the expansion of an ultra-small remote monitoring system with a Linux microcomputer operation (as previously developed by the authors). Specifically, the setting of the microcomputer for releasing the value of the power generation of solar panel, charge and discharge quantity of battery and the power consumption in a load as a graph using an HTTP server program was performed by commenting sensor modules to a microcomputer and taking in the longitudinal information data from the voltage/current/power sensors. After that, an amount of power generated by the solar cell panels, the remaining capacity of the battery and the power consumption of an electric device and similar were monitored from a remote place via the Internet and VPN. As a result, it was confirmed that the long-term and longitudinal information data of the current, voltage and electric power, which covers the basic electrical performance of the solar power generation facility can be easily remote-monitored from a remote location using the circuit that the authors designed and manufactured this time, which is included the sensor modules and the I2C interfaces. Moreover, the electric power generation and energy consumption of the equipment and similar were monitored over a long period of time by inserting into a waterproof and weather resistant type case and installing the set of the apparatus including a battery outdoors. In addition, the solar cell was also installed outdoors and connected to the equipment after waterproof treatment. Based on these results, it was confirmed that the proposed system can be used outdoors without being affected by rough weather. Finally, the relation between the power consumption of the remote monitoring system and the selecting method of the solar cell panel or battery for use in this system was also studied.

Key Words: *VPN, cellular network, remote monitoring, Raspberry Pi, solar power generation, sensor network*

1. Introduction

Recently, the sensor network (In this system, the devices with a microcomputer directly communicates information each other without the mediation server for data via LAN or public line) has attracted attention for application in various fields thanks to the growth of the Internet and information and communication technology [1, 2)]. This technology is also called machine-to-machine (M2M) or Internet of Things (IoT) and expected to expand to a wide range of applications not only for the system in factories and homes but also in agriculture, fishery, transportation, healthcare and tourism in cooperation with big data

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analytics. Specific examples of usage include moisture management in botanical gardens or home vegetable gardens and transmission of information by combining GPS (Global Positioning System) data from a mobile object based on installation of IoT units on cars and ships. Against this background, the authors constructed an extremely compact, inexpensive and versatile remote monitoring system that transmits information via the Internet at low operational cost [3]. The system combines a microcomputer on Linux as the interface for connection to the various sensors with an embedded VPN (Virtual Private Network) program. In addition, mobile broadband modem and various sensors are connected to microcomputer directly. Accordingly, the need for a VPN router and sensor information acquisition equipment are eliminated thanks to the installation of a VPN program that traverses firewalls and NAT (network address translation). However, it is necessary to understand the amount of generated electrical power by the natural energy, the power consumption by the battery for construction of telemeters and similar for defense against natural disasters by installing equipment outdoors, and to stably acquire data for use in agriculture and fishery. In this study, the authors improved the previously presented system using a Linux microcomputer and a solar power generation remote monitoring system was constructed to grasp the electric power generation amount of the solar power generation equipment and similar from a remote terminal device automatically (Until now, the recording work of the power generation amount was performed manually[4]) with reference to previous publications [5,6]. The voltage, current and electric power data of the solar cell panel, battery and load can be acquired using the proposed system with sensor modules, which is connected to the microcomputer. Moreover these longitudinal data are released from the HTTP sever (This program is also embedded into the microcomputer). Accordingly, the information from remote sensors could be acquire using a Smartphone or laptop pc via the Internet and VPN. Moreover, in this study, longtime observation of a power generation amount of a solar panel, electric power output from the battery and the power consumption of this remote monitoring system and similar were performed by inserting equipment set into the weather resistant case and installing outdoors and connected to the solar cell panel (The panel was also installed outdoors). As a result, it was confirmed that the proposed system can be operated outdoor for long period of time without being affected by the bad weather. Finally, the relationship between the power consumption of the remote monitoring system (which is required to be operated continuously) and a selection condition of the capacity of the solar cell and battery and similar were also studied based on above observed results.

2. System summary

The system newly constructed in this study is based on a combination of a microcomputer for the control of communication with a number of terminal device/sensor information acquisition and sensor modules for actual acquisition of the electrical voltage and current value of equipments as shown in **Fig. 1** and **2**. An INA226 (one chip sensor module IC, Texas Instruments) was chosen to acquire of the current, voltage and electric power value used for this system as shown in **Fig. 3**. A number of addresses can be chosen for communication with microcomputer via I2C (Inter-Integrated Circuit) interfaces when using this IC. The INA226 is the high-precision current shunt monitor IC included the 16-bit A/D converter and the converting time from an analog signal into a digital signal is up to 140μs. Moreover, the shunt resistance value of 0.002Ω a resistor of electrical current measurement was chosen in this current detection circuit of this system. Accordingly, the affect of resistance value increasing in the electric power detection circuit is very low because of the value of 0.002Ω is sufficiently smaller than the resistance of wiring cable. In addition, the upper limit of measurable voltage and current value are DC 36V and ±20A. Where, ± means the two-way electrical current value can be measured using this circuit. Accordingly, this circuit can be used for the monitoring of the charge and discharge phenomenon of the battery because of the current not only flowing out toward the load from the battery but also flows into the battery from the solar cell when using the rechargeable battery. Moreover, an electrical current value in excess of 10A can be measured with a resolution of the mA order without switching the measurement range using this monitoring system because of the value of the shunt resistance element mounted on a circuit board is extremely low. In addition, the electrical current detection circuit in this IC supports both high-side and low-side electric current measurement. The low-resistance value, high-precision and low-temperature coefficient type current sense resistor is employed for current sense circuit in this IC. Accordingly, the measurement precision of the offset voltage and gain error of this circuit are 10μV and 0.1%, respectively. In the proposed system, an I2C interface was adapted for sensor data transfer between the microcomputer and sensor module because of serial data transmission can be realized easily using this I2C interface. I2C is a serial computer bus protocol for the purpose of the communication between chips in an electric circuit. The sensor chip and the microcomputer were electrically connected as described below.

The SCL and SDA terminals of the sensor chip were connected to the SCL (No. 5) and the SDA (No. 3) terminals of microcomputer. Moreover, the VCC and GND terminals of the sensor chip were connected to the 3.3V (No. 1) and the GND (No. 6) terminals of microcomputer. In addition, the electrical connection between a microcomputer and three sensor modules with I2C interfaces were performed by an aerial wiring. The wiring on the board is shown in **Fig. 1**, which highlights the efficient location of devices such as the IC module, microcomputer, terminal block and charge-discharge controller.

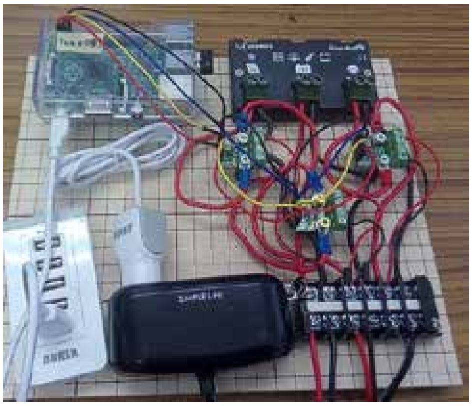

Figure 1 Overview of the proposed system

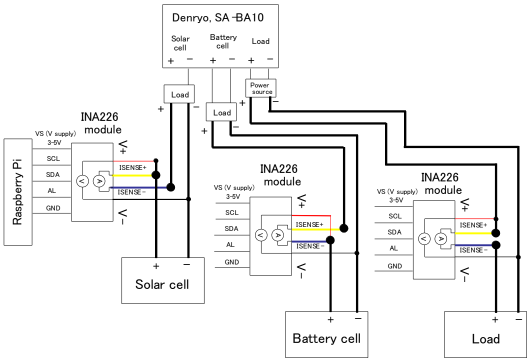

Figure 2 Circuit diagram of proposed system

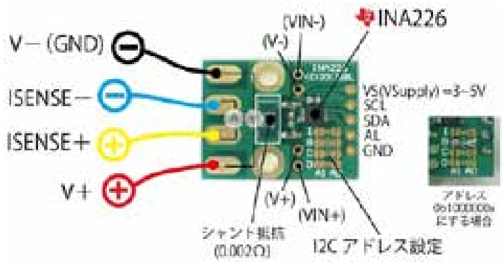

Figure 3 Electrical current and Voltage sense module

In this case, three I2C modules are connected to a microcomputer as shown in **Figs. 1** and **2**. Accordingly, three different I2C addresses should be assigned to each sensor modules for the purpose of a number of the INA226 sensor modules were located on the board and all sensor modules should be communicated with a microcomputer individually using I2C interfaces. In this rearch, 40h, 41h and 42h of three different hexadecimal adress were first chosen, respectively as shown in **Table 1**. Next, soldering of the land pattern for connection of the circuit was performed to correspond to each I2C adresses. Accordingly, above operation provides the individual serial communication between the each I2C modules and microcomputer.

Table 1. Relations with I2C adress and land pattern

I2C Adress	A1	A0
40	G-A1	G-A0
41	G-A1	1-A0
42	G-A1	D-A0

3. Adjustments to enable I2C communication

Next, the following command was input after connection of a sensor to the Raspberry Pi [7] via I2C terminals to enable I2C connection in the above sequence:

sudo nano /etc/modules

The device name “i2c-dev” was then added to the module setting file to enable recognition by Raspberry Pi. The default configuration for modules compatible with Raspberry Pi was also edited, and the black list was adjusted to disable I2C and SPI communication interfaces. Accordingly, the blacklist configuration file was first loaded using

sudo nano /etc/modprobe.d/raspi-blacklist.conf

Next, the line showing “i2c-bcm2708” was removed from the black list by adding “#” to the start of the line. Finally, the file was saved and blacklist file editing was ended using the commands “Ctrl+o” and “Ctrl+x.”

Next, i2c-tools functionality was installed on the Raspberry Pi. I2C is a serial data communication protocol for processor-device communication using SCL (serial clock) and SDA (serial data for bidirectional communication) wires. The circuit consists of a master device and a slave device, and a bus line is also included to accommodate multiple devices. First, the master device chooses the address of the slave device as set in advance when actual communication is made. The master device is then able to communicate with the slave device. The I2C protocol also provides a bit-rate choice of standard mode, fast mode or high-speed mode for transmission. In this study, the acquisition of the electric current, voltage and power data from the sensor modules was performed via the microcomputer from a sensor module using I2C interfaces. Accordingly, the microcomputer was set up by executing the two commands shown below and installing I2C and Python software.

sudo apt-get install i2c-tools
sudo apt-get install python-smbus

After installation of this software, the I2C function of the microcomputer was activated using the advanced options of “raspi-config” (the command for basic microcomputer settings; this process is very important). Once the microcomputer was able to communicate with various sensors using I2C, the following command was input to check the device address:

sudo i2cdetect -y 1

This resulted in output of three hexadecimal expressions “0x40”, “0x41”, and “0x42” as shown in **Fig. 4**, which confirmed that the microcomputer recognized the INA226 shunt current sensor module. The following command was also executed to check communication between the microcomputer and various sensors via the I2C interface:

sudo i2cget -y 1 0x40 0x00 w

This resulted in a response of “0x2741” from the sensor to the microcomputer, thereby confirming correct communication between the two units as also shown in **Fig. 4**.

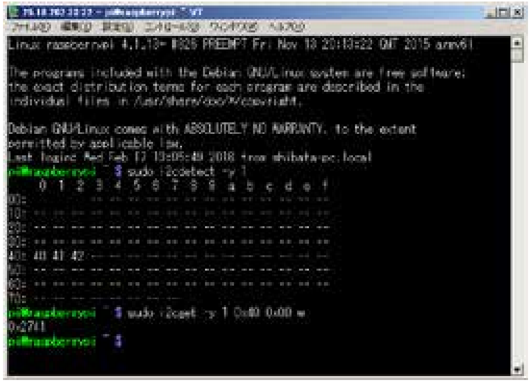

Figure 4 Confirmation of I2C device address and communication via I2C

4. Acquisition of electric current, voltage and power data

Where, the addresses of each resister for the acquisition of the electric current, voltage and power data using INA226 are shown in **Table. 2**. Accordingly, each function will be executed by inputting the command using following addresses.

Table 2. Resister address of INA226 electric current sensor

Pointer address	Resister name	Default value	Read or Write Type
00h	Configuration Resister	01000001 00100111	R/W
01h	Shunt Resistor Voltage Resister	00000000 00000000	R
02h	Bus Voltage Resister	00000000	R
03h	Power Resister	00000000	R
04h	Current Resister	00000000	R
05h	Calibration Resister	00000000 00000000	R/W
06h	Mask/Enable Resister		R/W
07h	Alert Limit Resister		R/W
FFh	Die ID Resister		R

First, the current resister and power resister is enabled by setting the appropriate value to the calibration resister as described later. The setting value for measurement of electric characteristics of the each device can be calculated as follows:

$$2.5\times 2048\div(\text{Shunt resistance value})\ [\text{m}\Omega]$$

Accordingly, the setting value for storing data in resister becomes 2560 when the value of the shunt resister is chosen to be 0.002Ω, thereby it is sufficient to make the calibration resister 05h is set to the hexadecimal expression “0A00h” from the decimal expression “2560” to acquire the exact electric characteristics of a circuit. Accordingly, the following command is then input to confirm the setting of the sensor module.

sudo i2cset -y 1 0x40 0x5a 0x000a w

Next, the voltage of both ends of the shunt resistance of the sensor module was read using following command:

sudo i2cget 1 0x40 0x01 w

From this command, the resulted in output of the hexadecimal expression “0x4201”. Next, the bus voltage was read using following command:

sudo i2cget 1 0x40 0x02 w

The resulted in output of the hexadecimal expression “0xb927”. Where, the hexadecimal expression “27B9” can be transformed to the decimal expression “10169” by the replacement of the first 2digit and next 2digit of this hexadecimal value. Accordingly, an inter-terminal voltage in a [mV] of shunt resistance can be expressed by multiplying above decimal value 1.25 times as follow:

$$10.169\times 1.25=12.711\text{V}$$

The current value of the battery can also be expressed from Ohm’s law as expressed by I=E/R under the condition that R=0.002Ω as follow:

$$I=3.55\times 10^{-4}/0.002=0.177\text{A}$$

On the other hand, the value of the power resister was obtained from the command as follow:

sudo i2cget 1 0x40 0x03 w

The resulted in output of the hexadecimal expression “0xc600”. Moreover, following command was input for acquisition of the value of the current resister:

sudo i2cget 1 0x40 0x04 w

The resulted in output of the hexadecimal expression “0x8f01”. Finally, these results are shown in **Table. 3**. It was thus confirmed that the battery voltage become 12.71V when the microcomputer is in operation. Moreover, it was confirmed that the current value flows out from the battery and the power consumption by the battery become 198mA and 9.98W, respectively.

Table 3. Operation result of measurement value at each resister

Step	Resister Name	Adress	Hex Value	Dec	LSB	Value
1	Configulation	00h	4127h			
2	Shunt Voltage	01h	008Eh	142	2.5uV	3.55×10^{4}
3	Bus Voltage	02h	27B9h	10169	1.25mV	12.711V
4	Calibration	05h	0A00h			
5	Current	04h	00C6h	198	0	198mA
6	Power	03h	018fh	399	$25\cdot 10^{-3}$	9.98W

5. Script-based automatic acquisition of data

The setting and input of commands described in the previous section resulted in the successful output of electric current, voltage and power data from the sensor module. However, such output was not possible without manual input of these commands. Accordingly, a PHP script was created to automate electric characteristics data acquisition with reference to [5]. First, the following setting file was opened using editor software:

sudo nano get_ina226panel.php

Next, the script shown in **Fig. 5** was added to the file. Finally, “Ctrl+o” was used to overwrite the file, and editing was ended with “Ctrl+x.”

```
<?php
// Acquisition of ina226 data

// Write the value of A00h to the Calibration resister
exec("sudo i2cset -y 1 0x40 0x05 0x000a w");

while (1){
  $vol = exec("sudo i2cget -y 1 0x40 0x02 w"); //  Reading voltage resinter
  $anp = exec("sudo i2cget -y 1 0x40 0x04 w"); //  Reading current resinter
  $pow = exec("sudo i2cget -y 1 0x40 0x03 w"); // Reding electric power resinter

  $vol = hexdec(substr($vol,-2).substr($vol,2,2)) * 1.25 / 1000;
  $anp = hexdec(substr($anp,-2).substr($anp,2,2));
  $pow = hexdec(substr($pow,-2).substr($pow,2,2)) * 0.025;

  printf("Panel voltage %.2f V  Current %.1f mA  Output power %.2f W\n",
$vol,$anp,$po$

  sleep(1);
}
?>
```

Figure 5 Automatic acquisition of voltage and current data using a PHP script file

After the previous process, the acquisition of sensor information regarding power generation, residual amount of the battery and similar can be acquired by executing following commands from the Linux command line.

php get_ina226panel.php
php get_ina226battery.php
php get_ina226load.php

Specifically, measurement value of electrical characteristic of the each sensors mounted on equipments were measured from the execution as shown in **Fig. 6**. The results were shown in Table. 4. These results confirmed that generated electric power by the solar cell panel, input/output power for the battery and output power toward the load becomes 11.5W, 8.28W and 2.78W, respectively. Where, the total current flowing trough equipments are generally becomes around 600mA under the condition that 5V load when the Wi-Fi adapter is connected to the Raspberry Pi B+. Accordingly, we confirmed that these results are appropriate value. Moreover, the measured generated electric power by the solar panel using equipments reached 34W after 11:00 on December 26th, 2015 as shown in **Fig. 7**. Thus, electrical characteristic data in decimal form was successfully acquired with single-command input.

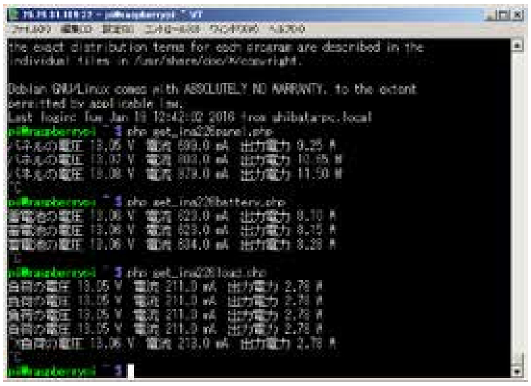

Figure 6 Automatic acquisition results using a PHP script

Table 4. Measurement electrical characteristic using the sensors mounted on equipments

	Voltage	Current	Output Power
Solar cell panel	13.08 V	879.0 mA	11.5 W
Battery	13.06V	634.0 mA	8.28W
Load	13.05V	213.0 mA	2.78 W

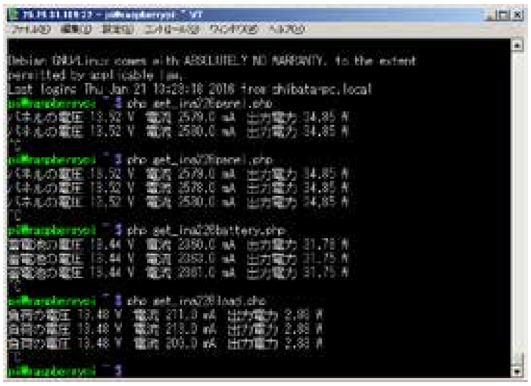

Figure 7 Automatic acquisition results using a PHP script

Moreover, following script was also created to automate longitudinal electric power data acquisition of each equipment with reference to [6]. Specifically, First, the following setting file was opened using editor software:

sudo nano /home/pi/get_ina226panel0a.php

Next, the PHP script shown in **Fig. 8** was added to the file. Finally, “Ctrl+o” was used to overwrite the file, and editing was ended with “Ctrl+x.”.

```
<?php
// Acquisition of INA226 data
// Writing “A00h” to Calibration resister
exec("sudo i2cset -y 1 0x40 0x05 0x000a w");
  $vol = exec("sudo i2cget -y 1 0x40 0x02 w"); //  Reading Voltage resinter
  $vol = hexdec(substr($vol,-2).substr($vol,2,2)) * 1.25 / 1000;
  printf($vol);
?>
```

Figure 8 Edited content of PHP script file

However, as only the root user can execute the generated script file “get_ina226panel0a.php,” execution authority was granted to all users with the following command from the Debian OS command line:

sudo chmod u+x get_ina226panel0a.php

Next, access authority was extended to other users with the following command:

sudo chmod 774 /home/pi/get_ina226panel0a.php

Finally, the following command was input:

php /home/pi/get_ina226panel0a.php

This resulted in the output of “11.34V” as shown in **Fig. 9.**

Figure 9 Automatic acquisition results of voltage data using a PHP script

6. Acquiring of time-series data on voltage, current and power at each observation points

The PHP script as shown in **Fig. 10** was edited to enable output and display of time-series voltage, current and power value using Munin software (These electrical characteristic values are observed by the sensor module INA226). Next, this script file was saved to “/usr/share/munin/plugins/solar”. And then, access authority was extended with a command of “chmod 775 solar”.

```
#!/bin/bash

 #%# family=auto
 #%# capabilities=autoconf

available="yes"
case $1 in
config)
    echo "graph_title Solar Power Generation Voltage/Power"
    echo "graph_category solar"
    echo "graph_vlabel Voltage(V) / Power(W)"
    echo "graph_args -l 0 –base 1000"
    echo "voltage.label Voltage"
    echo "voltage.draw LINE2"
    echo "power.label Power"
    echo "power.draw LINE2"
    exit 0
    ;;
autoconf)
    if [ "$available" = "yes" ]; then
      echo "yes"
      exit 0
    else
      echo "no (daemon isn't running)"
      exit 1
    fi
    ;;
snmpconf|suggest)
    exit 0
    ;;
*)
    ;;
esac
# Data reading
SOLAR=`php /home/pi/get_ina226panel0a.php`
SOLAR1=`php /home/pi/get_ina226panel0b.php`
echo "voltage.value $SOLAR";
echo "power.value $SOLAR1";
```

Figure 10 Munin script for acquisition of electric power generation amount

Next, a symbolic link was also generated using the following command:

sudo ln -s /usr/share/munin/plugins/solar /etc/munin/plugins/solar

Moreover, the following setting file was opened using editor software for the purpose of the Munin software can acquire the value from the sensor module as root user:

sudo nano /etc/munin/plugin-conf.d/munin-node

Next, these texts were added to the above setting file of Munin software.

[solar]
user root

[solar1]
user root

[solar2]
user root

Finally, Munin was restarted using the "sudo munin-node restart" command after the previous process had been killed.

After the setting of above software, we installed a set of the equipments on campus of Hachinohe institute of technology as shown in **Fig. 11**. Moreover, a 50W solar cell panel was installed on the flat roof of School building as shown in **Fig. 12**. And then, the solar panel was connected to the remote monitoring system via power cable by performing waterproof treatment.

Figure 11 Details of operation status in a remote monitoring system

Figure 12 Installation of solar cell panel on the flat roof of the building

We performed the long-time observation of the power generation amount by the solar cell panel, power consumption of remote monitoring system and similar during continuous operation of proposed system for more than one month since the end of December, 2015. As a result, voltage and electric power time-series data of solar cell panel, battery and load were successfully acquired as shown in **Figs. 13** and **14**. Accordingly, the consideration about above results was performed as follows:
First, it was confirmed that the power generation of more than 40W instantly from the graph of temporal variations in generated power and voltage during the two days from December 29th and 30th, 2015 in **Figure 13**. However, a large difference is seen between the power generation amount by the difference of the weather in fine or cloudy. Moreover, it can be seen that average generated power, including the non-power generation period at night is 3.3W in this measurement time period. Accordingly, the power consumption must be less than around 3.0W in Hachinohe region for always-on operation of this remote monitoring system when 50-watt solar cell panel was chosen. Accordingly, it was also confirmed that it is difficult to maintain operating the remote monitoring system with this conditions.

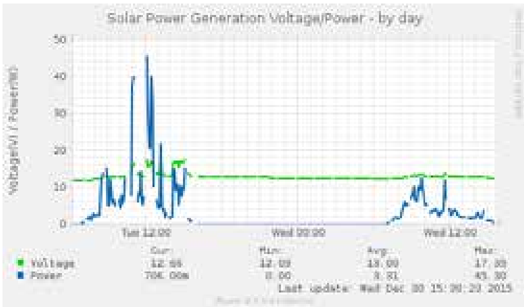

Figure 13 Two-day temporal variations in voltage/generated power of solar cell panel

On the other hand, the power consumption of this solar power generation remote monitoring system with microcomputer operation using a raspberry Pi becomes constant value of around 3.0W for two days as shown in **Fig. 14**. On the other hand, the both terminal voltage of an output load changed from 17V to 12V due to the effect of the power generation by the solar cell panel and the power consumption by output load. Moreover, **Figure 15** shows that time-variation in power generation and voltage by the solar cell panel of one week from December, 28th, 2015 to January, 5th, 2016 in Hachinohe city. The results show that the day gained enough power generation amounts was limited to 2 day on December 31st, 2015 and Janually, 5th, 2016.

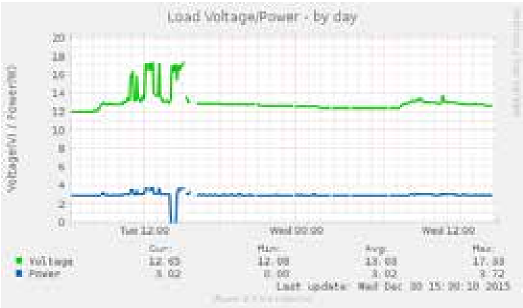

Figure 14 Two-day temporal variations in voltage/power of output load

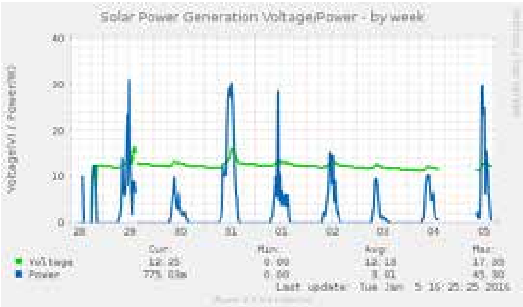

Figure 15 Reconrd of generated power by solar cell panel by week

However, thereafter, the proposed solar power generation remote monitoring system recorded the largest power generation on January, 22nd, 2016. A distinct difference can be seen between the 1st day and 2nd day as shown in **Fig. 16**. Specifically, a time in which the power generation amount continuously exceeds 35W is 3 hours or more on January, 22nd. Accordingly, I believe that the power generation amount exceeds $35 \times 4 = 140$Wh by considering an integration of the power generation amount at any time other than at 11:00 to 14:00. Where, a day's exact total power generation amount can be calculated by an integrated value in which instantaneous values of a power generation is time-integrated (arc area). Accordingly, embedding the program on the basis of above method to the proposed system is needed to grasp the exact power generation amount. On the other hand, these resulting values are considered to correspond to the champion data because of the characteristic curves of the power generation on that day drawn an ideal arc. Moreover, it was also confirmed that the power generation significantly reduces after 3PM from this Fig.. The reasons for this reduce of power generation are an increase of an incident angle of the sunbeam to the solar cell panel because of the sun declines to the west.

Moreover, things such as the following have come to light from these observations about for a month. It was confirmed that there were dates not to gain the generated electric power continuously over a period of several days in the winter. Accordingly, more large capacity type battery is needed for consumption of the electric power (It is stored on fine days) spending a long time. From these results, we could grasp an approximate generation characteristic using the solar cell panel in Hachinohe city. Accordingly, a study about the possibility of the continuous operation of equipments by the solar power generation in winter is needed in relation to Hachinohe's climate by continuing the long-term correction of data for the improvement of proposed system.

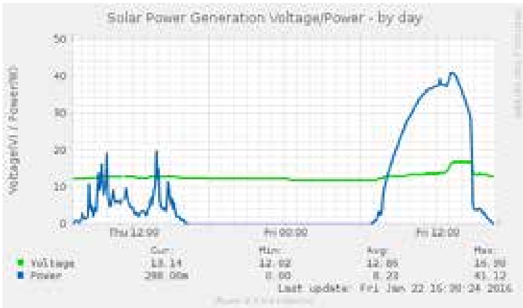

Figure 16 Power generation characteristic in the fine weather

7. Track recoard of outdoor installation and manufacturing cost

This system was expected to use in Hachinohe city, whose climate is cool and harsh in winter due to its location in a near-subfrigid zone. Accordingly, a set of system was enclosed in a water proof and weather resistant type case and installed this system outdoor. Next, the continuous operation test of proposed remote monitoring system was performed with also installing the solar cell panel outdoors for more than a month. This characterization is shown in **Fig. 17** to **19**. Moreover, the proposed system is performed the continuous stable operation in the spite of the heavy snow day as shown in **Fig. 20**. Finally, it was confirmed that the proposed system can be operated through long-time temperature cycle test from the result of above continuous stable testing operation including snowy, storm and rainy days. In near future, performing of the continuously conduct an operation test over more long period, especially by rise of ambient temperature in summer is also needed.

Figure 17 Machine operation status in fine weather

Figure 18 Machine operation status in the snow

Figure 19 Machine operation status in a heavy snowfall

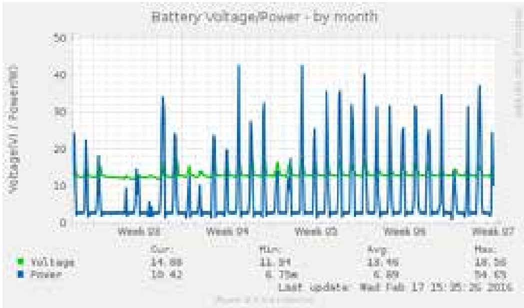

Figure 20 Machine operation status in a month

The name and price of primary equipments and parts for the construction of proposed remote monitoring system were listed as shown in **Table 5**. It was confirmed that the total price of this system is about JPY45000 per one system. Moreover, the cost of the solar cell panel and battery make up most of the total. On the other hand, the proposed system can also be applied in science teaching material, which can confirm the electric power generation condition by the solar cell. It is important to save power of the whole system by reducing the power consumption with a smaller wattage than that of a previous power consumption of 3.0W in the performance of microcomputer and each device. By these improvements, drastic const reduction is enabled by selecting the more low cost type solar cell panel and battery. In near future, additional study to reduce cost, consumption power and space by using the microcomputer and peripheral device which is small in power consumption is needed.

Table 5. Part list to construct the proposed remote minitoring system

Product name	Model number	Quantity	Price [JPY]
ARM-Linux microcomputer	Raspberry Pi 1 B+	1	3200
Wi-Fi Adapter	WLI-UC-GNM2		1500
TEXAS INSTRUMENTS Electric current and voltage Sensor module	INA226	3	1200
Battery （12V,12Ah）	WP22-12NE	1	7000
Solar cell panel	AT-MA50A	1	15000
Cahage-discharge controller	SA-BA10	1	5000
Solar cell panel connection cable	2SQ：H-CV(MC4)	1	4000
TAKACHI, Water proof type case	BCAP303018T	1	5000
TAKACHI, Attached base	BMP3030W	1	1500
TAKACHI, mounting feet for fixing	CK-26P or BFL-2	1	500
MIRAFLEKI-SS	MFS-16 (50 scroll)	1	500
PF pipe connector	MFSK-16G（10items）	1	300
Terminal block (6 terminals)	T10-06PM	1	300

8. Conclusion

In this study, a compact and inexpensive solar power generation remote monitoring system at low operational cost was constructed with the Linux computer operation and an embedded VPN. Moreover, the method for electric current, voltage and power data acquisition and information disclosing were also studied to grasp the power generation of the solar cell and charge-recharge condition of the battery in remote locations. The results of the study conducted indicate that longitudinal data on electric current and voltage can be easily acquired and remote-monitored in the long-term by connecting a sensor module featuring I2C interfaces to the microcomputer. Moreover, it was also confirmed that the proposed system can be perform the continuously operating over a long period of time despite the heavy snowfall by performing the long-term operation test by inserting into a waterproof and weather resistant type case and installing the set of the apparatus outdoors. In future work, it will be necessary to study the power saving by replacing the microcomputer and peripheral devices and reducing the capacity and size of a solar power cell panel and battery. On the other hand, the validation of the possibility of the long term operation by continuously testing under the blazing sun by installing outdoor in summer is also needed. Moreover, we also have plans to acquire the data by installing this system at a public institution and local tourist spot outdoor in Hachinohe city. Moreover, expansion as an electric and electronic engineering education by mass teaching of the advanced manufacturing and programming of this system is also needed. In addition, an act of meeting a requirement regarding the education of science, disaster prevention and environment problems by distributing this system to the elementary and middle schools and similar of the city and performing a visiting lecture is important issue. Moreover, in future work, the authors plan to clarify the relationship between electric power generation amount and sunshine quantity with the system set up in combination with temperature, humidity and sunshine quantity sensors and similar.

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