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In Situ Solar Panel Output Power Measurement Related To Climate Parameters Using Digital Recording

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***Abstract*—Solar energy in tropical area is one of potential renewable energy due to the sun's presence throughout the year regardless of the seasons (dry or rainy). The output power of the solar panel depends on climate parameters including solar radiation, humidity, cloud, rain, and dust decomposition. This paper explores the climate parameters that potentially affect the output power of solar panel and estimates the solar energy in such regions based on their climate parameters. To measure the climate and electric data, this work develops in house digital climate and electrical data recording that saves the data of humidity, wind speed, temperature, solar irradiance, current, and voltage sensors. The data are analyzed by equation of correlation between climate parameters, power output and solar panel temperature. The prototype of digital recording is tested at Politeknik Negeri Semarang located on latitude -7.054044 and longitude 110.434695 during dry season. Based on the correlation analysis of several climate parameters to solar panel output power, the correlation value of the humidity is -0.85, ambient temperature=0.87, solar irradiance=0.98, wind speed= -0.34 and cell temperature=0.83. This work can be used to estimate the solar panel output power in specific location using climate data.**

Keywords*—*solar panel, output power, climate, digital recording, correlation

I. Introduction

The electric power produced by PV panel is influenced by climate or weather parameters. Several parameters affect its power output involving temperature [1], and solar irradiance [2]. On the other hand, performance degradation due to the kind of materials [3] and dust deposition [4] can reduce its power output. Although in tropic areas the sun shines along the year during dry or rainy season, the solar energy cannot be obtained maximally due to the factors mentioned which reduce the solar energy. Knowing the potency of solar energy related to climate in such regions will help to design solar home system based on the loads of electricity. Generally parameter measurements are focused on several aspects namely solar irradiance, ambient temperature, module temperature, voltage, and current of PV module. This paper explores the climate and electrical parameters measurement mentioned above and it is expanded to other climate parameters such as humidity and wind speed utilizing data logger instrument developed using electronic sensors, microprocessor, and arduino system. The results of this research describe the correlation between climate parameters including solar irradiance, temperature, wind speed, and humidity with solar energy produced by PV module 50 WP in tropic areas. This paper is organized as follows: section 1 explains the introduction while section 2 reviews the related works regarding the topic of monitoring system of climate and electrical data using data logger. Section 3 explores the system design whereas section 4 discusses the testing and result. The final part concludes this research.

II. Related works

Investigation on the factors affecting the output power of solar module has been conducted by many researchers in the last few years using data logger to record several parameters of climate and electrical of PV system. Mellit and Pavan (2010) investigate the effect of solar irradiance, module and ambient temperature related to output power of 20 kWp grid-connected photovoltaic plant [5]. This work developed the data logger to record three such parameters and predicted the performance using Artificial Neural Network – Back Propagation. Other research carried out the characterization of PV CIS module based on ambient and module temperature, solar irradiance, voltage and current of 40-Wp Shell ST40 CIS module [6]. Digital data logger is also utilized in data acquisition of PV for water pumping system in desert of Tunisia that record the parameters such as water flow rate, global irradiation on an inclined and horizontal surface, voltage and current of photovoltaic field and ambient temperature. The data are transmitted to data center using satellite, radio, GSM, and GPRS [7]. Several researches also developed the instruments of data logger to save the data of climates and solar energy measurement using electronic sensors, microprocessor, and arduino [8].

Generally parameter measurements are focused on several aspects namely solar irradiance, ambient temperature, module temperature, voltage, and current of PV module. This paper explores the climate and electrical parameters measurement mentioned above and it is expanded to other climate parameters such as humidity and wind speed utilizing data logger instrument developed using electronic sensors, microprocessor, and arduino system. The results of this research describe the correlation between climate parameters including solar irradiance, temperature, wind speed, and humidity with electric power produced by PV module 50 WP in tropic area.

III. Research Methodology

A. Developing Climate and Electrical Data Recording System

There are two main parts of digital recording system including hardware and software components. In this system, hardware components involve solar panel 50WP, climate sensors (humidity, solar irradiance, wind speed, and temperature), electrical sensors (current and voltage), accumulator, microprocessor ATMEGA 32 and arduino kit. On the other hand software component utilizes arduino and CodeFusion AVR program to process data carried out from sensors and transmit to the computer using USB connection or Ethernet. System Design of climate and electrical digital recording is illustrated in Figure 1.

Figure 1 describes the architecture of climate and electrical digital recording system. This device can record climate and solar panel electrical data simultaneously. Climate data include temperature, wind speed, humidity, and solar irradiance while electrical data consist of voltage and current of solar panel. The architecture is composed four main components namely solar panel, master module, slave module, and accumulator. Solar Panel generates the electric voltage and current by converting solar irradiance to electricity. Slave module consists of several sensors (temperature, humidity, wind speed, solar irradiance, current and voltage), processor unit ATMEGA 32, and serial interface RS485. Master module comprises serial interface RS485, processor Arduino Mega, LCD graphic display, Real Time Clock, SD Card memory unit, Ethernet and USB interface. Accumulator or battery provides electricity to electric unit especially master and slave module.

Two programs are used in this device such as programs of slave module ATMEGA 32 (code fusion) and master module ARDUINO MEGA (arduino). Data from multiple sensors are processed by code fusion program in ATMEGA 32 processor and converted to serial data format using RS485 interface. The arduino program of Arduino Mega processor receives serial data from slave module containing the data of sensor measurements and processes them into the information displayed in LCD screen, plain text data saved in SD Card, and provides the data to be accessed by computer via USB and Ethernet ports. The flowchart of program is depicted in Figure 2.

Figure 2 describes the flow chart of slave module program developing by code fusion for ATMEGA 32. Slave modul receives data input from several sensors furthermore the processor calculates, processes, and converting the data to RS485 format. Firstly, the program defines I/O pins connected to the sensors SHT11, LM35, BH1750, Wind speed, current, and voltage. It also defines the variables will be used for the next codes. The program is also initializing Analog Data Converter (ADC), Serial UART with 9600 baud rates, 8 bits data, non parity, 1 bit stop, I2C, Interrupt Timer, Init Counter, and sensor BH 1750. Furthermore the program waits for 1000 milliseconds and resets the communication to sensor SHT11. The next process is calling the procedure of Lux meter reading to process data from BH1750 sensor and the data collected are saved to variable Intensity. The next step is executing the procedure of SHT11 reading that collects the hummidity and ambient temperature data and loads to variable temp1 and Hum. After that, the process calls the procedure ADC which reads the data carried out from the analogue sensors of LM35 (temperature of cell), Current, and Voltage. The data collected are saved to variable Temp2, Current, and Volt. The last step is reading the wind speed from the wind speed sensor and it is assigned to variable wind_speed. If the program is not stop the process goes to BH1750 initialization. There is another process performed while the register TCNT0 is overflow. This process is called Interupt Timer that inverts the Led status and set the Led to blink. Furthermore the program sends the data measurement from variables Intensity, Temp1, Temp2, Hum, wind speed, Current, and Volt to the serial port in RS485 format. The last step is re-initialization of TCNT0 value and back to the beginning (return).

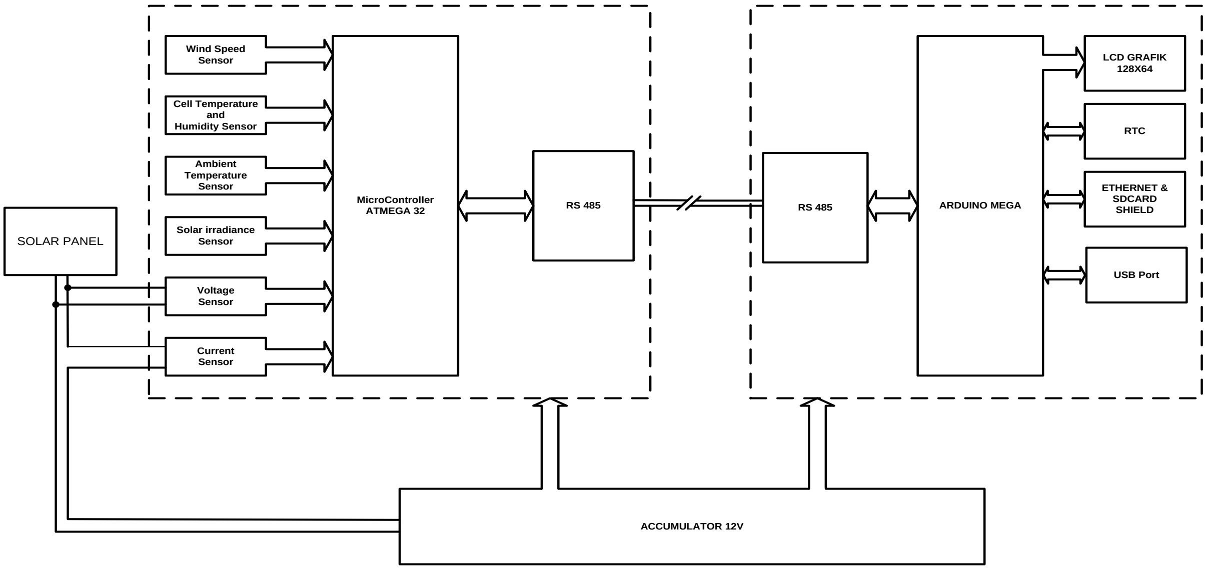

Figure 1. System Design of Climate and Electrical Digital Recording

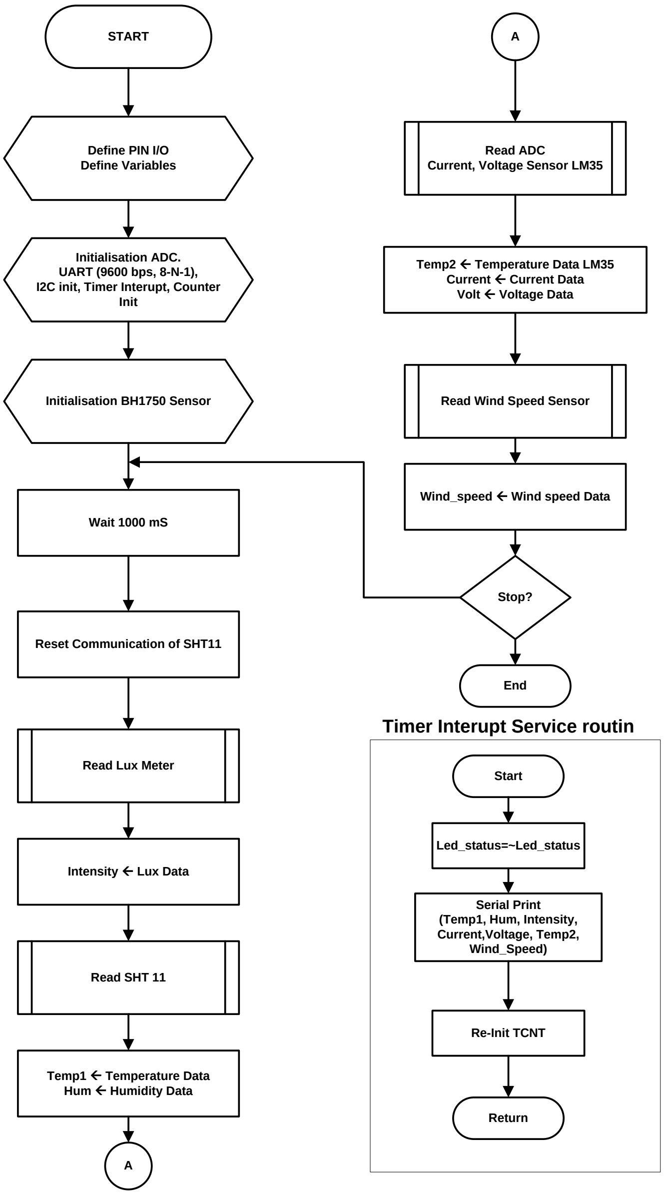

Figure 2. Flowchart of Slave Module Program

Figure 3 explains the flowchart of master module that receives the data from slave module via serial port RS485 and processes measurement data for displaying to the LCD display, transfers to the computer using USB port or ethernet, and saves to the memory card. Firstly program defines used I/O pin and declares the variables. Then the program detects the UART Serial0 and Serial1 with 9600 baud rates, initializes Real Time Clock (RTC), SPI for ethernet, and SD Card. The next step is calling the procedure to clear LCD dsiplay, furthermore the program calls procedure to get data of date and time from RTC and assigns to the variables second, minute, hour, date, month, and year. After defining and initializing I/O, variables, and RTC, the program reads the data in serial1 port. If the data existing in serial1, then the variable DataIn is loaded with the serial1 data up to the ENTER character ('\r') and variable Parsing is set to TRUE. This process iterates until all of the serial1 data is filled into DataIn. The next step is data parsing by separating group of data into the value indicating the measurement values involving temperature (cell and ambient), wind speed, solar intensity, voltage, and current. The program sets the Parsing to FALSE and reads the Serial0 and Ethernet ports. If the character obtained of two such ports is 'Q', then the data will be sent to the computer via Serial0 and/or Ethernet. The last step is showing the parameters including date, time, and measurement values to the LCD display and records them to the SD Card. Finally the program is return to Get Time RTC if the system does not go to stop.

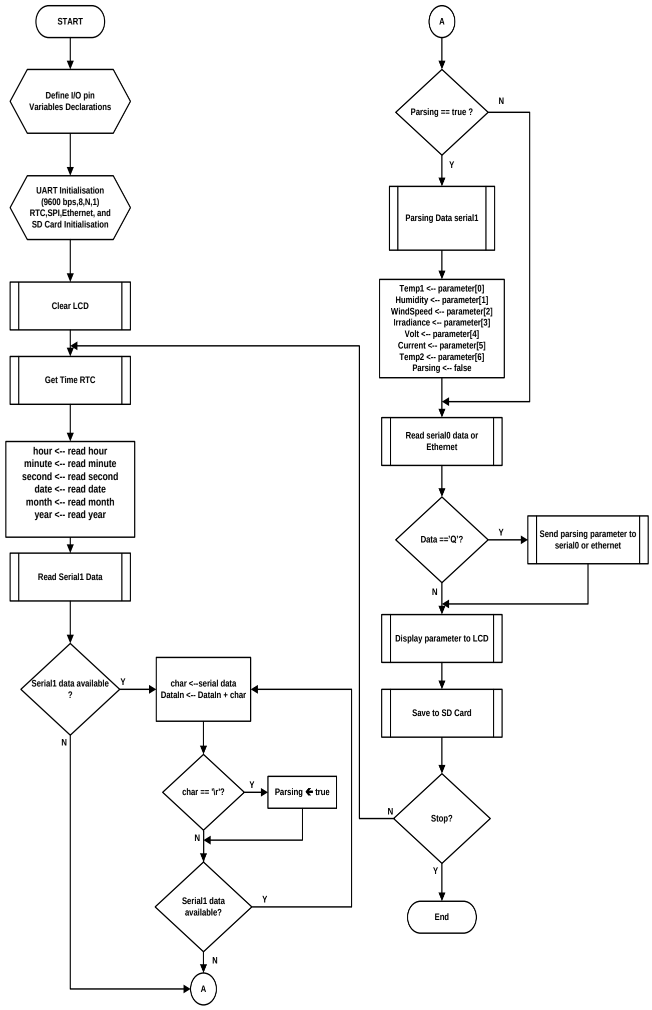

Figure 3. Flowchart of Master Module Program

B. In Situ Measurement

The digital recording system including hardware and software komponent has been developed and it is ready to test. The testing involves laboratory and in situ/outdoor testing. Fig. 4 illustrates the testing functionality of system in Laboratory of Politeknik Negeri Semarang. In this testing, each sensor carries out the data measurement according to the environment. The values shown in LCD display are compared to the other measurement devices (such as Lux meter, anemometer, thermometer, etc) to calibrate and get the percentage of error. Due to comparison of their result, the percentage of error is about 2%.

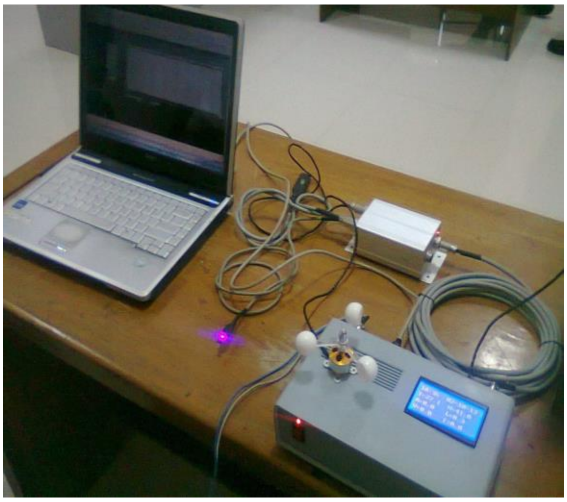

Fig. 4 Laboratory Testing

After conducting the laboratory testing, the device was tested outdoor where the solar panel and sensors are placed in 8 meters pillars (Fig.5).

Fig. 5 In situ testing

Fig. 5 illustrates in situ testing of climate and electrical data measurement. All of the sensors are placed around the solar panel. The measurement is performed on on October 13rd 2014 (one day) in sunny weather. The result of the measurement will be discussed in section 4.

C. *Analyzing Data using Correlation*

The data obtained from the sensors are saved to the data base using a software via USB port. The data are analyzed with Pearson correlation equation to get the correlation value between each climate parameters and ouput power of solar panel. The equation is stated as follow:

$$r = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{[n\sum x^2 - (\sum x)^2][n\sum y^2 - (\sum y)^2]}} \quad (1)$$

Where r : value of correlation
x : each climate parameter
y : output power of solar panel.

The result of r will be -1 up to 1 and it is so rarely get the value 0, -1, or 1. The result can be grouped as three catagories :

- High correlation : 0.5 to 1.0 or -0.5 to -1.0
- Medium correlation : 0.3 to 0.5 or -0.3 to -0.5
- Low correlation : 0.1 to 0.3 or -0.1 to -0.3

IV. Result and discussion

The location of testing is located on latitude -7.054044 and longitude 110.434695 in Semarang Indonesia. Measurement interval to read the data is 1000 milliseconds. The sample of data measurement is described in Table 1.

TABLE VIII. CLIMATE AND ELECTRICAL DATA

Data	Time	Tm	RH	v	Gi	Tam	Vm	Im	P
1	11:33:44	48.2	16.7	1	45695	41.2	15.8	3.4	53.72
2	11:33:45	48.1	16.8	1	45697	41.2	15.8	3.4	53.72
3	11:33:46	48.1	16.9	0.3	45724	41.2	15.8	3.4	53.72
4	11:33:47	48.1	16.9	0.3	45724	41.2	15.8	3.4	53.72
5	11:33:48	48.1	16.9	0.3	45724	41.2	15.8	3.4	53.72
6	11:33:49	48.1	16.9	0.3	45724	41.2	15.8	3.4	53.72
7	11:33:50	48	17	1.2	45875	41.3	15.8	3.4	53.72
8	11:33:51	48	17	1.2	45875	41.3	15.8	3.4	53.72
9	11:33:52	48	17	0.5	45938	41.2	15.8	3.4	53.72
10	11:33:53	48	17.1	0.5	45973	41.2	15.8	3.4	53.72
11	11:33:54	48	17.1	0.5	45973	41.2	15.8	3.4	53.72
12	11:33:55	48	17	0	45970	41.2	15.8	3.4	53.72
13	11:33:56	48	16.9	0	45988	41.2	15.8	3.4	53.72
14	11:33:57	47.9	16.9	1	46039	41.2	15.9	3.4	54.06
15	11:33:58	47.9	16.9	1	46000	41.2	15.9	3.4	54.06
16	11:33:59	47.8	17	1.4	46045	41	15.9	3.4	54.06
17	11:34:00	47.7	17.1	1.4	46039	40.8	15.9	3.4	54.06
18	11:34:01	47.7	17.1	1.4	46039	40.8	15.9	3.4	54.06
19	11:34:02	47.7	17.1	1.4	46039	40.8	15.9	3.4	54.06
20	11:34:03	47.3	17.4	2.2	46014	40.7	15.9	3.4	54.06

Where: Tm : Temperature of Module/Solar Panel (C)
RH : Relative Hummidity (%)
v : Wind Speed (m/s)
Gi : Solar Irradiance (Lux)
Tam : Temperature of Ambient (C)
Vm : Voltage of Module (Volt)
Im : Current of Module (Ampere)
P : Electric Power Vm x Im (Watt)

In this measurement, the software acquired 38013 rows of measurement data. The charts of climate data comparing to output power (P) as follows:

A. *Temperature of Module and Output Power*

Fig. 6 illustrates the chart of module temperature and output power. Temperature of module (Tm) goes down regarding to the time when the day towards the evening. The maximum Tm is 55.2 °C while minimum Tm is 31 °C, and average is 36.11 °C. The output power (P) data are also getting down towards the evening. The maximum, minimum, and average of P are 56.00 W, 5.40 W, and 26.41 W. There is P data indicating going down immediatelly at 11:44:42 AM. The output power decreases from 47 W to 27 W due to the reducing of solar irradiance from 42,393 lux to 23418 lux. This phenomenon was also occured at 12:12:46 PM, 12:13:13 PM, 12:27:02 PM, etc. The correlation between Tm dan P is depicted in Fig. 7. The correlation (r) of module temperature and output power is 0.83 (high positive correlation)

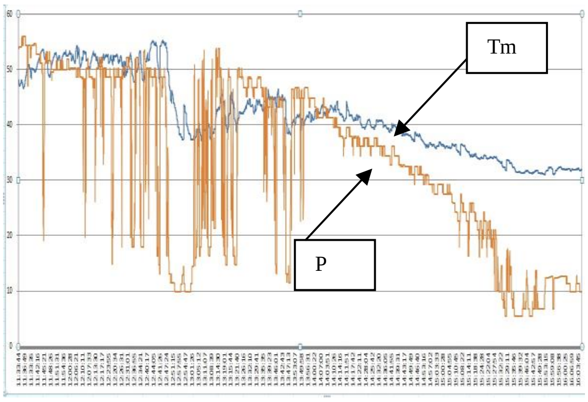

Fig. 6 Chart of Tm and P

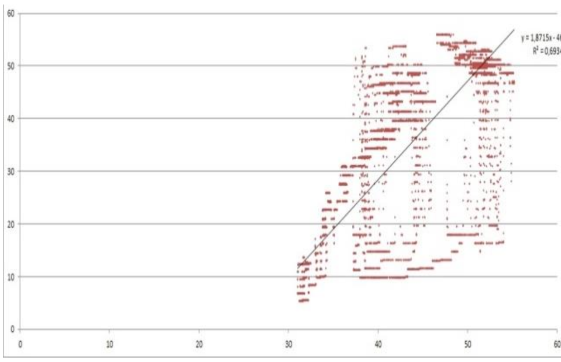

Fig. 7 Correlation Chart of Tm and P

B. Hummidity and Output Power

Fig. 8 describes the chart of hummidity and output power while Fig.9 shows their correlation. Based on the equation, the correlation is -0.85 (high negative correlation)

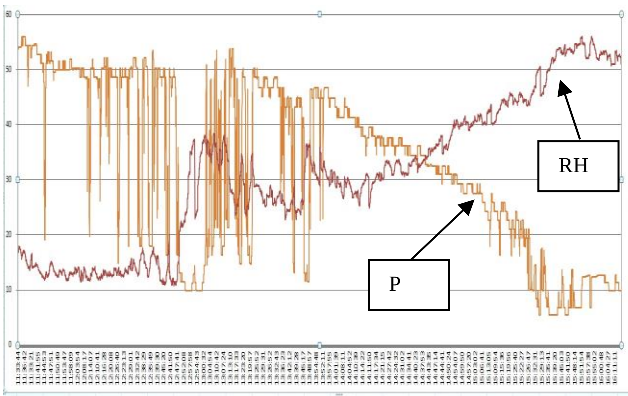

Fig. 8 Chart of RH and P

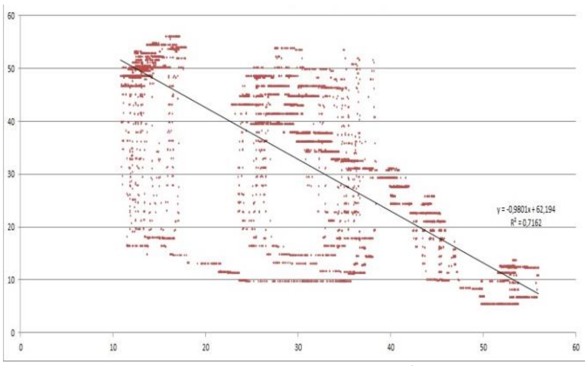

Fig. 9 Correlation Chart of RH and P

C. Wind Speed and Output Power

Fig. 10 and 11 explain wind speed and output power chart and their correlation. The result show that the correlation is -0.34 (medium negative correlation)

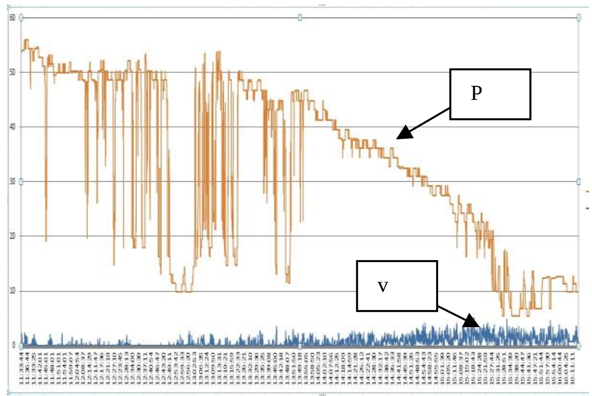

Fig. 10 Chart of v and P

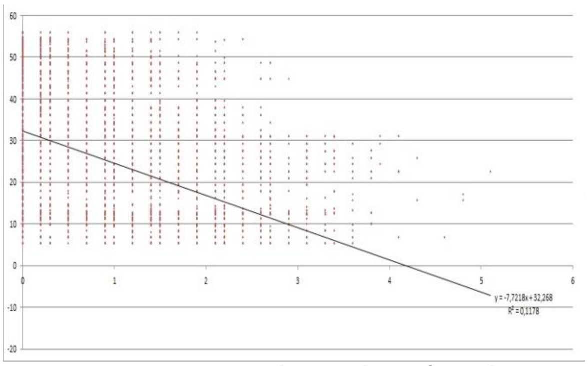

Fig. 11 Correlation Chart of v and P

D. Solar Irradiance and Output Power

Solar irradiance (Gi) is the most influenced factor to produce the power ouput of solar module. Fig. 12 shows the chart of solar irradiance and output power while Fig. 13 illustrates their correlation. Value of r is 0.98 (high positive correlation)

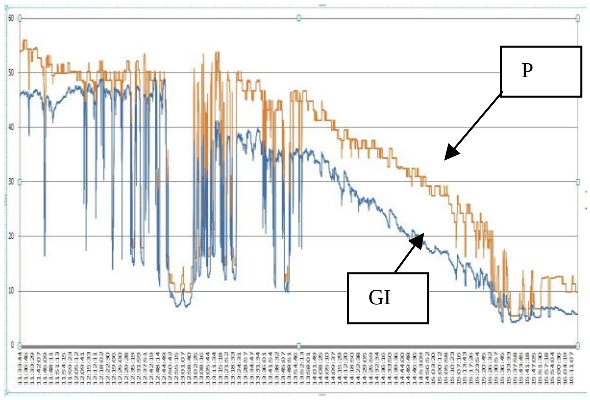

Fig. 12 Chart of Gi and P

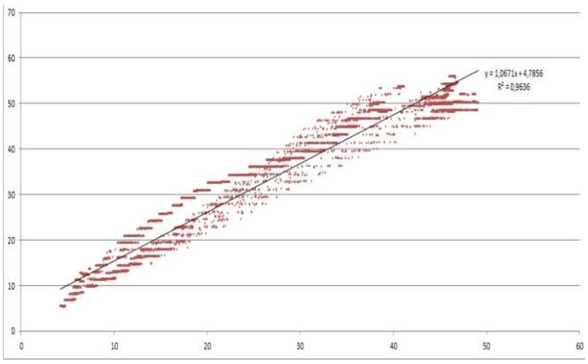

Fig. 13 Correlation Chart of Gi and P

E. Ambient Temperature and Output Power

Ambient temperature (Tam) is also affecting the power ouput of solar module. Fig. 14 shows the chart of ambient temperature and output power while Fig. 15 illustrates their correlation. Value of r is 0.87 (high positive correlation)

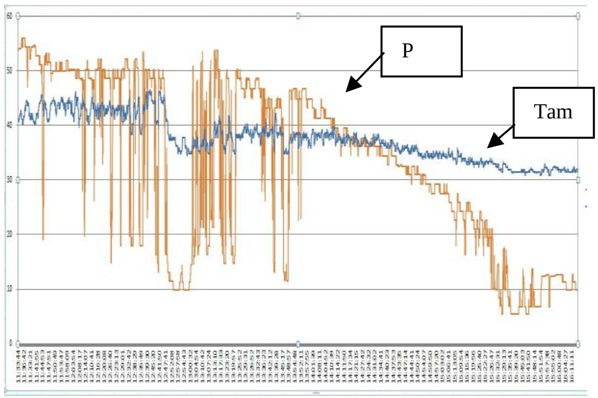

Fig. 14 Chart of Tam and P

The results can be summarized in Table 2.

TABLE IX. CORRELATION RESULTS

Parameters	r(correlation)	R^2	Description
Tm	0.83	0.69	high positive correlation
RH	-0.85	0.72	high negative correlation
v	-0.34	0.12	medium negative correlation
Gi	0.98	0.96	high positive correlation
Tam	0.87	0.75	high positive correlation

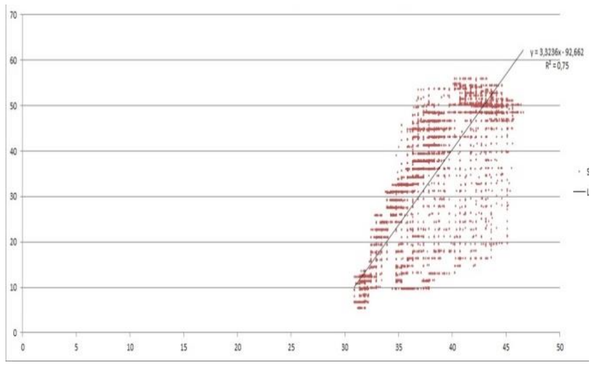

Fig. 15 Correlation Chart of Tam and P

V. Conclusion

This paper has explored the in situ measurement of climate and electrical parameters in solar module environment. Digital data recording or data logger has been succesfully developed and tested in Politeknik Negeri Semarang based on electronic sensors and arduino. The results show that the correlation betwen Tm, Tam, v, RH, and Gi to the output power of solar module are 0.83, 0.87, -0.34, -0.85, and 0.98. Future work is obtaining data measurement in rainy season and utilizing dry and rainy season as learning and testing data for intelligent software.

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