Dhaka Univ. J. Sci. 65(1) 67-72, 2017 (January)

A Data Acquisition System for Solar PV Module with Variable Load

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(Received: 20 June 2016; Accepted: 3 October 2016)

Abstract

This paper describes the design, development and performance of a locally developed data acquisition system for solar PV module with variable load. The system can automatically change the operating point of a PV module and acquire the output voltage and load current into computer and then analyze. To change the operating point, a variable load has been developed by *IRF250* MOSFETs. The current drawn by the load from the PV module is controlled by a staircase voltage, which is developed by a counter and a DAC. The count value of the counter and hence the voltage level of the staircase is changed by an Arduino-based controlling unit. To get the short-circuit current, the PV module is connected in series with a high ampere power supply and the voltage across the PV module is conditioned by a difference amplifier and fed to an ADC channel of the controlling unit. The output current of the PV module has been sensed by a Hall sensor, *ACS712*, and read by another ADC channel. To make the whole system automatic, a program has been developed using Arduino IDE and loaded in the Arduino board. With the help of this program, the system can measure the current and voltage of the PV module and send to a PC. This acquired data is processed by software and the performance of the PV module is obtained. The system has been developed in laboratory and its performance has been studied. Although, there are some fluctuations in the acquired data but with filtration satisfactory performance is obtained. This instrument can be used for PV module testing purpose.

Keywords: Solar PV Module, I-V Characteristics Curve, Hall-Current Sensor, Staircase Voltage Generator, Active Load, Differential Amplifier, Arduino Uno, etc.

I. Introduction

For its outstanding advantages solar Photovoltaic (PV) energy technology has already proven its potentiality as an alternative source of energy all over the world. This abundant and free form of energy has been under-exploited or less-exploited for a long time. Recently, Bangladesh government has given emphasis in this sector.

The government of Bangladesh has declared its vision to provide electricity for all by the year of 2020[1]. To fulfill this objective, utilization of photovoltaic energy technologies must play a vital role for off-grid solar electrification. The government has set its vision in the field of renewable energy – by the year of 2015, 5% of total generation and by the year of 2020, 10% of total generation[2] will be produced from renewable energy. To achieve the target, Government has taken various initiatives. Solar PV system installation has made mandatory for new connection of electricity[3]. The government is making the standard of Solar PV and other related equipment for Bangladesh and setting the Feed-in Tariff (FIT), giving permission to install Mega-Watt solar power plants and to sell the electricity to the national grid, etc.

As a result, solar photovoltaic electricity has become a promising alternative source in our country. It constitutes an important application of solar photovoltaic for the purposes like operating lights, fans, TV, mobile charger or even water pumping for both drinking and irrigation. By now, about 4.5 million Solar Home Systems have been installed all over Bangladesh[4]. The use of grid-tied systems is increasing in the urban landscape. Moreover, in the remote rural area, the use of solar based mini-grid is increasing. The government has made a map of location where there is no chance of installing REB line. As a matter of fact, many business companies have started business in this field. They import PV modules from abroad, mainly from China and sell in the local market. As the Chinese product has various qualities, some business men are importing low-quality modules for more profit. Hence, to ensure quality and to maintain the newly developed BSTI standard, we have to perform quality test of these modules. But, the equipments necessary to test the PV modules are very costly. The lowest price of a sun simulator is about 20 to 30 lakh BDT[5]. Hence, with an aim to develop a low-cost PV module tester, using local technology, this work has been done. Many researchers have done research on I-V curve tracing, modeling of PV modules, MPPT designing for PV etc.[6-16]. In Bangladesh, some work related with this has been done previously[17-18]. The limitation of one paper is, here Pico data logger has been used which is costly and parallel port of computer has been used which is not available for recent computers[17]. In another paper, an instrument is presented which can characterize only a cell, not a module[18].

In this work, an automatic data acquisition system has been designed and developed that can change the operating point of the PV module and can read the current and terminal voltage and log the data into a PC. By analyzing the acquired data, the performance of the PV module can be determined.

II. Block Diagram of the System

As shown in the following block diagram, the complete system consists of mainly four blocks. The Arduino

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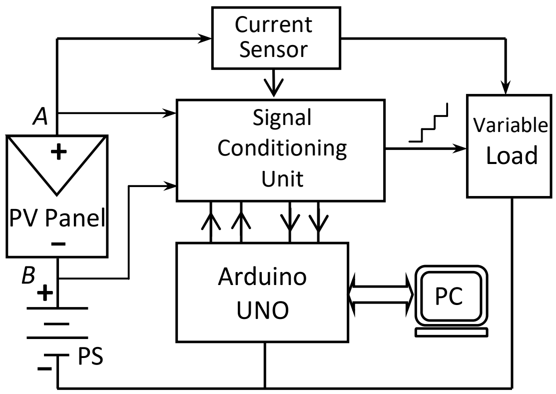

Fig. 1. Block diagram of the developed system

Uno is the main controlling unit, the Current Sensing unit converts the current into voltage, the Variable Load (Active Load) changes the output current of the PV module and the Signal Conditioning unit provides all necessary preprocessing of all signals. In fact, the signal conditioning unit has many subunits. The design method of every section of the system is described in the following subheadings.

PV Voltage Conditioning Circuit

If the active load would have been directly connected across the PV output, the short circuit current couldn't be achieved, because the active load has some resistance even at hard saturation. Hence, a high ampere PS (power supply) has been used in series with the PV Module. As the active load increases the output current of the PV module, the current from the PS also increases. When the load current equals the I_{SC} of the PV module, V_{PV}, becomes zero. This V_{PV} is a differential voltage (difference of voltage between points *A* and *B* of Fig. 1), but the ADC needs a common mode voltage (with respect to ground). To do this, a differential voltage amplifier has been designed which is given below.

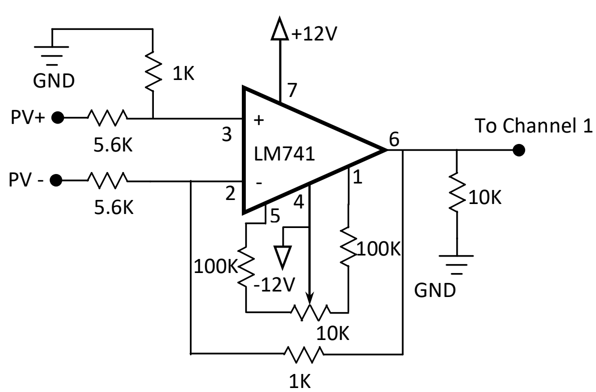

Fig. 2. Signal Conditioning Circuit for V_{PV}

The function of this circuit is two-fold. One is to convert the differential voltage V_{PV} into common mode voltage and to attenuate the high module voltage into a suitable value for ADC (here +5V mximum). The circuit is designed using a 741Op-Amp. To make the output offset-voltage null, two fixed resistors, and a potentiometer have been used with pins 5 and 1 (Fig. 2).

Current Sensing Unit

To measure the output current of the module, a current sensor, *ACS712*, has been used. This device uses Hall sensor and produces bipolar output voltage depending on the current direction. The output of this sensor has been processed by a conditioning circuit shown in Fig. 3. This circuit shifts the operating range of the current sensor from bipolar (-2.5V to +2.5V) to unipolar (0V – 5V). The gain of this circuit can be adjusted from 9 (nine) to 18 (eighteen) using S_1 and S_2 switches. This arrangement can increase or decrease the number of acquired data even for the same value of the current input. The output of this circuit is fed to channel-1 of A/D converter[8].

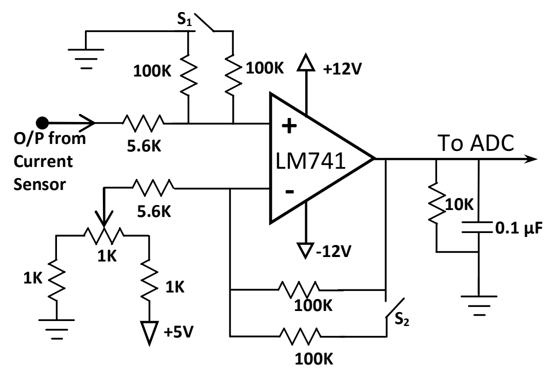

Fig. 3. Signal Conditioning Circuit for the Current Sensor

Active Load

MOSFET has very high input impedance and by changing gate-voltage its drain current can easily be changed. For this reason, MOSFETs (*IRFP250*) have been used to design the variable (active) load. The capacity of each *IRFP250* is 60V, 30A. Although one MOSFET is shown in the circuit (Fig. 4), the actual number will depend on the maximum current of the PV module. The MOSFETs have been used in their active region. Hence, heavy heat-sink has been used to protect the devices against thermal runaway.

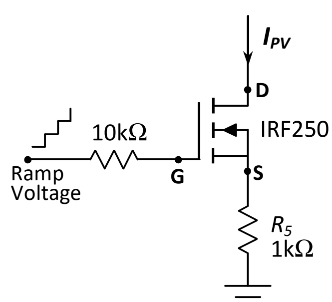

Fig. 4. Active load Circuit

The value of R_5 has been calculated as:

$$R_5 \leq \frac{V_{PS}}{I_{SC}} \tag{1}$$

Where, I_{SC} is the short circuit current of PV module and V_{PS} is the power supply voltage.

The threshold gate voltage level (V_T) of *IRF250* is 4.50V so minimum 4.5V is required at the gate for the initialization of its conduction[9]. After that threshold value, the current through this active load will gradually increase at every step of the ramp voltage.

Staircase (Ramp) Voltage Generator

The staircase voltage generator consists of mainly two units: i) the counter unit and ii) the digital to analog converter unit (DAC).

An 8-bit ripple counter has been developed by connecting two *74LS293* ICs. The MSB output of the first counter works as the CLK input to the second counter and the CLK of the first counter comes from the controlling unit. The MR (Master Reset) inputs of the ICs are connected in parallel and used by the controlling unit as the RESET input. The 8-bit output of the counter has been applied to the DAC.

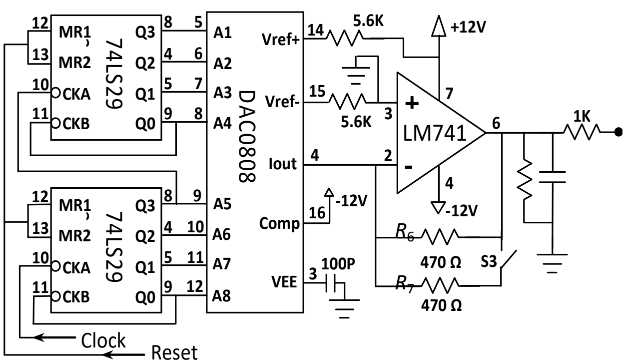

Fig. 5. Staircase voltage generator

As a digital-to-analog converter, *DAC0808*IC has been used. It is a current summing DAC; hence a current to voltage converter (CVC) has been used at the output. The gain of the CVC can be varied by changing the value of the feedback resistor. Here, two 270Ω resistors (R_6 & R_7) have been used as the feedback resistor (Fig. 5). R_7 can be connected or disconnect by S_3. Thus when S_3 is open, a staircase with large step size and when S_3 is closed, a staircase with smaller step size will be produced.

Threshold Supply Circuit

At every clock pulse, from the controlling unit, the staircase voltage will increase step by step starting from 0V (Fig. 8). The highest value of the staircase depends on the step size and the bit-size of the counter. To get precise data from the PV module the step-size should be as small as possible (Here 5mV). With an 8-bit counter, the maximum voltage will be 1.275V(5mV×255). Since the V_T of the MOSFET is 4.5V; the staircase voltage cannot start the conduction of PV load current. This problem has been overcome by adding 4.5V at the output of the staircase as shown in the Fig. 7. The amount of threshold voltage at zero count can be changed by the potentiometer R_8.

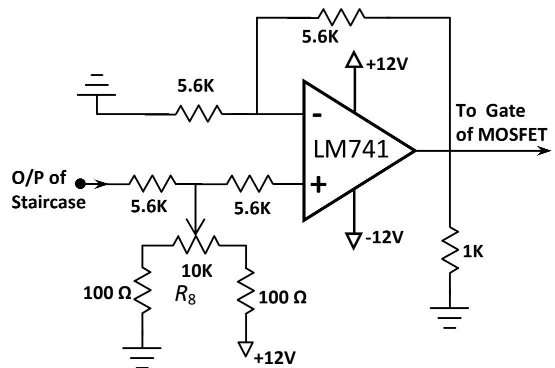

Fig. 7. Threshold voltage producing circuit

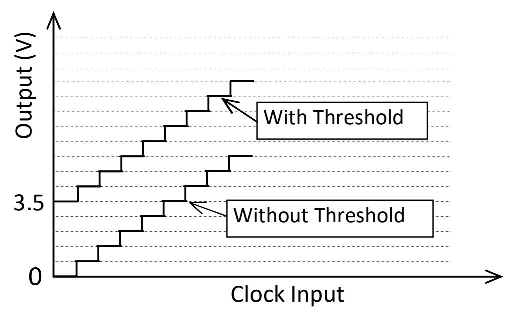

Fig. 8. Staircase voltage before and after using the Circuit of Fig. 7

Program Flowchart

The driver program of the whole system has been developed using Arduino IDE and uploaded into the Arduino board. The flowchart of the program is shown in Fig. 9. At the beginning of the data acquisition process of the PV module, the program sends a RESET pulse to the counter of the staircase generator, so that the active load turns OFF. This will give the open circuit condition of the PV module. Then it will read the module output current (I_{PV}) and the terminal voltage (V_{PV}). Ten samples of each variable are taken and averaged. The average values of I_{PV} and V_{PV} are assigned to the variables I_{PA} and V_{PA} and sent to the computer. Then, the program sends a clock pulse to the counter of the staircase generator so that the load current of the PV module increases by one step. Again, the value of I_{PA} and V_{PA} are determined and sent to the computer. This process is continued until the Counter recycles (Count=255) or V_{PA} becomes zero. Then the process stops sending another RESET pulse to the staircase generator.

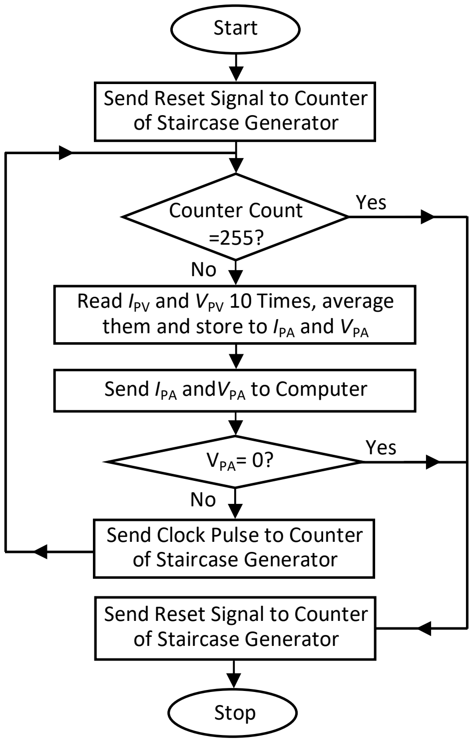

Fig. 9. Flowchart of the program

III. The Complete System

All of the subsections described above have been interconnected in a PCB and a 10A 12V power supply has been made and incorporated into the system. The photograph of the complete system is shown in Fig.10.

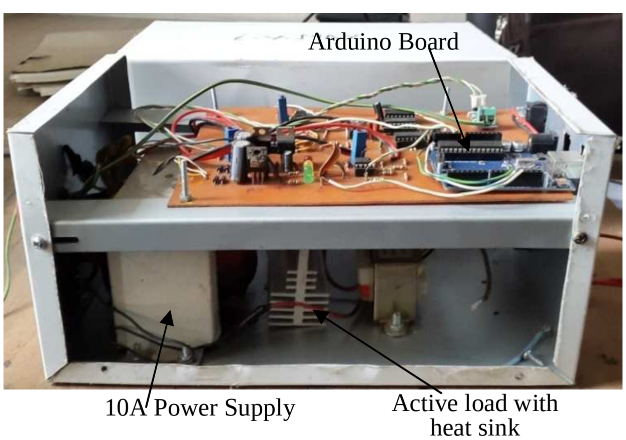

Fig. 10. Photograph of the developed system

IV. Performance Study of the System

Before studying the performance of the system, the linearity of different measuring units has been checked and the conversion factor has been determined by calibration.

Calibration of the Current Sensor

To calibrate and to confirm the linearity of the current measuring unit, different values of current has been measured by this unit and also by a precision current meter. A graph (Fig. 11) has been plotted using these data and the conversion factor has been calculated from the slope of the graph. From the graph, it is found that the response of the current sensor with other signal processing circuit is linear and the conversion factor is 0.004574 (Amp/ADC reading). The raw data acquired by the ADC from the current sensor has to be multiplied by this conversion factor to get actual current (in Ampere).

Calibration of the Voltage Sensor

The voltage measuring unit has also been calibrated using the same procedure as above and the graph of Fig. 12 is found. From this graph, it is clear that this section also works linearly and its conversion factor is 0.027043 (Volt/ADC-reading).

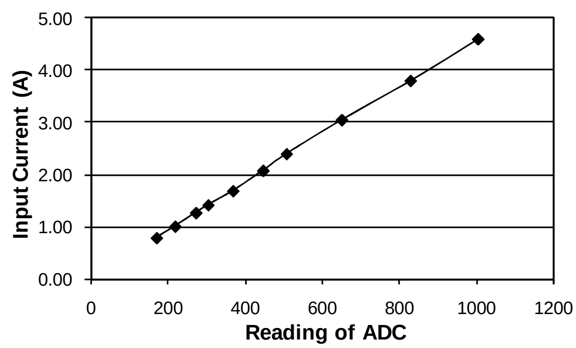

Fig. 11. Graph for calibration of current sensor

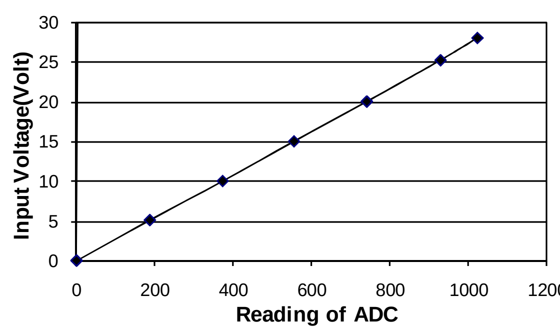

Fig. 12. Graph for calibration of current sensor

Test results of Modules Using the System

After determining the conversation factors, the current and voltage data of some PV modules have been acquired and analyzed. At first, a 30 Wp PV module is connected with the system and illuminated by a 2kW flash light. The distance of the panel from the light is adjusted to make the radiation uniform and 1kW/m^2 on the panel. By taking a trial run the appropriate positions of different resolution setting switches of the system have been set. Then the final test of the module has been done. The radiation level has been measured by a pyranometer and the area of the module has been measured manually. The acquired data have been converted using the conversion factor and plotted into a graph which is shown in Fig.13.

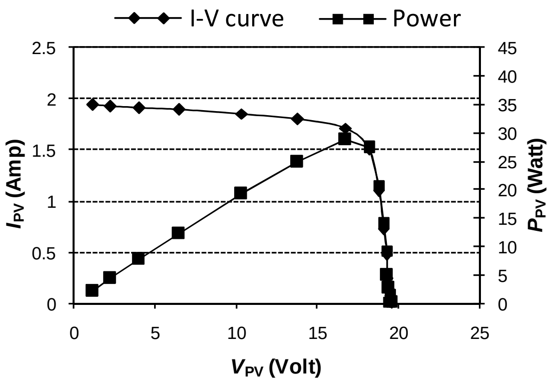

Fig. 13. I-V curve of a 30Wp module

After calculating the data the following (Table I) results have been found.

Table 1. Parameters found for 30Wp module

Parameters	Values on Data-sheet	Measured values
Output Power (Wp)	30	28.9
V_{OC} (Volt)	19.2	18.9
I_{SC}(Amp)	2.1	1.94
V_{MP}(Volt)	16.6	16.8
I_{MP}(Amp)	1.81	1.72
Efficiency (%)	16.2	15.61

The same test has been done for another 50 Wp module. The obtained graph is shown in Fig. 14 and the results are shown in Table II. Each of the graphs has been plotted by averaging every 10 raw data into a single data.

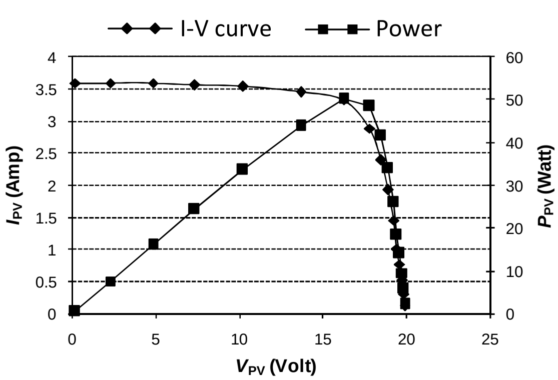

Fig. 14. I-V curve of a 50Wp module

From Table 1 and Table 2 it is found that the measured data are very close to the actual data.

Although the modules have been tested in indoor light, the system can also be used in outdoor. Since the whole data acquisition for a complete test is done only in few seconds, the measurement will not be affected by the fluctuations of solar radiation.

Table 2. Parameters found for the 50Wp module

Parameters	Values on Data-sheet	Measured values
Output Power (Wp)	50	50.2
V_{OC} (Volt)	19.3	19.83
I_{SC}(Amp)	3.63	3.6
V_{MP}(Volt)	16.5	16.3
I_{MP}(Amp)	3.34	3.34
Efficiency (%)	16.4	16.21

V. Conclusion

In this work, a low-cost data acquisition system has been designed and developed specially for acquiring the current and voltage from a PV module. To change the load current it has an active load. Using this data, I-V characteristics can be drawn and some other parameters, like I_{SC}, V_{OC}, efficiency, fill factor etc. of a PV module, can be determined. As the module is used in series with a power supply the short circuit current, I_{SC}, is easily found. The maximum capacity of the developed system is 100 Wp. But this capacity can be increased by increasing the number of MOSFETs in parallel. The accuracy of the system can be increased by increasing the bit-capacity of the DAC and the counter. The performance of the system has been studied by determining the characteristics of various PV modules of different Wp and compared with the data given in the label of the module. From these data, it is clear that within the power capacity limit, the system works very well.

Although, the I-V characteristics of Fig. 13 and 14 are very smooth, but in the acquired data there were little fluctuations due to different noise. The noise has been removed by software. The measured data are very close to the data provided on the cut-sheet of PV module. This data acquisition can be used for other application –Eg., to determine the characteristics of transistors, diodes etc.

VI. Acknowledgement

This research work was funded by the Ministry of Science and Information Technology, the People's Republic of Bangladesh.

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