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DESIGN OF A COST EFFICIENT PV PARAMETERS MONITORING SYSTEM

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Abstract

Photovoltaic (PV) parameters monitoring is very important for the implementation and optimum utilisation of solar energy as electricity source. Present PV monitoring systems are based on expensive tools and complicated designs. This paper describes the design of a simple and a cost-efficient PV monitoring system. The design system is composed of hardware processed by a microcontroller and a computer-based software designed in a user-friendly graphical program LABVIEW. The designed system is observed in realistic conditions and is working well.

Keywords: Photovoltaic, Renewable energy, Solar energy, Maximum Power, Solar parameters.

Introduction

Raising energy demands and climate changes are the main global issues. To overcome the energy limitations and environmental pollution, the world is widely focusing on alternative and cleaner energy utilisation. Minimum environmental effects, a long life and abundance of availability make the PV more popular amongst clean energies. However, there are few problems associated with PV technology which hinder its development, i.e., high cost and low efficiency (Markvart, 2000). Also, the optimum reliability is considered as an additional issue in this technology (Petrone et al., 2008). Recent research (Virtuani et al., 2011) showed that by using a PV module in outdoor application in accordance with the manufacturer specification gave errors and may cause a system failure later on. It is realised in Virtuani et al. (2011) and Petrone et al. (2008) that the monitoring of PV parameters in realistic condition is very essential for reliability, cost and performance improvements of a PV system. Also, the PV parameters monitoring is essential for evaluation, implementation and in returns on investment analysis of PV systems (Zimmermann and Edoff, 2012; Anwari et al., 2011; Sharko et al., 2011).

Presently, PV monitoring systems are complicated and expensive. Different PV parameters monitoring systems have been designed by Zimmermann and Edoff (2012), Anwari et al. (2011), Sharko et al. (2011) and Adamo et al. (2011). The complexity in PV monitoring system is due to the use of complicated control system, as in Zimmermann and Edoff (2012), to extract the maximum power from a PV module for analysis whilst Sharko et al. (2011) designed a PV monitoring system by employing some expensive tools like a general purpose interface bus card (GPIB) and precession measurement units (PMU). The same was accomplished by Adamo et al. (2011) via a PV parameters monitoring system, designed by using expensive components like pyranometer, GPIB, data logger and PMU. Less expensive with limited operations PV parameters monitoring system was designed by Anwari et al. (2011). To achieve the minimum cost, BPW photo diode is used for solar radiation monitoring instead of a pyranometer, whilst the role of PMU, GPIB and data logger is replaced by a microcontroller circuitry and a computer-based software.

Hence looking forward to the cost issues with PV implementation and the importance of PV parameters monitoring in utilisation and implementation of PV. This paper designs a cost-effective PV parameters monitoring system with a considerable range of accuracy. In order to

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evaluate the efficiency and performance of a PV module, the monitoring of real and simulated maximum power points of a PV module, effective irradiance and area of a PV module is required to be analysed. The designed system tracks the maximum power of PV module from real time short circuit current and open circuit voltage of PV module under the computational maximum power tracking technique (Zhihao and Xiaobo, 2009; Ahmad 2010). Instead of using expensive pyranometer and BPW photo diodes, the irradiance is sensed via designed LDR sensor. The data logger is replaced with a database organised in PC whilst LABVIEW GUI is used for data processing and monitoring. The accuracy of the designed system is verified by simulating it in a well known PV simulator PSIM and through real-time experimental results.

PV Parameter Monitoring System description

The PV parameter monitoring system consists of a microcontroller (AT89C51), voltage sensor, current sensor (ACS758), temperature sensor (LM135), irradiation sensor (LDR's circuit), analog-to-digital converter (ADC0809), a relay and IC (MAX232) that is serially interfaced with the PC. A PV module ARCO Solar-ASI-16-2300-20 is connected next to the designed hardware, the angle between the module and the horizontal plane is 45^{o} which is the optimal angle for winter season at the latitude of 34^{o}. The hardware collects the PV metrological parameters, i.e., ambient temperature and irradiance etc. and electrical parameters, i.e., short circuit current and open circuit voltage etc. of the module. It then sends those parameters serially to the PC. The obtained metrological and electrical parameters are then analysed by the software in the form of I-V and P-V curves and in term of efficiency of the PV module. The designed software also stores the PV parameters with respect to time and date in its data base. The block diagram of the designed PV parametric monitoring systems is shown in Fig. 1.

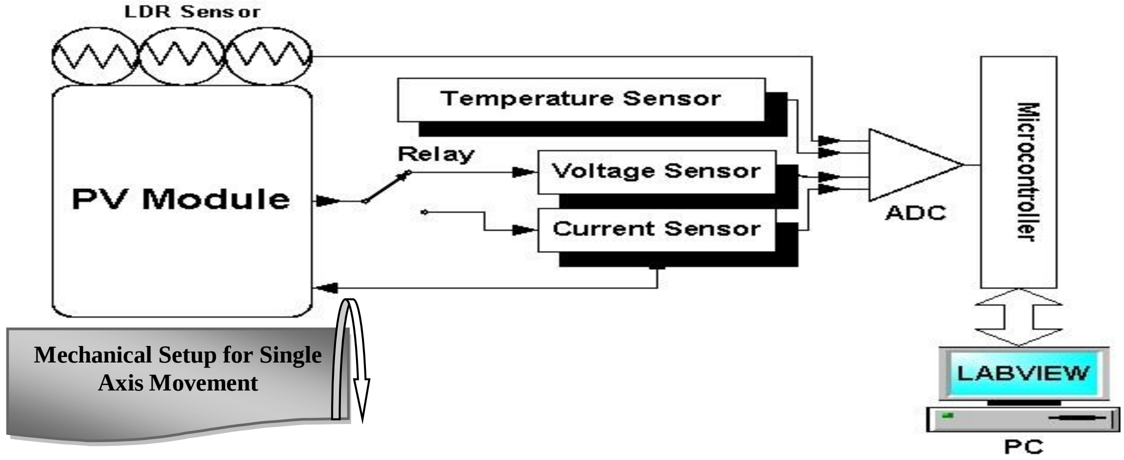


Fig. 1. Block diagram of designed PV parameters monitoring system.

Mathematical Models of the Designed System

Table 1 shows parameters of the investigated crystalline module. Taking into account the characterisation and parameters of the module, the I-V, P-V and efficiency of the module η may be determined according to Markvart (2000), as,

$$= \mathbf{V_{ocm}\ I_{scm}\ FF/GA} \quad \ldots \text{ Eq. 1}$$

where, V_{ocm} and I_{scm} are the open circuit voltage and short circuit current of the module. G is the intensity of solar radiation, FF is the fill factor which is approximated to 0.75 (Markvart, 2000) and A is the area of the module.

Using the monitored PV parameters and the specifications in Table 1, the software traces the I-V and P-V curves of the module by using photovoltaic module practical mathematical model given by Chang et al. (2010) which is given as,

$$\mathbf{Iscm} = \mathbf{N_p\, I_{PVm} - N_p I_S \left[\exp\left[\frac{Q(N_p V_{ocm} + N_s Rsm I_{scm})}{N_p N_s T_c K\, A_a}\right] - 1\right] - \frac{(N_p V_{ocm} + N_S I_{scm} Rsm)}{Rshm}} \quad \ldots \text{Eq. 1}$$

where I_{PVm} is the photo generated current by the PV module, N_p is the number of PV cells strings connected in parallel, N_s number of PV cells in each string, R_{sm} is the series resistance of module and R_{shm} is the shunt resistance of PV modules. It varies with intensity of solar radiation. Cell working temperature and is given by Chang et al. (2010) as,

$$\mathbf{I_{PVm} = [I_{scmn} - [K_i(T_c - T_{nc})]\,\frac{G}{G_n}} \quad \ldots \text{Eq. 3}$$

where I_{scmn} is nominal short circuit current of the module, G_n is nominal solar insulation, K_i is the temperature coefficient of short circuit current and is all mostly given in data sheet; T_{nc} is the nominal cell temperature and is normally about 298 K and T_c is the cell actual temperature and may be determined by Markvart as,

$$\mathrm{Tc} = \left[\frac{\mathrm{NOCT} - 20}{0.8}\right] \mathrm{G} + \mathrm{T_a} \quad \ldots \text{Eq. 4}$$

where T_a is the ambient temperature and NOCT is normal operating cell temperature and is usually between 43-47°C (Markvart, 2000). The cell saturation current I_S under the effect of cell temperature is determined by (Villalva et al., 2009) as,

$$\mathrm{I_S} = \mathrm{I_{omn}} - \left(\frac{T_c}{T_{cn}}\right)^3 \left[\exp\left[\frac{E_g Q\left[\frac{1}{T_{cn}} - \frac{1}{T_c}\right]}{K A_a}\right]\right] \ldots \text{Eq. 5}$$

where E_g is the energy gap of the semiconductor and is 1.12 for mono-Si and 1.14 for Poly-Si. A_a is the ideality factor and depends on PV module cell fabrication method. It is 1.026 for mono-Si and 1.025 for Poly-Si (Chang, et al., 2010). The cell reverse saturation I_{omn} at STC is given by Villalva et al. (2009) as,

$$\mathrm{I_{omn}} = \mathrm{I_{scmn}} + \mathrm{K_i} - \left[\exp\left[\frac{Q(V_{ocm} + K_V(T_n - T_c))}{N_s T_c K A_a}\right] - 1\right] \quad \ldots \text{Eq. 6}$$

where K_V is the temperature coefficient of open circuit voltage and is given by data sheet; Q is the electric charge and is 1.6×10^{-19} C, K is the Boltzmann's constant and its value is $1.38 \times 10^{-23} \frac{J}{K}$.

Table 1. Parameters of ARCO Solar-ASI-16-2300-20 PV Module under Standard Test Conditions.

Parameters	Values
Open circuit voltage, V DC.	**20.8**
Short circuit current, A.	**2.5**
Current at maximum power, A.	**2.3**
Voltage at maximum Power, V DC.	**16.1**
Number of Cells.	**35**
Length, M (In).	**0.304 (11.97)**
Width, M (In).	**0.09 (1.5)**
NOCT	**43-47**
Temperature coefficient of Voltage	**0.079 V/C**
Temperature coefficient of current	**0.0017 A/C**

Optimising the Model

The series resistance affects on the open circuit voltage characteristic of a module whilst the shunt resistance affects on the short circuit current characteristics of a module. Overall, the series and shunt resistance affect the I-V and P-V characteristics of a PV module. The series resistance is due to the metal contact with semiconductor; shunt resistance is due to the leakage current of the cells in a module and depends on the fabrication method of a PV cell. Usually, shunt resistance (Rs) is very small and high and most of the others (Markvart, 2000) ignore them; however, they must be considered for accurate I-V and P-V tracking (Adamo et al., 2011).

In order to obtain accuracy and a quick response in real-time I-V and P-V curves plotting, an iterative method is carried out by the designed system for the estimation of series and shunt resistances of PV module. The flow chart of the proposed method is shown in Fig. 2. It is the flexibility of the technique that it can estimate the series and shunt of a PV module in real conditions whilst Adamo et al. (2011) did it only for standard test conditions.

The real maximum power is represented by P_{ac} and can be calculated according to Markvart (2000), as,

$$P_{ac} = V_{ocm}\, I_{scm}\, FF \qquad \ldots \text{Eq. 7}$$

whilst the theoretical power P_{ap} is calculated according to Villalva et al.(2009), as,

$$P_{ap} = V_{max}\left[N_p\, I_{PVm} - N_p I_S\left[\exp\left[\frac{Q(N_p V_{max} + N_S Rsm I_{max})}{N_p N_S T_c K A_a}\right] - 1\right] - \frac{(N_p V_{ocm} + N_S I_{max} Rsm)}{Rshm}\right] \ldots \text{Eq. 8}$$

where V_{max} and I_{max} are the voltage and currents of the module at maximum power.

Solving P_{ap} for R_{shm}, it is observed that for each value of R_{shm} there will be a value of R_{sm} as shown below:

$$R_{shm} = \frac{Vmax(N_p V_{ocm} + N_S\, I_{max} Rsm)}{Vmax\left[N_p\, I_{PVm} - N_p I_S\left[exp\left[\frac{Q(N_p V_{max} + N_S Rsm\, I_{max})}{N_p N_S T_c K A_a}\right] - 1\right] - \frac{(N_p V_{ocm} + N_S I_{max} Rsm)}{Rshm}\right] - P_{ap}} \ldots \text{Eq. 9}$$

After calculating the real and theoretical maximum power points, the software continuously iterates the values of R_{sm} and R_{shm} in equation Pap. Iteration halts until when Pap becomes equal to Pa at any value of R_{sm} and R_{shm}. The obtained values of R_{sm} and R_{shm} are then used to plot I-V and P-V curves. This process is completed within milliseconds by the software. The proposed iteration procedure flow diagram is shown below:

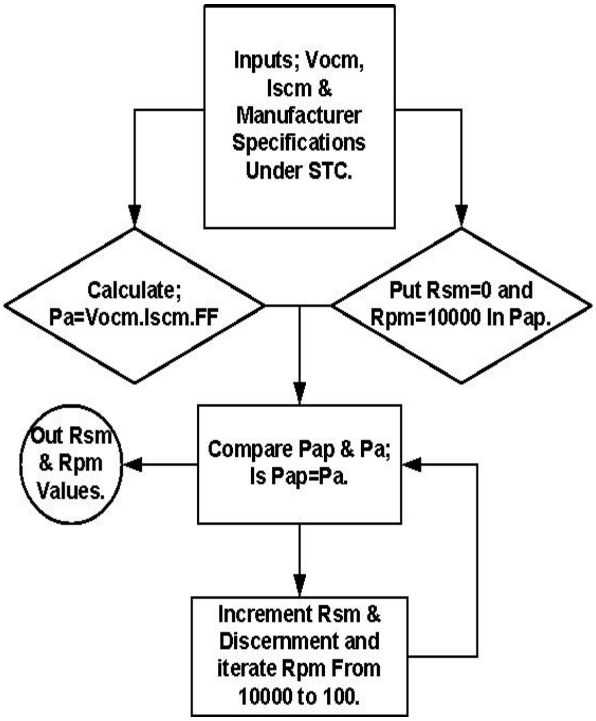


Fig. 2. Flow diagram R_{sm} and R_{shm} estimation at maximum power point

Performance analysis of the Designed PV Parameter Monitoring System

In order to obtain appropriate PV parameters, the PV module must be placed on optimal tilted angle. The optimal angle of inclination of PV module is weather dependent. Hence, in order to adjust the monitored PV module angle of inclination with respect to weather, a stand with a unidirectional moment has been designed.

Accuracy in real time I-V and P-V tracing was achieved by implementing the real model of a PV module in the system software. To verify the accuracy, the designed software code of I-V and P-V tracing is simulated for MSX-60 PV module at standard test conditions and the obtained results are then compared with the well-known PV simulator PSIM results, manufacturer data sheet results and with Adamo et al. (2011). Figure 3 shows the PSIM results; manufacturer data sheet specification and the designed software results for MSX-60 PV module under STC, I-V and P-V results are shown in Figures 4 and 5, respectively, whilst Figure 6 shows a screen shot of designed system software. Figure 7 shows the I-V and P-V characteristics of ARCO Solar-ASI-16-2300-20 PV module, simulated through designed software under STC and Figure 8 shows the current and voltage of Arco solar PV module monitored in a clear day.

Parameters	PSIM Results	Data Sheet Values	Designed Model Results
MPP	60.53 W	60 W	59.41W
Rshm	1000 ohm	N.A	915 ohm
Rsm	0.008 ohm	N.A	0.007 ohm

Fig. 3. **PSIM and manufacturer data sheet values verses designed software results for MSX-60 module.**

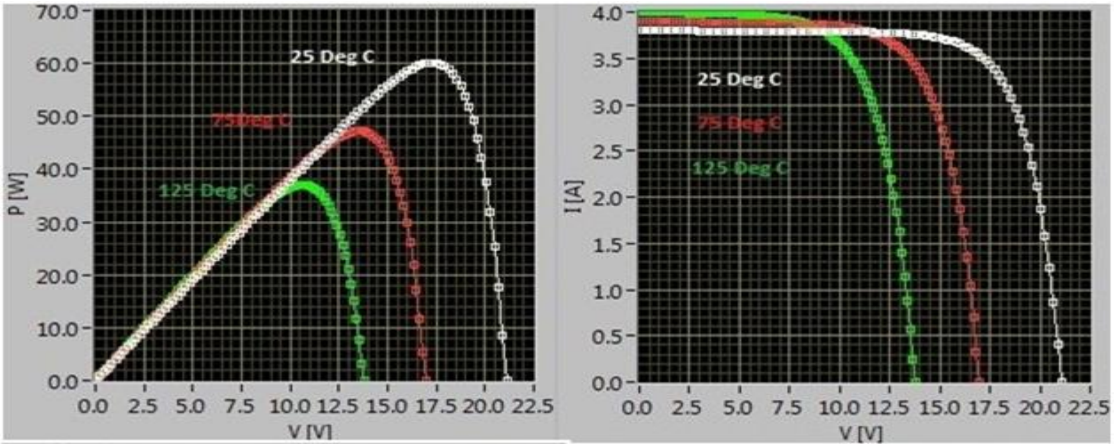


Fig. 4. **I-V and P-V curves of MSX-60 PV module at three different values of Temperature simulated through the designed software.**

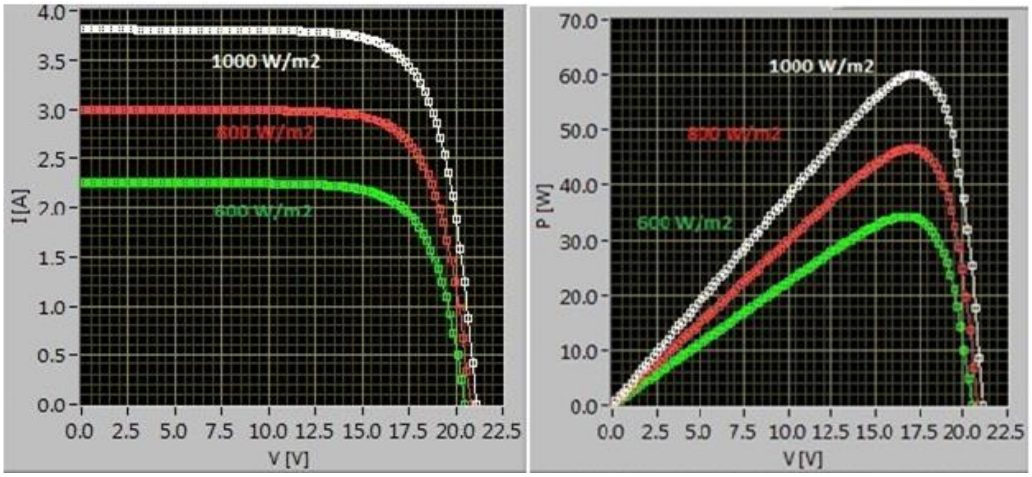
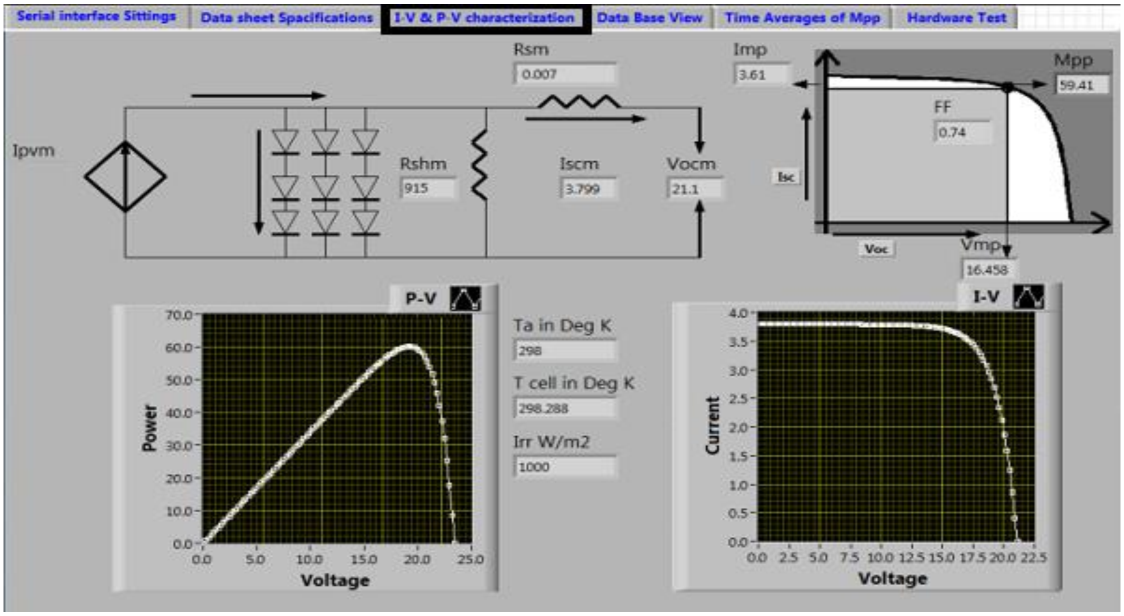


Fig. 5. **I-V and P-V curves of MSX-60 PV module at three different values of Irradiance in W/m2 simulated through the designed software**



Rsm 0.007

Imp 3.61

Mpp 59.41

FF 0.74

Rshm 915

Iscm 3.799

Vocm 21.1

Vmp 16.458

Ta in Deg K 298

T cell in Deg K 298.288

Irr W/m2 1000

Fig. 6. Screen short of designed system software in LABVIEW for MSX-60 module.

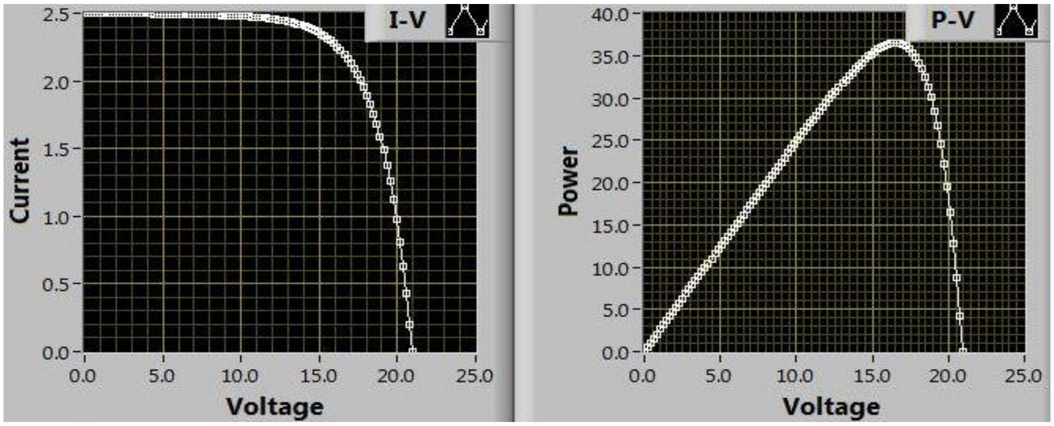


Fig. 7. I-V and P-V characteristics of ARCO Solar-ASI-16-2300-20 PV module simulated through the designed software under standard test conditions.

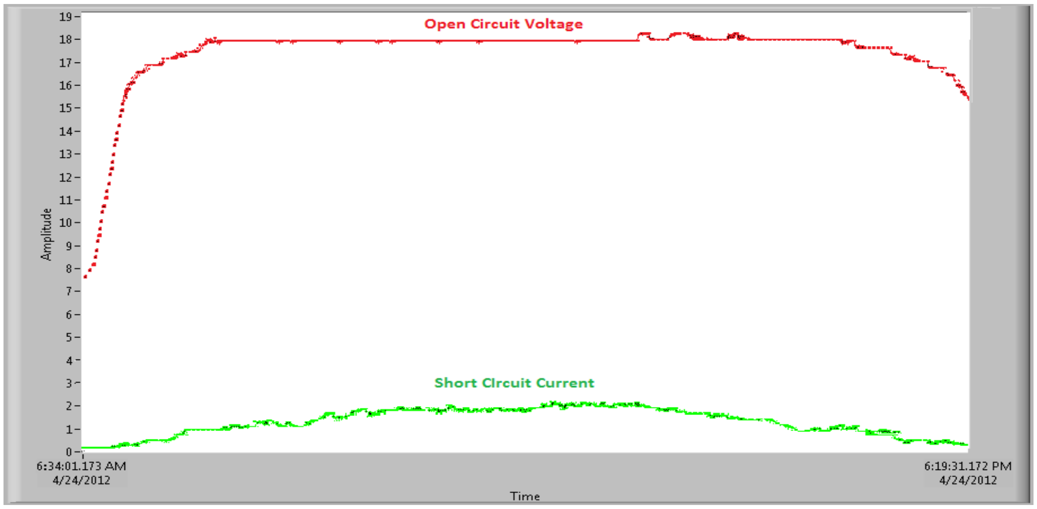


Fig. 8. I-V trace of ARCO Solar-ASI-16-2300-20 PV module monitored in a clear sunny day

The cost and performance analysis of the proposed system is performed below verses some recently proposed systems (Zimmermann and Edoff, 2012; Sharko et al., 2011; Adamo et al., 2011).

Table 2. Cost analysis of the designed system

Devices and Systems Performance	**Cost**	**Zimmermann and Edoff, 2012.**	**Sharko et al., 2011.**	**Adamo et al., 2011.**	**Designed System.**
Pyranometer	**450 $**	×	×	✓	×
Data Logger	**800 $**	×	✓	✓	×
ADC	**2 $**	✓	×	×	✓
Thermocouple	**1 $**	×	×	✓	×
Temperature sensor	**2 $**	✓	×	×	✓
Current Sensor	**10 $**	✓	×	×	✓
Microcontroller	**1 $**	✓	×	×	✓
GPIB	**130 $**	×	✓	✓	×
Precision SMU	**5000 $**	✓	✓	×	×
Data Base Facility	**------**	×	×	×	✓
Total Cost		**5015 $**	**5930 $**	**1381 $**	**15 $**

Conclusions

A cost effective, flexible and a portable PV parameter monitoring system was designed that consists of a current sensor, irradiance sensor, temperature sensor, ADC, Microcontroller and PC-based software with a database facility. Accuracy in I-V and P-V tracing was achieved by implementing the practical model of a photovoltaic module. The database facility in the system is also introduced for the evaluation of return on investment. The cost analysis of the designed system was performed. It is observed that the tool under consideration is an economical solution for photovoltaic system installations, life cycle cost analysis, PV grids performance analysis and for optimal PV installation. The main attractiveness in the designed system over other such systems is its minimum cost and multitasking capability.

The designed tool is also useful for the researchers to understand the behaviour of different photovoltaic technologies in natural conditions and for the analysis of degradations in PV modules with respect to age and environmental effects.

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