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Solar Simulator:Hardware implementation to analyse characteristic performance of solar cell

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ABSTRACT
In this paper, practical model of solar simulator is designed using halogen lamps as a source. This model is developed to analyse performance of solar cell at different circumstances. Basically, solar simulator generates power according to changing light intensity and temperature. It gives comparison between theoretical and experimental studies of solar cell, which provide a maximum power to the load at Maximum Power Point. Observations taken are compared with the basic electrical properties of solar cell. Different results are taken for same intensity of natural sun light. Experimental verification of two solar cells connected in series & parallel is carried out at different conditions to generate the power. As a result, I-V & P-V characteristics of solar cell with varying temperature and insolation are presented. From the results, it is observed that voltage is doubled when two cells are connected in series and current is doubled when cells are connected in parallel. Effects of variation in temperature of solar cells are studied. With the help of mathematical code, plots of measured I-V, P-V data can be observed. It helps to determine maximum electrical power output of the panels, as well as the parasitic effect in lowering maximum power and efficiency is effectively observed.
***Keywords* -** Halogen source, photovoltaic module, maximum power point, solar radiation level, temperature.

I. INTRODUCTION

The rapid trend of industrialization of nations and increased interest in environmental issues recently led us to explore the use of renewable forms such as solar energy. Photovoltaic (PV) generation is gaining increased importance as a renewable source [1-2] due to its advantages like absence of fuel cost, little maintenance, and no noise and wear due to the absence of moving parts, etc. in particular, energy conversion from solar cell arrays (SCAs) received considerable attention in the last two decades. At a particular solar isolation, there is a unique operating point of the PV generator at which its power output is maximum. Therefore, for maximum utilization efficiency, it is necessary to match the PV generator to the load such that the equilibrium operating point coincides with the MP point of the PV source. However, since the MP point varies with isolation and seasons, it is difficult to maintain MP operation at all solar insolations [3-4]. The regional approximation method is used for the analysis of internal electric properties and external characteristics of a solar module. The procedure of this analytical method consists of the two steps [4-5] firstly panels connected in series then connected in parallel and measured its electrical performance at different light intensity and different temperature[6-7]. This paper is organised as follows: Section II presents the mathematical modelling of PV system and its specifications. Section III presents details of designed simulator with experimental set-up of PV cell and section IV gives testing of cell under different conditions. Conclusions and experimental results are provided in Section V.

II. MATHEMATICAL MODELING OF PV SYSTEM

A photovoltaic module consists of a number of interconnected solar cells encapsulated into a single unit[7-8]. In order to predict the power extracted from the solar modules and the module current-voltage (I-V) characteristics, it is important to model the solar cell. Once the I-V characteristics of a single solar cell are determined using the model, one must then expand that model to determine the behavior of a PV array or module [9-10]. A Photovoltaic array comprises many solar cells wired in series and in parallel. A solar cell model is shown in Fig.1. The model, takes into account the variation of the photoelectric current, when the radiation and the temperature changes, and also the variation of the diode saturation current when the temperature changes. In this, the current generator IL represents the generated photoelectric current while the diode (D) and the resistance Rs, which takes into account the internal electrical losses, model the photovoltaic module [10-11].

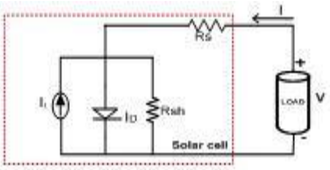

Fig.1. Schematic diagram of solar cell circuit

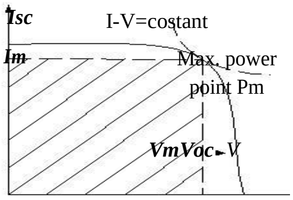

Fig. 2. I-V characteristic of solar cell

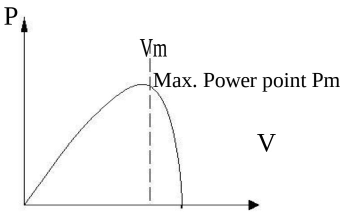

Fig.3. P-V characteristic of solar cell

III. SOLAR CELL PARAMETERS

SHORT CIRCUIT CURRENT (*Isc):* Ideally this is equal to the light generated current. This is the current produced, when junction not illuminated in this condition Current and voltage relationship [12-14].

$$I = I_0 \left\{ exp\left(\frac{v}{v_T} - 1\right) \right\}$$

Where,
I_0 is saturation current
v is voltage across pn junction
V_T is voltage equivalent of temperature at 20°C .

$$V_T = \frac{KT}{q}$$

K is Boltzman's constant
T is temperature in k°
q is charge of electron When p-n junction is illuminated, In this condition current voltage relationship.

$$I = I_{sc} - I_0 \left\{ exp\left(\frac{V}{V_t}\right) - 1 \right\}$$

OPEN CIRCUIT VOLTAGE *(Voc)***:** Voc is determined by the properties of semiconductor mainly by band gap and its temperature dependence on I0 (reserve saturation current).

$$V_{oc} = \frac{K_T}{q} ln\left[\left(\frac{I_{sc}}{I_0}\right) + 1\right]$$

SERIES RESISTANCE(RS) & SHUNT RESISTANCE *(Rsh)* : Series resistance is due to the combined effect ofload resistance, wires and contacts etc. The shunt resistance is caused by leakage across the p-n junction around the edges of the cell and in non peripheral regions in presence of crystal defects.[13]. Ideally: Rs=0 ohm and Rsh=∞ ohm.
FILL FACTOR *(FF)*: At a particular point on I-V curve, we get the point of maximum power (Pmax). Fill factor is the ratio of area of Pmax point (Vmp,Imp) and total area.

$$FF = \frac{V_m I_M}{V_{OC} I_{SC}}$$

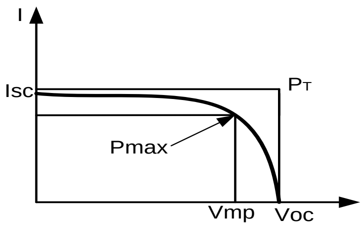

Fig.4. I-V curve to calculate fill factor

EFFICIENCY:

$$\eta = \frac{V_m I_m}{solar\ power} = \frac{FF\ V_{OC} I_{SC}}{solar\ power}$$

IV. DESIGN OF SOLAR SIMULATOR WITH EXPERIMENTAL I-V AND P-V MODULE

Hardware Designs : The simulator consist of main 5 parts, illustrated in a simplified hardware schematic in fig 5. A picture of actual simulator with description of the location of the different parts of the system is shown in fig.6.

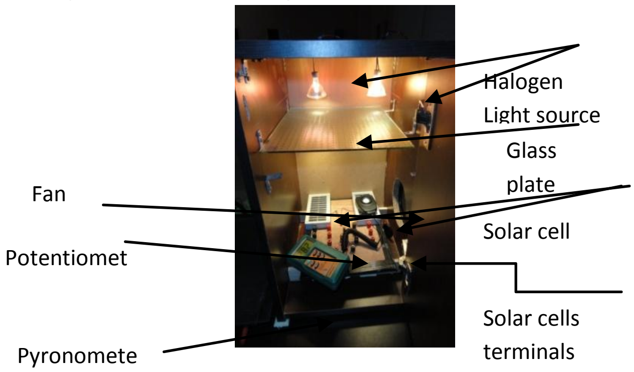

Fig.5. Complete view of Solar Simulator

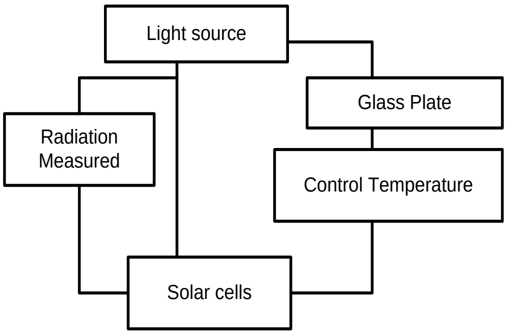

Fig.6. Simplified simulator hardware schematic

The two quartz halogen lamps used as light source in the solar simulator which is 50 W (230V) each. They are located in the top compartment as shown in the figure 3, A glass plate can be inserted between the lamps and the lower chamber. Two glass plates are provided: i) clear glass plate and ii) frosted glass plate. The glass plates are toughened to avoid breakage from heat of the lamps. The glass plates reduce the heat from the lamps reaching the solar cells. Frosted glass plate helps to diffuse the light and make it uniform. Intensity of the light, measured by using a radiometer (Pyranometer) under various conditions. Solar cells are located in the bottom chamber as seen in the fig. 5.

Table.1 Standard Test Condition Data

Electrical Characteristics	
Cell	Poly-crystalline silicon
No of cells and connection	36 in series
open circuit voltage(V_{oc})	21.75 V
Short circuit current(I_{SC})	4.75amp
Intensity	1000 w/m^2
temperature	25^O C

The obtained equations allow representing the I-V characteristics curve of one photovoltaic module under generic temperature and radiation conditions, when the characteristic parameters under standard conditions are known as given Table 1.The photocopy of the experimental setup of PV system is shown in Fig.7, which consists of 36 cells in series, with same manufacture data as given in Table 1 is developed and tested.

Fig. 7. Photocopy of the experimental setup of PV system.

V. TESTING OF SOLAR CELLS

Solar panels are tested under a sun simulator at different conditions. The sun simulator used in solar panels division contains Halogens lamps (T = 5800°K), which produces a spectrum closest to the sun spectrum. If necessary, suitable filters allow reaching the AM0, AM1 and AM1.5 specifications. A Halogen lamp uses to produce a bright white light that is similar to natural daylight[15]. A single solar cell produces only about 1/2 (.5) of a volt. However, a typical 12 volt panel about 25 inches by 54 inches will contain 36 cells wired in series to produce about 17 volts peak output. Multiple solar panels can be wired in parallel to increase current capacity (more power) and wired in series to increase voltage for 24, 48, or even higher voltage systems. Multiple solar panels can be wired in parallel to increase current capacity (more power) and wired in series to increase voltage for 24, 48, or even higher voltage systems. The advantage of using a higher voltage output at the solar panels is that smaller wire sizes can be used to transfer the electric power from the solar panel array to the charge controller& batteries.

The circuit diagram to evaluate I-V and P-V characteristics of modules connected in series and parallel are shown in fig. 6. and fig.7. respectively. From a PV system with modules in either series or parallel and a variable resistor (pot meter) with ammeter and voltmeter for measurement. Modules in series or parallel are connected to variable load (pot meter). The effect of load change on output voltage and current of the modules connected in series or parallel can be seen by varying load resistance (pot meter).

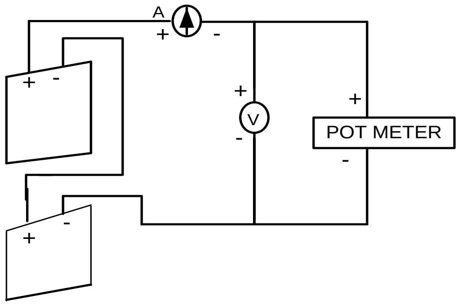

Fig. 8. Circuit diagram for evaluation of I-V and P-V characteristics of series connected module

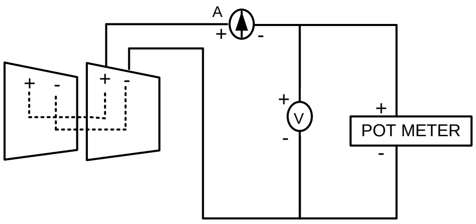

Fig 9. Circuit diagram for evaluation of I-V and P-V characteristics of parallel connected module.

VI. EXPERIMENTAL RESULT

Table.2 For Series connected module

Intensity1000w/m^2&Temp =26^0 C		
Voltage	**Current**	**Power**
0	0.41	0
2.4	0.4	0.96
3.8	0.4	1.52
6.4	0.4	2.56
8.7	0.39	3.39
11.2	0.39	4.368
13.1	0.39	5.104
15.6	0.39	6.084
17.6	0.39	6.864
20.8	0.38	7.904
22.9	0.37	8.473
24.4	0.37	9.028
26.0	0.36	9.36
27.1	0.35	9.485
31.4	0.33	10.362
33.3	0.31	10.323
35.3	0.29	10.323
36.8	0.27	9.936
37.6	0.25	9.776
39.0	0.25	9.75
39.8	0.23	9.154
40.0	0.19	7.6
40.2	0.16	6.432

Intensity800w/m2andTemp=28^0 C		
Voltage	**Current**	**Power**
0	0.33	0
13.6	0.32	4.352
22	0.31	6.82
24.1	0.3	7.23
28.1	0.28	7.868
30.2	0.27	8.37
31.9	0.26	8.294
32.9	0.25	8.225
33.9	0.23	7.79
35.7	0.22	7.854
36.3	0.21	7.623
37.9	0.19	7.201
38.3	0.18	6.894
38.4	0.17	6.528
38.5	0.16	6.16
38.4	0.15	5.76

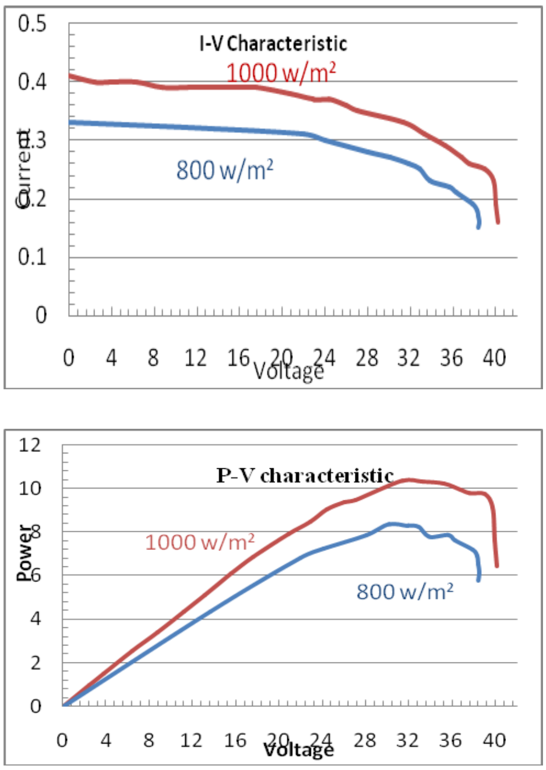

Fig.10. I -V & P -V Characteristics of Series module at radiation intensity 1000 w/m^2& 800w/m^2

Table.3 For Parallel connected module

Intensity 800w/m^2& T=28^{0}C		
Voltage	**Current**	**Power**
0	0.67	0
11.4	0.58	6.612
16.0	0.5	8
18.7	0.41	7.667
19.0	0.37	6.46
19.1	0.30	5.73
19.1	0.26	4.966
19.2	0.25	4.8
19.3	0.18	3.474
19.3	0.16	3.088
19.3	0.15	2.895
19.3	0.14	2.702
19.3	0.13	2.509
19.3	0.12	2.316
19.3	0.11	2.123
19.3	0.10	1.93
19.3	0.09	1.737
19.3	0.08	1.544
19.3	0.07	1.351
19.3	0.06	1.158

Intensity1000w/m^2& T= 26^{0}c		
Voltage	**Current**	**Power**
0	0.86	0
6.3	0.81	5.418
12.9	0.73	9.417
18.6	0.63	11.718
20.0	0..54	10.8
20.1	0.46	9.246
20.3	0.38	7.714
20.3	0.32	6.496
20.4	0.27	5.508
20.4	0.22	4.488
20.4	0.19	3.876
20.4	0.17	3.468
20.4	0.15	3.06
20.4	0.14	2.856
20.4	0.13	2.652
20.4	0.12	2.448
20.4	0.11	2.244
20.4	0.10	2.04
20.4	0.09	1.836
20.4	0.08	1.632
20.4	0.07	1.428

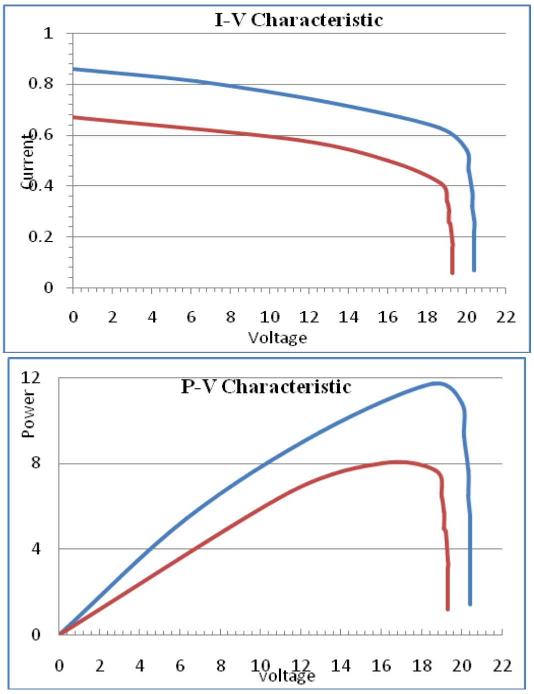

Fig.11 I–V & P -V Characteristics of Parallel module at radiation intensity 1000 w/m^2& 800w/m^2

To obtain the I-V and P-V characteristics of the proposed system, the modules voltage and current are measured, with various temperature and irradiance with the help of solar simulator. Irradiance is measured using Pyronometer. We get maximum power according to radiation and temperature of module, its shown in above tables, data obtained are recorded at different intensity and temperature with series and parallel connected modules, the irradiance varied from 800w/m^2 to 1000w/m^2, Temperature from 26 ^{0}C to 45°C,we get the maximum power at intensity 1000w/m^2 and temperature 26^{0c}.I-V and P-V experimental characteristics for different temperature and irradiance are shown in above Fig. and also we seen that what is effect of series and parallel connected module . From the above tables, it is observed that, in series connected modules increasing voltage and current will be contain and parallel connected modules current increasing and voltage will be contain at different intensity and temperature of modules.

VII. CONCLUSION

The proposed method can be used for instantaneous measurement of I-V and P-V characteristic of series and parallel connected modules at different light intensity and temperature. Here readings taken at intensity of 800w/m^2& 1000w/m^2 and temperature of 26^{0}c, 28^{0}C, 45^{0}C has shown that power generated increases at higher insolation but decreases with rise in temperature.

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