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Experimental Studies on Standard and Modified PV Module

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Abstract- A standard Solar PV Module has open circuit voltage V_{oc} of around 21.6 Volts and V_{max} around 17.3 Volts which is much higher than the required charging level of around 14.2 Volts for a 12 Volts battery. Often a charge controller is used for charging a battery using Solar PV Modules. The charge controller protects the battery from all possible damages.

In the present work, Solar PV Module is modified and manufactured for V_{oc} of 17.3 Volts and V_{max} 14.3 Volts, thereby eliminating the need of a charge controller. The panel operating voltage does not cross the upper limit of 14.3 Volts and thus does not damage the battery. Also the power gained from the modified PV module is higher than the standard PV module of the same power rating.

This paper describes the results of the experimentation carried out to study and compare the performance characteristics of standard and modified Solar PV Modules in terms of I-V and P-V characteristics.

A new term "module utilization factor" - defined as the ratio "useful power to the total power" produced by the panel, is suggested. It is a measure of effective power rating of the solar PV module when used in a 12 V battery system with charge controller.

Index terms: Charge controller, Module utilization factor, Open circuit voltage, Solar PV module

I. INTRODUCTION

Solar Photovoltaic (PV) is a method of generating electrical power directly from the solar energy using semiconductors that exhibit the photovoltaic effect. Solar Photovoltaic power generation employ solar panels composed of number of solar cells. [1]

Solar cells produce direct current electricity from the Sun light which can be used in power equipment or to recharge a battery. The output of a Solar Photovoltaic panel is generally used for charging a battery where the electrical energy is stored. This stored energy is then used for powering different equipment's during the day and night hours as the case may be.

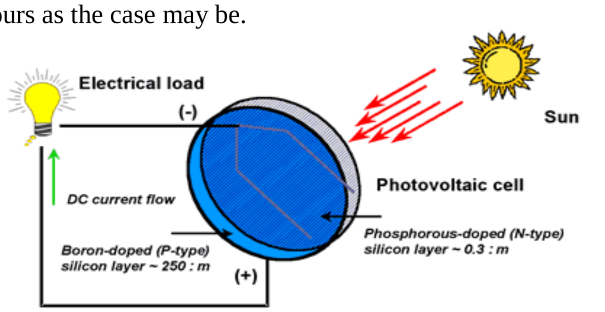

Fig. 1: Photovoltaics -wikipedia [1]

The rated photovoltaic power capacity is the maximum power produced by the panel (P_{max}) under standard test conditions (STC). The actual power output at a particular place may be less than or greater than this value, depending on the geographical location, time of the day, weather conditions, and other factors.

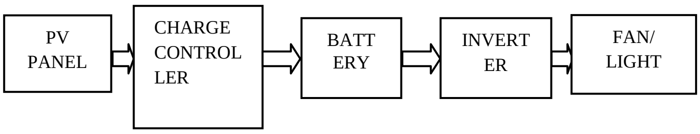

Fig.2: Schematic of solar PV system

Fig.1 shows a schematic diagram of a typical solar PV system. As shown in the figure, Solar PV panels are connected to battery bank through a charge controller and the battery bank to load through an inverter. The PV panels are connected in series and parallel depending upon the system power and the DC voltage required. Higher the system power more is the DC voltage required. The voltage is in multiple of 12 and can range from 12 volts to 360 volts for different applications. A suitable charge controller of the same DC voltage and the desired current capacity is used. In the present work, a 12 V DC system is considered.

Standard solar PV Modules have open circuit voltage V_{oc} in the range of 18 to 21.6 Volts, [5] which is much higher than the safe charging voltage of 14.2 volts as recommended by the battery manufacturers [2]. A charge controller is often used to limit the charging voltage to 14.2 V and thus protects the battery from any damage. The function of charge controller is to protect the battery from higher charging voltage and low battery voltage.[8]For protection against Higher charging voltage, it cuts off the charging supply to the battery at 14.2 Volts and again reconnects back at 13.6 volts[9].For protection against low battery voltage, it cuts of the supply to the load from battery at 10.6 volt. This is generally used in standalone system where the charge controller is placed in series with the battery and the load.[11].This feature of battery low protection is not used in higher capacity solar system (called as off-grid system) as the charge controller is placed in series between PV module and the battery and not in series of battery and the load. Because of the cut off at 14.2 Volts, the power generated by the panel beyond this point is wasted or remains unutilized as it is not fed to the battery nor it is directly supplied to the load. Also, this charge controller has its own conversion efficiency of about 90 % which reduces the total available output of the solar PV Modules.

We hereby propose Solar Photovoltaic module with new specifications of V_{oc} 17.3 Volts and V_{max} 14.3 Volts for a 12 Volt battery system. Hence the battery high voltage cut off is not required. At the same time, battery low protection is taken care by the inverter which cuts off the supply to load from the battery at 10.6 volt Different V_{oc} recommended for safe charging operation of other battery systems without charge controller is given in Table 1. These values are estimated based on the recommendations of the battery manufacturers [2].

TABLE I
PROPOSED WATTAGE AND V_{OC}

Sr. No	Module Wattage	Battery Voltage	V_{oc}
1	3 Watt	3 Volt	3.8 Volt
2	6 Watt	6 Volt	7.2 Volt
3	10 to 140 Watt	12 Volt	17.3Volt
4	150 to 300 Watt	24 Volt	35.2 Volt
5	300 to 450 Watt	36 Volt	52.8Volt
6	450 to 600 Watt	48 Volt	70.4 Volt

Such a design increases the power output of the panel compared to the standard one of the same power rating. Secondly, this will eliminate the need of charge controller and reduce size and cost of the SPV system.

Very little information is found available on such modified PV modules, although reference to "self regulated solar panels" can be seen in the literature. Detailed studies on these panels, however, could not be located.

To study the effect of these changed parameters on the performance of a solar PV system - especially the safe charging operation of the battery without any possibility of damage - this experimental work is undertaken. Also, the performance of the modified SPV module in terms of I-V and P-V characteristics was studied experimentally [3, 4].

II. EXPERIMENTAL SET UP

The experiments were performed in two stages
Stage - I: Charging of a 12 Volt battery by standard as well as modified PV panel without using a charge controller.
Stage- II: Experimentally establishing I-V and P-V curves for the standard as well as modified PV modules using Ecosense make load cell.
A line schematic of experimental setup used for the stage I of experimentation is shown in Figure 3. It consists of PV modules, a data logger, battery bank, an inverter and load-all connected as shown [7].The specifications are given in the Table 2.
A schematic of the experimental set up used for the Stage II of the experimentation is shown in Fig.4. It consists of Standard and modified PV modules, load cell, data logger interfaced with computer- connected as shown. The specifications of different components are given in the Table 2. All the experiments were performed considering a 12 Volt battery system. Solar radiations were measured separately using calibrated Pyranometer (Accuracy ± 1 %)[11].

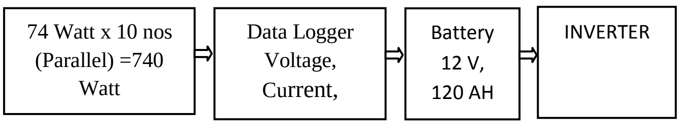

Fig. 3 Schematic of Experimental Setup-I

III. EXPERIMENTAL PROCEDURE

Stage 1

1. Standard/ modified Solar PV Modules are mounted on open, shadow free area facing south with an angle of 23^0 with horizontal.
2. The output of the Solar PV Module is fed to the battery through a data logger which records voltage, current & solar radiation. The output of the battery was connected to the load through inverter.

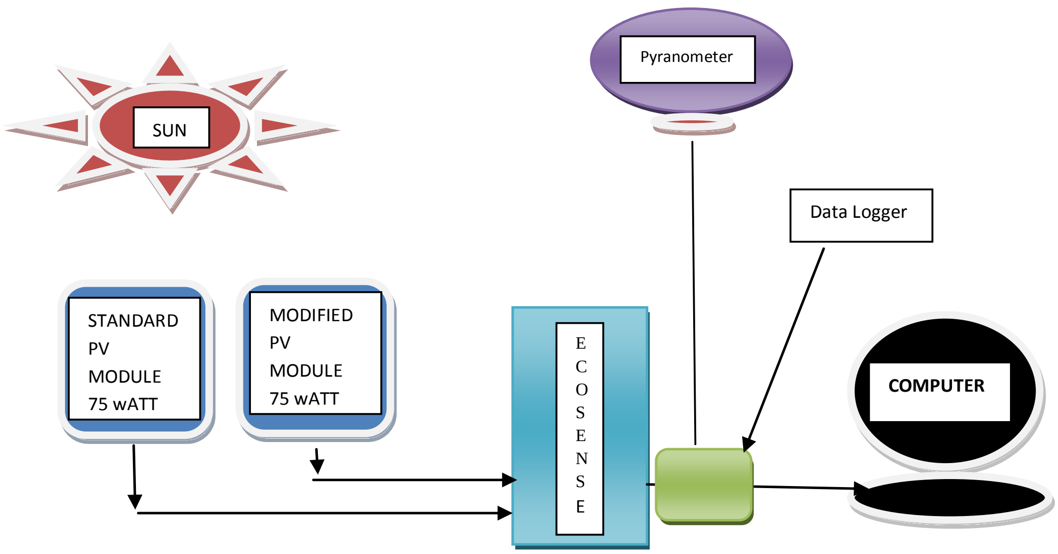

Fig. 4 Schematic of Experimental Setup-II

3. The battery was first drained by applying the load of fan and light, till the inverter tripped at battery low condition i.e. 10.6 Volt.
4. The system was ready for the reading.
5. The battery was allowed to charge to its maximum voltage with standard PV module without charge controller.
6. Voltage reached and charging current are recorded along with other parameters like ambient temperature, module temperature and solar radiation
7. The second sets of readings were taken with Modified Solar PV modules. Here also the battery was first drained off completely and then allowed to charge to its maximum voltage.
8. Voltage reached and charging current are recorded along with other parameters like ambient temperature, module temperature and solar radiation

Stage 2

1. Standard/ modified Solar PV Modules to be tested are mounted on open, shadow free area facing south with an angle of 23^0 with horizontal.
2. The output of the Solar PV Module is fed to an Ecosense load cell unit. This unit has a provision of testing of two PV modules simultaneously. This unit records the voltage and current output of the PV module from which the required I-V and P-Curves can be plotted.
3. Readings are obtained by varying the load on PV module with the help of potentiometer. For different load conditions (position of potentiometer), the voltage and current readings are recorded.
4. The generated data of various voltage and current readings is fed to computer through a data logger. This data is processed through software and finally I-V and P-V curves are obtained as the output.
5. The solar radiation is independently measured with the help of Solar Pyranometer.

TABLE II
DESCRIPTION OF STANDARD IEC – 61215 & MODIFIED SOLAR PHOTOVOLTAIC MODULE

Sr. No.	Description	Standard IEC – 61215	Modified Module
1	Type –	Multi-Crystalline	Multi-Crystalline
2	Id No. –	SS741400A276	120417365
3	Open Circuit Voltage (V_{oc}) STC	21.6 V	17.42 V
4	Short Circuit Current Isc (A) STC	4.26 A	5.985 A
5	Maximum Power Pmax. (W) at STC	75 W	75 W
6	Voltage at Maximum Power (Vmax) STC	17.7 V	14.30 V
7	Current at maximum Power Imax (A) STC	4.09 A	5.0342 A
8	No. of cells	36	32
9	Area of one cell (cm^2)	124.82	169.06
10	Area of Module(cm^2)	5360	5360
11	FF %	76	73.25
12	Cell Efficiency (%) STC	16.75	19.9
13	Inverter	Su-Kam 12 Volt, 800VA	
14	Data logger	Ecosense- 6Amp	
15	Battery	Quanta-26 AH	
16	Pyranometer	Portable	
17	Lap Top	HCL-I 7	

IV. RESULTS AND DISCUSSION

A. Stage I Results

As stated earlier, a 12 V battery was charged using the solar panels (standard and modified) without charge controller. Figure 6 shows the charging voltage attained on a typical day for standard as well as modified PV panels. Variation in the solar radiation is also plotted in the figure for reference[13].

It can be seen from the figure that

1. The solar radiation has its typical inverted parabolic variation with the maxima (880 W/m^2) occurring at noon around 12.30hrs.
2. The charging voltage for standard PV module exceeds the safe charging voltage (14.2 V) and remains so for about 3 hours. The charging voltage even crosses the 18 Volts and remains so for about 1 hour. This condition is very dangerous and harmful to the battery from life and safety point of view. Charge controllers are hence necessary for the safe operation of the solar system when used with standard PV module.
3. The charging voltage for the modified solar PV module, however, never exceeds the safe battery charging voltage and is around 14.2 Volts for about 6 hours. This condition is highly favorable to the battery from life and safety point of view. Thus the charge controller can be eliminated.

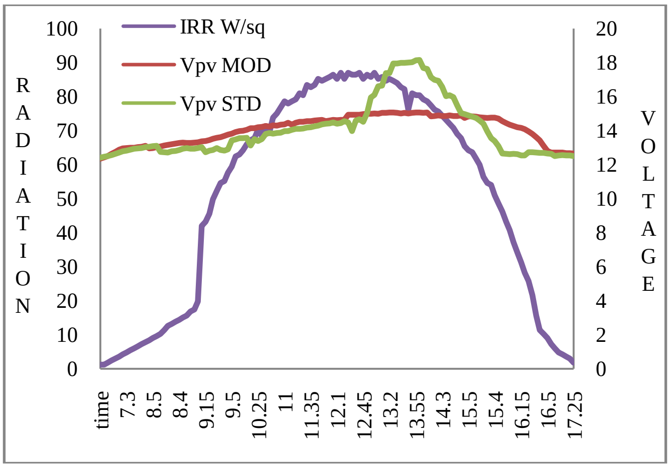

Fig.6. Charging voltage for Standard and Modified solar PV module with solar radiation

B Stage II Results

a) I-V curve for standard and Modified PV module

Fig.7 shows experimentally obtained I-V curves for both, standard and modified PV module. During the operation, outdoor conditions were as follows: [6]

For Standard PV module:

Solar intensity = 1012 ± 25W/m^2

Temperature = 46.5 ^{0}C

Panel temperature = 68 ^{0}C

For Modified PV module:

Solar intensity = 1012 ± 25W/m^2

Temperature = 46.5 ^{0}C

Panel temperature = 68 ^{0}C

It can be seen from I-V curves that

1. For both the modules- as the current decreases, voltage increases. The drop in the current is less initially but increases drastically beyond say 14 V. This is as expected.
2. In the case of standard PV module, the open circuit voltage V_{oc} is 19.2 Volts while the short circuit currentIsc is 3.8 A , whereas for the modified PV module, it is 14.2 Volts and 4.4 A respectively.
3. In the charging zone of the battery (i.e. 10.6 $\leq$ V $\leq$ 14.2 V), voltage and current generated by the standard PV module is less than those generated by the modified PV module.

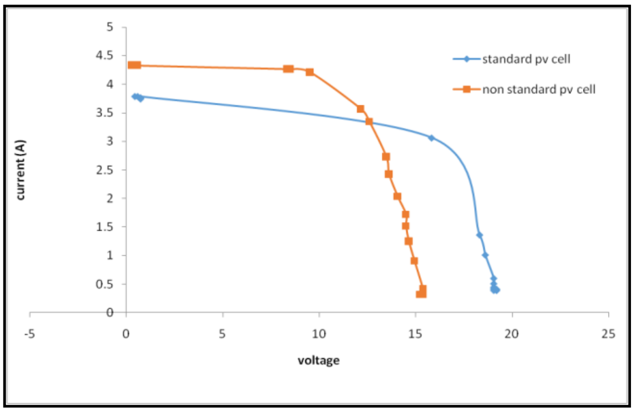

Fig.7 I-V Curve for Standard and Modified PV module

C. Power Generated

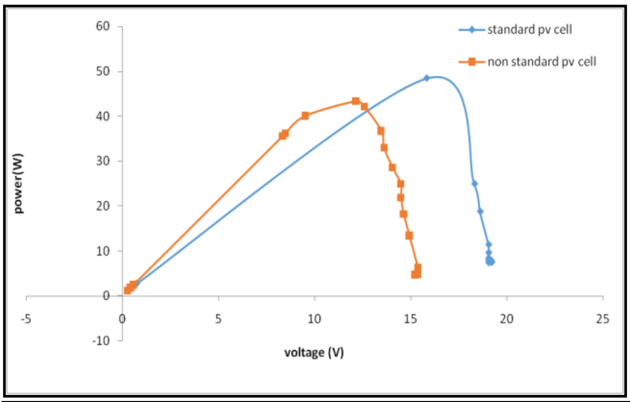

Fig. 8 Power generated by Standard and Modified Solar PV module

Fig. 8 shows Power generated by the Standard and Modified Solar PV module. It can be seen from this figure that

(i) The power produced by a panel increases with the voltage initially, attains a maximum value and then decreases sharply. This is an expected trend.

(ii) The maximum power produced by the standard PV module is 49 watt where as it is 43 watt for the modified PV module. This is less than the rated power of 75 W for both the panels. The reason behind this is that, during the experimentation, the temperature of the module was measured to be around 68^O C which is much higher than the standard testing conditions at 25 ^{0}C. Typically, the output power of the module decreases by 65% for every one degree rise in the panel operating temperature. Accordingly, the power produced by the panels is in the expected range.

(iii) The voltage at which P_{max} occurs is 17.0 Volts for standard and 12.4 Volts for modified module.

(iv) Usually standard panels are used with charge controllers for which the maximum "cut in" and "cut off" voltages are 13.6 V and 14.2 V respectively. The battery charging zone can be seen much below the rated power (or maximum power producing capacity) of the panel. The power generated beyond 14.2 Volts does not contribute to the power gain because in actual condition the battery gets disconnected from the PV module as soon as it reaches 14.2 Volts.

It is appropriate to introduce a new term module utilization factor defined as the ratio of "Maximum charging power supplied to the battery" to "the maximum power producing capacity of the panel." It is, in this case, is 45W/49W= 0.9 means in other words the panel is getting de-rated by 10 %. It is worth mentioning here that the panel has already been de-rated by about 35% due to higher operating temperature. Presently there is no control over the temperature attained by the solar panel while in operation.

(v) For modified panel however, there is no such cut in and cut off limit exists, hence has a wider charging zone (i.e. from 10.6 Volt onwards) it also utilizes the maximum power producing capacity of the panel. The module utilization factor in this case is 100%.

V. Conclusions

1. The battery charging voltage of the Standard PV Module having V_{oc} = 21.6 Volts without charge controller reaches up to 18.4 Volts which is much higher than the safe charging voltage as per the battery manufacturers recommendations. Hence charge controller is necessary for any solar system using standard PV module.
2. The charging voltage of Modified PV module having V_{oc} = 17.3 Volts, reaches up to 14.2 Volts. This is well within the safe charging voltage. Hence charge controller is not necessary. Since the cost of charge controller is eliminated, installation cost of the PV system also gets reduced.
3. Useful power generated by modified PV module is higher than the standard PV module under same test conditions by about 10 %.

4. Solar system cost is also reduced because of higher power gain.
5. If V_{oc} (open circuit voltage) is reduced to a suitable & safe value, the charge controller can be avoided and the safe charging of battery can also be ensured.
6. The Module utilization factor for 12 V battery system (P_{useful}/P_{max}) is higher for modified PV module (100%) compared to that of Standard PV module (90%). In other words, the use of charge controller downsizes the solar panel by about 10% for a 12 V battery system.

VI. Nomenclature

PV - Solar Photovoltaic
Wp - Watt peak
STC - Standard test conditions
Voc - Open circuit voltage
VA – Volt ampere
Isc - Short circuit current
I-V –Current-voltage
DC- Direct current

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