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A New Proteus Model to Analyse Shading Effect on PV Standalone System

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ABSTRACT

Shading phenomena on PV panels halt energy production to a great extent. Thus, an accurate, flexible, and yet simple PV system model is essential in shading effect assessment.

This paper presents a Proteus-based model for a standalone PV system using the more accurate two-diode model to assess the shading effect. Proteus program possesses the capability to model a wide range of practical microcontrollers through its powerful library while other simulation programs such as Matlab, PSCAD, and PSIM don't, which require modelling the controller circuit.

The Proteus Model thus can accurately emulate the power condition unit behavior and can easily simulate various maximum power point tracking (MPPT) algorithms by changing the programming code only without the need to change the controller model itself as compared to other programs.

Two-diode model parameters for a selected PV module were extracted to simulate the characteristics of PV panels accurately, especially at low irradiance levels.

The simulated PV panel results were compared with the corresponding manufacturer data to ensure model accuracy.

A complete Standalone PV system was modelled via Proteus software featuring a three-by-three series-parallel PV panel, DC-DC converter driven by incremental conductance maximum power point tracking technique, and a DC load.

The model was tested and was able to plot accurately system characteristics and track the maximum power point correctly.

Finally, short and narrow shadow pattern scenarios on the current-voltage (I–V) and power-voltage (P–V) characteristics are analyzed.

The proposed Proteus model proved to be accurate, simple, and fast in analyzing shading scenarios and more flexible to deal with changing conditions such as changing irradiance levels, tracking algorithms, and other factors.

Keywords: Photovoltaic, Partial Shading, Global Maximum Power Point, Proteus.

1 INTRODUCTION

Photovoltaic (PV) is becoming one of the most promising renewable energy sources having the highest growth rate among other renewable energy sources such as wind, biomass, and tidal [1]. A very distinguished merit PV systems possess is having various applications nowadays ranging from small-scale street lights to electrifying space crafts [2].

Shading on PV panels hinders the ability to harvest the maximum possible power from these affected panels and damages the PV modules while shading in most cases cant be avoided due to natural causes such as moving clouds and surrounding obstacles [3].

When shading affects sectors of the panels leading to Partial Shading Condition (PSC), the irradiance level on the PV modules becomes uneven, if no bypass diode is included across PV modules the shaded modules absorb power instead of generating it which decreases the net produced power and lead to the formation of hot spots on shaded modules while adding bypass diodes saves more energy and protect shaded modules this lead to changing the Power-Voltage (P-V) characteristics changes dramatically from a single peak curve to a multi-peak curve with a single Global Maximum (GM) and numerous Local Maximum (LM) depending on the number of shaded panels and intensity of shading as shown in Fig. 1 [4],[5],[6].

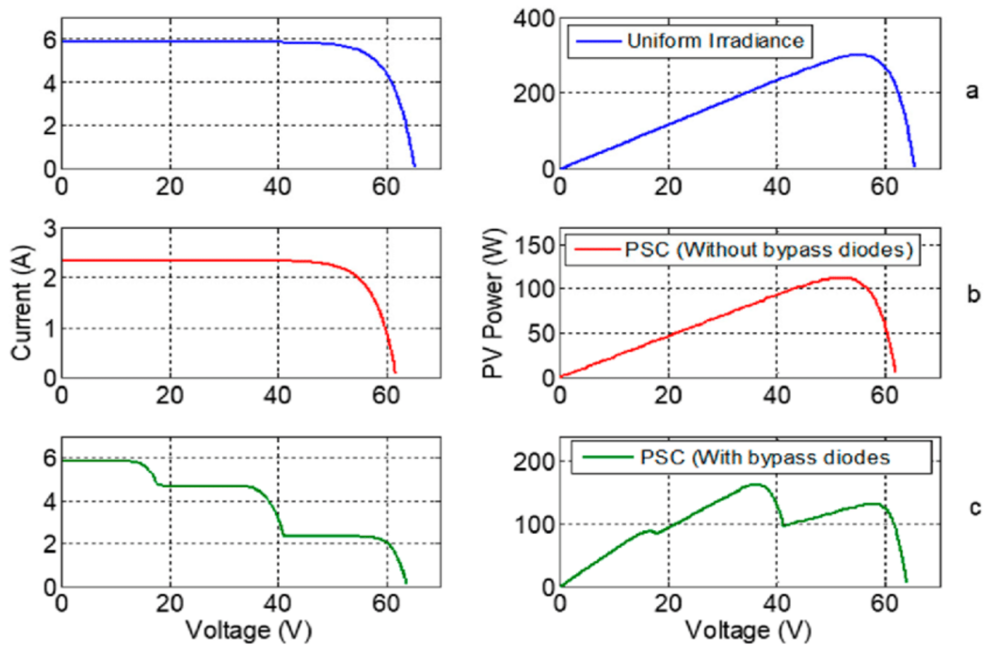

Fig.1. P-V Characteristics and I-V Characteristics Under Uniform Irradiance and PSC Without Bypass Diode and With Bypass Diode [7]**.**

It is of great importance to predict the system's behavior at various shading patterns that can most likely fall on the PV modules as a short and narrow shadow, short and wide shadow, long and narrow shadow, long and wide shadow, and diagonal shadow [4].

MATLAB is the most frequently used tool to simulate PV systems based on its wide library of electrical blocks making it a powerful tool although it lacks a model for practical microcontrollers used with Maximum Power Point Tracking (MPPT) systems to simulate real working conditions [8], besides changing the MPPT technique require altering the simulated blocks to simulate various MPPT techniques as perturb and observe, incremental conductance, hill climbing, constant voltage tracking, open-circuit voltage tracking and more [9].

PSCAD and PSIM are also used to simulate PV systems being more power system-oriented software with a wide library containing ready-made power system models, although it lacks also a model for practical microcontrollers [10].

Proetus Software is yet another powerful simulating software using the Spice simulation model in addition to printed circuit board layout with a wide range of practical models for microcontrollers where you can check various MPPT techniques by just altering the code downloaded to the selected microcontroller [11].

This paper aims to build a complete Proteus model for a standalone PV system under various shading conditions to assess system performance.

The paper is organized as follows: the first section models the PV module based on the two-diode model for more accurate results, especially at low irradiance levels, the second section presents a complete Proteus model for a standalone PV system compromising PV panels, microcontroller with MPPT algorithm and a load, the third section investigate system performance under various partial shading conditions, and the final section concludes the results.

2 PV PANEL MODELLING

2.1 Single Diode Model

PV possesses nonlinear P-V and I-V characteristics that are mainly dependent on irradiance level and temperature, to shape these characteristics the equivalent circuit model is widely accepted among researchers to model PV panels with the Single Diode Model (SGM) and the Double Diode Model (DDM) the most prominent models used [12] along with other models as three diode model [13] and dynamic model [14].

SDM is the simplest model shown in Fig.2 compromises a current source representing the photon current produced under solar irradiation, series resistance to represent conduction losses, and shunt resistance to represent leakage current losses, while the diode current represents the current loss due to recombination.

The governing equation is shown in (1)

$$I=Iph-\frac{U+I*R_S}{R_P}-I_0*(e^{(U+I*R_S)/n*V_T}-1) \quad (1)$$

Where I is the PV output current, U is the module output voltage, I_{ph} is the photo-current, R_S and R_P are the series and shut resistances respectively, while n,I_0 is the diode ideality factor and saturation current and V_t is the diode thermal voltage.

SDM, therefore, has five unknowns namely: I_{ph}, R_S ,R_P, n , and I_0 where a variety of bio-inspired metaheuristics methods is used to extract those parameters to accurately model the PV panel characteristics like Bird Mating Optimization (BMO), Cuckoo Search Optimization (CS), Flower Pollination Optimization (FPO), Gray Wolf Optimization (GWO), Moth-Flame Optimization (MFO) and Cat Swarm Optimization (CSO) [15]

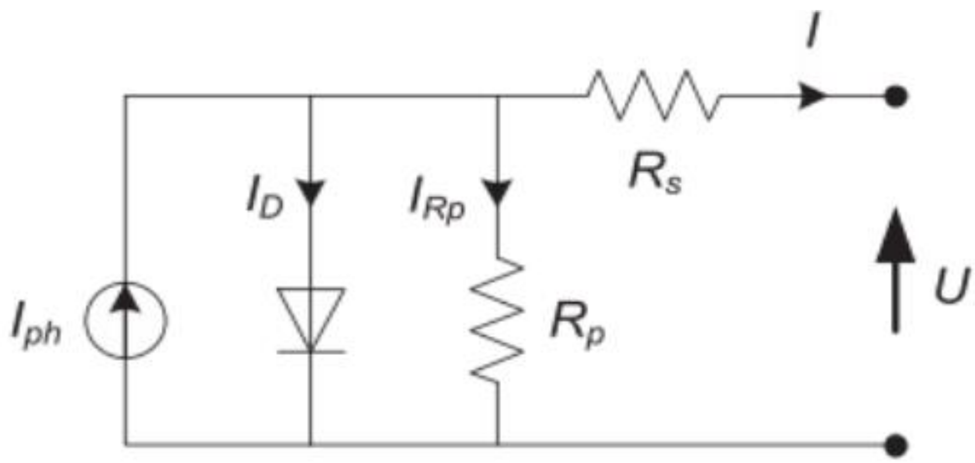

Fig.2. Single Diode Model

Although the SDM is the simplest PV model it fails to accurately model the recombination loss, especially at low irradiance

2.2 Double Diode Model

SDM doesn't take into consideration recombination losses thus reducing the model accuracy while the DDM model shown in Fig. 3, the PV module using two diodes eventually having seven unknowns namely I_{ph}, R_S ,R_P, n1,n2 , I_{01} and I_{02} where n1 and n2 are the first and second diode ideality factor respectively while I_{01} and I_{02} are the first and second diode saturation current respectively [16].

Equation (2) gives an illustration of the PV output current

$$I=Ipv-\frac{U+I*R_S}{R_P}-I_{01}*\left(e^{(U+I*R_S)/_{n1*V_T}}-1\right)-I_{02}*(e^{(U+I*R_S)/_{n2*V_T}}-1) \quad (2)$$

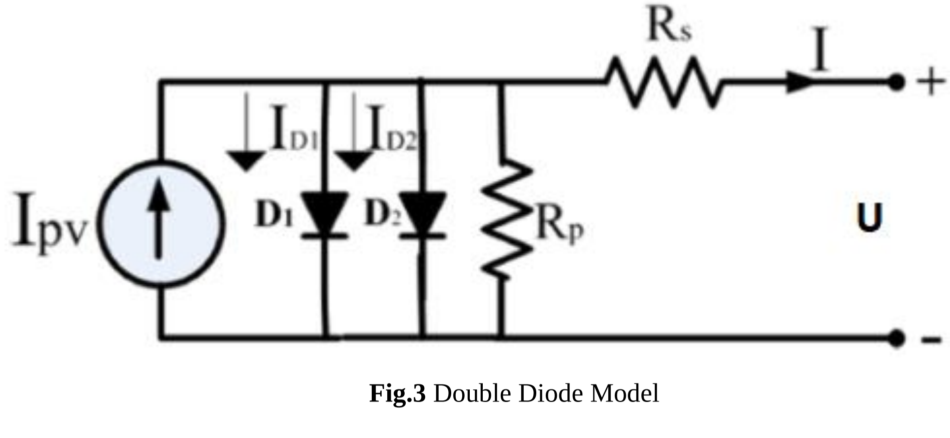

Fig.3 Double Diode Model

2.3 Extracting Double Diode Model Parameters.

In this section, the seven unknown parameters for DDM for the FOSERA FS1.5 PV module are extracted based on five practical test points shown in Table.1

Table 1. Five Test Points for FS1.5 PV Module

Test Point	Voltage [V]	Current [mA]
Short Circuit	0	370
Open Circuit	5.33	0
Maximum PowerPoint	4.33	340
Half Maximum PowerPoint	2.70	360
Average of Maximum power voltage and open-circuit voltage	4.91	240

An optimization problem is constructed to minimize the error between the model output current and the five test points as shown in (3)

$$F_{obj} = I_{Model} - I_{Test\ Points} \tag{3}$$

Where the problem variables are the DDM seven unknown, using Hybrid Flower Pollination Algorithm with Clonal Selection Algorithm (HFPA-CSA) [17] to solve the optimization problem.

The seven DDM parameters were extracted as shown in Table. 2 and the I-V curve was plotted given great accuracy in modelling the FS1.5 PV module in Figure 4.

Table.1 DDM Parameters for FS1.5 PV Module

Parameter	Value
I_{o1}	$5.74e^{-12}$ A.
I_{pv}	370 mA
n1	0.51.
R_p	300 Ω.
R_s	0.69 Ω.
I_{o2}	$6.81e^{-12}$ A
n2	0.47.

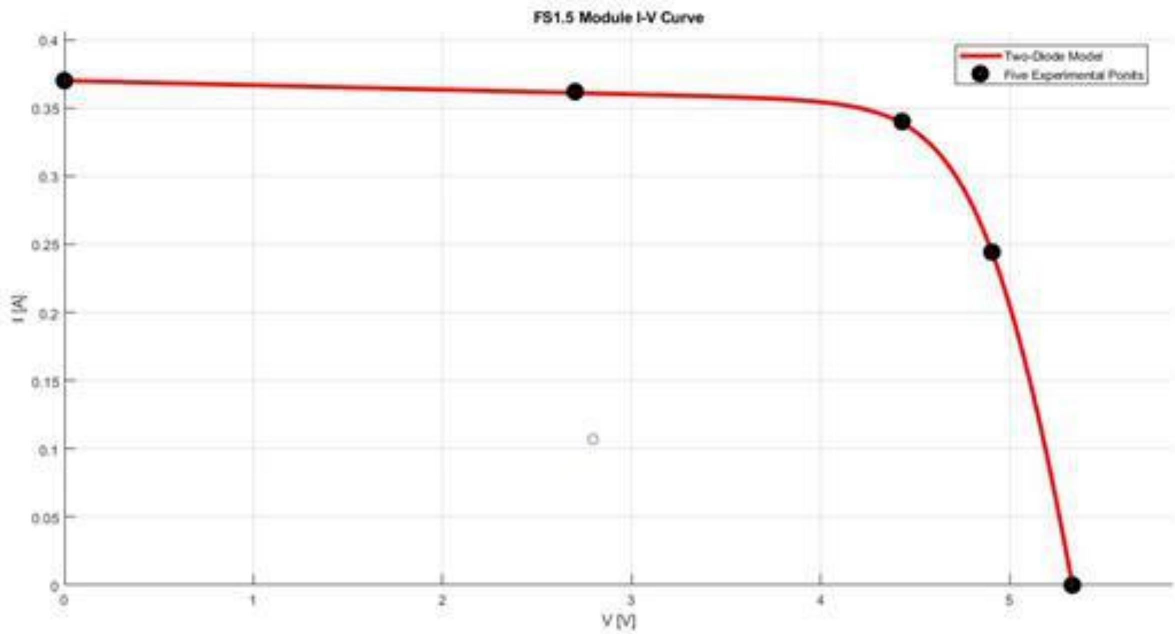

Fig.4 I-V Characteristics for FS1.5 PV Module Based on Extracted DDM Parameters

2.4 Proteus Model for FS1.5 PV Module

A Proteus model utilizing the DDM parameter was constructed as shown in Fig. 5 with the help of the Spice model for the two diodes to alter the parameters of the diode as required.

DC Sweep analysis was carried out to plot the I-V characteristics to ensure model validity as given in Figure 6.

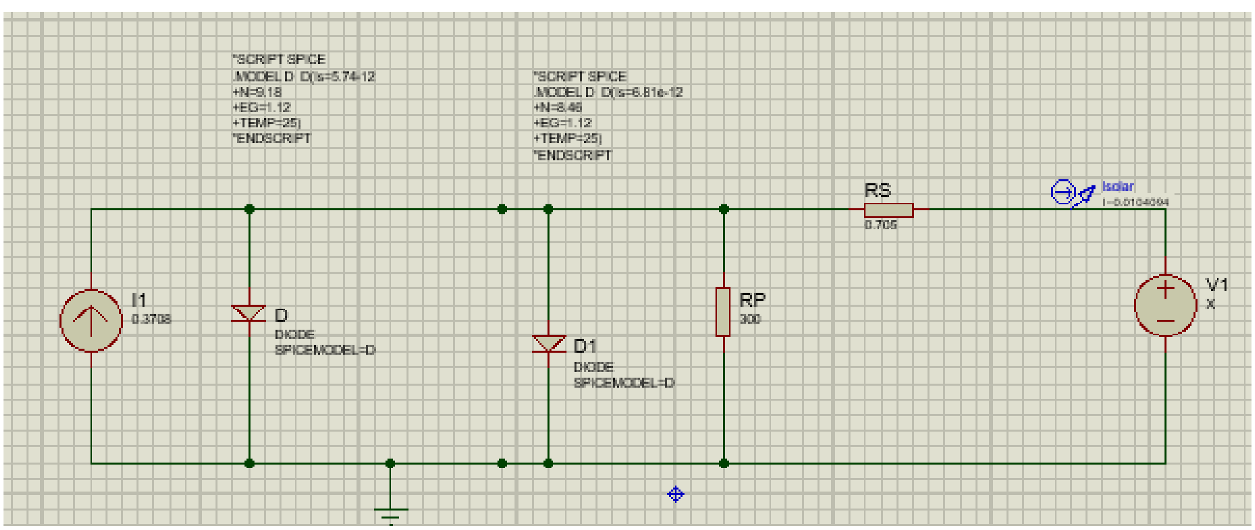

Fig. 5. Proteus DDM For FS1.5 PV Module.

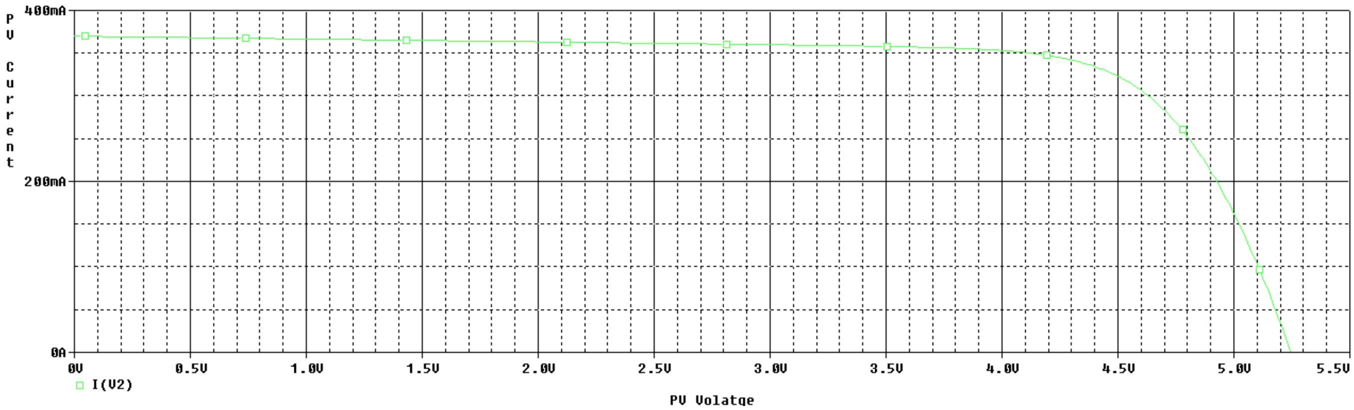

Fig.6. FS1.5 PV Module I-V Curve

Simulated results show accurate modeling of the Proteus DDM presents, to adapt the model to various environmental conditions namely temperature and irradiance the Proteus DDM was manipulated to accurately emulate system behavior, especially at shading conditions where the photon current. In [18] the effect of both irradiance and temperature on the Diode model was explored where the photon current relation is given by (4)

$$I_{PV} = (S/S_{ref}) * (I_{PV,ref} + K_{ISC} * [T - T_{Ref}]) \quad (4)$$

- Where S and Sref are the irradiance level and standard irradiance level at 1,000 w/m^2
- I_{PV} and $I_{PV,ref}$ are the photon current and standard irradiance level at 1,000 w/m^2
- K_{ISC} short circuit current temperature coefficient.

The new Proteus DDM taking into consideration environmental conditions is illustrated in Fig.7

3 PV SYSTEM MODELLING

Proteus software possesses the capability of emulating a wide range of practical microcontroller [19] boards which is very useful to simulate the behavior of a standalone PV system consisting of series-parallel PV panels, DC-DC converter with Maximum Power Point Tracking (MPPT), and a DC load.

A complete model for the previous system was built using Proteus software as shown in Fig.8 featuring three by-three series parallel FS1.5 PV modules based on the DDM extracted previously, voltage and current sensor models, DC-DC converter driven by MPPT algorithm featuring incremental conductance [20] written in C-code, thus providing a fixability to change the MPPT algorithm without changing the system itself.

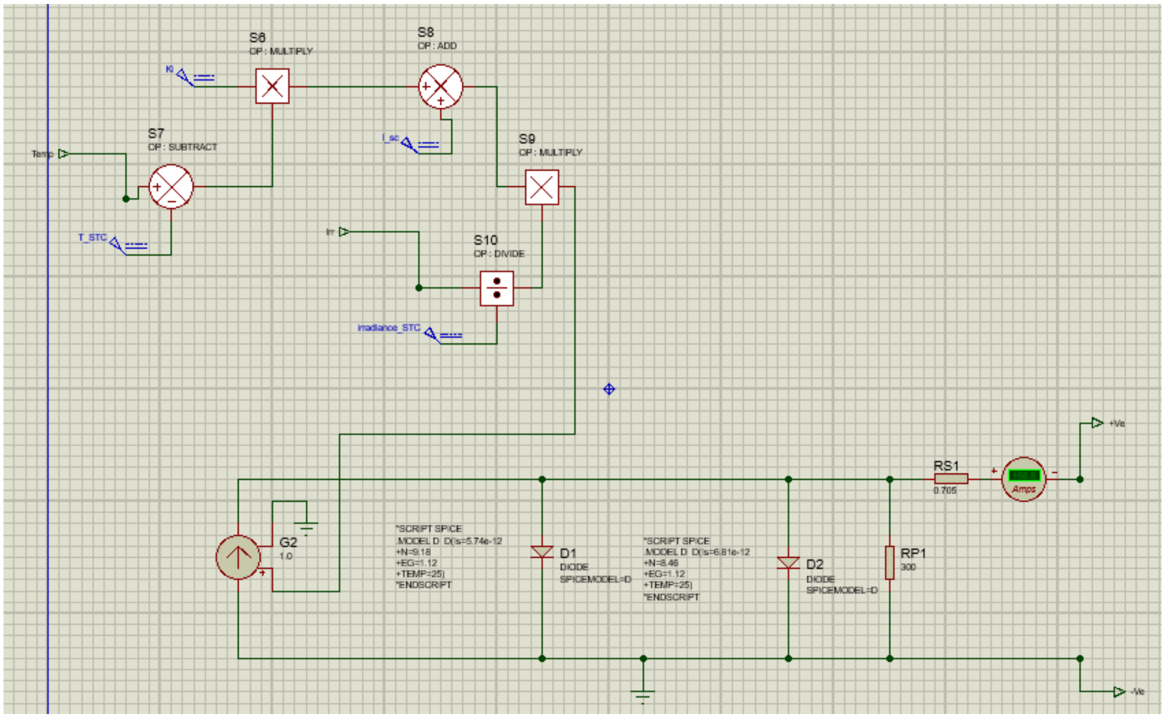

Fig. 7. Modified Proteus DDM

Simulation results are summarized in Table.2 where the simulated Proteus model results are shown in Fig.9. successfully simulates the system as compared with the expected theoretical result

Table.2. Proetus Model Results vs. Theoretical Results

	Proetus Model Results	Theoretical Results	Percentage Error
PV Output Power	13.56 watt	No. of Modules* P_{rated} =9*1.5=13.5 watt	0.4 %
PV Panel Voltage	13.34 V	No. of Series Modules*V_{MPP}=3*4.33=12.99 V	2.6 %
PV Panel Current	1.02 A	No. of Parallel Modules* I_{MPP}=3*0.34=1.02 A	0 %
			Overall≈1%

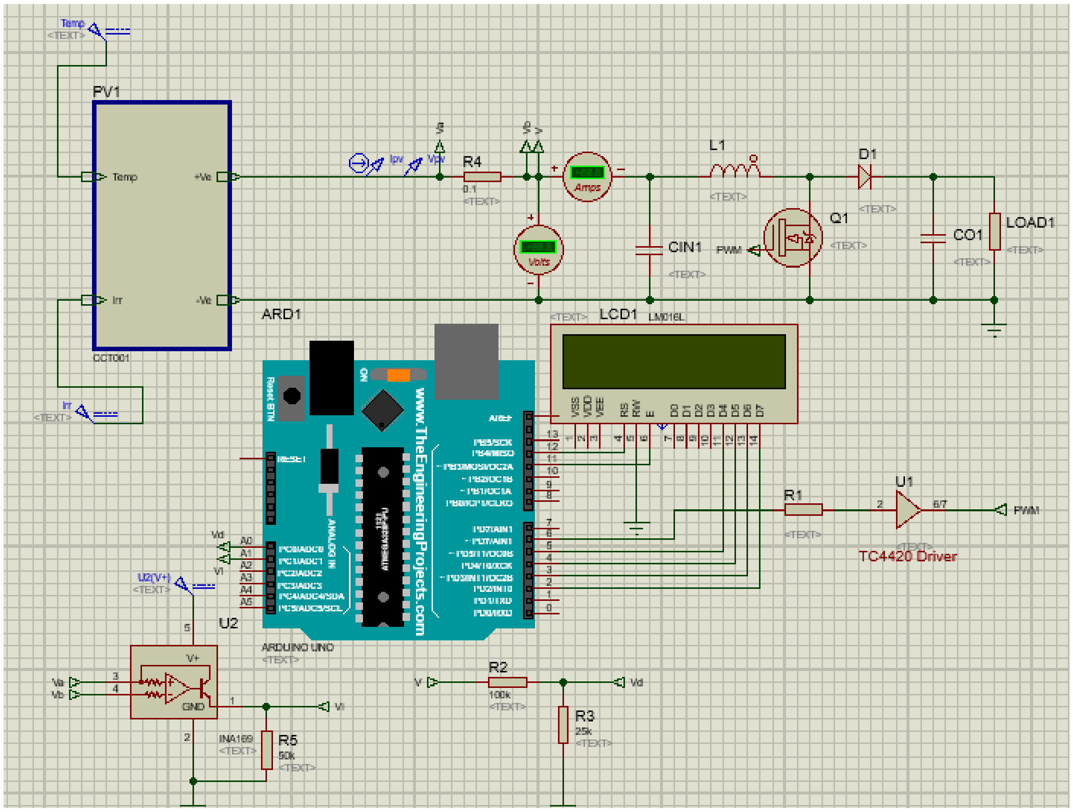

Fig. 8. Proetus Model for Standalone PV System

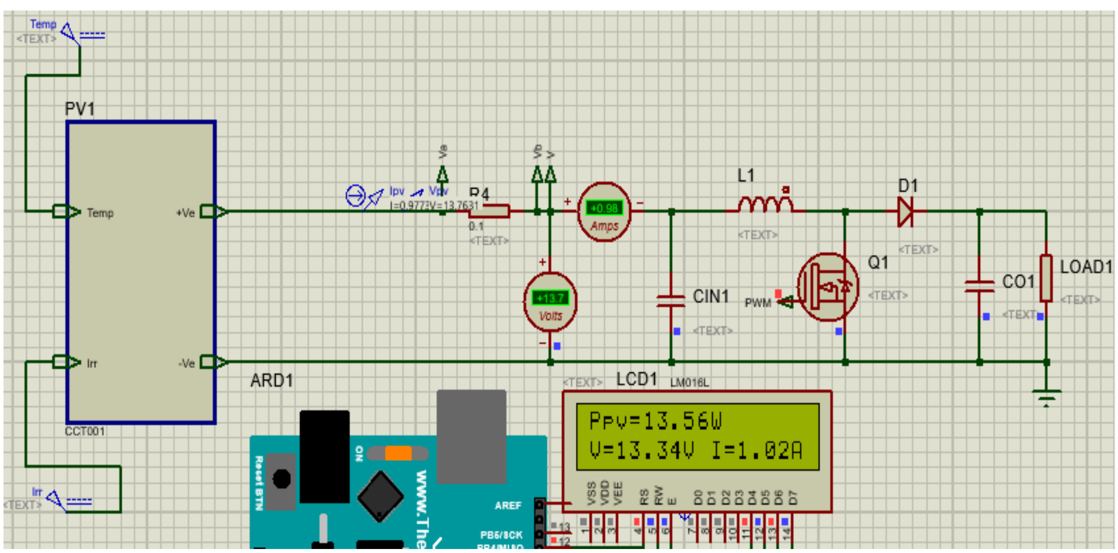

Fig.9. Simulated Proteus System Results

4 SHADING EFFECT

In this section and after examining the DDM accuracy and the overall system accuracy, the shading effect will be explored.

4.1 Uniform Irradiance.

DC sweep analysis is used to plot the I-V and P-V characteristics of the system at various conditions whereas Fig.10 shows those curves at 1,000 w/m^2 and uniform irradiance.

It can be seen that at a uniform irradiance level of 1,000 w/m^2, the P-V curve exhibits a single peak point producing about 13.5 watts, which makes it easy for the MPPT algorithm to track the MPP.

Fig. 10. PV Panel I-V & P-V Characteristics at 1,000 w/m2 Uniform Irradiance

4.2 Short and Narrow Shadow Without Bypass Diode.

A short and narrow shadow pattern featuring a one-shaded module at an irradiance level of 500 w/m^2 is studied without a bypass diode where the resulting curves are shown in Fig. 11

Fig. 11. PV Panel I-V & P-V Characteristics with short and narrow shadow without bypass diode

It can be seen that the P-V curve still exhibits a single peak point producing about 11.5 watts with the losses due to shading about 15 % due to a single module shaded and with the risk of formation of hotspot on the shaded module.

4.3 Short and Narrow Shadow with Bypass Diode.

Finally, a short and narrow shadow pattern featuring a one-shaded module at an irradiance level of 500 w/m^2 is studied with a bypass diode across each unit for protection where the resulting curves are shown in Fig. 12.

The P-V curve exhibits two peak points where the conventional MPPT algorithm can be trapped at the first local maximum point thus producing about 9 watts with a loss percentage of 30% while the global maximum point produces about 11.5 watts without the risk of formation of hotspots.

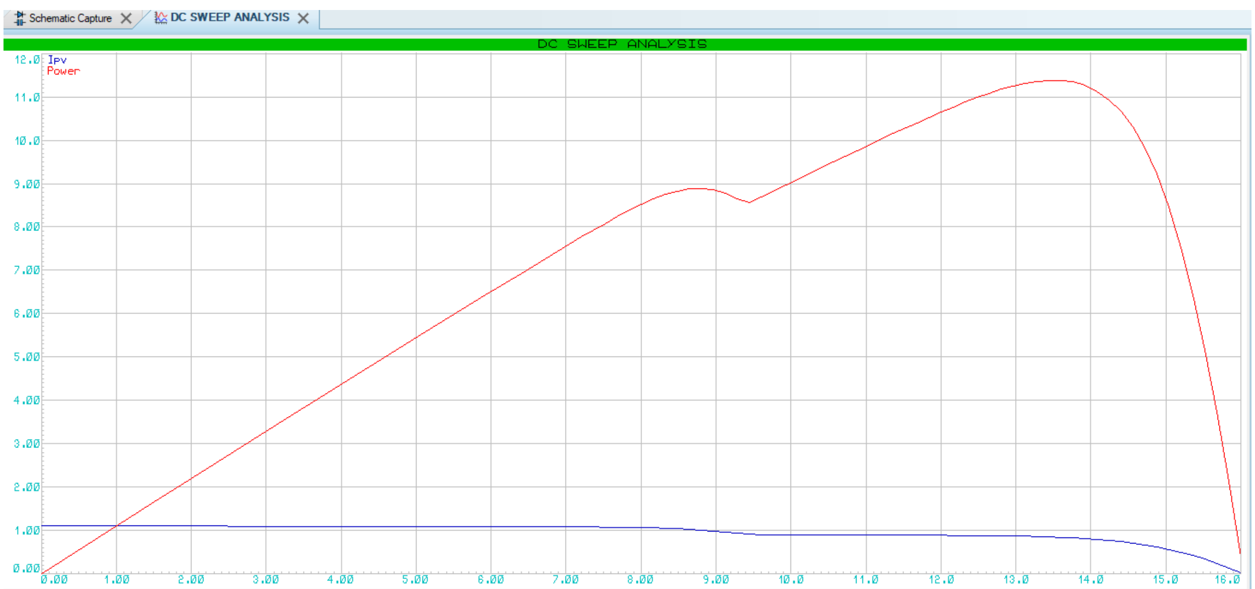

Fig. 12. PV Panel I-V & P-V Characteristics with short and narrow shadow with bypass diode

5 CONCLUSION

The proposed Proteus model successfully simulates the standalone PV system behavior.

Firstly, the DDM for the FS1.5 PV module was extracted via HFPA-CSA where the extracted parameters summarized in Table.1 were used to build up the Proteus model for PV modules.

The I-V curve for the FS1.5 PV module was plotted to ensure accurate fitting with test points which the results prove as shown in Fig.4 and Fig. 6.

Secondly, a complete Proteus model was proposed using the available microcontroller library to model the DC-DC converter along with its driving MPPT technique, and results were again summarized in Table.2, where the proposed system results were promising.

The Proteus software proved to be a more effective method to model PV systems, especially when dealing with power conditioning units as no need to model it as in Matlab or similar programs but it was straightforwardly chosen from the Proteus library to match the practical microcontroller used.

Another powerful point that the Proteus model posses over other simulation programs is the ability to alter the MPPT algorithm without the need to alter the system, where changing the microcontroller code is only needed to achieve that.

Finally, the proposed Proteus model was used to analyze the effect of shading on the previous standalone system with and without bypass diodes where it proved to be an efficient and easy way to analyze the shading effect on the system.

The Proteus model is applicable for various PV connections: series-parallel, total cross-tie, honey-comb…etc, and can be extended for larger systems compromising bigger modules.

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