Analysis of Efficiency of Single Diode Model And Double Diode Model of Photo-Voltaic Panel Based on Different Parameters

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Abstract- *This research paper is on comparative analysis between single diode and double diode model of photovoltaic (PV) solar cells to enhance the conversion efficiency of power engendering PV solar systems. Single diode model is simple and easy to implement, whereas double diode model has better accuracy which acquiesces for more precise forecast of PV systems performance. Investigation is done on the basis of simulation results and MATLAB software is used to serve this purpose. Simulations are performed by varying distinct model parameters such as solar irradiance, temperature, value of parasitic resistances, ideality factor of diode and number of series and parallel connected solar cells used to assemble PV array. Conspicuous demonstration is executed to analyze effects of these specifications on the efficiency curve and power vs. voltage output characteristics of PV cell for specified models.*

Keywords- Photovoltaic Cell , Single Diode Model , Double Diode Model , comparison

I. INTRODUCTION

The spectrum of the solar light coming from sun covers from about 250 nm to about 2500 nm in wavelength. The efficiency of silicon solar cells is in the range of 13-18%. The average of sun light power or solar power covering the entire spectrum is about 1KW/m2 peak, that is in the direction of the sun and when the sun has reached its peak power, not early in the morning or late in the evening. When light shines on crystalline silicon, electrons within the crystal lattice may be freed. But not all photons — as packets of light energy are called — are created equal.

Only photons with a certain level of energy can free electrons in the semiconductor material from their atomic bonds to produce an electric current. This level of energy, known as the "band gap energy," is the amount of energy required to dislodge an electron from its covalent bond and allow it to become part of an Electrical circuit. To free an electron, the energy of a photon must be at least as great as the band gap energy. [1]

Grid-connected PV systems do not require batteries. However, some grid connected systems use them for emergency backup power. And of course in remote areas, solar electricity is often an economic alternative to expensive distribution line extensions incurred by a customer first connecting to the utility grid. Electricity produced by solar electric systems in remote locations is stored in batteries. Batteries will usually store electricity produced by a solar-electric system for up to three days. What type of system to purchase will depend on the energy-efficiency of your home, your home’s location, and your budget before you size your system, try reducing energy demand through energy-efficient measures. Purchasing energy-saving appliances and lights, for example, will reduce your electrical demand and allow you to purchase a smaller solar-electric system to meet your energy needs or get more value from a larger system. Energy efficiency allows you to start small and then add on as your energy needs increase. [2]

This paper presents a comparison of single and double diode electrical equivalent mathematical models for a PV cell/module/array based on Shockley diode equation. The presented different models include single diode model and double diode model for PV cell, module & array, respectively. These models accept solar irradiance and temperature as input parameters and yield the P-V output characteristics. In this paper, the comparison of different models are performed on the basis of MPP tracking and values of the various parameters like peak current, peak voltage, open circuit voltage and short-circuit current value achieved from output P-V characteristics and their resemblance with manufacturer specified specifications. Best (efficient as well as simple) model that can be used for simulation purpose is selected. The selected model is useful for professionals who require simple and accurate PV simulators for their design. It is also useful in the analysis of

MPPT technologies and in the design of Power converter system. In addition to this, the paper also illustrates the effect of various parameters like diode ideality factor, series resistance, input sun radiation and cell temperature. No of series – parallel cells on single, diode model performance. Model evaluation is performed using adani ETERNAL series of 300W PV module. All mathematical models presented here are programmed using script file in MATLAB environment. Mathematical modeling of photovoltaic cell/module/array [3]

II. ELECTRICAL MODEL OF PV CELL

For various commercial operations, distinct types of photovoltaic (PV) cell technologies have been used. These cell technologies can be classified as multicrystalline, mono-crystalline and thin film. Single and double diode PV models have been widely used for modeling the output characteristic of a PV module.

Single diode model is the simplest as it has a current source in parallel to a diode. This model is upgraded by the inclusion of one series resistance, Rs. In spite of its simplicity, it exhibits acute deficiencies when suffered from temperature deviations. An accretion of the model which introduces a supplementary shunt resistance Rp exhibited in Figure (1). Although momentous development is attained, this approach claims significant computing exertion. Moreover its precision declines at low irradiance, particularly in the vicinity of open circuit voltage (Voc). Two-diode model (consisting Rp and Rs) shown in Figure 2 is recommended for improved accuracy.

III. SINGLE DIODE MODEL

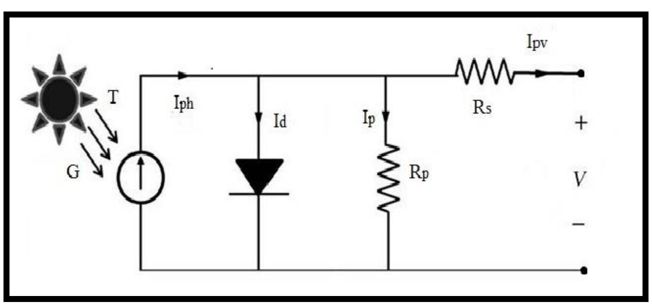

Figure 1: Single Diode Equivalent Circuit

Equivalent single diode circuit model is shown in figure (1) where current is generated from current source (Iph) , forward bias current of diode D is (Id) , cell resistance loss by (Rs and Rp). The remaining current is obtained at output terminal. [4][5][6][7]

Mathematical expression for single diode model:-

$$I = I_{ph} - I_0\left[\exp\left(\frac{V + IR_s}{aV_T}\right) - 1\right] - \frac{V + IR_s}{R_p} \quad (1)$$

$$Vt = \frac{NskT}{q} \quad (2)$$

$$Iph = \left(\frac{G}{Gn}\right)[Ipvn + ki\,(T - Tn)] \quad (3)$$

$$I_0 = Ion\left(\frac{Tn}{T}\right)^3 * \exp\left[\frac{qEg}{ak}\left(\frac{1}{Tn} - \frac{1}{T}\right)\right] \quad (4)$$

$$I_{0n} = \frac{I_{scn}}{\exp(V_{ocn}/aV_{Tn}) - 1} \quad (5)$$

IV. DOUBLE DIODE MODEL

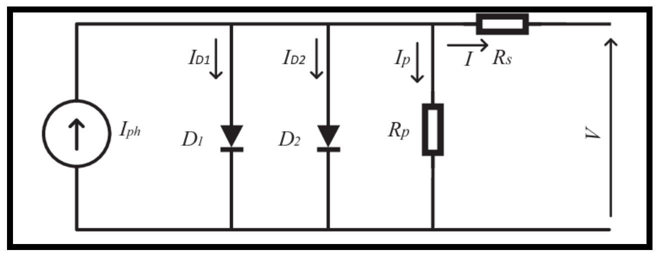

Figure 2: Electrical Model of Double Diode Cell

Equivalent double diode circuit model is shown in figure(2) where current is generated from current source (Iph) , forward bias current of diode D1 and D2 is (Id1 and Id2 respectively) , cell resistance loss by (Rs and Rp). The remaining current is obtained at output terminal. [8][9]

Mathematical expression for double diode model:-

$$I = Iph - Id1 - Id2 - Ish \quad (7)$$

$$Id1 = Io1\left[\exp\left(\frac{V + IRs}{a1 * Vt}\right) - 1\right] \quad (8)$$

$$Id2 = Io2\left[\exp\left(\frac{V + IRs}{a2 * Vt}\right) - 1\right] \quad (9)$$

$$Ish = \frac{V + IRs}{Rp} \quad (10)$$

$$Iph = \left(\frac{G}{Gn}\right)[Iscn + ki * (T - Tn)] \quad (11)$$

$$Io1 = Io2 = \frac{Iscn + Ki * (T - Tn)}{\exp\left(\frac{Vocn + Kv * (T - Tn)}{Vt}\right) - 1} \quad (12)$$

Different parameters used in above equations:-

- **K** is Boltzmann constant
- **q** Is electron charge
- **Tn** is surface temperature at STC.
- **Gn** is irradiation at STC
- **T** is surface temperature
- **G** is irradiation
- **Kv** is voltage coefficient
- **Ki** is current coefficient
- **Voc** is open circuit voltage
- **Isc is** short circuit current
- **Ns** is no. Of cells connected in series
- **Np** is no. Of cells connected in parallel
- **a1& a2** is ideality factor of diode D1 & D2 for double diode model respectively.
- **a** is ideality factor of diode D in single diode model
- **Iph** is photogenerated current
- **Io** is reverse saturation current of diode
- **Vt** is thermal voltage
- **Id** is diode current in single diode model
- **Id1 & Id2** is diode current of D1 & D2 respectively in double diode model
- **I** is total current at output.

V. FILL FACTOR (FF)

Voc is the open circuit voltage and Isc is short circuit current which gives maximum I-V curve and maximum power can get by manufacturer PV module. And the I and P is the actual output current and power of simulation model respectively, fill factor shows the gap between Voc-Isc curve and the actual I-V curve, it is the ratio of maximum power of module and the product of Voc and Isc. This shows the performance of pv module varies from 0 to 1, if this factor close to 1 better means the performance , most of the solar module have fill factor above 0.7.[10][11] Expression shown in below equation

$$FF = \frac{Vm * Im}{Voc * Isc} \tag{13}$$

VI. EFFICIENCY

Efficiency of solar module is get by ratio of maximum input power from sun or product of Vmpp and Impp, where Vmpp is Voltage at maximum power point and Impp is current at maximum power point respectively and the actual output power get from pv module. This shows the performance of PV module and simulation model at different conditions of Parameter. [12] In this paper efficiency is observed at different levels of parameters (Irradiation, temperature, series resistance, parallel resistance, no or cells in series & parallel and ideality factor)

$$EF = \frac{Voc * Isc * FF}{Pmax} \tag{14}$$

VII. SIMULATION AND OBSERVATION

In order to analyze the behavior of both PV model, simulation is done in MATLAB environment. To compare PV models & to inspect the effect of various parameters, same specifications are used of module Adani ETERNAL series of 300WP.

These specifications are

Table- 1: Adani ETERNAL Series Module Datasheet

Parameters	values
Maximum input power	300W
Open circuit voltage (Voc)	39.53V
Short circuit current (Isc)	10.01A
Voltage coefficient	-0.31%
Current coefficient	0.068%
Reference temperature	25°c/298k

7.1 IRRADIATION (G)

As soon as the irradiation rises the blackbody effect on cell output rises due to raise in input current Iph as seen in both the models whereas in double diode model output power and efficiency is higher than single diode model which shows double diode data is nearer to manufacturer's data than single diode model. [13][14] As the difference seen between figure (3), (4) and figure (5) (6)

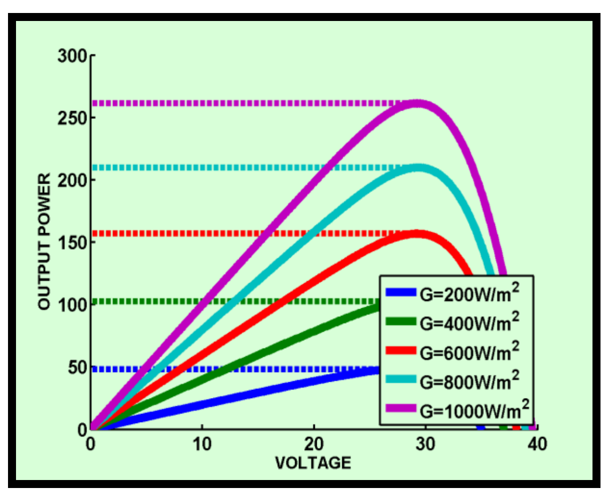

Fig 3: P-V Characteristics of Single Diode Model at Changing Irradiation

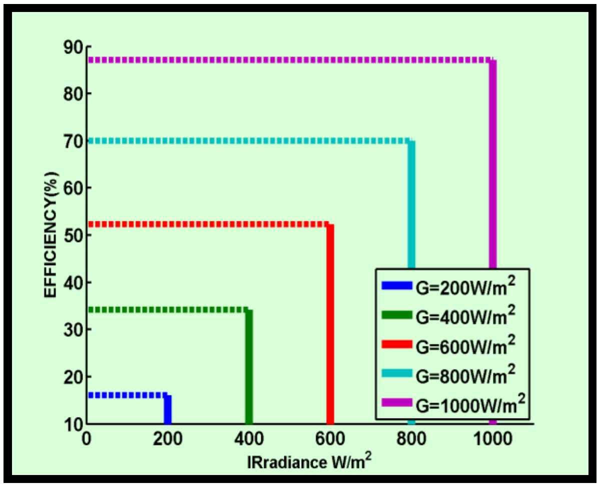

Fig 4: Efficiency of Single Diode Model at Changing Irradiation

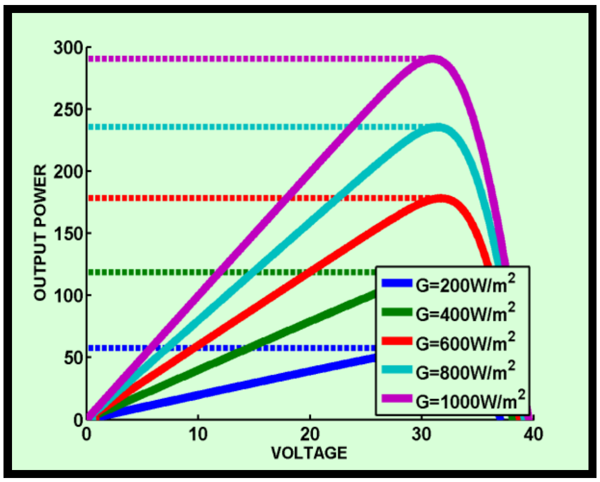

Fig 5: P-V Characteristics of Double Diode Model at Changing Irradiation

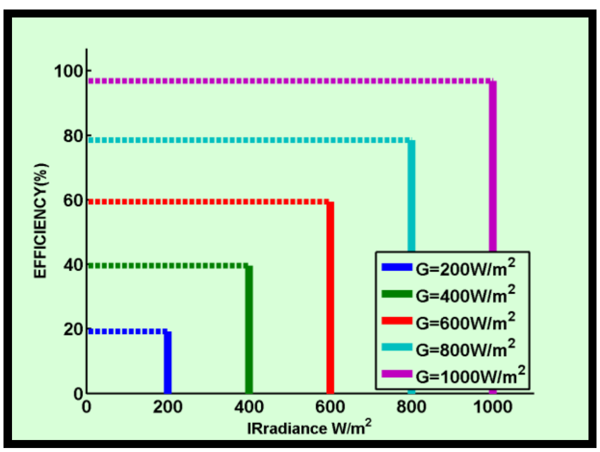

Fig 6: Efficiency of Double Diode Model at Changing Irradiation

7.2. TEMPERATURE (T)

As per the effect of temperature can be seen in both the models as temperature rises output power and efficiency decreases due to variation in photocurrent , saturation current and thermal voltage where double diode model is more accurate than single diode model which shows closer results to manufacturer data. [4][13][14][15] As seen from figure (7) (8) (9) (10)

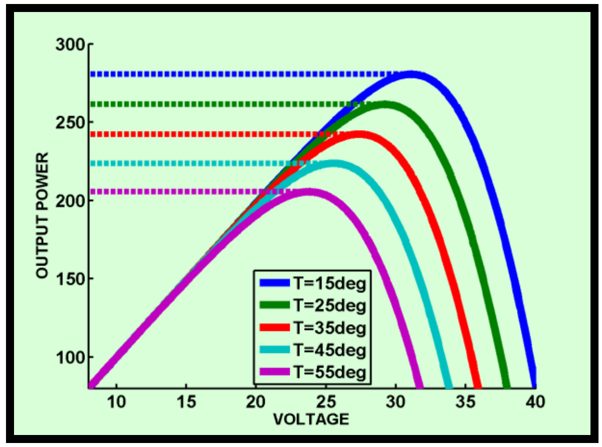

Fig 7: P-V Characteristics of Single Diode Model at Changing Temperature

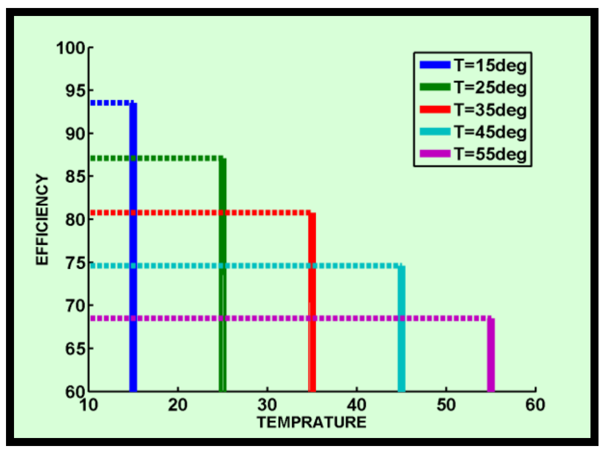

Fig 8: Efficiency of Single Diode Model at Changing Temperature

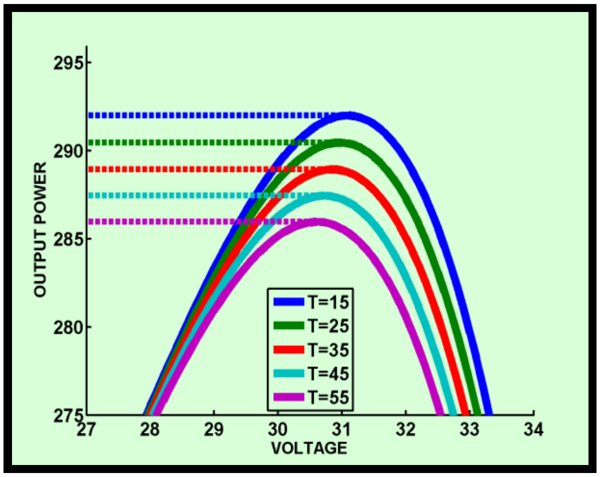

Fig 9: P-V Characteristics of Double Diode Model at Changing Temperature

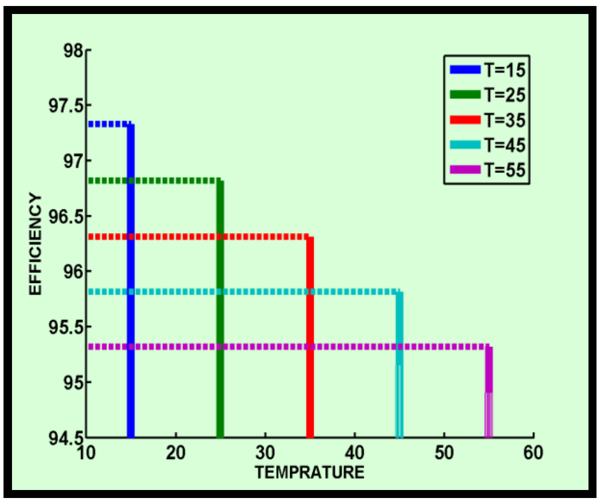

Fig 10: Efficiency of Double Diode Model at Changing Temperature

7.3. SERIES RESISTANCE (Rs)

As the effect of series resistance can be seen in both the models as series resistance raises output power and efficiency decreases. But as the double diode model is more accurate than single diode model which shows closer results to manufacturer's data. [13][14][9] As seen from figure (11) (12) (13) (14)

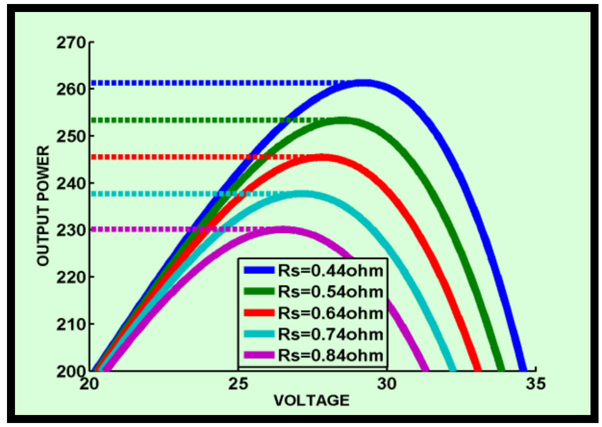

Fig 11: P-V Characteristics of Single Diode Model at Changing Series Resistance

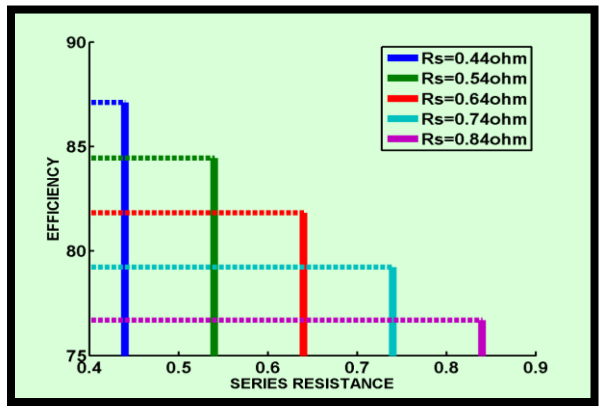

Fig 12: Efficiency of Single Diode Model at Changing Series Resistance

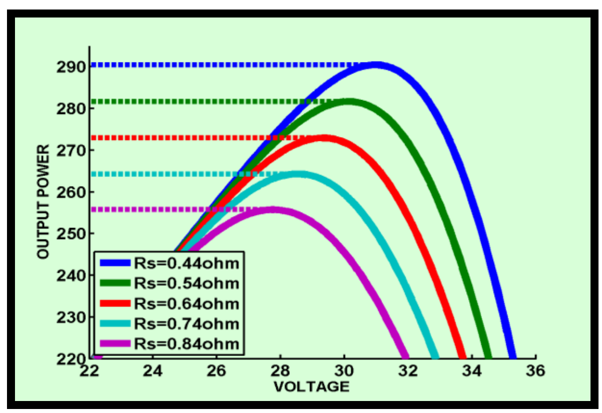

Fig 13: P-V Characteristics of Double Diode Model at Changing Series Resistance

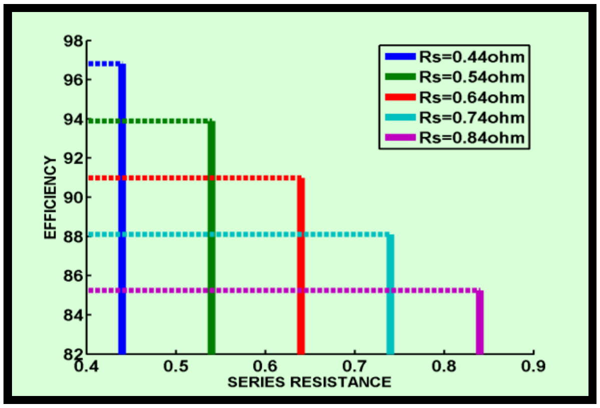

Fig 14: Efficiency of Double Diode Model at Changing Series Resistance

7.4. SHUNT RESISTANCE (Rp)

As the effect of shunt resistance can be seen in both the models as shunt resistance raises output power and efficiency also rises whereas other parameters such as temperature, series resistance, ideality factor are kept constant to observe actual effect of shunt resistance in both the models and comparison between them. As the double diode model is more accurate than single diode model which shows closer results to manufacturer's data. [15][16][13][14][4][7] As seen from figure (15) (16) (17) (18)

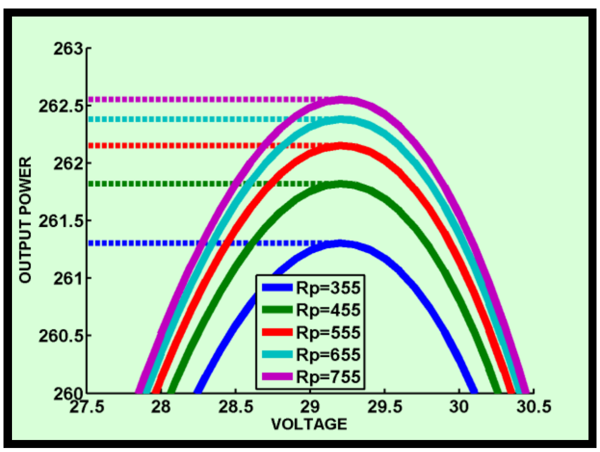

Fig 15: P-V Characteristics of Single Diode Model at Changing Shunt Resistance

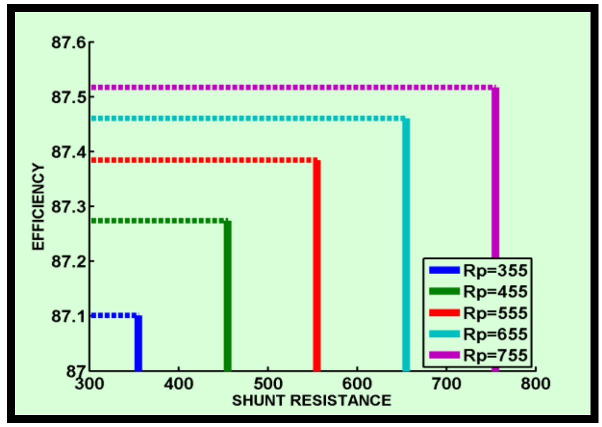

Fig 16: Efficiency of Single Diode Model at Changing Shunt Resistance

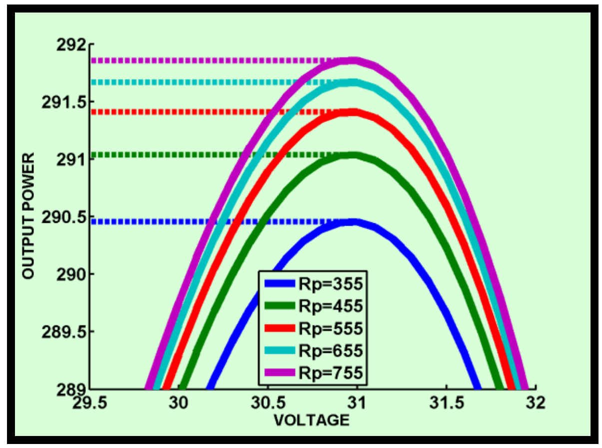

Fig 17: P-V Characteristics of Double Diode Model at Changing Shunt Resistance

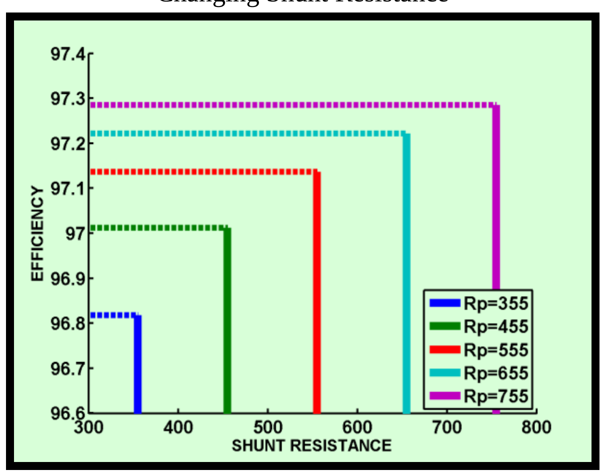

Fig 18: Efficiency of Double Diode Model at Changing Shunt Resistance

7.5. SERIES CELLS (Ns)

As the no. of series cells rises the output power and efficiency also raises because rise in voltage in both the models. But as the double diode model is more accurate than single diode model which shows closer results to manufacturer's datasheet.[17] as seen from figure(19)(20)(21)(22)

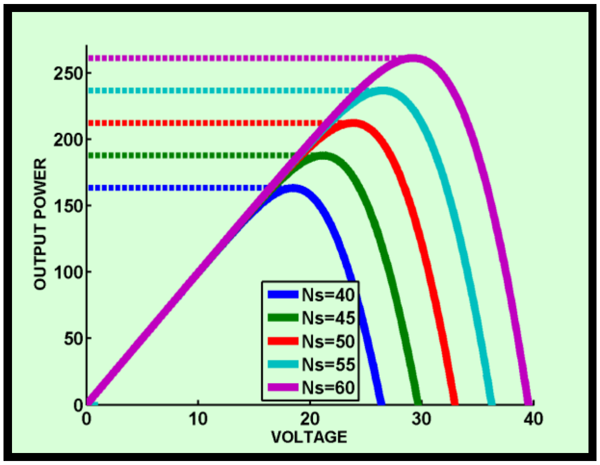

Fig 19: P-V Characteristics of Single Diode Model at Changing Series Cells

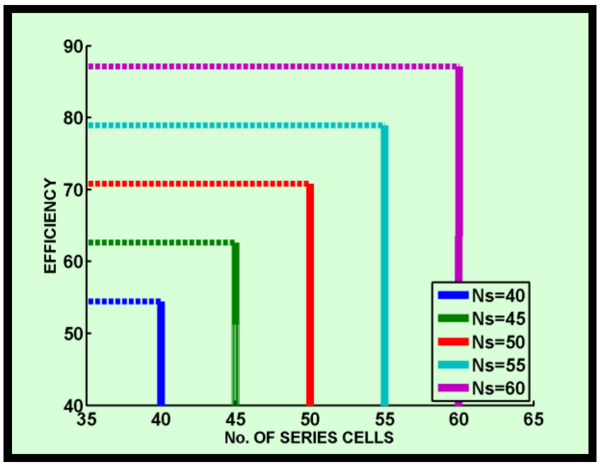

Fig 20: Efficiency of Single Diode Model at Changing Series Cells

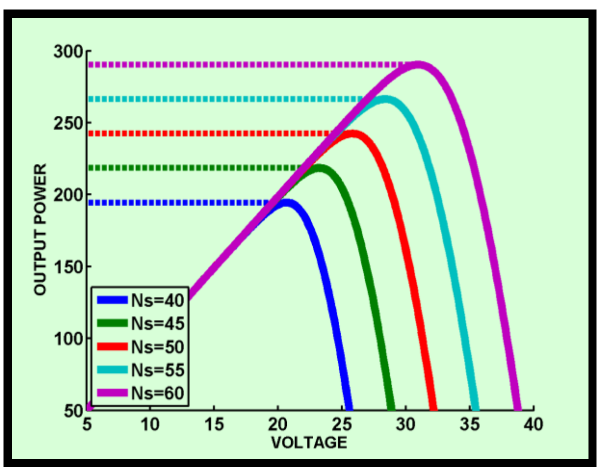

Fig 21: P-V Characteristics of Double Diode Model at Changing Series Cells

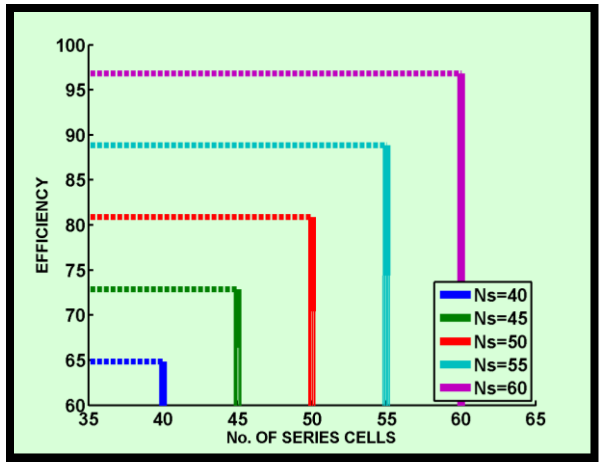

Fig 22: Efficiency of Double Diode Model at Changing Series Cells

7.6. PARALLEL CELLS (Np)

As the no. of parallel cells rises the output power and efficiency also raises because rise in current in both the models. But as the double diode model is more accurate than single diode model which shows closer results to manufacturer's datasheet. As seen from figure (23) (24) (25) (26)

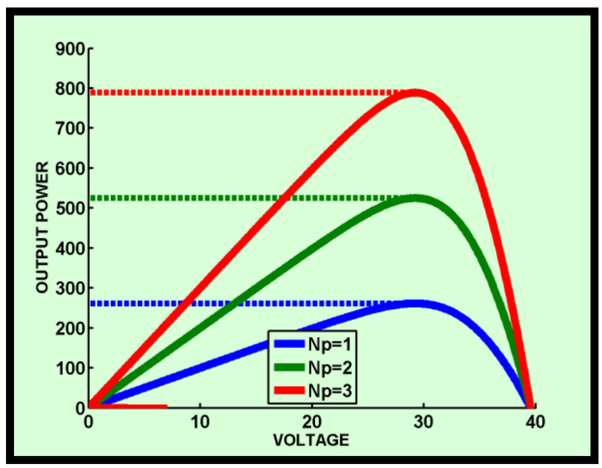

Fig 23: P-V Characteristics of Single Diode Model at Changing Parallel Cells

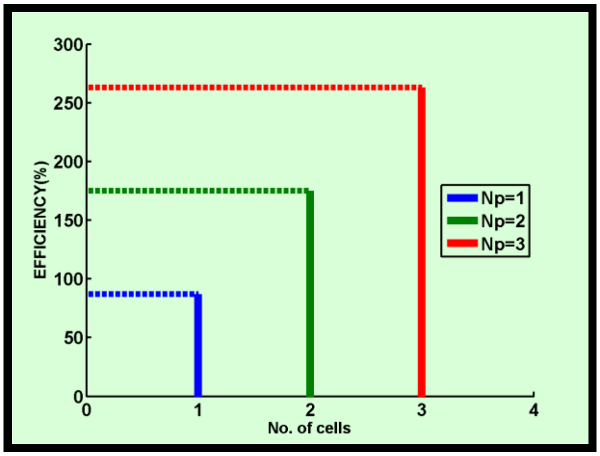

Fig 24: Efficiency of Single Diode Model at Changing Parallel Cells

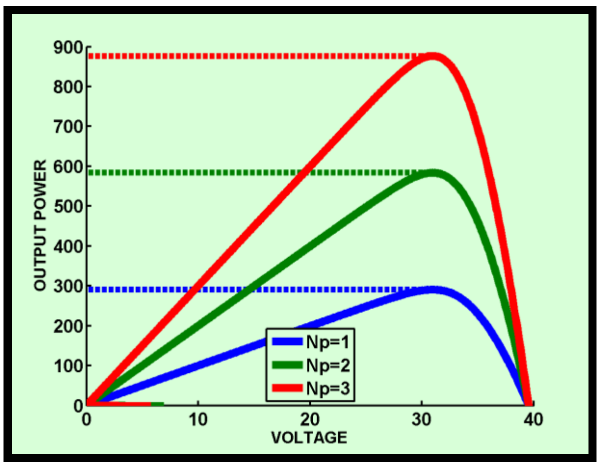

Fig 25: P-V Characteristics of Double Diode Model at Changing Parallel Cells

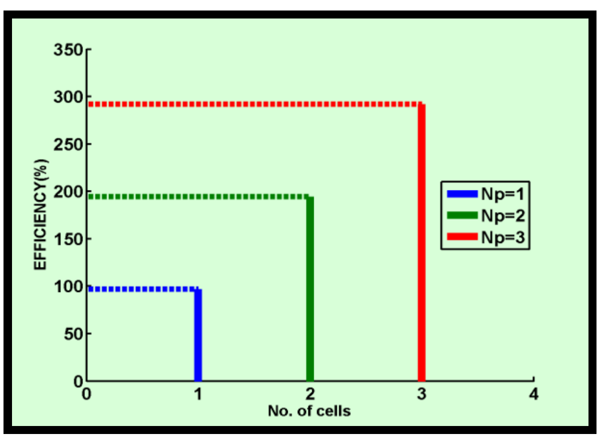

Fig 26: Efficiency of Double Diode Model at Changing Parallel Cells

7.7. IDEALITY FACTOR (A)

In single diode model if ideality factor (a) of diode D rises from 1.2 to 2 then the output power and efficiency decreases due to change in saturation current and diode current [5][8] [19] as shown in figure (27) (28) Where as in double diode case ideality factor(a1) is set to unity for ideal diode (D1) and increasing ideality factor (a2) of diode (D2) from 1.2 to 2 which shows after value 1.8 power and efficiency become constant which meant 1.8 is suitable max output as seen in figure (29)(30)

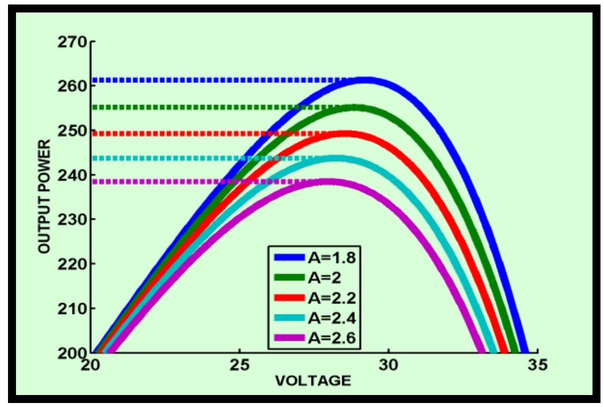

Fig 27: P-V Characteristics of Single Diode Model at Changing Ideality Factor

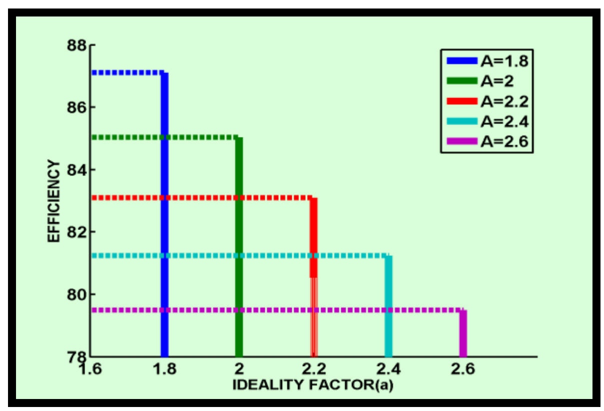

Fig 28: Efficiency of Single Diode Model at Changing Ideality Factor

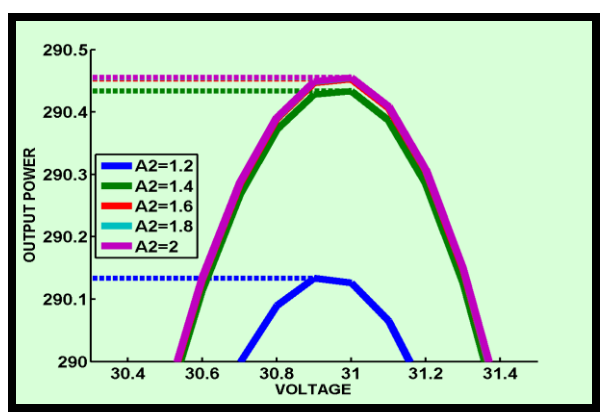

Fig 29: P-V Characteristics of Double Diode Model at Changing Ideality Factor

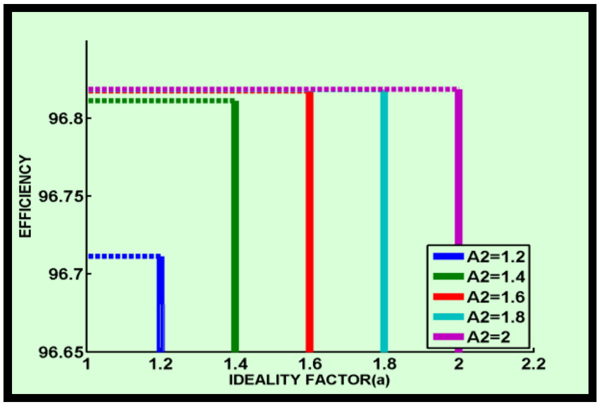

Fig 30: Efficiency of Double Diode Model at Changing Ideality Factor

VIII. CONCLUSION

Since this is on comparison between single diode and double diode model based on 7 parameters and there results described as

In irradiation at 200W/m^2 single diode model and double diode model gives output power as 48.29W and 57.49W respectively and efficiency is 3% higher when it reaches to 1000W/m^2 single diode model and double diode model gives output power as 261.3W and 290.45W and efficiency is 9.72% higher. That means output power is highly depends on irradiation and at low irradiation single diode model is fairly accurate and at high irradiation single diode model poorly accurate than double diode model.

In temperature at 15°c single diode model and double diode model gives output power as 280.57W and 292W respectively and efficiency is 3.81% higher when it reaches to 55°c single diode model and double diode model gives output power as 205.5W and 285.96W and efficiency is 26.82% higher. This shows at low temperature double diode model is fairly accurate than single diode model and as the temperature raises double diode model maintaining its accuracy whereas single diode model decreases in accuracy.

In series resistance at 0.44Ω single diode model and double diode model gives output power as 261.3W and 290.45W respectively and efficiency is 9.72% higher when it reaches to 0.84Ω single diode model and double diode model gives output power as 230.09W and 255.73W and efficiency is 8.54% higher. Observation of this parameter shows that at low series resistance accuracy gap between single and double diode model is fine large and as the series resistance raises this gap reducing to a constant point due to power in decreasing towards zero.

In shunt resistance at 355Ω single diode model and double diode model gives output power as 261.3W and 290.45W respectively and efficiency is 9.72% higher when it reaches to 755Ω single diode model and double diode model gives output power as 262.55W and 291.86W and efficiency is 9.77% higher. In this observation of shunt resistance the accuracy gap between single and double diode is fairly large but nearly constant during variations in shunt resistance.

No. of series cells at 40 single diode model and double diode model gives output power as 163.29W and 194.5W respectively and efficiency is 10.4% higher when it reaches to 60 single diode model and double diode model gives output power as 261.3W and 290.45W and efficiency is 9.72% higher .Observation on changing no. of series cells showed up that at low no. of series cells the accuracy gap between single diode model and double diode model is much higher and as it raises to certain no. of series cells this gap get slightly reduced that means in large no. of series cells single diode model can be used for faster calculation.

No. of parallel cell at 1 single diode model and double diode model gives output power as 261.3W and 290.45W respectively and efficiency is 9.72% higher when it reaches to 3 single diode model and double diode model gives output power as 788.62W and 876.65W and efficiency is 9.79% higher. By the observation of change in parallel cells it is seen that accuracy gap is high and on raising no. of parallel cells negligible changes is found.

Ideality factor at 1.2 single diode model and double diode model gives output power as 282.37W and 290.13W respectively and efficiency is 2.56% higher when it reaches to 2 single diode model and double diode model gives output power as 255.11W and 290.46W and efficiency is 11.78% higher. From the observation of change in ideality factor for both the models, the accurate result for single diode model is not clear while in double diode model it is seen that values near to 1.8 that is found at STC gives near constant values.

All the observation are observed in standard test condition’s while keeping all parameters constant except observed parameter , As from the observation of all above 7 parameters double diode is highly accurate than single diode model . It is seen that double diode model have 2 extra equations first diode current for diode D1 and another is saturation current for D1 to reduce equation same saturation is set for both diode D1 and D2. For further more accuracy observer can add one more diode in parallel to second diode.

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