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Impact of Parasitic Resistance on Modelling and Performance of Solar Photovoltaic Module

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***Abstract* - A solar cell is a transducer, converting light energy into DC power. Among all renewable energy, solar photovoltaic energy is a clean and green energy. Due to low cost and high efficiency power generation, it is most popular emerging technology towards energy transformation. Therefore modeling of SPV system is required to analyze the performance of SPV system. An increase in internal resistance either series or parallel of the photovoltaic (PV) cell effect the characteristics and the performance of the system. In this research, we have done the modeling of polycrystalline PV module on MATLAB. Modeling is done on 150 kW SPV systems. The field test is also done on same parameters in the city of Lucknow, Uttar Pradesh, India. Data collected from the MATLAB test shows the degradation in the conversion efficiency of power generation and affecting the system performance.**

Keywords— Conversion Efficiency, Parasitic Resistance, Power Degradation, Solar Energy, SPV Module

I. INTRODUCTION

The world utilizes all the energy from conventional energy sources such as charcoal, oil and gas, nuclear and hydropower. As conventional energy sources are having degrading effect on our environment, therefore, an alternative source of energy is very must to stop global warmings and climate mitigation [1]. But with time renewable sources of energy has replaced fossil fuels. Renewable sources of energy are sun energy, breeze energy, thermal energy and tidal energy. Renewable energy (RE) directly relate to the financial growth, clean and green surroundings of our country [2], where non-renewable sources of energy have its own constraints such as costly, creating hazard to environment and are responsible for climatic change. Among all these RE; solar energy take an important part in generation of electric power globally. Sun energy is abundant in nature and becoming booming area for generating electric power rapidly [3]. Now a day's photovoltaic modules (Mono-crystalline and Polycrystalline) modules are commercially available. Polycrystalline module is most popularly used due to its low cost. It is a eco- green energy and also sustainable, as the generation of electricity only involves photovoltaic effect without polluting the environment. Sustainable development (SD) stimulates everyone to maintain, protect and upgrade the resources [4]. The performance of SPV cell is dependent on specific parameters These are photo-current (I_{ph}) due to photovoltaic effect, resistance connected in series with the cell (R_s) as current flows through the material slab, diode dark current (I_o), parallel resistance (R_{sh}) as leakage current flows through it and the quality factor α is directly proportional to the rate of change of voltage d_v with respect to thermal voltage (v_t) and logarithm ratio of dark current to diode current (I_o) [6,7,8].

$$\alpha = \frac{dv}{v_t}\ln\frac{I_o}{I_d} \tag{1}$$

Ideality factor/quality factor (α) measures how precisely a diode go along with an ideal diode equation. The diode current equation is

$$I = I_o(e^{\frac{V_d}{\varepsilon V_t}} - 1) \tag{2}$$

The performance of the material are dependent upon two criteria, first is V_{oc} and next is α. Semiconductor materials such as S_i and G_e are commonly used for fabricating solar cells [6,8]. Quality factor of the PV cell modify as recombination shifts from bulk area. Diodes having 2 quality facto, recombination occurs due to higher rate injection form band to band with the aid of both charge carriers. Plenty of research has been done with 1 quality factor [8,9, 10]. As quality factor is increased from 1 to 2 characteristic performances (current-Voltage and Power-Voltage) of solar cell changes. In ideal diode recombination takes place directly from band to band or recombination through trap at bulk region but not at junction. In real diode, the types of recombination occurring with: quality factor: 1 is low level injection (Shockley-Read-Hall and band to band) where recombination is bound by minority charge carriers, quality factor: 2, is high level injection (Shockley-Read-Hall and band to band) where recombination takes place with both the charge carriers (i.e. majority and minority), quality factor: 2/3 is Auger where recombination takes place with two majority and one minority charge carriers.

II. MODELING OF PHOTOVOLTAIC CELL

Modeling of photovoltaic (PV) solar cell is done with several software tools such as MATLAB and P-SPICE [11]. In this paper, modeling of PV cell is done utilizing mathematical block modeling in MATLAB. The blocks of solar cell under SimElectronics module using MATLAB/simulink tool symbolize a light sensitive photodiode shunted with source current Iph, accompanying series and shunt resistance [13,14]. An ideals PV cell circuit is shown in figure 1 [8,9,10,11,12], whose current equation across the load is given below

$$I_L = I_{ph} - I_d \tag{3}$$

$$I_d = I_o(e^{\frac{v_d}{\alpha v_t}} - 1) \tag{4}$$

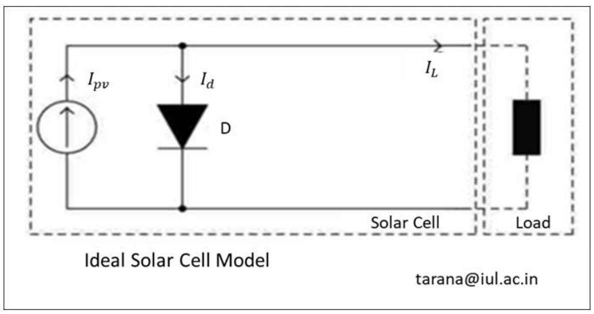

Fig 1. Ideal solar cell model

I_o == reverse saturation current/ dark current

Hence, equation (iii) becomes as shown below

$$I_d = I_{ph} - I_o(e^{\frac{v_d}{\alpha v_t}} - 1) \tag{5}$$

$$v_t = \frac{kT}{q} = 26mV$$

V_d = Diode forward voltage

I_{ph} = Current originated from irradiation,

I_o = Reverse saturation current

v_t = Thermal voltage of diode

q = Carrier charges (1.6×10^{-19} C)

k = Boltzmann constant, 1.3865×10^{-23}

T = Temperature (Kelvin)

α = Quality Factor

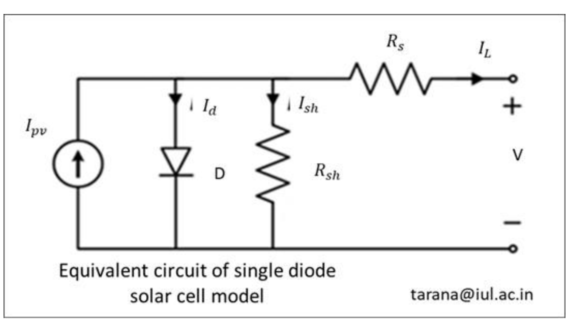

Fig 2. Single diode solar cell model equivalent circuit

Equivalent circuit of one diode PV cell model with series and shunt resistance [15,16] is shown in figure 2. Current source is modelled by photon related current. The photonic current passes through the diode in forwarded bias condition and rest of the current reaches the output circuit [17]. Parasitic resistance is also modelled showing the reverse saturation current and real resistance touching the semiconductor layer.

From equation (iii)

$$I_{ph} = I_L \tag{6}$$

The output current with shunt resistance is given by the equation (vii)

$$I_L = I_{ph} - I_d - R_{sh} \tag{7}$$

$$I_d = I_{ph} - I_o(e^{\frac{v_d}{\alpha v_t}} - 1) - [\frac{V + IR_{sh}}{R_{sh}}] \tag{8}$$

Solar cells are fabricated with resistance connected with shunt and series, thus forming a solar module. These solar cells produce the largest power of the solar module. Watt/m^2 is the unit of power (solar cell) which is directly dependent upon the solar irradiance. Solar cell (S_i) produces voltage in the range of 0.5- 0.6 Volts and current in the range of 28-35mA [8]. Characteristic of solar cell in illuminated and un-illuminated condition is shown in figure 3.

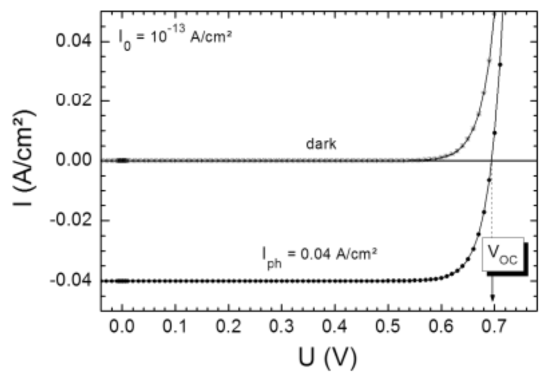

Fig 3. I-V Characteristic in dark and light condition

Thus area of one diode cell is 34.5 mm^2. Considering max voltage (i.e. 0.6V) and current (i.e. 35 mA) of a solar cell (polycrystalline), output power of a solar cell is 21 mW, and power density is 608 W/m^2. This value represents the solar cell; commercially available in the market, having 15% conversion efficiency. The work is based on the modeling techniques under STC of SPV module.

III. DESIGN AND MODELING OF SPV SYSTEM

Modeling of 150 kW solar power system is done using MATLAB /SIMULINK tool version 2013a. For modeling this system, solar panel of model RenewSys DESERV 3M6 was taken into consideration, fabricated by RenewSys. The module consists of 72 Cells-320 Watt. 150 kW, grid connected power plant is installed at the rooftop of our campus building. 460 modules are connected with 3 inverters each of 50KVA. 150 kW SPV system installed on the roof top of our university building is shown in figure 4.

Fig 4. 150 kW SPV System

The specifications taken into consideration for the modeling of 150 kW is given in table 1 [16]. The system is modelled under industry-wide standard parameters i.e. STC. For short circuit current, alpha (α) is +0.50%/ °C, for open circuit voltage, beta (β) is -0.30%/ °C and gamma (ϒ) for maximum power is -0.40%/ °C [16].

TABLE I
SPECIFICATIONS UNDER STC [16]

Material	**Multi Crystalline Silicon Modules**	
Electrical Parameters	**STC 1000W/m2**	**NOCT 800W/m2**
Maximum power (Pmax)	320W	238.15 W
Voltage at Pmax (Vmpp)	37.20 V	34.02 V
Current at Pmax (Impp)	8.61 A	07.01 A
Short circuit current (Isc)	9.06 A	07.41 A
Open circuit voltage (Voc)	46.18 V	42.93 V
Module Efficiency %	16.50	
Cell Temperature Coefficient		
Temperature coefficient of Isc (Alpha)	+0.50%/ °C	
Temperature coefficient of Voc – (Beta)	-0.30%/ °C	
Temperature coefficient of Pmax (Gamma)	-0.40%/ °C	

Figure 5 shows the modeling of 150 kW SPV systems with its internal simulator in figure 6.

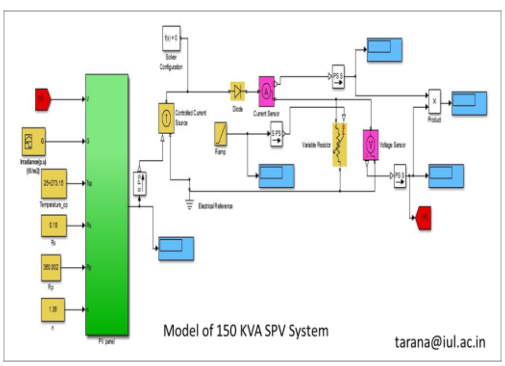

Fig 5. Model of 150 kW SPV system

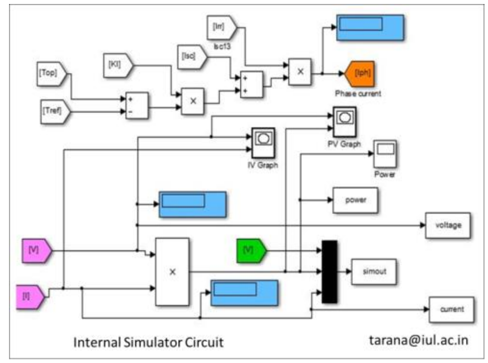

Fig 6. Internal simulator circuit

Equation (viii) shows the load current This load current is the product of irradiation current I_{ph} and total number of parallel connected solar cells (N_p) minus the diode current minus the current across the shunt resistance [17].

$$I_{Load} = I_{ph}N_p - I_{d1} - I_{sh} \quad (9)$$

$$I_d = I_{ph}N_p - I_o(e^{\frac{v_d}{\alpha v_t}} - 1) - [\frac{V + IR_{sh}}{R_{sh}}] \quad (10)$$

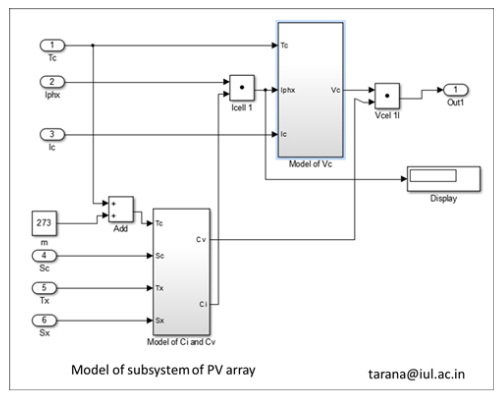

Fig 7. Subsystem model of PV Array

Subsystem of PV array shown in figure 7, consist of two models i.e. the voltage model V_{cell} shown in figure 8

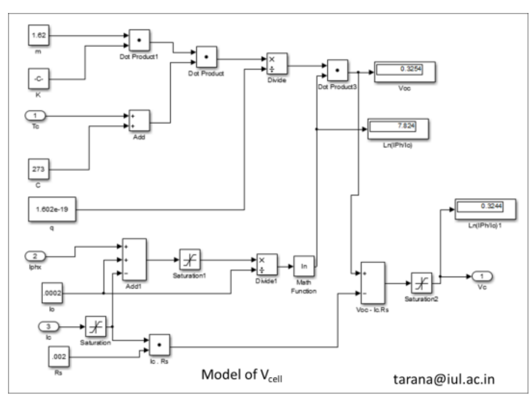

Fig 8. V_{cell} Model

and the current model I_{cell} is shown in figure 9.

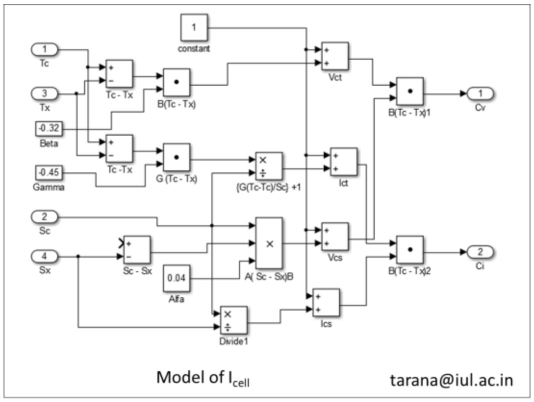

Fig 9. I_{cell} Model

From cell model, open circuit voltage V~~oc~~ is calculated by the equation given below

$$V_{oc} = \frac{nkt_{op}}{q}\ln(\frac{I_L}{I_o}+1) \tag{11}$$

And the photon current is given by

$$I_{ph} = G_k[I_{sc} + K(T_{op} - T_{ref})] \tag{12}$$

From cell model, open circuit voltage V_{cell} is calculated by the equation given below

where,

V_{oc} = Voltage; open circuit
I_{sc} = Current; short circuit
k = Boltzmann Constant
T_{op} = Temperature operating value
T_{ref} = Temperature reference value (25°C)
G_k = Ratio solar irradiance
N = Number of cells

$$G_k = \frac{G_{op}}{G_{ref}} + 1$$

The cell current is given as

$$I_{cell} = \frac{(T_{op} - T_{ref})\gamma}{G_k} \tag{13}$$

and

$$I_{sc} = \frac{G_{op}}{G_{ref}} + 1 \tag{14}$$

where,
G_{op} is the true irradiance and G_{ref} is the apparent irradiance

The current-voltage, power-voltage characteristics of 150kW SPV systems without parasitic resistance is shown in figure 10 and figure 11 respectively.

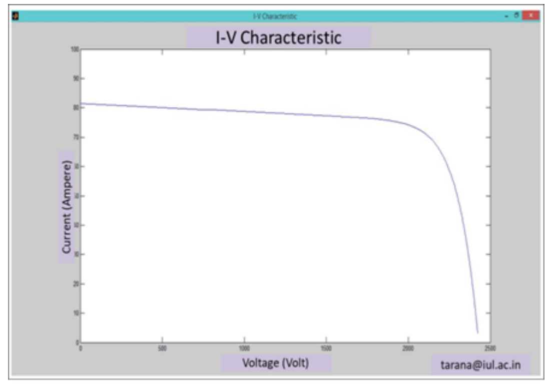

Fig 10. I-V Characteristic of SPV system

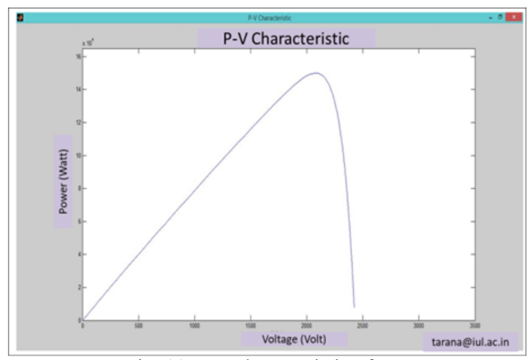

Fig. 11 P-V Characteristic of SPV system

V. SIMULATION RESULT OF 150KW SPV SYSTEM

Performance was observed by varying the series resistance of the SPV module. As resistance increases characteristic degrades. These changes are clearly visible in I-V characteristic (without and with parasitic) resistance in figure 12 in the proposed model of SPV system

A. I-V Characteristic (Sharp and Degradation) in the proposed model

Fig. 12a shows the normal I-V characteristic of PV module (without parasitic resistance)

Fig.12b shows degradation in sharpness of I-V characteristic (with parasitic resistance). This degradation is due to defects observed in cell fingers and interconnects bus bars.

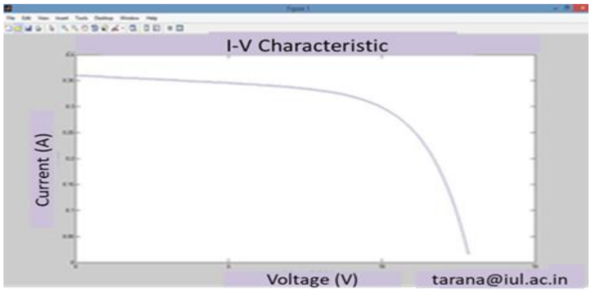

Fig. 12a I-V Characteristic (Sharpe Current Characteristic)

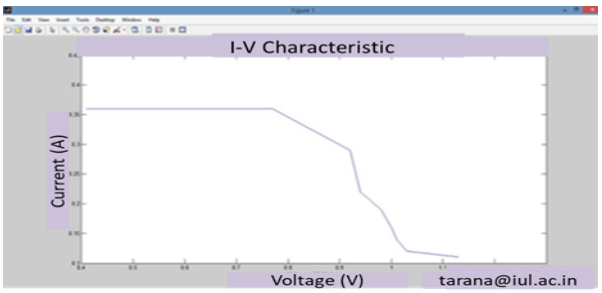

Fig. 12b I-V Characteristic (Degradation in current characteristic)

B. P-V Characteristic (Sharp and Degradation) in the proposed model

Fig. 13a shows normal P-V characteristic of module (without parasitic resistance), fig. 13b shows degradation in output power of module (with parasitic resistance). The effect of degradation is due to corrosion on the cell fingers and the interconnect bars [18,19,20].

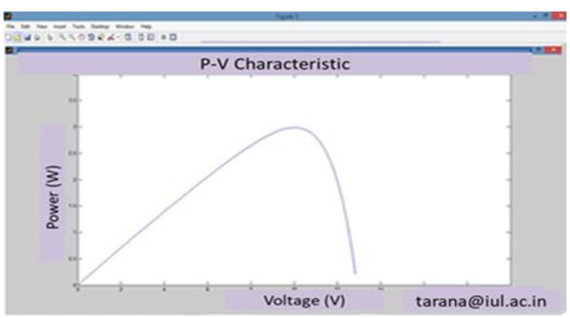

Fig. 13a: P-V Characteristic (Sharpe power Characteristic)

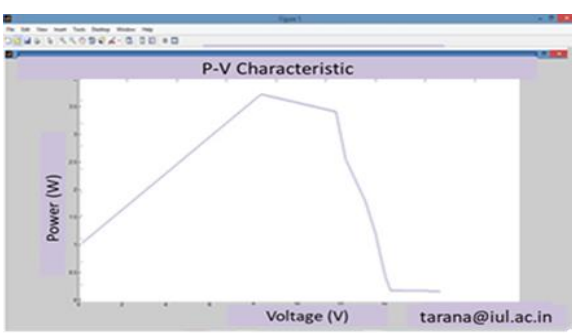

Fig. 13b P-V Characteristic (Degradation in power characteristic)

Parasitic resistance increases as defects in the material are increasing. As defect i.e. corrosion increases, current reduces while voltage increases which is clearly visible in fig.14 and fig. 15 respectively.

C. Impact of Parasitic Resistance in Current

Fig. 14 shows declinations in short circuit current with increase in parasitic resistance.

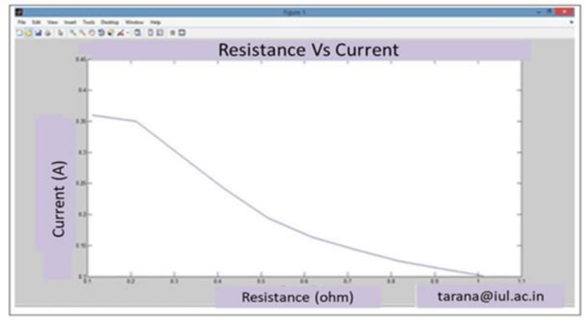

Fig.14 Reduction in short circuit current

D. Impact of Parasitic Resistance on Voltage

Fig. 15 voltage is increasing with resistance. This is due to increase in series resistance across metallic contacts in the proposed model due to corrosion [18-20].

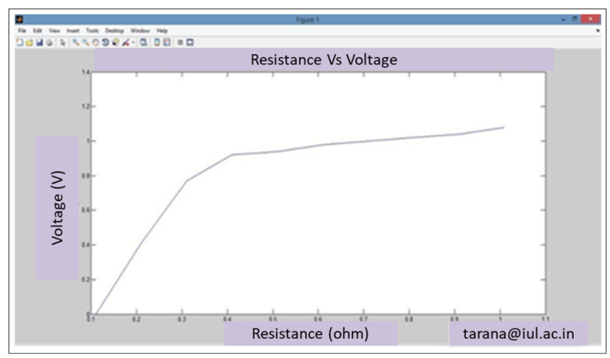

Fig. 15 Increase in open circuit voltage

V. RESULT OF 150KW SPV SYSTEM ON ROOFTOP

The short circuit current is reduced by 13%, due to increase in parasitic resistance as shown in figure 16.

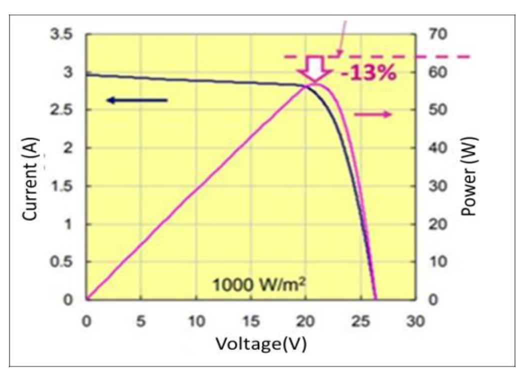

Fig. 16: Reduction in short circuit current

30% degradation in power is observed as shown in figure 17.

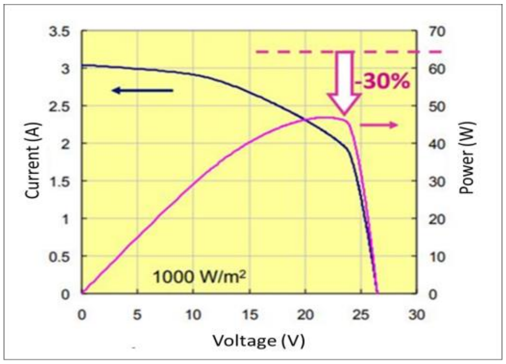

Fig. 17: Degradation in power

VI. CONCLUSION

In this study, the impact of parasitic resistances on the performance of PV panel was investigated. Research was done on 320 Watt SPV module. Simulation result shows that increase in series resistance decreases the current (I_{sh}) visible in fig. 12 and voltage (V_{oc}) gradually increases visible in fig. 15. From 150 KVA SPV system on rooftop, we observed decrease in the current by 13% and power (P*)* degrades by 30%, which is clearly visible in fig. 16 and fig. 17 respectively. Thus increase in parasitic resistance shows the defects i.e. corrossion in the bus bar or fingers of solar cell, effecting the power conversion efficiency. Hence degradation in output power of the module.

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