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Simulink model of PV cell-based Active Generator using MATLAB

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Abstract—*The development a active generator with the help of photo-voltaic cells for next-generation Photo-Voltaic (PV) installations to develop micro grid. It contains develop and storage units, provides flexibility to distribution system operators. In this paper, we give the main focus on the generation of energy. Here we developed a PV array for the voltage generation. We create a model with the help of diode for the single unit.*

Index Terms—*PV Cell, PV array, Insulation level (sunlight irradiance), renewable energy, Energy management, load forecasting, micro-grid, operational planning.*

[I] INTRODUCTION

A generalized PV model for active generator using PV cell, module, and array has been developed with MATLAB/Simulink and been verified with a PV cell and a commercial module. The proposed model takes sunlight irradiance and cell temperature as input parameters and outputs the V-I and P-V characteristics under various conditions [1]. This model has also been designed in the form of Simulink block libraries. The masked icon makes the block model more user-friendly and a dialog box the users easily configure the PV model. Such a generalized PV model is easy to be used for the implementation on MATLAB/Simulink modeling and simulation platform. Especially, in the context of the Sim-Power System tool, there is now a generalized PV model which can be used for the model and analysis in the filled of solar PV power conversion system.

[II] SOLAR ENERGY

2.1 Solar energy: It is an important, clean, cheap and abundantly available renewable energy. It is received on Earth in cyclic, intermittent and dilute form with very low power density 0 to 1 kW/m^2 [1]. Solar energy received on the ground level is affected by atmospheric clarity, degree of latitude, etc. For design purpose, the variation of available solar power, the optimum tilt angle of solar flat plate collectors, the location and orientation of the heliostats should be calculated.

2.2 Units of solar power and solar energy: In SI units, energy is expressed in Joule. Other units are Langley and Calorie where:-1 Langley = 1 calories / cm^2 / day, 1Calorie = 4.186 J
For solar energy calculations, the energy is measured as an hourly or monthly or yearly average and is expressed in terms of kJ/m^2/day or kJ/m^2/hour. Solar power is expressed in terms of W/m^2 or kW/m^2.

[III] SOLAR CONSTANT

3.1 Solar constant (S): Solar constant is the solar radiation received per unit area normal to the sun's rays in a space outside the earth's atmosphere. In SI units the value of S is 1353 W/m^2[3]. As shown in fig.1.

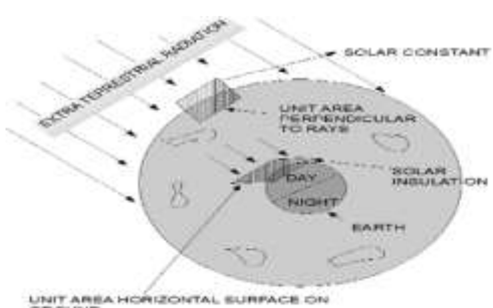


Fig.1 Solar Constant

3.2 Clarity index: While passing through the atmosphere, the beam radiation from the sun is partly absorbed and partly scattered by the atmospheric dust, gases, cloud, moisture etc. On a moderate cloudy day, reduction is 10-50%. During dark and cloudy day, radiation reduces to 1%. Flat plate collectors are better suited than focusing collectors for diffused sunlight (cloudy atmosphere). The effect of atmospheric conditions on the beam radiation is expressed by Atmospheric Clarity Index (ACI) given by:
ACI = It is the ratio of solar radiation (W/m^2) to solar constant (W/m^2)

3.2 Solar radiation data for India: India is situated in the Northern hemisphere of earth within latitudes 7^{O}N and 37.5^{O}N. The average solar radiation values for India are between 12.5 and 22.7 MJ/m^2.day [3]. Peak radiation is received in some parts of Rajasthan and Gujarat. Radiation falls by 60% during monsoon.

3.3 Solar radiation: Solar radiation is shown in fig.1. It is the solar radiation received on a flat, horizontal surface at a particular location on earth at a particular instant of time [4]. It depends on the following parameters:

- Seasonal variation and geographic location of the particular surface.
- Atmospheric clarity.
- Shadows of trees, tall structures, adjacent solar panels, etc.
- Area of exposed surface, m^2
- Angle of tilt of solar panel.

Modified Angstrom equation for Average Daily Global Radiation is used to determine the radiation at different places on earth. It is given as:

$$\frac{Hg}{Ho} = a + b\frac{Lh}{Lm} \qquad (2.1)$$

We have:

$$H_0 = \frac{H01 + H02 + H03 + \cdots \ldots\ldots\ldots\ldots\ldots\ldots\ldots H030}{30} \qquad (2.2)$$

and individual values of $H_{01}, H_{02}, H_{03}, \ldots\ldots\ldots H_{030}$ are calculated from

$$H_0 = \frac{24}{\pi} \text{ Isc}\{ 1+0.033.\text{Cos}(360n/365) \} \int \left[\left(\text{Sin}\varphi.\text{Sin}\delta\right) + \left(\text{Cos}\varphi.\text{Cos}\delta.\text{Cos}\omega\right)\right] dt \qquad (2.3)$$

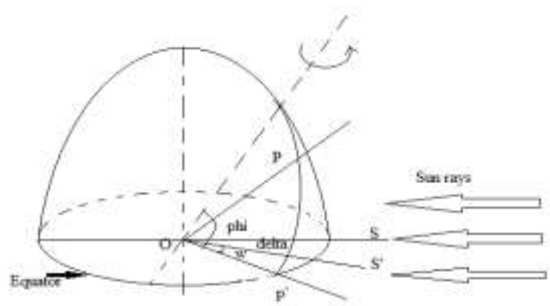


Fig. 2 Solar Radiation Geometry

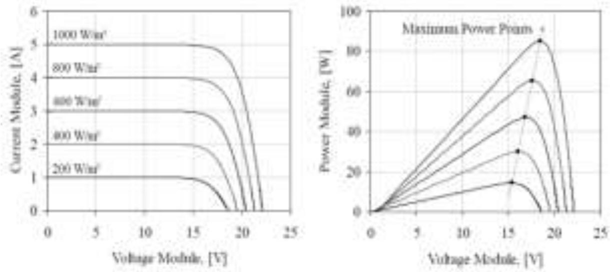
Photovoltaic Unit: Photovoltaic unit is made of semiconductor, which converts solar energy into electrical energy. It is explained as below:

[IV] CHARACTERISTICS

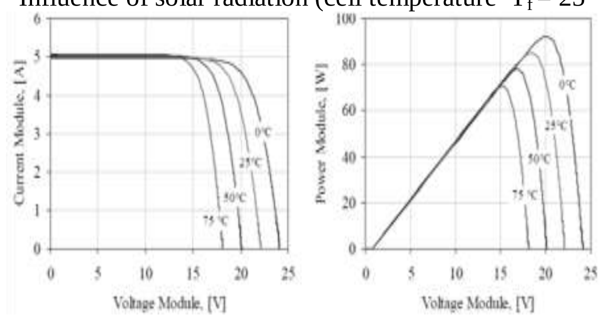
4.1 V-I Characteristics of a Photovoltaic Module: The performance characteristics of a photovoltaic module depend on its basic materials, manufacturing technology and operating conditions. Fig.4. shows typical current-voltage I-V and power-voltage P-V curves of a BP 585 High-Efficiency. Three points in these curves are of particular interest:

- Short circuit point, where the voltage over the module is zero and the current is at its maximum (short circuit current Isc).
- Maximum power point or MPP, where the product of current and voltage has its maximum (defined by I_{mpp} x V_{mpp}).
- Open circuit point, where the current is zero and the voltage has its maximum (open circuit voltage Voc).

The measurements taken for obtaining an I-V curve depend on controlling the load current. At open circuit, when no load current is generated, a first characteristic value can be measured; the open circuit voltage Voc [4]. The series of all measured pairs (V, I) yields the characteristic I-V curve of the module. From the characteristic curves of the module, it is clear that the open circuit voltage of the photovoltaic module, the point of intersection of the curve with the horizontal axis, varies little with solar radiation changes. It is inversely proportional to temperature, i.e., a rise in temperature produces a decrease in voltage. When the temperature varies, the maximum power points are generated in such a manner that the output current stays approximately constant.



(a) Influence of solar radiation (cell temperature $T_f = 25^0$



(b) Influence of cell temperature (solar radiation $E_o = 1kW/m^2$)

Fig. 3 (a) & (b) the I-V Curve and Maximum Power Point

4.2 Maximum Power Point Tracker (MPPT): Fig.4.Shows the I-V curve of the PV module simulated with the MATLAB model. A PV module can produce the power at a point, called an operating point, anywhere on the I-V curve. The coordinates of the operating point are the operating voltage and current [5]. There is a unique point near the knee of the I-V curve, called a maximum power point (MPP), at which the module operates with the maximum efficiency and produces the maximum output power [6].

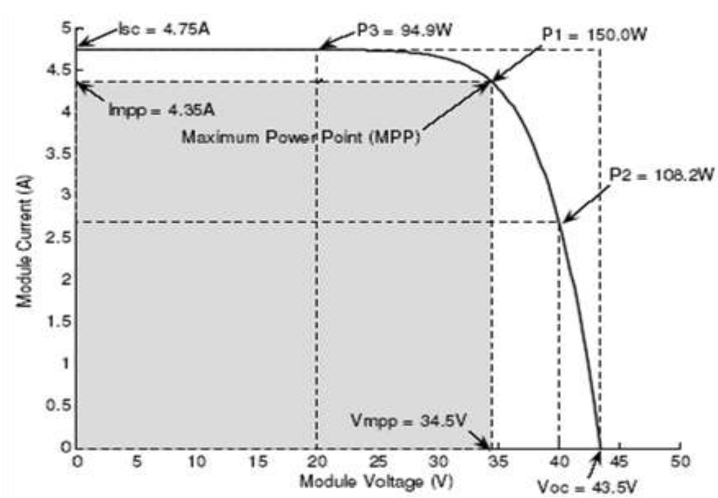


Fig.4 Simulated I-V Curve of PV Module

The position of the maximum power points on the PV generator characteristic depends strongly on the solar radiation and the cells temperature, as shown in Fig.4.It is used to adjust the actual operating voltage and current of the PV generator so that the actual power approaches the optimum value as closely as possible [12]. For this purpose, an electronic device, normally a power conditioning unit, capable of performing the function of a MPPT has to be connected between PV generator and the load. Therefore, a tracking of the MPP is only meaningful, if components for processing are available and the tracking of the working point does not bring additional energy losses and at small additional costs [12]. Many different techniques have been developed to provide maximum power tracking of PV generators.

4.3 Solar panel: Modern solar Cells make use of semiconductor materials usually based on single-crystal silicon. When doped with phosphorus, arsenic or antimony the silicon becomes an n-type semiconductor, and when doped with boron, Aluminum, Indium, or Gallium, it forms a p-type semiconductor [9]. If a p-type semiconductor is brought into intimate contact with one of the n-type, they form a p-n (or n-p) junction.. [10]. To be formed from two different semiconductor materials, such as CdS and Cu_2S. This is known as a hetero Jn. The Schottky Jn. is consisting of a semiconductor at the metal. This Jn. is formed by depositing a thin layer of a metallic conductor on to a p or n type semiconductor Schottky Jn. photovoltaic cells made with the so called amorphous Silicon are more efficient than homo Jn. p-n cells of the same materials. Cost of it, is also less [11].The MIS (metal insulator semiconductor) Solar cell is similar to the Schottky type except that a very thin layer (about 0.1 to 0.3 micro meter) of an insulator is deposited between the semiconductors or and the metallic conductor a conversion efficiency of more than 17% has been reported for an MIS solar cell made with single crystal silicon. PV cell is a light sensitive two-terminal N-P junction made of semiconducting material such as silicon. P type and N-type semiconductor and a solar cell are shown here.

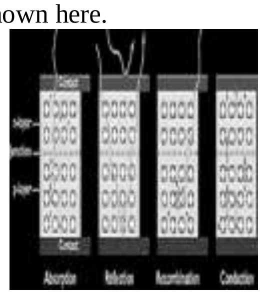


Fig.5 Solar panel

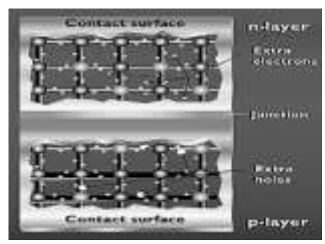


Fig.6. P-N layers of PV Cell

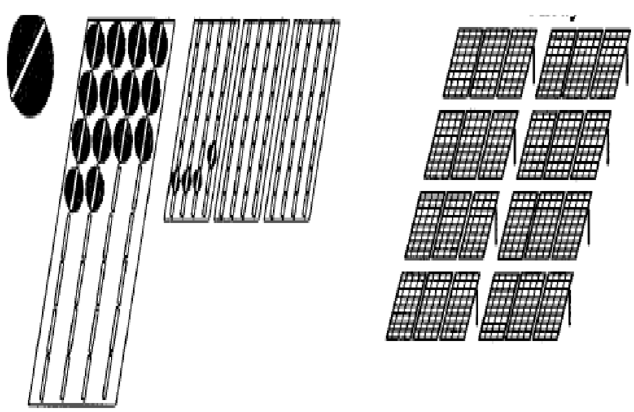


Fig.7 PV Cell, PV Module, PV Panel and PV Array

Fig.8 Unit of PV Array

Pictures of PV cell, PV module, PV panel and PV array are shown here in fig.6 and fig.7 these are made of Semiconductor materials.

[V] WORKING OF SOLAR CELL

5.1 Working of solar cell: A solar cell (also called a photovoltaic cell as shown in fig.8) is an electrical device that converts the energy of light directly into electricity by the photovoltaic effect. It is a form of photoelectric cell which, when exposed to light, can generate and support an electric current without being attached to any external voltage source [15]. The term "photo-voltaic" has been in use in English since 1849. Photovoltaics is the field of technology and research related to the practical application of photovoltaic cells in producing electricity from light, though it is often used specifically to refer to the generation of electricity from sunlight. The operation of a photovoltaic (PV) cell requires 3 basic attributes:

- The absorption of light, generating either electron-hole pairs.
- The separation of charge carriers of opposite types.
- The separate extraction of those carriers to an external circuit.

In contrast, a solar thermal collector collects heat by absorbing sunlight, for the purpose of either direct heating or indirect electrical power generation.

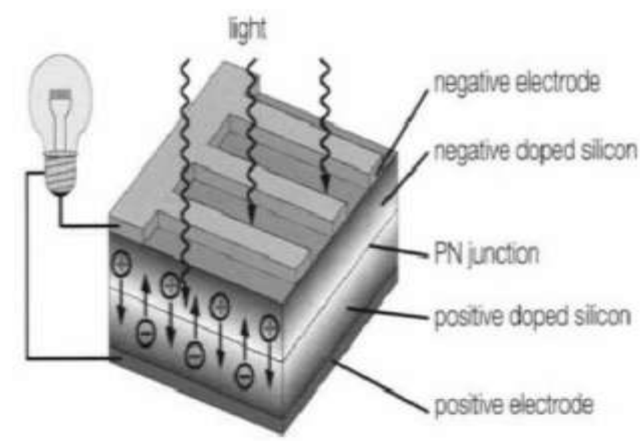


Fig.9 Solar Cell

"Photo electrolytic cell" (photo electrochemical cell), on the other hand, refers either a type of photovoltaic cell (like that developed by A.E. Becquerel and modern dye-sensitized solar cells) or a device that splits water directly into hydrogen and oxygen using only solar illumination..

5.2 Modeling of Photovoltaic Module: Solar PV module, pictured in fig.9, the module is made of 72 multi-crystalline silicon solar cells in series and provides 50W of nominal maximum power. Shows its electrical specification table.

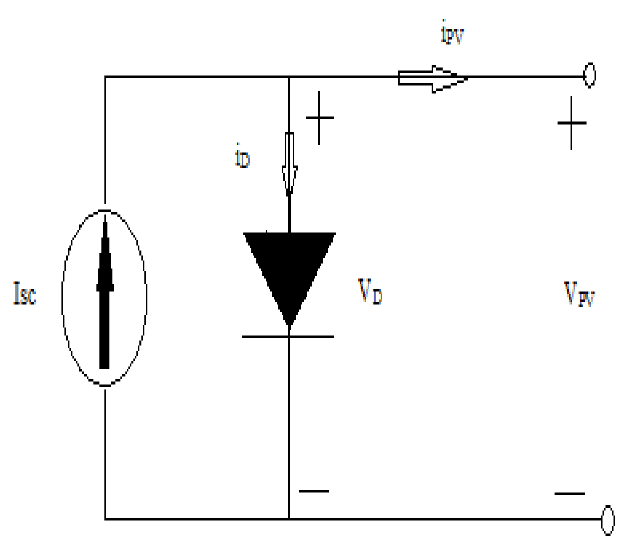


Fig.10. Equivalent circuit model of solar cell

[VI] ELECTRICAL CHARACTERISTICS PV MODULE

6.1 PV Module: The strategy of modeling a PV module is no s Equivalent circuit of solar cell contains short circuit current (Isc) parallel with diode as shown in fig.10 Equations for the above model are:

$i_D = Io.(e^{VD/VT}-1)$ (4.1)

Input equation: $V_D = V_{PV}$ (4.2)

Output equation: $i_{PV} = I_{SC} - i_D$ (4.3)

A single PV cell produces an output voltage less than 1V, about 0.6V for crystalline silicon (Si) cells, thus a number of PV cells are connected in series to archive a desired output voltage. When series-connected cells are placed in a frame, it is called as a module. Most of commercially available PV modules with crystalline-Si cells have either 36 or 72 series-connected cells.[13]

The modeling block diagram of PV array.

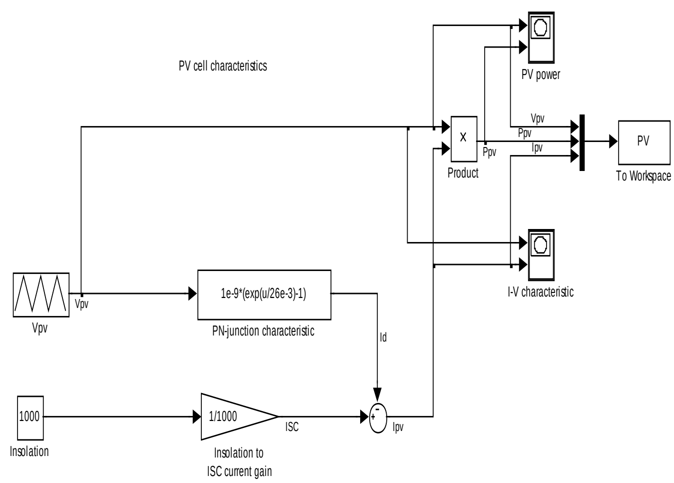


Fig.11 Modeling of PV array

Different characteristics I-V and P-V at the different radiation level. (As 1000W/m^2, 800W/m^2, 600 W/m^2):

1000W/m^2:

Electrical Characteristics	Rating
Maximum Power (P_{max})	150 W
Voltage at P_{max} (V_{mp})	34.5V
Current at P_{max} (I_{mp})	4.35A
Open-circuit Voltage (V_{oc})	43.5 V
Short-circuit Current (I_{sc})	4.75A
Temperature coefficient of I_{sc}	$0.065 \pm 0.015\% /^0C$
Temperature coefficient of V_{oc}	-160 ± 20 mV/^{0}C
Temperature coefficient of power	$-0.5 \pm 0.05\%/^0C$
NOCT	47 ± 2^0C

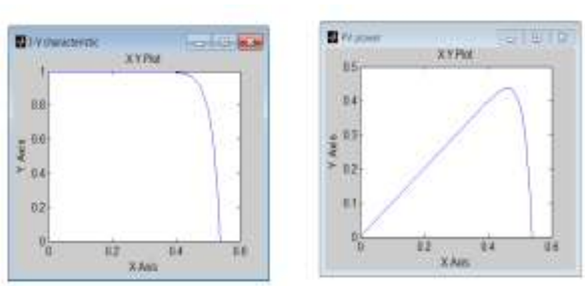


Fig.12. I-V and P-V characteristics (1000 W/m^2)

TABLE 1
V, P, & I OUTPUT (1000 W/m^2)

Voltage	Power	Current
0.012	0.012	1
0.026	0.026	1
0.04	0.04	1
0.054	0.054	1
0.068	0.068	1
0.18	0.18	0.999999
0.194	0.194	0.999998
0.208	0.207999	0.999997
0.222	0.221999	0.999995
0.236	0.235998	0.999991
0.474	0.434799	0.917297
0.488	0.41885	0.858299
0.502	0.380121	0.757214
0.516	0.301353	0.584017
0.53	0.152252	0.287268

Solar Radiation 1000W/m^2		
MPP Power	MPP Voltage	MPP Current
0.2550	0.4460	0.5718

800W/m^2:

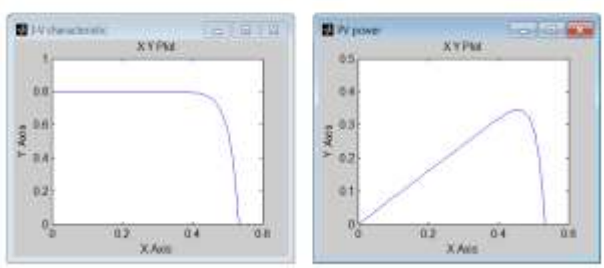


Fig.13 V-I and P-V characteristics (800 W/m^2)s

TABLE 2
V, P, & I OUTPUT (800 W/m^2)

Voltage	Power	Current
0.012	0.0096	0.8
0.026	0.0208	0.8
0.04	0.032	0.8
0.054	0.0432	0.8
0.068	0.0544	0.8
0.082	0.0656	0.8
0.18	0.144	0.799999
0.194	0.1552	0.799998
0.208	0.166399	0.799997

0.222	0.177599	0.799995
0.236	0.188798	0.799991
0.46	0.345796	0.751731
0.474	0.339999	0.717297
0.488	0.32125	0.658299
0.502	0.279721	0.557214

Solar Radiation 800W/m^2		
MPP Power	**MPP Voltage**	**MPP Current**
0.3458	0.4400	0.7517

To get more and more voltage. It is necessary to connect solar cells in series, Then it becomes a PV array. PV array for the output of 50kW is shown here.
PV ARRAY 50 KW OUTPUT

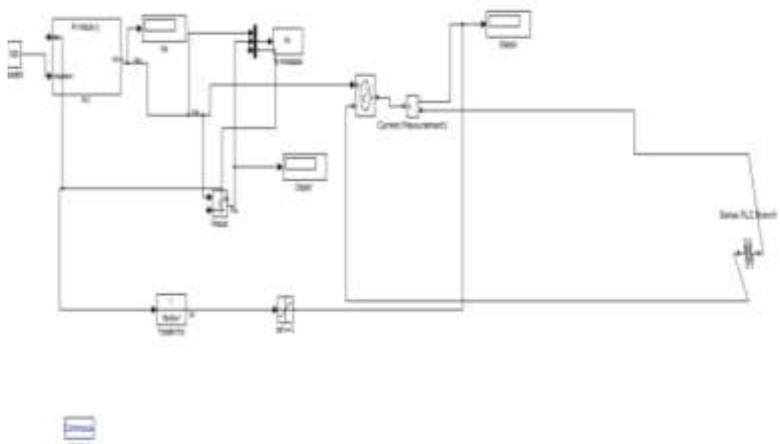


Fig.14 V-I and P-V characteristics

I_{sc} = 87.2, Voc = 888, I_{max} = 79.2, V_{max} = 704,
V= I*R, 888 = 87.2 R, so R = 10.18 Ω

TABLE 3
OUTPUT AT DIFFERENT RADIATION LEVELS

1000W/m^2 PV array 50 kW		
V	**P**	**I**
737.7	54.49	73.77
800W/m^2 PV array 50 kW		
V	**P**	**I**
655.7	43.08	65.57

•

6.2 The More Accurate Model: There are a few things that have not been taken into account in the simple model and that will affect the performance of a PV cell in practice.
1.Series Resistance: In a practical PV cell, there is a series of resistance in a current path through the semiconductor material, the metal grid, contacts, and current collecting bus.
2.Parallel Resistance: This is also called shunt resistance. It is a loss associated with a small leakage of current through a resistive path in parallel with the intrinsic device. [14]

[VII] RESULT

7.1. Simultaneous PV and FC result: Various inputs have been given to the prescribed model and for different Radiation Levels and loads the following results have been obtained:

TABLE 4
OUTPUT AT 50 kW LOAD

Radiation	Load	AC voltage	PV Cell				Fuel Cell		DC Bus	
			Cell	Converter						
			V	V	I	P	I	P	V	I
W/m^2	Kw	V(rms)	(V)	(V)	(A)	(kW)	(A)	(kW)	(V)	(A)
1000	50	415.3	961.3	986	51.1	50384.6	0	0	986	51.1
750	50	415.3	803.8	824.4	59.79	49290.876	0	0	824.4	59.79
500	50	415.1	510.3	798.8	32.51	25968.988	30	23943	798.1	62.51
250	50	415.1	500.5	800.1	12.18	9745.218	50	40005	800.1	62.18

7.2 Radiation 1000W/m^2 and 50 kW load :

Fig.15 Three phase output of Inverter at (1000W/m^2)

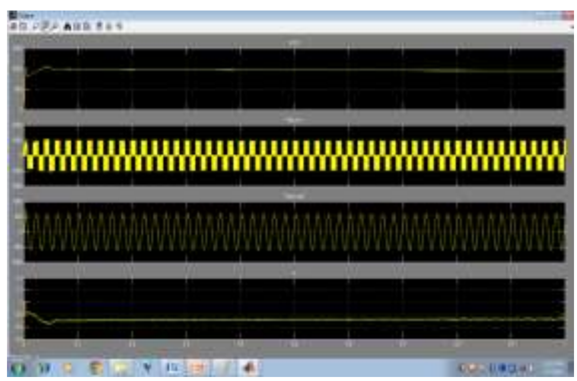


Fig.16 Output waveform of V_{dc}, V_{ab_inv}, V_{ab_load} and m at (1000W/m^2)

7.3 Radiation 800W/m^2 and 50 kW load:

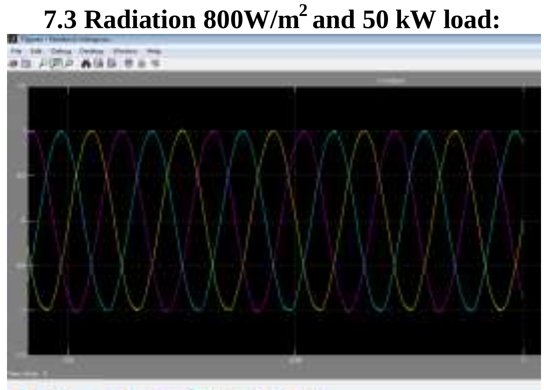


Fig.17. Three phase output of Inverter at (800W/m^2)

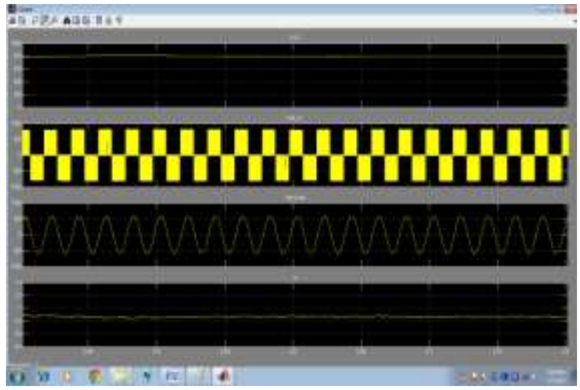


Fig.18 Output waveform of V_{dc}, V_{ab_inv}, V_{ab_load} and m at (800W/m^2)

[VIII] CONCLUSION AND SCOPE FOR FUTURE WORK

8.1 Conclusion: Various results of the dissertation in the form of voltage, current, power, and waveforms are discussed with the old work and following conclusions have been made from the comparative study of table no.1, 2 and 3,4.

'It has been seen that unlike the Micro grid PV Based System, here in the PVFC Hybrid System the Fuel Cell Unit is operated in parallel with the Photo Voltaic Unit and hence the voltage remains constant at output.'

'Also it has been observed from the comparative study from the table that the R.M.S. value of output voltage is 415 V (Approx.) and it remains constant in spite of the fluctuation in load and radiation.'

8.2 Advantages: Some of the advantages of PVFC Hybrid system are:

- .They is easy to operate.
- They do not create pollution.
- They have a long effective life.

8.3 Disadvantages:

- High in cost.
- Extra devices are required to storage the generated energy.

8.4 Application:

- Stand-alone PV/FC energy systems.
- Small village electricity supply,
- Water pumping and systems,
- Lighting and small appliances,

8.5 Scope for future work:

- Operates PV array at max power point.
- Connect grid to this Hybrid Generation model & set logic for optimum use of solar.

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