Energy Handling and Operation of a Microgrid Based on Photo Voltaic & Fuel Based Cells

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Abstract

A micro grid, which is based on Photo-Voltaic & Fuel cell (s) has been proposed in this research work. It provides information about the management, operation and its application of micro grid. Also a MATLAB model for the same has been developed and output has been obtained. Future scope of this model is also suggested. The proposed model is simulated with in real time to get the operation details.

Keywords - PV Cell, FC Cell Insulation level, micro-grid switch (SW).

Introduction

In this paper, a micro grid is developed with the help of PV & FC units. Energy from the sun or the details of solar energy is given below (Kanchev *et al.*, 2011):

- Total power radiated by the sun = 3.8 x 10^{26} W
- Received by earth out of this = 1.7 x 10^{17} W (Messenger and Ventre, 2004)
- The average solar radiation beyond the earth's atmosphere = 1.353 kW/m^2 [which may be varying from 1.43 kW/m^2 (in the month of January) to 1.33 kW/m^2 (in the month of July).

Solar constant (S)

He term 'solar constant' may be defined as the amount of solar radiation received by per unit surface area normal to the sun's rays in a space outside the earth's atmosphere. The value of solar constant is around 1353 W/m^2 (SI units) and often denoted by the symbol 'S'.

Clarity index

Clarity index is related with the decay in radiation of sun. Its value changes from 1-50% and also depends upon the nature of atmosphere. The Parallel beam radiation of Sun (because Sun is very far from us) is partly absorbed and partly scattered by the atmospheric present around the earth. (Atmosphere contains dust, gases, cloud, moisture etc.

Data (Solar radiation) in India

Geographically, India is situated in the Northern hemisphere of earth & its position is latitudes and 7^{O}N and 37.5^{O}N. Some state of India like Rajasthan, Punjab, U.P., Haryana and Delhi are very rich on point of view solar energy. The average solar radiation in India is in between 12.5 and 22.7 MJ/m^2.day The quantity of radiation reduces up to 50 to 60 % due to change in monsoon. This means, generally, collectors of flat plate type are better than focusing type collectors for diffused sunlight especially during cloudy atmosphere. Effect of atmospheric conditions on the parallel beam radiation is expressed as ACI.

ACI = It is the ratio of solar radiation (W/m^2) to solar constant (W/m^2)

Modeling of the Individual Components of Hybrid System

Modeling of Hybrid System (Photovoltaic & Fuel Cell Module)

Model of PVFC Hybrid system is shown here for modeling. The important parts of this system are shown here:

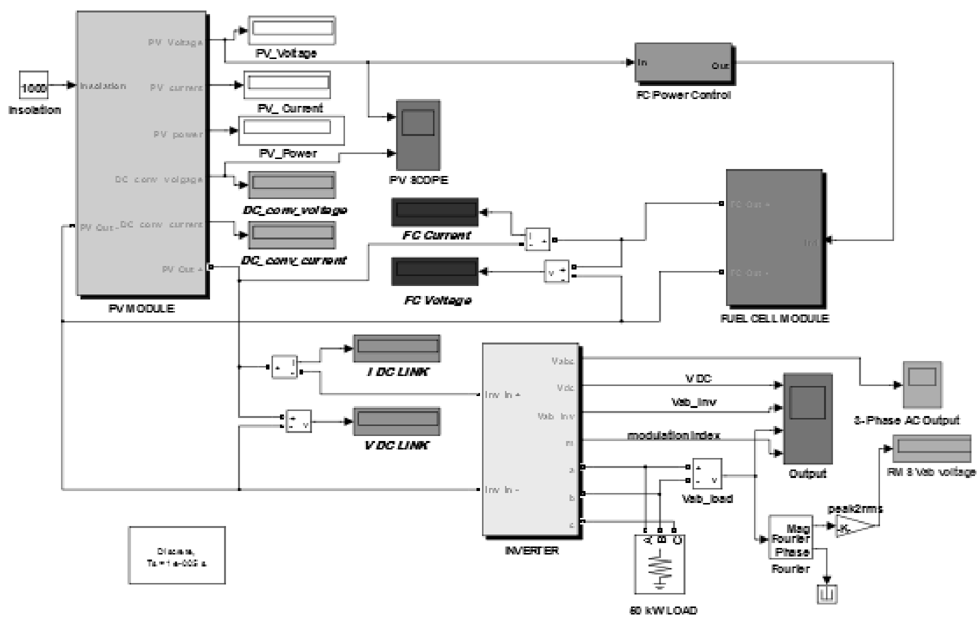


Figure 1: Modeling of Hybrid System

- Modeling of PV Cell
- Modeling of Fuel Cell Module
- Modeling of FC Power Control unit
- Modeling of DC to DC converter unit
- Modeling of Inverter & Electrical Load unit

Modeling of Photovoltaic Module

It is also found that less than 1V is produced by a single PV cell, so it is essential to connect a number of PV cells in series to achieve a standard output voltage.

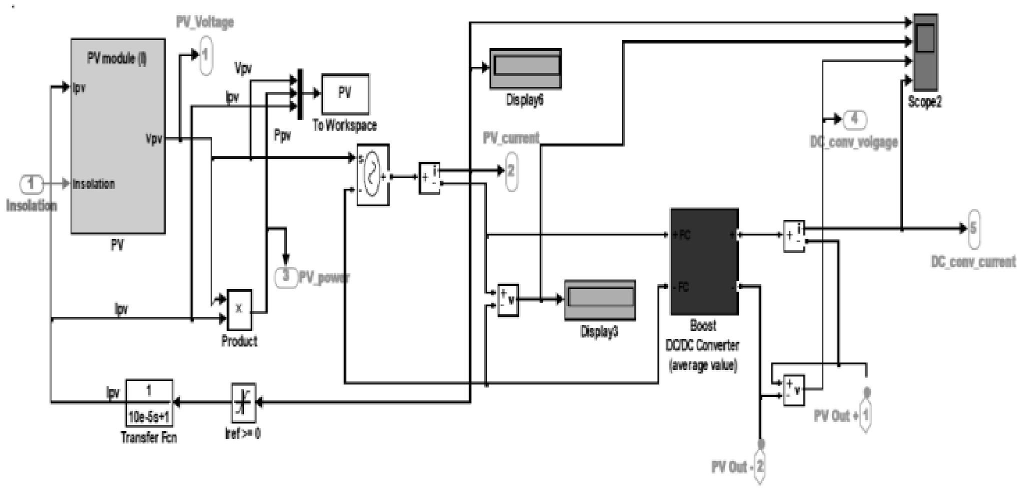


Figure 2: Modeling of P-V cell.

Similarly, when series-connected P-V cells are placed in a frame it is referred as a module. Most of commercially available PV modules have 36 or 72 series of cell in series (Hohm and Ropp, 2002). Here we developed a model having 36 cells in series. 12V DC is converted into 220 V AC with the help of inverter and 12 V DC is obtained by a module which is made by the series connection of 36 cells and similarly a series of 72-cell (module) is appropriate for a charging of 24V battery and process is so on.

Modeling of Fuel Cell Module

Fuel cell is nothing but simply an electro chemical device for the continuous conversion of the part of the free energy change in chemical energy in to electrical energy. When main system fails, this energy is used as a backup. This particular cell is different from a battery because it provides energy continuously with the help of hydrogen and oxygen.

Main components of a cell are:

- A fuel electrode
- An air electrode
- An electrolyte

Fuel Cells operated with Hydrogen & oxygen is efficient and the most highly developed cell. A low pressure Hydrogen oxygen cell is illustrated in the diagram. Two porous carbon or nickel electrodes are immersed in an electrolyte to flow the current. Catalyst is embedded in nickel electrodes.

Hydrogen is fed to one electrode and is absorbed gives free electrons and also reacts with hydroxyl ions of the electrolyte to form water (Kanchev *et al.*, 2011). The free electrons travel towards oxygen electrode through the external circuit. Chemical energy can flow with the flow of free ions.

It is prime requirement that the composition of electrolyte should not change as the cell operates. The cell operates at or slightly above atmospheric pressure and at a temperature about 90^0C (Koutroulis *et al.*, 2001). This type of cell are called low temperature cells in high pressure cells pressure is up to about 45 atmospheric and temperature up to 300^0C.

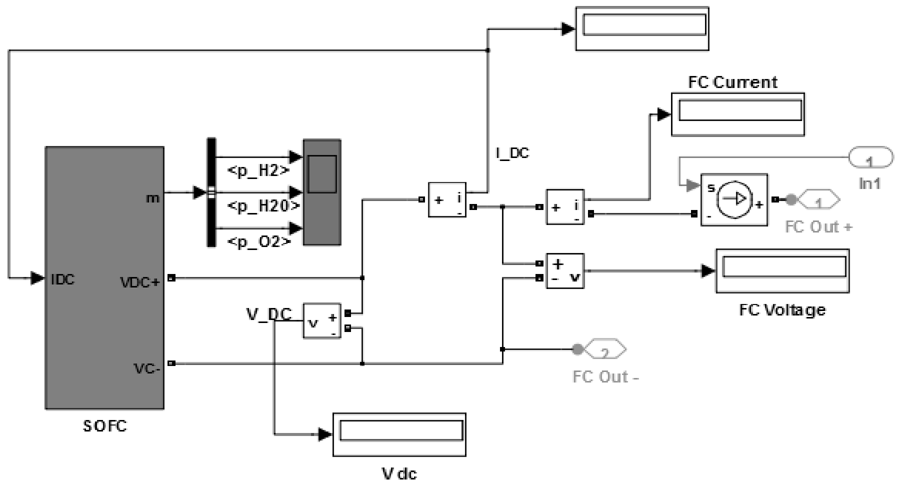


Figure 3: Modeling of Fuel Cell Module

A single unit of hydrogen oxygen cell can produce an emf of 1.23 volts at atmospheric pressure at a temperature of 25^0 Celsius. By interconnection of a no. of cells, it is quite possible to create potential difference in the range of 100 to 1000 volts and power levels of 1 kW to nearly 100 MW, which is shown in figure 3.

Modeling of FC Power Control Unit

This is known as FC power control unit, It run on the basis of LOOK-UP DATA. LOOK-UP DATA is a table Monitoring is the main work of this unit, which decides the operation of FC power control unit. Fuel cell unit come in action according to the low values of radiation of photovoltaic array (Veerachary *et al.*, 2002). Scope-1 is used for the Output wave form of FC power control unit.

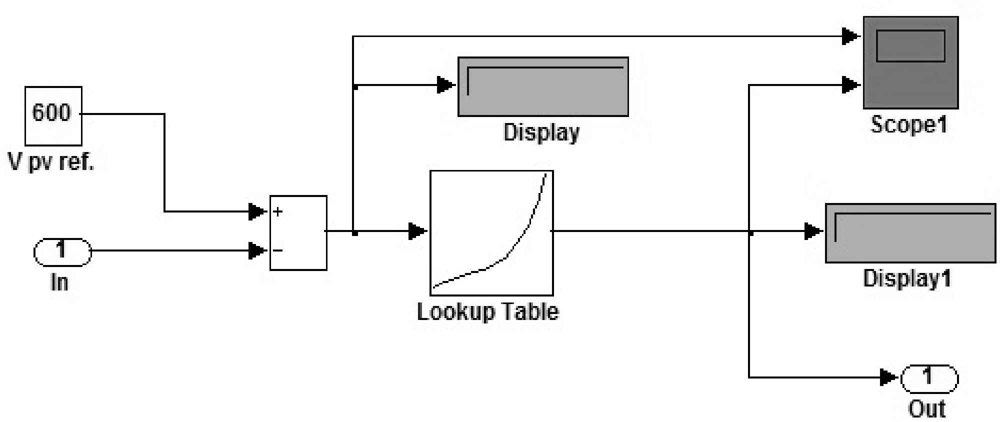


Figure 4: Modeling of FC Power Control Unit

Modeling of DC to DC (Boost) converter

The dc to dc converter (Boost converter) is a process in which power is transmitted, aborted and injected from solar panel, placed outside to grid-tied with inverter. We have connected four components by which absorption and injection is done in the boost converter, it is performed by a combination of four components as given below:

- An inductor
- Electronic switch
- Diode
- Capacitor

Simple diagram of a boost converter is shown in Figure.

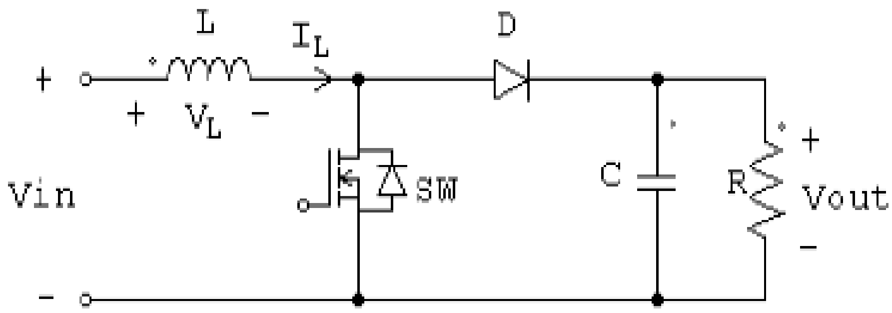


Figure 5: Converter Circuit Diagram

Subsequently the actual process of energy absorption and injection will constitute for a switching cycle as desired (Koutroulis *et al.*, 2001). The value of average output voltage is controlled by the switching action i.e. on and off time duration. (Keeping switching frequency constant & adjusting the on and off duration of the switch) It is called pulse-width-modulation (PWM) switching. The switching duty cycle is denoted by letter ‘k’. It is defined as follow. It is the ratio of the ON duration to the switching time period of the device. The possible types of modes can be:

- Continuous conduction mode also known as ‘CCM’
- Discontinuous conduction mode also known as ‘DCM’

Continuous Conduction Mode:

The continuous conduction mode of operation system is further divided into two modes. Mode-1 starts when the switch is turned ON at t = 0 as mentioned below:

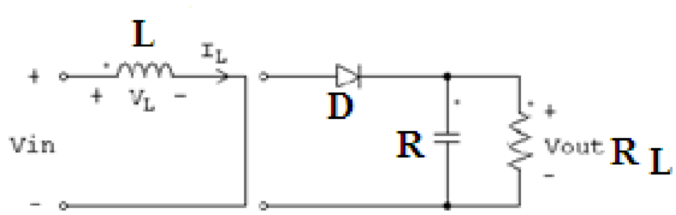


Figure 6: Boost converter during Mode-1

The input current which rises exponentially flows through inductor L and switch.

Energy is stored in the inductor = $0.5LI^2$

Energy is stored in capacitor = $0.5CV^2$

Energy is stored in the inductor is $0.5LI^2$ and load is supplied by capacitor current which is already charged and energy is stored as $0.5CV^2$. Mode-2 begins when the switch is turned OFF at t = kT. The current that was flowing through the switch would now flow through the inductor L, the diode D, the output capacitor C and the load R as shown in Figure 7.

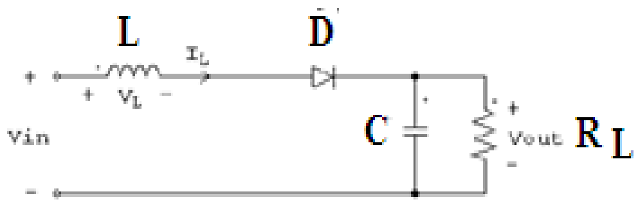


Figure 7: Boost converter during Mode-2

For the next cycle the inductor current falls until the switch is turned 'ON' again. During this time, energy is transferred to the load which is stored in the inductor as $0.5LI^2$ at same input voltage. Energy is stored in the inductor = $0.5LI^2$. Therefore, the value of output voltage become more than the value is greater than the input voltage and is expressed as

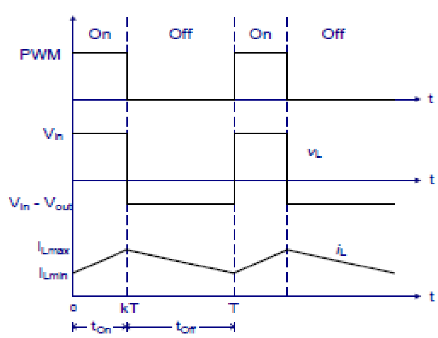
$$V_{out} = \frac{1}{1-k} V_{in}$$

where V_{out} = Output voltage, k = Duty cycle, V_{in} = Input voltage

$$L_{min} = \frac{(1-k)^2\, k\, R}{2\, f}$$

where L_{min} = It is the value of minimum inductance, R = Resistance, f = switching frequency

$$C_{min} = \frac{k}{R\, f\, V_r}$$



$$V_r = \frac{\Delta V_{out}}{V_{out}}$$

Figure 8: Boost converter waveform at CCM

Discontinuous Conduction Mode

Under this mode, inductor current (I_L) is interrupted which means that it does not flow continuously. Also there is an interval of time in which the current is found to be zero before the next turn when the switch is ON. The corresponding switching waveforms are shown in Figure 8.

$$V_{in}\, k\, T + (V_{in} - V_{out})\Delta_1\, T = 0$$

$$\therefore V_{out} = \frac{\Delta_1 + k}{\Delta_1} V_{in}$$

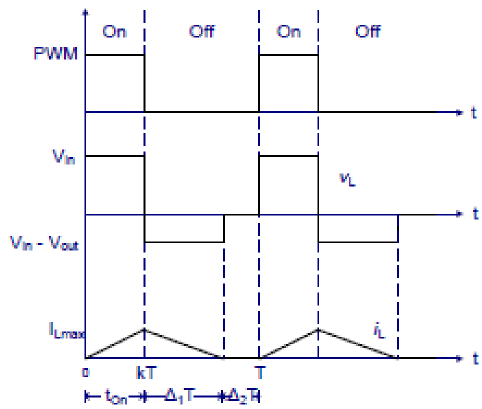


Figure 9: Boost converter waveform at DCM

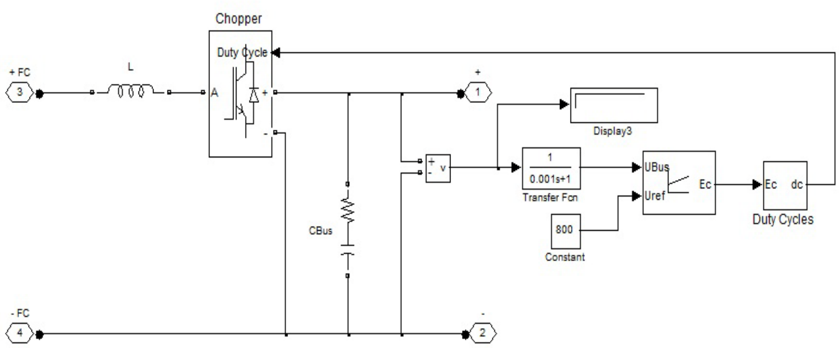


Figure 10: Modeling of DC to DC Boost converter

Modeling of Inverter Unit

Three phase inverter may be considered as three single –phase inverters and the output of each single phase inverter is shifted by 120^0. This is the unit which is run by diode and switchs. The voltage control techniquies is applied in three phase inverter (Gow and Manning, 1999).

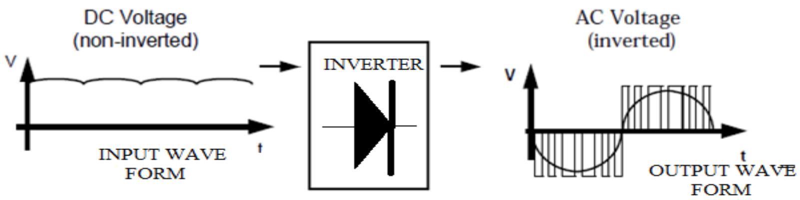


Figure 11: Inverter waveform

All the three phasees are separated by 120^0 electricity. Here we are doing elimination process as It is generated by eliminating the condition that two switching devices in the same arm can not conduct at the same time. Gate-commutated power devices, like BJT, MOSFET, IGBTs etc (Altas and Sharaf, 2007), are used for low-and medium-power applications. For high power applications, it is necessory to connect them in series and / or parrel combinations, which increase the circuit complexxity. To make the device fast and automatic fast-switching tyyristers are used. They are more prominent because of there voltage and current rating is down.

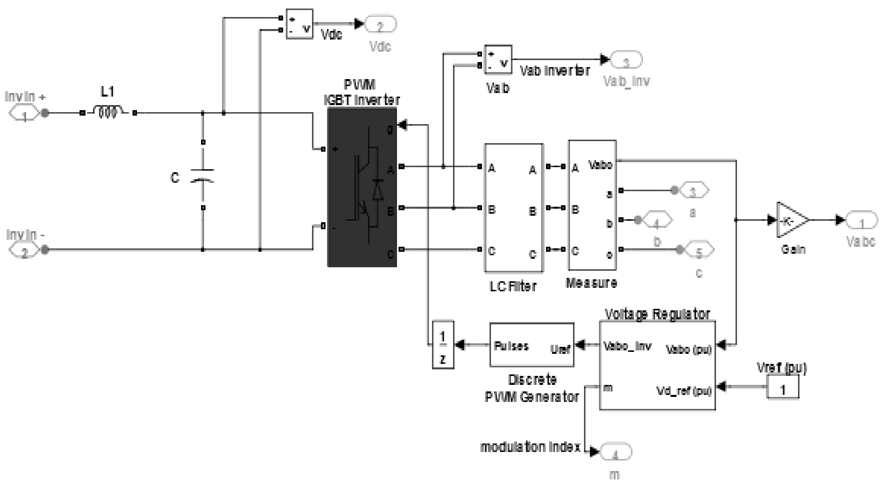


Figure 12: Modeling of Inverter Unit

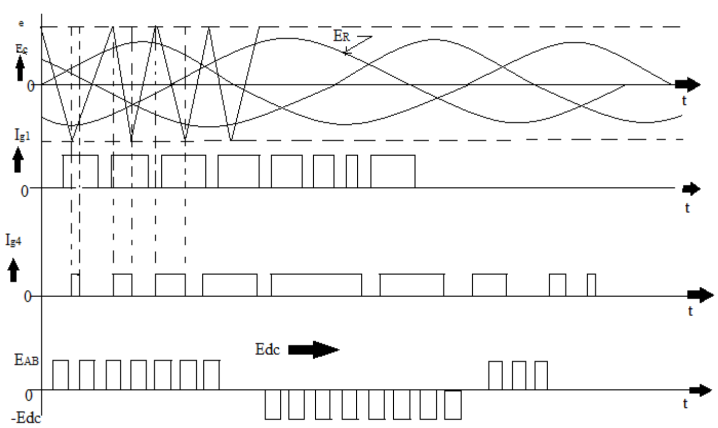


Figure 13: Sinusoidal pulse-with modulation for three-phase inverter

Modeling of Electrical Load

Here we arte modeling of electrical load. We use here three phase load as output. Output voltage may varry only by two reasons, one is change in radiation (Radiation) level of solar and other one is change in load. The output load may varry from microwatts up to mega watts by connecting more and more arrays of units in series. Here modeling is done for the three phase AC load of value 50kW. It is purely resistive load. A 415 constant voltage is made at the output(rms value) (Kim and Youn, 2005).

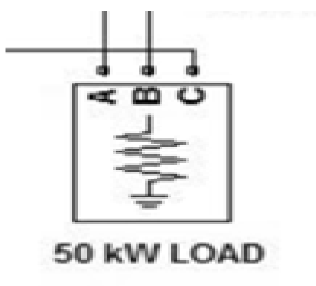


Figure 14 (a): 50kW Load

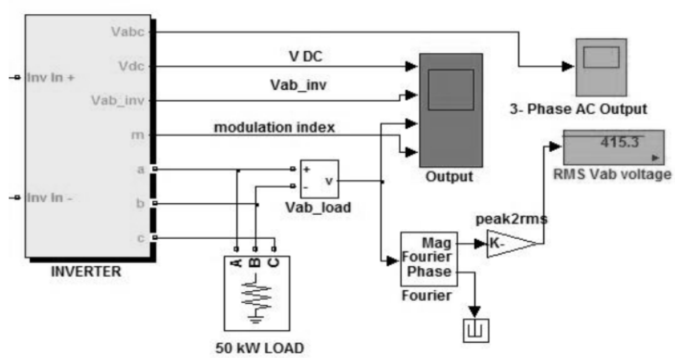


Figure 14 (b): Modeling of Electrical Load

While there is change in the output load stil we get a constant output voltage, it is obtained by the simultanious operation of PV and FC hybrid system (Mohamed *et al.*, 2008).

Result

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 1: Output at 50 kW load

Radiation	Load	AC voltage	PV Cell				Fuel Cell		DC Bus	
			Cell	Converter						
W/m²	Kw	V(rms)	V (V)	V (V)	I (A)	P (kW)	I (A)	P (kW)	V (V)	I (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

Table 2: Output at 60 kW load

Radiation	Load	AC voltage	PV Cell				Fuel Cell		DC Bus	
			Cell	Converter						
W/m²	kW	V(rms)	V (V)	V (V)	I (A)	P (kW)	I (A)	P (kW)	V (V)	I (A)
1000	60	415	925.4	949.2	63.91	60663.372	0	0	949.2	63.91
750	60	415.4	509.1	801	35.22	28211.22	40	32040	801	75.22

Table 3: Output at 70 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	70	415.3	867.7	889.8	80.82	71913.636	0	0	889.8	75.22
750	70	415.4	505.3	798.6	46.95	37494.27	40	31944	798.6	86.95

Radiation 1000W/m² and 50 kW load

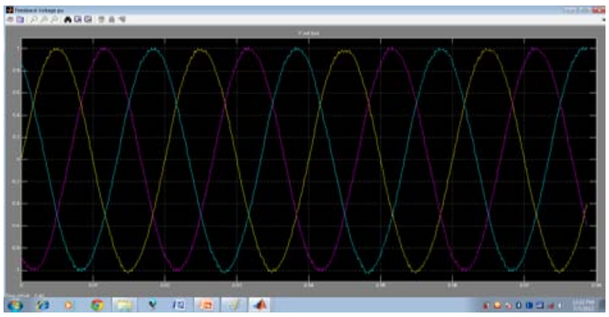


Figure 15: Waveform for three phase output of Inverter at 1000W/m^2

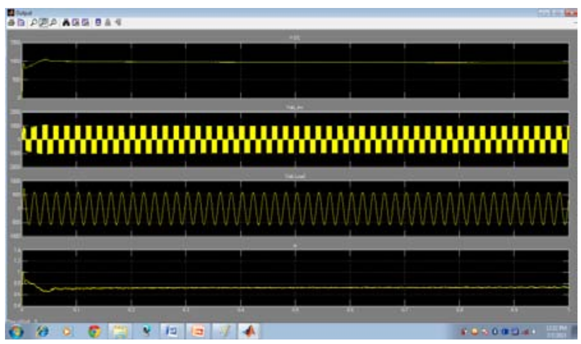


Figure 16: Output waveform for V_{dc}, V_{ab_inv}, V_{ab_load} at 1000W/m^2

Radiation 750W/m² and 50 kW load

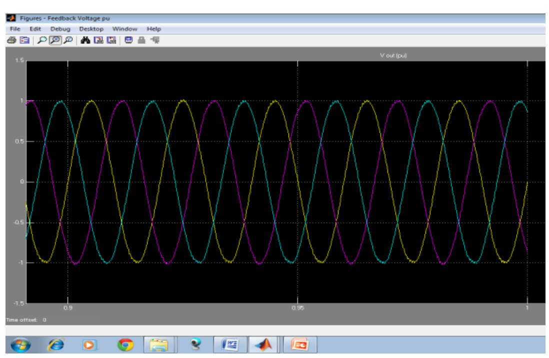


Figure 17: Three phase output of Inverter at 750W/m^2

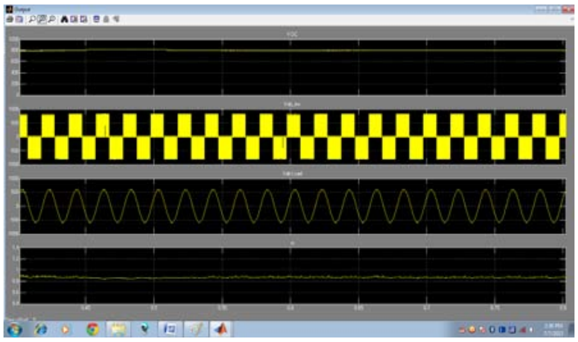


Figure 18: Output waveform of V_{dc}, V_{ab_inv}, V_{ab_load} at 750W/m^2

Radiation 500W/m^2 and 50 kW load

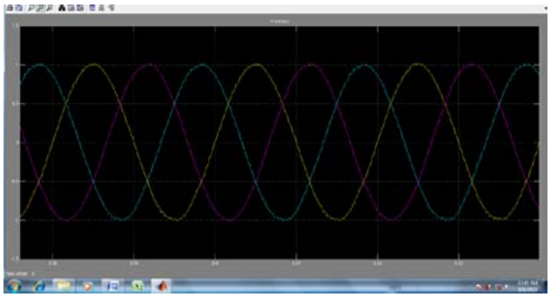


Figure 19: Three phase output of Inverter at 500W/m^2

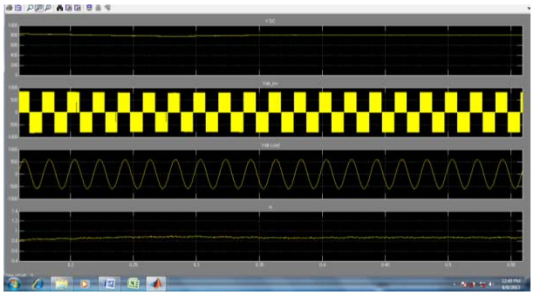


Figure 20: Output waveform of V_{dc}, V_{ab_inv}, V_{ab_load} at 500W/m^2

Radiation 250W/m^2 and 50 kW load

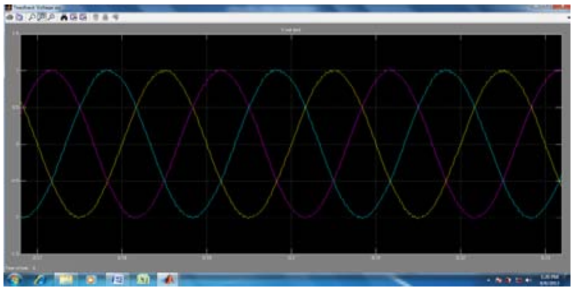


Figure 21: Three phase output of Inverter at 250W/m^2

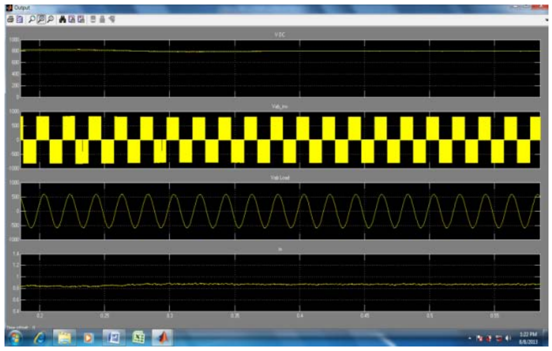


Figure 22: Output waveform of V_{dc}, V_{ab_inv}, V_{ab_load} at 250W/m^2

Conclusion and Scope for future work

The results of the PV-FC hybrid system in various forms as voltage, current, power, and waveforms provides the following conclusions. It is found out that 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. Additionally, it has been observed that the RMS value of the output voltage is approximately 415 V and it remains constant in spite of the fluctuation in the load and its associated radiation.

Advantages related with the PV-FC Hybrid system are as follows:

- High operating efficiency, advanced work is running to improve it, (It is about 45% and it is expected to reach 80%)
- Less maintenance.
- Fuel power plant may further cut generation costs by reducing transmission losses.
- Little noise, so that it can be readily acceptable in residential areas.
- Modular nature in which desired currents, voltages and power levels can be achieved by integration.

Disadvantage can be that as problem in case of cloudy and rainy session, extra devices are required to storage the generated energy and high installation cost is an additional drawback.

Applications can be a stand-alone PV/FC energy systems, small village electricity supply and water pumping for irrigation and emergency power backup. Scope for future work can be that we can make a smart grid with wind/solar/fuel cell.

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