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PV and Fuel Cell Hybrid System Connected to grid with Data Based MPPT Technique

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Abstract— ***This paper presents a control scheme which controls in which PV (Photovoltaic) and Fuel cell system are connected through a DC bus. In order to achieve maximum utilization of distribution generation, power supplied to load for day and night through renewable resources. PV power availability is depends upon the solar irradiation so that it becomes important to extract maximum possible power from PV system. To do that data based Maximum power point tracking (MPPT). Control technique is implemented in such a manner that system produce approximate constant power to local load and grid. Reactive power flow is also controlled from the PV and Fuel cell system to grid connected load as per the requirement of load or grid. PV and Fuel cell system can be connected to the grid using single stage or two stage method. In this paper we use single stage method and transformer less to reduce the cost and losses of the system. As we are injecting reactive power to grid even when there is no fuel cell power. To inject reactive power, system extracts active power from the grid even when there is no power from PV and fuel cell system. Therefore the converter has to work continuously with grid. This forces to use single stage system. PV and Fuel cell simulation is done using the basic equation. Passive filter is used to reduce the harmonic produced by inverter.***

Keywords— ***PV, FC, harmonic, bus and power.***

I. INTRODUCTION

Today's world is looking for the renewable energy resources to reduce the carbon emission in the atmosphere. There so many renewable resources are available such as wind, photovoltaic, geothermal, fuel cell. Fuel cell and photovoltaic (PV) generation is most demanding source of renewable energy. As energy need is rapidly increases for the development of any country keeping the environmental clean and safe for next generation. Distribution generation also helps for renewable resources as generation is near the load there losses in transmission are eliminated. Hybrid system is used for maximum utilization of any interconnected two or more renewable resources. At present, photovoltaic (PV) generation is assuming increased importance as a RES application because of distinctive advantages such as simplicity of allocation, high dependability, absence of fuel cost, low maintenance and lack of noise and wear due to the absence of moving parts. Furthermore, the solar energy is a clean, pollution free and inexhaustible energy source. In addition to these factors are the cost and prices of solar modules are decreasing, an increasing efficiency of solar cells, manufacturing-technology improvements and economies of scale [1 3]. Fuel cells are electrochemical device which generate DC electrical energy via an electrochemical reaction. There different types of fuel cells are available such as Alkaline Fuel cells, Proton Electrolyte Membrane Fuel cell, Phosphoric Acid Fuel cell, Molten Carbonate Fuel cell and Solid Oxide Fuel cell. Fuel cell system is simulated using basic equations [1]. There are two types of techniques used in photovoltaic system (Single stage and two stage technique). In single stage technique only inverter is used to convert DC to AC. Two stages technique consist of one DC to DC converter and DC to AC converter. In this paper we use single stage system which means only one converter is connected with the grid. Control scheme uses Parks transformation to control the active and reactive power of a grid connected fuel cell stack. Parks transformation converts three phase system to two phase system without changing the power. Control strategy applied in this also controls the reactive power in the absence power from fuel cell [2 6]. Single stage grid connected fuel cell system which consists of fuel cell stack, DC link capacitor, inverter, filter, grid source and controller.

II. MODELING AND CHARACTERISTIC OF THE FUEL CELL

In this paper a particular fuel cell stack is taken which is operating at nominal condition of temperature and pressure. The parameter of the equivalent circuit can be recalculated in reference to the polarization curve.

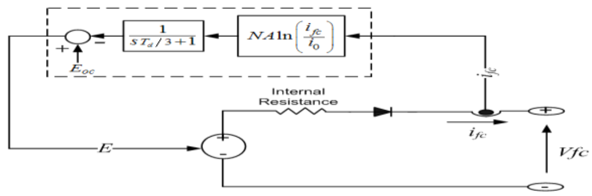

Fig-1: Simplified model of fuel cell

As per the polarization curve nominal and maximum operating points can be calculated. A typical polarization curve divided into three regions such as activation region, ohmic region and Mass transport region [1]

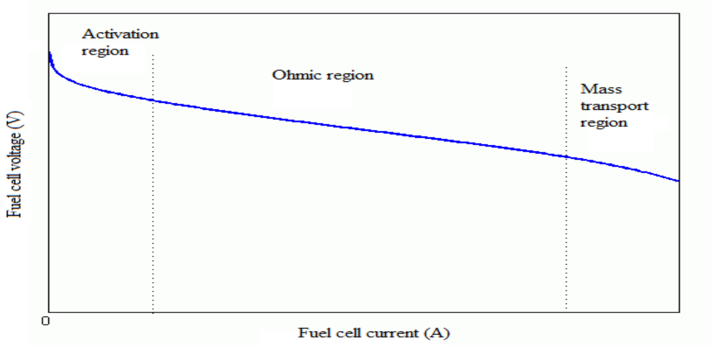

Fig-2 Polarization curve of typical fuel cell

III. MODELING AND CHARACTERISTIC OF PV CELL

PV module consists of solar cell which are basically a p-n semiconductor junction that directly convert solar radiation into dc current using the photovoltaic effect.Fig.1 depicts the well known equivalent circuit of the solar cell composed of a light generated current source, a diode representing the non linear impedance of the p-n junction and series and parallel intrinsic resistance.

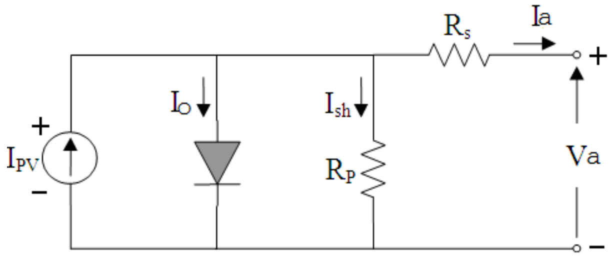

Fig-3 Equivalent circuit of the solar cell

Basic equation of PV Module [3].
Output current of PV module is given by:-
Ia=IphNp-NpIrs{exp[q/AKTc(Va/Ns+IaRs/Np)]-1}-Np/Rp[Va/Ns+IaRs/Np]
(1)
Np: Numbers of parallel solar cells.
Ns: Numbers of series solar cells.
Iph: Photon current.
Irs: solar cell reverse saturation current. (0.0003A)
q: Electron charge. (1.6 ×10^−19C)
A: P-N junction ideality factor (Between 1and 5)
K: Boltzmann's constant. (1.38×10^−23J/K)
Tc: Solar cell operating temperature.
Rs: Cell intrinsic series resistance. (0.001Ω)
Rp: Cell intrinsic parallel resistance.
Ia: Cell output current
Where
Iph=[Isc+Ki(Tc-Tref)]Sc/Sr
(2)
Isc: Short circuit current at STC
Ki: Cell temperature coefficient of the short-circuit current (STC).
Tr: Solar cell absolute temperature at STC. (20°C)
Sr:Total solar reference radiation at STC,1000W/m^2
Sc: Operating solar radiation.
From the equation (1) & (2) simulation of PV module is done, which done in following manner
Taking, Rp=∞, Np=1, Ns=1.
Equation become Ia=Iph-Irs{exp[q/AKTc(Va+IaRs)]-1}
(3)
And the Output voltage of the solar cell
Va=AKTc/qIn[(Iph-Irs-Ia)/Irs-RsIa]
(4)
Effect of solar irradiation and temperature on Iph and Va is given by the following equation.

$1/Sc(Sr-Sc)=\Delta si$
(5)
$Ki.\alpha s(Sr-Sc)=\Delta sv$
(6)
$Ki(Tc-Tr)=\Delta tv$
(7)
$Bt/Sc(Tr-Tc)=\Delta ti$
(8)
Therefore net change is as following
$Xtv=1+\Delta tv$
(9)
$Xti=1+\Delta ti$
(10)
$Xsi=1+\Delta si$
(11)
$Xsv=1+\Delta sv$
(12)
New values of the Iph and Va
$Iph(new)=Xti\ Xsi\ Iph$
(13)
$Va(new)=Xtv\ Xsv\ Va$
(14)
αs: Slope of the change in the cell operating temperature
Fitting factor A is used to adjust the I-V characteristics of the cell obtained from the equation to the actual characteristics obtained by testing. These models are operated only for specific temperature and solar irradiation. Because the temperature and irradiation level changes the corresponding operating temperature of the solar cell changes in order to the models on the other temperature we have to modify the model. Using above equations we get the solar cell block which give two signals one is solar output current and another is output voltage, with these two signals we can make the solar cell to work as a current source or as a voltage source. Series solar cells are connected by multiplying the output voltage signal with the number of solar cells to be connected. And output current is divided by number of solar cell to be connected in parallel. To make the solar cell as a current source, output current signal is given a current controlled current source and for voltage source output voltage source is given to the voltage controlled voltage source. To study the effect of the temperature and the solar irradiation on the solar cell we operate this model at different solar irradiation and temperature. When the solar irradiation changes the output current varies more as compare to voltage whose variation is small. Temperature increases, voltage of solar cell decreases and the current increases [2 3].

IV. **DATA BASED MPPT TECHNIQUE**

In this technique we generate the data from the photovoltaic module by simulating the module at different solar irradiation levels at different temperature. With change in the solar irradiation level the generated power of PV module changes. Output power of PV module depends upon output voltage of the PV module. At constant solar irradiation level different power can extracts from the module by changing the output voltage of the module. The output voltage of the modules can be changed by changing the output voltage we obtain the maximum power point at different solar irradiation levels and converting these results into data. From this data we generate optimum maximum power point for every solar irradiation at different temperature. As power also depend upon photovoltaic modules temperature. From this data which choose the maximum power point for a particular solar irradiation level at a specific temperature. For every particular maximum power point a reference voltage is generated. Modulation index of the inverter is changed with respect to the reference voltage which changes DC link voltage of the photovoltaic system. DC link voltage is limited in specific range up to which modulation index (0-1) can be varied.

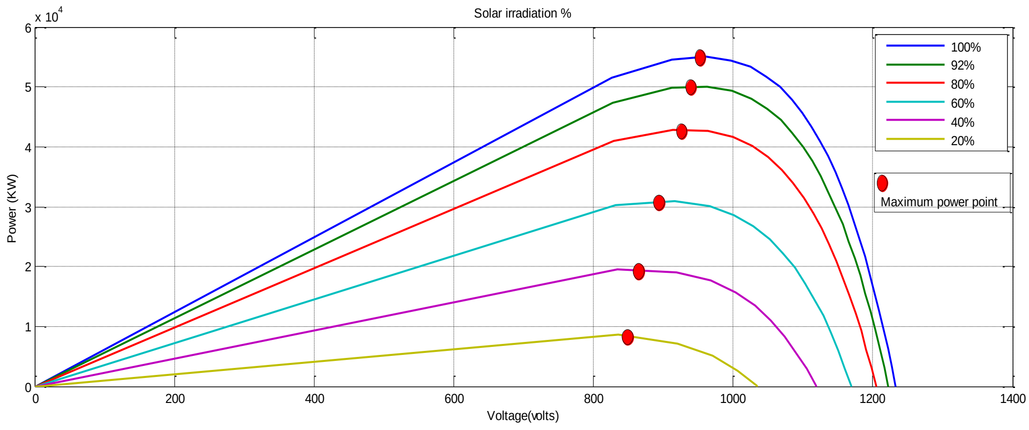

FIG-4 POWER V/S VOLTAGE CHARACTERISTICS OF PV MODULE

TABLE-1 Maximum power point at different solar irradiation

Sr.no	Solar irradiation	MPP PV voltage
1	200W/m^2	835
2	400W/m^2	860
3	600W/m^2	895
4	800W/m^2	915
5	920W/m^2	962
6	1000W/m^2	972

V. ROTATING REFERENCE FRAME TRANSFORMATION

Parks transformation converts three phase voltage to two phase voltage or three phase current to two phase current with power invariance. The abc_to_dq0 Transformation block computes the direct axis, quadratic axis, and zero sequence quantities in a two-axis rotating reference frame for a three-phase sinusoidal signal. The following transformation is used:

$$V_d = \frac{2}{3}(V_a Sin(wt) + V_b Sin(wt - \frac{2\pi}{3}) + V_c Sin(wt + \frac{2\pi}{3}))$$

(15)

$$V_d = \frac{2}{3}(V_a Cos(wt) + V_b Cos(wt - \frac{2\pi}{3}) + V_c Cos(wt + \frac{2\pi}{3}))$$

(16)

$$V_o = \frac{2}{3}(V_a + V_b + V_c)$$

(17)

where ω = rotation speed (rad/s) of the rotating frame.

VI. SYSTEM CONFIGURATION

Fig-5 shows a single stage grid connected hybrid system consist of PV and Fuel cell connected to DC bus. DC link capacitor, inverter, passive filter and Programmable voltage source as grid, Resistive-Inductive Load and controller.

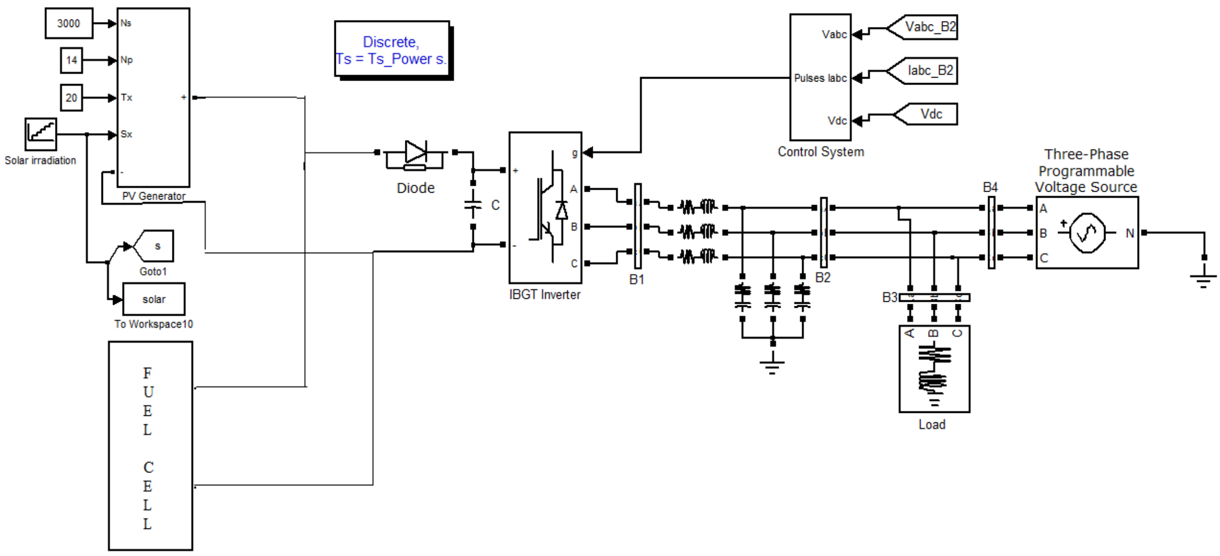

Fig-5 Power circuit

VII. OPERATION PRINCIPLE

The proposed work uses a SPWM inverter to interface the fuel cell system with the ac system. The idea is to make this system to operate as a controllable voltage source connected in parallel with the power grid. By controlling the inverter output voltage phase angle (ϕ) and amplitude in relation to the grid voltage, it is possible to have the fuel cell system supplying active (P) and reactive power (Q). In fact, the active power depends predominantly on the phase angle or load angle between the inverter voltage (Vi) and system voltages (Vs), and the reactive power is a function of the magnitudes of these voltages. Phase angle (ϕ) varies in such manner that it provides maximum power generated by the fuel cell system. Whenever inductive or capacitive load is connected with grid connected fuel cell system. The system will generate the required reactive power by increasing or decreasing the voltage level of the inverter output voltage. The inverter output voltage can be changed by changing the modulation index of the inverter. When the output voltage of inverter is higher than the grid voltage the reactive power is supplied by the FC system to grid. Reactive power is absorbed when inverse of action take place. Active power is transfer from leading to legging [4-5]. Therefore when inverter output voltage is leading the grid voltage active power will transfer from FC system to grid. Active power is consumed by FC system when inverse action takes place.

$$P = \frac{ViVs}{X} \sin\phi$$

(18)

$$Q = \frac{Vi^2 - ViVs}{X} \cos\phi$$

(19)

Control Scheme

Aim of the control scheme is to transfer constant power generated by the FC stack and PV module. In order to transfer constant power, FC power decreases as solar irradiation level increases therefore solar power increase. To extract that Maximum power from the PV module data based maximum power point tracking technique is implemented. In order to vary the power generated by the fuel DC and PV module DC link voltage is varied without any dc-dc converter which reduces the losses and cost due dc-dc converter and makes the control scheme simple to implement. To vary DC link voltage according to reference signal generated for a particular load, modulation index of the inverter is varied. DC link and DC link reference voltage are compared to generate error signal. The reference signal is varied according to data based Maximum point tracking technique. Behavior of FC and PV are opposite to each other as DC link voltage increases power generated from FC decreases and PV module power increases in reference to maximum power point. All the components and parameter are so selected that it generates approximate constant power through the day and night. In day system try to get most of the power from the PV module and in night total power supplied through the FC stack. Error signal given to (DC voltage regulator) PI controller which generates Idref as shown in diagram. To control reactive power Iqref signal is generated from the load side in order get unity power factor across load. Iqref signal is generated with help of Parks transformation. Iqref signal is compare with the actual signal from inverter side Iq to generate an error ΔIq. Similarly Idref signal is compare with the Id signal of the inverter. Error signal are given to PI controller (current controller) through which signal are converted into Vd, Vq as shown in the figure. Vd, Vq signal which are further converter in phi(ϕ) and modulation index(m). Using below given equations, atan2 is four-quadrant inverse tangent.

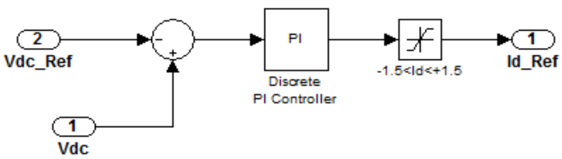

Fig-6 DC voltage regulator

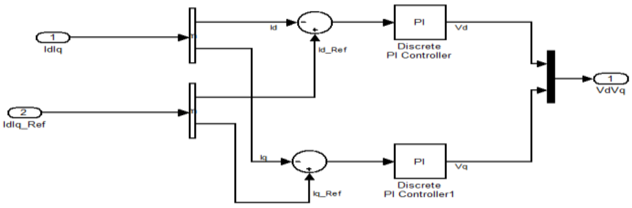

Fig-7 Current regulator

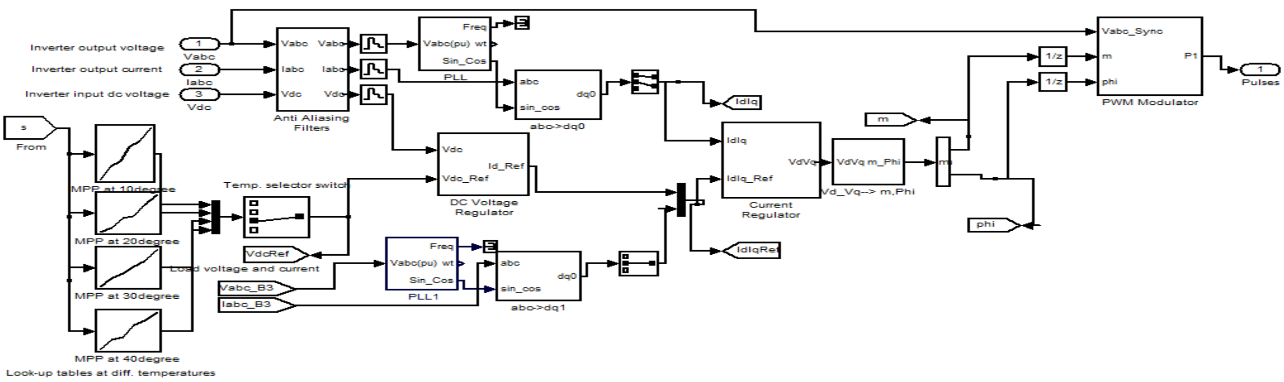

Fig-8 Control scheme

Modulation index and phi generates the pulses for inverter circuit using SPWM generator [3]. Where modulation index changes the magnitude of inverter output voltage to supply reactive power and phi changes the phase angle between the inverter voltage and grid voltage to supply the active power. Parks transformation is used to convert the Iabc to Iqd0. When there is no power from hybrid system even than system supply required reactive power to grid. At this situation system will extract active power from the grid to supply required reactive power. When active power is transfer from the grid to inverter. Inverter voltage is lagging behind the grid voltage.

VIII. SIMULATION RESULTS

Matlab software package was used in all simulation accomplished here which shows results obtained for voltage and current wave form, active and reactive power on the ac side supplied to the grid. The inverter model has been used to supply active and reactive power from hybrid system to a grid. The Matlab simulation studies, with the control implementation. The main objective of the control scheme is to supply constant power to grid and gird connected load.

TABLE-2 Power circuit parameters

Fgrid	Vdc	Cdc	Vgrid	Vinv
50Hz	Variable	2800µF	440V	440V

TABLE-3 Control system parameters

DC voltage controller		Current controller	
Kp	Ki	Kp	Ki
0.6	20	0.2	15

IX. RESULTS AND ANALYSIS

In fig-17 it is shown that at the initial stage transient and system get stable at 0.04 seconds this shows that controller working effectively. Fuel cell generates 55.5KW at 885V when 0% solar irradiation in 0 to 0.1 sec. As solar irradiation start increasing from 0 to 200W/m^2 data based MPPT technique changes the DC link voltage due that fuel generation reduces to 40.9KW and PV power reaches to 8.4KW. As solar irradiation reaches 400W/m^2 DC link again changes and PV power increases to 21KW and FC power reduces to 32.5KW. Similarly PV power for 600W/m^2, 800W/m^2, 1000W/m^2 increases to 33.7KW, 46.8KW, 57.7KW and FC power reduces to 21.6KW, 8KW, 0KW respectively. Using both the resources approximate constant power from inverter is obtained within 0 to 0.6 seconds. A 25KW resistive load and 10 KVAR inductive load is connected to grid and Hybrid system through inverter. In the fig-17 it can seen that local load is supplied through the inverter and rest of the power is transfer to the grid. As per the power quality is concern harmonic are reduce by using the passive filter. From the result it can seen that inverter current varies as DC link voltage changes and its THD(Total Harmonic Distortion) is 1.46% as shown in fig-(9-10). Load current remain same even when there change in DC link voltage or power change in fuel cell and its THD is 0% as shown in fig-(13-14). Total harmonic distortion of load, grid and inverter voltage is also 0%. Grid current varies with respect to inverter current and its total harmonic distortion is 2.70% as shown in fig (11-12). Fig-17 shows reactive power supplied by hybrid system. The Hybrid system generates reactive power as per the requirement of the load only or it can also generate more reactive power if required by the grid as shown in control scheme. Sudden change in DC link voltage level effect the reactive power which can be seen in fig-15 and also the reactive power supply the grid. Fig-16 shows the DC link voltage which varies according to the reference signal. The phase angle phi (ϕ) changes with change in the Idref signal. According to phase angle phi (ϕ) active power transfer from PV system to grid.

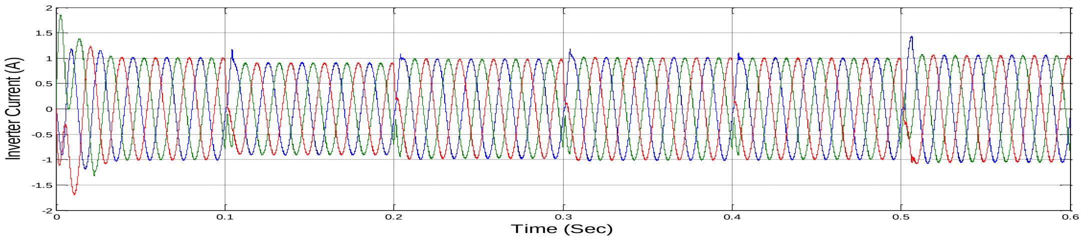

Fig-9 Inverter current

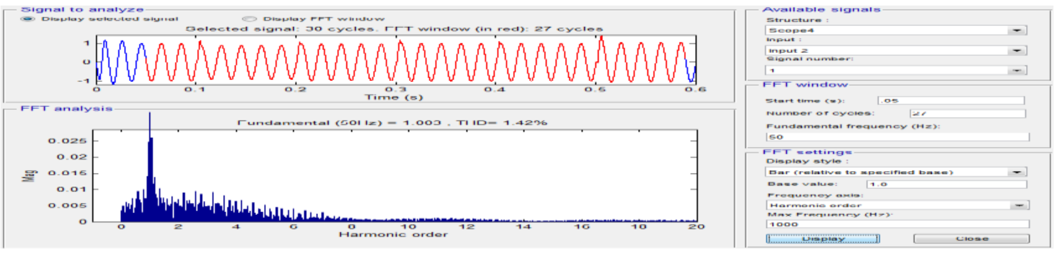

Fig-10 THD of Inverter current

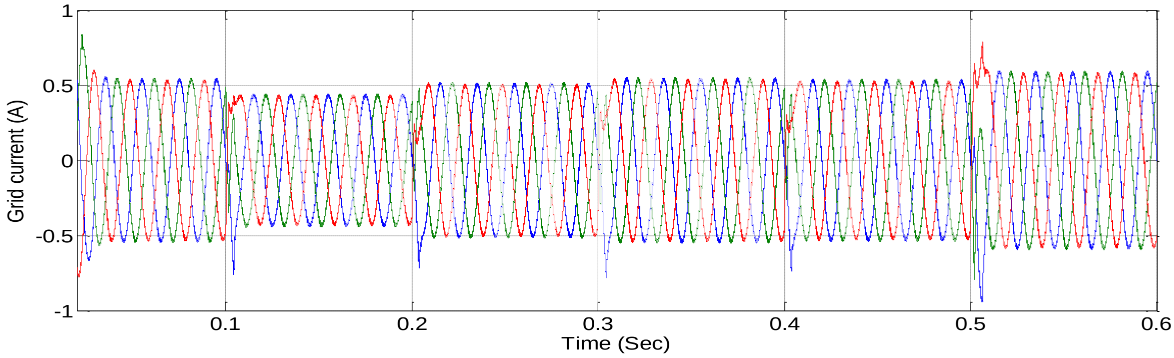

Fig-11 Grid current

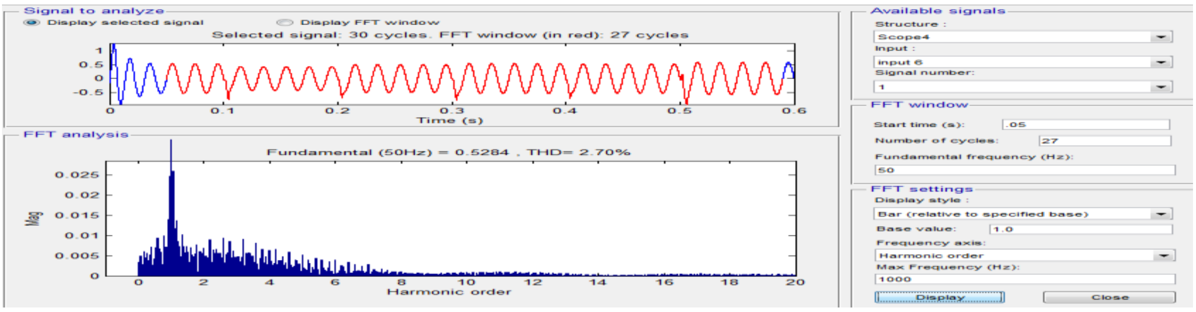

Fig-12 THD of Grid current

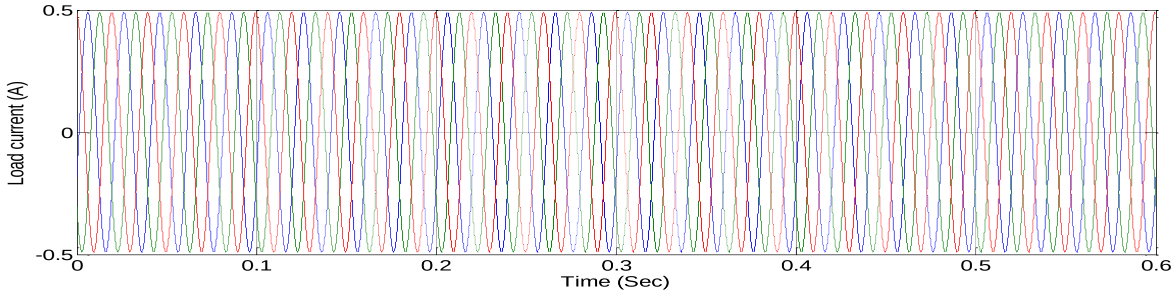

Fig-1 Load current

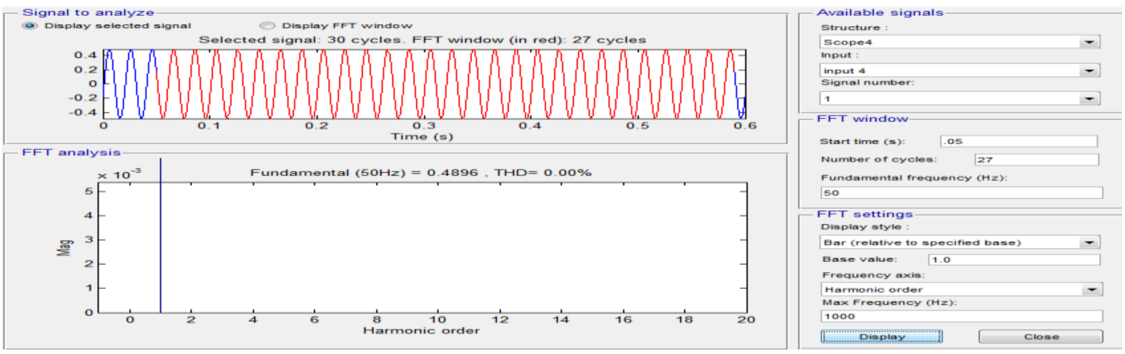

Fig-14 Load current

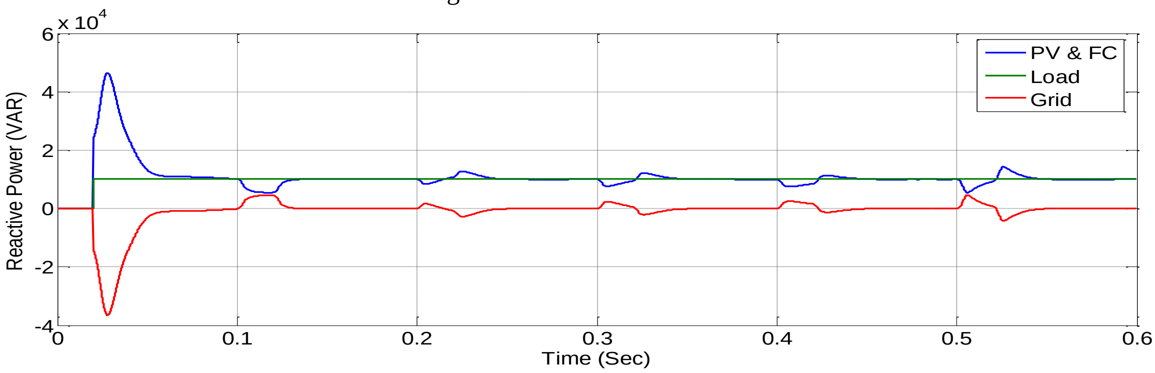

Fig-15 Reactive power

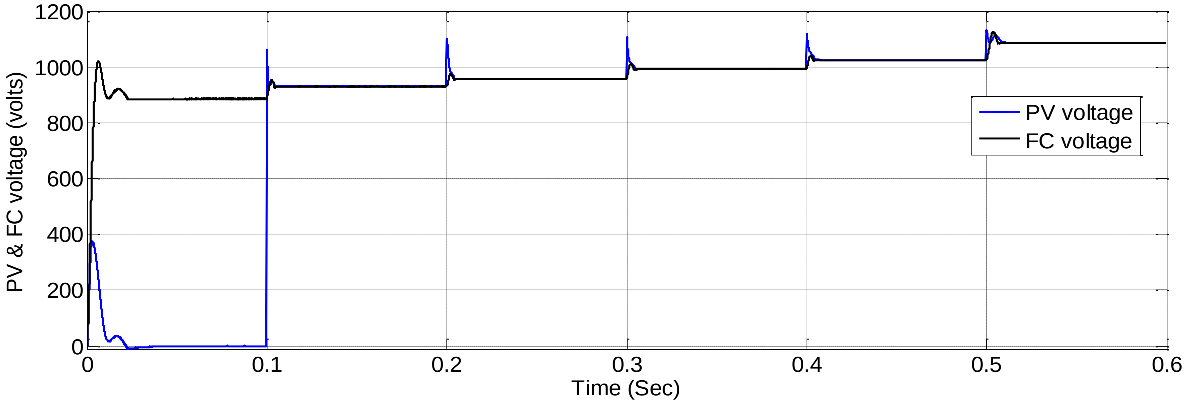

Fig-16 DC link Voltage

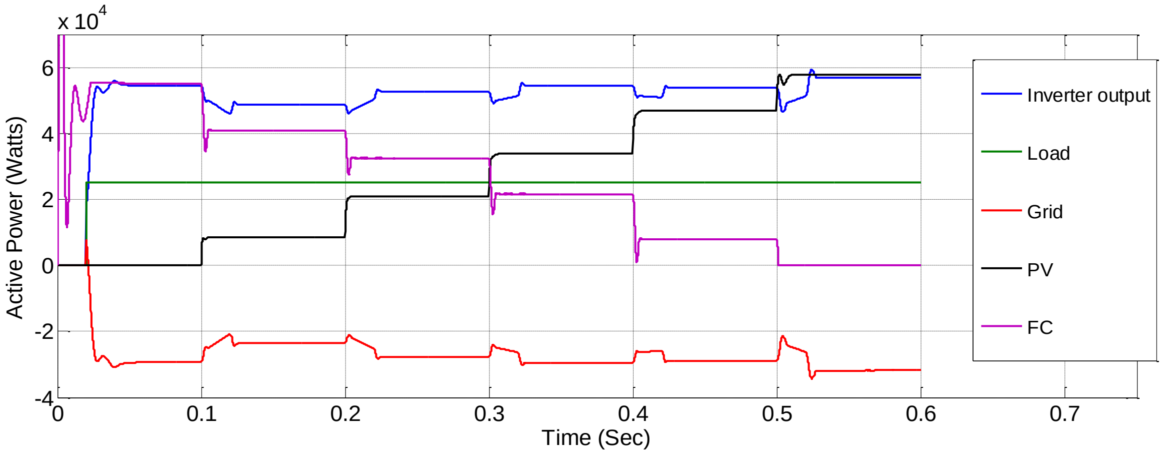

Fig-17 Active power

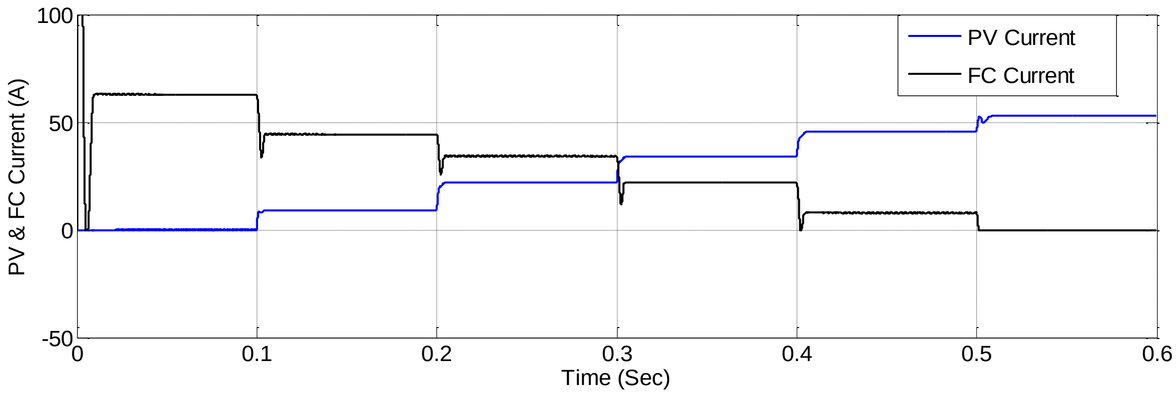

Fig-18 DC Current of PV and FC

X. Conclusions

This paper has presented PV and FC hybrid system in such a manner that local load completely supplied through renewable energy sources and extra power supplied to grid. A constant power supplied from through hybrid system with variable solar irradiations. To extract maximum power from PV module data based MPPT technique is implemented. Active power flow control approach for a single distributed generation unit connected to the utility grid with a local load. Control technique uses Parks transformation. Reactive power is supplied as required by local load or grid. Passive filter is implemented in order to reduce maximum possible harmonic produce by inverter. Interconnected system's grid current THD is bellow the permissible limit as per the IEEE 519-1992 recommended limits (< 5%). The proposed scheme is implemented in MATLAB Simulink software, tested and good results are obtained.

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