Research Article

An innovative correlation of PV and Fuel cell Microgrid Power generating System

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Abstract— Recently revolting centres,banks domain is the Microgrid,the intensification, declined costs, revealed involvement and evolving concession are its advantages. A Microgrid method of working is the self-sustained system which contributes power to the load unaccompanied to integrate with the utility grid. Microgrid have solicitations in faraway and unreachable places where the utilizers survive in the absence of power supply. In secluded and hinterland places the power connection is not technologically attainable,at such kind of areas microgrid meet the stipulation of these places. On the basis of the customer urge this system is composed of a Photovoltaic energy and a Solid oxide fuel cell (SOFC) energy conjointed to configure a microgrid system which is fasten to the load. The impetus of this paper is to design the components of a PVFC microgrid system needed to accomplish the electricity demand for the secluded places.This combines the improvement of small power distributed sources and also to enhance their technologies. Microgrid is an emerging technique and it This microgrid scheme manifests of distributed generators, energy storage devices, loads and interfaces. A persistant amount of power generation cannot be provided by most of the DGs so, a conventional controlling strategy is required to maintain the microgrid to operate at steady state and reliable.

Keywords- Microgrid system, Modeling of Photovoltaic energy system, Modeling of Fuel cell energy system.

1. Introduction

Non-renewable sources like the natural gas, petroleum and coal are being exhausted briskly. Apart from that they cause problems of greenhouse effect and pollution which will pose adverse effect on environment. In recent decades renewable energy sources are enchanting high contemplation as an substitute energy sources. Out of all the accessible renewable energy sources, extensively pre-owned mainly in low energy utilization are the Photovoltaic (PV) energy. Photovoltaic source of energy transforms the solar energy without any intermediary into electrical energy. Photovoltaic energy sources have a plenty of expedience which is inadequate and pollution less. They are replacing electricity generators from other generating ways.Most of the places , the oscillating capability of solar energy that are entirely PV power generators for inconspicuous grid utilization were enormous and also expensive. To overcome this problem, one of the method is to assimilate the photovoltaic system with other energy systems such as fuel cell (FC), or battery source as a backup. The diesel source can be utilized as a backup source along with the PV energy to have a continuous supply of power to the consumers. But it has its drawbacks such as noise and exhaustible gases pollution emitted from it. Apart from that, the diesel back-up sources are available for limited power range may be above 5kW, which is immense for some sort of the implementations.

A very promising source as backup power supply is the fuel cell energy system which can be utilized with an alternative generating source like PV source as the fuel cell system has numerous prominent characteristics like efficiency, fastest response and fuel affability. To resolve the innate problem of infrequent power generation, this fast reacting capacity of the fuel cell power system, a photovoltaic-fuel cell (PVFC) microgrid system can be incorporated.

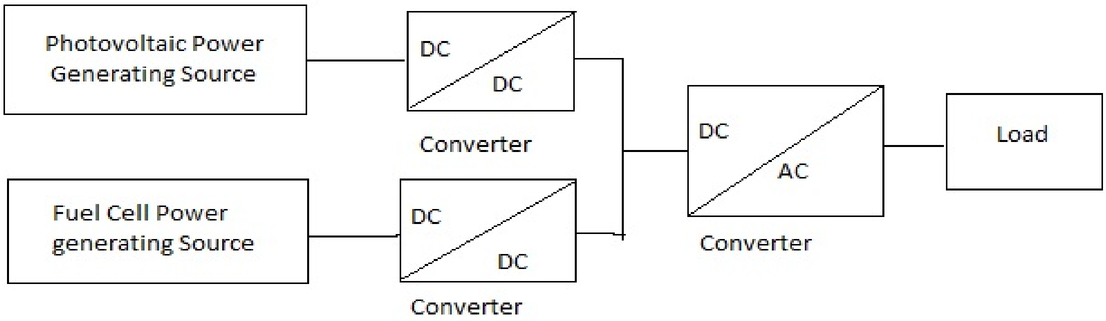


Figure 1. Block diagram of Microgrid System

A high aspect power generated from the PVFC micro system is obtained for 24 hours. In conjunction to available other fossil fuels the environmental influence of the fuel cell power generation are analogously compact in disparity to other fossil fuels. It requires less sulphur content fuel due its chemical reactions in interior of the fuel cell mass are virtuoso by catalysts. The less outrush proficiency of the fuel cell power system allows some uses to counterbalance the costs of positioning and other emission control appliances.

2. Introduction to microgrid

Microgrid systems that utilizes more than a single power source can considerably intensify the conviction of load demand.Increasing production capabilities can be attained by microgrid system. In self governing system we are free to dispense variation less output to the load.All these benefited the enhancement of the microgrids.In further sections this will be demonstrated in depth.

A. Photovoltaic Energy System

It is the most promising source of renewable energy and its schemes are extremly classified as either passive solar or active solar depends on how it apprehends and dispense solar energy or change it into solar power. Active solar techniques incorporate the usage of photovoltaic systems, concentrated solar power to strap the energy,where as the Passive solar techniques inculcate intending a building to the Sun, and sorting out materials with approving thermal light disseminating properties, and conniving capacity that naturally spread air.The individual PV cell arrangement is shown in the figure.

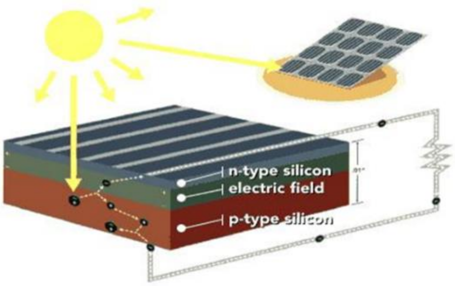


Figure . 2 Module of PV Cell

B. Fuel Cell Energy System

An enhanced fuel cell is that which consisting of an electrochemical cell that metamorphoses the chemical energy of a fuel (often hydrogen) and an oxidizing agent (often oxygen) into electricity with the utilization of a pair of redox reactions.Unlike that of the batteries the fuel cells are unique which requires a continuous source of fuel and oxygen (usually from air) to sustain the chemical reaction, whereas in a battery the chemical energy usually comes from metals and their ions or oxides that are often that inbuilt in the batteryThe ability of the fuel cells cancontinuously produce electricity until the fuel and oxygen are provided.

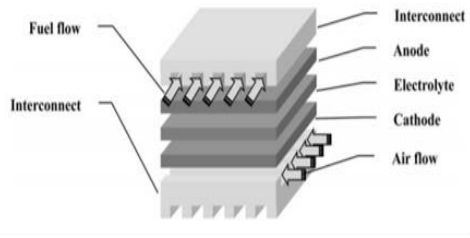


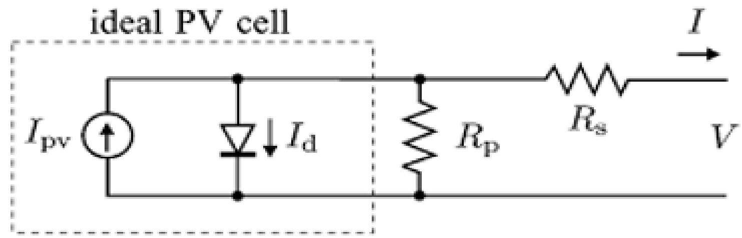
Figure 3. Representation of Fuel cell with layer arrangement

The principle of working of SOFCs are formed which depends on the oxygen pressure and mainly the distinctive between the cathode and anode sides. In the air the level of oxygen is about 21% which was contributed at the cathode, on the other side of the anode, in order to acquire oxygen at very low pressure, is supplied by fuel, which employes the negatively charged oxygen ions conveyed from the cathode through the electrolyte to the anode. In the negatively charged surplus oxygen ions are enternched back to the cathode side of the SOFC through an electrical circuit accomplished between anode and cathode electrodes, ensuing in an electrical current path in the circuit. Oxidation of fuel is attained in the level of oxygen pressure on the anode side at 10−16 Pa, evolving about a voltage of 1 V from a single cell.Apart from this,fuel cell doesnot pollute the environment.

3. Modeling of power generating sources

A. Modeling of PV system

By the working principle,the photovoltaic system can transform the sunlight radiation in to electricity without any calamitous effect on the environment. The rudimentary section of PV array is the PV cell, nothing but unadorned p-n junction device.The equivalent circuit of PV cell is demonstrated in the figure shown. The circuit represents a current source which is basically a photocurrent, a diode which is connected parallel to it, a resistor in series which resembles an internal resistance for the purpose of the flow of current and a shunt resistance which reveals a leakage current. The current which is contributed to the load is given as



$$I = I_{PV} - I_0[\exp((V+IR_S)/(AV_T)) - 1] - (V + IR_S)/R_P \quad (1)$$

I_{PV}= light generated current or photo current

I_0 = cell saturation of dark current

A– Ideality factor
V- Voltage across the diode
V_T –Thermal voltage
A = ideal factor
R_P = shunt resistance
R_S= series resistance

Figure .4 . Equivalent circuit of PV cell

PV cell photocurrent depends on the radiation and temperature, and it can be expressed as

$I_{PV} = (I_{PV\_STC} + K_1\Delta T)G/G_{STC}$ (2)

Where

K_1 = Temeperature coefficient of cells short circuit current

G= solar irradiation in W/m^2

G_{STC} = nominal value of solar irradiation in W/m^2

I_{PV_STC} = Radiation generated current under standard test

The reverse saturation current varies as a cubic function of temperature, which is expressed as
On the other hand, the cell's saturation current varies with the cell temperature which is described as

$$I_O = I_{O\_STC}\left(\frac{T_{STC}}{T}\right)^3 \exp\left[\frac{qE_g}{aK}\left(\frac{1}{T_{STC}} - \frac{1}{T}\right)\right] \quad (3)$$

I_{o_STC} = nominal saturation current

E_G = Energy band gap of semiconductor

T_{STC} = cell's reference temperature

T = cell's working temperature

q= charge of electrons

This model is composed of a lightgenerated current source, two diodes, a series resistance and a parallel resistance.In general, the PV efficiency is insensitive to variation in R_P and the shunt-leakage resistance can be assumed to approach infinity without leakage current to ground. On the other hand, a small variation in R_S will significantly affect the PV output power.As a function of temperature improved reverse saturation current can be expressed as

$$I_O = \frac{\left(I_{SC\_STC} + K_I\Delta T\right)}{\exp\left[\frac{\left(V_{OC\_STC} + K_V\Delta T\right)}{aV_T}\right] - 1} \quad (4)$$

I_{SC_STC}- short circuit current at standard test condition

V_{OC_STC}– short circuit voltage at standard test condition

K_V– temperature coefficient of open circuit voltage

B. Modeling of Fuel cell

In Solid oxide fuel cell each single cell consists of four layers which are stacked together which was about of only a few millimeters thickness.Then hundreds of these cells are connected in series to configure as "SOFC stack".In the ceramics used in SOFCs the ceramics which are used do not set off electrically and ionically active till they reach very high tem1perature and has results , these stack has to maintain at temperatures flutuating from 500 to 1,000 °C. Depletion of oxygen into oxygen ions come about at the cathode.These ionic diffusion through the solid oxide electrolyte to the anode where the electrochemical oxidization of the fuel can be obtained. In this process, the water as the byproduct is emanated along with the two electrons.

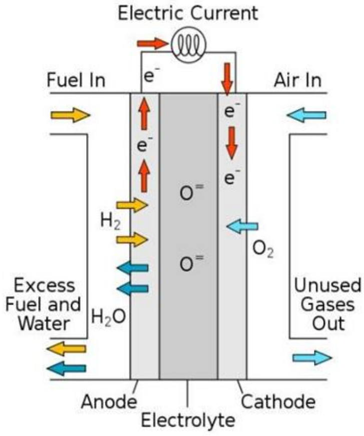


Figure .5 Representation of SOFC

In a fuel cell, anode is also represented as 'fuel electrode'; as the fuel is provided to the system through this electrode. Where the hydrogen fuel amalgamates with the oxygen ion at the electrolyte interface, anode reaches the reduction environment at very high temperatures 973-1273K.The cathode is setoff at 1273 K in an oxidizing environment either air or oxygen and also comes up with the oxygen reduction reaction. With the aid of cathode catalyst and other two electrons appearing from the external circuit, cathode and electrolyte interface oxygen/air is reduced to oxygen ions. The main component in the solid oxide fuel cell is the electrolyte. Therefore, the entire composition of the fuel cell elucidates the quality of the oxide electrolyte material.

The relationship between the molar flow of any gas (hydrogen) through the valve and its partial pressure inside the channel can be expressed as

$$q_{H2}/P_{H2}=K_{an}/\sqrt{M_{H2}} \tag{5}$$

For hydrogen molar flow, there are three significant factors: hydrogen input flow, hydrogen output flow and hydrogen flow during the reaction. The relationship among these factors can be expressed as

$$\text{d/dt}(P_{H2}) = \text{RT}/V_{an}(q_{H2}^{in}-q_{H2}^{out}-q_{H2}^{r}) \tag{6}$$

According to the basic electrochemical relationship between the hydrogen flow and the FC system current, the flow rate of reacted hydrogen is given by

$$q_{H2}^{r} = N_O I_{FC}/2\text{F} = 2\text{Kr}I_{FC} \tag{7}$$

Using Equation (6) and (7) and applying Laplace's transform, the hydrogen partial pressure can be obtained in the s domain as

$$P_{H2} = 1/K_{H2}/1+\tau_{H2}\text{S}\ (q_{H2}^{in}-2\text{Kr}I_{FC}) \tag{8}$$

Where $\tau_{H2} = V_{an}/K_{H2}\text{RT}$ (9)

Similarly, the water partial pressure and oxygen partial pressure can be obtained. The polarization curve for the SOFC is obtained from the sum of Nernst's voltage, the activation over voltage and the ohmic over voltage. Assuming constant temperature and oxygen concentration, the FC output voltage may be expressed as

$$V_{cell} = \text{E}+\eta_{act}+\eta_{ohmic} \tag{10}$$

$$\eta_{act} = -\text{Bln}(\text{C}I_{FC}) \tag{11}$$

$$\eta_{ohmic} = -R_{int}I_{FC} \tag{12}$$

Now, the Nernst's instantaneous voltage may be expressed as

$$\text{E} = N_O[E_O+\text{RT}/2\text{Flog}\ (P_{H2}\sqrt{P_{o2}}/P_{H2o})] \tag{13}$$

The fuel cell system consumes hydrogen according to the power demand. The hydrogen is obtained from a high pressure hydrogen tank for the stack operation. During operational conditions, to control the hydrogen flow rate according to the FC power output, a feedback control strategy is utilized. To achieve this feedback control, the FC current from the output is taken back to the input while converting the hydrogen into molar form. The amount of hydrogen available from the hydrogen tank is given by

$$q_{H2}^{req} = N_0 I_{FC}/2FU \tag{14}$$

Depending on the FC system configuration and the flow of hydrogen and oxygen, the FC system produces the dc output voltage.

TYPES OF BOODT CONVERTERS

Basically a boost converter acts a switching mode DC to DC converter by which the output voltage is higher than the given input voltage which resembles as step up converter. Since $V_{in} < V_{out}$ in a boost converter, then that the output current can be less than the input current. Therefore in a boost converter the relationship is given as $V_{in} < V_{out}$ and $I_{in} > I_{out}$

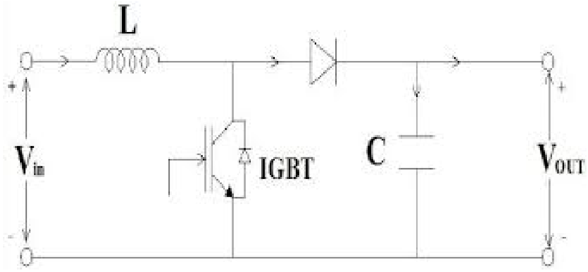


Figure .6 Boost converter schematic diagram

A. Working Principle of Boost Converter

The operating principle that strives the boost converter is the propensity of an inductor to oppose changes occurring in current by disrupting magnetic field. The output voltage is always greater than the input voltage in a boost converter.

- The operating mode when the switch is in closed position,the current flow in the inductor will be in the clockwise direction and by enhancing the magnetic field in the inductor,which stores energy by generating a magnetic field. Polarity of the left side of the inductor is positive polarity as indicated.
- In the second mode of operation that is the switch is opened, as the impedance is large the current tends to reduce. To sustain the current intended to the load, the magnetic field in turn produced before will be annoyed accordingly. As the polarities getting reversed, the polarity at the left side of the inductor is negative. Consequently the two sources will be in series giving raise to a higher voltage which charges the capacitor through the diode D.

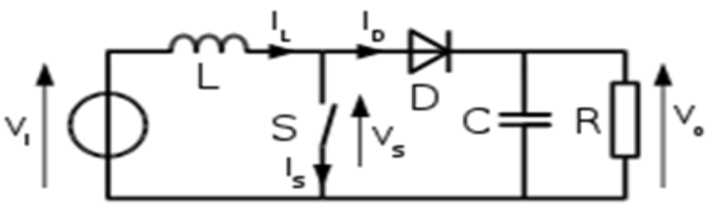


Figure .7 Circuitry diagram

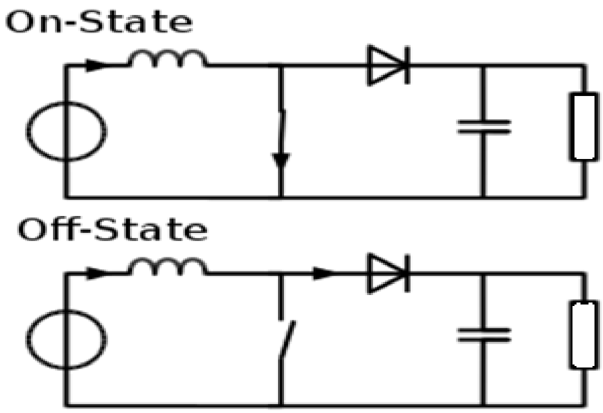


Figure .8 Two modes of switching operation

B. Continuous Mode

When a boost converter operates in continuous mode of operation of a boost converter, it resembles that the current through the inductor (IL) never distorted to zero.

Under the steady state condition, after every cycle the inductor the inductor goes back to the same state as the voltage is proportional to the rate of change of current and the DC (average) voltage across the inductor must be zero. The average value of V_S is (1-D)* $V_{O,}$ where D is known the duty cycle. By this we can extract the ideal transfer function.

$$V_i = (1-D)^* \; V_0 \;\text{ or }\; V_0/\,V_i = 1/\,(1-D) \qquad (15)$$

- when the switch S is closed in the ON state, which fuses the input voltage (Vi) to arrive across the inductor, which tends to a change in current (IL) which allows through the inductor in the time period (t) given by the formula

$$\frac{\Delta\, I_L}{\Delta t} = \frac{V_i}{L} \qquad (16)$$

L is the inductance value

In the ON state the increased value of I_L

$$\Delta I_{Lon} = {}^{1}/_{L} \int_0^{DT} V_i\, dt = \frac{DT}{L}\; V_i \qquad (17)$$

- When the switch S is open in the OFF state, makes the current flow through the inductor and so flows through the load. If we consider zero voltage drop in the diode, and a capacitor large enough for its voltage to remain constant, the value of I_L is

$$V_O - V_i = L\frac{dI_L}{dt} \qquad (18)$$

the value of I_L during the Off-state

$$\Delta I_{Loff} = \int_{DT}^{T} (V_i - V_o)\, dt\, /L = (V_i - V_o)\,(1\text{-}D)T/L \qquad (19)$$

Under steady state condition the energy stored in the inductor is given by

$$E = \frac{1}{2} L I_L^2 \qquad (20)$$

The overall change in current is given as and assuming the sum of the changes to be zero

$$\Delta I_{Lon} + \Delta I_{Loff} = 0 \qquad (21)$$

Substituting ΔI_{Lon} and ΔI_{Loff} gives the expression

$$\Delta I_{Lon} + \Delta I_{Loff} = \frac{V_i DT}{L} + (V_i - V_o)\,(1\text{-}D)\,T/L \;= 0 \qquad (22)$$

Rewritten as

$$\frac{V_o}{V_i} = \frac{1}{1-D} \qquad (23)$$

Rearranging the equation the duty cycle become

$$D = 1 - \frac{V_i}{V_0} \tag{24}$$

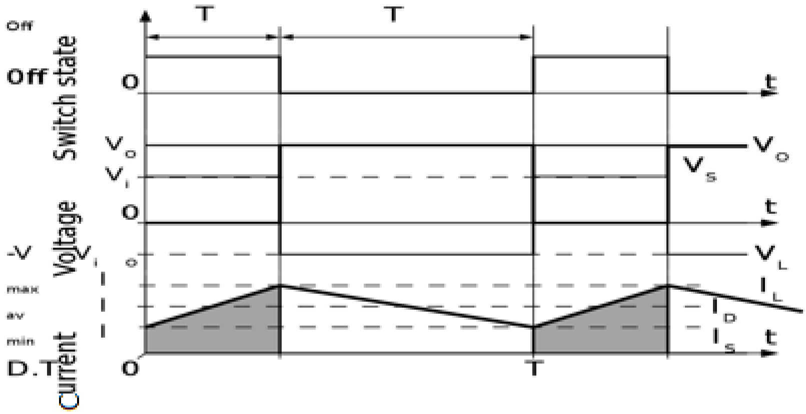


Figure. 9 continuous mode boost converter waveforms

C. Discontinuous Mode

In this mode of operation, the current through the inductor falls to zero during certain period of time . Even though the variation is small,it impacts a strong effect on the output voltage equation. The voltage gain can be calculated as

As the inductor current at the beginning of the cycle is zero, its maximum value I_{Lmax} (at t = DT)

$$I_{Lmax} = \frac{V_i DT}{L} \tag{25}$$

I_L falls to zero after δT

$$I_{Lmax} + (V_i - V_o)\,\delta T / L = 0 \tag{26}$$

Using the above two equations, δ is

$$\delta = \frac{V_i D}{V_0 - V_i} \tag{27}$$

The average diode current (I_D) is equal to the load current I_O,during the off state condition the diode current is equal to the inductor current.The average value of I_o can be demonstrated,further the output current can be manifested as

$$I_O = \bar{I}_D = \frac{I_{Lmax}}{2}\,\delta \tag{28}$$

Rearranging the I_{max} and δ by their expressions

$$I_O = \frac{V_i DT}{2L} \cdot \frac{V_i D}{V_0 - V_i} = \frac{V_i^2 D^2 T}{2L(V_o - V_i)} \tag{29}$$

the output voltage gain can be expressed as

$$\frac{V_o}{V_i} = 1 + \frac{V_i^2 D^2 T}{2L I_o} \tag{30}$$

When the equation in the continuous mode of operation is correlated then the output voltage gain, this expression is much more convoluted. In discontinuous mode of operation, the output voltage gain not only depends on the both the parameters one is duty cycle (D), and the other is inductor value (L), the input voltage (V_i), the commutation period (T) and the output current (I_o).

Substituting $I_o = V_o/R$ into the equation where the value R is the load, the output voltage gain can be valuated as

$$\frac{V_o}{V_i} = \frac{1 + \sqrt{1 + \frac{4D^2}{K}}}{2} \tag{31}$$

where $K = \frac{2L}{RT}$

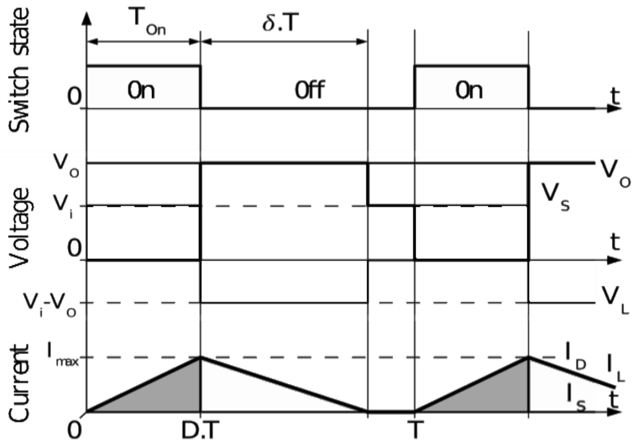


Figure. 10 Discontinuous mode boost converter waveform

4. Simulink models

A. Simulink Model when only PV system is presented

For the modelling of Simulink model of PV system the design parameters used are

IGBT:-

Resistance Ron=0.001Ω
Inductance Lon=0 H
Forward voltage V_f =1 V
Current fall time T_f=1e-6
Current tail time T_t=2e-6
Initial current I_c=0
Snubber resistance R_s=1e5
Snubber capacitance C_s=1nF

DIODE:-

Resistance Ron=0.001Ω
Inductance Lon=0 H
Forward voltage V_f =0.8 V
Initial current I_c=0
Snubber resistance R_s=500 Ω
Snubber capacitance C_s=250e-9

UNIVERSAL BRIDGE:-

Number of bridge arms=3
Snubber resistance R_s=1e5 Ω
Snubber capacitance C_s=inf
Power electronic device=igbt/diode
Resistance Ron=1e-3Ω
Forward voltage V_f =0 V
Current fall time T_f=1e-6
Current tail time T_t=2e-6

THREE PHASE RLC LOAD:-

Configuration=Y(grounded)
Nominal phase-to-phase voltage V_n=380(rms)

Nominal frequency f_n=50 Hz
Active power P=10e3W
Inductive reactive power Q_L=0
Capacitive reactive power Q_c=0

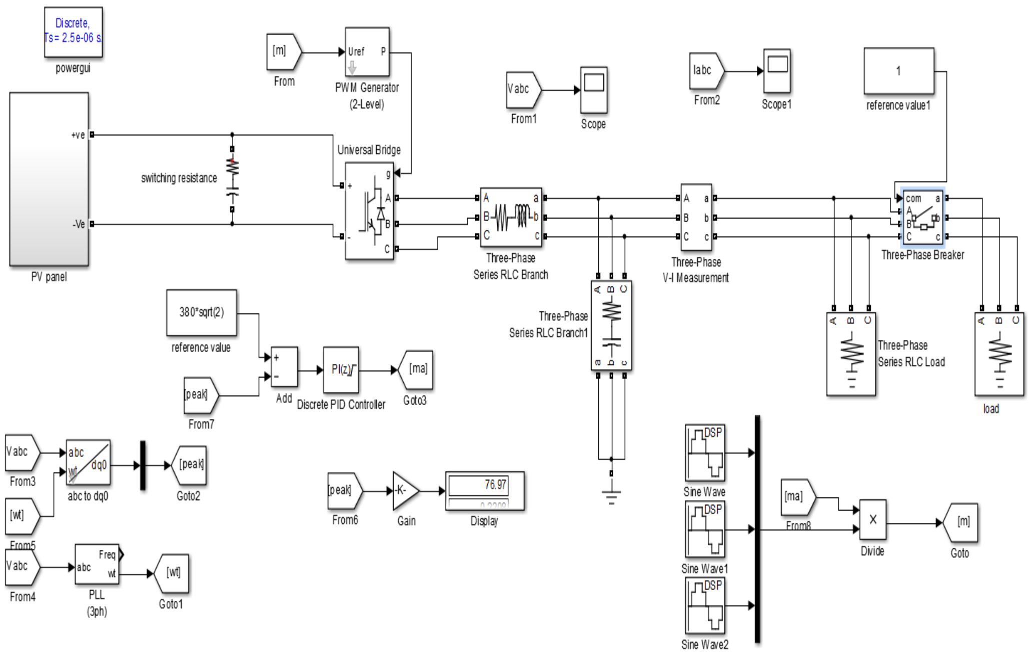


Figure . 11 Simulink design of PV system

B. Simulink design of only Fuel cell system is presented

For the modelling of Simulink model of Fuel cell system the design parameters incorporated are

<u>IGBT:-</u>

Resistance Ron=0.001Ω
Inductance Lon=0 H
Forward voltage V_f =1 V
Current fall time T_f=1e-6
Current tail time T_t=2e-6
Initial current I_c=0
Snubber resistance R_s=1e5
Snubber capacitance C_s=1nf

<u>DIODE:-</u>

Resistance Ron=0.001Ω
Inductance Lon=0 H
Forward voltage V_f =0.8 V
Initial current I_c=0
Snubber resistance R_s=500 Ω
Snubber capacitance C_s=250e-9

<u>THREE PHASE RLC LOAD:-</u>

Configuration=Y(grounded)
Nominal phase-to-phase voltage V_n=380(rms)
Nominal frequency f_n=50 Hz
Active power P=10e3W
Inductive reactive power Q_L=0

Capacitive reactive power Q_c=0

FUEL CELL MODEL:-

Absolute temperature k=1273
Initial current A=100
Faradays constant =96.48e6 c/kmol
Universal gas constant K=8314 J/Kmol
Ideal standard potential v=1.18
Number of cell in series=450
Maximum Fuel utilization=0.9
Minimal fuel utilization=0.8
Optimal fuel utilization=0.85
Value molar constant for hydrogen =8.43e-4kmol/s atm
Value molar constant for water=2.81e-4 kmol/s atm
Value molar constant for oxygen=2.52e-3 kmol/s atm
Response time for hydrogen=26.1 s
Response time for water=78.3 s
Response time for oxygen=2.91 s
Ohmic loss per cell=3.2813e-004 ohms
Electrical response time=0.8 s
Fuel processor response time=5 s
Ration of hydrogen to oxygen=1.145

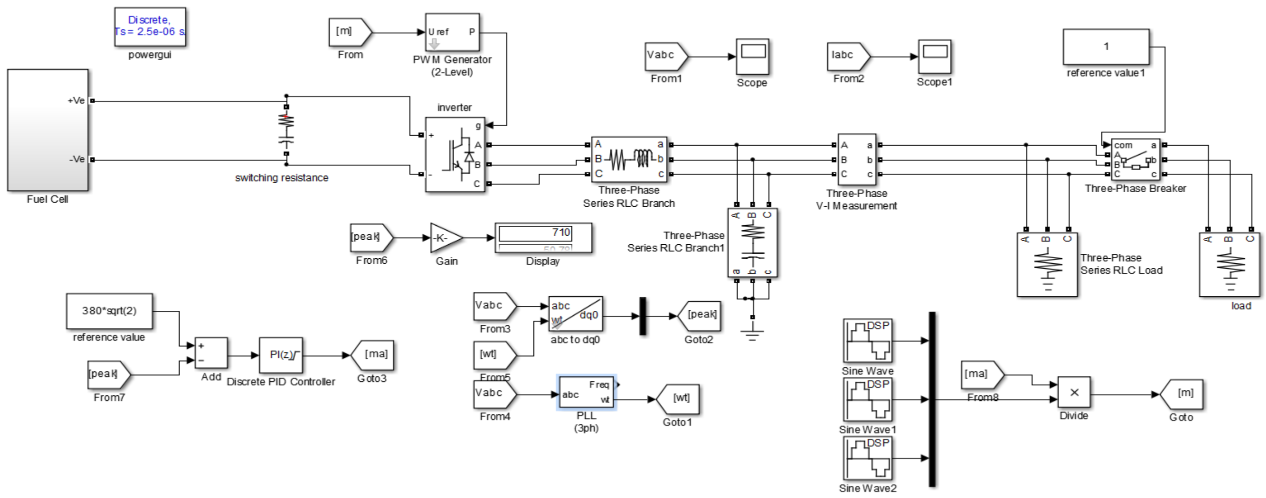


Figure. 12 Simulink design of Fuel cell system

C. Simulink design of Integrated Microgrid system

The absolute microgrid model is acquired by incorporating the PV system and FC system in conjunction and the prior mentioned blocks and their parameters the same are employed here. The integrated model of solar and fuel cell microgrid system is as shown in figure.

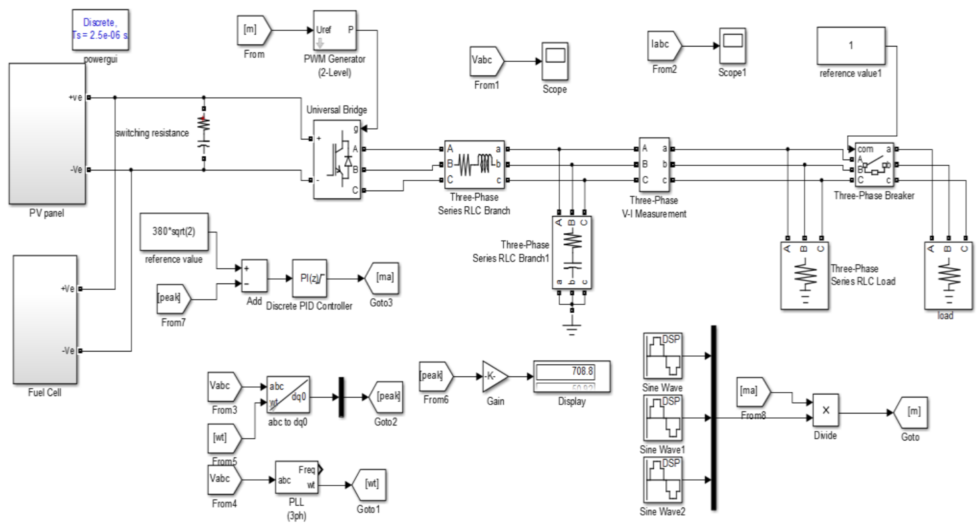


Figure 13.Simulink design of integrated PV and Fuel cell Microgrid system

RESULTS

The below figure demonstrates the output values when only PV source is incorporated.

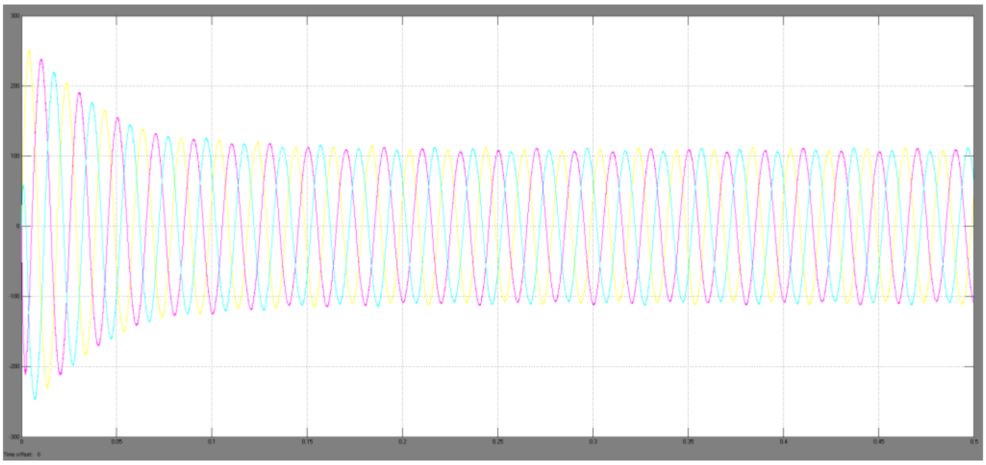


Figure . 14 output voltage of PV system

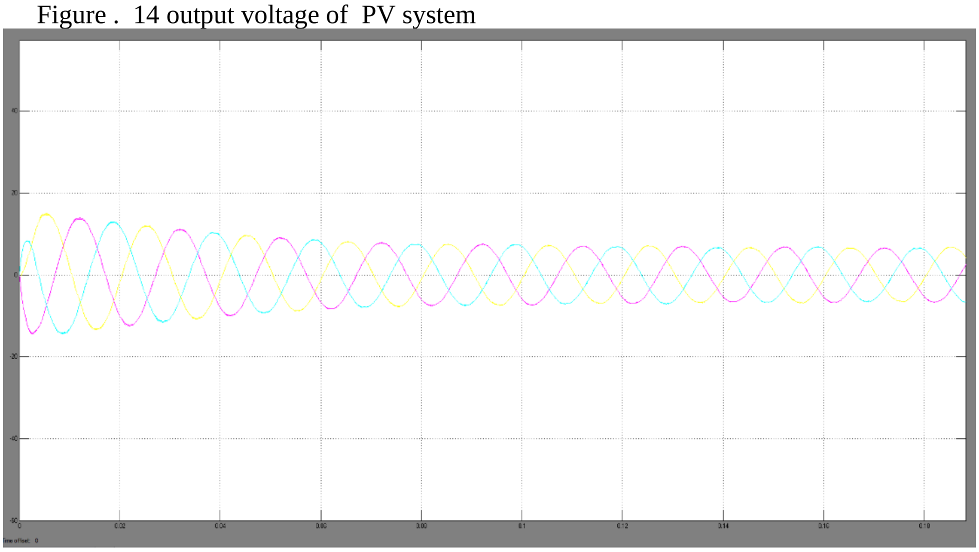


Figure . 15 output current of PV system

The mentioned figures are correlated when only Fuel cell system is present

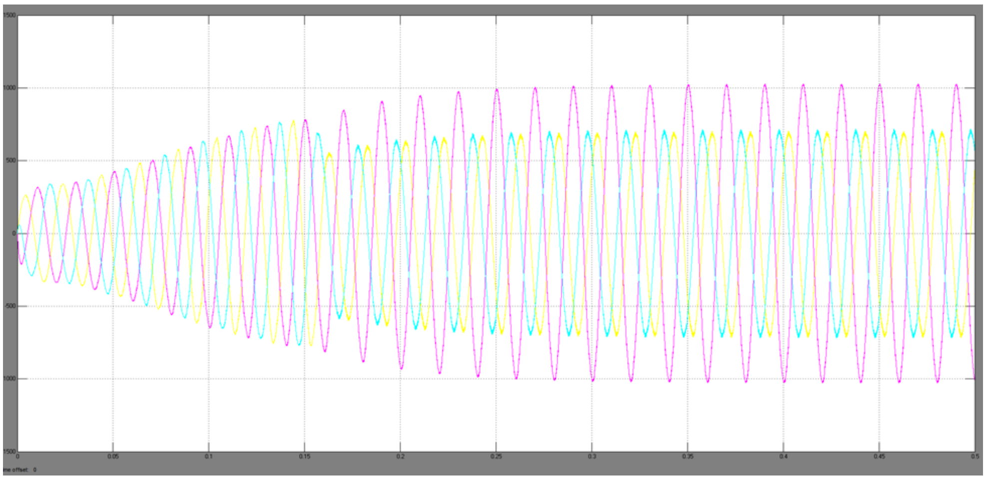


Figure 16. output voltage of Fuel cell system

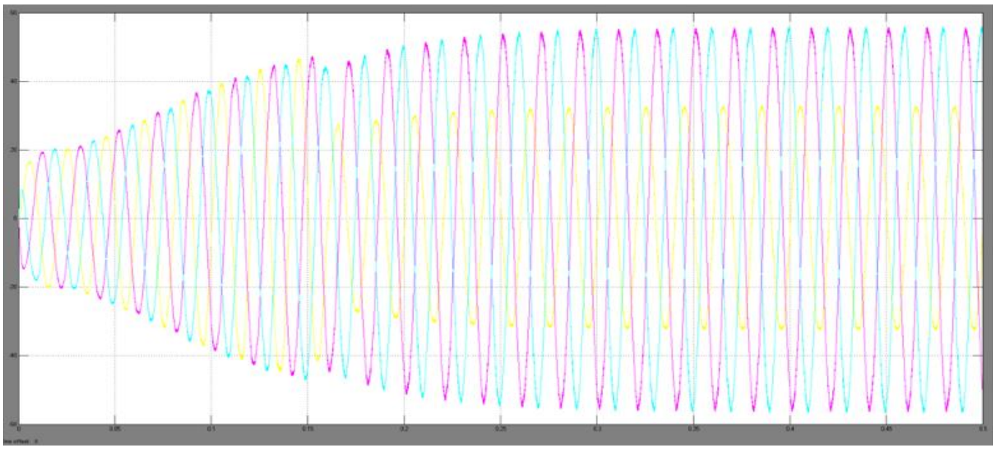


Figure .17 output current of fuel cell system

The design implements the PV power generating source and Fuel cell collectively forming the enhanced Microgrid system.

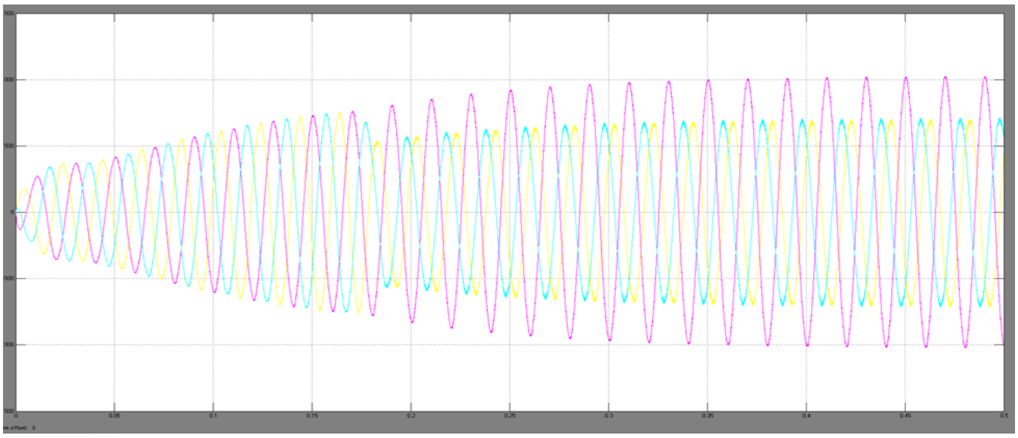


Figure.18 output Voltage of the enhanced Microgrid system

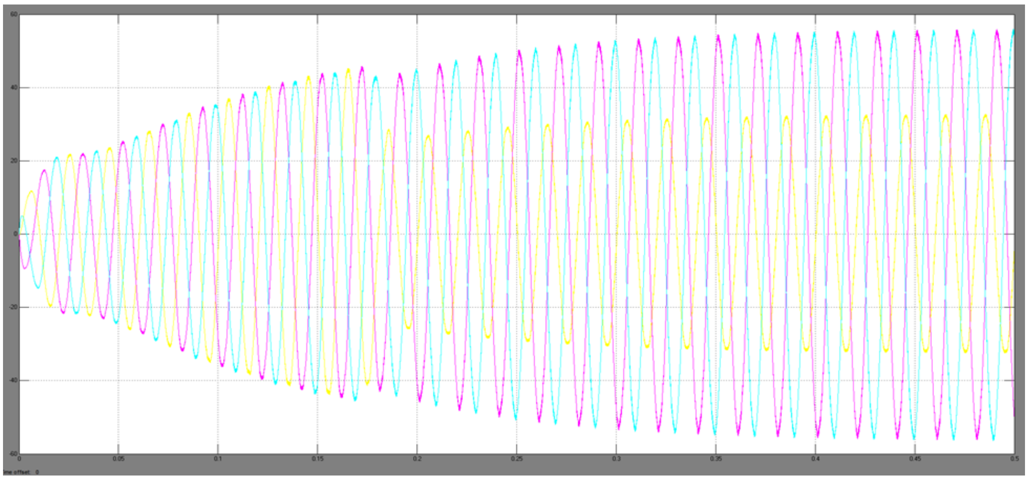


Figure.19 output current of enhanced Microgrid system

5. Conclusion

As illustrated the PV- fuel cell microgrid power system is designed and modelled for a grid-unconstrained consumer with fascinated power flow controllers. The generated power from the renewable energy sources is exceedingly contingent on influencing conditions such as intensity of solar energy. To enhance this inacdequency of the solar system, we unify photovoltaic generator with the fuel cell system using a distinct manifestations.The purpose of this paper is to modelling and simulation of an autonomous microgrid power system, manifested as "Photovoltaic-Fuel Cell (PVFC) microgrid system". This topology exhibits magnificent proficiency to any kind of variance in the solar radiation and consumer power requirements. This model system can be used for non-interconnected secluded areas.

The demonstrated Photovoltaic and Fuel Cell microgrid generating system model is accomplished using Matlab/Simulink simulation Interface and attended to acquire result which are furnished. The DC-DC boost converter is also manifested and the results are obtained from the converter with constant DC input supply and by interconnecting the PV system module with it. The results which are manifests the closest relation between the output of converter with constant DC input and the PV fed converter. The output voltage and current of the PV fed DC-DC boost converter obtained for according to the effect of irradiation at constant temperature is accomplished. Inverter model was used for interfacing SOFC and PV source to the utility system.

6. Future scope

To enhance the performance of PVFC microgrid systems, the following recommendations for the future work are mentioned here. The possibility of the suitable conceptualization should be based on the type of application, adding other renewable sources such as a wind turbine to the system. A wind energy conversion would reduce the required PV generator area, and reduce the hydrogen storage volume.

A practical limitation on the system design is the voltage operating range of the available power conditioning units, which are designed mainly for lead-acid batteries rather than fuel cells or super capacitors. Thus, designing a new power conditioning units and new innovative extended controllers that can match the characteristics of these components is recommended and also to enhance the reliability and optimization techniques summarizing based on the future demand. In hydrogen PVFC microgrid system without battery energy storage, such as in this work, the annual numbers of the on and off switching of the electrochemical components and also the annual operating times of these components are large.

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