Multi Input Converter for Distributed Renewable Energy Sources

Mr.K.Saravanan and Dr. H. Habeebullah Sait

ABSTRACT: In renewable energy sources, such as wind, solar energy, the generated voltages often vary because of environmental changes. A hybrid distribution system fed by photovoltaic (PV) and fuel cell (FC) is proposed. It works to feed the load without any interuption.PV is used as the primary source of power operating near maximum power point (MPP), with the FC section, acting as a current source, feeding only the deflict power. The multi input converter eliminates the use of a separate conventional DC/DC boost converter stage required for PV power processing, resulting in reduction of the number of devices, components and sensors. The generated power is fed to the load and battery. In case of power demand battery is used to compensate the load. The other advantages of this system include low cost, compact structure and high reliability. The analytical, simulation and results of this research are presented.

Key Word: Hybrid Power System (HPS),Solar cell (PV),Maximum power point (MPP),Multi input converter (MIC),Fuel cell (FC),lead acid battery and pulse width modulation(PWM).

1. INTRODUCTION:

With increasing concern of global warming and the depletion of fossil fuel reserves, many are looking at sustainable energy solutions to preserve the earth for the future generations. Other than hydro power, wind and photovoltaic energy holds the most potential to meet our energy demands. Wind energy alone is capable of supplying large amounts of power but its presence is highly unpredictable as it can be here one moment and gone in another. Similarly, solar energy is present throughout the day but the solar irradiation levels vary due to sun intensity and unpredictable shadows cast by clouds, birds, trees, etc. The common inherent drawback of wind and photovoltaic systems are their intermittent natures that make them unreliable. So, the number of applications which need more than one power source is increasing. Fuel cell is used to overcome this. Distributed generating systems or micro-grid systems normally use more than one power source or more than one kind of energy source. A parallel connection of converters has been used to integrate more than one energy source in a power system.

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2. NEED FOR MULTIPLE CONVERTER SYSTEM:

In most power electronic systems, input power, output demand, or both instantaneously change and are not exactly identical with each other at any time instant. Hence, providing a good match between them is a complicated task to deal with if not impossible. Furthermore, due to the wide variation of processed power, overall efficiency of the system is not high. Hence, additional energy sources are required to assist the main source in fulfilling the load demand. Hence multi-input converter play an important role due to power demand.

2.1 MULTI INPUT CONVERTERS (MIC):

Placing converters either in parallel or series results in use of more number of components, more losses, and less efficiency. Hence, use of a single multi-input converter is preferred to using several multiple converters. One approach of deriving multi-input converters is using the principle of flux additivity . In this type of systems, energy sources are combined in the magnetic form by adding up their produced magnetic flux together in the magnetic core of the coupled transformer instead of combining them in the electric form.

However,a multiple-input converter (MIC) can generally have the following advantages compare to a combination of several individual converters. They are cost reduction, compactness, more expandability and greater manageability. First, this study suggests MIC topology comparison criteria that can be used as a decision guide for choosing a MIC topology depending on the application. The above said converters gives a brief introduction about their topologies, connections and consideration for using multi-input converters.

3. RENEWABLE ENERGY:

3.1 SOLAR:

Solar power is the conversion of sunlight into electricity, either directly using photovoltaic (PV), or indirectly using concentrated solar power (CSP .Photovoltaic convert light into electric current using the photoelectric effect. Photovoltaic were initially used to power small and medium-sized applications, from the calculator powered by a single solar cell to off-grid homes powered by a photovoltaic array. Solar cells produce direct current (DC) power, which fluctuates with the intensity of the irradiated light. This usually requires conversion to certain desired voltages or alternating current (AC), which requires the use of inverters. Multiple solar cells are connected inside the modules. Modules are wired together to form arrays, then tied to an inverter, which produces power at the desired voltage, and for AC, frequency/phase. Renewable energy sources are gaining more interest in recent years. Among them, photovoltaic (PV) panels, that offer several advantages such as requirement of little maintenance, no environmental pollution. Recently, PV arrays are used in many applications such as battery chargers, solar powered water pumping systems, grid connected PV systems, solar hybrid vehicles, and satellite power systems.

3.1.1 Photovoltaic Characteristic:

Solar cells have a nonlinear I/V characteristic which is dependent on the level of solar irradiation and the cell temperature. A solar cell can be accurately modeled by a current source in parallel with a diode, as illustrated in Fig. RP and RS are the shunt and series resistances representing the losses in the photovoltaic conversion process and connections to the cell respectively.

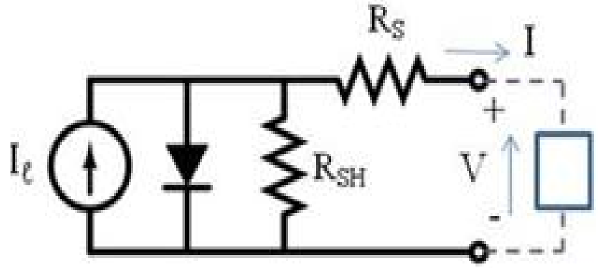

Figure. 1. Single PV Cell

$I(S,T,V)=I_{ph}(S)-I_{rs}(T)\ [\exp(V+(R_{S1}/mvt)\ -1)]$ (1)

Using the model of Figure 3. 1, the output current of a solar cell can be described in terms of the solar irradiation, cell temperature and voltage. Where S is the level of solar irradiation in W/m2, T is the solar cell temperature in Kelvin, V is the voltage across the cell in Volts and m is the dimensionless P/N junction ideality factor of the diode in the model. VT (T) is the thermal voltage for a given temperature in Kelvin, given by VT(T)=kT/q where k is the Boltzmann constant (1.39x10- 23J/K) and q is the electron charge (1.6x10-19C). RS and RP are the series and shunt resistances in Ohms. The photocurrent IPH, generated by the photovoltaic conversion process, can be expressed in terms of the solar irradiation S, a reference level of solar irradiation Sr and the photocurrent in Amps at the reference irradiation level.

$I_{pm}(S)=I_{phr}(S/S_r)$ (2)

The reverse saturation current IRS is a loss in the conversion process due to a reverse current which flows through the diode, dependent on temperature. It can be expressed in terms of the cell temperature T (K), a reference temperature T_r (K), the reverse saturation current at the reference temperature I_{rsr} (A), the band gap energy of the semiconductor used to manufacture the cell ε (1.12eV for silicon), the diode ideality factor, m, and VT and VTR which are the thermal voltages at T and TR respectively in volts.

$I_{rs}(T)=I_{rsr}(T/T_r)\exp[(S/m)((1/V_{tr})-(1/Vt)$ (3)

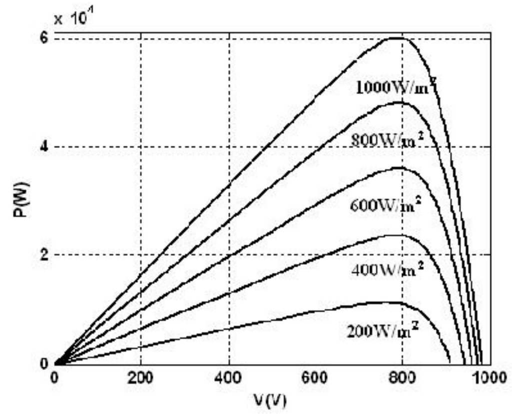

Figure. 2. Characteristics of PV

The output power of a PV cell is indeed a non linear function of the operating voltage and this function has a maximum power point (MPP) corresponding to a particular value of voltage. In order to operate at the MPP, an energy power converter must be connected at the output of a PV array, such converter forces the output voltage of the PV array is equal to the optimal value, also taking into account the atmospheric condition.

3.1.2 MAXIMUM POWER POINT TRACKING ON PV:

The maximum power point tracking (MPPT) is usually an essential part of a photovoltaic power generation system, because of nonlinear characteristics of photovoltaic array. As such, many MPPT methods have been developed and implemented. When the entire array does not receive uniform solar irradiance (i.e. partial shading condition), the multiple local maxima appear on P-V characteristic curve of PV array. Inspite of conventional popular MPPT methods (i.e. P&O, IncCond, RCC, Two-mode etc.) are effective under uniform solar irradiance, the presence of multiple local maxima reduces the effectiveness of the conventional MPPT methods

3.1.3 INCREMENTAL CONDUCTANCE:

The incremental conductance method is based on the fact that the slope of the PV array power curve is zero at the MPP, positive on the left of the MPP, and negative on the right, as given by

$dP/dV=0$, at MPP (4)

$dP/dV>0$, left of MPP (5)

$dP/dV<0$, right of MPP (6)

Since

$dP/dV=d(IV)/dV= I + V(dI/dV) =I+V(\Delta I/\Delta V)$ (7)

(can be rewritten as)

$\Delta I/\Delta V=-I/V$, at MPP (8)

$\Delta I/\Delta V>- I/V$, left of MPP (9

$\Delta I/\Delta V<-I/V$, right of MPP. (10)

The MPP can thus be tracked by comparing the instantaneous conductance (I/V) to the incremental conductance (ΔI/ΔV). Vref is the reference voltage at which the PV array is forced to operate. At the MPP, Vref equals to VMPP. Once the MPP is reached, the operation of the PV array is maintained at this point unless a change in ΔI is noted, indicating a change in atmospheric conditions and the MPP. The algorithm decrements or increments Vref to track the new MPP. The increment size determines how fast the MPP is tracked. Fast tracking can be achieved with bigger increments but the system might not operate exactly at the MPP and oscillate about it instead; so there is a tradeoff. A method is proposed that brings the operating point of the PV array close to the MPP in a first stage and then uses IncCond to exactly track the MPP in a second stage. By proper control of the power converter, the initial operating point is set to match a load resistance proportional to the ratio of the open-circuit voltage (VOC) to the short-circuit current (ISC) of the PV array. This two-stage alternative also ensures that the real MPP is tracked in case of multiple local maxima. In a linear function is used to divide the I–V plane into two areas, one containing all the possible MPPs under changing atmospheric conditions. The operating point is brought into this area and then IncCond is used to reach the MPP. A less obvious, but effective way of performing the IncCond technique is to use the instantaneous conductance and the incremental conductance to generate an error signal

$$e=I/V+dI/dV \quad (11)$$

A simple proportional integral (PI) control can then be used to drive e to zero. Measurements of the instantaneous PV array voltage and current require two sensors.

The most popular MPPT algorithms according to the number of publications are P&O, InCond and Fuzzy Logic. It makes sense because they are the simplest algorithms capable of finding the real MPP. The performance of these three algorithms is analyzed. They were selected because of their simplicity and popularity. In the case of P&O and InCond some modifications are proposed, which overcome the limitations of the original methods in tracking the MPP under irradiation slopes. The FLC is designed according to the references and its dynamic efficiency is tested and compared to the hill-climbing MPPT methods.

3.2 FUEL CELL OPERATION

The fuel cell is an electrochemical devise, which converts chemical energy of the fuel to electricity by combining gaseous hydrogen with air in the absence of combustion. The basic principles of operation of the fuel cell is similar to that of the electrolyser in that the fuel cell is constructed with two electrodes with a conducted electrolyte between them. The heart of the cell is the the proton conducting solid Proton Exchange Membrane (PEM). It is surrounded by two layers, a diffusion and a reaction layer. Under constant supply of hydrogen and oxygen the hydrogen diffuses through the anode and the diffusion layer up to the platinum catalyst, the reaction layer. The reason for the diffusion current is the tendency of hydrogen oxygen reaction.Two main electrochemical reactions occur in the fuel cell. One at the anode (anodic reaction) and one at the cathode. At the anode, the reaction releases hydrogen ions and electrons whose transport is crucial to energy production.

$$H_2 \rightarrow 2H^+ + 2e^- \quad (12)$$

The hydrogen ion on its way to the cathode passes through the polymer membrane while the only possible way for the electrons is though an outer circuit. The hydrogen ions together with the electrons of the outer electric circuit and the oxygen which has diffused through the porous cathode reacts to water.

$$2H^+ + ½\,O_2 + 2e^- \rightarrow H_2O \quad (13)$$

The water resulting from this reaction is extracted from the system by the excess air flow. The reaction is:

$$H + ½\,O_2 \rightarrow H_2O \quad (14)$$

This process occurs in all types of fuel cells.

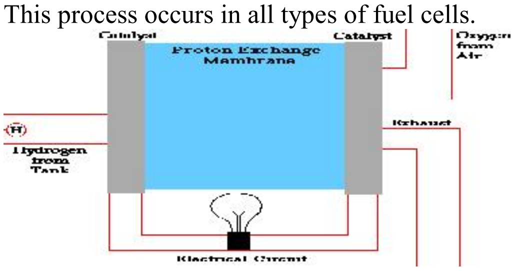

Figure .3. Fuel Cell

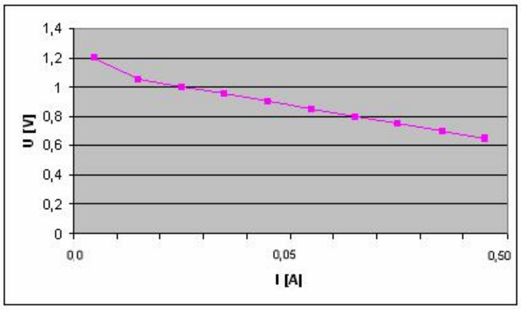

Figure .4. Voltage- Current Characteristics

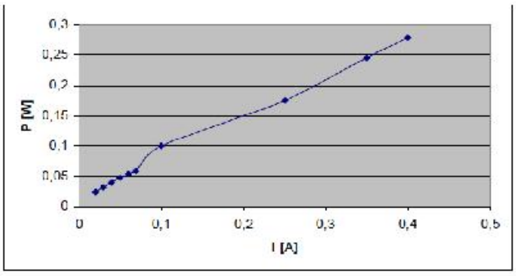

Figure .5. Power- Current Characteristics

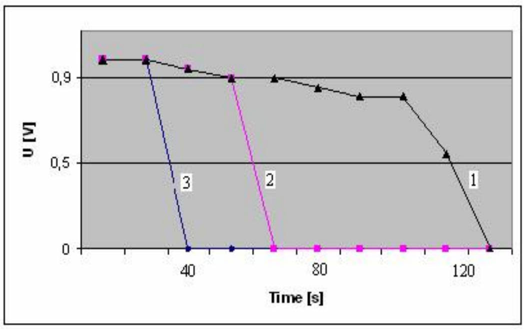

Figure .6 .Load Characteristics

4. MULTI INPUT CONVERTER FOR SOLAR CELL AND FUEL CELL

The general block diagram of the three-input dc–dc boost converter is represented in Figure 7. As seen from the Figure 7, the converter interfaces two input power sources *v*1 and *v*2, and a battery as the storage element. This converter is suitable for hybrid power systems of PV, FC, and wind sources. Therefore, *v*1 and *v*2 are shown as two dependent power sources that their output characteristics are determined by the type of input power sources. For example, for a FC source at the first port, *v*1 is identified as a function of its current *iL*1. The PV source at the second port, *v*2 is identified as a function of its current *iL*2 depends upon light intensity, and ambient temperature. In the converter structure, two inductors *L*1 and *L*2 make the input power ports as two current sources, which result in drawing smooth dc currents from the input power sources. Figure 8, represents the equivalent design circuit of the proposed system.

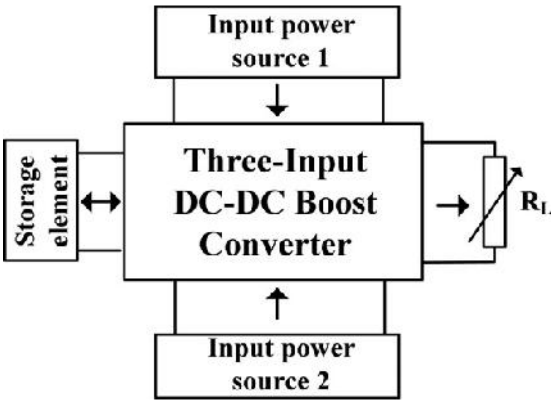

Figure .7. General block Diagram

The R_L is the load resistance, which can represent the equivalent power feeding an inverter. Four power switches *S*1 , *S*2 , *S*3 , and *S*4 in the converter structure are the main controllable elements that control the power flow of the hybrid power system. The circuit topology enables the switches to be independently controlled through four independent duty ratios *d*1 , *d*2 , *d*3 , and *d*4, respectively. As like as the conventional boost converters, diodes *D*1 and *D*2 conduct in complementary manner with switches *S*1 and *S*2.

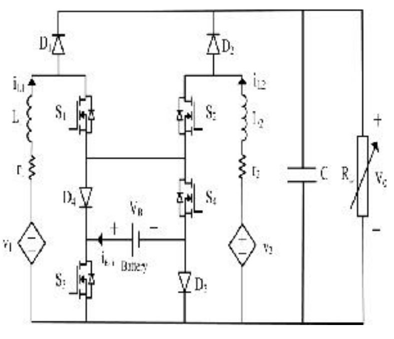

Figure .8. Circuit Topology Of The System

The converter structure shows that when switches *S*3 and *S*4 are turned ON, their corresponding diodes*D*3 and*D*4 are reversely biased by the battery voltage and then blocked. On the other hand, turn-OFF state of these switches makes diodes *D*3 and *D*4 able to conduct input currents *iL* 1 and *iL* 2. In hybrid power system applications, the input power sources should be exploited in continuous current mode (CCM). For example, in the PV or FC systems, an important goal is to reach an acceptable current ripple in order to set their output power on desired value. Therefore, the current ripple of the input sources should be minimized to make an exact power balance among the input powers and the load. Therefore, in this paper, steady state and dynamic behavior of the converter have been investigated in CCM In general, depending on utilization state of the battery, three power operation modes are defined to the proposed converter. These modes of operation are investigated with the assumptions of utilizing the same saw tooth carrier waveform for all the switches, and *d*3, *d*4 <min (*d*1,*d*2) in battery charge or discharge mode. Although exceeding duty ratios *d*3 and *d*4 from *d*1 or *d*2 does not cause converter malfunction, it results in setting the battery power on the possible maximum values. In order to simplify the investigations, it is assumed that duty ratio *d*1 is less than duty ratio *d*2. Further, with the assumption of ideal switches, the steady-state equations are obtained in each operation mode.

4.1 FIRST POWER OPERATION MODE (SUPPLYING THE LOAD WITH SOURCES V1 AND V2 WITHOUT BATTERY EXISTENCE)

In this operation mode, two input power sources *v*1 and *v*2 are responsible for supplying the load, and battery charging/ discharging is not done. This operation mode is considered as the basic operation mode of the converter. As clearly seen from the converter structure, there are two options to conduct input power sources currents *iL* 1 and *iL* 2 without passing through the battery; path 1: *S*4–*D*3 , path 2: *S*3–*D*4.

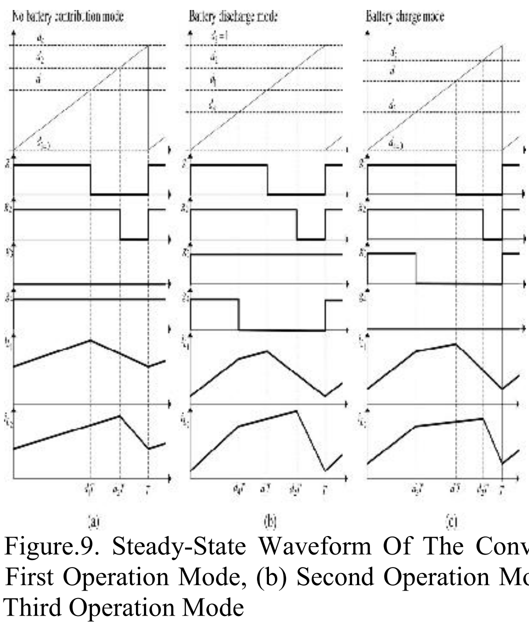

Figure.9. Steady-State Waveform Of The Converter In (a) First Operation Mode, (b) Second Operation Mode And (c) Third Operation Mode

Switching state ***1 (0 < t < d1 T):*** At $t = 0$, switches $S1$ and $S2$ are turned ON and inductors $L1$ and $L2$ are charged with voltages across $v1$ and $v2$.

Switching state 2 (d1 T < t < d2 T): At $t = d1T$, switch $S1$ is turned OFF, while switch $S2$ is still ON (according to the assumption $d1 < d2$). Therefore, inductor $L1$ is discharged with voltage across $v1 - vo$ into the output load and the capacitor through diode $D1$, while inductor $L2$ is still charged by voltage across $v2$.

Switching state 3 (d2T < t < T): At $t = d2T$, switch $S2$ is also turned OFF and inductor $L2$ is discharged with voltage across $v2 - vo$, as like as inductor $L1$. In this operation mode, the control strategy is based on regulating one of the input sources on its reference power with its corresponding duty ratio, while the other power source is utilized to regulate the output voltage by means of its duty ratio.

4.2 SECOND POWER OPERATION MODE (SUPPLYING THE LOAD WITH SOURCES V1, V2 AND BATTERY CHARGING PERFORMANCE)

Switching state 1 (0 < t < d3 T): At $t = 0$, switches $S1$, $S2$, and $S3$ are turned ON, so inductors $L1$ and $L2$ are charged with voltages across $v1$ and $v2$, respectively .

Switching state 2 (d3 T < t < d1 T): At $t = d3\ T$, switch $S3$ is turned OFF while switches $S1$ and $S2$ are still ON (according to the assumption). Therefore, inductors $L1$ and $L2$ are charged with voltages across $v1 - vB$ and $v2 - vB$ respectively.

Switching state 3 (d1 T < t < d2 T): At $t = d1\ T$, switch $S1$ is turned OFF, so inductor $L1$ is discharged with voltage across $v1 - v0$, while inductor $L2$ is still charged with voltage across $v2 - vB$.

Switching state 4 (d2 T < t < T): At $t = d2\ T$, switch $S2$ is also turned OFF and inductor $L2$ as like as $L1$ is discharged with voltage across $v2 - v0$.

In this operation mode, if the total generated power of the input sources becomes more than the load power, the battery charging performance will be possible if duty ratio $d3$ is utilized to regulate the output voltage. With this control strategy, duty ratios $d1$ and $d2$ are

utilized to regulate powers of the input sources, while duty ratio $d3$ is utilized to regulate the output voltage through charging the battery by the extra-generated power.

4.3 THIRD POWER OPERATION MODE (SUPPLYING THE LOAD WITH SOURCES V1 AND V2 AND THE BATTERY)

Switching state 1 (0 < t < d4T): At $t = 0$, switches $S1$, $S2$, and $S4$ are turned ON, so inductors $L1$ and $L2$ are charged with voltages across $v1 + vB$ and $v2 + vB$.

Switching state 2 (d4T < t < d1T): At $t = d4T$, switch $S4$ is turned OFF, while switches $S1$ and $S2$ are still ON. Therefore, inductors $L1$ and $L2$ are charged with voltages across $v1$ and $v2$.

Switching state 3 (d1T < t < d2T): At $t = d1T$, switch $S1$ is turned OFF, so inductor $L1$ is discharged with voltage across $v1 - v0$, while inductor $L2$ is still charged with voltages across $v2$.

Switching state 4 (d2T < t < T): At $t = d2T$, switch $S2$ is also turned OFF and inductors $L1$ and $L2$ are discharged with voltage across $v1 - v0$ and $v2 - v0$. By applying voltage–second and current–second balance theory to the converter, following equations are obtained. In this operation mode, the control strategy is based on regulating both of the input power sources on their reference powers by means of their corresponding duty ratios $d1$ and $d2$, while the battery discharge power is utilized to regulate the output voltage by duty ratio $d4$.

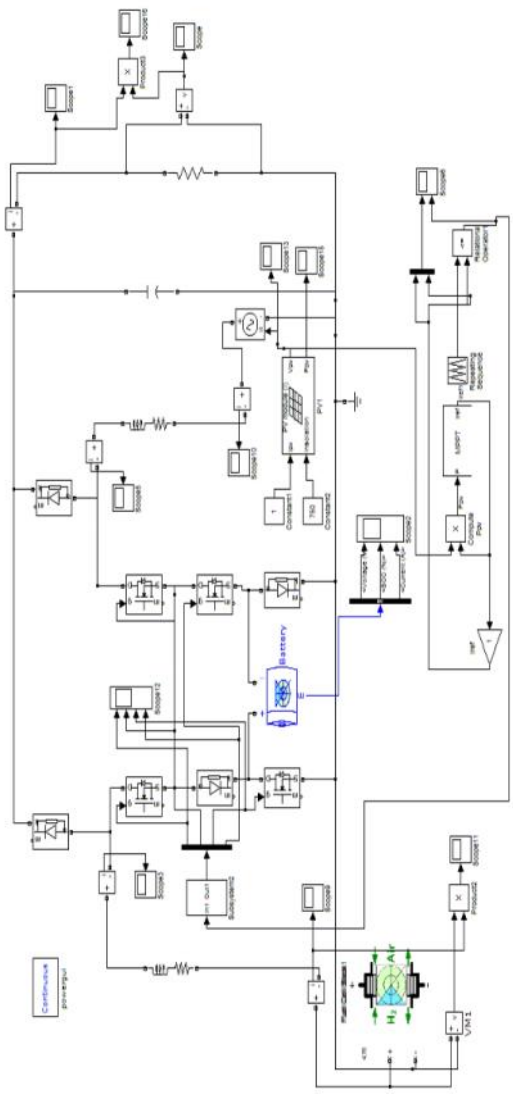

Figure 10 Simulation Diagram

5.SIMULATION

5.1 FIRST SIMULATION STAGE

In this stage, the requirement of load power *PL* is 100W while the maximum available PVpower is 140W and the maximum available FC power is 150W.The sun irradiation level is G = 750W/m^2. There is no need to charge the battery. First, second, third and fourth duty ratios are set as d1=0.7,d2=0.75,d3=0 and d4=1. By setting $d3$ = 0 and $d4$ = 1, which result the battery power to be set on zero value. The FC current is regulated by d1,which shows iL1 =0.85A. The PVcurrent is regulated by d2, which shows iL2 =0.45A. The results are shown in the Figure 11,12,13.The required load voltage is maintained for its entire operating time.

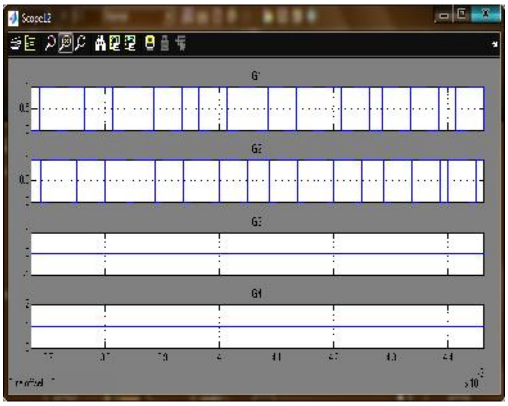

Figure 11 Gate Pulse For Four Switches G1,G2,G3 And G4 Vs time

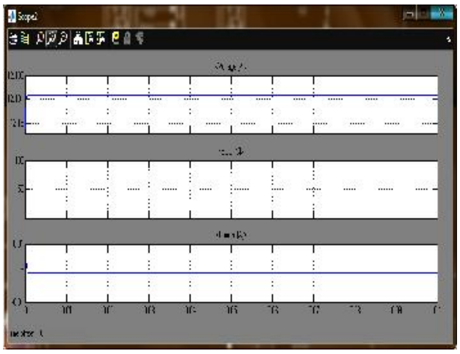

Figure 12 Battery Output Voltage ,Current Value Vs Time For First Operating Mode

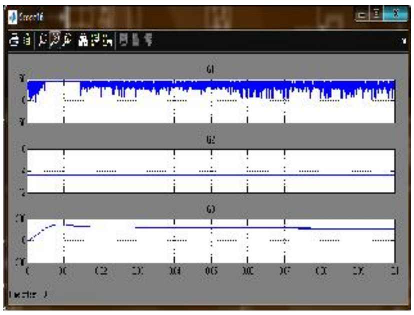

Figure 13 Compasison Of Voltages Of Solarcell, Fuelcell And Load Vs Time

5.2 SECOND SIMULATION STAGE

In this stage, the sun irradiation level increase to G =1000W/m2, while the load power remains constant at *PL* = 100W. In addition, in this stage, the battery charging is assumed to be performed, so the third operation mode is chosen for the converter. In this condition, battery remains in charging due to increase in sun irradiation level. As shown in Figure, the battery has been charged. The FC current is regulated on $iL1$ = 8.85 to 0.9A with duty ratio d = 0.73, while the maximum power of the PV source is tracked with regulating the PV current at $iL2$ =0.3A and adjusting the first duty ratio at $d1$ = 0.79. Moreover, controlling the third and fourth duty ratios at $d3$ = 0.45 and $d4$ = 0, respectively, results in providing the charging power of the battery in addition to regulating the output voltage Which are shown in Figure 14,15,16.

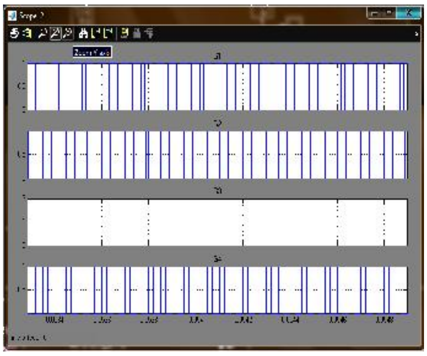

Figure 14 Gate Pulse For Four Switches G1,G2,G3 And G4 Vs Time

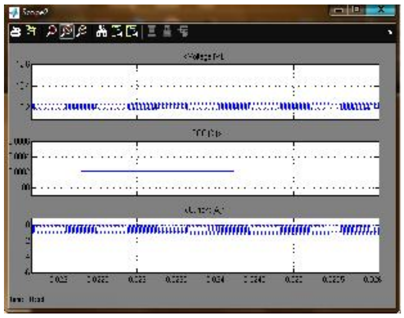

Figure 15 Battery Charging Voltage,Current, SOC Vs Time For Mode Second Operating

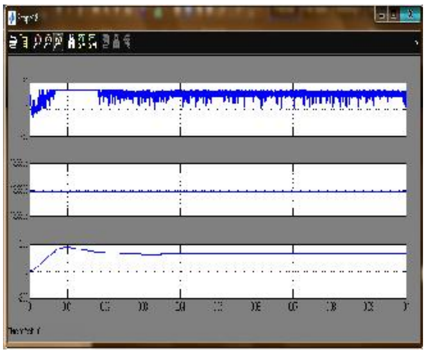

Figure 16 Compasison Of Voltages Of Solarcell, Fuelcell And Load Vs Time

5.3 THIRD SIMULATION STAGE

This stage occurs in a condition that solar power decreased certain value in which the load requires *PL* =100W and the PV power is simultaneously decreased due to sun irradiation level of *G* = 500 W/m2. From the maximum deliverable power of the PV, it is obviously understood that the PV is not able to completely supply the power deficiency thus, the remained power should be supplied by the battery. Therefore, the second operation mode is chosen. The PV is accomplished by regulating its current at *iL*2 =0.24A and adjusting the first duty ratio at *d*2 = 0.73, while the maximum power of the FC is delivered at *iL*2 =1.25 A with adjusting the second duty ratio at *d*2 = 0.71. The controlling the third and fourth duty ratios at *d*3 = 1 and *d*4 = 0.4 results in discharging the battery which are shown in Figure 17, 18.

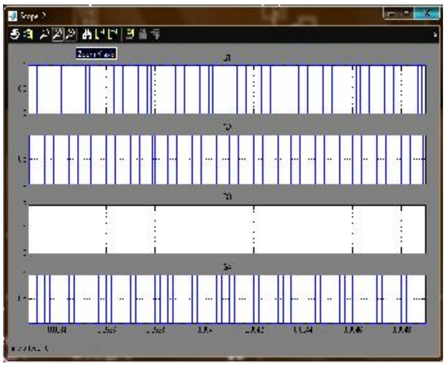

Figure 17 Gate Pulse For Four Switches G1,G2,G3 And G4 Vs Time

PARAMETER	MODE1 750W/m^2	MODE2 1000W/m^2	MODE3 500W/m^2
Load current	0.6A	0.6A	0.78A
Load voltage	126.5V	126.5V	126.5V
Load power	75.9W	75.6W	98.6W
Battery voltage,current and SOC	---	Charging	Discharging
Fuel cell voltage	45V	50V	45V
Fuel cell current	0.78A	0.9A	1.35A
Fuel cell power	35W	45W	49.5W
Solar voltage output	13.9V	13.9V	13.2V
Solar current output	0.49A	0.49	0.24A
Power output from solar cell for 2 Cell in Series	6.811W	6.811W	6.336W
Power output from solar cell for 12 cell	40.86W	40.86W	38.016W

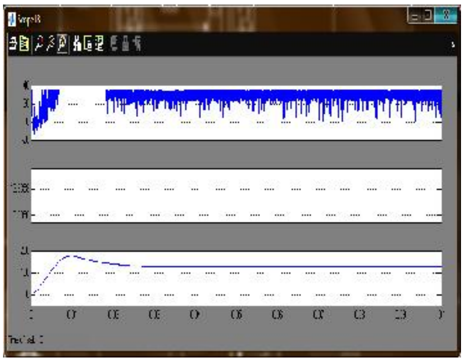

Figure 18 Compasison Of Voltages Of Solar Cell, Fuelcell And Load

Table 1 Simulation Results

CONCLUSION AND FUTURE WORK

In this work, literature review for various types of multiple input converter has been studied. Multi input boost converter was designed for fuel cell and solar panel. Since the cost of fuel cell is high and it depends upon hydrogen source at any instant fuel is required. And cost of fuel cell is high. So that is replaced by wind turbine in future. As per the requirement load requires 100w power which is continuously supplied by two sources. Alternatively battery backup is supplied during power deficiency. Results show that a photovoltaic fuel-cell hybrid system can perform well to meet the external load using energy produced by the system. It defines the downside of other types of hybrid power resources. Thus the system has been designed, optimized and control strategy has been considered for DC load only. In order to supply AC load, which are more frequently used, the system requires inverters to convert DC power to AC. However, the choice of the components in any case should rather be determined by economic consideration. Thus, the addition of battery to the system helps the fuel cell to handle the load where it draws the power from the battery until the fuel cell supports the increased of load demand. The battery provides additional power for any period of time. The boost converter is responsible for the energy conversion of the fuel cell and converts the power to a higher voltage application.

REFERENCES

[1] Chen Y. M, Liu Y. Ch. and Wu F. Y.(2002) 'Multi-input DC/DC converter based on the multi winding transformer for renewable energy applications',*IEEE* Trans. Ind. Electron., vol. 38, no. 4, pp. 1096–1103.

[2] Chen Y. M, Liu Y. Ch, Hung S. C. and Cheng C. S.(2007) 'Multi-input inverter for grid-connected hybrid PV/Wind power system',*IEEE* Transactions on Power Electronics, vol. 22, no. 3, pp. 1070–1077.

[3] Chuang Y. C. and Ke Y. L.(2008) ' High-efficiency and low-stress ZVT-PWM DC-to-DC converter for battery charger', *IEEE* Transactions on Power Electronics,vol. 55, no. 8, pp. 3030–3037.

[4] Duarte J. L, Hendrix M. and Simoes M. G.(2009) 'Three-port bidirectional converter for hybrid fuel cell systems',*IEEE* Transactions on Power Electronics ,vol. 22, no. 2, pp. 480–487.

[5] Farzam Nejabatkhah, Saeed Danyali, Seyed Hossein Hosseini(2012) 'Modeling and Control of a New Three-Input

DC–DC Boost Converter for Hybrid PV/FC/Battery Power System' , *IEEE* Transactions on Power Electronics*,* vol. 27, no. 5

[6] Gopinath R, Kim S, Hahn J. H, Enjeti P. N, Yeary M. B. and Howze J. W.(2004) 'Development of a low cost fuel cell inverter system with DSP control',*IEEE* Transactions on Power Electronics*,*vol. 19, no. 5, pp. 1256–1262.

[7] Huang X, Wang X, Nergaard T, Lai J. S, Xu X, and Zhu L.(2004) 'Parasitic ringing and design issues of digitally controlled high power interleaved boost converters',*IEEE* Transactions on Power Electronics*,* vol. 19, no. 5, pp. 1341–1352.

[8] Jia J, Li Q, Wang Y, Cham Y. T. and Han M.(2009) 'Modeling and dynamic characteristic simulation of a proton exchange membrane fuel cell', *IEEE* Transactions on Energy Converservation vol. 24, no. 1, pp. 283–291.

[9] Jiang W. and Fahimi B.(2010) 'Active current sharing and source management in fuel cell- battery hybrid power system',*IEEE* Transactions on Power Electronics.vol. 57, no. 2, pp. 752–761.

[10] Jin K, Ruan X, Yang M. and Xu M.(2009) 'A hybrid fuel cell power system',*IEEE* Transactions on Power Electronics*,* vol. 56, no. 4, pp. 1212–1222.