PV-FC System with Multilevel Boost Converter Fed Asymmetrical 7 Level Inverter

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Abstract-*This paper presents, a simulation of photo voltaic (PV) and Fuel cell (FC) system with multilevel boost converter fed Asymmetrical 7 level inverter. The power source consists of PV generator and proton exchange membrane (PEM) fuel cell. Modified P and O maximum power point tracking (MPPT) algorithm is used to extract the maximum power from PV system. Both boost converter (BC) and multilevel boost converter (MLBC) fed Asymmetrical cascaded multilevel inverter (ACMLI) system. The proposed system has higher output voltage and higher output power from the same sources (PV-FC) and same load resistance. By using Asymmetric multilevel inverter, the number of switches reduced and the harmonic content reduced. Due to the less number of switches the conduction losses decreases and efficiency improved. The proposed PV-FC system with multilevel boost converter fed Asymmetrical 7 level inverter has been simulated through MATLAB/SIMULINK.*

Key words: PV cell, PEM fuel cell, MPPT, Multilevel boost converter, ACMLI.

1. INTRODUCTION

Right now, India is one of the quickly developing nations as far as energy utilization. Right now, it is the fifth biggest consumer of energy on the planet and will become the third biggest by 2030 [1]. The nation is heavily dependent on fossil sources of energy for most of its demand. In response to present scenario of energy consumption, India is slowly concentrating towards renewable energy resources. Currently demand for electricity is increasing very rapidly so to reduce the gap between demand and supply, India has focused 20GW of Solar Power by 2022.Most of the energy is in the form of light and heat, which can be gathered and utilized for generating electricity. Photovoltaic (PV) cells are large-area semiconductors that convert daylight into electricity. PV systems turn into an extremely appealing arrangement because of the energy crisis and environment issues such as pollution and global warming effect. The foremost challenge in harvesting of solar energy is that the PV panel is a variable power source. This is the prime challenge in integrating them with grid or using them as standalone systems. It is theoretically known that temperature, humidity, wind speed, air pressure, air temperature, solar collector area etc. influence the outcome in terms of performance. MPPT algorithms are very much needed in PV applications because the power extracted from a typical solar panel varies with the insolation and temperature. Hence we need to use MPPT algorithms to obtain the maximum power from a solar PV array. In this paper, modified P&O MPPT algorithm is used for PV system to track maximum power. Also PEM Fuel cell is used as another source. Most of the research works used conventional boost converters for step up the voltage obtained from the sources but here Multi level Boost converters [2] are used to step-up the voltage obtained from the sources. Comparison of BC and MLBC based multilevel inverter for hybrid PV-FC system is done.

2. SYSTEM DESCRIOTION

The block diagram of the existing BC-MLI system is illustrated in Fig. 1. The output of PV cell & Fuel Cell are stepped up using boost converters. The outputs are applied to the seven level Asymmetrical multilevel inverter systems.

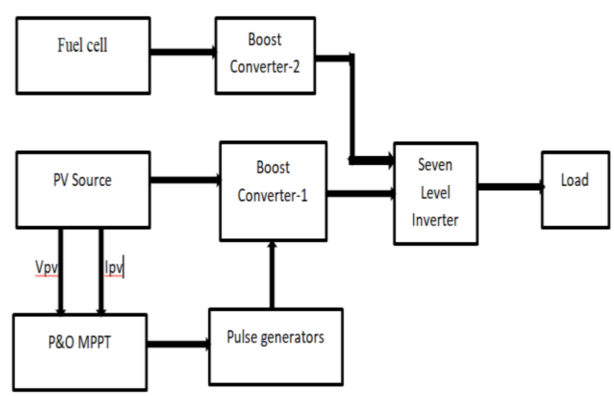

Fig-1: Block diagram of existing BC-MLI system

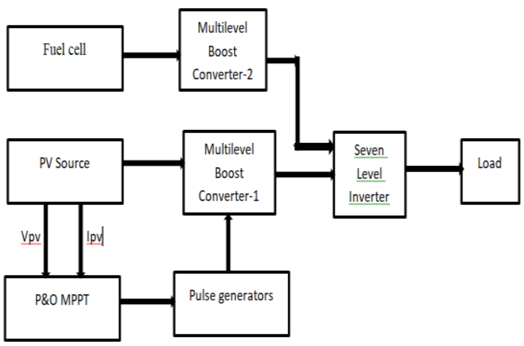

Fig-2: Block diagram of proposed MLBC-MLI system

3. MODELLING OF PV ARRAY

A solar cell is a solid state device that converts the energy of sunlight directly into electricity by the photovoltaic effect. Photovoltaic (PV) is a technique for creating electrical power by changing over sun based radiation into dc current with the help of semiconductors.

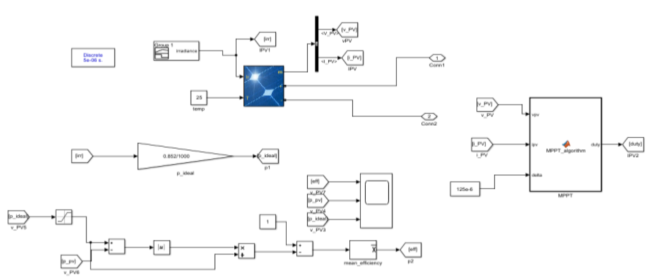

Fig-3: Photo voltaic model circuit

A photovoltaic array (PV system) is an interconnection of modules which in turn is made up of many PV cells in series or parallel. The power produced by a single module is seldom enough for commercial use, so modules are connected to form array to supply the load. The connection of the modules in an array is same as that of cells in a module. Modules can also be connected in series to get an increased voltage or in parallel to get an increased current.

PV cells are described by using different models which are based on current and voltage characteristics (I-V) curve of a PN junction.

The basic equation from the theory of semiconductors that mathematically describes the I–V characteristic of the ideal PV cell is

$$I = I_{pvcell} - I_{0,cell}[\exp(\frac{qv}{\alpha KT})-1] \text{ -------------- (1)}$$

To increment the current the cells must be connected in parallel and to increment the voltage the cells must be connected in series. Practical arrays are composed of several connected PV cells and the observation of the characteristics at the PV array requires the inclusion of additional parameters to the basic equations

$$I = I_{pv} - I_0\left[\exp\left(\frac{V+IR_s}{V_t\alpha} - I\right) - \frac{V+IR_s}{R_p}\right] \text{ ------------ (2)}$$

4. MODELING OF PEM FUEL CELL

A Fuel cell is an electrochemical cell that converts the chemical energy of a fuel (often hydrogen) and an oxidizing agent (often oxygen) into electricity through a pair of redox reactions.

There are many types of fuel cells, but they all consist of an anode, a cathode, and an electrolyte that allows ions, often positively charged hydrogen ions (protons), to move between the two sides of the fuel cell. At the anode a catalyst causes the fuel to undergo oxidation reactions that generate ions (often positively charged hydrogen ions) and electrons. The ions move from the anode to the cathode through the electrolyte. At the same time, electrons flow from the anode to the cathode through an external circuit, producing direct current electricity. At the cathode, another catalyst causes ions, electrons, and oxygen to react, forming water and possibly other products.

PEM fuel cell has a high proton conductivity membrane such as solid organic polymer is used as electrolyte between anode and cathode. On the anode side, hydrogen diffuses to the anode catalyst where it later dissociates into protons and electrons. These protons often react with oxidants causing them to become what are commonly referred to as multi-facilitated proton membranes. The protons are conducted through the membrane to the cathode, but the electrons are forced to travel in an external circuit (supplying power) because the membrane is electrically insulating. On the cathode catalyst, oxygen molecules react with the electrons (which have traveled through the external circuit) and protons to form water. Each single cell produces about 0.6 V so to get required voltage and power the cells should be connected as fuel cell stack. The operating temperature is in the range of 70-100°C.The Fuel Cell model used in this paper is realized in MATLAB and Simulink.

5. P&O MPPT ALGORITHM

The I-V & P-V characteristics of PV cell are nonlinear so it is very much difficult to determine maximum power point. To produce maximum power, it should be operated always at or near where the product of voltage and current is the maximum. This point can be considered as maximum power point of PV cell.

The proposed system utilizes multilevel dc-dc converter along with the modified perturb-and-observe (P&O) algorithm for its wide usage in MPPT owing to its simple structure and requirement of only a few measured parameters. It periodically perturbs (i.e., increment and decrement) the duty ratio and compares the PV output power with that of the previous perturbation cycle. If the power is increasing, the perturbation would continue in the same direction in the next cycle; otherwise, the direction would be reversed. This means that the duty ratio is perturbed every MPPT cycle; therefore, when the MPP is reached, the P&O algorithm will oscillate around it.

The modified P&O algorithm is implemented in the dc-dc multilevel boost converter. The output of the MPPT is the duty cycle function. The flowchart of the modified P&O algorithm used for tracking the maximum power from PV array is shown in Fig.4. Most MPPT techniques attempt to find the PV voltage corresponding to the maximum power point, Vmpp or to find the PV current, Impp corresponding to the maximum power point. The proposed algorithm tracks neither the Vmpp nor the Impp. However, it tracks directly the maximum possible power that can be extracted from the PV through the duty ratio of converters.

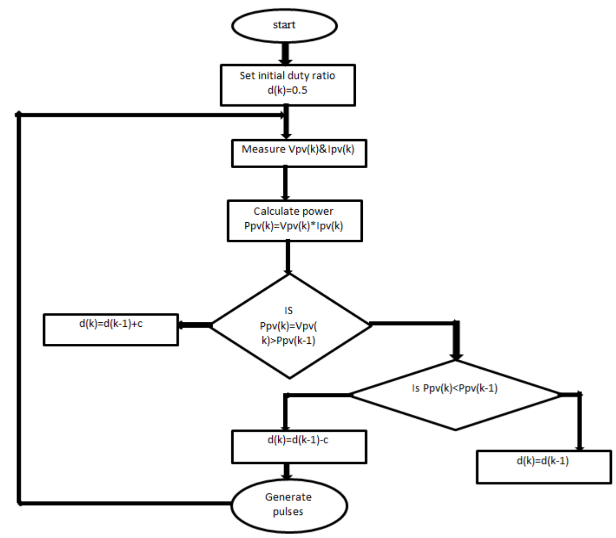

Fig-4: Flow chart of the P&O MPPT Algorithm

6. MULTILEVEL BOOST CONVERTER (2-LEVEL)

The DC–DC multilevel boost converter [2] is a converter which combines the boost converter and the switched capacitor. It provides different levels of output voltages and a self-balanced voltage across capacitors by using only one driven switch, one inductor, 2N-1 diodes and 2N-1 capacitors for an N level MBC. The power circuit for 2 level boost converters is shown in Fig.5. This consists of one switch(S), one inductor (L), 3 diodes and 3 capacitors.

During the Switch OFF state, the input voltage, V_{inp} charges capacitor C2 through inductor and D1. Also the capacitor C1 is charged by V_{inp} through inductor, L and D2 during OFF state. In ON state, the capacitor C1 is discharged and V_{inp}charges the capacitor C3 through inductor, switch and D3.

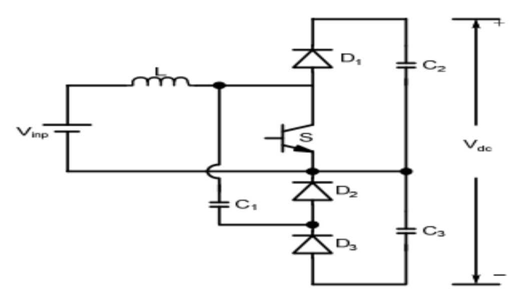

Fig-5 Power circuit of MLBC

6.1 Design of MBC

The output voltage of the conventional boost converter is

$$V_{dc} = \frac{V_{inp}}{1-d} \text{ --- } (6)$$

But in multilevel boost converter the output voltage is

$$V_{dc} = \frac{n \times V_{inp}}{1-d} \text{ --- } (7)$$

Where n is no of levels in MLBC, $V_{inp}$is input voltage from PV array, Vdc is output voltage across MLBC and d is the duty cycle.

Size of inductor is chosen such that current ripples do not exceed 5% and the value of inductance is designed by following equation

$$L_{min} = \frac{5\times(R_{out}(1-d)^2)dT_s}{n^2} \text{ ----------------------- } (8)$$

Where T_s is switching period=1/Fs , n is number of levels, Rout is load resistance.

The value of capacitance is designed such that voltage ripples should be less.

$$c_1 = c_2 = c_3 = d \times \frac{V_O}{\Delta V_{in} * F_s * R_{out}} \text{ ----------------- } (9)$$

The values of capacitors c_1, c_2 , c_3 are same.

7. SEVENLEVEL ASYMMETRICAL CASCADED H-BRIDGE MULTILEVEL INNVERTER

If the Cascaded H-bridge multilevel inverters are excited with unidirectional DC sources, we can obtain Asymmetric hybrid multilevel inverter. In this work, ACHBMLI with two separate DC-bus levels, one with low voltage switches and the other with high voltage switches are used. Switches S1- S4 are low voltage switches like IGBT and switches S11- S41 are high voltage switches like GTO. By using ACHBMLI with unidirectional DC voltages, it is possible to get more number of levels in the output voltage with less number of Cascaded H-Bridges. So with this configuration the number switches used reduce and at the same time we can reduce the harmonic content. In ACHBMLI the DC voltage sources for the H bridge cells are not equal. In the seven-level topology the DC voltages for H bridge1 and H bridge2 are Vdc and 2Vdc respectively. The two-cell inverter leg is able to produce seven voltage levels: 3Vdc, 2Vdc, Vdc, 0, –Vdc, –2Vdc, and –3Vdc. In the proposed system Vdc given from Output of MLBC-2 and 2Vdc given from output of MLBC-1 converter.

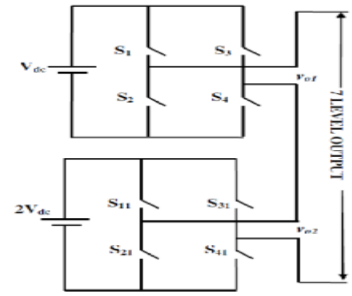

Fig-6: Seven level asymmetrical Multi level inverter

8. RESULTS

The parameters used for the present simulation study is given in table 1.

Table -1.Simulation Parameters of PV System

Parameters of PV system	Specifications
Open circuit voltage	20V
Short Circuit Current	3.2A
Voltage at Maximum Power	55.16V
Current at Maximum Power	15.5A
Temperature	298K
Irradiance Level	$1000w/m^2$

Simulation of conventional boost converter fed multilevel inverter and multilevel boost converter fed multilevel inverter with PV & FC sources by using MATLAB/SIMULINK and is shown in fig 7. The simulink diagrams of boost converter and seven level inverter circuits are separately shown in fig 8 and fig 9.

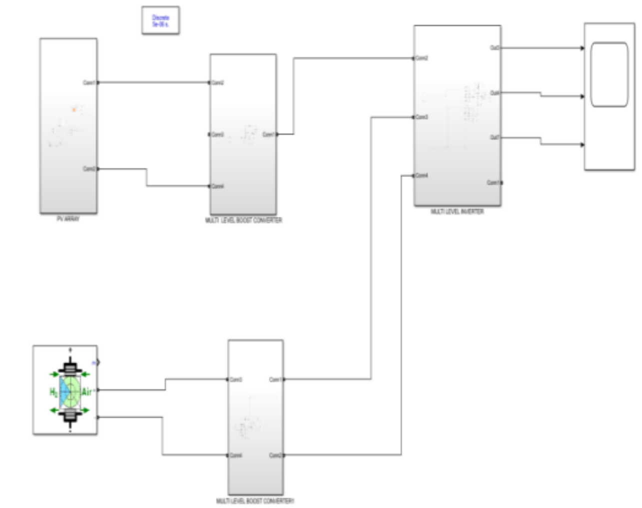

Fig-7: Simulink diagram for multilevel boost with 7 level multilevel inverter

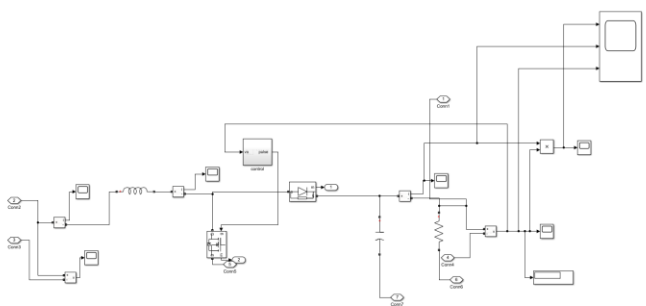

Fig-8: Simulink diagram of boost converter

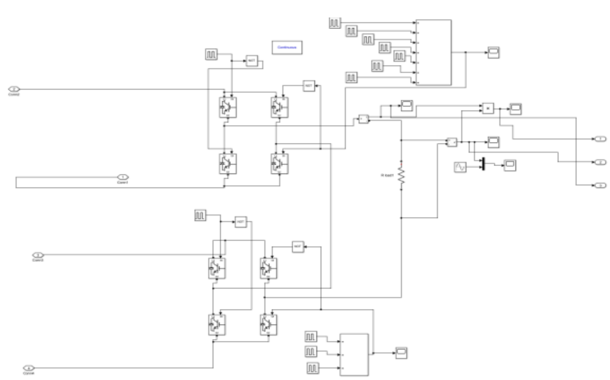

Fig-9 Simulink diagram of Asymmetrical 7-level inverter

The results for the circuit with ordinary boost converter are given in the figures from fig. 10 to fig 14.

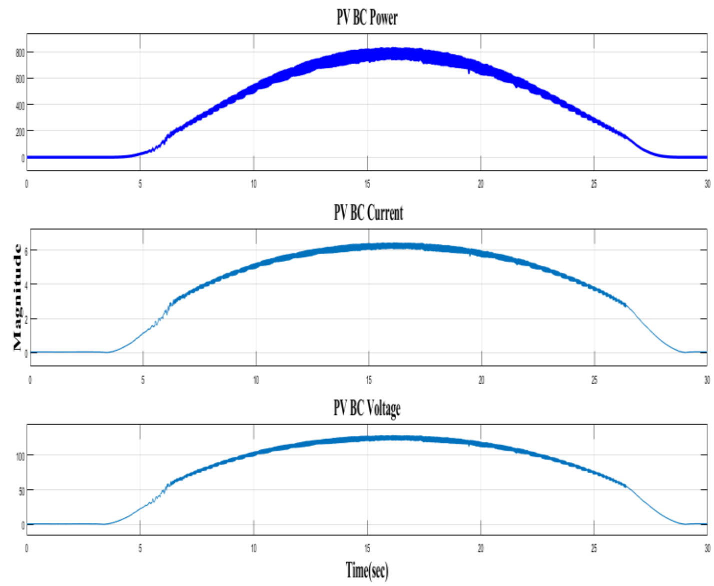

Fig-10: PV output voltage, current, power of PV at irradiation=$1000\,{}^{W}/_{m^2}$ and Temp=25°C

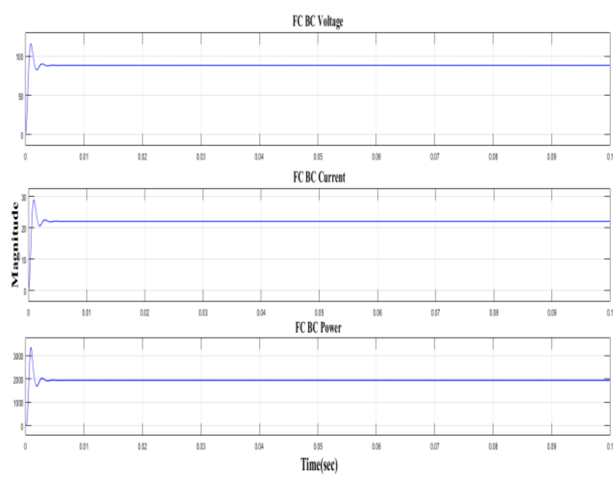

Fig-11: Output Voltage, current, Power of Fuel Cell with BC-2

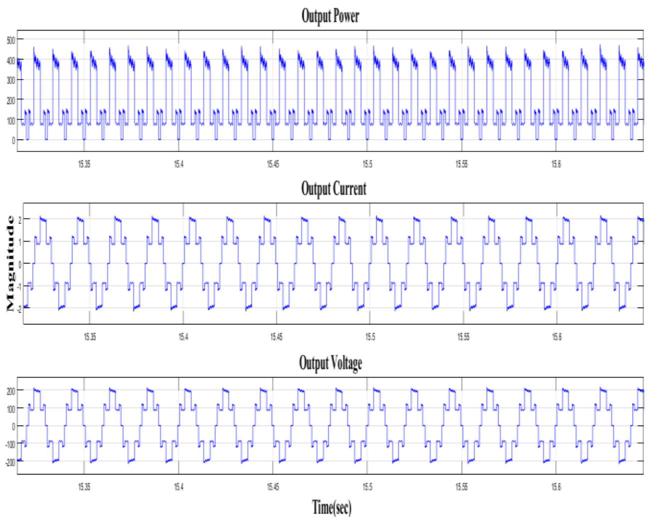

Fig-12: Output Voltage, Current, Average Power of 7-level Asymmetrical MLI

The simulink diagram of multilevel boost converter is shown in fig 13. The simulation results for the circuit with multilevel boost converter are shown in fig.14, fig 15 and fig. 16. Comparisons were given in tables 2 and 3.

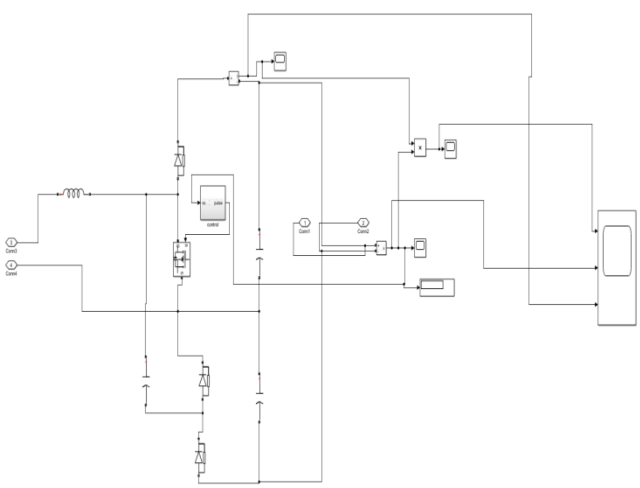

Fig-13: Simulink diagram of multilevel boost converter

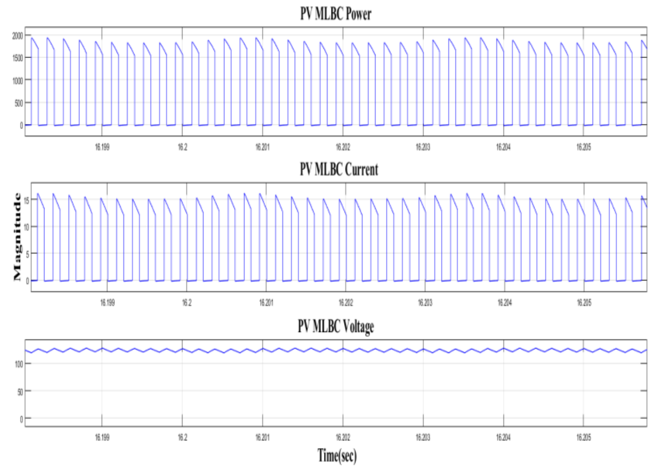

Fig-14: Output Voltage, Current, Power of PV with MLBC-1

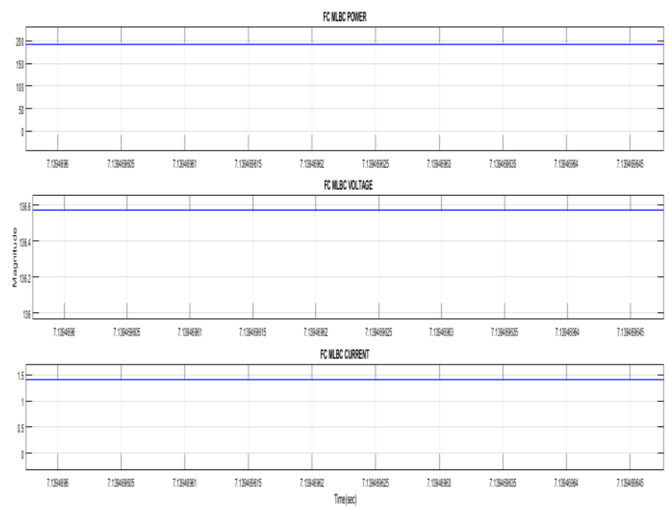

Fig-15: Output Voltage, Current, Power of FC with MLBC-2

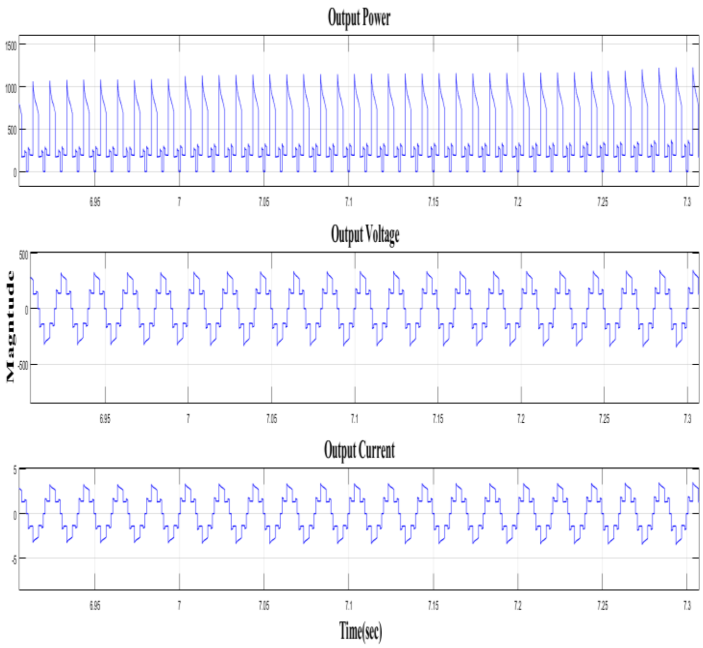

Fig-16: Output Voltage, Current, Average Power of 7-level asymmetrical MLI with MLBC

Table-2 Comparison of Output Voltage,&

Power of converters with duty ratio=0.55

	PV BC-1	PV MLBC-1	FC BC-2	FC MLBC-2
Input Voltage	55V	55V	33V	33V
Output Voltage	120V	240V	60V	120V

Table-3 Comparison of Voltage & Power of AMLI

	MLI with BC	MLI with MLBC
Output Voltage(max)	200V	450V
Average Power	450w	1000W

9. CONCLUSION

Conventional BC –MLI and MLBC-MLI systems are modeled and simulated using MATLAB Simulink and their results are compared. The simulation results indicated that the output voltage of MLBC is twice that of BC-MLI system. Therefore MLBC-MLI system has better performance. The contribution of this work is to replace BC with MLBC in PVFC hybrid system. The advantages of the proposed system are higher output voltage and higher output power for the same input voltage to the converters from the sources (PV-FC) and same load resistance. The disadvantage of MLBC is that it requires more number of capacitors. The scope of the present work is based on open loop MLI systems. The comparison of responses with closed loop PI and FOPI based MLI systems will be done in future.

10. REFERENCES

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