International Journal of Research & Development Organisation

ISSN-4567-7860

JOURNAL OF ELECTRICAL AND ELECTRONINS ENGINEERING

# Integration Of Renewable Energy Sources Using Asymmetrical Multi-Level Inverters

S Siva Sankara Vara Prasad
PG Student
GITAM University
Visakhapatnam, India
siva220sai@gmail.com

M.Dileep Krishna
Asst.Professor,EEE Dept
GITAM University
Visakhapatnam, India
dileepkrishnaeee@gmail.com

**Abstract: Renewable energy sources like wind, solar and fuel cell can be integrated by using multilevel inverter to generate electricity. In this paper asymmetric hybrid inverter is proposed for the integration of wind, solar and fuel cell. The control technique is used for multilevel output is Modified PWM technique which is specially designed for reduction of losses in the inverter. A modified PWM operation of asymmetrical hybrid multi-inverter (AHMI) is proposed for the reduction of THD in the output during PWM operation. The Matlab/Simulink circuit is used to study the nine level output of inverter in wind, solar and fuel cell hybrid power systems.**

***Keywords: Boost converter, Cascaded multilevel inverter, Fuel cell, Hybrid asymmetrical inverter, MPPT technique, PWM technique, Photo Voltaic (PV) array, Total harmonic distortion, Wind energy.***

## I.INTRODUCTION

Renewable energy resources are become popular nowadays because of the advantage of using two or more sources in power generation with the help of power electronics. Example for this is wind and solar hybrid generating systems. Both the sources of energy are random in nature. But they are used since they are environment friendly and they can replace nonrenewable energy resources like oil and gas. These can be integrated by using proper power electronics technology.

For the integration of wind and solar energies two separate inverters can be used at wind and PV array of hybrid wind-PV generating system. Alternative approach is to use cascaded multilevel inverter [1]. This will allow different energy sources to be connected over other topologies of multilevel inverters. The cascade topology allows the use of several levels of dc voltages to synthesize a desired ac voltage. The dc levels are considered to be identical since all of them are fuel cells or photovoltaic, batteries, etc. It can reduce the cost and increase the performance of the system. In this paper various sources are interfaced through nine level hybrid inverter.

Proposed configuration is best suited for hybrid generating systems as shown in fig. (1).Wind energy source can be used as source of main inverter. Auxiliary inverters are connected to solar panels and fuel cells at same rating. As main inverter is operated at high power ratings hence it is operated in square wave mode. Auxiliary inverter-1 is operated in PWM mode to get final multilevel output as PWM cascaded H-bridge inverter. Since auxiliary inverter-2 is operated in square wave mode it is preferred to use fuel cells as source of energy.

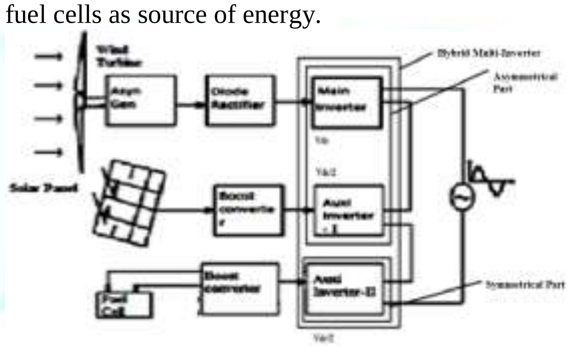



Fig.1 Block diagram of hybrid generating system

## II. CASCADED MULTILEVEL INVERTER TOPOLOGY

The selected cascaded multilevel inverter topology uses series connected submultilevel converters. Fig. 2 shows the basic unit for a submultilevel converter [3] & [4].

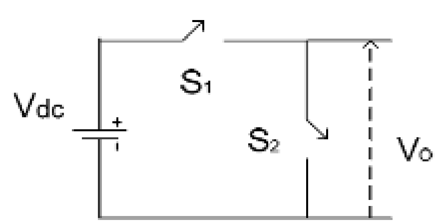



Fig. 2 Basic unit for a sub-multilevel converter

This topology of inverter uses submultilevel inverter part and polarity creator as shown in Fig. 2. The submultilevel converter gives either zero or positive output as shown in Fig. 3. When the inverter operates as a symmetrical inverter, Vi=Vdc[5] where as in asymmetrical inverter Vi is equal to either

$V_i = 2^{(i-1)} V_{dc}$ or $3iV_{dc}$ (1)
where i=1, 2,⋯ , n.

## III. CONTROL TECHNIQUES

The Control techniques selected for the symmetrical as well as asymmetrical inverters are fundamental frequency modulation and pulse width modulation techniques. Out of these techniques fundamental frequency operation is easy to control. In order to apply the conventional PWM techniques for the topology selected it needs some modifications. The Proposed PWM technique is derived from level shifted carrier PWM technique.

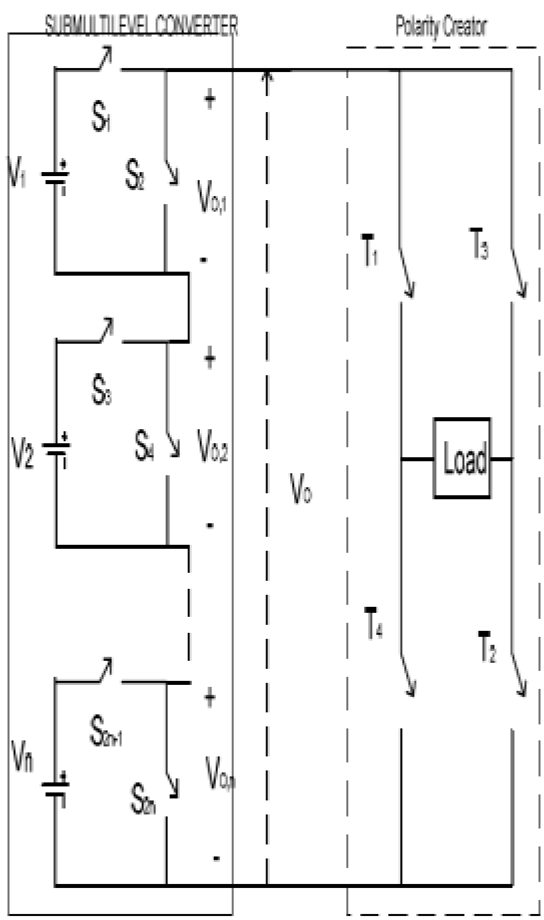



Fig. 3 Topology for symmetric and asymmetric inverter

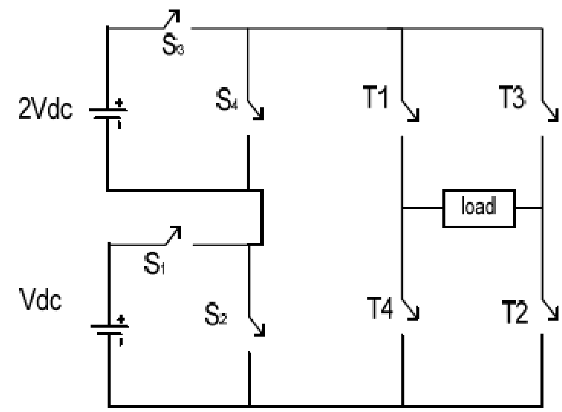



Fig. 4 Seven level asymmetric inverter

### *A) Fundamental Frequency Modulation technique*

In this technique gate signals of inverter are derived in such a way to get all the levels in the output waveform. Here H-bridge is operated to generate polarities of ac output. The seven level asymmetric topology is given in Fig .4 and control signals are given in the Fig.5. Ø1, Ø2, and Ø3 are calculated such that major harmonics in the output voltage waveform are to be eliminated [6]. These values are called as optimum angles and these can be calculated by using control algorithms. Advantage of this technique is that it uses low frequency switches over the other control techniques. The disadvantage of the technique is presence of lower order harmonics in the output, to eliminate this lower order harmonics size of the filter increases.

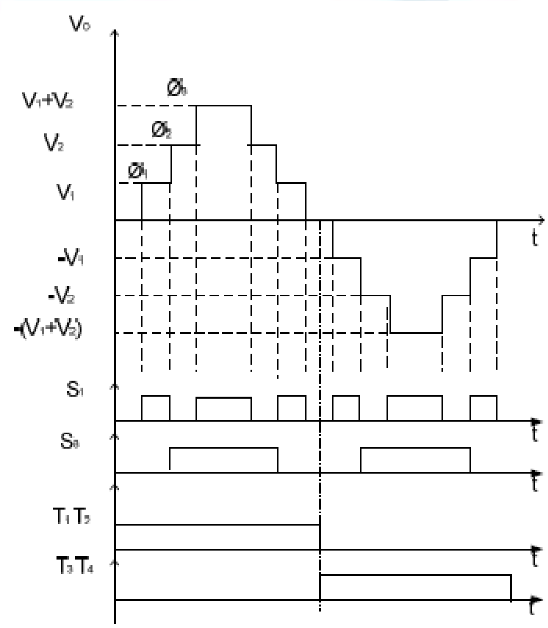


Fig. 5 Output of Seven level inverter with fundamental frequency modulation technique

*B) Pulse Width Modulation*

For the seven level asymmetric multilevel inverter PWM techniques are used in order to get the controlled output. Since the same configuration is used for symmetrical and asymmetrical inverters, same PWM technique can be applied to the both the inverters. The difficulty arises in applying gate signals directly to the asymmetric inverter which are derived from the comparison of the reference and carrier signals in the PWM operation. This is mainly due to the random distribution of turning on of the switches in the inverter in each half cycle. The modified PWM technique shown in Fig. 6 gives the contiguous gate signals which are not suitable for the specific arrangement of turning on of the switches in the asymmetric topology. By using logic circuits any PWM control signal can be modified in such a way that it is suitable for the specific arrangement of gate signals to turn on the switches in the inverter. For example for the seven level asymmetric inverter PWM operation control signals are derived from the samelevel symmetric inverter PWM control signals.

Control signals for seven level asymmetrical inverter are fabricated by using following mathematical equations (1-3).

$$f(t) = \frac{(n-1)}{2} * ma*\sin(\omega t) \quad (2)$$

$$r(t) = |f(t)| \quad (3)$$

$$C_1(t) = f(t);\ f(t) \geq 1 \quad (4)$$

Where,

f(t) reference signal

N number of level, n=7

$m_a$ modulation index (0-1.0)

r(t) PWM reference signal

$C_1(t)$ Multiplexing signal

Three carrier signals are required above the zero reference and in general (n-1)/2 carrier signals are required where n is the number of levels. Multiplexing signals for obtaining given gate pattern varies with the number of levels. Here C1 is multiplexing signal and it is used to obtain the PWM gate signal for switch S1 with the help of logic circuit shown in Fig. 7.

From the output of seven level inverter it is observed that fundamental component of output is more deviated from the approximate sine wave. This results in high value of THD and poor voltage quality. This is mainly due to the unequal pulses at each step of multilevel output when high voltage source is operated alone to obtain higher levels of the multilevel output. For example seven level hybrid asymmetric inverter output given in Fig .8 shows that when higher voltage source is operated alone in PWM mode then it results into pulses of magnitude 2V1 in the second step of output and in the remaining two steps the pulse magnitude is V1 as the same rated sources are giving the pulsed output in these steps. Thus PWM operation in asymmetric inverter results in high THD and poor output quality as compared to fundamental frequency modulation.

Even if the number of levels is increased inherently with asymmetric topology, output gets poor quality during PWM operation. Seven level asymmetric inverter results in a THD=28.97 % which is far away from the value 17.17% with fundamental frequency modulation and 17.93 % of its counterpart symmetric topology. Apart from this when high voltage source acts alone in the PWM output, it causes high dv/dt across the switch which adversely affects the high frequency switches.

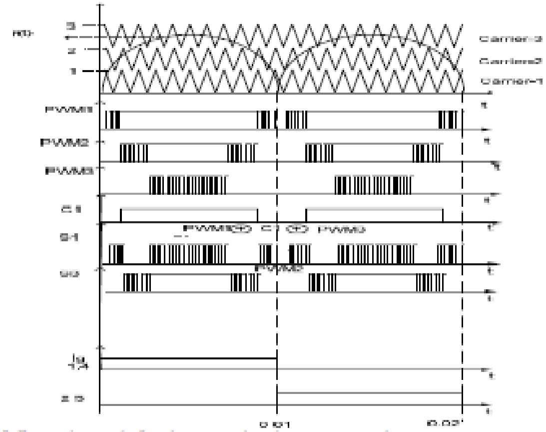



Fig. 6 Control signals for the seven level asymmetrical inverter

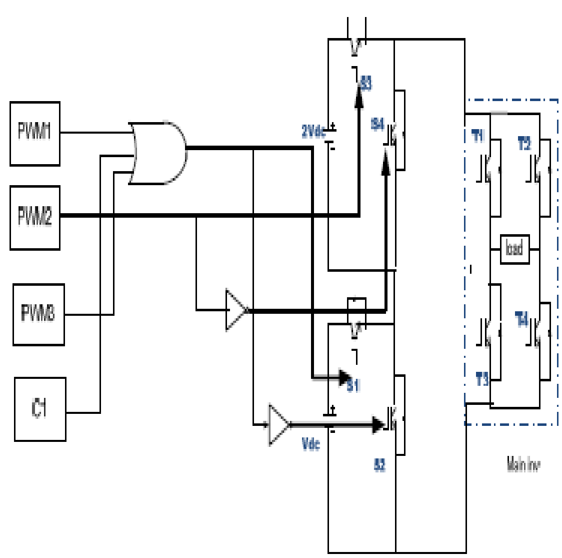


Fig. 7 Logic circuit for obtaining gate signals

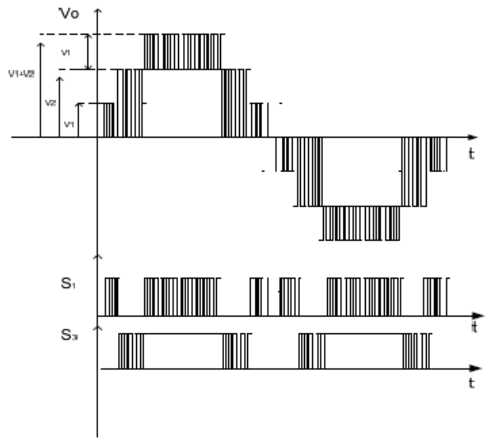



Fig. 8 Output of the seven level asymmetrical inverter with proposed PWM operation

The main advantage of asymmetric topology is that as the number of levels are increased per phase with the given number of sources as compared to symmetric topology, it results in better output quality. But during PWM operation of the asymmetric inverter, it loses the above advantage of the better quality output. To maintain its advantages during this mode a modified PWM operation is proposed.

## IV.MODIFIED PWM OPERATION

In the proposed hybrid inverter, the basic blocks have same rated source as that of the lowest rating source of asymmetric inverter. These are added in the submultilevel converter of asymmetrical inverter as shown in Fig. 9. The basic blocks are grouped and named as symmetric part and the remaining blocks are called as asymmetric part..

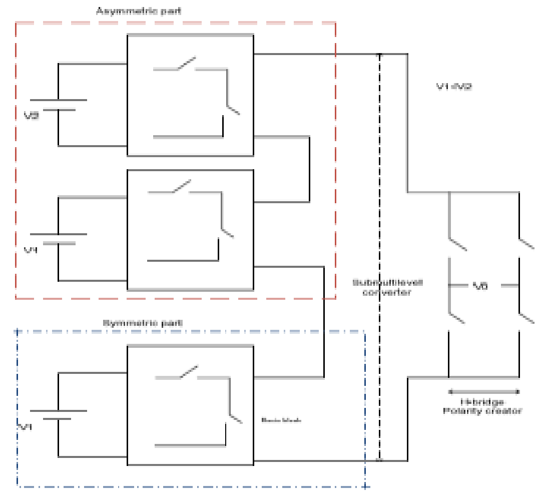



Fig. 9. Proposed Hybrid Multilevel Inverter Configuration

To eliminate the unequal pulses in the output of asymmetrical inverter, the high voltage sources in the inverter should not give pulsed output when they are operated alone. Instead of operating an asymmetric part in the PWM mode, symmetric part of the hybrid inverter is operated in PWM mode. Since symmetric part of the inverter uses same rating sources, the pulses in the multilevel output will be equal. Asymmetric part of the inverter is operated in square wave mode and it gives square wave type output. Finally asymmetric part is used for level creation and symmetric part is used for equal pulses in each step. Thus the multilevel output is better controlled and gives less THD which is equal to the same level of symmetric topology.

## V.DESIGN OF SYSTEMS

*A. Design of Wind Turbine:*

A wind turbine is used to convert the linear motion of wind into rotational energy that can be used to drive generator..

In this paper wind –turbine asynchronous generator in isolated network model given in Simulink is used as wind system. Turbine speed is driven at 10 m/sec to supply the sufficient power to the given load [7]. When asynchronous machine operates in generator mode its speed is above synchronous speed.

The total power generated by wind is given by following equations.

$$P_r = 0.5\rho s v^3 \quad (5)$$

$$s = \pi r^2 \quad (6)$$

Where,

ρ is the air density in $Kg/m^3$,
s is surface swept in $meter^2$,
v is the speed of wind turbine in meter per second,
r is the wind mill radius in meter,
Pr is the total power available from wind in watts

*B. Design of Solar Cell:*

Solar cells produce current when sunlight irradiates on them. In this paper the solar cell is simulated for any ambient temperature, sun light intensity and other internal parameters. An equivalent circuit is developed for easy analysis of solar cell [8]. The PV cell is a electrical device, which produces electrical power when exposed to sunlight and they are connected to boost converter. In proposed model the current is considered as constant, and the voltage changes based on the irradiation level. So the equivalent model contains a constant current source. The equivalent model is shown in Fig 10.

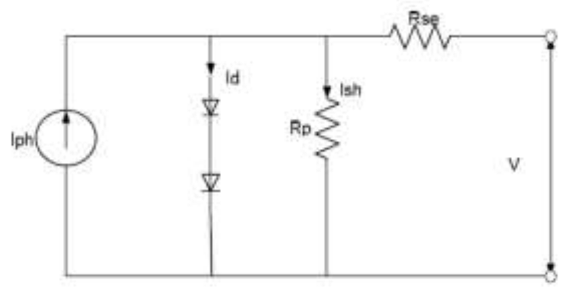



Fig.10 Equivalent model of solar cell

From the equivalent circuit, the current produced by the solar cell is given by,

$$I = I_L - I_D - I_{SH} \quad (7)$$

Where,
I = Output current (Amperes)
$I_L$ = Photo generated current (Amperes)
$1_D$ = Diode current (Amperes)
$I_{SH}$ = Shunt current (Amperes)

The current through these elements is governed by the voltage across them,

$V_j = V + IR_s$

where,
Vj = Voltage across both diode and resistor $R_{SH}$(Volts)
V = Voltage across the output terminals (Volts)
I = Output current (Amperes)
Rs =Series resistance (n)

By the Shockley diode equation, the current diverted through the diode is,

$$I_D = I_O \{exp\left[\frac{q*Vj}{nkT}\right]-1\} \quad (8)$$

where,
$I_o$ = Reverse saturation current (Amperes)
n = Diode ideality factor (1 for an ideal diode)
q = Elementary charge
k = Boltzmann's constant
T = Absolute temperature
By Ohm's law, the current diverted through the shunt resistor is,

$$I_{sh} = \frac{Vj}{Rsh} \quad (9)$$

Substituting these into the Equation (7) produces the characteristic equation of a solar cell, which relates solar cell parameters to the output current and voltage,

$$I = I_L - I_O \{exp\left[\frac{q[V+IRs]}{nkT}\right]-1\} - \frac{V+IRs}{Rsh} \quad (10)$$

*C. Design Of Fuel cell*

A fuel cell is a device that converts the chemical energy from a fuel into electricity through a chemical reaction with oxygen or another oxidizing agent. Fuel cell technology is based upon the simple combustion reaction given in equation (11)

$$2H_2 + O_2 \rightarrow 2H_2O \quad (11)$$

Fuel cells have been used in many other applications. Fuel cells are used for primary and backup power for commercial, industrial and residential buildings and in remote or inaccessible areas. They are also used to power fuel cell vehicles, including forklifts, automobiles, buses, boats, motorcycles and submarines

## VI SIMULATION & RESULTS

The Simulink model consists of asymmetric and symmetric parts of inverter. In asymmetric part, wind and Solar energy systems are used. In symmetric part, fuel cell system is used. In Wind energy system, wind turbine asynchronous generator in isolated network model is used [5].

In solar system, PV panel is connected to boost converter which forms the solar energy system.

Output of boost converter is given to auxiliary inverter I, is shown in fig. 1.

In fuel cell energy system, fuel cell is connected to boost converter and its output is connected to auxiliary inverter II is used.

*A.Wind Energy System:*

LC-filter is connected to the diode rectifier to get ripple free output. Design of the filter depends on the acceptable ripple content in the final output dc. As the asynchronous machine operates in generator mode, its speed is slightly above the synchronous speed (1.011pu). According to turbine characteristics, for a 10 m/s wind speed, the turbine output power is 0.75pu (206 kW). Because of the asynchronous machine losses, the wind turbine produces 200 kW. As the main load is 50 kW, the secondary load absorbs 150 kW to maintain a constant 60 Hz frequency. The output of wind energy system is shown in Fig. 9(a), At rectifier end output is 950V

Rectifier filter is designed to get low ripple content in the dc output. The values of L-C filter are L = 0.2μ H, C = 1 μF, R= 1 Ω. These designed values can be changed based on the ripple factor. The wind PMSG simulated circuit is shown in below Fig.11

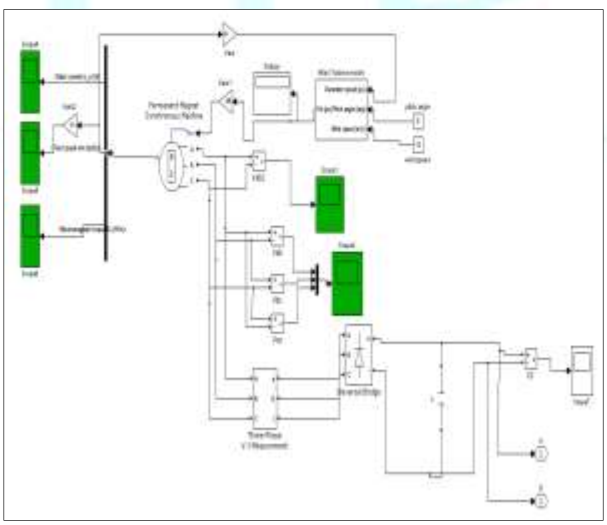


Fig. 11 The wind PMSG simulated circuit.

The output waveforms of rectifier are shown in fig 12.

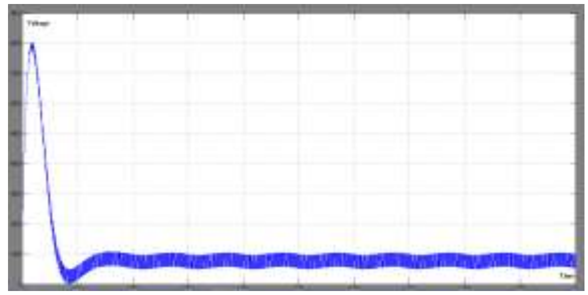


Fig. 12 The rectifier output waveform

*B.Solar Energy System*

Simulink model of PV panel is built by solar cell of Simscape / Matlab as shown in Fig. 4. 108 cells are connected in series to get 64 volts at the PV panel output. The entire day data is taken in the subsystem with the solar energy constant "G" and the temperature "T" as the outputs as the susystems. Thses are then given as inputs to the SMMPT block where in the m-file for the Maximum Power Point Algoretihm using The Golden Section Search Technique is kept as a user-defined function. It is a level-2 M-file s-fucntion. This allows us to specify the name of an m-file containing a MATLAB S-function in order to use that specified m-file function.

Boost converter is designed to get 150 V dc output as shown in Fig. 9. Designed values of boost converter are: L= 0.002 H, C = 1 μF, R=10Ω, D=33.54%, fs=1K hertz. The waveforms of boost converter are shown in fig 13.

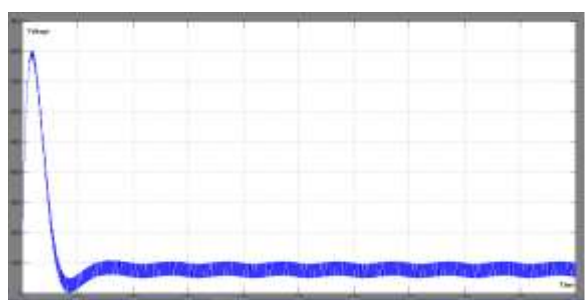


Fig. 13 The boost converter waveform.

*C. Design Of Fuel Cell:*

The simulank model of fuel cell stack is shown in Fig. 12

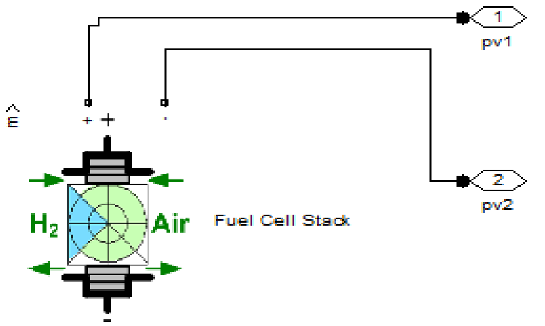
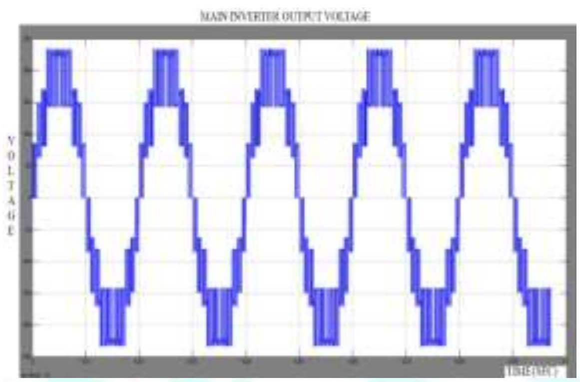
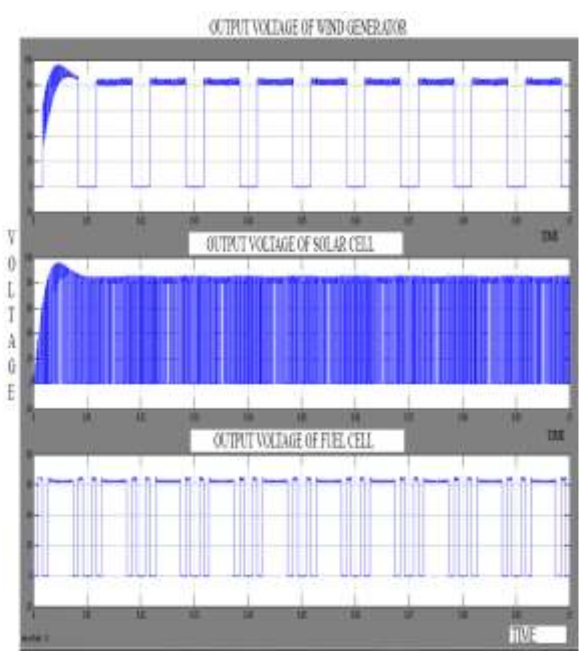



Fig. 14 Fuel cell design

The corresponding output waveforms of nine level Inverter, Main Inverter, Auxiliary Inverter 1&2 are shown below:




(a)




(b)

Fig.9 (a)Simulation result of nine level inverter
(b)Main inveter,Auxiliary inverter 1&2

## CONCLUSION

Hybrid multilevel inverter with symmetric and asymmetric parts produces nine level output in PWM mode with wind, solar and fuel cell as an input energy. Hence with the proposed modified PWM operation in the HMI it is possible to get better THD. So the integration of different renewable sources like wind, solar and fuel cell system is possible with the hybrid asymmetric inverter. This supply system can be used in rural places where regular power supply is not available.

## REFERENCES

[1] S. Khomfoi and A. Chatrchai, “A 5-level cascaded hybrid multilevel inverter for interfacing with renewable energy resources”, *International Conference on Electrical Engineering/Electronics, Computer,Telecommunications, and Information Technology, (ECTI-CON 2009),*Pattaya, Thailand, Vol. 1, pp. 284-287, 6-9 May 2009.

[2] J.Rodriguez, J.S. Lai, and F. Z. Peng, “Multilevel inveters: A survey of topologies, controls and applications,” IEEE trans.Ind..Electron., Vol. 49, No. 4,pp. 724-738, Aug. 2002

[3] Ebrahim Babaei and Seyed Hossein Hosseini, “New multilevel converter topology with minimum number of gate driver circuits”, *International Symposium on Power Electronics, Electrical Drives, Automation and Motion (SPEEDAM)*, pp. 792-797, 2008.

[4] Ebrahim Babaei, Mohammad Farhadi Kangarlu, and Farshid Najaty Mazgar, “Symmetric and asymmetric multilevel inverter topologies with reduced switching devices”, *Elsevier Journal of Electric Power Systems Research*, pp. 122– 130, 2012.

[5] Ebrahim Babaei and Seyed Hossein Hosseini, “New cascaded multilevel inverter topology with minimum number of switches”, *Elsevier Journal of Energy Conversion and Management*, vol.50, pp. 2761–2767,Nov. 2009.

[6] N. Mohan and T. M Undeland, *Power electronicsconverters, applications and design*, 3rd Edition, John Wiley & Sons, New York, 2003.

[7] K. Samuel and Ramani, “Multilevel inverter control for windphotovoltaic generation systems”, *International Conference on Computing, Electronics*

*and Electrical Technologies (ICCEET)*, pp.457-462, 2012.

[8] I.R Ibrahim, Z. Hussain and A.M.Omar, “Modelling and simulation of the dual-power pv-grid energy system utilizing multilevel inverter”, *International Conference on Control System, Computing and Engineering (ICCSCE)*, pp. 575-579, 2011.

[9] M.Dileep Krishna, K.Vinod Kumar, P.Nageswara Rao "A Hybrid Asymmetric Cascaded Multilevel Inverter for Reduction of THD in PWM Mode" Proceedings of 6th IRAJ International Conference, pp.78-83, 2014.

[10] M.Dileep Krishna , Shelly Vadhera "A 7-level Cascaded Hybrid Multilevel Inverter With Modified PWM Technique For Interfacing With Hybrid Generating Systems" National Conference On Electrical Systems And Energy Technologies (ESET-2013). pp.330-333, 2013.