

# ANALYSIS OF A NINE-LEVEL INVERTER TOPOLOGY WITH HYBRID INPUT SOURCES

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**Abstract** — This paper deals with the analysis of a nine-level multilevel inverter topology with hybrid input sources. The total number of input sources present in the topology is two which is arranged in asymmetrical arrangement. Solar PV system and fuel cell are used as the hybrid input sources to the multilevel inverter topology. The nine-level MLI is a reduced number of switch type inverter topology. The Multicarrier PWM technique is the simplest for implementation and flexibility in PWM waveforms generation for such type of MLI with hybrid input system. The construction of the MLI is done using power electronic devices which are then loaded and tested with a single phase induction motor. The operation of the multilevel inverter, induction motor and the hybrid sources are analysed. The simulation work is done in MATLAB Simulink and the results are verified. The system is tested with a real time prototype and the output is verified successfully.

**Index Terms**— Hybrid input sources, multi carrier PWM, multilevel inverter, power electronic devices, single phase induction machine.

## I. INTRODUCTION

In the last two decades, environmental organizations have encouraged the power industry to use renewable power. As the depletion of the fossil fuels is forcing the industries to move on to an alternative fuel and in the other hand the global

warming threatens the world to go green [1]. The energies such as wind, photovoltaic (PV), fuel cell and tidal are encouraged to be used as a replacement fuel instead of fossil fuels. The renewable energy may be considered to have neutral impact on the atmosphere and also considered as “greener” energy. Hence the change over from non-renewable sources to renewable sources is processed at a fast rate in the current scenario.

Solar PV systems are one of the most and fast growing renewable energy sources compared to all the other sources. The solar PV systems are enhanced with various other components like dc-dc converter, MPPT and inverter making it an efficient system [11]. The fuel cell in the other hand can provide safe, clean, efficient and sustainable electrical energy continuously since it uses hydrogen as a fuel. It also acts like a green battery because of its low operational temperature, high power densities, long life and also it is the most commercially spread type.

The multilevel inverters are gaining a fast recognition in the present dc-ac converter methodology. This method is opted due to the reduction of harmonics, less stress on the power electronic switches and high efficiency compared to conventional inverter methodology [3]. As the number of levels in the multilevel inverter output waveform increases the waveform replicates a sinusoidal waveform. The multilevel inverter

topologies are also a part of research area where the work is done in finding out a best multilevel inverter with reduced number of switches, reduced number of sources and maximizing the number of levels in the output waveform. Due to fewer harmonic in the output the operation of a single phase induction motor has an advantage to the MLI [19].

In this work a nine-level multilevel inverter topology with reduced number of switches, reduced number of sources and maximizing the number of levels is analysed with hybrid input sources. The combination of the solar PV system and fuel cell is given as the input to the multilevel inverter. The inverter is then loaded with a single phase induction machine analysing its operation. The working of such systems proves to have better performance and efficiency. The working of the nine-level multilevel inverter topology with hybrid input sources is split up into various sessions as follows, session I and II deals with the system description, session III and IV is about the operation & results and finally the conclusion.

## II. SYSTEM DESCRIPTION

The main components present in the entire system are a nine-level multilevel inverter, solar PV system, fuel cell and a single phase induction machine. The solar PV panel and the fuel cell act as the hybrid input sources to the nine-level multilevel inverter topology. The dc voltages from both the sources are supplied in an asymmetrical way so that the additive and subtractive values of the sources bring out the nine-level waveform.

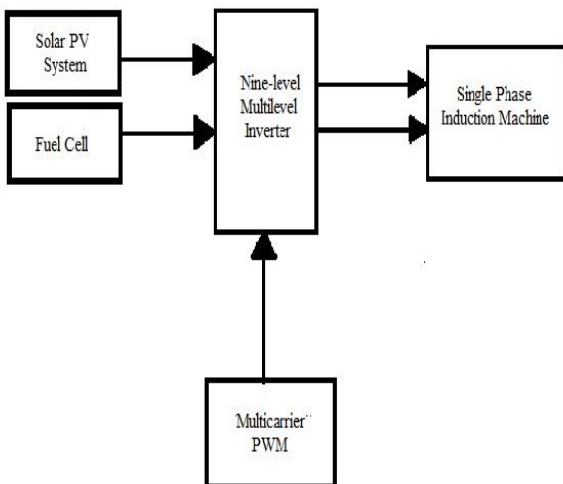


Fig. 1. Block Diagram of the Proposed System

The nine-level multilevel inverter is triggered with multicarrier PWM technique such that the nine-level output is attained. The obtained nine-level ac output waveform is fed to a single phase induction motor.

## III. PRINCIPLE OF OPERATION

### A. Solar Photovoltaic System

Three solar panels in series connection are the input DC sources to the multilevel inverter taken in the ratio 1:3. Each panel has 72 cells with an open source voltage (Voc) 57.5V and the short circuit current (Isc) 8.63 A. The three solar PV panels connected in series are taken as E1 in the nine-level multilevel inverter topology.

A single solar cell is constructed using a resistance that is connected in series with a parallel combination of a Current source consisting of single diode with a shunt resistance. Solar cell uses photoelectric effect converting solar energy directly into electric energy. Thus electrical characteristics like current, voltage and resistance vary when light is incident upon it. This results in generation of electric current without being attached to any external voltage source.

### B. Fuel Cell System

A fuel cell is the one which converts the chemical energy from a fuel into electricity through a chemical reaction of positively charged hydrogen ions with another oxidizing agent. The fuel cell is taken as the second dc source E2 for the nine-level multilevel inverter topology.

A fuel cell, on the other hand, uses an external supply of chemical energy and can work as long supply is given with a source of hydrogen and a source of oxygen (usually air). All fuel cells are based on a design using two electrodes separated by an electrolyte carrying electrically charged particles between them. A catalyst is often used to increase the swiftness of the reactions at the electrodes.

### C. Multilevel Inverter

With two DC sources, there can be nine possible combinations obtained in the output waveform, resulting in a nine level inverter. The topology is with two input DC sources for nine-level output. The topology has eight switches and to obtain any voltage level, three switches need to be ON simultaneously. A comparison of proposed topology with the classical topologies shows that

the device count is appreciably reduced for a given number of levels in the output. The voltage source (E1) is thrice the value of that of voltage source (E2) connected. The additive and subtractive combinations of the voltage sources bring out the 9 levels in the output waveform.

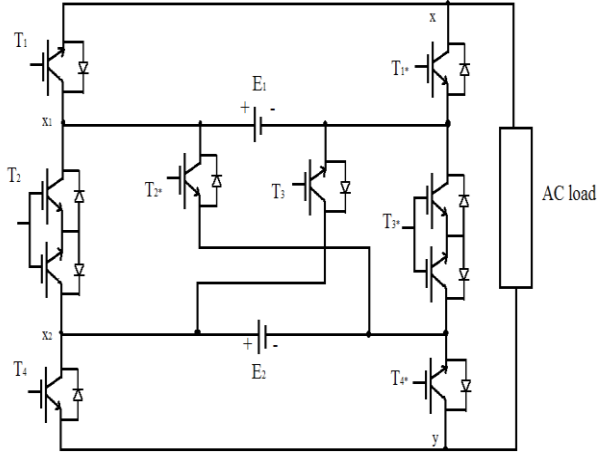


Fig.2. Nine level inverter topology

For two DC sources the possible combinations are:

- (i) Taking one level : E1, E2, -E1 and -E2.
- (ii) Taking two levels at a time: (E1+E2), (E1 - E2), (E2 - E1) and (E1 + E2).
- (iii) Zero level: one.

The multilevel inverter topology used is a reduced number of switching device topology compared with conventional multilevel topologies has less count.

Table 1 Lookup table - 9 level inverter

Output Level	Switch states (1- ON & 0- OFF)							
	T1	T2	T3	T4	T1	T2	T3	T4
E1 + E2	1	0	1	0	0	0	0	1
E1	1	0	1	1	0	0	0	0
E1 - E2	1	0	0	1	0	0	1	0
E2	1	1	0	0	0	0	0	1
0	1	1	0	1	0	0	0	0
-E2	1	0	0	1	0	1	0	0
E2 - E1	0	1	0	0	1	0	0	1
-E1	0	1	0	1	1	0	0	0
-E1 - E2	0	0	0	1	1	1	0	0

This is the switching state look-up table; each level is obtained at the inverter output when the MOSFETs are switched as per the look-up table.

#### D. MULTIPLE CARRIER SINUSOIDAL PULSE WIDTH MODULATION (SPWM)

Level shifted PWM is obtained from the carrier disposition method for a nine -level inverter; this strategy needs N-1 triangular carrier waves having similar amplitude and frequency so that they fully occupy the contiguous band ranging from +VDC to -VDC. A single sinusoidal waveform is then compared with each of the carrier signals to determine output voltages for the inverter. Three PWM techniques used are:

- (i) Phase Disposition (PD)
- (ii) Phase Opposition Disposition (POD)
- (iii) Alternative Phase Opposition Disposition (APOD)

The switching pulse generated is of Phase opposite disposition (POD) for triggering the MOSFETs. The nine-level multilevel inverter output voltage and output current is also monitored.

#### IV. SIMULATION MODEL

The simulation was done using MATLAB R2013a Simulink. The various modules were modelled and the overall system was simulated. The overall system model consists of the Solar PV panel, Fuel cell, Multilevel inverter, Switching circuit and induction motor. The details of various modules and SIMULINK diagrams including output are described below.

The multilevel inverter is constructed with power MOSFETs and the two dc sources are solar PV panel and fuel cell. This is the simulation model of the nine-level multilevel inverter topology with hybrid input sources. The dc source present at the top of the inverter is solar PV panel and the second one is the fuel cell. The load connected to the inverter is a single phase induction machine.

The induction machine type chosen is a capacitor-start-run type. Induction motor is block available in MATLAB Simulink is used for simulation studies. Three solar panels are connected in series to act as a single source and the second source is powered by fuel cell making this a hybrid input source system.

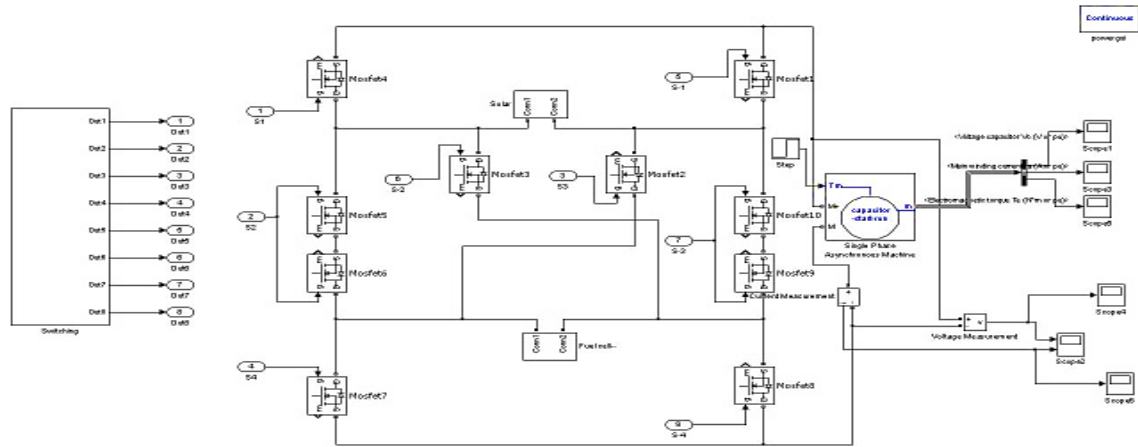
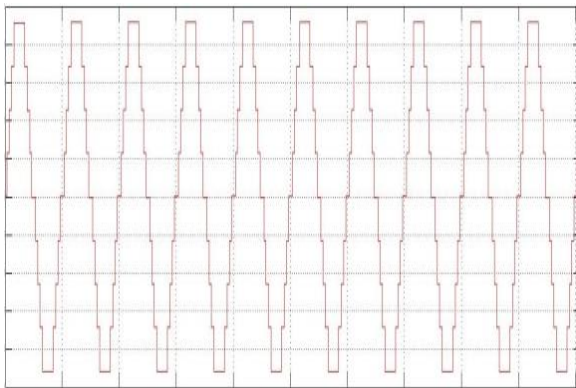
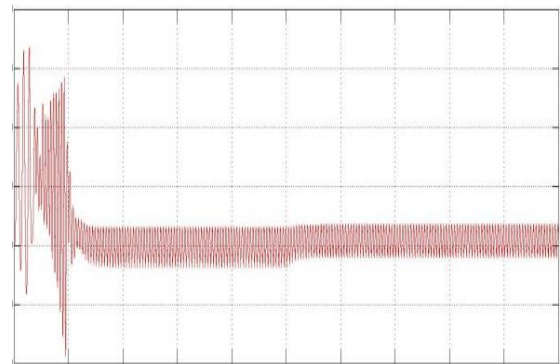


Fig. 3. Simulink Model

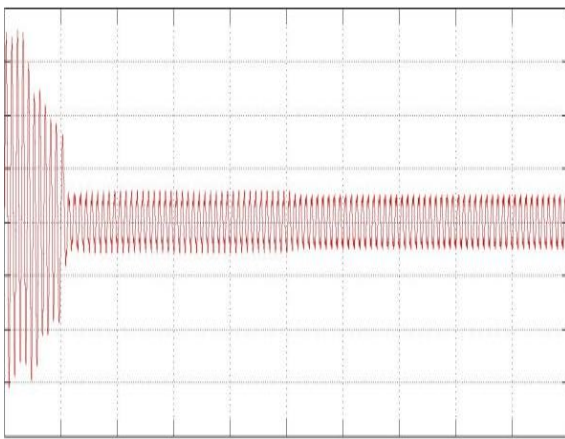
## V. SIMULATION RESULTS



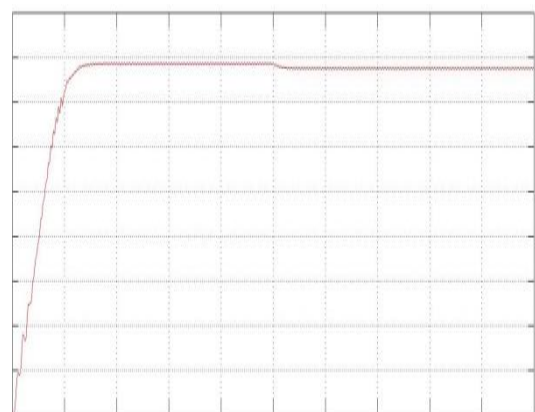
(a)



(c)



(b)



(d)

Fig. 4. Hybrid source MLI fed induction machine  
(a) Multilevel inverter output voltage  
(b) Stator current

- (c) Electromagnetic torque
- (d) Rotor speed

The simulation result analysis clearly depicts the working of the Hybrid source MLI fed induction machine. The results of the nine-level multilevel inverter, induction machine's stator current, electromagnetic torque and rotor speed are displayed above.

The multilevel inverter output voltage shown in Fig. 4. (a). is a nine-level output waveform. The number of levels is increased in order to reduce the harmonics and replicate the sinusoidal waveform. The hybrid sources sever as the input DC supply the inverter which is inverted into AC supply and fed to the induction machine.

The stator main winding current is shown in Fig.4.(b). Initially the stator current of the induction machine shoots up to 60A at the starting and attains a steady state. The stator current attains steady state within 0.2 seconds and remains constant.

The electromagnetic torque is shown in Fig.4.(c). Initially the electromagnetic torque of the induction machine shoots upto 80Nm at the starting and attains a steady state. The electromagnetic torque also attains steady state within 0.2 seconds and remains constant.

The rotor speed is shown in Fig.4.(d). Initially the rotor speed of the induction machine starts slowly and reaches the steady state remains constant at 1500rpm. The rotor speed also attains steady state within 0.2 seconds and remains constant.

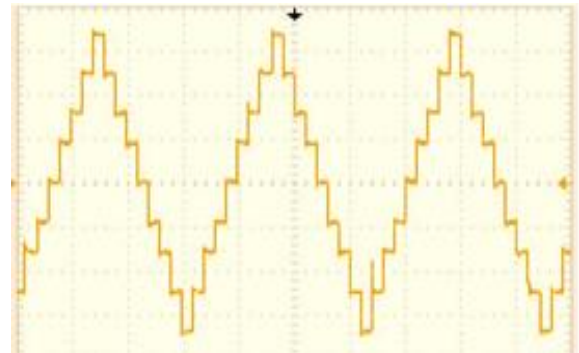
From the overall simulation result analysis it is clear the hybrid source multilevel inverter fed induction machine the harmonics is reduced as the number of output levels is high and the steady state point is attain within 0.2 seconds for the induction machine.

The Total harmonic distortion (THD) of the multilevel inverter output is shown above. The THD value of the fundamental component is 11.43%. The harmonic content is less compared with the conventional inverter topologies.

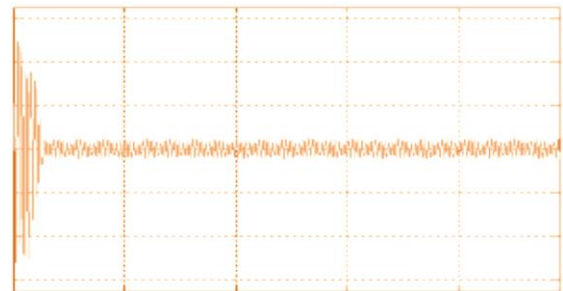
## VI. HARDWARE IMPLEMENTATION

The hybrid source multilevel inverter fed induction machine real-time hardware prototype was developed. The multilevel inverter topology was constructed using IRF 640N MOSFETs with appropriate driver circuits. TLP 250 opto coupler driver IC was used for driving the MOSFETs. The switching signals are fed to the hybrid source multilevel inverter using PIC microcontroller. The results of the MATLAB Simulink simulation and the real-time prototype are compared and validated.

## VII. HARDWARE RESULTS



(a)



(b)

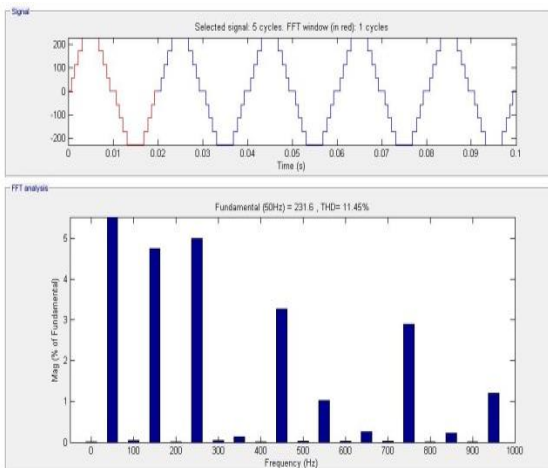
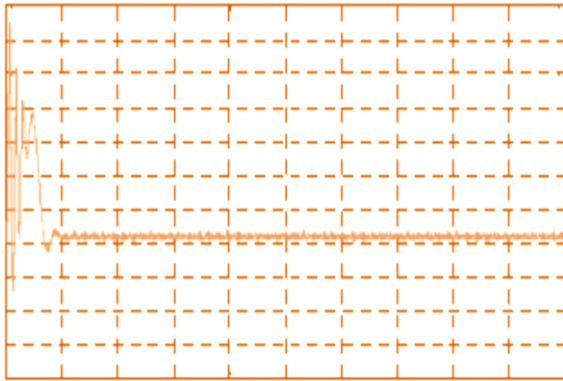
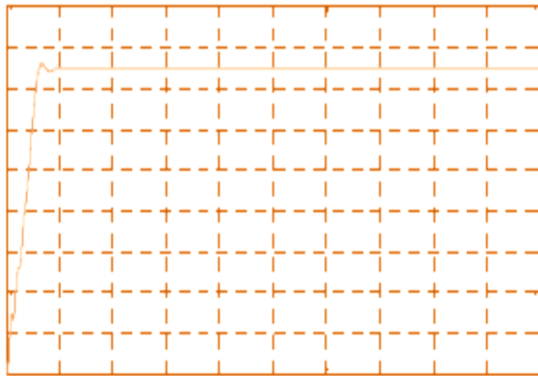


Fig. 5. THD window of Multilevel inverter





(c)



(d)

Fig. 5. Hybrid source MLI fed induction machine

- (a) Multilevel inverter output voltage
- (b) Stator current
- (c) Electromagnetic torque
- (d) Rotor speed

These results are the output waveforms of the Hybrid source MLI fed induction machine. The results of the nine-level multilevel inverter, induction machine's stator current, electromagnetic torque and rotor speed are displayed above.

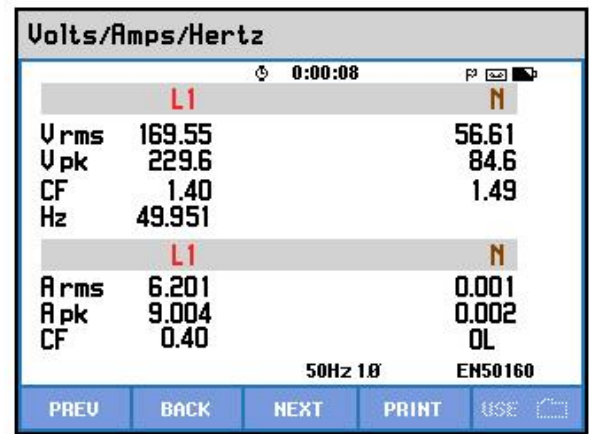
The multilevel inverter output voltage shown in Fig. 5. (a). is a nine-level output waveform. The number of levels is increased in order to reduce the harmonics and replicate the sinusoidal waveform. The hybrid sources serve as the input DC supply the inverter which is inverted into AC supply and fed to the induction machine.

The stator main winding current is shown in Fig.5.(b). Initially the stator current of the induction machine shoots up to 65A at the starting and attains a steady state. The stator current attains steady state within 0.2 seconds and remains constant.

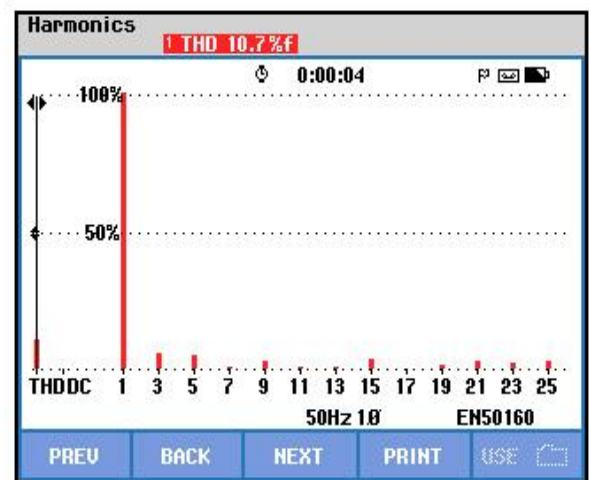
The electromagnetic torque is shown in Fig.5.(c). Initially the electromagnetic torque of the induction machine shoots up to 75Nm at the starting and attains a steady state. The electromagnetic torque also attains steady state within 0.2 seconds and remains constant.

The rotor speed is shown in Fig.5.(d). Initially the rotor speed of the induction machine starts slowly and reaches the steady state remains constant at 1500rpm. The rotor speed also attains steady state within 0.2 seconds and remains constant.

From the overall result analysis made between the simulation results and the hardware prototype results are proven to be similar.



(a)



(b)

Fig. 5(a, b). Voltage and THD of Multilevel inverter

The Total harmonic distortion (THD) of the hardware prototype of the hybrid source multilevel inverter output is shown above. The THD value of

the fundamental component is 10.70%. The harmonic content is almost equal compared with the simulation multilevel inverter result.

## VIII. CONCLUSION

The analysis of a single phase induction machine with a nine-level multilevel inverter topology with hybrid input sources was studied. The simulation modelling of the solar PV system, fuel cell, multilevel inverter and multicarrier PWM technique was done using MATLAB 2013a. The working of the multilevel with the hybrid model and the output of the inverter when the induction machine connected was examined. The simulation work is done in MATLAB Simulink and the results are verified.

The same simulation work was replicated into a real-time hardware prototype. The system was developed and the same conditions were tested. The results of the real-time hardware prototype was taken and analysed with the MATLAB Simulink simulation results. Both the results showed similar values and the operational response of the induction machine was efficient. Hence such type of hybrid source multilevel inverter topologies can bring forth even better performance and efficiency in the mere future. Thus operation of the nine-level multilevel inverter fed induction motor with hybrid sources is analysed.

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