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Fuel Cell Fed Five Level Inverter for Induction Motor Load

R.G.S Lakshmi
Department of Electrical and Electronics Engineering,
Sai Ganapathi Engineering College,
Visakhapatnam, Andhra Pradesh 531173, India.

J.A Ganeswari
Department of Electrical and Electronics Engineering,
Sai Ganapathi Engineering College,
Visakhapatnam, Andhra Pradesh 531173, India.

Ch.Susila
Department of Electrical and Electronics Engineering,
Sai Ganapathi Engineering College,
Visakhapatnam, Andhra Pradesh 531173, India.

Abstract

In this paper, a new configuration of a three-phase five-level multilevel voltage-source inverter is introduced. The proposed topology constitutes the conventional three-phase two-level bridge with three bidirectional switches. A multilevel dc link using fixed dc voltage supply and cascaded half-bridge is connected in such a way that the proposed inverter outputs the required output voltage levels. The fundamental frequency staircase modulation technique is easily used to generate the appropriate switching gate signals. The methodology used in this project consists of Sinusoidal Pulse Width Modulation and Space Vector Pulse Width Modulation. 12 IGBT's are used, out of which the pulse generation for the 6 switches is Sinusoidal PWM and for another 6 switches the pulse generation is Space Vector Modulation. The Multilevel Concept is shown with 5 different cases and the voltage levels are produced with the help of Modulation Index. The Outputs are analyzed by the simulation results. The Continuation of the Project is made by replacing the DC Cells with the Fuel Cells as the Input, and the output is measured from the Speed – Torque Characteristics of the Induction Motor for application purpose.

Index Terms— fuel cell, multi level inverter, induction motor.

I. Introduction

Multilevel inverters consist of a group of switching devices and dc voltage supplies, the output of which produces voltages with stepped waveforms. Multilevel technology has started with the three-level converter followed by numerous multilevel converter topologies[1]. Different topologies and wide variety of control methods have been developed in the recent literature. The most common multilevel inverter configurations are neutral point clamped (NPC), the flying capacitor (FC), and the cascaded H-bridge (CHB) [2].

These topologies reduce the cost and size of the inverter and improve the reliability since minimum number of power electronic components, capacitors, and dc supplies are used. The hybrid multistage converters consist of different multilevel configurations with unequal dc voltage supplies. With such converters, different modulation strategies and power electronic components technologies are needed. On the other hand, for the purpose of improving the performance of the conventional single- and three-phase inverters, different topologies employing different types of bidirectional switches have been suggested. Comparing to the unidirectional one, bidirectional switch (IGBT – Insulated Gate Bipolar Transistor) [3] is able to conduct the current and withstanding the voltage in both directions. Bidirectional switches with an appropriate control technique can improve the performance of multilevel inverters in terms of reducing the number of semiconductor components, minimizing the withstanding voltage and achieving the desired output voltage with higher levels.

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Based on this technical background, this paper suggests a novel topology for a three phase five-level multilevel inverter. The number of switching devices, insulated-gate driver circuits, and installation area and cost are significantly reduced. The magnitudes of the utilized dc voltage supplies have been selected in a way that brings the high number of voltage level with an effective application of a fundamental frequency staircase modulation technique. The functionality verification of the five Level Inverter is done using Simulink tool of Matlab Software.

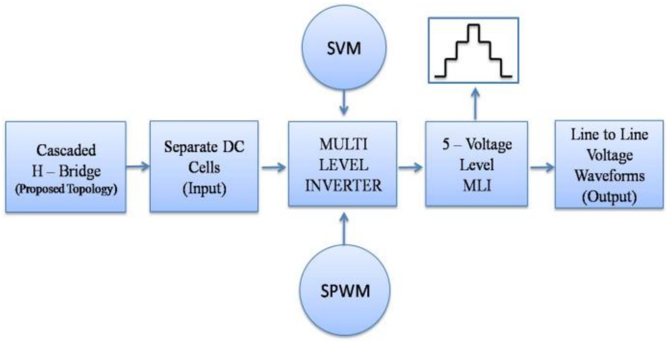

Fig 1: Base Model of the Project

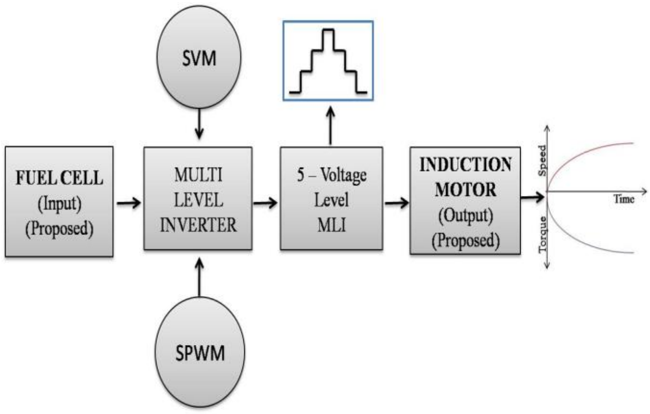

Fig 2: Continuation of the Project for Application Purpose

II MULTILEVEL INVERTERS

The multilevel inverters have drawn tremendous interest in the power industry. It may be easier to produce a high-power, high-voltage inverter with the multilevel structure because of the way in which device stresses are controlled in the structure. Increasing the number of voltage levels in the inverter without requiring higher ratings on individual devices can increase the power rating. The unique structure [4] of multilevel voltage source inverters allows them to reach high voltages with low harmonics without the use of transformers or series-connected synchronized-switching devices. As the number of voltage levels increases, the harmonic content of the output voltage waveform decreases significantly.

Multilevel inverters include an array of power semiconductors and capacitor voltage sources, the output of which generate voltages with stepped waveforms. Figure shows a schematic diagram of one phase leg of inverters with different numbers of levels, for which the action of the power semiconductors are represented by an ideal switch with several positions. A two-level inverter generates an output voltage with two values (levels) with respect to the negative terminal of the capacitor [see Figure 3], while the three-level inverter generates three voltages, and so on. Figure 3 (a) Two Levels,3 (b) Three Levels and 3 (c) n Levels [5].

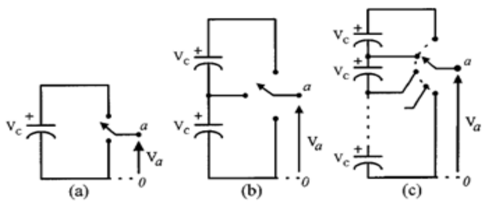

Fig 3 multi level inverter

III CARRIER-BASED PWM SCHEMES:

The carrier-based modulation schemes for multilevel inverters can be generally classified into two categories: **Phase-shifted** and **level-shifted modulations**. Both modulation schemes can be applied to the CHB inverters.

Phase-Shifted Multicarrier Modulation

In general, a multilevel inverter with m voltage levels requires (m – 1) triangular carriers. In the phase-shifted multicarrier modulation, all the triangular carriers have the same frequency and the same peak-to-peak

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amplitude [6], but there is a phase shift between any two adjacent carrier waves, given by

$$\varnothing_{cr} = 360°/(m-1) \quad \ldots\ldots\ldots\ldots (2.1)$$

The sinusoidal signal $V_{control}$ is phase-modulated by means of the angle α.

i.e., $V_A = \sin(\omega t + \delta)$

$V_B = \sin(\omega t + \delta - 2\pi/3)$

$V_C = \sin(\omega t + \delta + 2\pi/3)$

The modulated signal $V_{control}$ is compared against a phase shifted triangular signals in order to generate the switching signals for the VSC valves. The Fig. shows the pulses for one phase. The main parameters of the phase shifted PWM scheme are the amplitude modulation index of signal, and the frequency modulation index of the triangular signal.

The amplitude index is kept fixed at 1 pu, in order to obtain the highest fundamental voltage component at the controller output.

$$M_a = \frac{V_{control}}{V_{tri}} = 1p.u \quad \ldots\ldots\ldots\ldots\ldots (2.2)$$

Where

Vcontrol is the peak amplitude of the control signal.

Vtri is the peak amplitude of the triangular signals.

The switching frequency is set at 2000 Hz. The frequency modulation index is given by

$$M_f = f_s/f_1 \quad \ldots\ldots\ldots\ldots\ldots (2.3)$$

Where f_1 is the fundamental frequency

The modulating angle is applied to the PWM generators in phase A. The angles for phases B and C are shifted by 240^0 and 120^0, respectively. It can be seen in that the control implementation is kept very simple by using only voltage measurements as the feedback variable in the control scheme. The speed of response and robustness of the control scheme are clearly shown in the simulation results [7].

The **total number of active switches (IGBTs)** used in the CHB inverters can be calculated by

Nsw = 6(m-1)

CONTROLLER:

The aim of the control scheme is to maintain constant voltage magnitude at the point where a sensitive load is connected, under system disturbances. The control system only measures the r.m.s voltage at the load point, i.e., no reactive power measurements are required. The VSC switching strategy is based on a sinusoidal PWM technique which offers simplicity and good response. Since custom power is a relatively low-power application, PWM methods offer a more flexible option than the Fundamental Frequency Switching (FFS) [8] methods favored in FACTS applications. Besides, high switching frequencies can be used to improve on the efficiency of the converter, without incurring significant switching losses.

The controller input is an error signal obtained from the reference voltage and the value rms of the terminal voltage measured. A PI controller the output is the angle δ, which is provided to the PWM signal generator [9], processes such error. It is important to note that in this case, indirectly controlled converter, there is active and reactive power exchange with the network simultaneously: an error signal is obtained by comparing the reference voltage with the rms voltage measured at the load point. The PI controller process the error signal generates the required angle to drive the error to zero, i.e., the load rms voltage is brought back to the reference voltage.

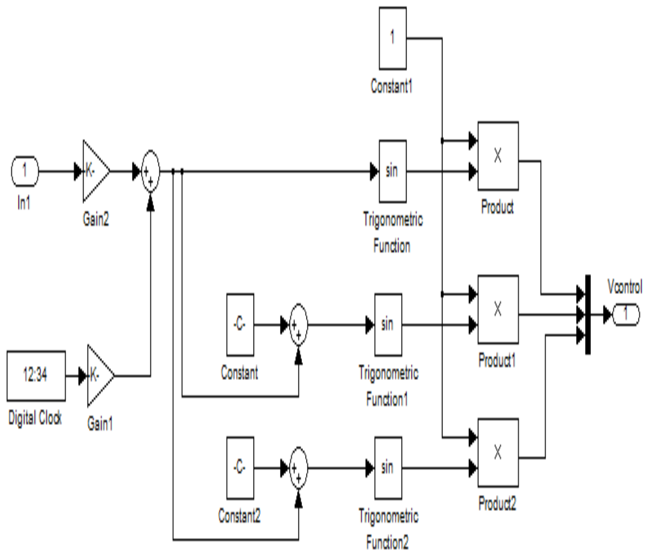

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Fig4: Generation of reference control signals for PWM controller

FIVE- LEVEL CASCADED H- BRIDGE LEG:

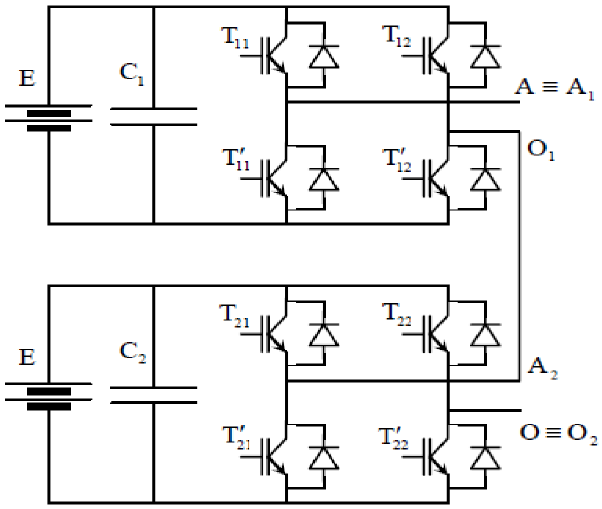

Fig 5: Five level cascaded H-bridge leg

The voltage level and switching state of the five level CHB (Cascaded H-bridge inverter) is as shown in the below Table 1.1:

Table 1: Operation for five-level h-bridge multilevel inverter:

Switches state								
T_{11}	T_{12}	T_{21}	T_{22}	T'_{12}	T'_{12}	T'_{21}	T'_{22}	V_{AO}
1	0	1	0	0	1	0	1	2E
1	1	1	0	0	0	0	1	E
1	0	0	0	0	1	1	1	E
1	0	1	1	0	1	0	0	E
0	0	1	0	1	1	0	1	E
1	1	1	1	0	0	0	0	0
1	1	0	0	0	0	1	1	0
1	0	0	1	0	1	1	0	0
0	1	1	0	1	0	0	1	0
0	0	1	1	1	1	0	0	0
0	0	0	0	1	1	1	1	0
0	1	1	1	1	0	0	0	-E
0	0	0	1	1	1	1	0	-E
0	1	0	0	1	0	1	1	-E
1	1	0	1	0	0	1	0	-E
0	1	0	1	1	0	1	0	-2E

Output waveform for pulse generator for five-level:

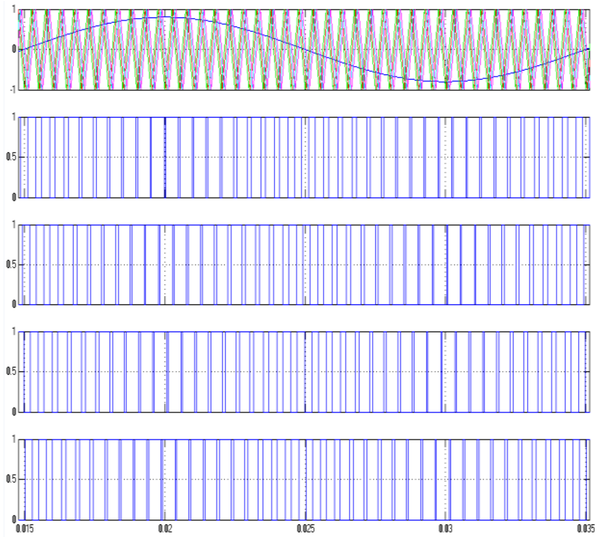

Fig 6 pulses for one phase of 5-level MLI

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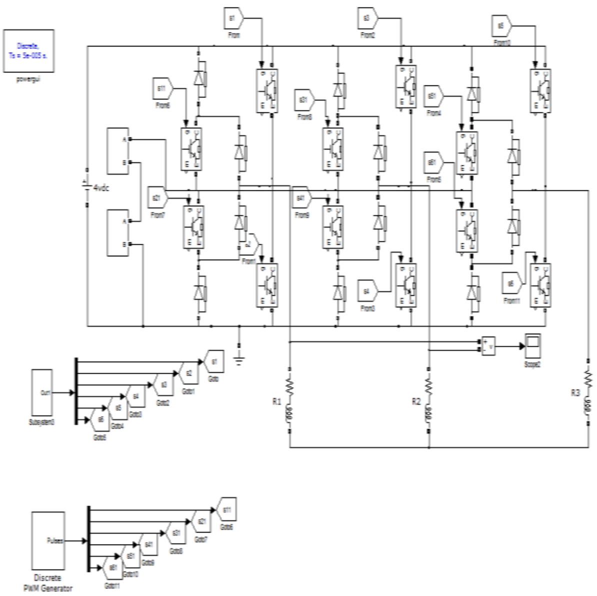

Fig 7 : Simulink Model Of The Proposed Three-Phase Five-Level Multilevel Inverter:

IV Five-Level Multilevel Inverter.

Three bidirectional switches (S1–S6, Da1–Dc2), two switches–two diodes type, are added to the conventional three-phase two-level bridge (Q1–Q6). The function of these bidirectional switches is to block the higher voltage and ease current flow to and from the midpoint (o). A multilevel dc link built by a single dc voltage supply with fixed magnitude of 4Vdc and CHB [7] having two unequal dc voltage supplies of Vdc and 2Vdc are connected to (+, –, 0) bridge terminals. Based on the desired number of output voltage levels, a number of CHB cells are used. Since the proposed inverter is designed to achieve five voltage levels, the power circuit of the CHB makes use of two series cells having two unequal dc voltage supplies. In each cell, the two switches are turned ON and OFF under inverted conditions to output two different voltage levels.

- The first cell dc voltage supply Vdc is added if switch T1 is turned ON leading to Vmg =+Vdc where Vmg is the voltage at node (m) with respect to inverter ground (g) or bypassed if switch T2 is turned ON leading to Vmg = 0.
- The second cell dc voltage supply 2Vdc is added when switch T3 is turned ON resulting in Vom =+2Vdc where Vom is the voltage at midpoint (o) with respect to node (m) or bypassed when switch T4 is turned ON resulting in Vom = 0.

The peak voltage rating of the switches of the conventional two level bridge (Q1–Q6) is 4Vdc whereas the bidirectional switches (S1–S6) have a peak voltage rating of 3Vdc. In CHB cells, the peak voltage rating of second cell switches (T3 and T4) is 2Vdc while the peak voltage rating of T1 and T2 in the first cell is Vdc.

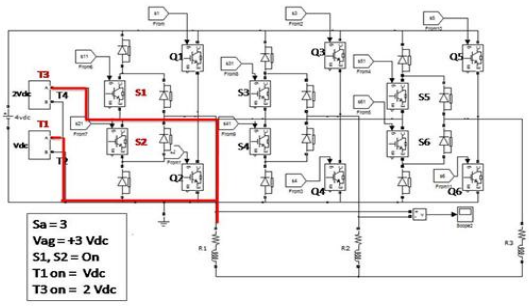

Fig 8 Proposed model

V INDUCTION MOTOR

The two names for the same type of motor, Induction motor and Asynchronous motor, describe the two characteristics in which this type of motor differs from DC motors and synchronous motors. Induction refers to the fact that the field in the rotor is induced by the stator currents, and asynchronous refers to the fact that the rotor speed is not equal to the stator frequency. No sliding contacts and permanent magnets are needed to make an induction motor work, which makes it very simple and cheap to manufacture. As motors, they rugged and require very little maintenance. However, their speeds are not as easily controlled as with DC motors. They draw large starting currents, and operate with a poor lagging factor when lightly loaded.

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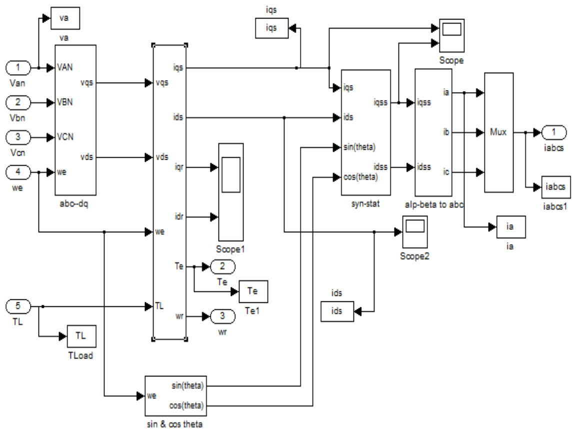

Fig 9: Induction motor modelling

VI FUEL CELL

As energy consumption rises, one must find suitable alternative means of generation to supplement conventional existing generation facilities. In this regard, distributed generation (DG) will continue to play a critical role in the energy supply demand realm. The common Technologies available as DG are micro-turbines, solar, photovoltaic systems, fuel cells stack and wind energy systems.

A fuel cell is an electro chemical device that converts the chemical energy of the fuel (hydrogen) into electrical energy. It is centered on a chemical reaction between fuel and the oxidant (generally oxygen) to produce electricity where water and heat are byproducts. This conversion of the fuel into energy takes place without combustion. The efficiency of the fuel cells ranges from 40-60% and can be improved to 80-90% in cogeneration applications. Fuel cell technology is a relatively new energy-saving technology that has the potential to compete with the conventional existing generation facilities. Among the various DG technologies available, fuel cells are being considered as a potential source of electricity because they have no geographic limitations and can be placed anywhere on a distribution system. Fuel cells have numerous benefits which make them superior compared to the other technologies. Benefits include high efficiency, high power quality and service reliability, few or no moving parts which leads to low noise, fuel flexibility, modularity and low maintenance.

Operating Principle:

The structure and the functioning of a fuel cell is similar to that of a battery except that the fuel can be continuously fed into the cell. The cell consists of two electrodes, anode (negative electrode) and cathode (positive electrode) separated by an electrolyte. Fuel is fed into the anode where electrochemical oxidation takes place and the oxidant is fed into the cathode where electrochemical reduction takes place to produce electric current and water is the primary product of the cell reaction [9].

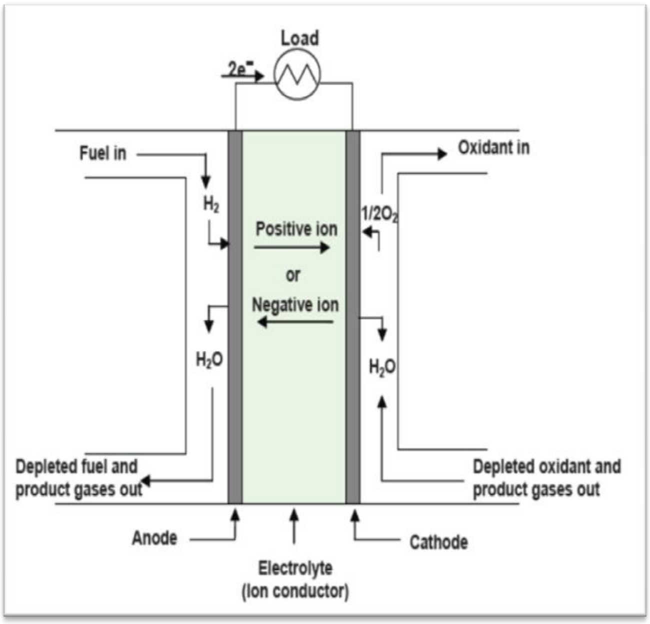

Figure 10: Schematic of an Individual fuel cell

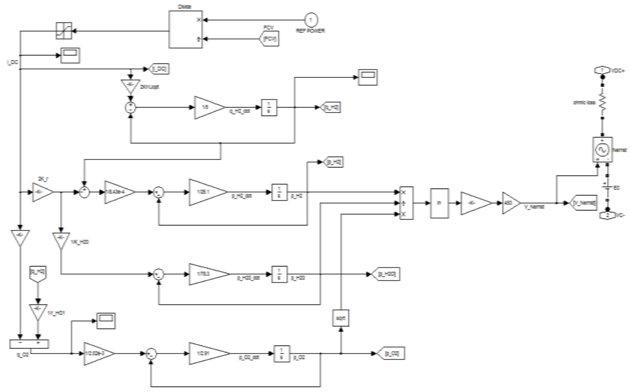

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Fig 11: Simulation Model of Fuel Cell

VII SIMULATION CIRCUITS AND RESULTS

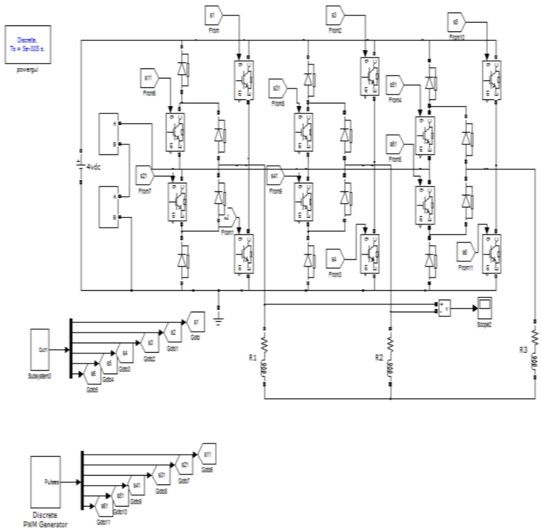

Fig 12: Circuit Diagram Of The Proposed Three-Phase Five-Level Multilevel Inverter

13) MODULATION INDEX (Ma) = 1.15

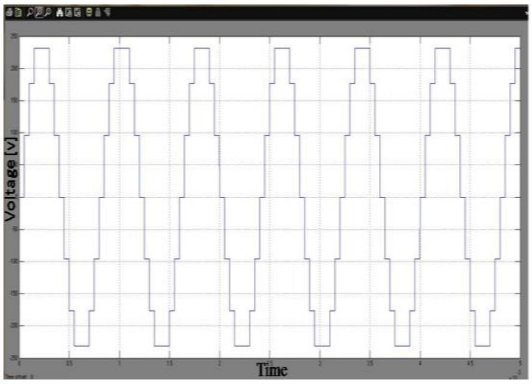

Fig 13: Output Waveform with Modulation Index = 1.15

THD ANALYSIS: 11.87%

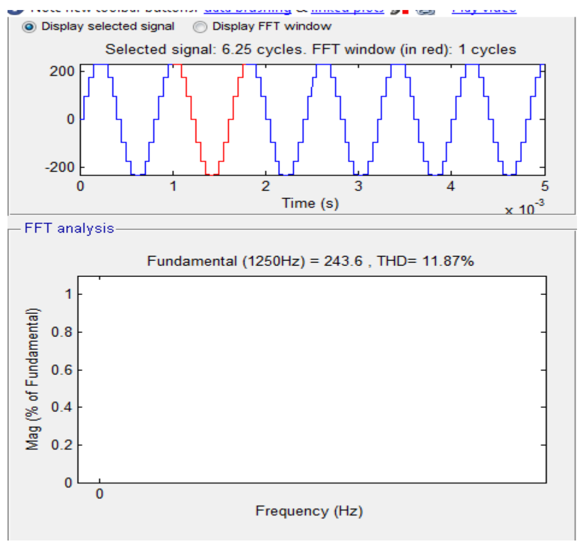

Fig 14: THD Analysis for waveform with MI = 1.15

FUEL CELL BASED MULTILEVEL INVERTER FOR AN INDUCTION MOTOR:

Input – DC Cells replaced with Fuel Cells

Output – Induction Motor is taken at Load and the Speed Torque Characteristics are Obtained.

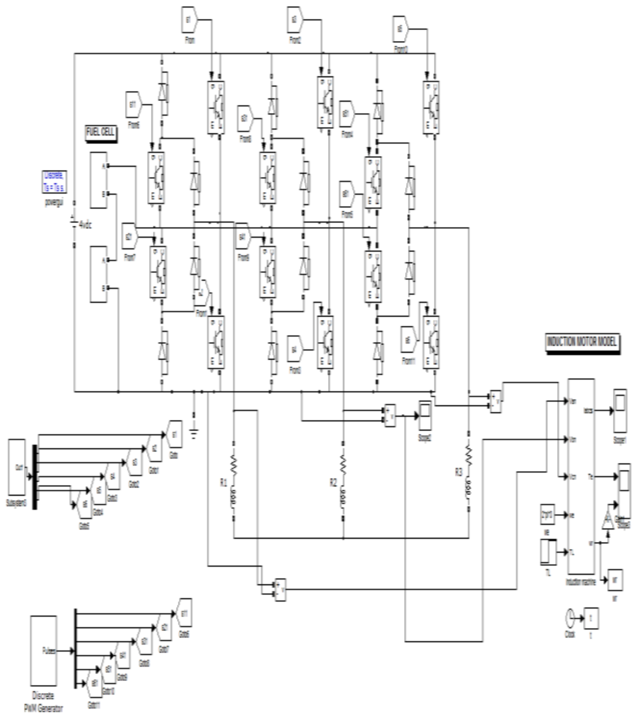

Fig 15: Model of Fuel Cell Based Multilevel Inverter For An Induction Motor:

FUEL CELL MODELLING:

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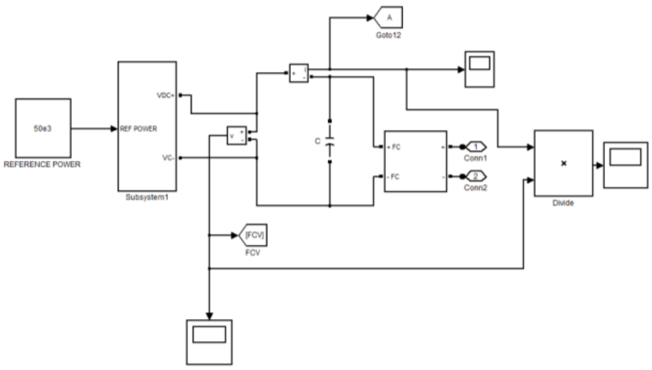


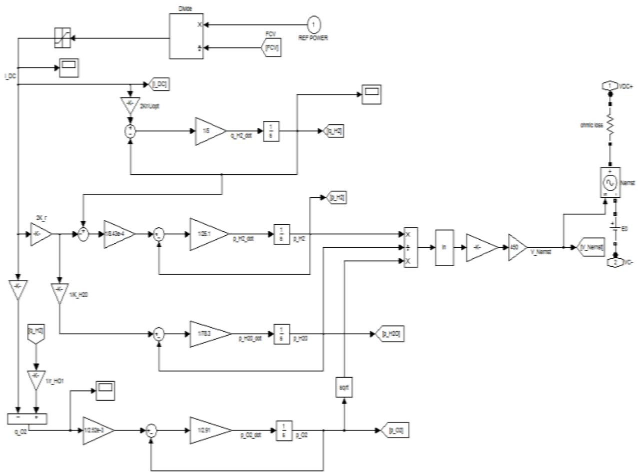


Fig 16: Fuel Cell Modelling

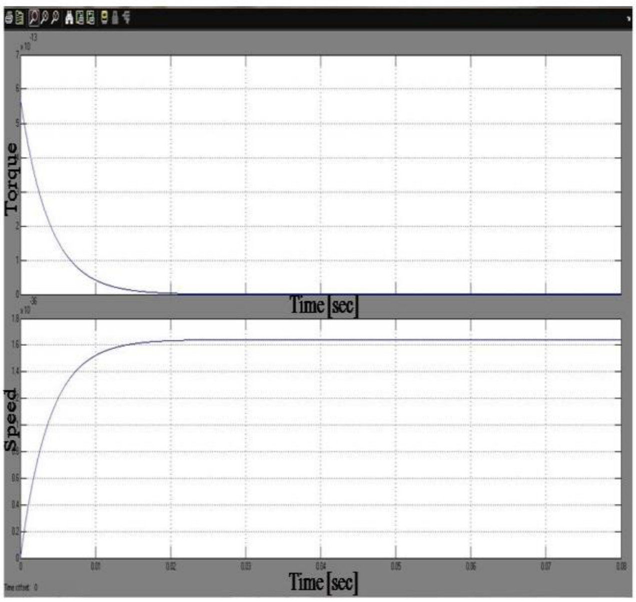
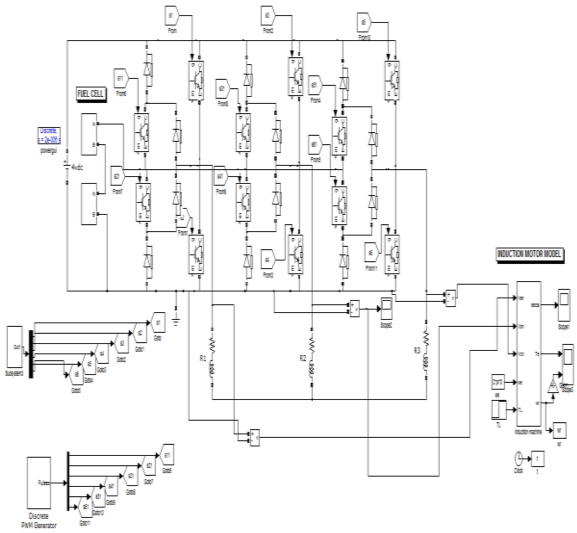


Fig 17: Speed Torque Characteristics of Induction Motor



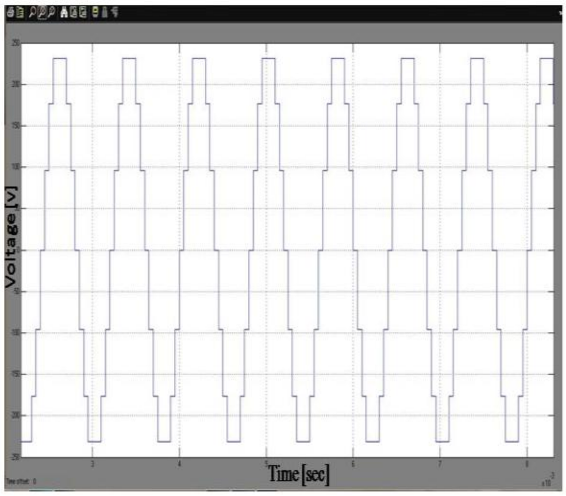


Fig 18: Output Waveform across Single Phase Load

CONCLUSION

A new topology of the three-phase five-level multilevel inverter was introduced. The suggested configuration was obtained from reduced number of power electronic components. Therefore, the proposed topology results in reduction of installation area and cost. The fundamental frequency staircase modulation technique was comfortably employed and showed high flexibility and simplicity in control.

In order to verify the performance of the proposed multilevel inverter, the proposed configuration was simulated, and the outputs are verified with the

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Modulation Index Values. The THD analysis is also done.

The Fuel cells implementation in the place of DC Cells was well executed in Simulink and the outputs are verified with the 3 phase Induction Motor Load, whose Speed – Torque characteristics are shown.

Hence, subsequent work in the future may include an extension to higher level with other suggested methods. For purpose of minimizing THD%, a selective harmonic elimination pulse width modulation technique can be also implemented. The slight disturbance in the waveforms of the Speed – Torque Characteristics can be minimized by emplyoying a feedback concept.

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