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# Simulation of Fuel Cell Based Three Phase Five – Level Multilevel Inverter with Induction Motor Load



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### Abstract:

In this paper, a new configuration of a three-phase fivelevel multilevel voltage-source inverter is introduced using the Fuel Cells as the Input. 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 with the help of lesser number of power electronic components. As in industrial applications, the DC supply is cost effective, so the fuel cells are proposed as a replacement of DC cells input and the modeling of fuel cell is shown in Simulink. The fundamental frequency staircase modulation technique is 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. 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 taking Induction Motor as the load and the Torque - Speed Characteristics are obtained with the help of the Simulation results.

### **Index Terms:**

Fuel Cell, Bidirectional Switches, Pulse Width Modulation, fundamental frequency stair case modulation, Multilevel Inverter.

## I. INTRODUCTION:

Multilevel inverter output voltage produce a staircase output waveform, this waveform look like a sinusoidal waveform. A multilevel inverter is power conversion device that produces an output voltage in the needed levels by using DC voltage sources applied to input.



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Multilevel inverter which performs power conversion by using the discrete DC voltage sources was firstly introduced in 1975. The multilevel inverter output voltage having less number of harmonics. If the multilevel inverter output increase to N level, the harmonics reduced to the output voltage value to zero. Multilevel inverter technology has emerged recently as a very important alternative in the area of high-power medium-voltage energy control. 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. The primary advantage of multi level inverter is their

•Small output voltage, results in higher output quality, •They can generate output voltages with extremely low distortion and lower order harmonics.

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. 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 Hbridge (CHB).

•The deviating voltage of neutral-point voltage in NPC.

- •The unbalanced voltage in the dc link of FC.
- •The large number of separated dc supplies in CHB are considered the main drawbacks of these topologies.

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

Volume No: 2 (2015), Issue No: 12 (December) www.ijmetmr.com



A Peer Reviewed Open Access International Journal

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 threephase inverters, different topologies employing different types of bidirectional switches have been suggested. Comparing to the unidirectional one, bidirectional switch (IGBT - Insulated Gate Bipolar Transistor) 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. 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.

### **II. PROPOSED TOPOLOGY:**

One 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 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 bridges (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 1: Circuit diagram of the proposed three-phase five-level multilevel inverter for diodes placed across switches S1-S6



Volume No: 2 (2015), Issue No: 12 (December) www.ijmetmr.com

December 2015 Page 599



A Peer Reviewed Open Access International Journal

#### Fig 2: Circuit diagram of the proposed three-phase five-level multilevel inverter for diodes placed across switches Q1-Q6

Line to Ground Voltages is determined with the equation (1):

$\begin{bmatrix} Vag \\ Vbg \\ Vcg \end{bmatrix} =$	$\frac{4Vdc}{N-1} \times$	Sa Sb Sc	(1)
		-004	(1)

N = No of Voltage levels = 5

The Table below describes the switching states for a 5 level Multilevel Inverter:

Sa	Vag	Ql	Q2	S1	S2	T1	T2	T3	T4
0	0 Vdc	off	on	off	off	on	off	off	on
1	1 Vđc	off	off	on	on	on	off	off	on
2	2 Vdc	off	off	on	on	off	on	on	off
3	3 Vdc	off	off	on	on	on	off	on	off
4	4 Vdc	on	off	off	off	on	off	on	off

### **III. PWM TECHNIQUES:**

The space vector modulation techniques differ from the carrier based in that way, there are no separate modulators used for each of the three phases. Instead of them, the reference voltages are given by space voltage vector and the output voltages of the inverter are considered as space vectors. There are eight possible output voltage vectors, six active vectors U1 - U6, and two zero vectors U0, U7



### **IV. FUEL CELL:**

Dynamic model of solid oxide fuel cell (SOFC) is done. Fuel cells operate at low voltages and hence fuel cells need to be boosted and inverted in order to connect to the utility grid. A DC-DC converter and a DC-AC inverter were used for interfacing SOFC with the grid. These models are built in MATLAB/SIMULINK. 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. 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.



## Figure 4: Schematic of an Individual fuel cell

The typical anode and cathode reactions for a hydrogen fuel cell are given by Equations (6.1) and (6.2), respectively



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$$\frac{H2}{4} - \frac{2H^{+} + 2e^{-}}{4} - \frac{(6.1)}{4}$$

## **V. INDUCTION MOTOR:**

The inputs of a squirrel cage induction machine are the three-phase voltages, their fundamental frequency, and the load torque. The outputs, on the other hand, are the three phase currents, the electrical torque, and the rotor speed. The d-q model requires that all the three-phase variables have to be transformed to the two-phase arbitrary rotating frame. Consequently, the induction machine model will have blocks transforming the three-phase voltages to the d-q frame and the d-q currents back to three-phase. There are four important blocks present in D-Q model implementation of simulink.

- 1. ABC to da-qa transformation
- 2. Flux linkages calculators
- 3. Current Calculation
- 4. Speed dynamics

### VI.SIMULATION CIRCUITS AND RE-SULTS:

1) SIMULATED WAVEFORMS AT DIFFERENT MODULATION INDICES FOR THE MULTILEVEL INVERTER WITH FUEL CELLS (Diodes placed across switches S1-S6)



Fig 5: MLI with Fuel Cells and Induction Motor



### **MODULATION INDEX (Ma) = 0.9**

2) SIMULATED WAVEFORMS AT DIFFER-ENT MODULATION INDICES FOR THE MULTILEVEL INVERTER WITH FUEL CELLS (Diodes placed across switches Q1-Q6)



Fig 6: MLI with Fuel cells and Induction Motor MODULATION INDEX (Ma) = 1.3



Volume No: 2 (2015), Issue No: 12 (December) www.ijmetmr.com December 2015 Page 601



A Peer Reviewed Open Access International Journal

## **MODULATION INDEX (Ma) = 0.8**



**3) OUTPUT WAVEFORM OF FUEL CELL** 



4) TORQUE-SPEED CHARACTERISTICS OF INDUCTION MOTOR:



VII. 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 Modulation Index Values. 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 Total Harmonic Distortion, 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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A Peer Reviewed Open Access International Journal

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Volume No: 2 (2015), Issue No: 12 (December) www.ijmetmr.com

December 2015 Page 603