Harmonic Torque Reduction/Elimination using 3-Level and 5-Level Inverter for Three Phase Induction Motor

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Abstract - **The multilevel inverter power structure plays a vital role in the power industry. It is easier to produce a high-power, high-voltage inverter with the multilevel structure. The topologies of multilevel inverter have several advantages such as lower total harmonic distortion (THD), lower electromagnetic interference (EMI) generation, reduction of voltage ratings of the power semiconductor switching devices and high output voltage. This paper presents a universal control scheme based on multicarrier PWM methods and its implementation in threelevel, five-level and nine-level cascaded inverters feeding a three phase induction motor. This paper compares total harmonic distortion values of voltage and current waveforms of induction motors between different levels.**

Index Terms - List key index terms here. No mare than 5.

I. INTRODUCTION

Power electronic converters, especially dc/ac PWM inverters have been extending their range of use in industry because they provide reduced energy consumption, better system efficiency, and improved quality of product, good maintenance and so on. It should be noted that lower switching frequency usually means lower switching loss and higher efficiency. Large electric drives and utility applications require advanced power electronics converter to meet the high power demands. As a result, multilevel power converter structure has been introduced as an alternative in high power and medium voltage situations[1]. A multilevel converter not only achieves high power ratings, but also improves the performance of the whole system in terms of harmonics, dv/dt stresses, and stresses in the bearings of a motor. Several multilevel converter topologies have been also developed i) diode clamped, ii) flying capacitors, and iii) cascaded or H-bridge. Referring to the literature reviews, the cascaded multilevel inverter (CMI) with separated DC sources is clearly the most feasible topology for use as a power converter for medium & high power applications due to their modularization and extensibility[2]. The Hbridge inverter eliminates the excessively large number of (i) bulky transformers required by conventional multilevel inverters, (ii) clamping diodes required by multilevel diode-clamped inverters and (iii) flying capacitors required by multilevel flying-capacitor inverter. As a preliminary study the thesis examined and compared the most common multilevel topologies found in the published literature[3].

In this paper, a universal control scheme based on multicarrier PWM methods and its implementation in three-level, five-level and nine-level cascaded inverters feeding a three phase induction motor is presented. Advantage of using cascaded-inverter is circuit layout flexibility. Modularized circuit layout and packaging is possible because each level has the same structure, and there are no extra clamping diodes or voltage balancing capacitor. The number of output voltage levels can be easily adjusted by adding or removing the full-bridge cells. Modulation topology proposed in this paper is Multicarrier Pulse Width Modulation, which is one of the primitive techniques and is used to suppress harmonics presented in the quasi-square wave. Only triangular carrier is considered in this paper. Simulation studies are carried out using 3-Phase, 50HP, 400V, 50Hz, and 15.

II. PRINCIPLE OF THE PROPOSED METHOD 1500 RPM INDUCTION MACHINE

The below diagram specifies a multilevel inverter(5).for simplicity the vectors are not depicted .due to adjacent vectors small triangles are formed are called sectors. Such six sectors around a voltage space vector forms a hexagon called sub hexagon [14], [15]. Multi-level inverters can be viewed as composed of a number of such sub hexagon. The shaded regions in Fig. 1 show two sub hexagons. They are represented as “sub hexagon I” (referred as inner sub hexagon) having the vector 000 as the center and “sub hexagon II” having the vector 330 as the center. The inner sub hexagon can be viewed as a space vector diagram of a two-level inverter whose inverter voltage vectors switch between the lowermost levels. Sub hexagon II can be also viewed as a space vector diagram of a two-level inverter, whose voltage vectors involve higher levels. The shifting of the sub hexagons in the space vector diagram of a multilevel inverter to the zero vector 000 simplifies the switching time calculations associated with multilevel inverters [13]–[15]. The shifting of sub hexagon II in the space vector diagram of a multilevel inverter toward the zero vector 000 involves the mapping of the sectors of sub hexagon II to the voltage space vectors associated with any sub hexagon By subtracting this vector at the center of the sub-hexagon, the reference space vector can be mapped.

III. Multilevel Inverter

Multilevel inverters have drawn tremendous interest in the power industry. They present a new set of feature that are well suited for use in reactive power compensation. Multilevel inverters will significantly reduce the magnitude of harmonics and increases the output voltage and power without the use of step-up transformer. A multilevel inverter consists of a series of H-bridge inverter units connected to three phase induction motor. The general function of this multilevel inverter is to synthesize a desired voltage from several DC sources. The AC terminal voltages of each bridge are connected in series. Unlike the diode clamp or flyingcapacitors inverter, the cascaded inverter does not require any voltage clamping diodes or voltage balancing capacitors.[1-4],[10],[13]. This configuration is useful for constant frequency applications such as active front-end rectifiers, active power filters, and reactive power compensation. Choosing appropriate conducting angles for the H bridges can eliminate a specific harmonic in the output waveform. The required conduction angles can be calculated by analyzing the output phase voltage of cascade inverter assuming that four H-bridges have been used, the output voltage Vao can be given as: Vao = Va1 +Va2 +Va3 +Va4 +Va5… Since the wave is symmetrical along the x-axis, both Fourier coefficient A0 and An are zero. Just the analysis of Bn is required. It is given as:

where j = Number of dc sources n = odd harmonic order Therefore, to choose the conducting angle of each H bridge precisely, it is necessary to select the harmonics with certain amplitude and order, which needs to be eliminated. [3],[4],[5] To eliminate 5th, 7th, and 11th harmonics and to provide the peak fundamental of the phase voltage equal to 80% of its maximum value, it needs to solve the following equation with modulation index

M = 0.8: $\cos(5\alpha 1) + \cos(5\alpha 2) + \cos(5\alpha 3) + \cos(5\alpha 4) = 0$

$\cos(7\alpha 1) + \cos(7\alpha 2) + \cos(7\alpha 3) + \cos(7\alpha 4) = 0$

$\cos(11\alpha 1) + \cos(11\alpha 2) + \cos(11\alpha 3) + \cos(11\alpha 4) = 0$

$\cos(\alpha 1) + \cos(\alpha 2) + \cos(\alpha 3) + \cos(\alpha 4) = 0.8*4$

IV. Five Level and Seven Level Inverter Circuits using only Two Cascaded H- Bridges

There are several types of multilevel inverters but the one considered in this paper is the cascaded multilevel inverter (CMI). The structure of the CMI is not only simple and modular but also requires the least number of components compared to other types of multilevel inverters. This in turn, provides the flexibility in extending the CMI to higher number of levels without increase in circuit complexity as well as facilitates packaging.

A. Single phase structure of a five level Cascaded Multilevel inverter

A single-phase structure of an m-level cascaded inverter is illustrated in Fig 1. Each separate dc source (SDCS) is connected to a single-phase fullbridge,or H-bridge, inverter. Each inverter level can generate three different voltage outputs, $+V_{dc}$, 0, and$-V_{dc}$ by connecting the dc source to the ac output by different combinations of the four switches, S11, S12,S13, and S14. To obtain $+V_{dc}$, switches S11 and S14are turned on, whereas $-V_{dc}$ can be obtained by turning on switches S12 and S13. By turning on S11 and S12 or S13 and S14, the output voltage is 0. The ac outputs of each of the different full-bridge inverter levels are connected in series such that the synthesized voltage waveform is the sum of the inverter outputs.

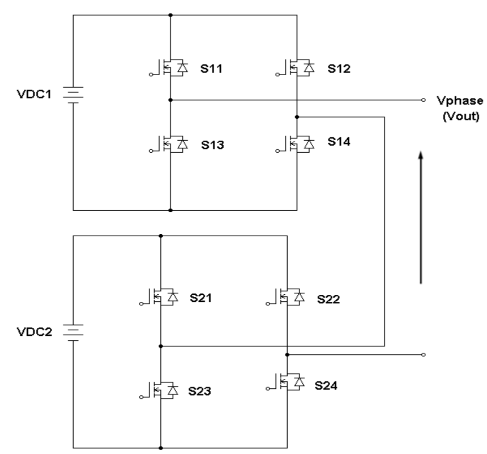


Fig. 1 Single Phase Structure of Cascaded Multilevel inverter

The structure shown in Fig.1 is used to produce Five Level Inverter output voltage by giving same DC source value and Seven Level Inverter output voltagsby giving unequal DC source value. Here for Five Level output 225V is given for both upper and lower H-bridge and for Seven Level output 150V and 300Vis given for upper and lower H-bridge respectively.

B. Three phase structure of Cascaded Multilevel Inverter

The Three Phase Structure of CascadedMultilevel inverter is illustrated in Fig.2. Each dcsource is connected to an inverter. Each inverter levelcan generate three different voltage outputs, +V_{dc}, 0,and –V_{dc} using various combinations of the fourswitches. The ac outputs of the different full bridgeinverter levels are connected in series such that thesynthesized voltage waveform is the sum of theinverter outputs.

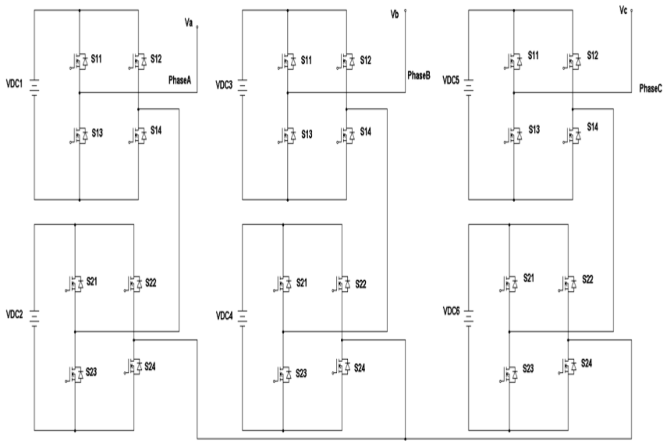


Fig. 2 Three Phase Structure of Cascaded Multilevel inverter.

V. SYNCHRONOUS MOTOR DRIVE

Synchronous speed of Induction Motor is directly proportional to the supply frequency. Hence, by changing the frequency, the synchronous speed and the motor speed can be controlled below and above the normal full load speed. The voltage induced in the stator, E is proportional to the product of slip frequency and air gap flux. The motor terminal voltage can be considered proportional to the product of the frequency and flux, if the stator voltage is neglected. Any reduction in the supply frequency without a change in the terminal voltage causes an increase in the air gap flux. Induction motors are designed to operate at the knee point of the magnetization characteristic to make full use of the magnetic material. Therefore the increase in flux will saturate the motor. This will increase the magnetizing current, distort the line current and voltage, increase the core loss and the stator copper loss, and produce a high pitch acoustic noise. While any increase in flux beyond rated value is undesirable from the consideration of saturation effects, a decrease in fluxis also avoided to retain the torque capability of the motor. Therefore, the variable frequency control below the rated frequency is generally carried out by reducing the machine phase voltage, V, along with the frequency in such a manner that the flux is maintained constant. Above the rated frequency, the motor is operated at a constant voltage because of the limitation imposed by stator insulation or by supply voltage limitations.

VI. SIMULATION MODEL AND RESULTS

Multilevel inverter fed induction motor drive inverter is implemented in MATLAB SIMULINKwhich is shown in Fig.3. The MATLAB SIMULINKmodel of Single leg of five level Cascaded Multilevelinverter using two H-bridge configuration is shown inFig.4.

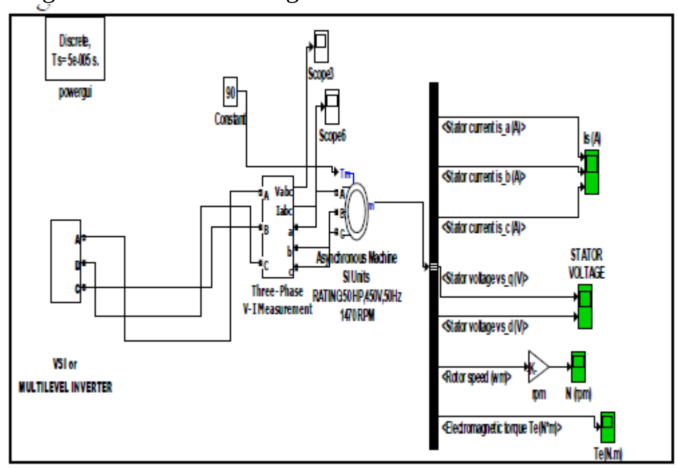


Fig. 3 Matlab/Simulink model of Multilevel Induction Motor dive.

The single phase five level inverter output isin Fig.5. The three phase five level inverter output phase voltage after feeding to induction motor is shown in Fig.6. The stator currents with respect to three phases are shown in Fig.7. The Variation in speed is shown in Fig.8. The speed increases and settles at 1470 rpm. The Torque is shown in Fig.9.FFT analysis is done for the voltage and current and the corresponding spectrum is shown in Fig.10 andFig.11 respectively. It can be seen that the magnitude of fundamental voltage for five level inverter fed induction motor drive is 222.4 Volts. The total harmonic distortion is 4.95 percent and the magnitude

of fundamental current is 97.93 Amperes. The total harmonic distortion is 1.57 percent.

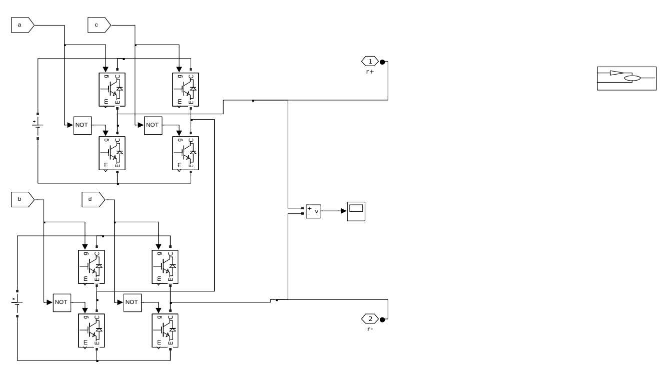


Fig. 4 Matlab/Simulink model of single leg of three phase Five level Multilevel Inverter.

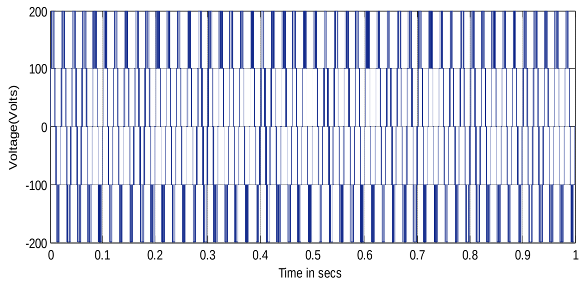
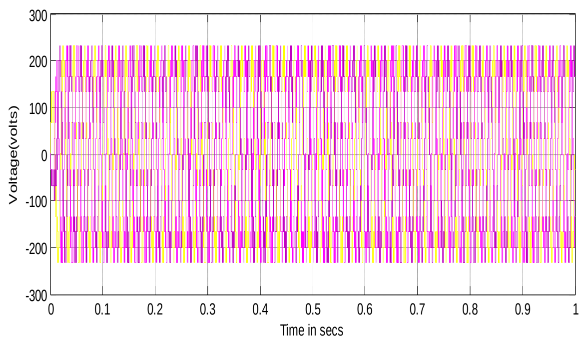


Fig: 5Three phase input voltage wave form



Fig; 6 Three phase output voltage wave form

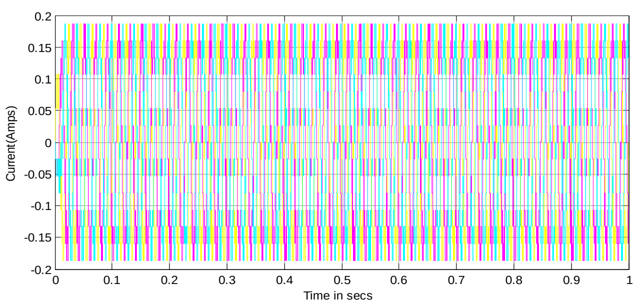


Fig: 7 Three phase output current wave form

CONCLUSION

Three level and five level inverter fed induction motor drive are simulated using the blocks ofsimulink. The results of three level and five level systems are compared. It is observed that the total harmonic distortion produced by the seven level inverter system is less than that of a five level inverter fed drive system. Therefore the heating due to three level inverter system is less than that of a five level inverter fed drive system. The simulation results of voltage, current, speed and spectrum are presented. This drive system can be used in industries where adjustable speed drives are required to produce output with reduced harmonic content. The scope of this work is the modeling and simulation of three level and Five level inverter fed induction motor drive systems. Experimental investigations will be done in future. Seven level inverter system is aviablealternative since it has better.

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