

SPECIFIC HARMONIC ELIMINATION SCHEME FOR NINELEVEL CASCADED H- BRIDGE INVERTER FED THREE PHASE INDUCTION MOTOR DRIVE

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ABSTRACT

A method is presented that a cascaded H-Bridge multilevel inverter can be implemented using unequal dc power sources and less number of switches. A standard cascade multilevel inverter requires hdc sources for $2h + 1$ levels. Proposed scheme allows less number of unequal DC power sources without the requirement of transformers. Cascaded H-Bridge multilevel inverter fed induction motor shows the better performance due to fundamental frequency switching scheme. High quality output power is derived due to the absence of lower order harmonics. High conversion efficiency is also achieved for induction motor drive when it is operated by the proposed method. The performance of three phase cascaded H-Bridge multilevel inverter with unequal dc source is simulated by using MATLAB/Simulink. Harmonic analysis is done on cascaded H-Bridge nine level inverter to demonstrate the superiority of the proposed system.

Keywords:Fundamental frequency switching control, multilevel inverter, Total Harmonic Distortion (THD), Unequal dc sources.

1. INTRODUCTION

The recent development in solid-state electronics is widely used in industries to control motor drives, computers and communications, power systems, switching mode power supplies, automotives, etc. The inverter is one of the most extensive assemblies in power electronics. The main aspects for the development of multilevel inverters are multilevel voltage waveform, low total harmonic distortion and division of voltage to the switching devices [1]. Multilevel inverters have received high attention because of their reliable operation, high efficiency and low electromagnetic interference (EMI). The desired output of a multilevel converter is synthesized by several sources of dc voltages [2]- [8]. With an increasing number of dc voltage sources, the inverter output voltage approaches nearly sinusoidal waveform while using a fundamental frequency switching scheme. Transformerless multilevel inverters are uniquely suited for this application because of the high VA ratings possible with these inverters [2]. Structure of the multilevel voltage source inverters allows them to reach high voltages with low harmonics without the use of transformers or series-connected synchronized switching devices. Multilevel inverters also have several advantages with respect to hard switched two

level pulse width-modulation (PWM) variable-speed drives. Motor damage and failure have been reported by industry as a result of some variable-speed drives operated by the inverters which has high voltage change rates (dv/dt), which produced a common-mode voltage across the motor windings.

The main problems of high frequency switching are “failure of motor bearing” and “insulation breakdown in motor winding” because of dielectric stresses, circulating currents, voltage surge and corona discharge [9]–[11]. Multilevel inverters can able to overcome these problems because their individual devices have a much lower stress per switching and they can operate at high efficiencies because they can switch at a much lower frequency than PWM-controlled inverters.

There are variety of topologies are available in multilevel inverters. They are diode-clamped, flying capacitor and H-bridge cascaded multilevel inverters. Compare with diode-clamped multilevel inverter and flying capacitor multilevel inverter, the cascaded inverter needs less number of components and simple control methods. In high voltage fields, the cascaded multilevel inverters are widely used. Now a day, the existing PWM inverters are replaced by cascaded multi-level inverters [12], [13]. In multilevel inverters,

cascaded H-bridge multilevel inverter with unequal dc voltage sources is smart because it does not affect from capacitor voltage balancing. But switching devices are subjected to unequal voltage stress [14], [15]. Multilevel inverter which uses bulk capacitors, need for an adequate control or modulation strategy to balance the voltage in the capacitors.

This paper presents a new topology of multilevel inverter which uses less number of unequal dc sources, switching devices and eliminates the need of capacitors. In this work, a method is given to compute the switching angles for a multilevel converter so as to produce the required output voltage while at the same time cancel out specified higher order harmonics. Particularly, a complete analysis is given for a nine level converter.

2. CASCADED H- BRIDGE MULTILEVEL INVERTER TOPOLOGY

If all dc-voltage sources are not equal, then the inverter is known as an asymmetric multilevel inverter. Consider a single-phase structure of cascade multilevel inverter with two H-bridges as shown in Fig.1. Separate dc source is connected to each H-bridges of a single-phase multilevel inverter. The ac output of each level is connected in series such a way that the synthesized voltage waveform is the sum of the H- bridge outputs. V_1 is the output voltage of the first H-bridge and V_2 is the output voltage of the second H-bridge, so that the output of this cascade multilevel inverter is denoted by

$$V_0 = V_1 + V_2 \quad (1)$$

For the asymmetric multilevel inverter, the value of the each dc source is obtained as follows:

$$V_k = 3^{(k-1)} V_{dc}, k = 1, 2, \dots, h \quad (2)$$

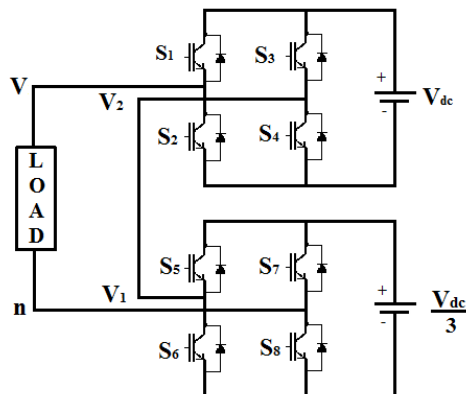


Fig.1 Single Phase Structure of Asymmetrical Cascaded Nine level inverter

With these values of the dc sources (h), any number of voltage levels can be obtained at the output. The number of output voltage levels and switching devices can be written as follows:

$$N_L = 3^h \quad (3)$$

$$N_S = 4h \quad (4)$$

The maximum output voltage can be written as follows in terms of the number of the dc sources,

$V_{o,max} = (3^h - 1)V_{dc}/2 \quad (5)$ For producing nine level output, the symmetric multilevel inverter require 16 switching devices, the proposed asymmetric multilevel inverter uses only 8 switching devices for the same output voltage levels. This is the advantage of the asymmetric topology over the symmetric topology. However, this kind of multilevel inverter requires dc voltage sources with different values, providing of the dc voltage sources with different values which is a challenging issue.

3. SELECTION OF SWITCHING ANGLES

Pulse width modulation control or space vector PWM methods are widely used techniques in the inverter control. These conventional methods will cause extra losses due to high frequency switching. To overcome this problem, low switching control methods¹⁸⁻¹⁹ are used. In this proposed method, fundamental frequency switching is used. Output voltage of the waveform can be evaluated by Fourier series expansion as given,

$$V(\omega t) = \left(\frac{V_{dc}}{2}\right) \frac{4}{n\pi} \sum_{n=1,3,5}^{\infty} [\cos(n\theta_1) + \cos(n\theta_2) + \cos(n\theta_3) + \cos(n\theta_4)] \sin n\omega t \quad (11)$$

From equation (11), it is clear that 5th, 7th and 11th order harmonic can be eliminated. The triplen harmonics will be cancelled automatically in the three phase system. Where V_1 is the desired fundamental voltage and to determine the switching angles $\theta_1, \theta_2, \theta_3$ and θ_4 so that (11) becomes $V(\omega t) = V_1 \sin(\omega t)$. In practice, it can be done approximately. In this case, the desire is to cancel the 5th, 7th and 11th order harmonics as they tend to dominate the total harmonic distortion. Mathematically, the statement of these conditions is then

$$\left(\frac{4V_{dc}}{4\pi}\right) [\cos(\theta_1) + \cos(\theta_2) + \cos(\theta_3) + \cos(\theta_4)] = V_1 \quad (12)$$

$$\left(\frac{4V_{dc}}{20\pi}\right) [\cos(5\theta_1) + \cos(5\theta_2) + \cos(5\theta_3) + \cos(5\theta_4)] = 0 \quad (13)$$

$$\left(\frac{4V_{dc}}{28\pi}\right) [\cos(7\theta_1) + \cos(7\theta_2) + \cos(7\theta_3) + \cos(7\theta_4)] = 0 \quad (14)$$

$$\left(\frac{4V_{dc}}{44\pi}\right) [\cos(11\theta_1) + \cos(11\theta_2) + \cos(11\theta_3) + \cos(11\theta_4)] = 0 \quad (15)$$

Four transcendental equation set can be solved to get the four unknowns θ_1 , θ_2 , θ_3 and θ_4 . The widely used methods are resultant theory, iterative method such as the Newton-Raphson method²⁰. MATLAB nonlinear solver can also be used to solve the above set of equations. Total harmonic distortion (THD) is calculated for the arrived set of solutions to select the set which generate the lowest harmonic distortion (mostly due to the 11th and 13th harmonics). Percentage of total harmonic distortion (THD) is defined by

$$THD\% = \frac{\sqrt{V_3^2 + V_5^2 + V_7^2 + \dots + V_{19}^2}}{V_1} \times 100 \quad (16)$$

The quality of the multilevel waveform depends on the selection of switching angles. Varying the switching angle to control the magnitude of rms value of output waveform also affect the total harmonic distortion (THD).

4. SIMULATION STUDY

The simulation of three phase nine level cascaded H-Bridge multilevel inverter fed three phase induction motor is done using MATLAB/Simulink. In the simulation study all the switches are considered to be ideal. The frequency of the output voltage is 50 Hz. In this proposed multilevel inverter, only eight switches are required to obtain the output voltage for each phase. More switches are required to achieve the same output voltage in the symmetrical type where equal dc sources are used. The dc voltage sources used in the simulation studies are separate dc sources. In this method, the switching angles can be obtained to eliminate some selected harmonics or minimization of total harmonics distortion. The control method used in this paper is based on generating an output voltage waveform which has minimum error with its reference value.

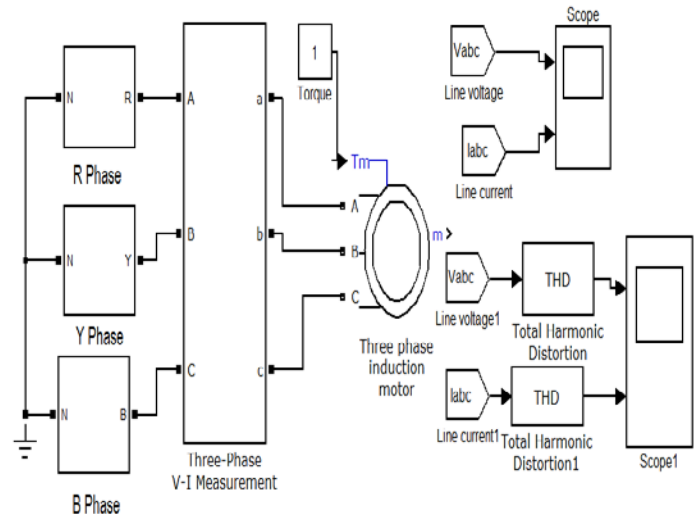


Fig.2 Simulation diagram of three phase cascaded H-bridge nine level Inverter

In case of the symmetrical type, the voltage of each switch is limited to the value of dc source. Since the proposed multilevel inverter uses unequal dc sources the voltage stress among the switches will be asymmetrically distributed. Hence care should be taken while selecting power switches for this type of configuration. The simulation diagram of three phase ninelevel cascaded H-Bridge multilevel inverter is shown in Fig.2.

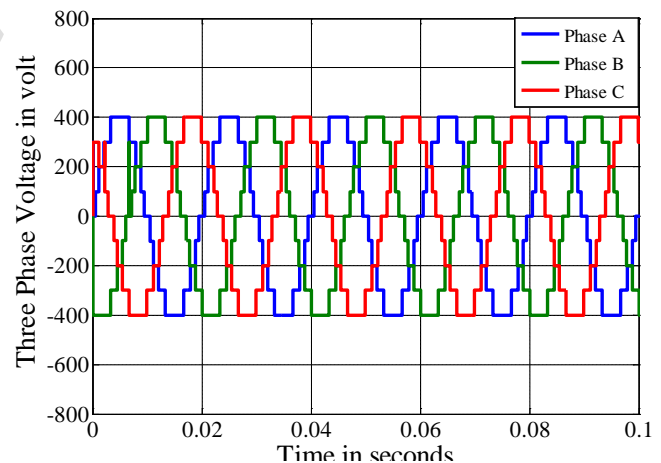


Fig. 3 Three phase voltage waveform

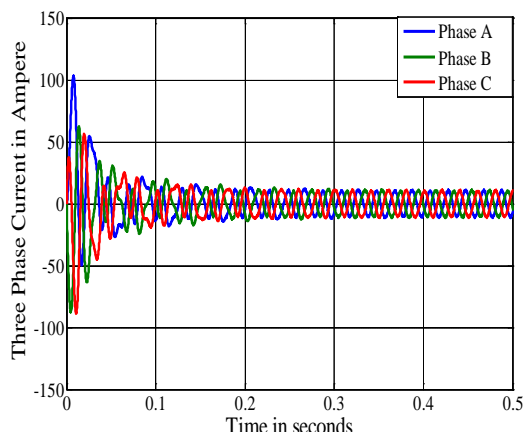


Fig. 4 Three phase stator current waveform

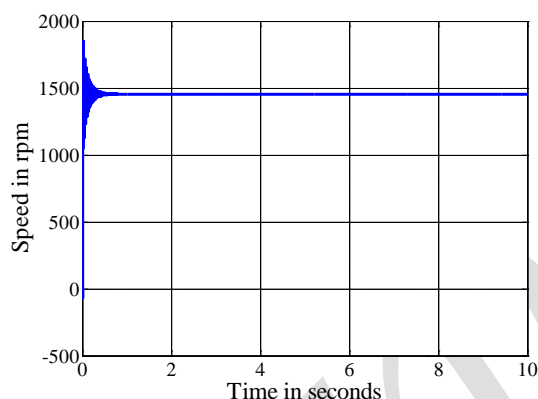


Fig. 5 Rotor Speed

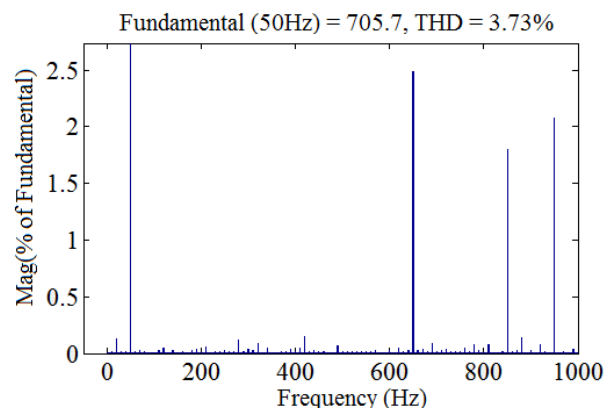


Fig. 6 FFT Spectrum of line voltage waveform

The spectrum of the output current is taken to determine the Total Harmonic Distortion (THD) of three phase induction motor drive. The simulation results of three phase voltage and current, rotor speed are presented in the Fig.3, Fig.4 and Fig.5. It clearly

shows that all of the desired voltage levels are generated. FFT spectrum of line voltage proposed cascaded H-bridge nine level inverter is presented in Fig.6. From the Fig.3 and Fig.4, it is clear that the output current waveform is smoother than the output voltage. From the normalized FFT analysis shown in Fig.6, it can be derived that the magnitude of lower order harmonics are very low and the magnitude of higher order harmonics are nearly equal to zero.

Table 1: Comparison between conventional and proposed cascaded H- bridge nine level inverter

Topology Parameters	Conventional cascaded H- Bridge Nine level inverter	Proposed cascaded H- Bridge Nine level inverter	Percentage Reduction
Number of switches per phase	16	8	50%
Number of DC sources per phase	4	2	50%
THD%	8.67%	3.73%	4.94%

Comparison between conventional cascaded nine level inverter and proposed cascaded nine level inverter is given in Table.1. The proposed cascaded H-Bridge Multilevel inverter topology has the advantage of its reduced number of switches and dc sources compared to conventional cascaded H-bridge multilevel inverter. Cost and weight also reduced. Switching losses are considerably reduced, in turn, heat produced in the converter is also reduced. It can be extended to any number of levels. The above features give the keen interest to use the proposed cascaded nine level inverter in the industry where the conventional inverters are used.

5. CONCLUSION

The proposed cascaded H-Bridge multilevel inverter fed three phase induction motor uses unequal dc power sources for producing desired multilevel voltage is simulated. A fundamental frequency switching control algorithm is developed. The total harmonic distortion is reduced considerably. The simulation result of stator current waveforms shows

that the lower order harmonics have been reduced and also higher order harmonics are eliminated. Harmonic elimination reduces the heat generated in the stator winding of the induction motor. The torque of the induction motor is improved with the markable level due to the elimination of the harmonics (fifth, seventh and eleventh), which is the main cause for the production of negative torque.

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