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Induction Motor Performance Fed from Six-level Diode Clamped Multilevel Inverter

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ABSTRACT: This paper presents performance of induction motor (IM) fed by six-level diode clamped multilevel inverter (DCMLI) as three phase power supply unit. The accessible model consist of five series connected dc sources, a six-level DCMLI and a three phase induction motor as load. The simulation results and total harmonic distortion (THD) has been mathematically verified

KEYWORDS: Fundamental switching, DCMLI, harmonic elimination, multilevel inverter.

I.INTRODUCTION

The voltage source inverter produce an output voltage or a current with levels either 0 or +/- Vdc. They are known as the two- level inverter. To get a quality output voltage or current waveform with a minimum amount of ripple content, they require high switching frequency along with various pulse width modulations (PWM) strategies. In high voltage and high power applications, these two level inverters, however, have some precincts in operating at high frequency mainly due to switching losses and constraint device rating. Moreover, the semiconductor switching devices should be used in such a manner as to avoid problems associated with their series- parallel combinations that are necessary to obtain capability of handling high voltage and currents.

The multilevel inverter has drawn tremendous interest in power industry. They present new set of features that are well suited for reactive power compensation. It may be easier to produce high power, high voltage inverter with the multilevel structure. Increasing the number of voltage levels in the inverter without requiring higher ratings on individual devices can increase the power rating. The distinctive structure 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 level increases, the harmonic content of the output voltage waveform decreases significantly [1]. The three basic and most well-known topologies of multilevel inverter are the Cascaded H-Bridge Multilevel Converter (CHB), Neutral Point-Clamped Multilevel Converter (NPC) and the Flying Capacitor Multilevel Converter (FCC). For industrial use these three basic topologies have been broadly acknowledged [2]. Among three types of these converters diode clamped inverter has less number of capacitors as compared to dc link with the same capacity per unit, but requires additional clamping diodes. Flying capacitor inverters require large number of capacitors, where cascaded inverters are considered as having the simplest structure. Cascaded H-bridge multilevel inverter for PV power supply system is proposed for stand-alone and grid-connected operations [3]-[7]. Comparing H-bridge multilevel inverters and diode-clamped multilevel inverters (DCMLIs), the latter shares same dc level and former require too many separate dc sources for each phase. Hence, there is decrease in dc cabling and losses on the dc side in DCMLI.

Wind turbine and fuel cell as proposed in [8], for three-phase power supply system, a single-stage dc to ac multilevel inverter is presented in this paper. To develop a low cost, reliable and efficient power supply unit is the main objective. Using low voltage MOSFETS as switching devices, a six-level DCMLI is used in the referred topology.

When voltage levels are increased, the harmonic content of output voltage waveform decreases. At appropriate switching frequency, conduction and switching losses are also reduced. Due to lower total harmonic distortion, the efficiency of motor increases. The induction motor, when fed from the inverter, is subjected to voltage changes. This leads to voltage harmonics (frequency components above the fundamental frequency). Depending on the type of PWM

employed, the output of inverter produces voltage which comprises of harmonics. The harmonics leads to temperature, noise and vibration levels increase at the motor side. Thus increasing the losses of motor and decrease in efficiency.
The motor iron losses depends on the frequency. As the frequency is increased, the iron losses are increased. So it is desirable to apply the frequency in a considerable range with respect to voltage, so that V/f (supply volts per Hertz) ratio is constant. In order to have constant torque, this term comes out to be constant.

A. Multilevel Inverter

To create a sinusoidal voltage from several levels of voltages is the general structure of the multilevel inverter. The so-called "multilevel" starts from three-levels. The main advantages and disadvantages of multilevel inverter are:

Advantages:
- For the fundamental switching frequency multilevel inverter has high efficiency.
- When the number of levels is high enough, the harmonic content is low enough to avoid the need of filters.
- As all phases share a common dc link, the capacitor required by the inverter is reduced.
- It can eliminate the need for the step-up transformer and reduce the harmonics produced by the inverter.

Disadvantages:
- Due to relation between number of diodes and number of levels, packaging of inverter with a high number of levels could be a problem.
- Without the appropriate control, DC level tends to be irregular.
- Excessive clamping diodes are required when the number of levels is high.
- It is difficult to control the real power flow of individual converter in multi-converter system.

Few applications using Multilevel Diode Clamped Inverter are:
- Static VAR compensation.
- High power medium voltage variable speed drives (VSD).
- An interface between High voltage direct current transmission line (HVDC) and High voltage alternating current (HVAC) transmission line.

II. CIRCUIT TOPOLOGY FOR SIX-LEVEL DCMLI

A diode – clamped (m-level) inverter (DCMLI) typically consists of (m-1) capacitors on the dc and produces m levels on the phase voltages. The referred six-level DCMLI powered by five dc sources which drive a three phase induction motor is shown in fig. 1. The numbering order of the switches is Sa1, Sa2, Sa3, Sa4, Sa5, Sa'1, Sa'2, Sa'3, Sa'4, Sa'5. The dc bus voltage consists of five capacitors C1, C2, C3, C4 and C5. An m-level inverter leg requires (m-1) capacitors, 2(m-1) switching devices and (m-1) X (m-1) clamping diodes. A common dc bus is shared by each phase of the inverter, which has been subdivided by five dc sources into six levels; Vdc is the voltage across each DC source.

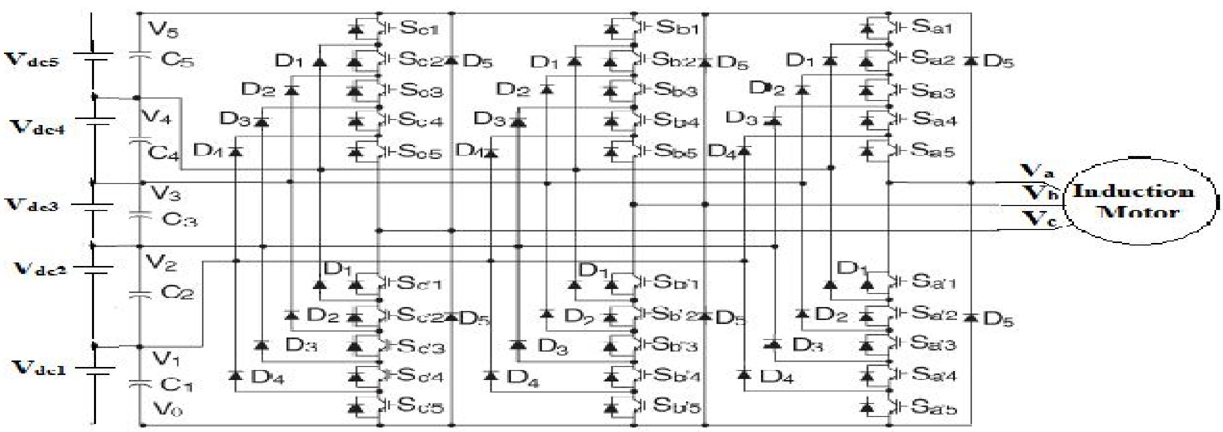

Fig. 1. PV module as dc source connected to three phase six-level DCMLI

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There are six switch combinations to synthesize six-level voltages across phase (a) and neutral (n).

1. Voltage level $V_{an} = 5V_{dc}$, turn on the switches from S_{a1} to s_{a5}.
2. Voltage level $V_{an} = 4\ V_{dc}$, turn on the switches from S_{a2} to $s_{a'1}$.
3. Voltage level $V_{an} = 3\ V_{dc}$, turn on the switches from S_{a3} to $s_{a'2}$.
4. Voltage level $V_{an} = 2\ V_{dc}$, turn on the switches from S_{a4} to $s_{a'3}$.
5. Voltage level $V_{an} = V_{dc}$, turn on the switches from S_{a5} to $s_{a'4}$.
6. Voltage level $V_{an} = 0$, turn on the switches from $S_{a'1}$ to $s_{a'5}$.

Table1. DCMLI Voltage Levels and Switching States

Voltage V_a	Switch State									
	S_{a1}	S_{a2}	S_{a3}	S_{a4}	S_{a5}	S'_{a1}	S'_{a2}	S'_{a3}	S'_{a4}	S'_{a5}
$V_5=5V_{dc}$	1	1	1	1	1	0	0	0	0	0
$V_4=4V_{dc}$	0	1	1	1	1	1	0	0	0	0
$V_3=3V_{dc}$	0	0	1	1	1	1	1	0	0	0
$V_2=2V_{dc}$	0	0	0	1	1	1	1	1	0	0
$V_1=V_{dc}$	0	0	0	0	1	1	1	1	1	0
$V_0=0$	0	0	0	0	0	1	1	1	1	1

For one phase of the inverter, the possible output voltage levels are listed in Table 1, with V0 as reference. The switch is on for switching state 1 and off for switching state 0.

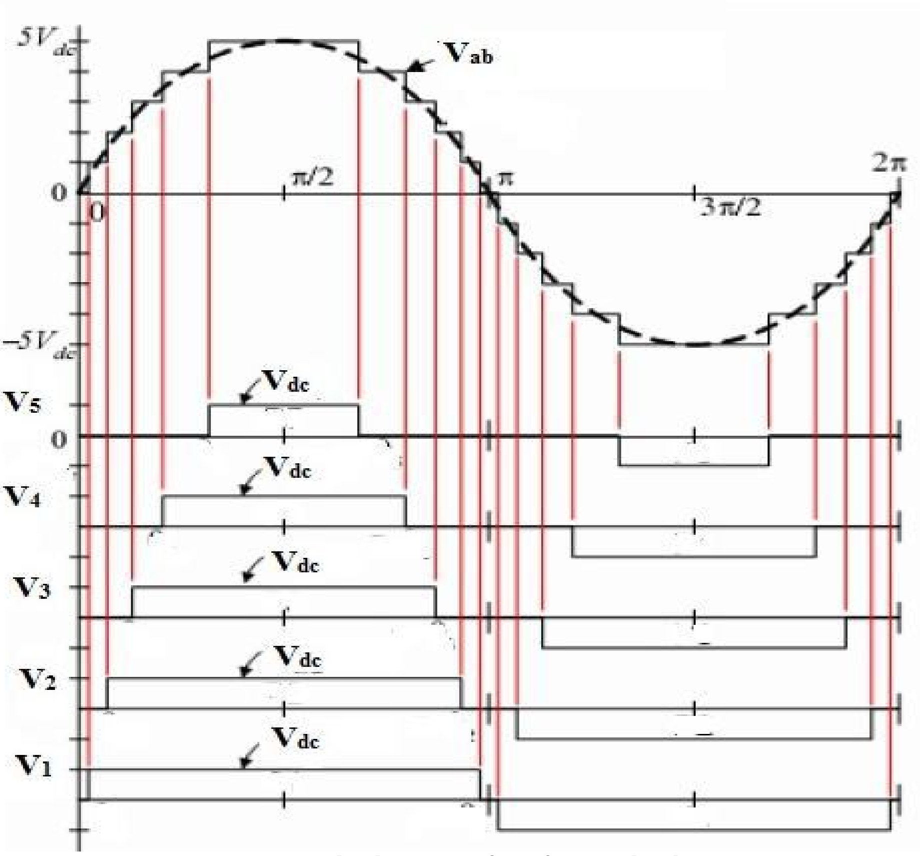

Fig. 2. Line to Neutral voltage waveform for a six-level DCMLI.

One of the line to neutral voltage waveform for six-level DCMLI is shown in Fig. 2. The resulting line voltage is an 11-step staircase waveform. The line voltage Vab consists of phase leg a voltage and phase-leg b voltage. This means that an m-level diode-clamped inverter has an (2m-1) level output line voltage and a m-level output phase voltage.

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III. SIMULATION RESULTS

The electrical parameters of Matlab/Simulink software package is used for implementing simulation. The output quantities like line voltage, THD spectrum for line voltage, and torque, speed waveforms of induction motor are obtained. The three-phase line voltages shown in Fig.3, demonstrate that the current waveform is almost sinusoidal

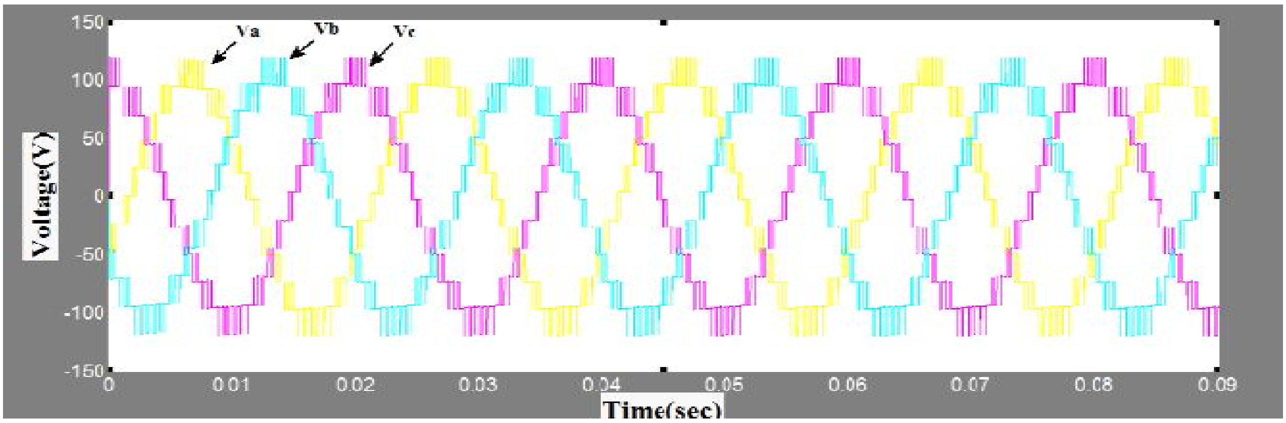

Fig. 3. Line voltage waveforms of the DCMLI output for 50 Hz.

In the referred topology, pulse width modulation (PWM) strategies are modified to use in multilevel inverters. For controlling the active devices in a multilevel inverter, a two-level multilevel carrier-based PWM technique has been extended. The most admired and easiest technique to implement uses several triangular carrier signals and one reference. The PWM method generates switching signals by comparing one sinusoidal signal and five triangular wave signals, which have DC bias for each voltage level. In this modulation method, the ratio of the sine wave amplitude to the triangular carrier signal amplitude is used to determine the duty cycle for each voltage level. That is, modulation factor is determined by sine wave amplitude, and one modulation factor generates only one pattern of output pulse width. Using PWM modulation explained above, simulations has been conducted. By triangular and sinusoidal wave comparison in Matlab/Simulink blocks the gate signals of six-level DCMLI power circuit are produced. The three-phase output (line) voltages are shown in fig. 3. are sinusoidal in shape and have very low THD level in lower switching frequency. A fast Fourier transform (FFT) is applied to obtain the spectrum of the output voltage and also total harmonic distortion (THD) level of the waveform, which is shown in Figure 4. The THD of the output voltage is found to be 13.56%. The harmonic spectrum of line voltage six-level DCMLI is shown in fig. 4. When inverter is operated as pulse width modulated inverter, harmonics are abridged, low frequency harmonics are purge, related losses are reduced and smooth motion is obtained at low speeds also.

As shown in Fig. 4. the fifth order harmonic has a significant magnitude. In order to eliminate the fifth order harmonic, the switching angles are needed to be assorted.

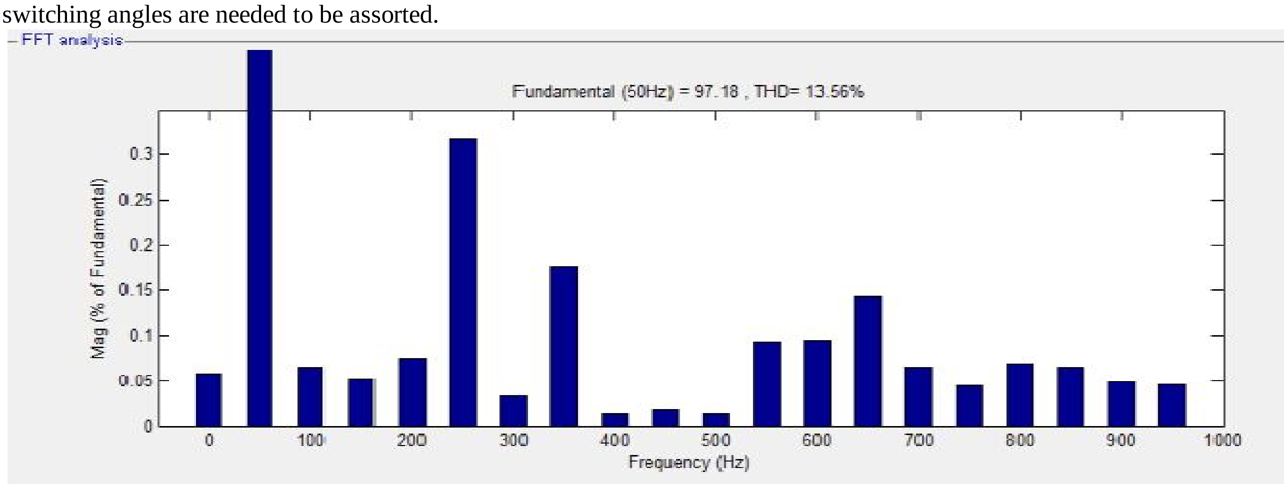

Fig. 4. Harmonic Spectrum of Line Voltage of six-level inverter

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IV. INDUCTION MOTOR PERFORMANCE

When mechanical load is applied to the shaft of the motor, it will begin to slow down. The motor and mechanical load will soon reach at state of equilibrium when motor torque equal to load torque. At this state, the speed will cease to drop anymore and the motor will run at the new constant speed which can be seen in fig. 5. When the load is applied, speed decreases which in turn produces a large rotor current. The increased rotor current produces a higher torque to meet the increased load on the motor. The electromagnetic torque, rotor current and stator current of induction motor are shown in fig. 9, 10. Simulation parameters are given in Table II.

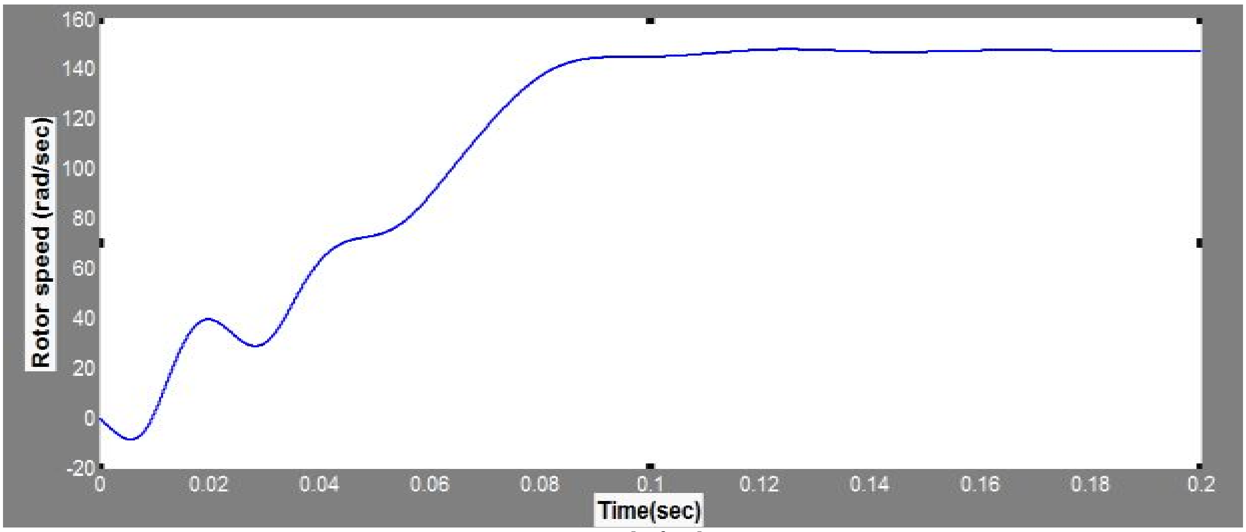

Fig. 5. Rotor speed of induction motor

When conventional inverter is connected to induction motor its THD is higher as compared to multilevel inverter. Similarly, when R-L load is considered, voltage waveform of conventional inverter has more harmonics as compared to multilevel inverter. In turn, THD is more in case of conventional inverter as compared to multilevel inverter. However, from electromagnetic torque waveform; which is shown in fig. 8 and 9. for conventional inverter and multilevel inverter respectively, it can be concluded that the electromagnetic torque has more transients when conventional inverter is feeding induction motor as compared to multilevel inverter such as, six-level DCMLI. Thus, net motor torque with multilevel inverter is more.

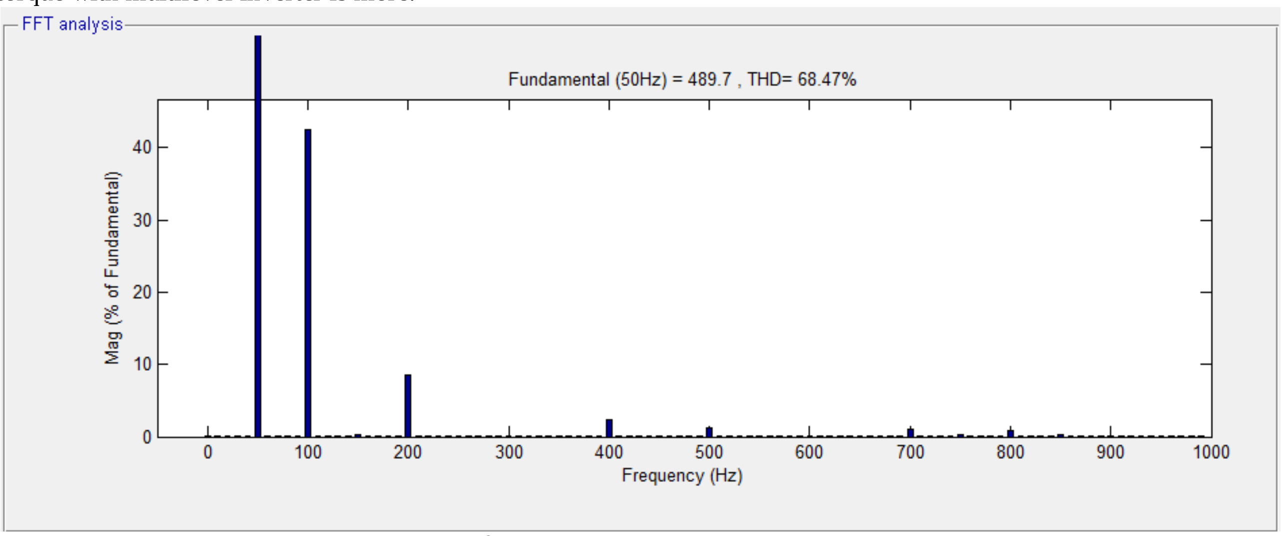

Fig. 6. Harmonic spectrum of two level with R-L(R=15 ohm and L=24.2 mH) as a load.

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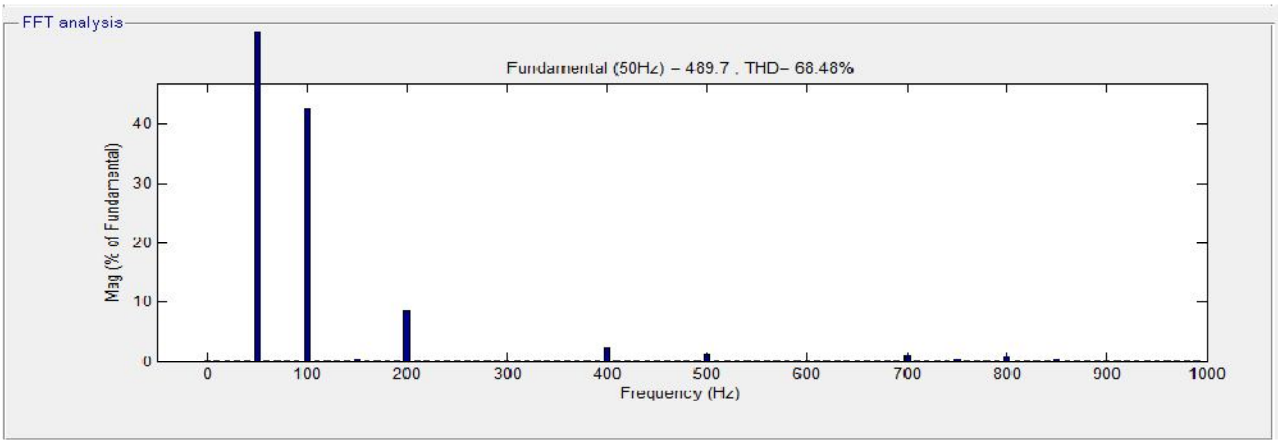

Fig. 7. Harmonic spectrum of two level with induction motor as a load with a load of 26.7 N-m

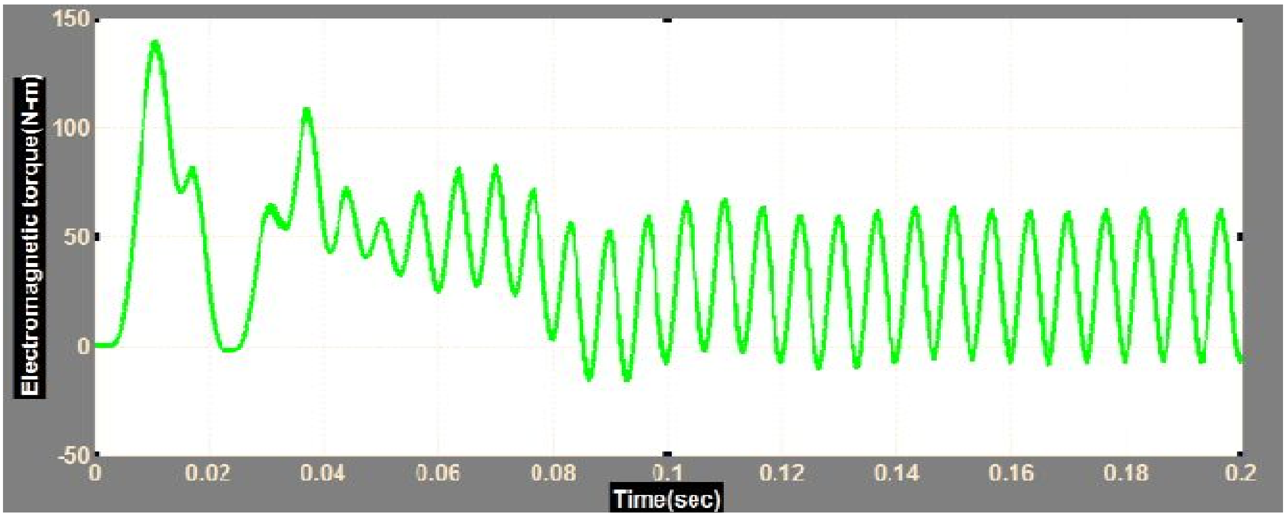

Fig. 8. Electromagnetic torque of induction motor when fed from two-level inverter with a load of 26.7 N-m

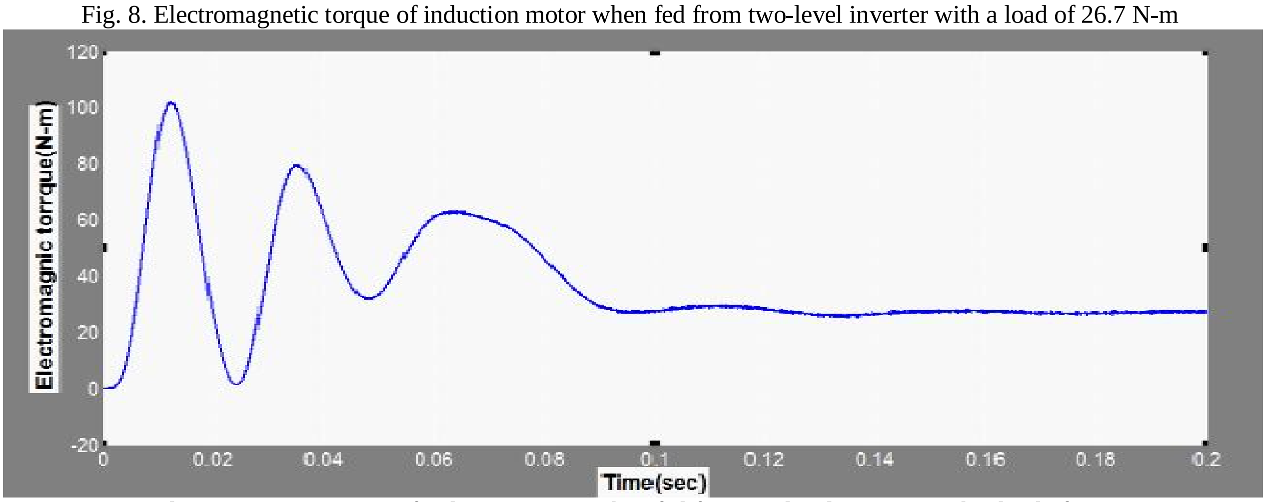

Fig. 9. Electromagnetic torque of induction motor when fed from six level DCMLI with a load of 26.7 N-m.

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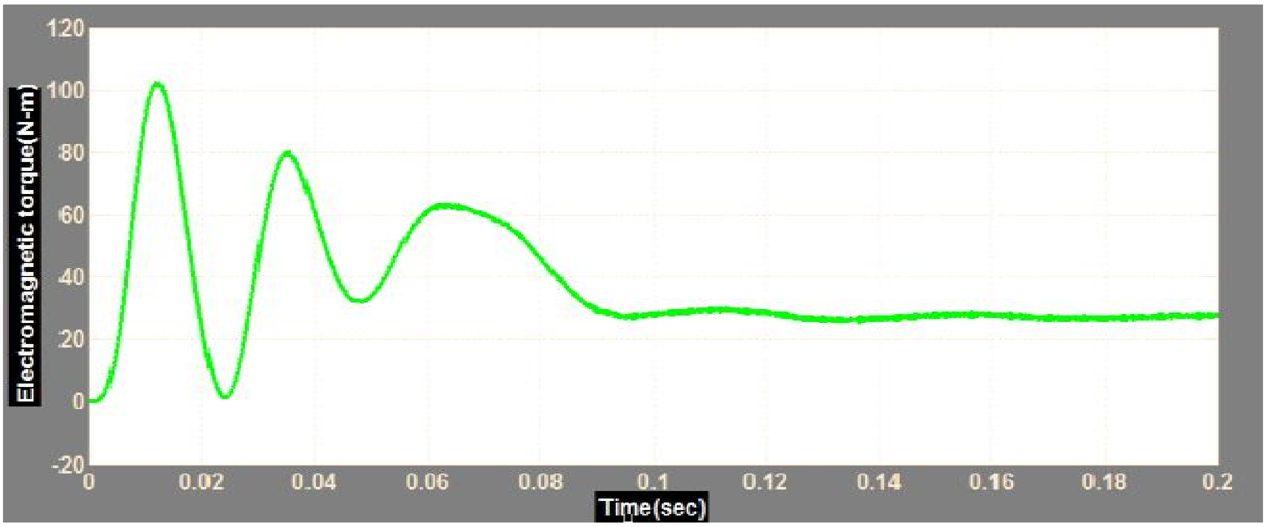

Fig. 10. Rotor current of induction motor

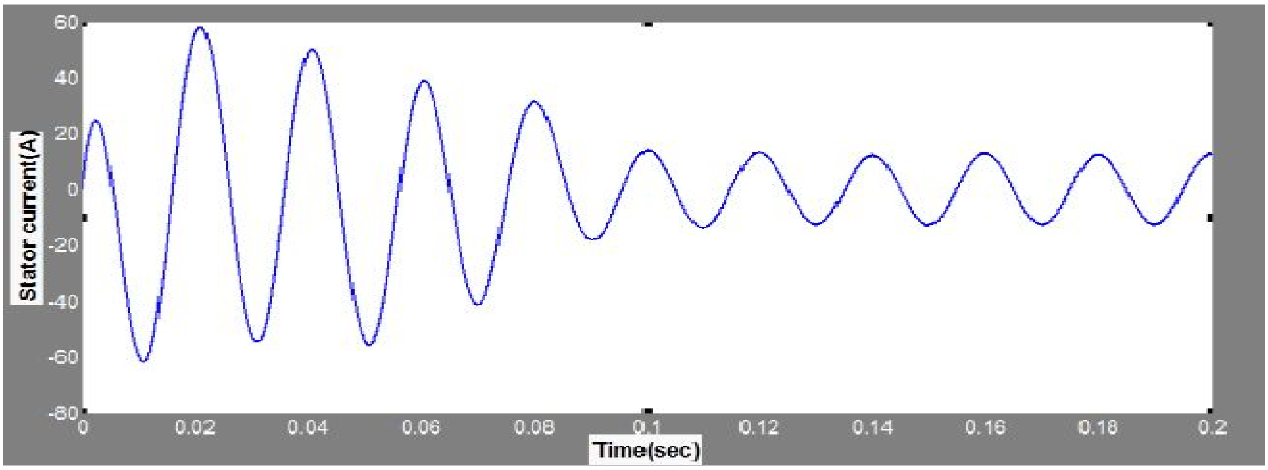

Fig. 11. Stator current of induction motor

Simulation Parameters

Switching frequency	2400 Hz
Power Frequency	50 Hz
DC Bus voltage	113 V
Power	4 kW

V. CONCLUSION

The three phase six-level inverter with induction motor as load has been modeled in MATLAB/SIMULINK. The inverter have been modulated by using the SPWM technique. The output quantities like line to line voltage, THD spectrum for line to line voltage, rotor current and stator current waveform and torque, speed waveforms of induction motor are obtained. In PWM method, the lower order harmonic distortion is largely reduced in fundamental switching.

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Also, as the numbers of voltage levels of inverter are increased, the THD of inverter reduces, reducing the lower order harmonics. The referred six-level DCMLI presents several advantages. First, it converts power from relatively low dc voltage source to ac. Second, in order to have high efficiency and lower weight of overall system it increases output voltage levels without any transformer. Third, as higher order harmonics are eliminated, it does not require an output filter. It is found that at switching frequency of 2400 Hz, THD is 13.56%. In DCMLI, diodes are used to limit the voltage stress. For increasing power and reducing harmonics of an ac waveform multilevel inverter is an effective solution.

In the referred topology, induction motor is fed from inverter which produces nearly sinusoidal supply results in less harmonics and thereby low total harmonic distortion and reduced losses. Thus, increasing efficiency of the motor. On the other hand when motor is fed from conventional inverter, it produces large harmonics of low frequency in the output voltage waveform. Due to this, the motor losses are increased at all speed causing derating of the motor. It also develops pulsating torque which causes jerky motion of the rotor at low speeds.
The conventional voltage source inverter produces output voltage with levels either 0 or +/- V. This result in square wave output waveform which has more harmonics as compared to multilevel voltage waveforms obtained from multilevel voltage source inverters. In conventional VSI the efficiency of the whole system is dominated by the rectifier losses. However, multilevel VSI efficiency at any load is better compared to conventional VSI.

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