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Performance Analysis of Induction Motor Fed by Two-Level Inverter and Multi Level Inverter

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ABSTRACT
This paper presents a comparative study to evaluate the performance characteristics of induction motor fed by a conventional two-level inverter and a multi-level inverter. Multi-level inverters are developed recently to overcome the drawbacks of two-level inverters. However, their topologies consist of large number of power switches. As a result, developed topologies are investigated to reduce the number of power switches. In this paper, a five-level H-bridge inverter with reduced count of switches has been presented. It consists of H-bridge and two auxiliary bi-directional switches. Both drives are simulated in MATLAB/SIMULINK environment to evaluate the induction motor performance. Sinusoidal pulse width modulation technique is used to control both inverters. The total harmonic distortion of motor voltage and current waveforms in both drives are investigated and compared. Also, the motor torque and speed curves in both drives are compared and evaluated. Simulation results enhances the improved impact of proposed multi-level inverter on electrical grid over two-level inverter. However, they approximately have the same impact on motor performance.

***Keywords**: multi-level inverter; two-level inverter; induction motor.*

1. Introduction

Induction Motors (IMs) are the most common machines used in industrial and residential applications. They are featured by inherent merits, such as ruggedness, low cost, low maintenance, simplicity of control and work in different environments. Conventional Voltage Source Inverter (CVSI), which has two-level output voltage, is widely used to control the speed of IMs [1]. However, it suffers from high switching frequency, low efficiency, high dv/dt, electromagnetic interference [2]. As a result, Multi-Level Inverters (MLIs) are developed to overcome these drawbacks. MLIs are distinguished by lower harmonic distortion, reduced filter size and lower blocking voltage over switches [3]. However, their structures contain large number of power switches resulting in increasing the system cost, increasing control complexity and reducing the system efficiency [2].

The conventional configurations of MLIs are diode-clamped MLIs, flying-capacitor MLIs and cascaded H-bridge MLIs [4-7]. Among these types, Cascaded H-Bridge MLIs (CHBMLIs) have received great attention due to their inherent merits of modularity and feasibility [8]. According to the magnitude of dc voltage sources, CHBMLIs are classified into symmetric and asymmetric types. For the same magnitude of dc voltage sources, they are known as symmetric cascaded MLIs [9], while for different magnitude of dc voltage sources, they are denoted as asymmetric cascaded MLIs [10]. Great research efforts have been paid to develop CHBMLIs and produce alternative topologies having improved properties [11-17] Each of these developed topologies has its merits and demerits.

In this paper a modified structure of a five-level H-bridge inverter with reduced count of switches has been proposed. It comprises H-bridge and two auxiliary bi-directional switches. A comparison study is conducted between IM fed by proposed five-level inverter and a conventional two-level inverter. With the aid of MATLAB/SIMULINK software, specifically Sim Power System toolbox, two simulation models have been developed and executed for both drives. Motor voltage and current waveforms in both drives are compared in terms of Total Harmonic Distortion (THD). In addition, a comparison is held between the motor torque and speed curves in both drives. The results reveal that proposed MLI improves the grid performance over CVSI, while, the motor performance is not changed.

2. Proposed Five- Level Inverter Fed Induction Motor Drive

Figure (1) shows a schematic diagram of proposed five-level inverter fed three-phase IM. To understand the principle of operation of proposed five-level inverter, consider a single phase configuration shown in Figure (2). It consists of four main switches of H-bridge and two auxiliary bi-directional switches. The bi-directional switch represents one uni- directional switch and four diodes. The main switches of H-bridge are responsible for determining the polarity of output voltage levels. While, the auxiliary switches are used to generate the voltage levels. The principle of operation of proposed MLI can be detected using Table (1), which demonstrates the switching states of power switches and the corresponding output voltage levels.

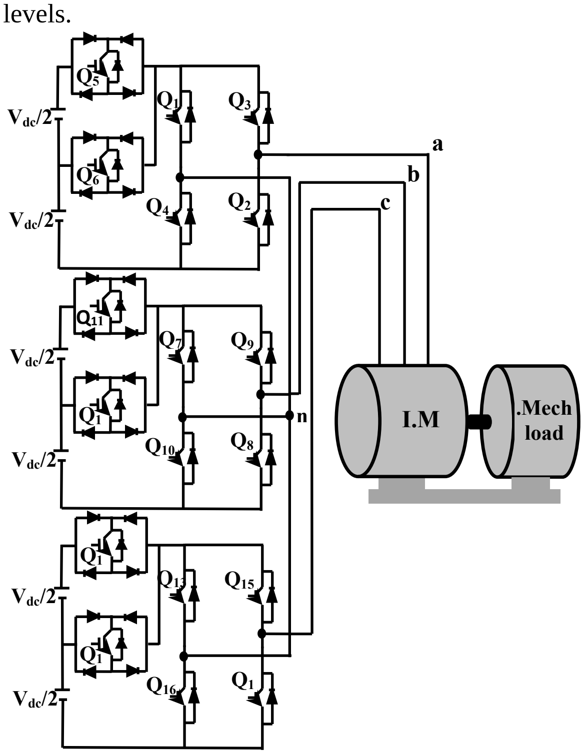


Figure 1- Three-Phase Induction Motor Fed by Proposed Five-Level Inverter

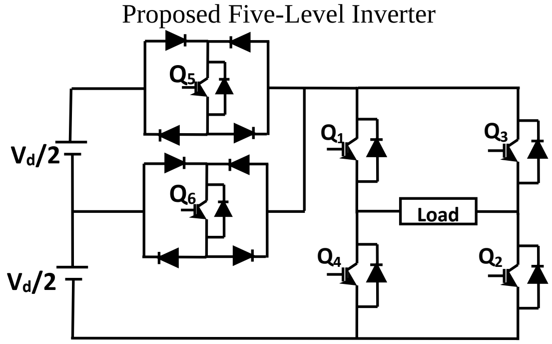
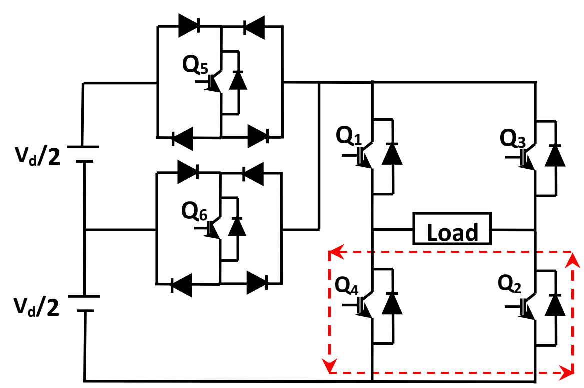


Figure 2- Single-Phase Configuration of Proposed Five-Level Inverter

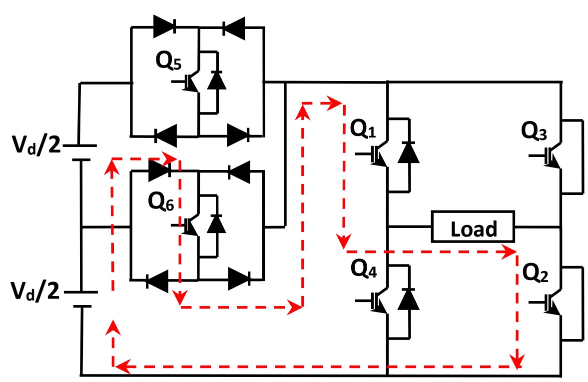
Table 1- Switching Pattern of Proposed MLI

Output voltage level	Q_1	Q_2	Q_3	Q_4	Q_5	Q_6
Zero	0	1	0	1	0	0
$V_d/2$	1	1	0	0	0	1
V_d	1	1	0	0	1	0
$-V_d/2$	0	0	1	1	0	1
$-V_d$	0	0	1	1	1	0

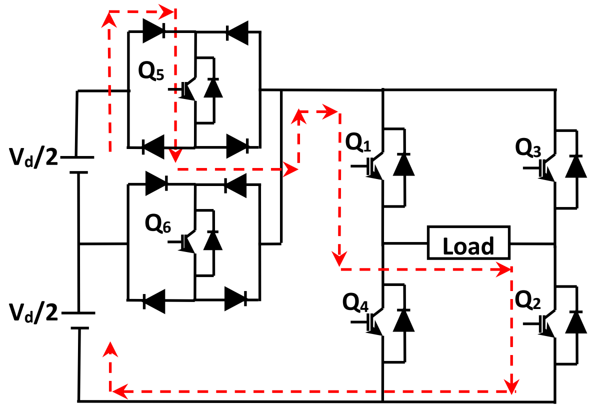
At first, zero-level can be achieved by either two states: switching on Q_1 with Q_3 simultaneously or Q_2 with Q_4. The voltage level ($V_d/2$) is obtained by operating Q_1, Q_2 and Q_6 simultaneously. While, Q_1, Q_2 and Q_5 are turned on to generate the voltage level (V_d). For negative voltage levels, switching on Q_3, Q_4 and Q_6 yields the voltage level ($-V_d/2$). Whereas operating Q_3, Q_4 and Q_5 produces the voltage level ($-V_d$). Current paths for five voltage levels of the proposed inverter are shown in Figure (3).



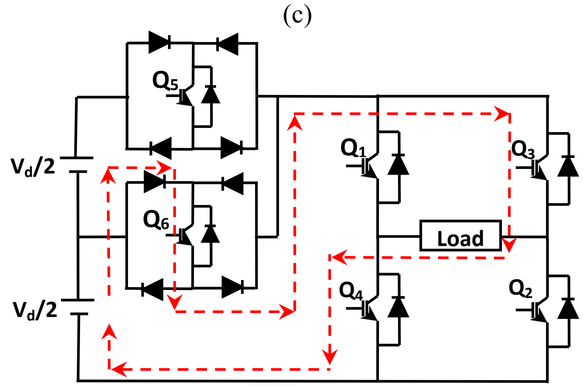
(a)



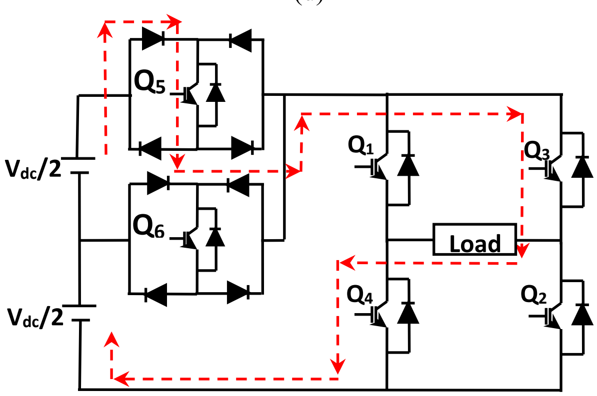
(b)



(c)



(d)



(e)

Figure 3-Current Paths of Five Voltage Levels: (a) Voltage Level 'Zero'; (b) Voltage Level '$V_d/2$'; (c) Voltage Level 'V_d'; (d) Voltage Level '-$V_d/2$'; (e) Voltage Level '-V_d'

There are various modulation techniques used for controlling MLIs. Among them, multi carrier sinusoidal Pulse Width Modulation (PWM) technique is the most common due to its simplicity and good capability of voltage generation [18]. In-phase disposition PWM method is chosen here to control proposed MLI. In this method, four triangular carriers, which are in phase and have the same magnitude, are compared with three sinusoidal reference signals shifted 120° as shown in Figure (4). This results in obtaining the desired output voltage levels according to the switching states mentioned in Table 1

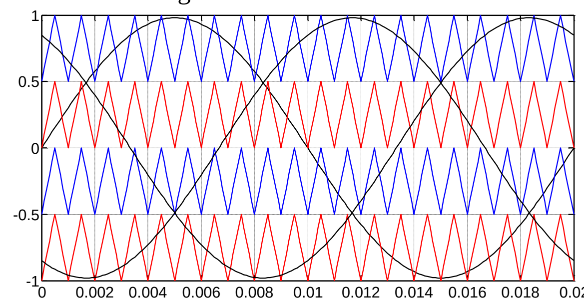


Figure 4- Level-Shifted Multi-Carrier Modulation Scheme for Five-Level Inverter

3. Mathematical Modelling of Induction Motor

The mathematical model of IM in arbitrary reference frame is expressed as following [19]:
At first, stator and rotor voltage equations are given by:

$$V_{qs} = R_s i_{qs} + p\lambda_{qs} + \omega\lambda_{ds} \quad (1)$$
$$V_{ds} = R_s i_{ds} + p\lambda_{ds} - \omega\lambda_{qs} \quad (2)$$
$$V_{qr} = R_r i_{qr} + p\lambda_{qr} + (\omega - \omega_r)\lambda_{dr} \quad (3)$$
$$V_{dr} = R_r i_{dr} + p\lambda_{dr} - (\omega - \omega_r)\lambda_{qr} \quad (4)$$

Flux linkage equations can be written as:

$$\lambda_{qs} = L_{ss} i_{qs} + M i_{qr} = L_{ls} i_{qs} + M(i_{qs} + i_{qr}) \quad (5)$$
$$\lambda_{ds} = L_{ss} i_{ds} + M i_{dr} = L_{ls} i_{ds} + M(i_{ds} + i_{dr}) \quad (6)$$
$$\lambda_{qr} = L_{rr} i_{qr} + M i_{qs} = L_{lr} i_{qr} + M(i_{qr} + i_{qs}) \quad (7)$$
$$\lambda_{dr} = L_{rr} i_{dr} + M i_{ds} = L_{lr} i_{dr} + M(i_{dr} + i_{ds}) \quad (8)$$

The developed torque equation is expressed as:

$$T_e = \frac{3}{2}\frac{P}{2}\left(\lambda_{ds} i_{qs} - \lambda_{qs} i_{ds}\right) \quad (9)$$

Where: P is the number of poles.

Throughout the simulation procedure, as will be discussed in the following section, a ready block of IM is chosen for implementation. It is already set to run at rotor reference frame, where ω equal to ω_r. Accordingly, the speed (ω) in the voltage equations mentioned above should be replaced by ω_r.

4. Simulation Results and Discussion

Both drives of proposed MLI and CVSI fed three-phase IM are simulated in MATLAB SIMULINK environment using Sim Power Systems toolbox. A preset model of squirrel cage IM of rating 5.4 HP (4KW), 400 V, 50Hz 1430 rpm is selected for both models. It has stator resistance and leakage inductance of 1.405 ohms and 5.839 mH respectively. The rotor resistance and leakage inductance referred to stator are 1.395 ohms and 5.839 mH respectively. The magnetizing inductance is 172.2 mH.

The motor is loaded by a constant load toque equal the rated torque. Modulation index is taken 0.95 and the switching frequency is 5KHz for both models. The value of dc voltage source is chosen so that the output voltage achieves the rated rms value of IM. It is taken 650V in IM drive based on two-level inverter. While, in proposed MLI fed IM drive, it is taken 320V divided into two identical values. The results of both simulation models are given as following:

4.1 Voltage and current waveforms

The output line voltage of proposed MLI and its harmonic analysis are shown in Figure (5) and Figure (6) respectively. It is observed that the line voltage has five-levels with THD of 17.34%. On the other hand, Figures (7) and (8) illustrate the output line voltage of CVSI and its Fast Fourrier Transform (FFT) plot respectively. The line voltage here has two-levels with THD of 73.86%. It is clear that the line voltage of proposed MLI has lower THD and better waveform than CVSI.

The output current of proposed MLI and its FFT plot are shown in Figure (9) and Figure (10) respectively. It has THD of 0.69%. In other words, the output current of CVSI and its harmonic spectrum are illustrated by Figure (11) and Figure (12) respectively. It has THD of 3.57%. It is observed that the waveform of output current of proposed MLI has lower THD than that of CVSI, however they seem to have the same behavior. This similarity can be interpreted by the large value of equivalent inductance of IM that is seen by the inverter. It acts as a current filter reducing the distortion in CVSI output current and making it close to pure sine wave.

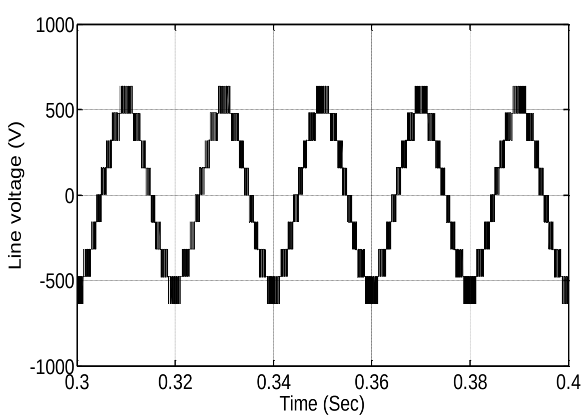


Figure 5- Output Line Voltage of Proposed MLI

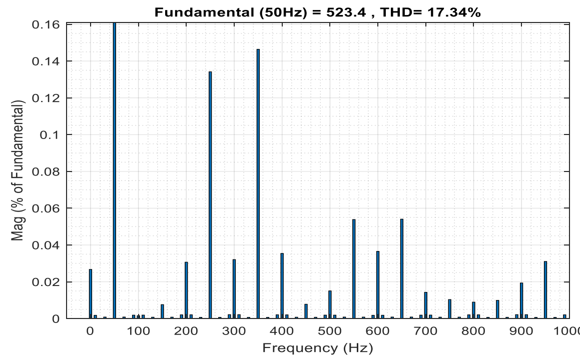


Figure 6- FFT Plot of Output Line Voltage of Proposed MLI

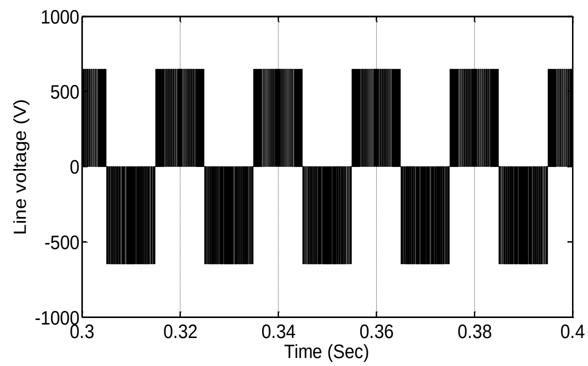


Figure 7- Output Line Voltage of CVSI

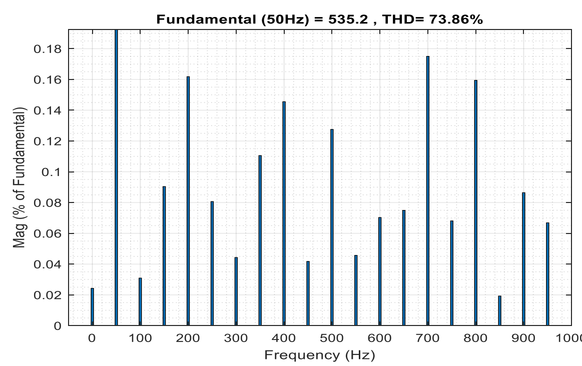


Figure 8- FFT Plot of Output Line Voltage of CVSI

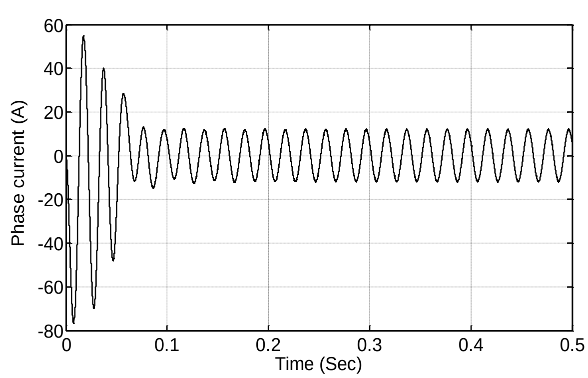


Figure 9- Output Current of Proposed MLI

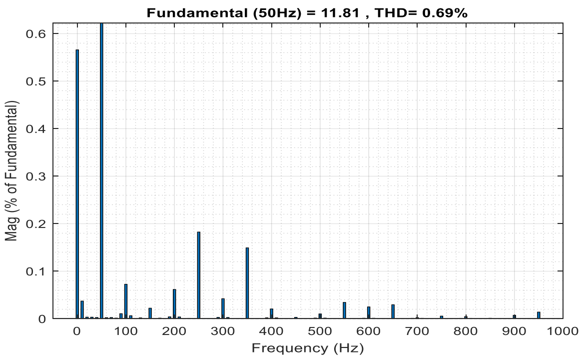


Figure 10- FFT Analysis of Output Current of Proposed MLI

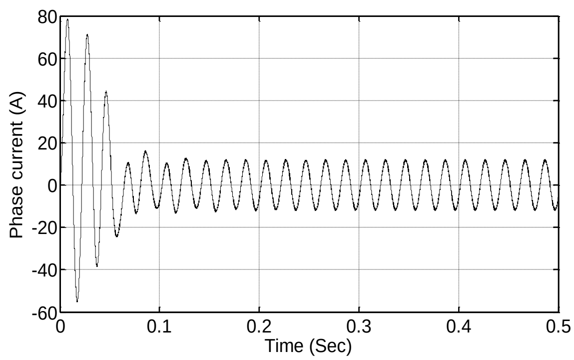


Figure 11- Output Current of CVSI

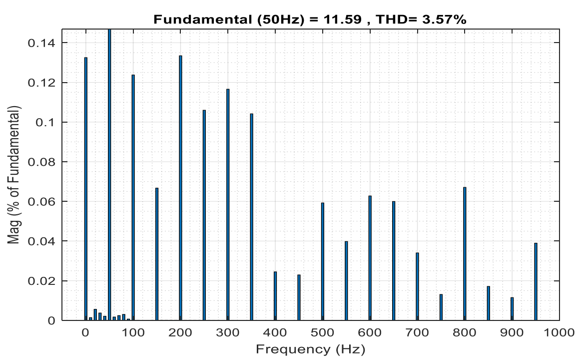


Figure 12- FFT Analysis of Output Current of CVSI

4.2. Motor torque and speed curves

The developed torque of IM fed from proposed MLI and CVSI are shown in Figure (13) and Figure (14) respectively. It is observed that they have the same behavior but the motor torque in case of CVSI has small oscillations. The similarity in torque behavior is attributed to the similarity in current behavior as above mentioned. However, the small oscillations in motor torque in case of CVSI can be interpreted by the little distortion in CVSI current waveform. In other words, the speed curves for two drives are comparable as illustrated by Figure (15) and Figure (16). This is resulted from the similarity in torque behavior. However, the reason of being the speed, in case of CVSI, does not respond to the small and fast oscillations of torque, is the inertia of IM.

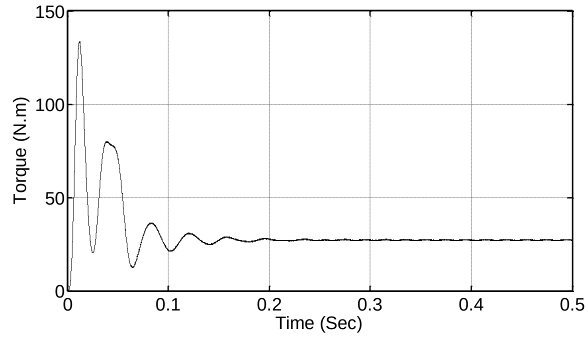


Figure 13- Developed Torque of IM Fed From Proposed MLI

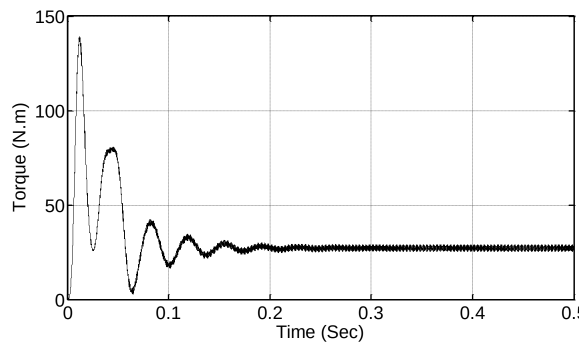


Figure 14- Developed Torque of IM Fed by CVSI

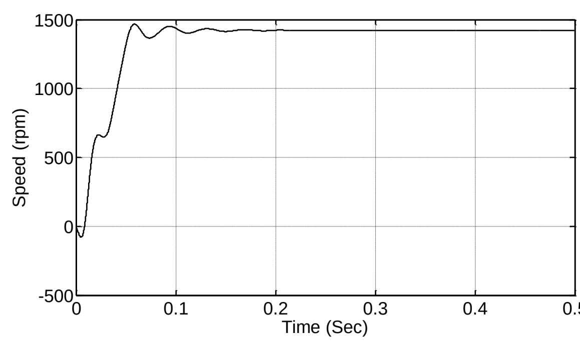


Figure 15- Speed of IM Fed from Proposed MLI

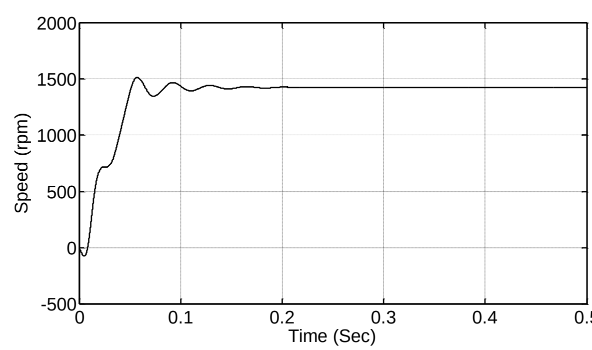


Figure 16- Speed of IM Fed by CVSI

5. Conclusions

In the present work, a five-level H-bridge inverter with reduced number of switches has been proposed. A comparison study is performed between the performance of IM fed by proposed MLI and CVSI. Using Sim Power Systems toolbox in MATLAB/ SIMULINK, two simulation models have been developed and implemented for both drives. The results reveal that the output voltage and current waveforms of proposed MLI have lower THD than CVSI. This positively affects the electrical grid. However, the torque and speed curves in both drives are approximately comparable except the small oscillations in motor torque in case of CVSI. This means that the benefit from using MLI in IM drive instead of CVSI is restricted to the electrical grid.

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