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A CASCADED MULTILEVEL INVERTER USING THI METHOD FOR ELECTRIC TRACTION DRIVE

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ABSTRACT

Pulse Width Modulation variable speed drives are increasingly applied in many new industrial applications that require superior performance. Recently, developments in power electronics and semiconductor technology have lead improvements in power electronic systems. This proposed technique provides more flexibility to designers and can generate more voltage levels without losing any level which worsens THD characteristics. The possibility of extension or series connection of this basic in two topologies has been studied. As we increase the number of levels of the output voltage of the inverter , the output waveform has increased number of steps, which produces a staircase wave that approximates to a sinusoidal waveform. Hence, as the level of the output voltage increases, the harmonic distortion of the output wave decreases. As seen from the simulation results, THIPWM have a superior performance compared to SPWM. The SPWM technique is very popular for industrial converters. It is the easiest modulation scheme to understand and implement. This technique can be used in single-phase and three-phase inverters. The THIPWM technique operates by adding a third harmonic component to the sinusoidal modulating wave. It is possible to increase the fundamental by about 15.5% and, hence, allow a better utilization of the DC power supply. From the shape of the line-to-line voltages, the resulting flat-topped waveforms allow over-modulation with respect to the original SPWM technique. Space Vector Modulation technique and Direct Torque Control strategy can be implemented in the cascaded rectifier inverter configuration.

Keywords: Bidirectional Switch, Multilevel Inverter, PWM, Electric Traction, Total Harmonic Distortion.

I. INTRODUCTION

Electric traction drive has now been considered to be an efficient way of transmitting power to the traction motors that can deliver as much as two and half times the tractive power output of equivalent diesel traction. Its high power-to-weight ratio results in faster acceleration and higher tractive effort [1]. It requires medium voltage and high power operation. This can be achieved with the help of multilevel inverters [2]. The traction trans former steps down the centenary voltage to a level convenient for traction motors to improve the efficiency and reliability of the steam traction drive lead to the electrification of the railway system.

A multilevel inverter is a power electronic system that synthesizes a desired output voltage from several levels of dc voltages as inputs. Recently, multilevel power conversion technology has been developing the area of power electronics very rapidly with good potential for further developments. As a result, the most attractive applications of this technology are in the medium to high voltage ranges [3]. Its applications are in the field of high-voltage high-power applications such as laminators, mills, compressors, large induction motor drives, UPS systems, and static var compensation. Its working principle is based on producing small output voltage steps which results in better power quality. They operate at low voltage levels and also at a low switching frequency so that the switching losses are also reduced.

The principle includes as the number of levels in the inverter increases, the output voltage has more step generation i.e. staircase waveform, which has a reduced harmonic distortion.

The multilevel inverter is a promising inverter topology for high voltage and high power applications. This inverter synthesizes several different levels of DC voltages to produce a stepped AC output that approaches the pure sine waveform. It has the advantages like high power quality waveforms, lower voltage ratings of devices, lower harmonic distortion, lower switching frequency and switching losses, higher efficiency, reduction of dv/dt stresses etc. It gives the possibility of working with low speed semiconductor in comparison with the two-level inverters. Numerous of MLI topologies and modulation techniques have been introduced. But most popular MLI topology is Diode Clamped [4], [5] Flying Capacitor [6], [7] and Cascaded Multilevel Inverter (CMLI) [8] - [11].

II. MULTILEVEL INVERTER

Generally conventional multilevel inverters include an array of switching devices and voltage sources which generate voltages with stepped waveform in the output. A cascade multilevel inverter consists of several single-phase full bridge inverters connected in series. The proposed symmetrical topology uses only one dc supply to generate complete three phase output which is a unique achievement over conventional topologies.

Fig. 1 shows a three phase of 7-level symmetrical structure inverter. V_{dc} is the smallest DC - voltage that is equal to step size.

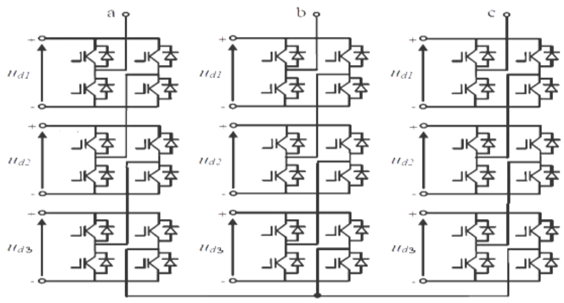

Fig.1.A three phase of 7-level symmetrical inverter

Multilevel Inverter in Traction System The railway electric traction requires high voltage operation. This can be fulfilled by the series or parallel combination of various semi-conductor devices. But because of the differences in their inherent characteristics, it will damage the devices. This limitation can be overcome with the help of multilevel converter [12].

III. MODULATION

With advances in solid-state power electronic devices and microprocessors, various pulse-width-modulation (PWM) techniques have been developed for industrial applications.

The modulation control techniques can be classified into Pulse Width Modulation (PWM), Selective Harmonic Elimination (SHE) Modulation and Optimized Harmonic Stepped Waveform (OHSM) [13]. The PWM technique can be open loop type like sinusoidal PWM, Space Vector Modulation, sigma delta and closed loop type like hysteresis current controller, linear current controller etc. PWM can be considered to be an efficient modulation technique as it does not require additional components, lower harmonics can be eliminated or minimized leaving higher order harmonics which can be easily filtered out. But the requirement of SCRs in this technique with low turn-on and turn-off times makes it expensive.

Sinusoidal Pulse Width Modulation (SPWM) is the simplest technique that can be implemented in both two level and multilevel inverters [14].Two signals one is a sinusoidal reference signal and other a high frequency carrier signal (triangular signal) is compared to give two states (high or low). The amplitude of the fundamental component of the output voltage of the inverter can be controlled by varying Modulation Index (MI). MI is defined as the ratio of the magnitude of the reference signal (Vr) to that of the magnitude of the carrier signal (Vc). Thus, by keeping Vc constant and varying Vr, the modulation index can be varied.

Multicarrier Pulse Width Modulation Techniques

The carrier based PWM techniques for cascaded multilevel inverter can be broadly classified into: phase shifted modulation and level shifted modulation [15]. In both the techniques, for a m level inverter, (m-1) triangular carrier waves are required. And all the carrier waves should have the same frequency and the same peak to peak magnitude.

Phase Shifted Multicarrier Modulation

In phase shifted PWM (PS-PWM), there is a phase shift φ_{cr} between the adjacent carrier signals. The phase shift is given by (1),

$$\Phi_r = \frac{360}{(m-1)} \qquad (1)$$

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For a three phase inverter, the modulating signals should also be three phase sinusoidal signals with adjustable magnitude and frequency. For this modulation scheme, the frequency modulation index m_f and the amplitude modulation index m_a is given by (2), (3), respectively.

$$m_f = \frac{f_{cr}}{f_m} \qquad (2)$$

And,

$$m_a = \frac{v_{mA}}{v_{cr}} \qquad (3)$$

Where f_{er}, f_m are the frequency of the carrier and the modulating signals respectively. are the peak amplitudes V_{cr},V_{er} of the carrier and modulating signals respectively. The amplitude modulation lies in the range of 0 to 1. The switching frequency of the device can be calculated as .$f_{aev}= f_{er}= f_r \times m_f$. The switching frequency of the inverter can be found from the device switching frequency as $f_{inv}=(m-1)\times f_{aev}$.

Level Shifted Multicarrier Modulation

In Level Shifted PWM (LS –PWM), the triangular waves are vertically displaced such that the bands occupy are contiguous. The frequency modulation is given by $m_f = \frac{f_{cr}}{f_m}$ and amplitude modulation index is $m_a = \frac{v_{mA}}{v_{cr}}$ where fm and fcr are the frequencies of the modulating and carrier waves and V_{mA} and V_{cr} are the peak amplitudes of modulating and carrier waves respectively. The amplitude modulation lies in the range of 0 to 1. Based on the disposition of the carrier waves, level shifted PWM can be In Phase Disposition PWM (IPD – PWM), Phase Opposition Disposition PWM (POD – PWM) and Alternate Phase Opposition Disposition PWM (APOD – PWM).

IPD PWM

In this modulation, all the triangular carrier waves are in phase.

POD PWM

In this form of modulation, the carrier waveforms are in all phases above and below the zero reference value. However there is 180 degrees phase shift between the ones above and below zero respectively.

APOD –PWM

In this form of modulation, the carrier waves are displaced from each other by 180 degrees alternately. In this modulation, the inverter switching frequency and the device switching frequency are given by and respectively. In LS-PWM, each carrier is associated with the gating signals of NPC converter whereas in PS-PWM, a pair of carriers is associated with each cell of the CHB and FC converters. Because of the phase shifting of the carriers, power is evenly distributed among the cells which results in the smooth operation of CHB and the natural voltage balancing of the FC. Therefore, LS-PWM is mainly used for NPC converter whereas PS-PWM is practically used for CHB and FC converter. Even though IPD PWM results in low THD as compared to PS-PWM, the small difference in the high frequency content can be filtered out [12,16].

IV THIRD HARMONIC INJECTION

The utilization rate of the DC voltage for traditional sinusoidal PWM is only 78.5% of the DC bus voltage, which is far less than that of the six-step wave (100%). Improving the utilization rate of the DC bus voltage has been a research focus in power electronics.

This problem of the under-utilization of the DC bus voltage led to the development of the third-harmonic-injection pulse-width modulation (THIPWM). It is similar to sinusoidal modulation but the difference is that the reference ac waveform is not sinusoidal but consists of both a fundamental component and a third-harmonic component. As a result, the peak-to-peak amplitude of the resulting reference function does not exceed the DC supply voltage Vs, but the fundamental component is higher than the available supply Vs. This is 15% higher in amplitude than that achieved by the sinusoidal PWM. Therefore, the third-harmonic PWM provides better utilization of the dc supply voltage than the sinusoidal PWM does [18].

V. SIMULATION RESULTS

Here simulation is carried out in several cases, in that proposed cascaded multilevel inverter operated under several modulation schemes by using Matlab/Simulink tool.

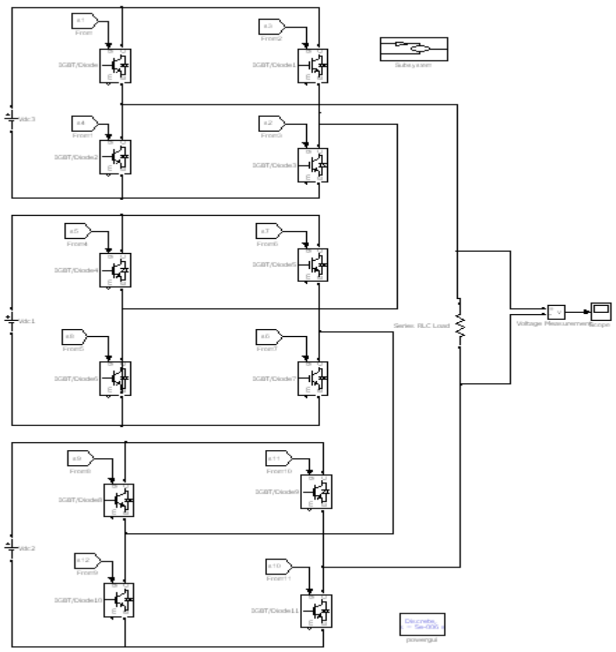

Fig.2 Matlab/Simulink Model of 1-phase symmetrical Cascaded Multilevel Inverter Operated under several modulation techniques

Fig.2 shows the Matlab/Simulink Model of Proposed symmetrical Cascaded Multilevel Inverter Operated under several modulation techniques using matlab/Simulink environment.

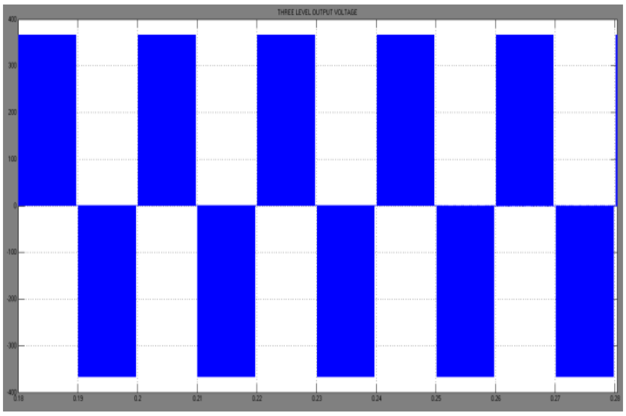

Fig.3 Three level Output Voltage using PSPWM

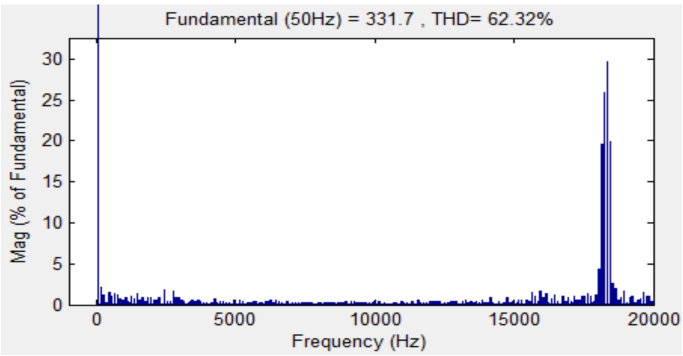

Fig.4 FFT Analysis of 3-level Output Voltage using CHB fed PSPWM

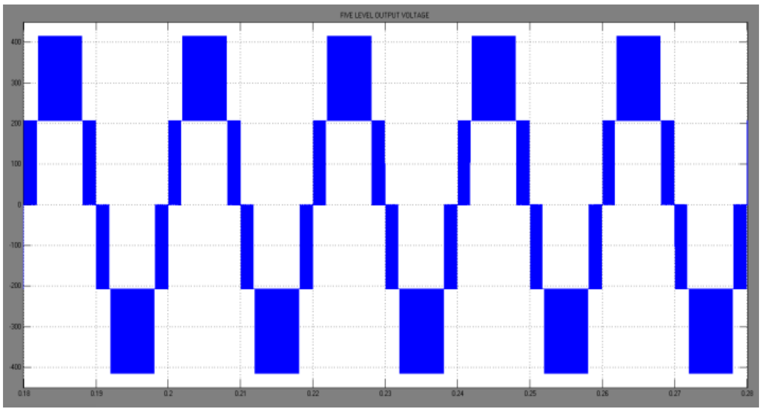

Fig.5-Level Output Voltage of CHB Inverter Fed PSPWM

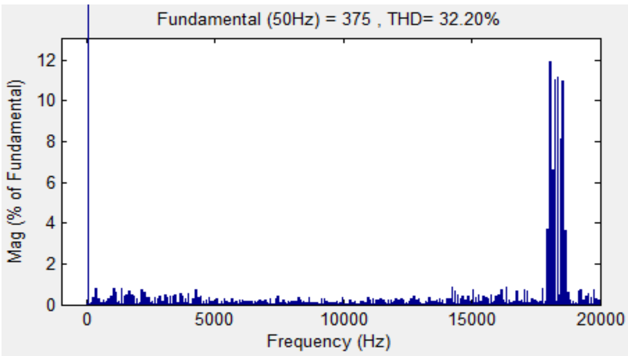

Fig.6 FFT Analysis of 5-level Output Voltage of CHB Inverter Fed PSPWM

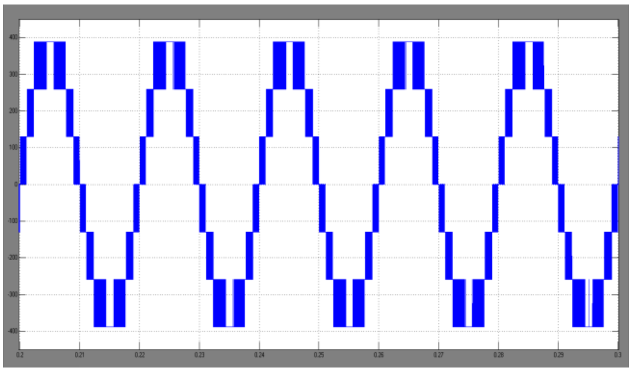

Fig.7 7-Level Output Voltage of CHB Inverter Fed PSPWM

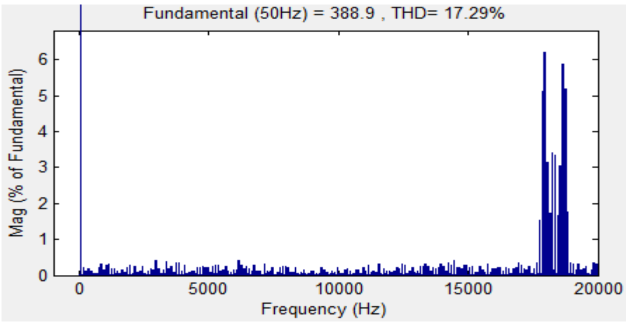

Fig.8 FFT Analysis of 7-level Output Voltage of CHB Inverter Fed PSPWM

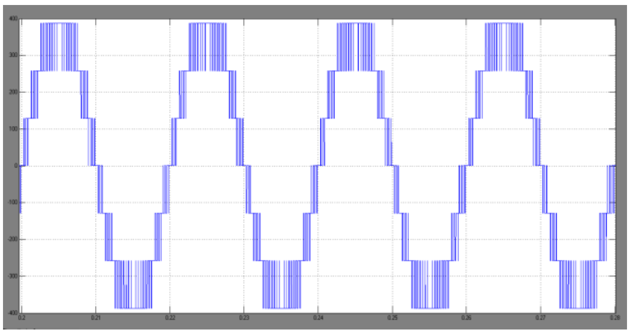

Fig.9 7-Level Output Voltage of CHB Inverter Fed LSPWM-IPD Scheme

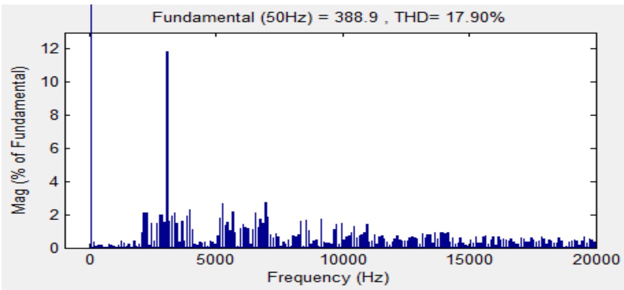

Fig.10 FFT Analysis of 7-level Output Voltage of CHB Inverter Fed LSPWM-IPD Scheme

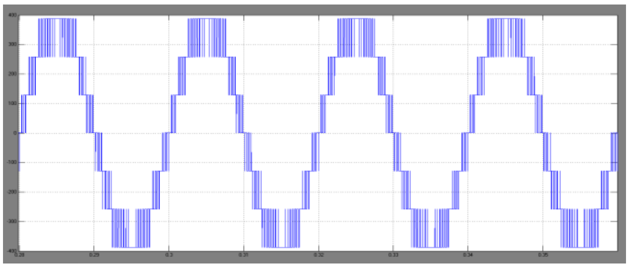

Fig.11 7-Level Output Voltage of CHB Inverter Fed LSPWM-POD Scheme

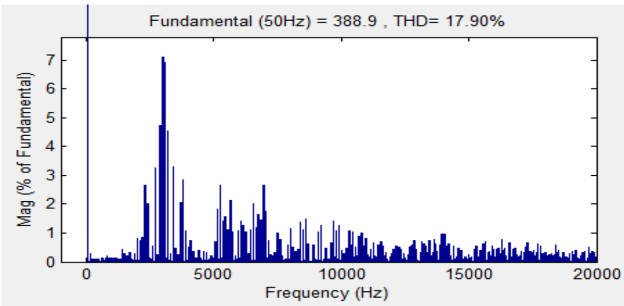

Fig.12 FFT Analysis of 7-level Output Voltage of CHB Inverter Fed LSPWM-POD Scheme attains

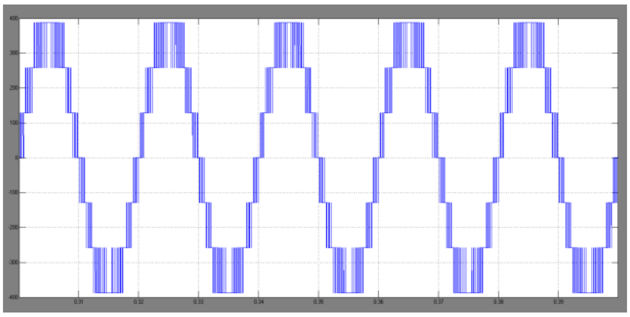

Fig.13 7-Level Output Voltage of CHB Inverter Fed LSPWM-APOD Scheme

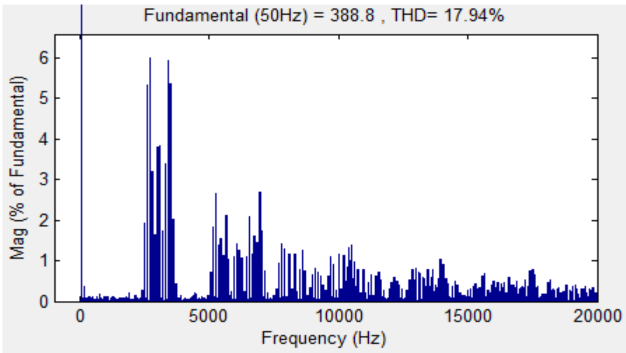

Fig.14 FFT Analysis of 7-level Output Voltage of CHB Inverter Fed LSPWM-APOD Scheme

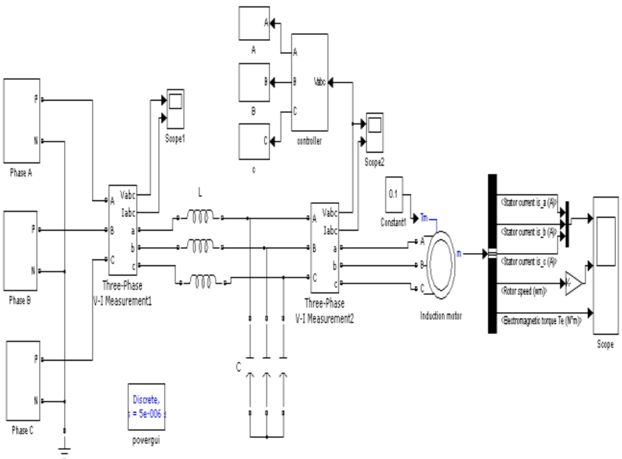

Fig.15 Matlab/Simulink Model of Proposed Three Phase CHB Inverter Fed Induction Machine Drive Operated Under LS-PWM Modulation Scheme with Filter & Controller

Fig.15 shows the Matlab/Simulink Model of Proposed Three Phase CHB Inverter Fed Induction Machine Drive Operated under LS-PWM Modulation Scheme using Matlab/Simulink tool.

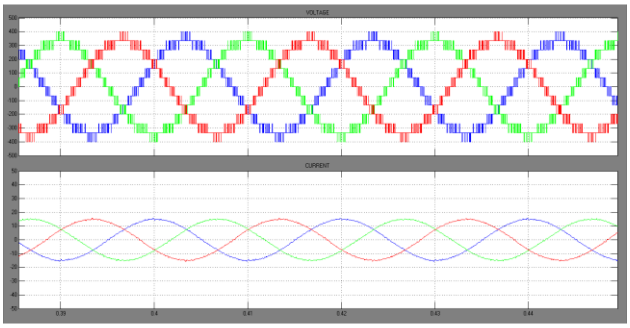

Fig.16 Output Voltage & Current

Fig.16 Output Voltage & Current of Proposed Three Phase CHB Inverter Fed Induction Machine Drive Operated under LSPWM Scheme Before filter.

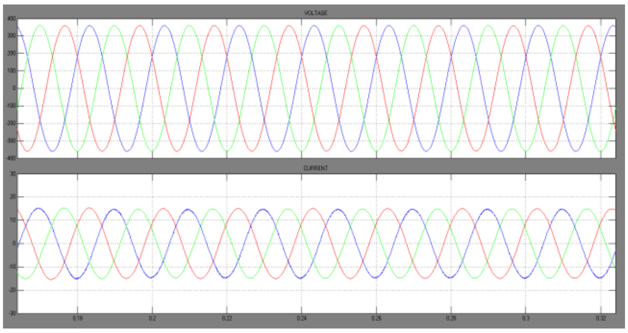

Fig.17 Output Voltage & Current

Fig.17 Output Voltage & Current of Proposed Three Phase CHB Inverter Fed Induction Machine Drive Operated under LSPWM Scheme After filter.

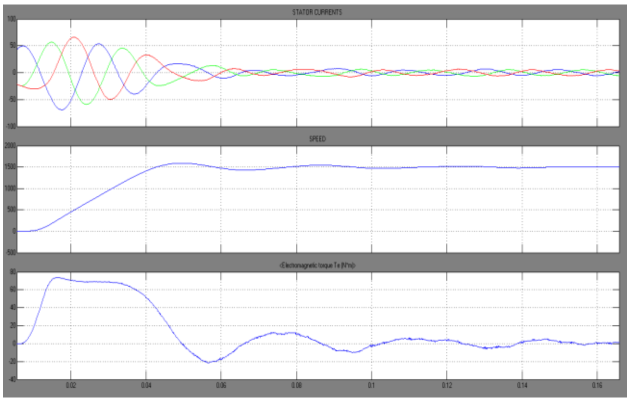

Fig.18 Induction Machine Drive Characteristics

Fig.18 Simulation Results of Proposed Three Phase CHB Inverter Fed Induction Machine Drive Operated under LSPWM Scheme.

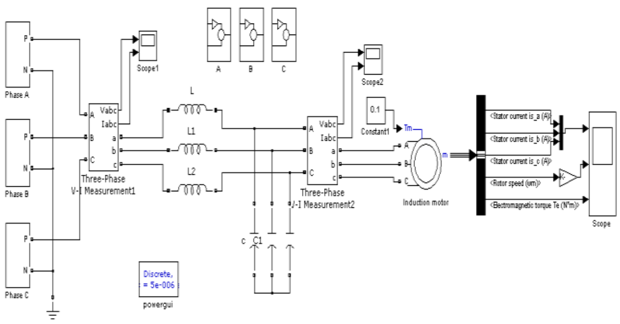

Fig.19 Matlab/Simulink Model of Proposed Three Phase CHB Inverter Fed Induction Machine Drive Operated under THI-PWM Modulation Scheme

Fig.19 shows the Matlab/Simulink Model of Proposed Three Phase CHB Inverter Fed Induction Machine Drive Operated under THI-PWM Modulation Scheme using Matlab/Simulink tool.

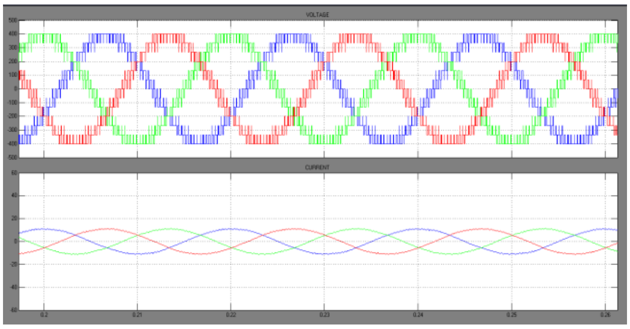

Fig.20 Output Voltage & Current

Fig.20 Output Voltage & Current of Proposed Three Phase CHB Inverter Fed Induction Machine Drive Operated under THIPWM Scheme before filter

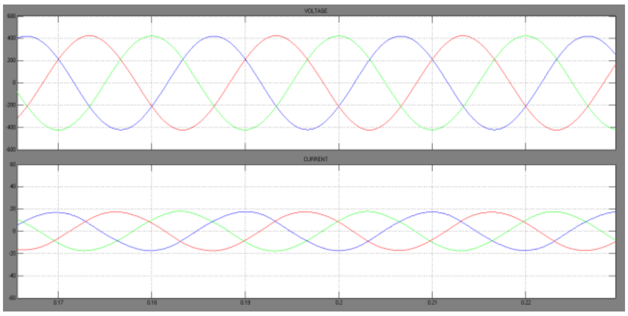

Fig.21 Output Voltage & Current

Fig.21 Output Voltage & Current of Proposed Three Phase CHB Inverter Fed Induction Machine Drive Operated under THIPWM Scheme after filter

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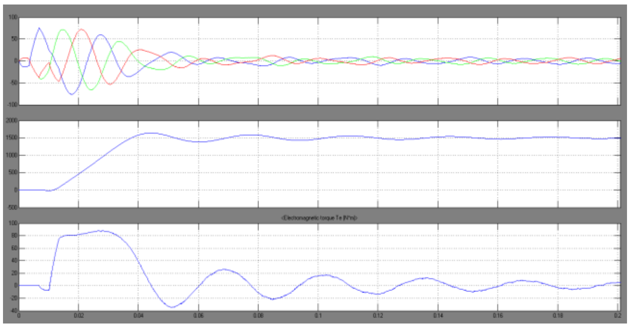

Fig.22 Induction Machine Drive Characteristics

Fig.22 Simulation Results of Proposed Three Phase CHB Inverter Fed Induction Machine Drive Operated under THIPWM Scheme.

V. CONCLUSION

Pulse Width Modulation variable speed drives are increasingly applied in many new industrial applications that require superior performance. Recently, developments in power electronics and semiconductor technology have lead improvements in power electronic systems. This proposed technique provides more flexibility to designers and can generate more voltage levels without losing any level which worsens THD characteristics. The possibility of extension or series connection of this basic in two topologies has been studied. As we increase the number of levels of the output voltage of the inverter, the output waveform has increased number of steps, which produces a staircase wave that approximates to a sinusoidal waveform. Hence, as the level of the output voltage increases, the harmonic distortion of the output wave decreases. As seen from the simulation results, THIPWM have a superior performance compared to SPWM. The SPWM technique is very popular for industrial converters. It is the easiest modulation scheme to understand and implement. This technique can be used in single-phase and three-phase inverters. The THIPWM technique operates by adding a third harmonic component to the sinusoidal modulating wave. It is possible to increase the fundamental by about 15.5% and, hence, allow a better utilization of the DC power supply. From the shape of the line-to-line voltages, the resulting flat-topped waveforms allow over-modulation with respect to the original SPWM technique. Space Vector Modulation technique and Direct Torque Control strategy can be implemented in the cascaded rectifier inverter configuration.

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