Performance Evaluation of Induction Motors With Cross Switched T-Type Multilevel Inverter

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ABSTRACT
This paper examines the performance of induction motor using a new cross-switched T-Type Multilevel Inverter (MLI). A MATLAB/SIMULINK model is implemented by combining the proposed MLI topology and an induction motor for evaluating system behavior under practical conditions. The recommended MLI highlights the potential for improving service life, operating reliability and energy efficiency of electrical driven applications compared to other systems such as ease of control with a fewer number of switches, lower harmonic distortion content and capability to deliver higher voltage levels. Moreover, this study aims at finding out if waveform optimization together with system efficiency can be enhanced by narrowing down on phase opposing disposition pulse width modulation (POD PWM) control method. By providing experimental results, we are able to prove the applicability and benefits of the proposed MLI to reduce harmonic distortion, enhance motor performance, and ensure system stability. The study shows that the proposed MLI improves motor performance and efficiency with respect to the PWM inverter. The results emphasis for more efficient electric motor drives and provide interesting applications in industrial automation and smart grid systems.

Keywords
Multilevel inverter, POD PWM, T-Type MLI, Voltage control, Motor drives

1. INTRODUCTION
Power electronics has developed as an essential constituent in the control of efficient asynchronous motor drives used for industrial purposes and factory automation [1]. This is a rapidly evolving technology whose applications are still expanding. Specifically, power electronic converters are important in electrical engineering. Variable frequency drives (VFDs) take advantage of modern control strategies such as vector control and direct torque control (DTC), which have been facilitated by advances in solid-state converters, to achieve high performance. Induction motors are widely used in industries, commercial establishments, utilities as well as in homes [1]. Nonetheless, running induction motors without power electronic converters entail some disadvantages including limited speed regulation, lack of efficiency, low power factor and difficult starting procedures.

Luckily, inverters can do this by offering motor variable frequency and voltage control. With such a feature, the motor is able to run at different speeds and under various loads leading to improved efficiency, lower energy consumption and extended life span [2]. Inverters are known to enhance the power factor of motors leading to overall increase in efficiency and minimal power losses. Besides that, inverters have soft-starting capabilities that prevent voltage drop during initial start-up thus improving motor lifespan as well as reliability [3]. However, use of inverters results in no sinusoidal waveforms with harmonic distortion [4] which can lead into increased power losses, less efficient operation and electromagnetic interference [5]. Several multilevel inverters have been developed to counter these harmonics. Through combining many voltage levels towards generating sinusoidal waveform output from them, these inverters significantly reduce harmonic distortions on the output waveform thereby enhancing their performance in terms of efficiency.

The application of multilevel inverters especially in VFDs for induction motors is increasingly becoming popular due to its numerous advantages compared to traditional ones [6]. Some of these benefits include reduced harmonic distortion, improved efficiency, higher power density and lower component voltage stress. Numerous topologies of the Multilevel Inverter (MLI) are defined as follows [7]:

1. Cascaded H-bridge

2. Diode-clamped multilevel inverter

3. Multilevel inverter with Aerial Capacitor

New topologies for multilevel T-type inverters have been recently developed and presented with improved output voltage levels employing fewer switches and lower switching losses. Fewer power electronics switches produce an output voltage with more levels and, associated with this, higher output voltage and power rating with less switching losses, while keeping costs low. It allows negative voltage to be produced without additional switches. This design can also be easily expanded to produce additional output voltage levels [5].

2. RELEVANT LITRATURE
Over the past several decades, academics around the world have conducted numerous research studies on MLI. In order to minimize conduction losses and make module balancing easier, Goetz, S.M., et al.'s model of the photovoltaic system with cascaded H-Bridge Inverter [8] suggests that CHB inverters integrate every single PV element into modules which can be tied to their intended locations in both series and parallel.

The asymmetrical multilevel inverter topologies were compared by Bibi Asma Batool et al. [9] in their article published in 2008. The asymmetrical topologies used fewer switches overall, but they still generated high-level output. Taking into account that CHB provided balanced DC link voltages and a similar amount of layers at a lower complexity. With the use of 15-level CHB MLI, J. Gowri Shankar et al. [10]

determined the high output voltages for the photovoltaic system. He showed isolated sources and asymmetric CHB. The sources are binary duplicates of each other, as intended. As phase disposition pulse width modulation offers the greatest potential to minimize THD, it was chosen as the switching technique. The 19-level asymmetrical CHB was suggested by H R Ramesh et al. [11] and the outcomes were contrasted with those of the symmetric CHB. In addition to using uneven DC sources, the suggested architecture also examined several factors such THD and high output levels. The topology achieved the intended outcomes by using equal phase modulation. When the results were compared to symmetrical CHB, it became clear that other metrics had also dropped and that THD had dropped from 16.5% to 11%. An enhanced cascaded MLI topology has been presented by Marif Daula Siddique et al. [12]. The topology that was planned featured fewer switches and sources. With other parameters tuned, the topology was able to reach a large number of levels. Applying the selective harmonic removal approach produced the output voltage. The results were then contrasted with traditional MLI topologies. A novel MLI configuration was created by ST MERAJ et al. [5] that uses the fewest power-consuming electric equipment. It is a two-back-to-back T-type module combination with two cross-connected switches. DC sources with the same or differing voltage ratings were used to power this converter. A high-quality output voltage was generated using the closest level control low-frequency modulation approach. Raj el al [13] presented cross switched multilevel inverter. The output voltage levels of the converter are controlled with nearest level modulation and multicarrier PWM control schemes. CTJ Jerin [14] proposed thirteen level cascaded H- bridge multilevel inverter output is fed into induction motor and the speed, mechanical torque response is calculated.

Because of the quantity of switches and control circuits, variable frequency drives (VFDs) are frequently complex, expensive, and bulky. As a result of the high switching frequency, switches experience increased voltage stress, reducing drive efficiency. Our work seeks to examine more effective and reduced device inverter topology in order to increase VFD performance and accessibility. This study presents a MATLAB simulation of an induction motor coupled with a five-level multilevel inverter.

3. PROPOSED T MULTILEVEL INVERTER

The development of the MLI explains why the traditional inverters lack in terms of higher numbers of voltage levels with lesser switches required. Additionally, this invention allows parallel connection of various dc voltages boosting up performance and efficiency [15]. Harmonic distortion can be minimized by increasing its voltage levels to imitate a sinusoidal wave which would improve the quality of its output waveform. Besides, using less switches simplifies design as well as enhance switching losses reducing reliability at system level.

Figure 1 is an outline depicting the integration of a suggested induction motor with a DC Switched Multilevel Inverter via MATLAB/SIMULINK model. It explores complex interlinkages between motor, inverter and control system hence giving a comprehensive idea on how the whole system works. The latter is a useful simulation and analysis tool designed for evaluating performance of proposed MLI design as well as assessing its effects on overall efficiency and functionality of induction motor systems. This proposal is an option to embrace MLI into induction motors because it has numerous applications in both industries and homes. The use of MLI reduces rate of power loss across electric motors since it is able to lower harmonics by controlling voltage levels precisely. On top of that, these power management systems allow multiple dc sources to run together which become scalable so that they can be used for variable operational needs or energy optimization purposes.

To summarize, the multilevel inverter proposed herein is an excellent advancement in power electronics technology which offers a desirable way of surmounting limitations associated with conventional inverters. This research aims at opening up doors for more efficient and reliable electric motor systems which will drive industrial automation improvements, renewable energy integration as well as smart grid applications.

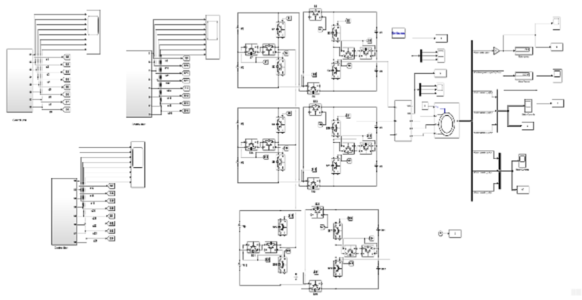

Figure 1 Induction Motor Model with Planned DC Switching MLI

As seen from Figure 2, this shows how the DC switched supply works by interconnecting power switches having opposite polarities of dc source connected to each other strategically. It

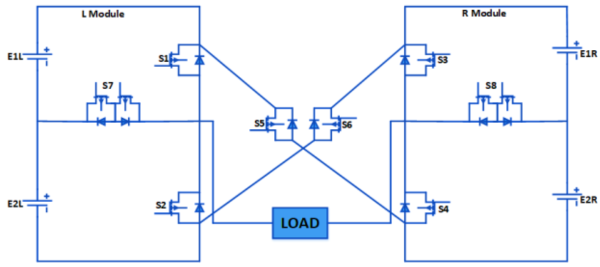

Figure 2 The suggested DC-Switched MLI

should be noted that this arrangement permits accurate regulation of flow of electrical energy within the system making Multilevel Inverter (MLI) easier to operate.

This plan guarantees smooth transitions between various operational modes and maximizes the use of several DC voltage sources. It enhances the integrated induction motor system's power quality and energy efficiency by carefully regulating voltage levels. All things considered, the DC switched source scheme is a cornerstone of the suggested MLI design and exemplifies a cutting-edge method of power control and management in electrical motor systems. The Figure 3 demonstrates 9 different modes of conductions for proposed multi-level inverter.

A switching method generates 8 carrier signals for the phase opposite disposition PWM control system, making sure that each signal has a 45-degree phase difference to the others. The goal of this exact synchronization is to enhance the output waveform's power factor and decrease total harmonic distortion (THD) [16]. The switching technique is painstakingly created to maximize the Multilevel Inverter's (MLI) performance, guaranteeing effective energy use and raising the overall standard of the electrical power.

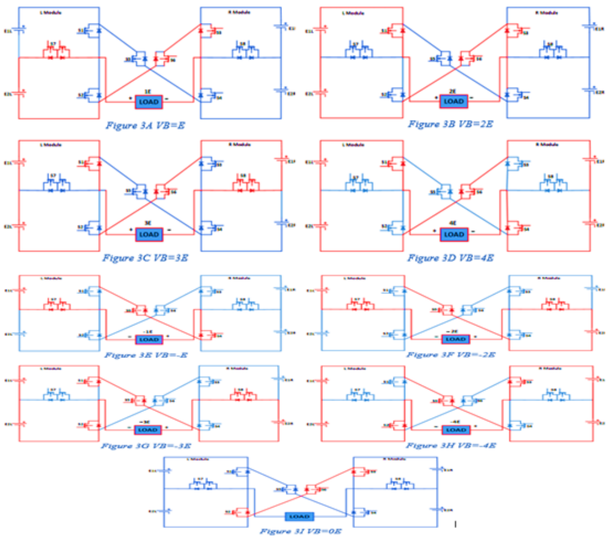

Figure 3 Modes of operation for DC Switched MLI

This method helps the MLI manage voltage levels more accurately and minimize distortion—important for applications that demand stable systems and high-quality power supply. The Figure 4 shows the phase voltage control using POD PWM scheme

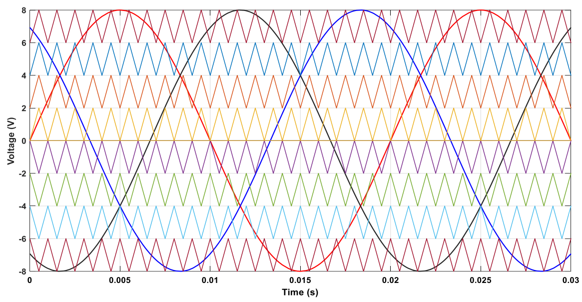

Figure 4 Phase voltage control using POD Sinusoidal PWM scheme

Every half-cycle of the reference sine wave is divided into six equal segments by the switching algorithm. A sequence of pulses with widths proportionate to the amplitude of the reference sine wave is produced by this method, in which each carrier signal is active for two of the segments and deactivated during the remaining four segments. Following their merging, these PWM signals create the three-level output wave. The top two carrier signals mix together for the positive portion of the waveform, while the lower two signals are combined for the negative half. As a result of no carrier signal, the intermediate level is created. This output waveform with three levels is useful for controlling the voltage and current of different loads, such as power supply and motors.

PWM technology allows for precise control of the output waveform, promoting high power factor, reducing total harmonic distortion (THD) and high efficiency. By manipulating the pulse width, the PWM control method provides a way to customize the output to specific needs, ensuring high efficiency and stability in electrical networks. Applications that require reliable power supply and energy-efficient utilization necessitate such degree of control; this underscores how important PWM strategy becomes when improving operation and effectiveness of MLI (multi-level inverter).

Output voltage	Switching states							
VBB	S1	S2	S3	S4	S5	S6	S7	S8
4E	1	0	0	1	0	1	0	0
3E(i)	1	0	0	0	0	1	0	1
3E(ii)	0	0	0	1	0	1	1	0
2E(i)	1	0	1	0	0	1	0	0
2E(ii)	0	1	0	1	0	1	0	0
2E(iii)	0	0	0	0	0	1	1	1
E(i)	0	0	1	0	0	1	1	0
E(ii)	0	1	0	0	0	1	0	1
0(i)	0	1	1	0	0	1	0	0
0(ii)	0	1	0	1	1	0	0	0
-E(i)	0	0	0	1	1	0	1	0
-E(ii)	1	0	0	0	1	0	0	1
-2E(i)	0	0	0	0	1	0	1	1
-2E(ii)	0	1	0	1	1	0	0	0
-2E(iii)	1	0	1	0	1	0	0	0
-3E(i)	0	1	0	0	1	0	0	1
-3E(ii)	0	0	1	0	1	0	1	0
-4E	0	1	1	0	1	0	0	0

Figure 5 Proposed scheme for control signals

Since S1, S3, S6 and S7 are not active at this time due to mode 8 they do not feed any load thus resulting into an output with zero voltage. On the other hand, the output produces E1 voltage in the 1st mode and 2E voltage in the second. A mixture of the voltages in E1 and E2 is the 3rd and 4th mode's output. On the other hand, negative voltages appear at the output for the remaining modes. This sequential procedure demonstrates the Multilevel Inverter's (MLI) dynamic nature, wherein different modes determine the generation of different voltage levels to satisfy the load's requirements.

4. RESULTS AND DISCUSSIONS

The total harmonic distortion of the output voltage in Fig. 6 is given as 30.40 percent. The generation of harmonics is based on fundamental frequency of 50 Hz and is used to produce higher order harmonics in its forms. Consequently, the same harmonics are then sampled at a Nyquist rate to ensure that their

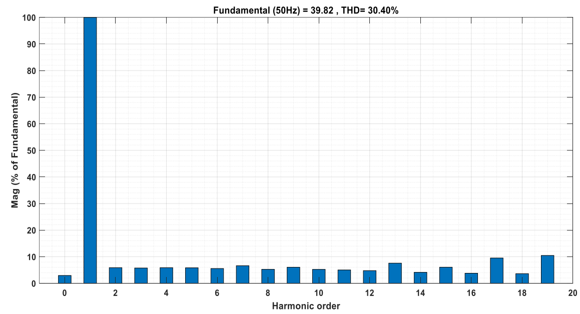

Figure 6 Voltage THD for stator output

samples represent them correctly. On the y-axis of the graph, there is a corresponding amplitude for each harmonic while on x-axis represent harmonic order. This figure provides an understanding of the harmonic contents contained in the output voltage which is important when evaluating effectiveness of Multilevel Inverter (MLI) system. Line voltages for induction motor stator are illustrated in Figure 7.

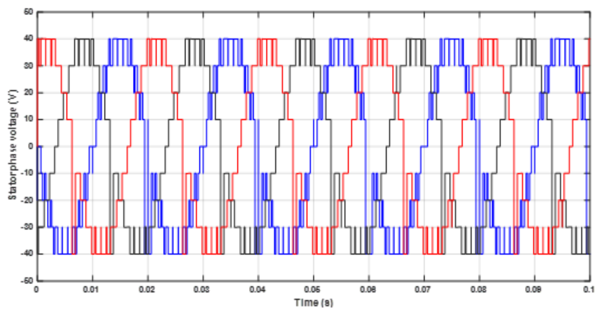

Figure 7 Waveform of the Stator Line Output Voltage

Figure 8 indicates that the total harmonic distortion of current in the stator is 29.22%. The fundamental frequency of 50 hertz, as shown in figure 9, is responsible for the generation of harmonics and serves as a platform for generating other harmonics. Later on, these harmonics are then sampled at Nyquist frequency in order to ensure accurate representation in the sampled data. On this graph's y-axis lies a measure of the magnitude appropriate for each individual harmonic while on its x-axis there is an index number representing each individual harmonic. It is worth mentioning that this graphical display offers a clear understanding of what makes up the Harmonic spectrum present in output Voltage which helps evaluate how well functioning can it be described.

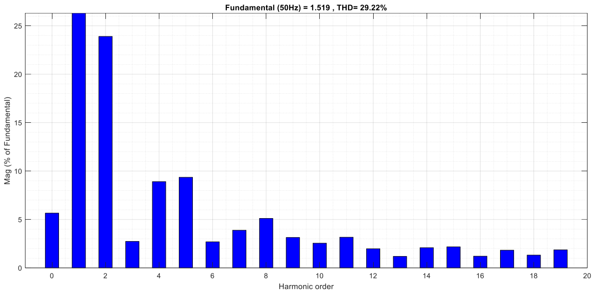

Figure 8 The harmonic spectrum of the stator current

The motor RPM with respect to time is plotted in Figure 9. The speed remains constant after 2 seconds. The electromagnetic torque that the machine produces is depicted in Figure 10. The torque output has a discernible amount of noise as the stator is supplied by a PWM inverter. But because of the machine's inertia, this noise is efficiently filtered out of the speed measurement. On Figure 11 and Figure 12 it shows currents of all three stator phases. In contrast, Figure 13 displays rotor currents instead. When speed is measured, noise has been filtered out from rotor and stator currents but still can be seen showing how PWM invertor influences electrical characteristics of system gave it much emphasis. Thus this finding underlines the importance of comprehending and controlling influence that PWM modulation may have on motor performance especially where torque accuracy is highly essential.

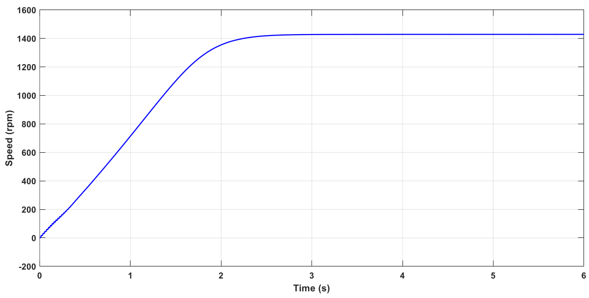

Figure 9 Motor RPM and Speed

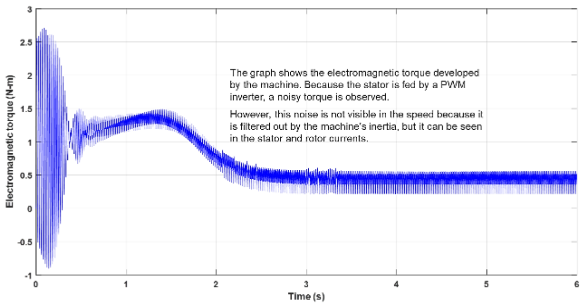

Figure 10 Generated Torque by induction motor

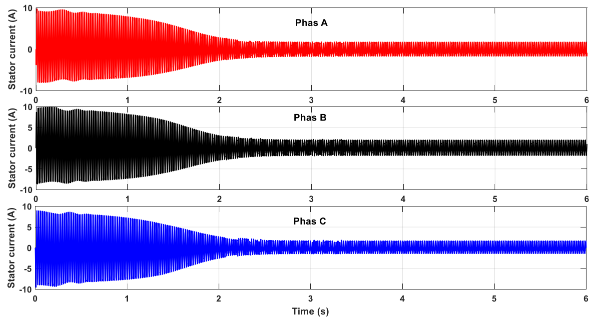

Figure 11 Stator Currents for all phases

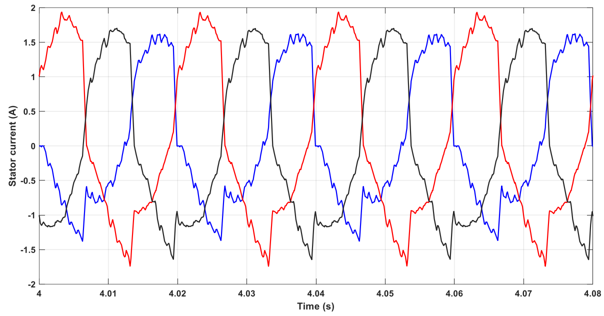

Figure 12 Stator Current's Zoomed View

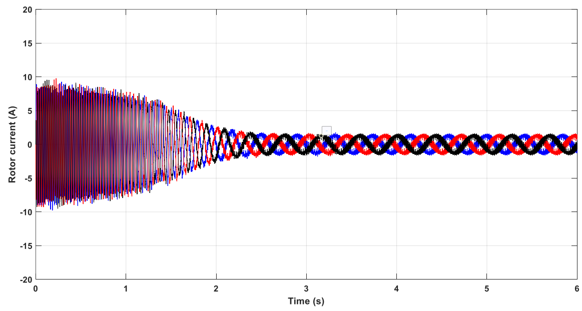

Figure 13 Rotor Current using DC Switched ML1

The above graphs demonstrate the electromagnetic torque produced by the machine. The noise of this torque is seen due to the PWM inverter feeding power to the stator. However, it can be noted that this noise is filtered out by the inertia of a machine from its speed but it is apparent in stator and rotor currents.

5. CONCLUSION

In this report, investigations of performance analysis of induction motors using T switching multilevel inverters were presented. It presents how harmonic distortion may be reduced by multilevel inverters and therefore enhance overall system efficiency through reviewing relevant academic papers and suggesting new MLI design. The researchers were able to conduct a thorough evaluation of motor performance by incorporating this recommended MLI into their MATLAB/SIMULINK model which resulted in higher voltage levels, less harmonic distortion and easier operation. However, there are some difficulties in the process of application such as the noise of PWM inverters, but experimental results have shown a good improvement in system stability and motor performance. The study's findings offer a variety of attractive options for potential uses of proposed MLI architecture, including smart grid systems, industrial automation and renewables integration. Operating at increased voltage levels and with reduced harmonic distortion, this MLI could increase the life expectancy, efficiency and reliability of electromechanical drives. This is an important contribution to the field of power electronics technology as it paves the way towards next generations' more reliable and efficient electric motor systems. To maximize use of multilevel inverters and encourage further development in electric motor technology research is necessary in this area.

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