

Enhanced DTC induction motor drives for THD minimization performance improvement with multilevel inverter

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ABSTRACT

Direct torque control (DTC) is a method applied in induction motor (IM) drives to control the speed and torque of IM accurately and independently without feedback signal. However, in fast fourier transform (FFT) analysis, the total harmonic distortion (THD) of the IM drives is high in DTC method with conventional inverter (CI). Therefore, the purpose of this study is to minimize the THD without affecting the drive's performance. A DTC IM drive with multilevel inverter (MLI) is proposed in this study to reduce THD and preserve good speed and torque response of IM simultaneously. DTC IM drive with proposed MLI based THD minimization has several advantages over the DTC IM drive with CI, including higher generated output voltage with low distortion, operate under low switching frequency, and work with renewable energy. In order to prove the effectiveness of the proposed MLI based THD minimization in DTC IM drive, MATLAB Simulink is used to investigate the response of the IM drive and THD under different operating condition. From this study, proposed MLI based THD minimization DTC IM drive is able to reduce THD with a maximum of 13% in low speed operation as compared to DTC IM drive with CI.

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1. INTRODUCTION

Induction motor (IM) is an alternating current (AC) electric motor that is extensively used in household appliances and manufactory industrial that consume about 54% of the total consumed electrical energy [1]–[4]. IM consist of two parts which are stator and rotor. The magnetic field of the stator winding induces the magnetic flux in the rotor to produce rotating torque and rotate the mechanical load devices that are connected to the rotor by using the shaft [5], [6]. Basically, the efficiency of IM is high when operation of IM is at rated speed and load torque conditions [7]. However, for a variable speed and load operation, the application of the IM at rated flux will cause the efficiency of IM to decrease dramatically [8], [9]. Therefore, to achieve the efficiency optimization of the IM drive system at partial load, it is important to obtain the flux level that minimizes the total motor losses [10].

IM drives that having speed control has enormous use in the industry sector [11], [12]. These IM drives occupy more than 75% of the load in the industry of any country [13], [14]. High performance IM drives application needs high efficiency, low cost and simple control circuitry for the complete speed range

[15], [16]. There are two different approaches for IM drives efficiency optimization. The first approach uses analytical computation of motor losses to optimize the efficiency that is named as losses model controller method. This method has the main advantage of not requiring additional hardware but needs accurate knowledge of motor parameters. The second approach will gradually search the flux level to obtain maximum efficiency, named as online or search efficiency optimization control method. This method has the advantage that it is completely insensitive to motor parameters variation.

Total harmonic distortion (THD) of IM drive is significant since minimization of THD will increase the efficiency of the motor drive [17]–[19]. THD variation analysis of current source inverter fed electric motor drive system during various fault conditions is conducted in [20] and it shows that during a fault condition, the THD of motor drive increases [21]. THD minimization can be done using various methods, out of which multi-level inverter (MLI) fed IM drive preferably used to reduce THD in IM drive [22]–[24]. This is because MLI are good power quality and have higher voltage capability [25]–[27]. MLI not only achieves a higher power rating but also enables the use of renewable energy sources [28], [29].

A three-phase DTC IM drives with and without MLI is presented in this paper to validate the proposed THD minimization of the motor drive at different operating speeds with variable load applied by using MATLAB Simulink. The simulation testing for the proposed MLI based DTC and conventional inverter (CI) IM drive is conducted and compared at low speed (300 rpm), medium speed (850 rpm) and high speed (1400 rpm) with variable load applied to IM under the same conditions. This paper has been divided into few sections. In section 2 research method of this project is discussed. Section 3 will discuss the simulation result of the proposed MLI based THD minimization DTC IM drives obtained from MATLAB/Simulink. Section 4 will conclude the findings of the proposed MLI based DTC in THD minimization performance improvement.

2. ENHANCED MLI BASED DTC FOR THD MINIMIZATION

The aim of this study is to apply MLI in DTC IM drive that can reduce the THD of the drive system. The block diagram of the proposed MLI based THD minimization DTC IM drive is illustrated in Figure 1. Figure 2 and Figure 3 show the Simulink model of the DTC IM drive with conventional two-level inverter and the proposed five-level MLI based THD minimization DTC IM drive, respectively.

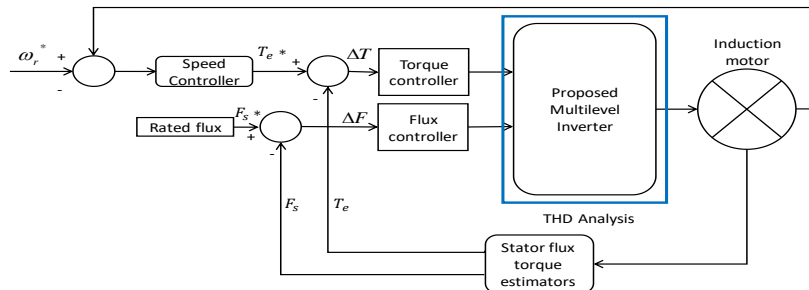


Figure 1. Block diagram of proposed MLI based THD minimization DTC IM drive

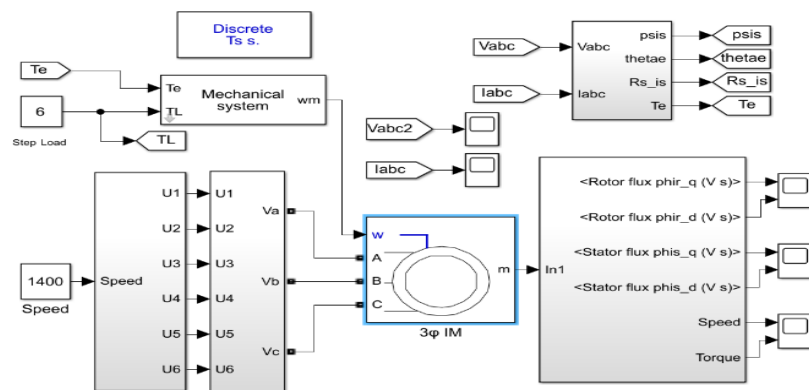


Figure 2. DTC IM with CI

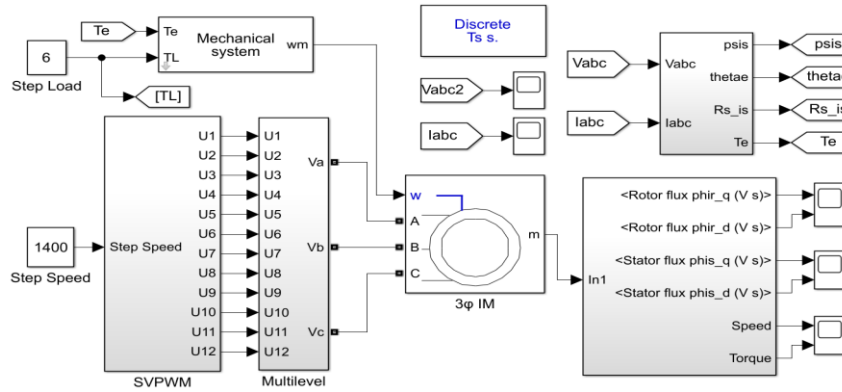


Figure 3. Proposed MLI based THD Minimization DTC IM drive

A conventional two-level inverter consists of an equal amount voltage source and many switches for controlling voltage or current. For high power and high voltage applications, using a conventional two-level inverter at high frequency results in switching losses and constraints of the power device ratings. On the other hand, the proposed five-level MLI based THD minimization DTC IM drive gives a better dynamic performance as compared to CI based DTC.

Theoretically, MLI can achieve THD minimization in DTC IM drive. The higher the level of MLI in DTC IM drive, the better the performance of MLI in THD minimization. However, increase the level of MLI in DTC IM drive will increase the drive system complexity. To verify the effectiveness of MLI in THD minimization for DTC IM drive, MATLAB Simulink is used for testing under different conditions.

3. RESULTS AND DISCUSSION

Table 1 shows the specification of IM used in this study. The proposed MLI based DTC will be tested along with the conventional inverter (CI) based DTC under three different conditions, which are step load torque variation with constant low speed (300 rpm) conditions, medium speed (850 rpm) conditions, and high rotating speed (1400 rpm) conditions. In each different MATLAB/Simulink testing, the corresponding result of THD, speed response, and load torque response is observed and compared.

Table 1. IM specification

Specification of IM	Parameters
Number of phases	3
Mechanic power	5.4 HP, 4 KW
Rated voltage	400 V
Rated frequency	50 Hz
Rotor speed	1430 rpm
Number of poles	4
IM parameters and types of frames	
Reference frame	Stationary
Stator resistance	1.405 Ω
Rotor resistance	1.395 Ω
Stator inductance	5839 mH
Rotor inductance	5839 mH

In Matlab Simulink, the load on IM is initially set at 0Nm, and start from 2s, the load on IM increase to 6 Nm. The load on IM continues to increase to 12Nm after 6s and decrease to -6 Nm after 7 s. And lastly, increase back to 6 Nm after 9 s. In step load testing, the resulting THD obtained are compared between the DTC IM drive with CI and the proposed MLI based THD minimization DTC IM drive. Figure 4 (a) and Figure 4 (b) show the results of the proposed MLI based DTC compared with the CI based DTC, respectively, with step load and fixed slow speed (300 rpm). Table 2 shows the FFT result of current I_a , I_b and I_c respectively and Figure 5 (a) and Figure 5 (b) shows the THD reduction comparison in three-phase line current, I_a in MATLAB Simulink. Based on the THD reading obtained from both Figure 5 (a) and Figure 5 (b), it is obvious that the THD is reduced by 12.87% in IM drive with proposed MLI as compared to IM drive with CI.

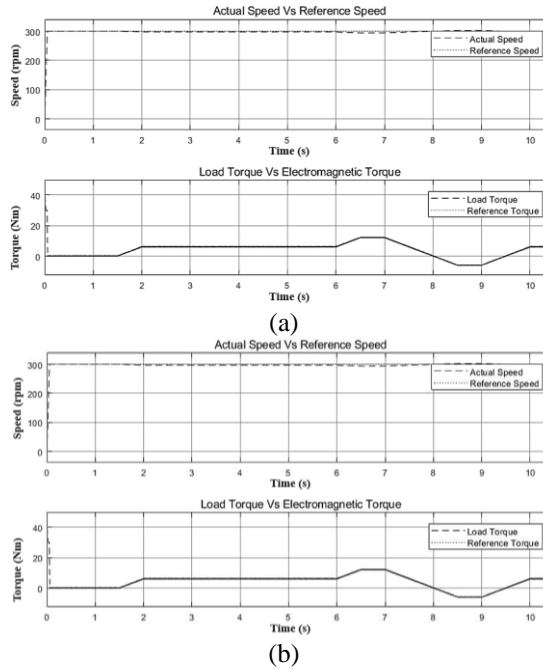


Figure 4. Speed and load torque performance of proposed MLI based THD minimization DTC IM drive at low speed (a) DTC IM drive with CI and (b) DTC IM drive with MLI

Table 2. THD of DTC IM drives with and without MLI corresponding to step load and 300rpm fixed speed

Type of Inverter	CI-DTC (%)	MLI-DTC (%)
I_a	67.03	54.16
I_b	75.68	61.22
I_c	76.82	62.76

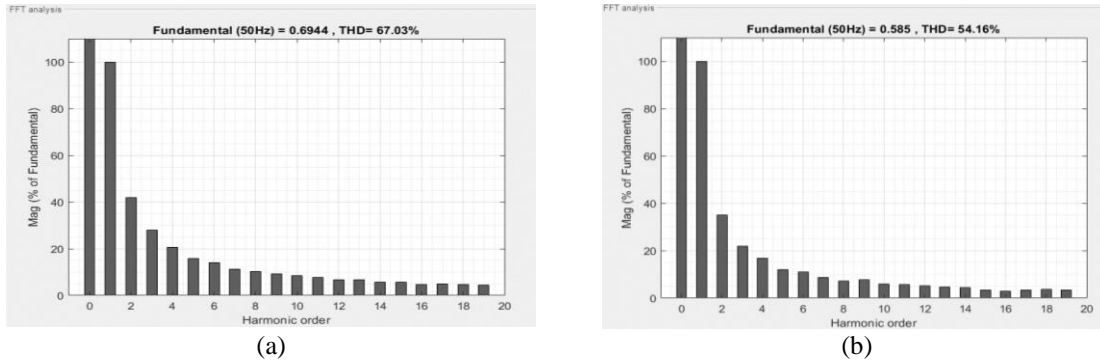


Figure 5. FFT result of current, I_a with step load at slow speed (300 rpm) (a) DTC IM drive with CI and (b) DTC IM drive with MLI

Figure 6 (a) and Figure 6 (b) show the results of the proposed MLI based DTC compared with the CI based DTC with step load and fixed medium speed (850rpm), respectively. Table 3 shows the FFT result of current I_a , I_b and I_c respectively and Figure 7 (a) and Figure 7 (b) shows the THD reduction comparison in three-phase line current, I_a in MATLAB Simulink. From Figure 7 (a) and Figure 7 (b), THD is reduced by 13.17% in IM drive with proposed MLI as compared to IM drive with CI.

Figure 8 (a) and Figure 8 (b) show the results of the proposed MLI based DTC compared with the CI based DTC with step load and fixed high speed (1400 rpm), respectively. Table 4 shows the FFT result of current I_a , I_b and I_c respectively and Figure 9 (a) and Figure 9 (b) shows the THD reduction comparison in

three-phase line current, I_a in MATLAB Simulink. By referring to Figure 9 (a) and Figure 9 (b), the THD is reduced by 1.43% in IM drive with proposed MLI as compared to IM drive with CI.

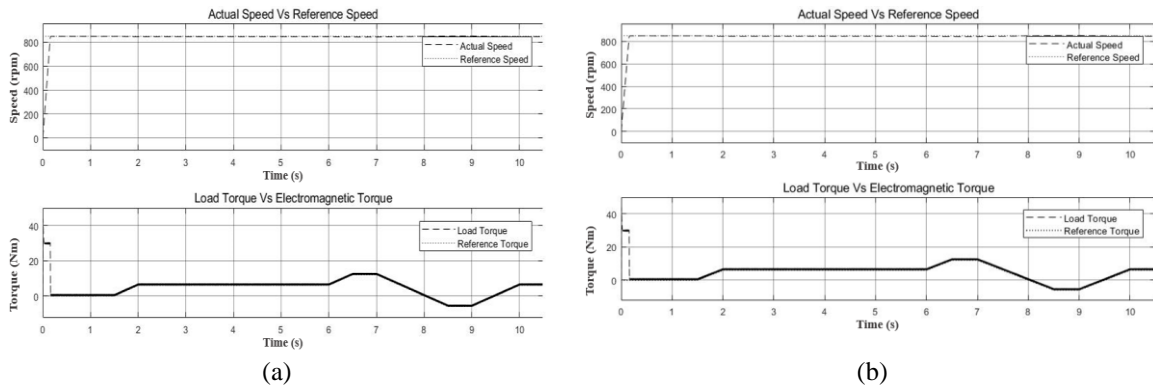


Figure 6. Speed and load torque performance of proposed MLI based THD minimization DTC IM drive at medium speed (a) DTC IM drive with CI and (b) DTC IM drive with MLI

Table 3. THD of DTC IM drives with and without MLI corresponding to step load and 850 rpm fixed speed

Type of Inverter	CI-DTC (%)	MLI-DTC (%)
I_a	40.01	26.84
I_b	56.55	45.59
I_c	45.49	31.57

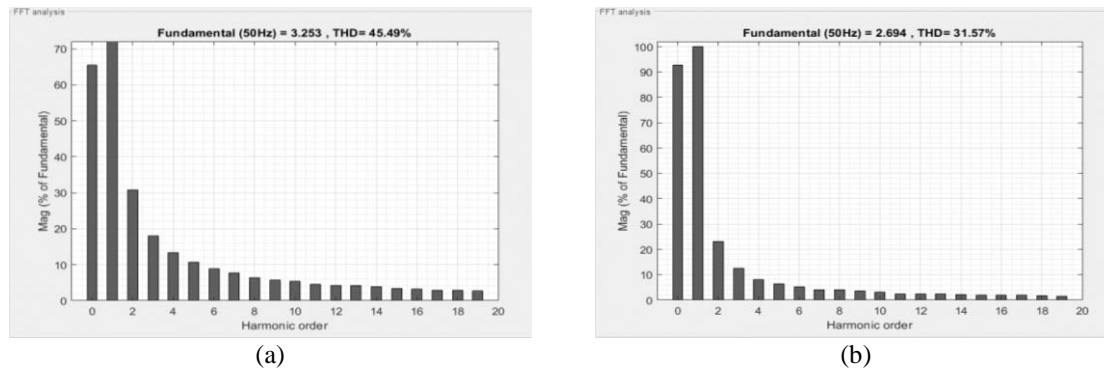


Figure 7. FFT result of current, I_c with step load at medium speed (850 rpm) (a) DTC IM drive with CI and (b) DTC IM drive with MLI

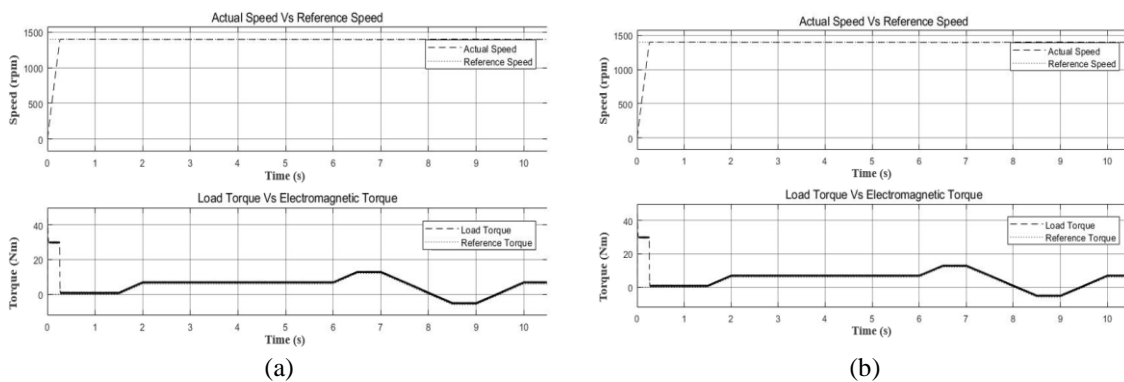
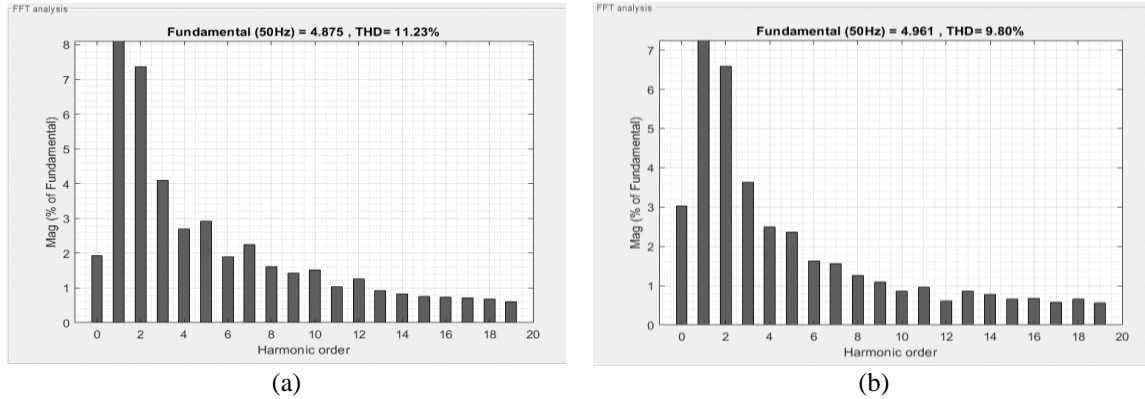


Figure 8. Speed and load torque performance of proposed MLI based THD minimization DTC IM drive at high speed (a) DTC IM drive with CI and (b) DTC IM drive with MLI

Table 4. THD of DTC IM drives with and without MLI corresponding to step load and 1400 rpm fixed speed

Type of Inverter	CI-DTC (%)	MLI-DTC (%)
I_a	11.23	9.80
I_b	5.93	5.18
I_c	9.53	8.58

Figure 9. FFT result of current, I_a with step load at high speed (1400rpm) (a) DTC IM drive with CI and (b) DTC IM drive with MLI

The THD for the proposed MLI based THD minimization DTC IM drive and DTC IM drive with CI with step load at slow speed, medium speed and high rotating speed of IM are summarised in Table 5. From the result obtained, with the proposed MLI based THD minimization DTC IM drive, the THD of the IM drive is significantly reduced as compared with CI based DTC IM drive. THD is minimum when IM operates at rated condition (1400 rpm). From this study, the IM's speed and load torque are consistent in an outstanding performance with the proposed MLI based THD minimization DTC IM drive as shown in Figure 4, Figure 6 and Figure 8 for various speed load conditions. Furthermore, based on the results obtained, the THD of the DTC IM drive can be reduced at least 0.75% at rated speed and a maximum of 14.46% at low speed with the proposed MLI based THD minimization DTC IM drive.

Table 5. THD of DTC IM drives with and without MLI corresponding to step load and different fixed speed

Speed (rpm)	THD (%)					
	300		850		1400	
Type of inverter	Conventional inverter	Proposed MLI	Conventional inverter	Proposed MLI	Conventional inverter	Proposed MLI
I_a	67.03	54.16	40.01	26.84	11.23	9.80
I_b	75.68	61.22	56.55	45.59	5.93	5.18
I_c	76.82	62.76	45.49	31.57	9.53	8.58

4. CONCLUSION

In conclusion, with the proposed MLI based THD minimization DTC IM drive applied in this study, the simulation result shows that the appropriate operation of the MLI results in reducing the THD of the motor drive system. The MATLAB Simulink result of CI based DTC IM drive offers the robustness and simplicity of the motor drive system, but there are high switching loss and torque ripples as compared to the proposed MLI based THD minimization DTC IM drive. For the proposed MLI based THD minimization DTC IM drive, it offers advantages in reducing the switching losses and torque ripples, but MLI will increase the drive system complexity. From this study, MATLAB Simulink results of DTC IM drive with the proposed MLI based THD minimization shows that the THD of the DTC IM drive with fixed speed and step load condition can be lowered approximately at an average 13.80% for low speed operation, 12.68% for medium speed operation and 1.04% for high speed operation.

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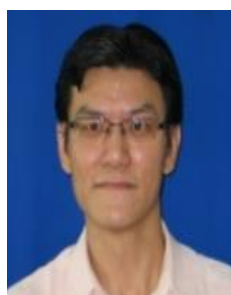
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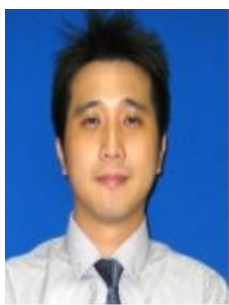
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


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