

5-level torque-hysteresis controller for DTC based IM drive

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Abstract

In the recent trade demand, the AC machines and drives are extensively utilized. Normally, the AC drives exploit with high efficacy as well as high performance. Among other things, one of the best control strategies is Direct torque control (DTC). For this article, the induction motor drive is projected very simple amended DTC scheme in accordance with the hysteresis controller. By the reason of its modest assembly & effective execution, DTC is used for AC as well as DC drive as associated to other monitoring structures. The presence of high ripple content in output torque for DTC scheme is only an obstacle. This article approaches extenuation of the ripples in torque by varying the predictable 5-level torque hysteresis controller used in DTC. The expansion of distinctive switching approach has been generated for chosen voltage vector. On the basis of ripple content simulation outcomes fulfilled in MATLAB/SIMULINK for hysteresis torque controller to minimized the ripples.

Keywords: Induction Motor (IM), Direct Torque Control (DTC), torque ripple.

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This paper was earlier presented at the SDCEE-2021: 1st International Online Conference on Sustainable Development in Civil and Electrical Engineering, National Institute of Technology Kurukshetra, Kurukshetra, India, December 17-19, 2021 and substantially improved for this Special Issue. Guest Editors: (i) Dr. Sri Niwas Singh, Professor (HAG), Department of Electrical Engineering, Indian Institute of Technology Kanpur, 208016 (U.P.) India, Director, ABV-Indian Institute of Information Technology & Management Gwalior; (ii) Dr. Ashwani Kumar, SMIEEE, Fellow IE (I), Fellow IETE (I), LMISTE, LMSCIEI, Professor and Head, Department of Electrical Engineering, NIT Kurukshetra Haryana, India. Dr. Kumar has 27 years teaching experience and an industrial experience of 2 years, 8 months.

1. Introduction

For variable speed application, DC machines are extensively utilized in previous decades. Within the armature and field current control, the decoupled technique of torque as well as flux that can be succeeded in DC machines. In many prospect, DC drives are expedient in conveying high starting torque, simplicity to control (Aimer et al., 2009). However, there are some detriments such as heavy cost, cannot operate in explosive and hazardous condition. To overcome the detriments by using Induction Motor (IM) due to the strength, low cost, the superior enactment and the affluence of maintenance used in industrial applications or general applications. Over the last years, several technique of control has been developed toward influenced the IM drive (Casadei et al., 1994; Lin and Lee, 1996). Besides commercial processes, the developments of the AC motor control mechanism are crucial. Now days, the Induction Motor input frequency, phase and magnitude can be changed using modern high switching frequency power converters controlled by microcontrollers, hence the speed of the motor and torque can be controlled. IM drives are controlled by

the scalar control strategy and the vector control strategy (Zidani and Said, 2005; Abdul Wahab and Sanusi, 2008; Halleh et al., 2008).

The IM module neglects the coupling effect due to just the variation of the control variable in magnitude. Such issues have been resolved by vector control approaches, such as Field-Oriented Control (FOC) and Direct-Torque Control (DTC) strategy. The multilevel inverter has been used in vector control techniques for high-power applications (Takahashi and Nouguchi, 1986; Mane and Hadke, 2020). The control of AC machine is classified into scalar and vector control. The scalar control concern with only magnitude and frequency of voltage, current and linkage flux which are in steady state condition to control the motor drives (Kang et al., 1999; Thakre and Matale, 2020). The vector control concern with not only magnitude and frequency but also instantaneous position of voltage. As FOC approaches generating maximum torque, the flux module is being maintained at the operating level of the rated flux (Youb and Craciunescu, 2009; Kumar et al., 2020). Throughout the DTC control system, the electromagnetic torques, as well as the stator flux magnitude, were verifiably estimated with the help of the stator current and voltage. To decrease (Mirzaei and Dastfan, 2019) more harmonics and ripple content in torque by using a 5-level torque controller linked to DTC control technique. Using space vector control, these compares the performance of the 3-level and 5-level DTC with modifying hysteresis comparator based on induction motor drive. The direct-axis and quadrature-axis flux variation is a representation of the vector control system (Kazmierowski, 1995; Thakre and Borse, 2020).

The objective of the paper is a comprehensive analysis of 3-level and 5-level hysteresis controller with DTC controllers while implemented to induction motor drives. The effectiveness of this 3-level and 5-level torque controller is evaluated by comparing based on torque flux and speed with the help of MATLAB Simulink simulation software. Both studies illustrate in the outcomes there is a variance in the efficiency and performance of the Induction Motor drive.

This article has been planned as follows: the drive technology for DTC has been explained in section 2. Development of 5-Level Torque Controller is discussed in segment 3. The simulation outcome for behavior of the Induction Motor in segment 3. The assumption is given in segment 4.

2. Drive Technology for DTC

The control of the flux as well as torque directly is aided with DTC technology. There is combination of voltage vectors for optimal inverter by the application of IM drive illustrate in Figure.1. To restrict the errors in flux linkage and torque via a proper selection of voltage vectors of relevant flux and torque comparators for the evaluation of stator flux and torque, there is requirement of available feedback. The availability of feedback is required for estimated values of flux in stator and torque (Hakami et al., 2019; Djagarov et al., 2021). The available feedback is in the form of stator three-phase voltage and current that transforms into a stationary axis. The estimator for torque and flux has been evaluated by instantaneous value of flux as well as torque in the type of AC motor. To obtain the errors in torque and flux values for the hysteresis controller in real-time can be evaluated by link with the reference input values. The drive seems Eq. (1)-(6) for linked between torque as well as the flux:

$$V_{sr} = R_s I_{sr} + \frac{d\lambda_{sr}}{dt} \tag{1}$$

$$V_{ss} = R_s I_{ss} + \frac{d\lambda_{ss}}{dt} \tag{2}$$

$$\lambda_{sr} = (V_{sr} - R_s I_{sr}) dt \tag{3}$$

$$\lambda_{ss} = (V_{ss} - R_s I_{ss}) dt \tag{4}$$

$$\lambda_s = \sqrt{\lambda_{sr}^2 + \lambda_{ss}^2} \tag{5}$$

$$T_e = \frac{3}{2} p (\lambda_{sr} I_{ss} - \lambda_{ss} I_{sr}) \tag{6}$$

2.1 Assessment of flux as well as torque

The calculation for the electromagnetic torque by the only use of linkage flux and current through flux based in the stator utilized the calculated method. To dependency of mutual as well as rotor inductance for the evaluation of motor are deserted in the situation. For the computation of motor only consider the stator resistance has been employed for the linkage flux (Chowdhary and Thakre, 2020). The $V_{as}, V_{bs}, V_{cs}, i_{as}, i_{bs}, i_{cs}$ are 3-phase inverter outputs in the form of voltage & current which are converted into the 2-phase stationary frame, i.e., d-q axes voltages as well as currents as shown in Eq. (7)-(10):

$$V_{qs} = V_{as} \tag{7}$$

$$V_{ds} = \frac{1}{\sqrt{3}}(V_{cs} - V_{bs}) \tag{8}$$

$$i_{qs} = i_{as} \tag{9}$$

$$i_{ds} = \frac{1}{\sqrt{3}}(i_{cs} - i_{bs}) \tag{10}$$

$$\lambda_{qs} = \int (V_{qs} - R_s i_{qs}) dt \tag{11}$$

$$\lambda_{ds} = \int (V_{ds} - R_s i_{ds}) dt \tag{12}$$

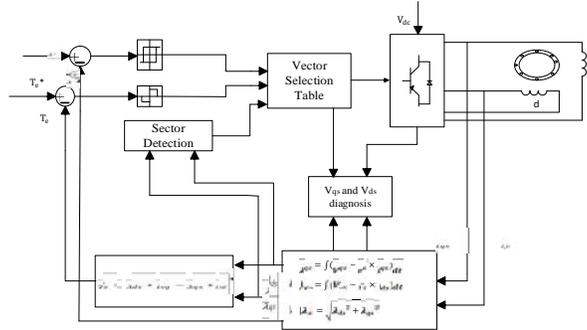


Figure 1. DTC of IM drive.

3. Development of 5-Level Torque Controller

There is no requirement of PWM modulator in torque hysteresis controller of DTC which driven by selecting switching states exhausting a switching table. The generation of required voltage vector for T_e and λ_s for the influence the above drawback by employing 5-level torque-hysteresis controller. However, there is no modification in the two-level flux controller. Using SVM modulator or exception of the increment in sampling frequency demonstrate that minimizes the torque and speed ripples (Vas, 1998; Thakre and Borse, 2020).

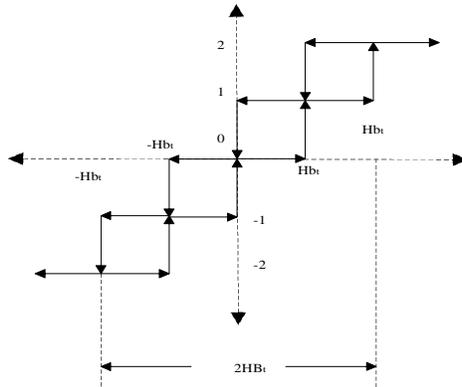


Figure 2. 5-level Hysteresis torque comparator

The Figure.2 seems the 5-level torque-hysteresis controller DTC. Within the bands, the torque vector at two levels each for positive and negative limits further zero value i.e. the value of torque vector changes twice for exceeding its upper and lower values. For the same stator flux selected accurate selected voltage vectors through switching sequence as shown in Table 1. The innovative switching strategy is intended for torque hysteresis controller to succeed the preferred voltage vector. In the novel switching strategy, the involvement of 12 active vectors and 2 null vectors for a switching space vector in 5-level torque controller (Abdul Wahab and Sanusi, 2008; Shrivastava et al., 2021). At synchronous speed, the switching states are designed which has been influenced by the position of the stator flux and the consequence of the 2-level flux and 5e-level torque controllers.

Table 1. Assortments of switching applied on sector 1 for 5-level hysteresis controller

O/P of Flux Controller	O/P of Torque Controller	Duty (%)
1	2	$V_4/100$
	1	$V_4/50$ & $V_0/50$
	0	$V_0/100$
	-1	$V_2/50$ & $V_0/50$
	-2	$V_2/100$
0	2	$V_5/100$
	1	$V_5/50$ & $V_7/50$
	0	$V_7/100$
	-1	$V_3/50$ & $V_7/50$
	-2	$V_3/100$

The assortments of switching vectors as illustrated in Figure. 5. The 12 active voltage vectors classified into V_1-V_6 & $V_{10}-V_{60}$ which are combined to V_1-V_6 acquired the exact voltage vector. Also, the V_0 & V_7 are null voltage vectors which are applied for 50% duty. Table 2 demonstrate that the changes in the control of conventional switching technique in DTC scheme for 5-level torque controller. The null vectors appeal that the torque error lies inside 2nd Hbt band which has been obtained the enhanced inverter switching frequency defined in Figure. 3.

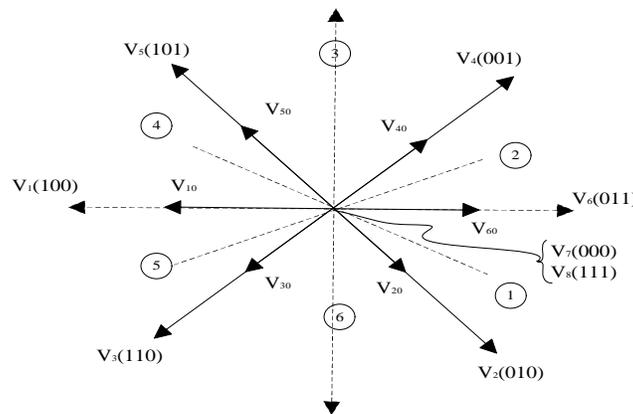


Figure 3. Vector diagram of DTC IM drive

Table 2. Assortment of 5-level voltage selection

$d\lambda_s$	dT_s	S(1)	S(2)	S(3)	S(4)	S(5)	S(6)
1	2	V_4	V_5	V_1	V_3	V_2	V_6
	1	V_{10}	V_{50}	V_{10}	V_{30}	V_{20}	V_{60}
	0	V_0	V_7	V_0	V_7	V_0	V_7
	-1	V_{20}	V_{60}	V_{40}	V_{50}	V_{10}	V_{30}
	-2	V_2	V_6	V_4	V_5	V_1	V_3
0	2	V_5	V_1	V_3	V_2	V_6	V_4
	1	V_{50}	V_{10}	V_{30}	V_{20}	V_{60}	V_{40}
	0	V_7	V_0	V_7	V_0	V_7	V_0
	-1	V_{30}	V_{20}	V_{60}	V_{40}	V_{50}	V_{10}
	-2	V_3	V_2	V_6	V_4	V_5	V_1

4. Outcomes and Discussion

The execution of proposed hysteresis-based DTC as linked to conventional DTC via MATLAB-Simulink software. For the implementation the value for 0.01 Wb and 0.5 N-m are set to flux as well as torque of the hysteresis comparator respectively. The gain value in terms of proportional as well as integral is 100 and 1.5 respectively for torque controller. The gain value in terms of

proportional as well as integral is 4000 and 250 respectively for flux controller. The Organization of IM constraints used in the simulation is shown in Table 3.

Table 3. Organization of IM constraint

Constraints	Value
Power assessment	3.6 KW
Torque assessment	5 Nm
Flux assessment	0.3 Wb
Speed assessment	1400 rpm
Line-line voltage assessment	415 Volts
Frequency	50 Hz
Resistance in stator	0.435 Ω
Resistance in rotor	0.820 Ω
Inductance in stator	2 mH
Inductance in rotor	2 mH
Mutual inductance	63.16 mH
Inertia	0.089 kg.m ²
Poles	2

The alteration of ripple content in speed as well as torque has been demonstrated that the steady state behavior of system. Primarily, there is null value of an element of speed as well as torque for induction motor. At 50 Hz frequency, the assessment speed are 1500rpm and it varies with time at standard. The rotor speed is less than synchronous speed under the operating condition. Figure.4 shows the speed response of 3-level torque hysteresis controller. At starting the speed increased 60 rad/sec & constant up to 1.5 sec. After 1.5 sec. it will increase 110rad/sec., decreased at 1.8 sec. & then it will be constant. Figure. 5 shows the speed response of 5-level torque hysteresis controller. At starting the speed increased 50 rad/sec & constant up to 1.5 sec. After 1.5 sec. it will increase 100rad/sec., decreased at 1.8 sec. & then it will be constant. Figure. 6 Torque behavior of 3-level torque hysteresis controller. The torque ripple content is 24 to 15 Nm at 0.3 sec. It will decrease at 0.34 sec. & constant with torque ripple content 13 to 6 Nm. Figure.7 Torque behavior of 5-level torque hysteresis controller. The torque ripple content is 22 to 17 Nm at 0.3 sec. It will decrease at 0.34 sec. & constant with torque ripple content 12 to 8 Nm. Flux behavior of Figure.8 illustrate that ripple content is more as compare to Figure. 9. Table 4 shows the study performance of speed as well as torque for DTC with modifying hysteresis controller.

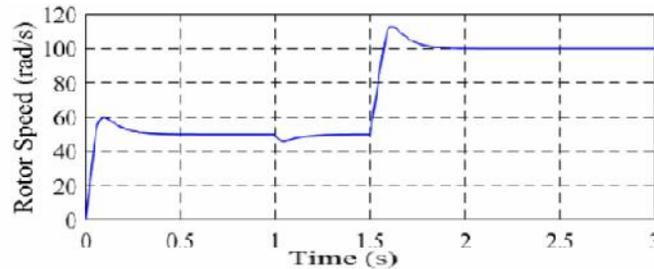


Figure 4. Speed behavior of 3-level hysteresis torque controller

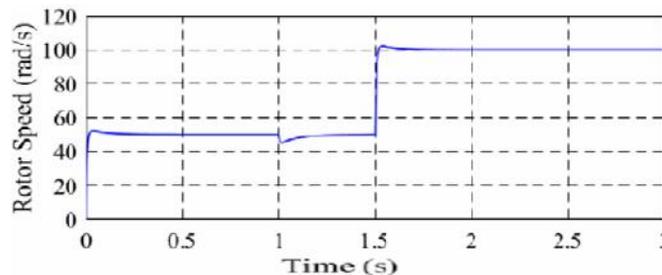


Figure 5. Speed behavior of 5-level hysteresis torque controller.

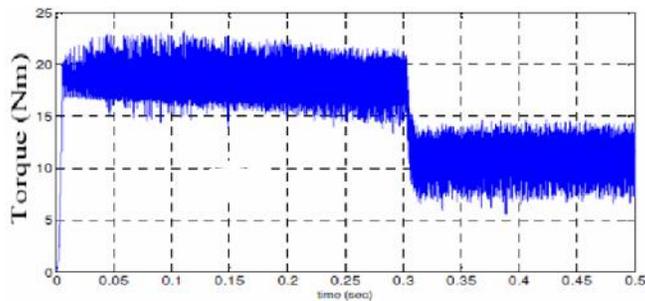


Figure 6. Torque behavior of 3-level hysteresis torque controller.

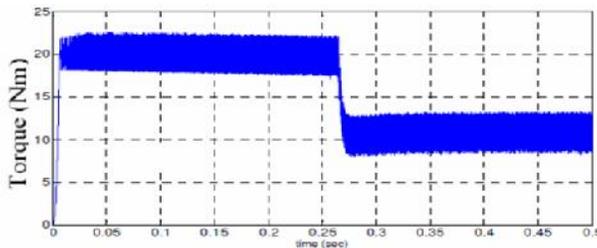


Figure 7. Torque behavior of 5-level hysteresis torque controller.

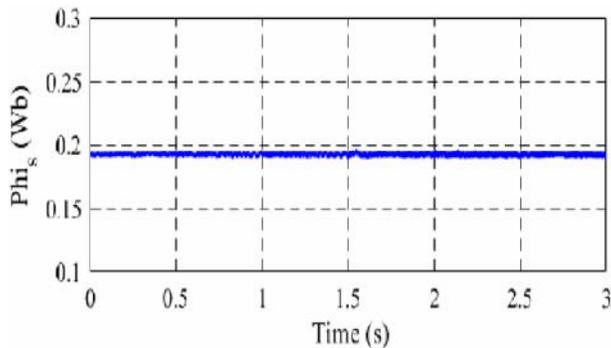


Figure 8. Flux behavior of 3-level hysteresis torque controller.

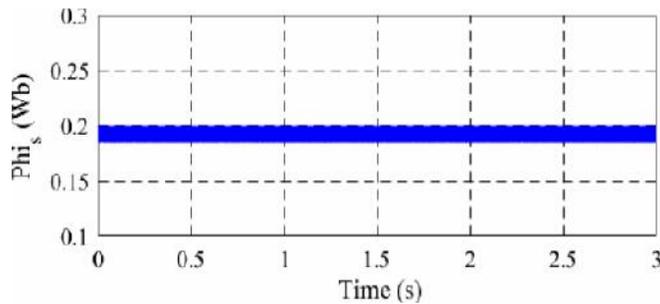


Figure 9. Flux behavior of 5-level hysteresis torque controller.

Table 4. Revision Structure Enactment of speed as well as torque

Constraints	DTC	DTC with modifying hysteresis controller
Response for Torque (Nm)	± 1.6 Nm	± 0.3 Nm
Response for Speed (rad/sec)	± 3.0 rpm	± 4 rpm

4. Conclusions

This paper presents the 5-level hysteresis torque controller to curtail the ripple content. The main aim is to developed 5-level torque hysteresis controller devoid of amendment in 2-level flux controller. There is modification in hysteresis torque controller which base on flux error for the operation of motor speed has better performance in the proposed DTC. The simulation outcomes support to validate the behavior of numerous constraints and effectiveness of the proposed DTC scheme. The simulation results carried out comparative study between 3-level & 5-level torque hysteresis controller can be analyzed. From the examination, the following achievements have been made:

- The enactment for dynamic response has been improved.
- The ripple content for flux and torque can be curtailed.
- Mechanism of speed for IM can be flourished.

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