International Journal of Power Electronics and Drive System (IJPEDS)
Vol. 8, No. 2, June 2017, pp. 522~533
ISSN: 2088-8694, DOI: 10.11591/ijpeds.v8i2.pp522-533

Modified Look-Up Table for Enhancement of Torque Response in Direct Torque Controlled Induction Machine

Goh Wee Yen[1], Nik Rumzi Nik Idris[2], Auzani Jidin[3], Tole Sutikno[4]
[1,2]Department of Electrical Power Engineering, Universiti Teknologi Malaysia (UTM), Malaysia
[3]Department of Power Electronics and Drives, Universiti Teknikal Malaysia Melaka (UTeM), Malaysia
[4]Department of Electrical Engineering, Universitas Ahmad Dahlan (UAD), Indonesia

Article Info

Article history:

Received Mar 2, 2017
Revised May 2, 2017
Accepted May 15, 2017

Keyword:

Direct torque control
Duty ratio
Induction machine
Proposed voltage vector
Torque response

ABSTRACT

Basically, the direct torque control (DTC) drive system is operated at light load. At light load, supplying the drive system with rated flux will decrease the efficiency of the system. To maximize the efficiency of drive system, an optimal flux has been applied during steady-state but when a torque is suddenly needed, for example during acceleration, the dynamic of the torque response would be degraded. Therefore, a modification to the voltage vector as well as look-up table has been proposed for the torque response improvement. The proposed voltage vector is generated by adding two adjacent conventional voltage vectors and implemented by using duty ratio. The duty ratio is used to estimate the activation time of each conventional voltage vector in order to produce the proposed voltage vector.

Corresponding Author:

Nik Rumzi Nik Idris,
Department of Electrical Power Engineering,
Universiti Teknologi Malaysia (UTM),
81310 UTM Skudai, Johor, Malaysia.
Email: nikrumzi@fke.utm.my

1. INTRODUCTION

A simple control structure of DTC that has been proposed by Takahashi [1] has gained popularity in industrial motor drive applications. Due to its simpler control structure and faster dynamic control compared to FOC system, the popularity of DTC system is increased rapidly in the past decades [1]-[3]. In FOC, the torque and flux are controlled based on stator current components whereas in DTC, the torque and flux are controlled directly and independently via an optimized selection of voltage vectors using look-up table.

In order to fully utilized the power and lengthen the life span of induction motor, an optimal efficiency of the drive system is an important factor to be implemented in EV applications. Usually, induction motors are operated at light load and thus, supplying the motor at its rated flux will decrease the power factor and efficiency of the drive [4]. Two main methods have been proposed to maximize efficiency in DTC drive system. These methods are known as flux search controller (SC) [4]-[12] and loss model controller (LMC) [13]-[16]. The former method measures input power or stator current of the system while decreasing the flux value in a consecutive step. When the input power or stator current is at its minimized value, the optimal flux is obtained. Meanwhile, by applying loss model equations, the optimal flux of latter method is determined. When copper losses are approximately equal to iron losses, the optimize efficiency of drive system is achieved.

Several modifications to the voltage vectors are carried out to improve the performance of DTC drive system. In terms of reducing the current and torque ripples, the voltage vectors in [17] and [18] are generated based on the flux and torque errors by using the discrete space vector modulation (SVM). The cycle period is divided into three time interval equally and thus, 19 voltage vectors are produced in each sector with four look-up table for low, medium and high motor speed. But to improve the torque response of DTC, the voltage vectors in [19] is estimated in a deadbeat tehnique to control the flux and torque directly. Then, the SVM is applied to calculate the duty cycle of inverters. A more simplified method is proposed in [20] by holding a voltage vector within a subsector. Each of the flux sectors is divided into two subsectors equally, identified as former and latter of subsectors. During the torque increasing, the voltage vector that is applied to increase the flux will be activated at the former of subsectors whereas the voltage vector that is implemented to decrease the flux will be applied at the latter of subsectors.

Researchers have been working on the modification of voltage vectors in recent years but there is still no suitable method to achieve the fast instantaneous torque response of DTC drive during efficiency. In open-end induction machine, two voltage source inverters are required to connect to each side of phase windings in order to produce 12 active voltage vectors and two zero voltage vectors [21]. But in this paper, the 12 active voltage vectors are obtained without adding additional voltage source inverter. The proposed voltage vector is obtained by adding two adjacent conventional voltage vectors. During transient state, a total of 12 voltage vectors can be applied instead of six voltage vectors in conventional DTC. In the modified DTC, the flux sector is divided into 12 sectors. When the torque is increasing, the proposed voltage vectors are applied to the even sector (or odd sector) when the flux is required to increase (or decrease). As proven in the simulation results, the modified look-up table of DTC drive systems enhances the torque response during efficiency.

2. CONVENTIONAL DIRECT TORQUE CONTROL

The simple control structure of DTC is illustrated in Figure 1. This control system consists of three-phase voltage source inverter (VSI), hysteresis comparators, stator flux and torque estimators, as well as look-up table. Since the stator flux and electromagnetic torque are decoupled, they can be controlled independently by using two-level and three-level hysteresis comparators, respectively. To satisfy its flux and torque requirement, an appropriate voltage vector is selected based on look-up table, as shown in Table 1. Then, the induction machine is operated based on the switching state of selected voltage vector.

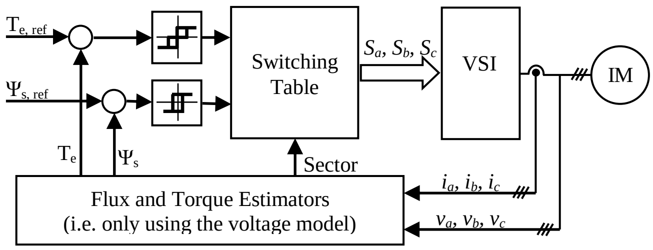


Figure 1. Simple Control Structure of DTC

Table 1 Conventional Look-Up Table

Flux Error	Torque Error	Sector 1	2	3	4	5	6
1	1	V_2	V_3	V_4	V_5	V_6	V_1
	0	V_0	V_7	V_0	V_7	V_0	V_7
	-1	V_6	V_1	V_2	V_3	V_4	V_5
0	1	V_3	V_4	V_5	V_6	V_1	V_2
	0	V_7	V_0	V_7	V_0	V_7	V_0
	-1	V_5	V_6	V_1	V_2	V_3	V_4

As illustrated in Figure 2(a), the circular stator flux is divided equally into six sectors, with 60° apart from the adjacent sectors. A three-phase voltage source inverter (VSI) is required to convert the DC-link voltage to the desired AC voltage. In each inverter leg, there are two power switches that are complementary to each other. The switching state of an inverter leg is 1 when the upper switch is ON and the lower switch is OFF, and vice-versa. Therefore, the VSI can be simplified into three two-position switches and the switching states can be represented in square brackets [S_a S_b S_c]. The voltage vector of the corresponding switching states is shown in Figure 2(b). The combination of switching states can produce two zero voltage vectors and six non-zero voltage vectors.

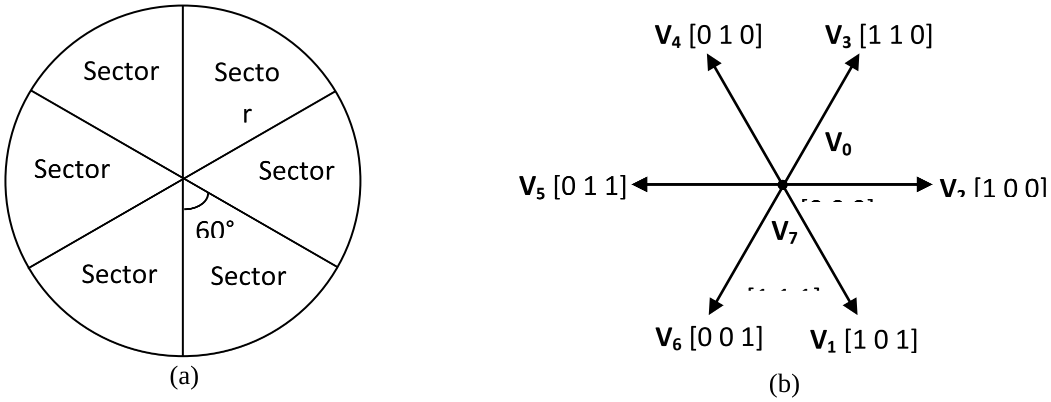


Figure 2. (a) Circular Stator Flux, and (b) Conventional Voltage Vectors

3. RESEARCH METHOD

In conventional method, the six non-zero voltage vectors has limited effects on satisfying the torque and flux error. Thus, a proposed voltage vector of 30° adjacent to conventional voltage vector is produced by applying the addition of voltage vectors. In Figure 3(a), adding V_3 to V_4 will obtain $V_{3\text{-}4}$, and their respective equations are calculated in (1). The switching state of proposed voltage vector can be achieved by applying the duty cycle's method, as shown in (2). Based on Figure 3(b), the black line illustrates the conventional voltage vector and blue line indicates the conventional voltage vector that is required to produce the red line of proposed voltage vector. Since the switching of voltage vector is undetermined in DTC drive system, a flux differentiation can be used to determine the total period of signal. The flux differentiation is achieved when the stator flux is increasing from optimal to rated flux.

$$\mathrm{V}_{s,3-4} = \left[\left(\mathrm{V}_{sd,3} + \mathrm{V}_{sd,4}\right), \left(\mathrm{V}_{sq,3} + \mathrm{V}_{sq,4}\right)\right] \tag{1}$$

$$D = \frac{T}{P} \times 100\% \tag{2}$$

where D is the duty cycle, T is the activation time of each conventional voltage vector and P is the total period of a signal.

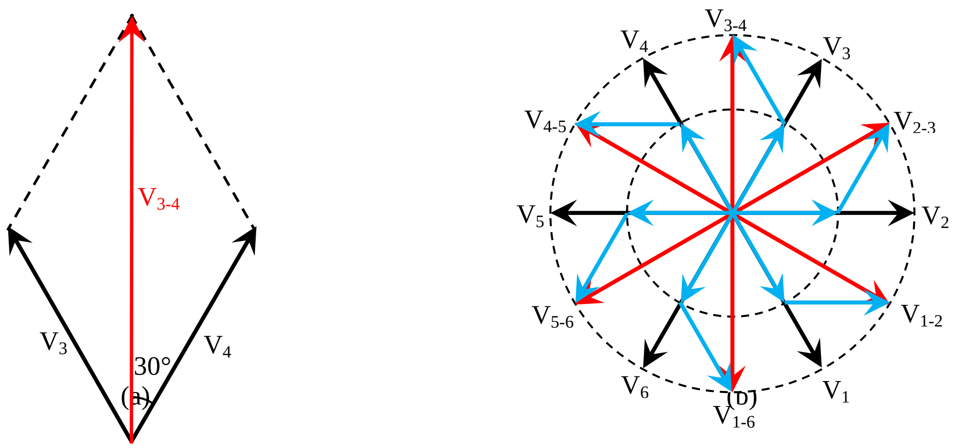
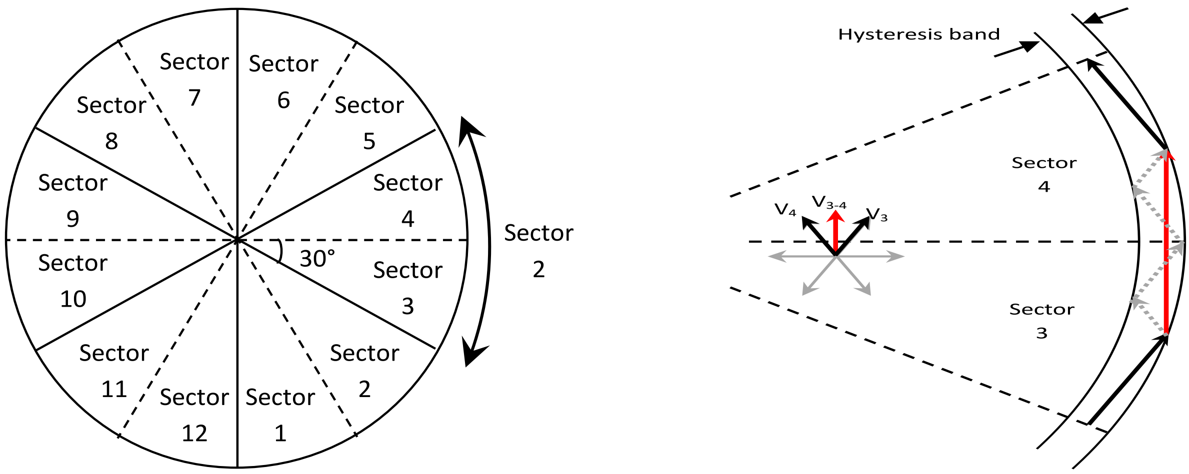


Figure 3. (a) Vector's Parallelogram Law, and (b) Duty Cycle's Method

As stated in [22], the switching of voltage vector to increase or decrease the flux is more regular in the middle of a sector compared to the beginning and end of a sector. Thus, each of the sectors in circular stator flux will be divided into two subsectors equally, as illustrated in Figure 4(a). Table 2 is a look-up table that has been modified according to the proposed voltage vector and modified sector. Based on Table 1 and Figure 2, the V_3 is applied to increase the flux whereas V_4 is applied to decrease the flux in sector 2. Both of V_3 and V_4 are capable to increase the torque as well. But according to Figure 4(a), the sector 2 in Figure 2(a) is divided into two equally sectors, namely as sector 3 and 4. The principle for application of voltage vector to increase or decrease the flux is depicted in Figure 4(b). In sector 3, the V_3 is applied to increase the flux whereas V_{3-4} is applied to decrease the flux; meanwhile, in sector 4, the V_{3-4} is applied to increase the flux whereas V_4 is applied to decrease the flux. Note that the V_3 and V_4 are triggered four times but V_{3-4} is activated once only to reach the upper hysteresis band at sector 4. For the same degree of sector, two voltage vectors have been selected to increase and decrease the flux in conventional method whereas three voltage vectors have been applied to increase and decrease the flux in the proposed method.



(a) (b)

Figure 4. (a) Circular Stator Flux, and (b) Circular Flux Control

Table 2 Modified Look-Up Table

Flux Error	Torque Error	Sector 1	2	3	4	5	6	7	8	9	10	11	12
	1	V_2	V_{2-3}	V_3	V_{3-4}	V_4	V_{4-5}	V_5	V_{5-6}	V_6	V_{6-1}	V_1	V_{1-2}
1	0	V_0	V_0	V_7	V_7	V_0	V_0	V_7	V_7	V_0	V_0	V_7	V_7
	-1	V_{5-6}	V_6	V_{6-1}	V_1	V_{1-2}	V_2	V_{2-3}	V_3	V_{3-4}	V_4	V_{4-5}	V_5
	1	V_{2-3}	V_3	V_{3-4}	V_4	V_{4-5}	V_5	V_{5-6}	V_6	V_{6-1}	V_1	V_{1-2}	V_2
0	0	V_7	V_7	V_0	V_0	V_7	V_7	V_0	V_0	V_7	V_7	V_0	V_0
	-1	V_5	V_{5-6}	V_6	V_{6-1}	V_1	V_{1-2}	V_2	V_{2-3}	V_3	V_{3-4}	V_4	V_{4-5}

Activating the proposed voltage vector can reduce the switching of voltage vector and thus, it does not increase the torque ripple. The torque is more dynamic when it is at the beginning of a sector [22] because the corresponding voltage vector is activated for a longer period. Hence, it can be seen that in Table 2, the same voltage vector is activated even the flux goes into the next sector. In conventional method, the torque response is deteriorated, especially when the flux is at the end of a sector. But with the proposed voltage vector, the torque response is enhanced even at the end of a sector due to the longer activation period of a voltage vector.

4. RESULTS AND ANALYSIS

The simulation of DTC drive system has been constructed using MATLAB's SIMULINK blocks, as shown in Figure 5. The specifications and parameters of induction machine used in the simulation are given in Table 3. The modified look-up table has been attached in parallel to the conventional look-up table. In order to improve the dynamic of output torque, the modified look-up table is implemented only during transient state. Meanwhile, the conventional look-up table is applied during steady-state.

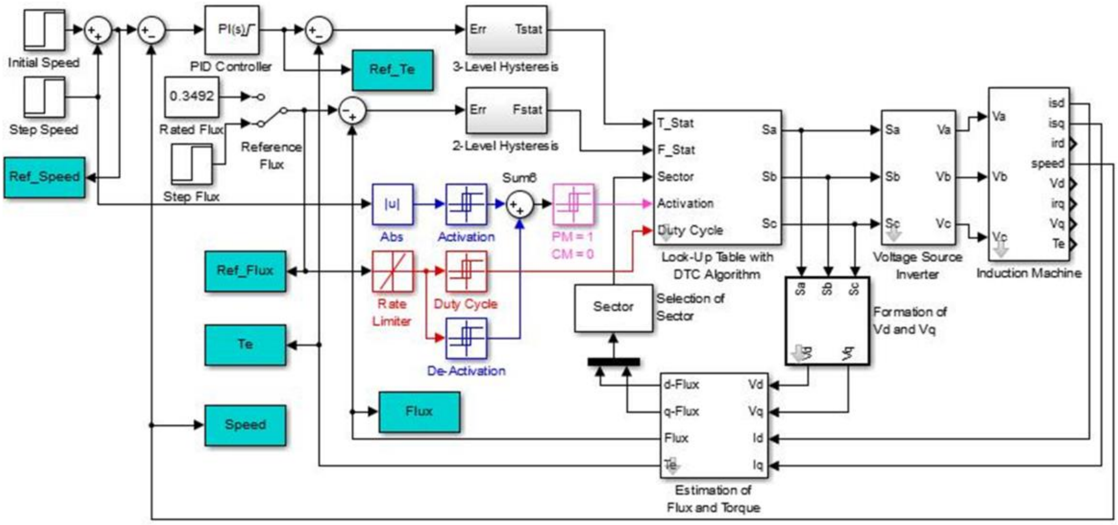


Figure 5. Simulation of DTC Drive System

Table 3. Specifications and Parameters of Induction Motor

DC voltage	150V
Stator resistance, R_s	9.9Ω
Rotor resistance, R_r	8.15Ω
Stator inductance, L_s	278.6mH
Rotor inductance, L_r	285.3mH
Mutual inductance, L_m	265.1mH
Frequency,f	50Hz
Inertia motor, J	0.001118kgm^2
Viscious friction, B	0.0006076Nms
Load torque, T_{load}	0.085Nm
Pole pairs, p	2
Sampling time	55µs
Rated flux	0.3492Wb
Rated torque	1Nm
Rated current	1.4A

When a step speed and flux are detected, the modified look-up table will be implemented. The activation time of proposed method is determined by a flux differentiation. The flux differentiation is obtained when the flux is increasing from optimal to rated value. The time taken for flux to reach its rated value can affect the torque performance. Thus, an analysis of the flux differentiation at the beginning, middle and end of a sector in conventional method has been simulated to obtain the best performance of torque response. As illustrated in Figure 6, the sector 2 and the flux differentiation with slope of 10 to 100 has been examined. Figure 6(a), 6(c) and 6(e) showed the flux differentiation with slope of 10 to 100 and the best performance of flux differentiation for dynamic torque response is depicted in Figure 6(b), 6(d) and Figure 6(f). At the beginning of sector 2 (Figure 6(a) and 6(b)), the torque response is dynamic regardless of the slope of flux differentiation. At the middle of sector 2 (Figure 6(c) and 6(d)), the flux differentiation with slope of 10 and 30 has the dynamic torque response whereas the flux differentiation with slope of 40 has deteriorated the torque response. Meanwhile, at the end of sector 2 (Figure 6(e) and Figure 6(f)), the flux differentiation with slope of 30 to 70 has improved the torque response while the torque response is degraded with the flux differentiation of slope of 100. Consequently, the flux differentiation with slope 30 is being applied in the system due to its best performance in spite of the position of flux sector. The time required for the increasing optimal flux to rated flux is 1.6ms, as estimated from the flux differentiation in Figure 6.

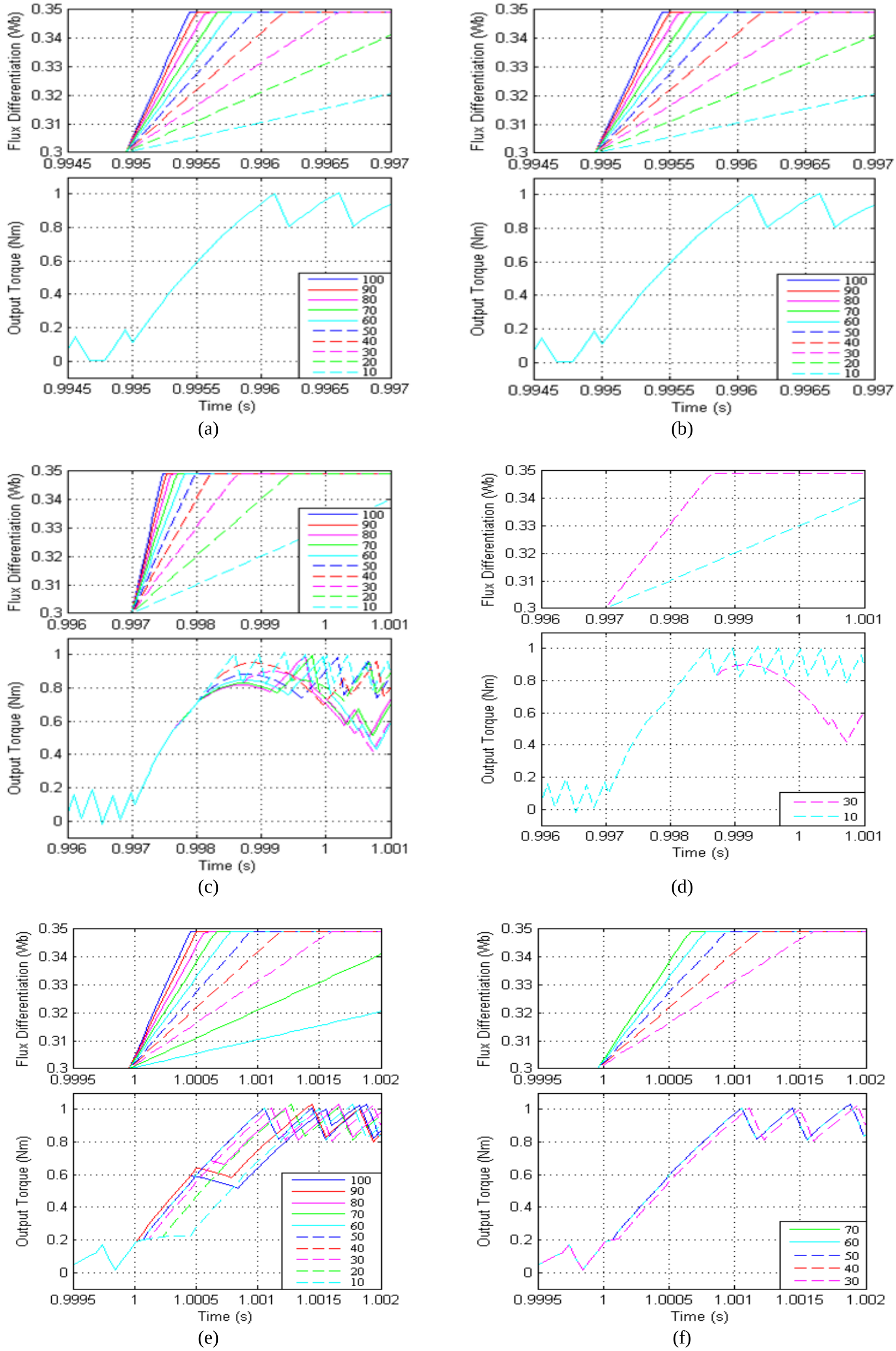
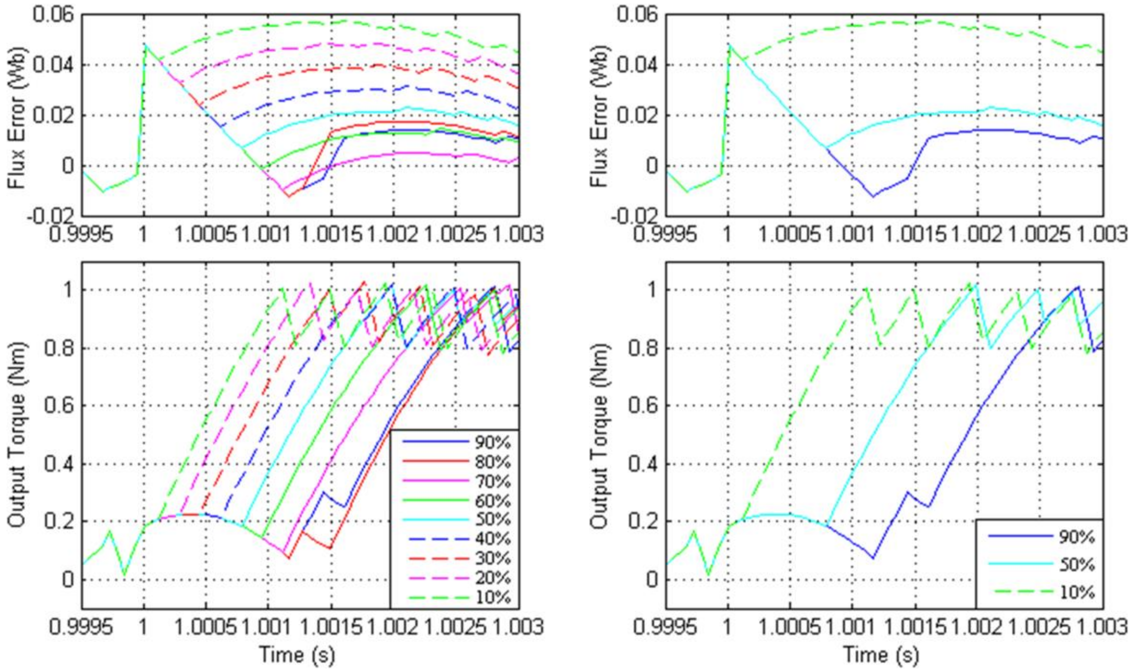


Figure 6. Flux differentiation at the (a) - (b) Beginning, (c) - (d) Middle, and (e) - (f) End, of a sector.

Besides the activation time of modified look-up table, the duty ratio of the proposed voltage vector has been investigated also to study its effect on torque response. Different activation time of each conventional voltage vector to produce proposed voltage vector can affect the performance of the torque response. Since the torque response is most degraded at the end of a sector in conventional DTC, the duty ratio has been analysed at the end of sector 2, as demonstrated in Figure 7. The duty ratio of 10% to 90% has been simulated and shown in Figure 7(a) whereas a few duty ratios are selected at Figure 7(b) for a clearer observation. The torque reponse is most deteriorated for duty ratio of 90% as it required 2.8ms to reach its rated torque. Meanwhile, the torque response is improved when the duty ratio of 50% is applied and it needed 2ms to achieve its rated torque. By applying duty ratio of 10%, the most improved torque response can be achieved as it required 1.1ms to reach its rated torque. Therefore the duty ratio of 10% is implemented in the proposed DTC. For example, in order to produce V_{3-4}, the V_3 is activated for duty ratio of 10% and V_4 is triggered for 90% of duty ratio.



(a) (b)

Figure 7. Application of duty ratio

With the activation time of modified look-up table for 1.6ms and duty ratio of 10%, a step speed of 80rad/s to 100rad/s and a step flux of 0.3Wb to 0.3492Wb has been implemented to the drive system at different position of flux sector. At t=0.995s, a step speed and flux has been applied in which it is at the beginning of sector 2 in conventional DTC and sector 3 in proposed DTC, as illustrated in Figure 8. Note that the flux sector is defined differently in conventional and proposed DTC. In both of conventional and proposed DTC, the torque required 1.1ms to reach its rated torque. This is because the V_3 [110] which is tangential to the stator flux is activated to increase the torque and flux. Thus, the performance of flux and torque in conventional DTC is similar to those in proposed DTC.

Then, a step speed and flux is applied at t=0.997s, at the middle of sector 2 in conventional DTC but in proposed DTC, it is at the end of sector 3 and beginning of sector 4, as depicted in Figure 9. In conventional DTC, the torque response needed 2.7ms to reach its rated torque. This is because the V_3 [110] is activated longer than V_4 [010]. Note that the torque response is dynamic at the beginning of activation of V_3 but it is degraded after some time. Meanwhile, the V_4 showed a more dynamic torque response compared to V_3. Therefore, to improve the torque response in proposed DTC, the V_3 is activated in sector 3 and when the flux is in sector 4, the V_{3-4} is activated. Even though the V_3 is activated for a very short period in sector 4, it does give a big impact on the torque response. Indeed, the torque response required 1.6ms to reach its rated torque and the torque performance is improved by 1.1ms. However, activating V_4 for a longer period caused the flux to be reduced.

In Figure 10, a step speed and flux has been applied at t=1.0s in which it is at the end of sector 2 in conventional DTC and sector 4 in proposed DTC. The torque response in conventional DTC required 2.8ms to reach its rated torque. Activating the V_3 [110] at the end of sector 2 deteriorated the dynamic torque and it is enhanced by V_4 [010] when the flux enters sector 3. In proposed DTC, the $V_{3\text{-}4}$ is activated and even the flux enters sector 5, V_4 is still triggered to increase both of flux and torque. Consequently, the torque response in proposed DTC achieved its rated torque at 1.1ms and it is improved by 1.7ms compared to conventional DTC.

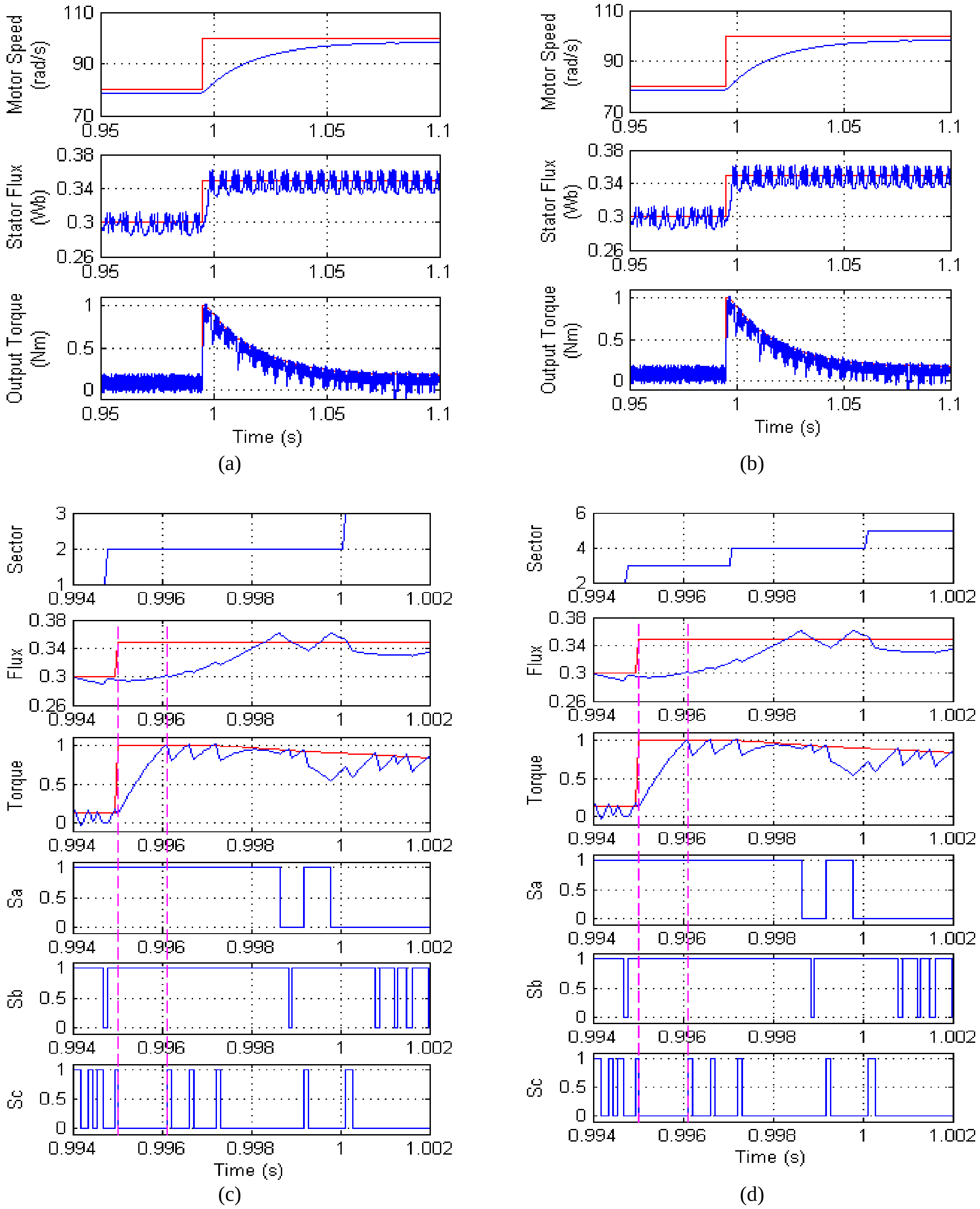


Figure 8. Beginning of sector for (a) and (c) Conventional DTC, and (b) and (d) Proposed DTC

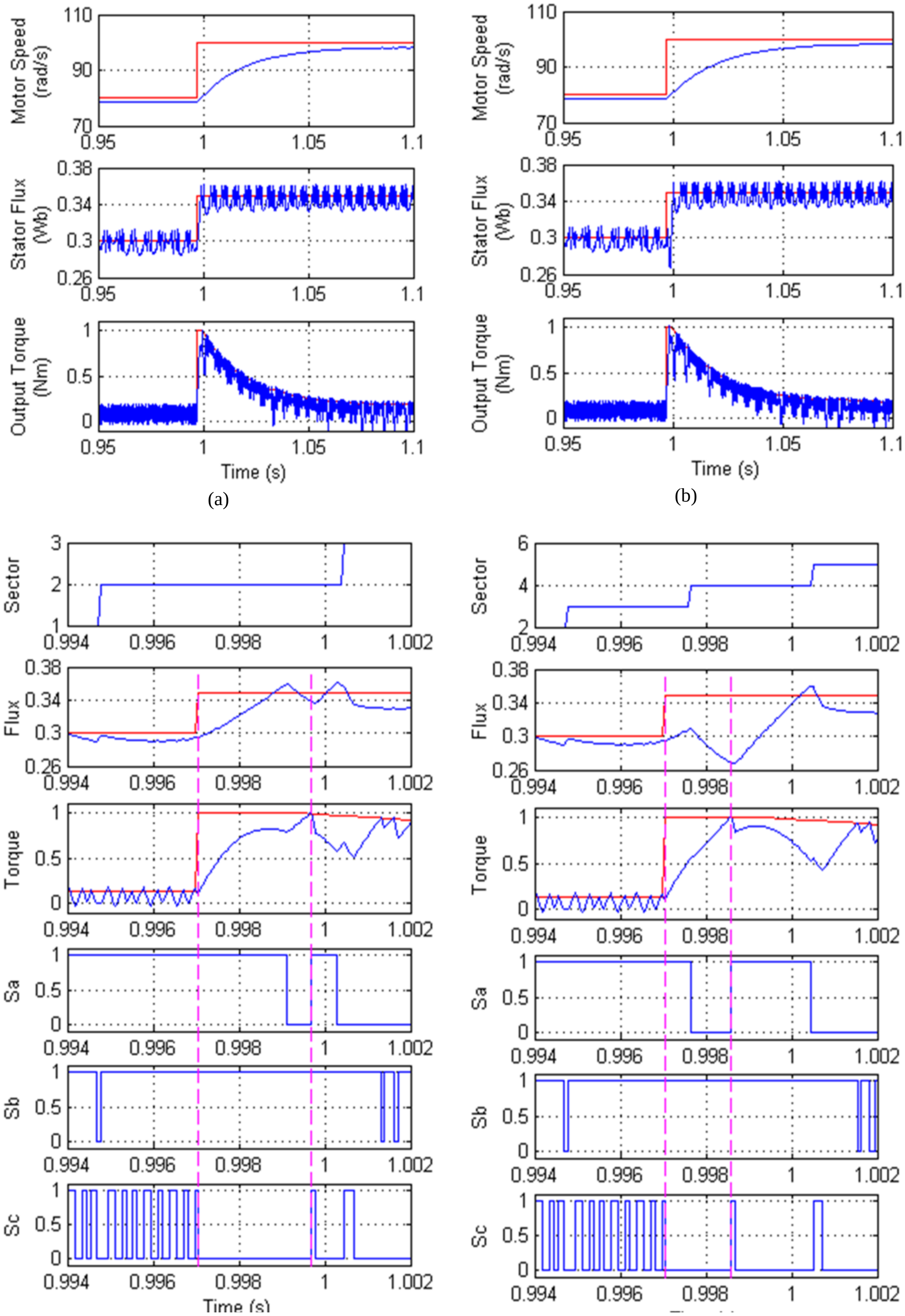


Figure 9. Middle of sector (a) and (c) Conventional DTC, and (b) and (d) Proposed DTC

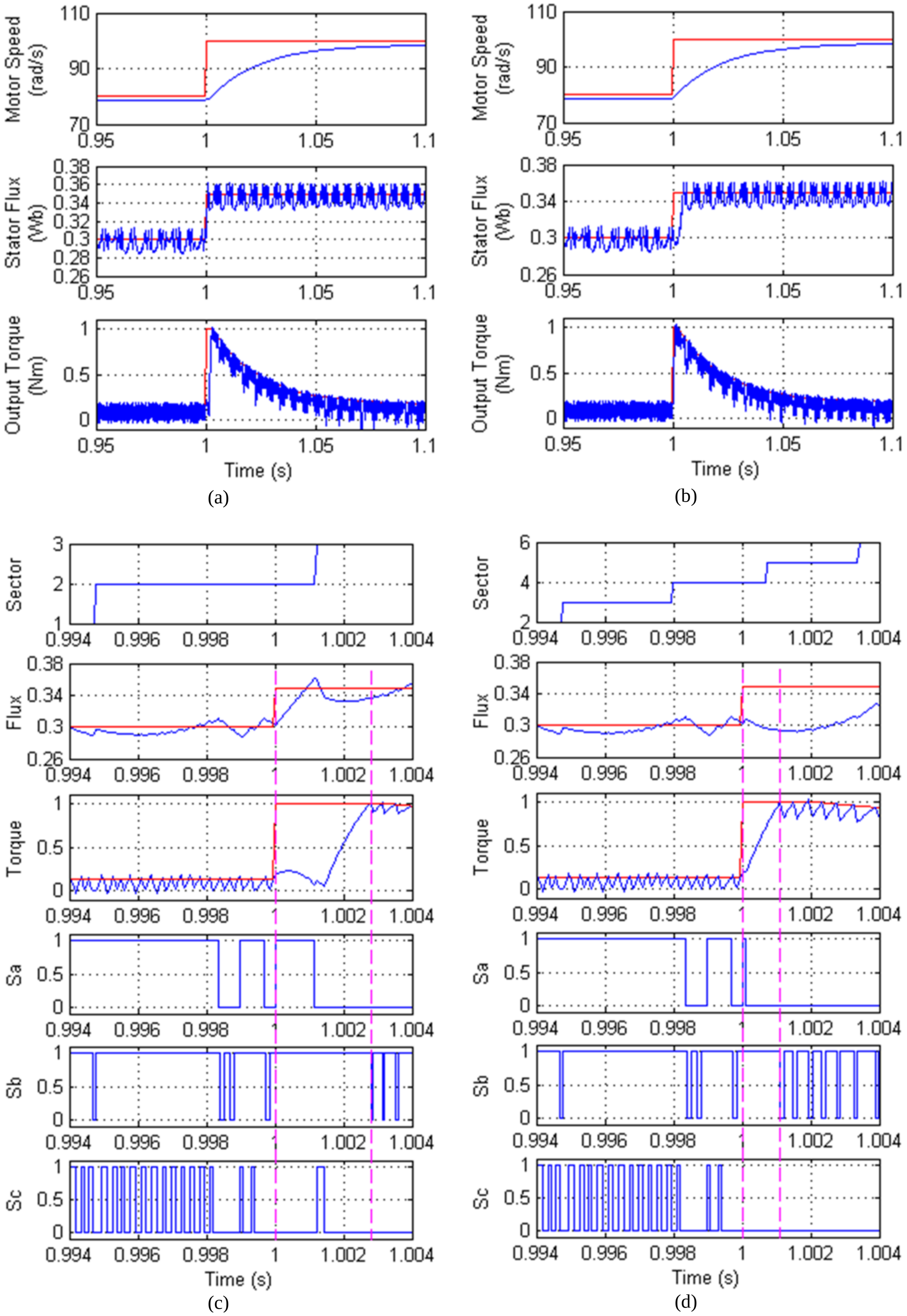


Figure 10. End of sector for (a) and (c) Conventional DTC and (b) and (d) Proposed DTC

5. CONCLUSION

Due to the limited number of voltage vector, the selection of voltage vector to satisfy the torque and flux requirements is restricted. By adding two conventional voltage vectors, the number of voltage vector can be increased in which 12 voltage vectors can be produced by three-phase VSI. The increasing number of voltage vectors does not increase the complexity of DTC drive system. A modification to the look-up table has been constructed for the implementation of proposed voltage vector. Based on the results, the torque response is improved regardless of the position of flux in the sector. Therefore, the efficiency of the drive system can be achieved and at the same time, the torque response is enhanced during efficiency with the implementation of proposed DTC.

ACKNOWLEDGEMENTS

The authors would like to express their appreciation to Universiti Teknologi Malaysia (UTM) for providing Zamalah's Scholarship and Ministry of Education for fund research grant (R.J130000.7823.4F380) in this research.

REFERENCES

[1] I. Takahashi and T. Noguchi, "A New Quick-Response and High-Efficiency Control Strategy of an Induction Motor," *Industry Applications, IEEE Transactions on,* vol. IA-22, pp. 820-827, 1986.

[2] T. Abe, T. G. Habetler, F. Profumo, and G. Griva, "Evaluation of a high performance induction motor drive using direct torque control," in *Power Conversion Conference, 1993. Yokohama 1993., Conference Record of the*, 1993, pp. 444-449.

[3] I. Takahashi and T. Noguchi, "Take a look back upon the past decade of direct torque control [of induction motors]," in *Industrial Electronics, Control and Instrumentation, 1997. IECON 97. 23rd International Conference on*, 1997, pp. 546-551 vol.2.

[4] S. Kaboli, E. Vahdati-Khajeh, M. R. Zolghadri, and A. Homaifar, "A fast optimal flux search controller with improved steady state behavior for DTC based induction motor drives," in *Electric Machines and Drives, 2005 IEEE International Conference on*, 2005, pp. 1732-1736.

[5] S. Kaboli, M. R. Zlghadri, and A. Emadi, "A Fast Flux Search Controller for DTC Based Induction Motor Drives," in *Power Electronics Specialists Conference, 2005. PESC '05. IEEE 36th*, 2005, pp. 739-744.

[6] S. Kaboli, M. R. Zolghadri, and E. Vahdati-Khajeh, "A Fast Flux Search Controller for DTC-Based Induction Motor Drives," *Industrial Electronics, IEEE Transactions on,* vol. 54, pp. 2407-2416, 2007.

[7] S. Kaboli, E. Vahdati-Khajeh, M. R. Zolghadri, and A. Homaifar, "on the Performance of Optimal Flux Search Controller for DTC Based Induction Motor Drives," in *Electric Machines and Drives, 2005 IEEE International Conference on*, 2005, pp. 1752-1756.

[8] S. Kaboli, M. R. Zolghadri, D. Roye, and A. Emadi, "Online optimal flux controller for DTC based induction motor drives," in *Industrial Electronics Society, 2004. IECON 2004. 30th Annual Conference of IEEE*, 2004, pp. 1391-1395 Vol. 2.

[9] N. Sadati, S. Kaboli, H. Adeli, E. Hajipour, and M. Ferdowsi, "Online Optimal Neuro-Fuzzy Flux Controller for DTC Based Induction Motor Drives," in *Applied Power Electronics Conference and Exposition, 2009. APEC 2009. Twenty-Fourth Annual IEEE*, 2009, pp. 210-215.

[10] S. Vamsidhar and B. G. Fernandas, "Design and development of energy efficient sensorless direct torque controlled induction motor drive based on real time simulation," in *Industrial Electronics Society, 2004. IECON 2004. 30th Annual Conference of IEEE*, 2004, pp. 1349-1354 Vol. 2.

[11] G. Calzada-Lara, F. Pazos-Flores, and R. Alvarez-Salas, "A new Direct Torque Control for a better efficiency of the induction motor," in *Power Electronics Congress (CIEP), 2010 12th International*, 2010, pp. 78-83.

[12] I. Kioskeridis and N. Margaris, "Loss minimization in scalar-controlled induction motor drives with search controllers," *Power Electronics, IEEE Transactions on*, vol. 11, pp. 213-220, 1996.

[13] D. Gan and O. Ojo, "Efficiency Optimizing Control of Induction Motor Using Natural Variables," *Industrial Electronics, IEEE Transactions on,* vol. 53, pp. 1791-1798, 2006.

[14] X. Zhang, H. Zuo, and Z. Sun, "Efficiency optimization of direct torque controlled induction motor drives for electric vehicles," in *Electrical Machines and Systems (ICEMS), 2011 International Conference on*, 2011, pp. 1-5.

[15] G. Bhuvaneswari and A. P. Satapathy, "ANN based optimal flux determination for efficiency improvement in Direct Torque controlled induction motor drives," in *Power and Energy Society General Meeting, 2010 IEEE*, 2010, pp. 1-6.

[16] I. Kioskeridis and N. Margaris, "Loss minimization in induction motor adjustable-speed drives," *Industrial Electronics, IEEE Transactions on,* vol. 43, pp. 226-231, 1996.

[17] D. Casadei, G. Serra, and A. Tani, "Improvement of direct torque control performance by using a discrete SVM technique," in *Power Electronics Specialists Conference, 1998. PESC 98 Record. 29th Annual IEEE*, 1998, pp. 997-1003 vol.2.

[18] D. Casadei, G. Serra, and K. Tani, "Implementation of a direct control algorithm for induction motors based on discrete space vector modulation," *IEEE Transactions on Power Electronics,* vol. 15, pp. 769-777, 2000.

[19] T. G. Habetler, F. Profumo, M. Pastorelli, and L. M. Tolbert, "Direct torque control of induction machines using space vector modulation," *Industry Applications, IEEE Transactions on,* vol. 28, pp. 1045-1053, 1992.
[20] A. Jidin, N. R. N. Idris, A. H. M. Yatim, T. Sutikno, and M. E. Elbuluk, "An Optimized Switching Strategy for Quick Dynamic Torque Control in DTC-Hysteresis-Based Induction Machines," *IEEE Transactions on Industrial Electronics,* vol. 58, pp. 3391-3400, 2011.
[21] C. Patel, P. R. P, A. Dey, R. Ramchand, K. Gopakumar, and M. P. Kazmierkowski, "Fast Direct Torque Control of an Open-End Induction Motor Drive Using 12-Sided Polygonal Voltage Space Vectors," *IEEE Transactions on Power Electronics,* vol. 27, pp. 400-410, 2012.
[22] W. Y. Goh, A. Monadi, N. R. N. Idris, A. Jidin, and T. Sutikno, "Proposed Voltage Vector to Optimize Efficiency of Direct Torque Control," *International Journal of Power Electronics and Drive Systems (IJPEDS),* vol. 4, pp. 578-586, 2014.

BIOGRAPHY OF AUTHORS

Goh Wee Yen received the B.Eng. degree in power electronic and drive from Universiti Teknikal Malaysia Melaka (UTeM), Melaka, Malaysia, in 2012, and currently, she is pursuing her Ph.D degree at Universiti Teknologi Malaysia (UTM), Johor Bahru, Malaysia. She is currently a Research Assistant in the Department of Electrical Power Engineering, Faculty of Electrical Engineering, and UTM. Her research interests include motor drive systems and DSP applications in power electronic systems.

Nik Rumzi Nik Idris received the B.Eng. degree in electrical engineering from University of Wollongong, Wollongong, Australia, in 1989, the M.Sc. degree in power electronics from Bradford University, Bradford, U. K., in 1993, and the Ph.D. degree from Universiti Teknologi Malaysia (UTM), Johor Bahru, Malaysia, in 2000. He is currently an Associate Professor in the Department of Electrical Power Engineering, Faculty of Electrical Engineering, and UTM. His research interests include AC drive systems and DSP applications in power electronic systems.

Auzani Jidin received the B.Eng., M.Eng. and Ph.D degrees in power electronics and drives from Universiti Teknologi Malaysia (UTM), Johor Bahru, Malaysia, in 2002, 2004 and 2011, respectively. He is currently a Senior Lecturer in the Department of Power Electronics and Drives, Faculty of Electrical Engineering, Universiti Teknikal Malaysia Melaka (UTeM), Melaka, Malaysia. His research interests include the field of power electronics, motor drive systems, field-programmable gate array, and DSP applications.

Tole Sutikno received his B.Eng degree in electrical engineering from Diponegoro University, Indonesia, in 1999, the M.Eng. degree in electrical engineering from Gadjah Mada University, Indonesia, in 2004, and currently he is pursuing his Ph.D degree at Universiti Teknologi Malaysia (UTM), Johor Bahru, Malaysia. He is currently an Associate Professor in the Department of Electrical Engineering, Universitas Ahmad Dahlan (UAD), and Indonesia. His research interests include the field of power electronics, industrial electronics and informatics, embedded systems and electric drives. He is an Editor-in-Chief of TELKOMNIKA Indonesian Journal of Electrical Engineering and Editor in international journals in electrical and computer engineering, power electronics, motor drive systems and FPGA applications areas.