DTC BASED PMSM DRIVE FOR TORQUE RIPPLE REDUCTION - A SURVEY

K.Satheeshkumar[1], A.Vijayadevi[2], T.Senthilkumar[3]
[1,2]*Assistant Professor,*[3]*UG Student*
[1,2,3]*Department of EEE,*
[1,2,3]*Kalaignarkarunanidhi Institute of Technology, Coimbatore.*
Email id:[1]satheeshkumargceb@gmail.com
Email id: [2]vijayadevi.91@gmail.com
Email id: [3]senthiltsk304@gmail.com
Contact No: [1]9940965657

ABSTRACT- This paper presents a review of recently used Direct Torque control (DTC) techniques for Voltage Source Inverter (VSI) fed PMSM. A variety of techniques to reduce the torque ripples are described as follows space vector modulation (SVM), Multi rate control strategy, 12 sector based DTC, FDTC, ANN based DTC are presented.

Key words -PMSM, DTC, VSI, SVM, SVPWM

1. INTRODUCTION

The Permanent Magnet Synchronous Motor (PMSM) is becoming more and more attractive due to its high efficiency and high torque to current ratio. For a PMSM drive system, mechanical sensors are often required for correct communication of the inverters the use of mechanical sensors however reduces the reliability and increases the cost of the system. To overcome these disadvantages, sensor-less control scheme is much desired. Nowadays, the Direct Torque Control scheme is increasingly used in PMSM drive systems, because of its fast torque response and possibility of eliminating the mechanical sensor if the initial rotor position is known.

Variable speed drives are used in all industries to control precisely. The speed of electric motors driving loads ranging from pumps and fans to complex drive on paper machines, rolling mills, cranes and similar drives. In some places of the industries, it is required to maintain the torque constant with independent of the speed. Some examples for this are conveyors, mixers, screw feeders, positive displacement pump and majority of the electrical machine applications.

2. DTC SCHEME

DTC becomes more popular due to the advantages, such as elimination of current controller, elimination of the speed position sensor, lesser parameter dependence, no coordination transformation required. DTC is an optimized AC drive control principle, where the inverter switching directly controls the motor variables flux and torque. In higher speeds the method is not sensitive to any motor parameters, all calculations are done in stationary coordinate system.

For that, the knowledge about stator resistance, stator voltage and stator current alone required. In [1] this DTC scheme is established by I Takahashi et al., in mid 1980‟s from that onwards DTC scheme became more and more popular due to the above said its advantages.

A.BASIC PRINCIPLE

The basic block diagram of DTC scheme is given in the figure 2.1. The motor stator voltage, current, and stator resistance is measured, from that the actual flux and torque are estimated. That is compared with the reference flux and torque respectively in the comparator section as shown in the above figure 2.1. The error between the actual and reference is given to the hysteresis controller depending on the controller output, the voltage vector from the switching table is selected. The selected voltage vector is applied to the voltage source inverter through which the reference torque is achieved. The torque and flux are estimated by using the following equations.

$$Test = (3/2)\, p\, (\Psi_d \,.\, i_q - \Psi_q \,.\, i_d) \qquad (1)$$
$$\Psi_d = L_d\, i_d + \Psi\, p \qquad (2)$$
$$\Psi_q = L_q\, i_q \qquad (3)$$

Where,
Test=Estimated Torque
p=No of poles
$\Psi_{d,q}$= d and q axis flux
L_d,L_q= d and q axis inductance

i_d, i_q=d and q axis current

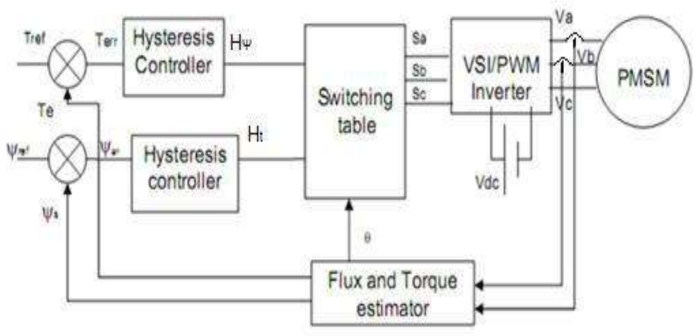

Figure 2.1 Basic Block Diagram

Torque ripples in this conventional DTC scheme are considerable. Many techniques are implemented to improve the performance of this conventional DTC scheme and some of them are discussed in this paper. The limitations of these methods are drift in the stator flux linkage estimation due to effect of the DC offset error in measurements and error in the estimation of stator flux linkage due to variation of stator flux linkage due to variation of stator resistance and requirement of a mechanical position sensor to detect the initial position. These three problems of DTC scheme for PMSM is analyzed and solutions are presented by Muhammad Fazlur Rahman et al., in [8].

B.SIX SECTOR CONCEPT

The entire section is divided into 6 sectors and each sector having 60°. Depending upon the actual and reference value, the corresponding switching vector is selected in the corresponding section. The switching table for the 6 sector based direct torque control is given in Table 1. It implemented the 3 level torque hysteresis and two level flux hysteresis controllers. Here 8 voltage vectors combinations for the 6 sector based switching table is implemented. The voltage vectors V0 and V7 are used as zero voltage vectors. If any one of these vector is selected, there is no change in the torque and flux. If any other voltage vector selected, the corresponding torque and flux deflection is obtained. The connection of power switches in a VSI with three-phase windings of a PMSM is shown in Figure 2.2, where the power switches of this voltage source inverter are 180° conducting mode, which means only three switching signal S_a, S_b and S_c are needed to uniquely determined the status of six switchers. If S = 1, the switches in upper leg of certain phase is on otherwise, S=0 represents the switches are connected with the lower leg of the three phase VSI.

H_ψ	H_T	S1	S2	S3	S4	S5	S6
	1	V2	V3	V4	V5	V6	V1
1	0	V0	V7	V0	V7	V0	V7
	-1	V6	V1	V2	V3	V4	V5
	1	V3	V4	V5	V6	V1	V2
-1	0	V7	V0	V7	V0	V7	V0
	-1	V5	V6	V1	V2	V3	V4

Table 1 Switching table for six sectors based direct torque control scheme

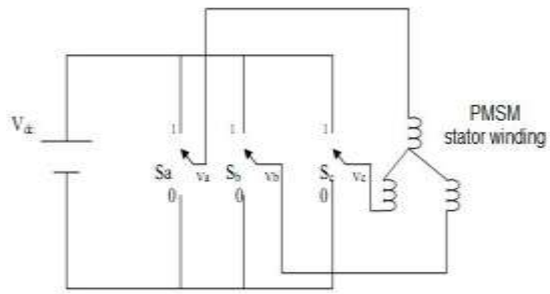

Figure2.2 Voltage Source Inverter Connections to PMSM

The inverter keeps the same state until the output of the hysteresis controllers changes their outputs at the sampling period. Therefore, the switching frequency is not fixed.

3. TYPICAL DTC SCHEMES TO REDUCE THE TORQUE RIPPLE

In the conventional DTC scheme the torque ripples are considerable in account. Many strategies were come to reduce this torque ripple for VSI fed PMSM drives on DTC based concept. However the torque ripple reduction was not impressive due to the transition between different sectors. In this paper some of the methods to reduce the ripples in the torque are analyzed and they are presented.

A.SPACE VECTOR MODULATION FOR DTC

Habetler introduced the concept of space vector modulation for DTC scheme in 1991[2]. The basic concept of this SVM is shown in the figure 3.1. One voltage space vector can be synthesized by two nearby basic voltage space vectors. During one switching period the most proper synthesized voltage space vector can be selected. The best way of selecting the proper voltage vector is select the vector which is having minimum switching activity required in the inverter when the sector changes. Then one zero vector and two non-zero vectors were used in every sector for reducing the torque ripple in [3]. To compensate the error between the reference and the actual torque and stator flux linkage. By selecting the proper synthesized voltage space vector the ripples in the torque gets reduces.

The problems of large torque and flux linkage pulsations and variable switching frequency can be solved effectively with the same hardware topology as that in the conventional DTC. The simulated and experimental results are compared by P.R. China et al, by using this SVM for DTC concept, and it is concluded with the following points. By using this SVM method the switching frequency of inverter can be fixed and the use of zero vectors in this SVM increases the performance of PMSM.

In recent years, some researchers tried to modify the SVM method based on power electronic techniques, to not only achieve better performance, but also improve the power efficiency of the system. Hybrid Space Vector Pulse Width Modulation (HSVPWM) techniques were implemented for reduction of stator current ripple, which indirectly leads to the reduction of the torque ripple and switching loss in [4]. In [5], DTC was developed based on the five zones HSVPWM to reduce the ripples in torque and flux. Brahmananda introduced a seven zones based HSVPWM method into DTC [13] in 2006. However, it requires relatively complex Calculation of the stator voltage equations.

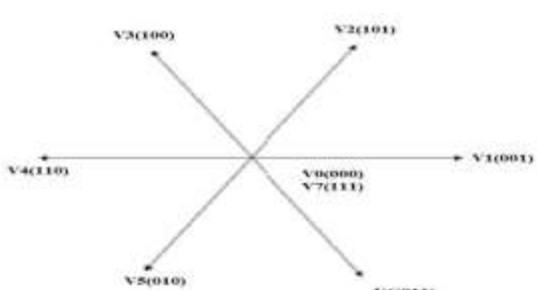

Figure 3.1 Selections of vectors by SVM

B.MULTI RATE CONTROL TRATEGY FOR DTC

N.Pandya et al., implemented the multi rate sampling interval time strategy with DTC for various control loops. The conventional DTC scheme is having single rate SVPWM. The performance of the PMSM drives gets increased by implementing the proposed technique in [11]. This concept is explained by the figure 3.2 Accuracy of DTC depends upon the estimated value of torque, and flux. Which in turn depends upon the accuracy of the flux integrator, and its accuracy is depends upon its sampling time. Consider the fundamental sampling time; this sampling time is used to take the samples from the motor stator current, voltage, speed sensors. Those estimated values are used for flux and torque estimation. Due to multiple of fundamental sampling time in the torque, flux loop and in the speed loop, the number of samples gets increases, which leads to the accuracy of flux, and torque estimation. When the control system is complex, contains more than one control loop, to operate the whole system with a single sampling frequency is not acceptable, Time lag will occurs among the different loops presents in the system. This time lag is depends upon the loop parameters. Because of this time lag data loss is possible in discrete system. To avoid all these facts, in the present work multi rate sampling control system in Space Vector Modulation based DTC has been introduced. The performance of this proposed drive is examined and compared with single rate Space Vector Pulse Width Modulation based (SVPWM) DTC in [9].

The limitations of this sampling time selections are, the sampling time for flux and torque loop should be less than speed loop sampling time. Reason behind it is the change in speed of motor will take some time to settle down. So we need to consider this mechanical time lag. Until the settled value of speed is not obtained, the difference in the reference speed and estimated speed causes speed error and this will cause wrong torque reference selection which leads to misbehaviour of the system.

Figure 3.2 sampling time selection

This method is applicable only when the sampling time of speed loop and torque loop must be integer multiple, and we should assure that must be rational multiple of fundamental sampling time. By properly selecting the sampling time the accuracy of the motor drive gets increased, and the ripples in the torque decreased in DTC. By using the same digital signal processor the performance of 3-ph induction motor drive is improved using multi rate SVPWM DTC technique than single rate SVPWM DTC technique.

C.12 SECTOR BASED DTC

S.Pavithra et al., discussed this 12 sector concept to reduce the torque ripples in the basic DTC scheme. The conventional circular locus is divided, six sectors into 12 sectors circular locus, by each sector is having 30º. The switching table is constructed by 27 voltage vectors, the voltage vectors are shown in the figure 3.3, and they used 3 level diode clamped neutral point voltage source inverter. In those 27 voltage vectors 3 vectors are zero vectors, 6 vectors are large scale vectors, 12 vectors are small scale vectors and 6 are medium scale vectors. In this proposed work by this paper a 5 level hysteresis controller for torque, and three level hysteresis comparator for flux is implemented, which produce the better quantification of input variables and the 12 sector division causes the many voltage vectors with variable flux and torque variation. 12 voltage vectors are used to construct the switching table in [12], instead of using all the available 27 voltage vectors.

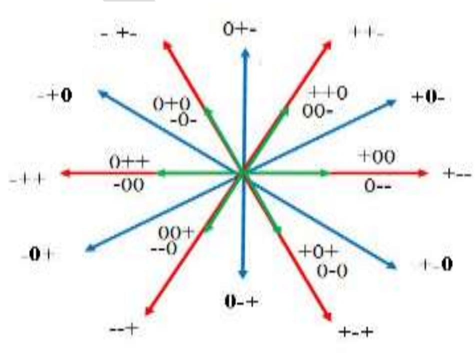

Figure 3.3 Switching State Vectors for 12 sectors

Zero vectors: V0, V25, and V26. Large vectors: VI, V3, V5, V7, V9, V11.
Medium vectors: V2, V4, V6, V8, V0, V12. Small vectors: V13,V14,V15,V16,V17,V18,

V19,V20,V21,V22,V23,V24.

This 12 voltage vectors consists of only zero, medium and large voltage vectors. By selecting the correct switching state, torque and the stator flux are regulated to their reference values. The basic DTC with a two level inverter finds no difference between small and large flux and torque errors. But in this proposed work for large and small error values, the corresponding large and small voltage vectors are selected to reduce the torque ripples.

D.DEAD-BEAT DTC-SVM SCHEMES

Habetler et al., in [2], proposed this technique. At first the changes in the torque and flux over one sampling period is predicted from the motor equations, and then to obtain the command value of stator voltage vector in stationary coordinates a quadratic equation is solved. This is a time-consuming algorithm and used in steady state. During transient state, an alternative algorithm is adopted and the appropriate voltage vector is selected prior from a switching table, which includes only active vectors. The main idea of the dead-beat DTC scheme is to force torque and stator flux magnitude to achieve their reference values in one sampling period, by simply synthesizing a suitable stator voltage vector applied by SVM method. Deadbeat control is not always possible, due to the limitation of inverter voltages and currents.

E. FUZZY BASED DTC

Modern control theories were used in power and dynamic control systems, in the past decades. Many new DTC controllers were realized by combining conventional DTC scheme with modern control computational methods like fuzzy logic, and artificial neural network (ANN). Mir introduced the FDTC in 1994[6]. FDTC controller was used to replace the switching table to select the space voltage vector in the conventional DTC system, and the two hysteresis controllers.

The errors of torque and flux and the angular position of the stator flux linkage are given as the inputs to the fuzzy logic controller. FDTC was applied for PMSM by Dan [7] in 2004. The errors in the torque, stator flux linkage and flux linkage angular position of the PMSM, are fuzzified into several fuzzy rules in order to select a suitable space voltage vector to obtain fast and smooth torque response. In a DTC controller, fuzzy logic method is used to obtain more available vectors to minimize the torque and flux ripples.

Based on DTC principle, the neural network controller is divided into the following five subnets, which are all individually trained:

- Optimum switching table subnet.
- Hysteresis comparator subnet
- Flux estimation subnet
- Torque calculation subnet
- Flux angle and magnitude calculation subnet

This ANN DTC scheme reduces the computation delay of every cycle. In 2006, an ANN based DTC controller was proposed for PMSM in [10]. Comparison between Back Propagation network and Radial Basis Function Network (RBFN) are done in that paper. The flexible neural network structures were used to implement the conventional DTC scheme for a voltage source inverter-fed PMSM drive. Based on the fundamental principle of DTC, an individual training strategy is employed for the neural network controller design. From the results obtained using the simulations concluded that the RFBN presents a good alternative to BP network. It was proved that ANN controller is possible to replace switching table of the DTC of PMSM, high and smooth torque response is obtained.

F. OTHER SIMPLE TECHNIQUES FOR DTC PERFORMANCE IMPROVEMENT

In [8], the basic problems of DTC like DC offset error, stator resistance variation, and the requirement of initial rotor position requirement are discussed by Muhammad Fazlur Rahman et al., and simple remedies are also presented in that paper. A programmable cascaded LPF can be used to compensate for the offset error, when the integrator is reset by the cascaded LPF. The flux locus remains centered and the ripple in speed has been significantly reduced. The stator flux vector is highly affected by the stator resistance variations at low speed. The stator resistance is continuously measured and updated during operation of the machine the error between the stator resistance of controller and the motor will causes the error in the estimated flux and torque so the resultant torque is also not an exact output. To avoid this PI stator resistance estimator is updated in the controller section the initial rotor position is detected by applying the high frequency sinusoidal voltage and considering the effects of the saliency on the amplitude of the corresponding stator current component. The magnetic pole is identified using the effect of magnetic saturation. This does not depends upon the load level (or) any motor parameters and suitable for DTC drive.

4. CONCLUSION

The main features of DTC can be summarized as follows.

- DTC needs only the stator parameters to flux and torque estimation and, therefore, it is not sensitive to rotor parameters.
- DTC is a motion-sensor less control method.
- DTC has a simple control structure

- The performance of DTC strongly depends on the quality of the estimation of the actual stator flux and torque.

In this paper the basic conventional DTC concept for PMSM motor is discussed and the Remedies to the DTC problems like DC offset, stator resistance variation, and initial rotor position requirement are discussed and the various techniques like SVM, Multi Rate sampling techniques, 12 sectors based DTC, FDTC, ANN based DTC are discussed to improve the performance of the DTC based system by reducing the torque ripples.

REFERENCES:

[1] IsaoTakahashiand Toshihiko Noguchi „ A New Quick-Response and High Efficiency Control Strategy of an Induction Motor ‟- IEEE Transactions on Industry Applications, vol.122.No.2. - 1986.
[2] T. G. Habetler, F. Profumo, and M.pastorelli “Direct torque control of induction machines over a wide speed range,” in Conf. Rec. IEEE-IAS Annu. Meeting, pp. 600–606 - 1992.
[3] D. Sun, J. G. Zhu, and Y. K. He, “Continuous direct torque control of permanent magnet synchronous motor based on SVM,” in Proc. 6th Int.Conf. On Electrical Machines and Systems, 9-11, Vol. 2, pp.596-599Nov. 2003.
[4] H. Krishnamurthy, G. Narayanan, V. T. Ranganathan, and R. Ayyar, “Design of space vector-based hybrid PWM techniques for reduced current ripple,” in Proc. IEEE-APEC, Vol. 1, pp. 583-588 2003.
[5] U. Senthil, and B.G. Fernandes, “Hybrid space vector pulse width modulation based direct torque controlled induction motor drive,” in Proc. IEEE Power Electronics Specialists Conf, Vol. 3, pp. 1112- 1117-2003.
[6] S. A. Mir, M. E. Elbuluk, and D. S. Zinger, “Fuzzy implementation of direct self-control of induction machines,” IEEE Trans. Ind. Appl., Vol. 30, No. 3, pp. 729-735, May/Jun. 1994.
[7] D. Sun, Y. K. He, and J. G. Zhu, “Fuzzy logic direct torque control for permanent magnet synchronous motors,” in Proc. 5th World Congress on Intelligent Control and Automation, Vol. 5, pp. 4401-4405,Jun. 2004.
[8] Muhammed Fazlur Rahman, Lixin Tang, and Limin Zhong, “problems associated with the direct torque control of an interior permanent-magnet synchronous motor drive and their remedies”, 0278-0046-2004.
[9] T. B. Reddy, B. K. Reddy, J. Amarnath, D. S.Rayudu, and Md. H. Khan, “Sensorless direct torque control of induction motor based on hybrid space vector pulse width modulation to reduce ripples and switching losses-a variable structure controller approach,” in Proc. IEEE Power India Conf.,10-12 Apr. 2006
[10] C. Zhang, B. Ma, H. Liu, and S. Chen, “Neural networks implementation of direct torque control of permanent magnet synchronous motor,” in Proc. IMACS Multiconf. On Computational Engineering in Systems Appl.,Vol. 2, pp. 1839-1843, 4-6 Oct. 2006.
[11]Saurabh N. Pandya, and J. K. Chatterjee “Torque Ripple Minimization in Direct Torque Control based IM Drive Part-II: Multirate Control Strategy” 978-1- 244-1762-9-2008 [12]Pavithra.S, Sivaprakasam.A and T.Manikandan Performance Improvement of DTC for Induction Motor with 12-sector Methodology” IEEE- 978-1-61284-764-1 April 2011.