Review on Improved Techniques of DTC for IMs

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Abstract - *At present, electric motor drives are acting like backbone of modern industry. In industry sector, around 70% of used motors are three phase induction motors. Induction motors are so popular in industries because of their maintenance free operation, robustness and simple construction. However, DC motor were used before decades because of complex speed and torque control of induction motor drives. But after the introduction of DTC (Direct Torque Control), the method become widely used for its speed control and torque control of induction motor drives. DTC method become popular because of its simplicity and good torque control characteristic but still method is affiliated with huge torque Ripple, variable switching frequency and high current total harmonic distortion. Many remedies and improvements for these problems were suggested in the course of time. the aim of this paper is to give a wide review on Some of the improved methods and make comparative analysis between them.*

Key Words: **DTC, SMC-DTC, MPC-DTC, SVM-DTC, Switching table**

NOMENCLATURE

Sa, Sb and Sc : - Switching Stages

Ψref :- Reference Flux

Tref :- Reference Torque

Ψs :- Stator flux

Te :- Electric Torque

Udc :- DC Bus Voltage

IM :- Induction Motor

ε :- Error

ΨSα :- Alpha Component of Stator Flux

ΨSβ :- Beta Component of Stator Flux

VSα :- Alpha Component of Stator Voltage

VSβ :- Beta Component of Stator Voltage

iSα :- Alpha Component Of Stator Current

iSβ :- Beta Component Of Stator Current

1.INTRODUCTION

The magnetic effect of an electric current was discovered by Hans Christian Oersted, A danish chemist and physicist. It was first time when connection between magnetism and electricity was found. Which leads the history towards the electric motor. Further in 1831, Faraday discovered electromagnetic induction. This Discoveries leads the invention of AC synchronous machine in 1883 by Nikola Tesla. Still after more than a century we are using these same electric motors based on Tesla, Hans Christian Oersted and faradays principles and theories.

Still after the invention of AC synchronous motor, DC motors where preferred to use for several decades. DC motors where preferred due to its simplicity ease of control, low-cost maintenance [4] and high starting torque [3]. But with all of this merits there are many demerits also: - the complex dynamic behavior of machine, nonlinear performance, strongly coupled and multivariable [1,2]. And thus, for several year research has been done to find alternatives.

After several decades two researcher Toshihiko Noguchi and Isao Takahashi has introduced the world with completely new method for speed control of induction motors. The method has good robustness and steady dynamic performance for variation in parameters of machine. This method is named as direct torque control method [5].

After the introduction of DTC, method become rapidly famous for the speed control of induction motors drives due to its

i. Simple Control structure

ii. Elimination of current controller

iii. The rotor position sensor not required

However, the use of DTC is quite Limited due to its demerits such as high current THD variable switching frequency and large torque Ripple [6].

Fortunately, after the introduction of DTC, wide research is carried out to overcome these problems and find the better solution. During the research period many methods based on basic DTC has been proposed such as space Vector modulation DTC sliding mode control DTC model predictive DTC and many other.

2 Classical DTC

In 1980's Depenbrock and Takahashi proposed DTC method for IM's. This method is more insensitive towards the parametric vibrations of IM's compered to vector control and due to absence of PWM of current controllers, its control algorithm is not complex. For eliminating the saturation related problems of PI regulators and for improving dynamics skills, PI regulators loops are avoided. This method provides fast and accurate torque dynamics and also ensure high operating efficiency.

Figure 1 shows the control diagram for Classical DTC. As the control diagram shows, classical DTC has two inputs stator reference flux and reference torque. Both inputs are compared with their estimated values at comparators. Then the output of comparator is given to stator selection table, where sector is selected from estimated values of stator flux and torque. By using switching table Sa, Sb and Sc is generated and supplied to voltage source inverter and further the output of inverter is supplied to induction motor [7]. The value of stator voltage and stator current generated are used for estimate values of torque and stator flux.

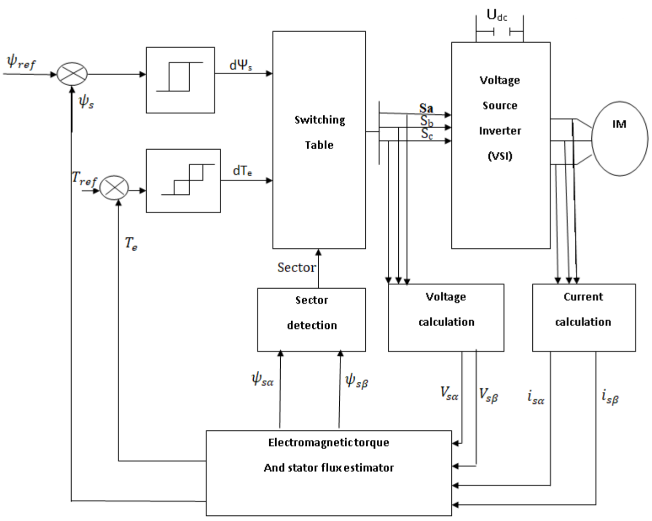

Figure 1: - Control Diagram of Classic DTC

Sector		1	2	3	4	5	6
$d\Psi_s$	dT_e						
1	1	V_2	V_3	V_4	V_5	V_6	V_1
	0	V_7	V_0	V_7	V_0	V_7	V_0
	-1	V_6	V_1	V_2	V_3	V_4	V_5
-1	1	V_3	V_4	V_5	V_6	V_1	V_2
	0	V_0	V_7	V_0	V_7	V_0	V_7
	-1	V_5	V_6	V_1	V_2	V_3	V_4

Table 1 Switching Table

Basic DTC is sensitive for the constant variation of machine parameters as compared to vector control. As the current controllers and parks transformation is absent, makes the control algorithm simple. Even with these advantages there are some serious issues with the classic DTC. Hysteresis controller makes high ripples in the electromagnetic torque and flux generated [7,8]. And the quality of output power is degraded because of current distortions and variable switching frequencies. After the classical DTC, A vast research is done on advance methods of DTC to overcome problems. All these new methods are based on same basic principles of DTC.

3. SPACE VECTOR MODULATION (SVM-DTC)

In late 1980s, A German scholar group presented space Vector modulation DTC for first time. Thereafter, a lot of research on the implementation of SVM technique is done [9-11]. The method has Many advantages such as:- lower THD, lower torque Ripple, lower switching losses, better DC Bus utilization and easy To implement [12].

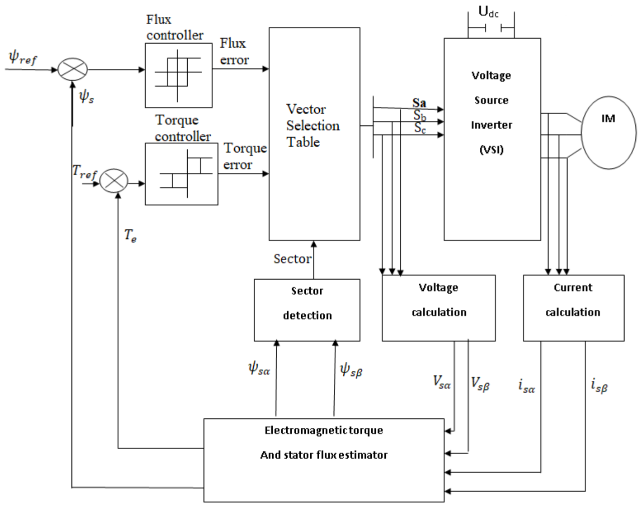

Figure 2: - Control Diagram of SVM-DTC

In SVM DTC, stator current and voltage parameters are used to predict the actual flux and torque values. Then the reference flux and torque values are compared with predicted values. After comparing, the error obtain is given to flux and torque controller [13]. Thereafter, process is same as basic DTC. The flux error and torque error obtained from flux controller and torque controller is given to vector selection table. Where the sector is selected by using lookup table. Further, output given to inverter and then to induction motor

4. SLIDING MODE CONTROL DTC (SMC-DTC)

Figure 3 shows the control diagram for SMC DTC. The cascaded command is used for control of speed and electromagnetic torque. The Adjustment of torque, flux and speed is control by using sliding control algorithms. The stator flux estimator block is used only for the measurement of stator currents and voltages in the reference. The sliding mode control DTC is known for its robustness towards the variation machine parameters [68-71].

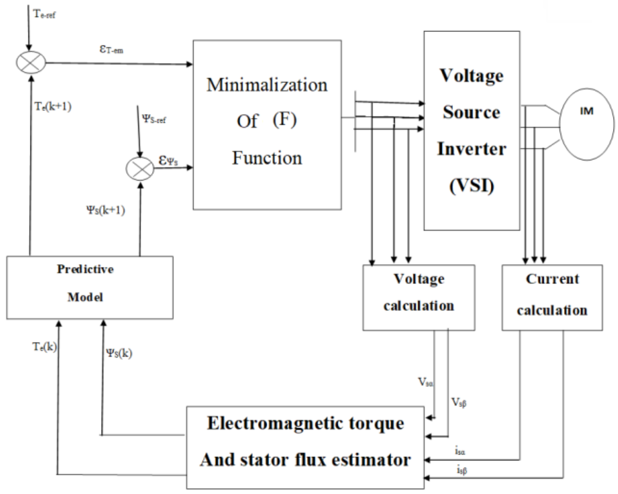

Figure 3: - Control Diagram of SMC-DTC

5. MODEL PREDICTIVE DTC

The model predictive DTC technique works on the principle of calculating the future values of the system, in order to be able to use this value for optimization of the values of adjustment parameters [18] and also for reduce the error. The model predictive DTC gives the better results in the terms of accuracy and speed [19]. This technique also helps to minimize the switching frequency.

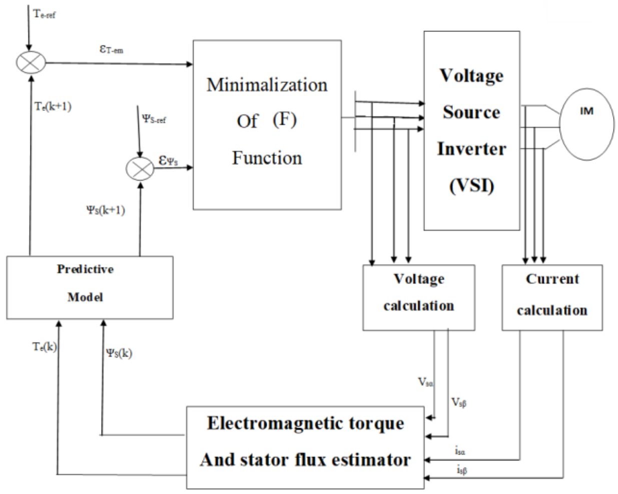

Figure 4: - Control Diagram of MPC-DTC

The implementation of model predictive DTC algorithm can be done Three stages

1. Non measurable values estimation

2. System future behavior prediction

3. According to function (F), optimize the control output

For getting new iteration at its sampling time Stage complete procedure is repeated.

6. FPGA BASED DTC

In recent year the development of VLSI Technology and created an opportunity for evolution of compact and complex performance controllers. For well-organized control of induction motor. Which has Complex system required components of different nature: - control system and power controller built containing linear and nonlinear elements, and electrical machines [20]. thus, for productive simulation and modelling required software tool which can hold all the functions in integrated environment.

Now a days, due to some advantages DSP is replaced by FPGA. Control system requires for fast algorithm which can be achieved in FPGA, as it executes multiple operation in parallel.

In simulation figure. 6 to run the algorithm FPGA, Xilinx system generator software, and MATLAB simulation Toolbox is used. The use of high-end programming tool become easy due to achievement of Xilinx generator.

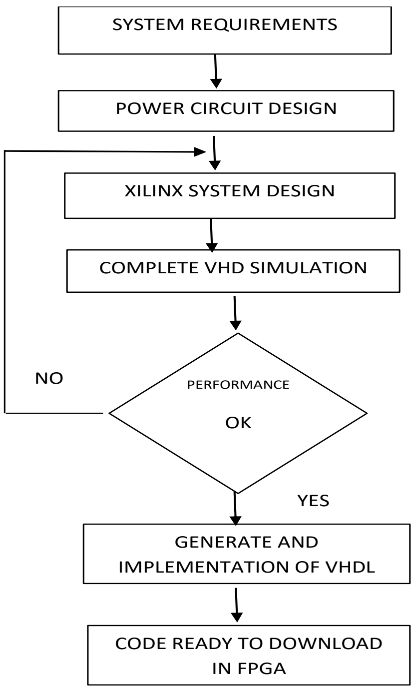

Figure 5 Flow chart for FPGA Controller design

The detail step for implementation is shown in the flowchart diagram.

Step 1: - the parameters of power electronics section are determined and used to design a model. And also, the prototype board's hardware Section can be simulated with mathematical model. In this way the exact replica of real system can be done by simulating control algorithm.

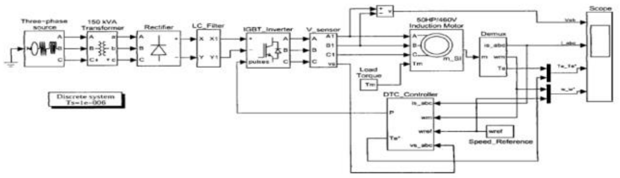

Figure 6: - Simulation Diagram for FPGA based DTC

Step 2: - only Xilinx system generator is used to build control algorithm.

Step 3: - complete system simulation is done in Simulink and Xilinx system generator block is used to generate VHDL code. The complete process is self-executing excluding the choice of FPGA model. The VHDL code produced only once.

Step 4: - implementation and synthesis the VHDL code, which is done by using Xilinx software. A configuration file is acquired permitting programming FPGA. If some update in system required, only few steps needed to be done again. And the process will be much faster.

8. ANN BASED DTC

The ANN broadly used in numerous technical fields applications. The ANN is also used for difficult case problems which cannot be solved by using mathematical approach [21]. The field of application is quite wide for ANN: - Speech processing, image processing, estimation, classification [22,23] and also for electrical system. many researchers have published research papers on integrating ANN system [24]. Many case studies have been simulated to judge the contribution of ANN. and the results of study ensure that there is an improvement in performance and robustness of induction machines.

Many research papers have proposed techniques to select this state of VSI switches by using ANN in DTC control induction machines [24-30]. The is to replace conventional switching table by the artificial neural selector which is capable to work in same way. The block diagram for direct torque neural control is in figure no. 7. Hear the both comparators and selection table are replaced by multi-layer ANN.

As compared to conventional technique the application of ANN to DTC makes sure of good flux and torque dynamic response which fixed switching frequency. This leads to significant reduction in harmonics and torque ripples [24]. In addition to this system become more robust against various uncertainties. Although it has a disadvantage of complex internal structure.

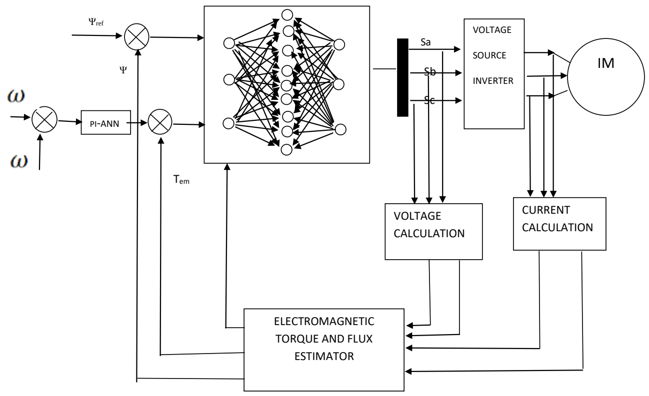

Figure 7 Control diagram for ANN based DTC

Parameters	Classic DTC	SVM-DTC	SMC-DTC	MPC-DTC	FPGA BASED DTC	ANN BASESD DTC
Torque and Flux Ripple	High	Low	Medium	Low	Low	Very low
Torque dynamic response	Fast	Fast	Fast	Fast	Very Fast	Very Fast
Switching Frequency	Variable	Constant	Nearly constant	Constant	Constant	Constant
Switching Loss	High	Low	Medium	Low	Low	Very low
Algorithm Complexity	Simple	Simple	Complex	Simple	more complex	more complex
Computation Time	Low	Medium	High	Medium	low	High
Speed Dynamics	Poor	Good	Good	Good	Very good	Very good

Table 2 Comparative Analysis

9. Comparative analysis

The comparative analysis of these improvement methods is done on the basis of Current THD, Switching Frequency, switching losses, Torque and Flux Ripple, torque dynamic response, algorithm complexity and computation time in table 2

10. Conclusion

Some improved methods for DTC are viewed in this paper. As we can see switching losses and the minimization of ripples are the main objectives for improved methods. A comparative analysis of these methods is done in this paper. We can conclude that the basic DTC is the simplest technique on the basis of complexity. But it is very hard to conclude with the best method for torque and speed control of induction motor. The control method choice is depends on the other characteristics also such as hardware availability reliability and system requirements.

References

[1] Sen, P. C. (1990). Electric motor drives and control past, present, and future. IEEE Transactions on Industrial Electronics, 37, 562 575.

[2] Karagiannis, D., Astolfi, A., Ortega, R., & Hilairet, M. (2009). A nonlinear tracking controller for voltage-fed induction motors with uncertain load torque. IEEE Transactions on Control Systems Technology, 17, 608–619.

[3] Martins, C. A., & Carvalho, A. S. (2001). Technological trends in induction motor electrical drives. In IEEE Porto power tech proceedings (Vol. 2).

[4] Costa, B. L. G., Graciola, C. L., Angelico, B. A., Goedtel, A., & Castoldi, M. F. (2018). Metaheuristics optimization applied to PI controllers tuning of a DTC-SVM drive for three-phase induction motors. Applied Soft Computing, 62, 776–788.

[5] Takahashi, I., & Noguchi, T. (1986). A new quick response and high efficiency control strategy of an induction motor. IEEE Transactions on Industry Applications, IA-22(5), 820–827.

[6] Reza, C. M. F. S., Islam, M. D., & Mekhilef, S. (2014). A review of reliable and energy efficient direct torque controlled induction motor drives. Renewable and Sustainable Energy Reviews, 37, 919–932.

[7] Buja, G., Casadei, D., & Serra, G. (1997). Direct torque control of induction motor drives. In Proceedings of the IEEE international symposium on industrial electronics.

[8] Sutikno, T., NikIdris, N. R., Jidin, A., & Cirstea, M. N. (2013). An improved FPGA implementation of direct torque control for induction machines. IEEE Transactions on Industrial Informatics, 9(3), 1280–1290.

[9] Belkacem, S., Naceri, F., & Abdessemed, R. (2011). Improvement in DTC-SVM of AC drives using a new robust adaptive control algorithm. International Journal of Control, Automation, and Systems, 9, 267–275.

[10] Rodriguez, J., Pontt, J., Silva, C., Kouro, S., & Miranda, H. (2004). A novel direct torque control scheme for induction machines with space vector modulation. In IEEE annual power electronics specialists conference (pp. 1392–1397).

[11] Pizzo, A. D., Marino, P., & Visciano, N. (2002). Harmonic and interharmonic impact of DTC-based induction motor drives on 3-wire network. In IEEE international industrial electronics conference.

[12] Del Toro, X. G., Arias, A., Jayne, M. G., Witting, P. A., Sala, V. M., & Romeral, J. L. (2005). New DTC control scheme for induction motors fed with a three-level inverter. Automatika, 46, 73–81.

[13] Gdaim, S., Mtibaa, A., & Mimouni, M. F. (2010). Direct torque control of induction machine based on intelligent techniques. International Journal of Computer Applications, 10, 0975–8887.

[14] Tanvir, A., Beig, A. R., & Al-Hosani, K. (2013). Sliding mode-based DTC of three-level inverter fed induction motor using switching vector table. In Asian control conference.

[15] Ayyarao, T. S. (2019). Modified vector controlled DFIG wind energy system based on barrier function adaptive sliding mode control. Protection and Control of Modern Power Systems, 4(1), 4.

[16] Rodic, M., & Jezernik, K. (2002). Speed-sensorless sliding-mode torque control of an induction motor. IEEE Transactions on Industrial Electronics, 49, 87–95.

[17] Mehmet, D. (2005). Sensorless sliding mode direct torque control (DTC) of induction motor. In Proceedings of the IEEE international symposium on industrial electronics.

[18] Camacho, E. F. (1993). Constrained generalized predictive control. IEEE Transactions on Automatic Control, 38(2), 327–332.

[19] Camacho, E. F., & Bordons, C. (2007). Model Predictive control. Advancedn Textbooks in Control and Signal Processing, Springer-Verlag: London.

[20] Amol A. Kalage, Vasant M. Jape, Sarika V. Tade, Manik M. Hapse and Ravindra G. Dabhade (2009). Modelling and Simulation of FPGA based direct Torque Control of Induction Motor Drive. International Journal of Recent Trends in Engineering, Vol 1, No. 4, May 2009

[21] Mondal, S. K., Pinto, J. O., & Bimal, K. B. (2002). A neural-network-based space-vector PWM controller for a three-level voltage-fed inverter induction motor drive. IEEE Transactions on Industry Applications, 38, 660–669.

[22] Faa-Jeng, L., Jyh-Chyang, Y., & Mao-Sheng, T. (2001). Sensorless induction spindle motor drive using fuzzy neural network speed controller. Electric Power Systems Research, 58, 187–196.

[23] Singh, B., Pradeep, J., Mittal, A. P., & Gupta, J. R. P. (2006). Neural network based DTC IM drive for electric vehicle propulsion system. In IEEE conference on electric and hybrid vehicles.

[24] Hammoumi, A., Massoum, A., Meroufel, A., & Wira, P. (2012). Application des Reseaux de Neurones pour la Commande de la Machine Asynchrone sans capteur mécanique. Acta Electrotehnica, 53, 99–104.

[25] Zemmit, A., Messalti, S., & Harrag, A. (2016). Innovative improved direct torque control of doubly fed induction machine (DFIM) using artificial neural network (ANN-DTC). International Journal of Applied Engineering, 11, 9099–9105.

[26] Jadhav, S., Kirankumar, J., & Chaudhari, B. (2012). ANN based intelligent control of induction motor drive with space vector modulated DTC. In IEEE international conference power electron, drives energy systems (PEDES) (pp. 1–6).

[27] Grzesiak, L. M., & Ufnalski, B. (2005). DTC drive with ANN-based stator flux estimator. In European conference on power electronics and applications.

[28] Bossoufi, B., Karim, M., Silviu, S., & Lagrioui, A. (2011). DTC Control based artificial neural network for high performance PMSM drive. Journal of Theoretical and Applied Information Technology, 33, 165–176.

[29] Grzesiak, L. M., Meganck, V., Sobolewski, J., & Bartlomiej, U. (2006). On-line trained neural speed controller with variable weight update period for direct-torque-controlled AC drive. In 12th international power electronics and motion control conference (pp. 1127–1132).

[30] Kumar, R., Gupta, R., Bhangale, S., & Gothwal, H. (2007). Artificial neural network based direct torque control of induction motor drives. In IET-UK international conference on information and communication technology in electrical sciences (pp. 361–367).