ANALYSIS OF IMPROVEMENT IN DIRECT TORQUE CONTROL OF THREE PHASE INDUCTION MOTOR USING FLC TECHNIQUE

Brundha.R[1] | Vaikundaselvan.B[2]

[1](Dept of EEE, PG Student, Kathir College of Engg, Coimbatore-641062, Tamilnadu, India, raj.brundha@gmail.com)
[2](Dept of EEE, Professor, Kathir College of Engg, Coimbatore-641062, Tamilnadu, India, eeehod.kce@gmail.com)

Abstract—*This paper presents the use of a Fuzzy logic controller and PI controller technique to emulate the traditional switching look up table method for induction motor Direct Torque Control(DTC)obtaining optimal switching patterns for torque ripple reduction.The aim of this paper is to analyze DTC principles, the standards and the problems associated with its implementation and the possible improvements using optimization technique .In optimization technique fuzzy logic is implemented to minimize the torque ripple. The proposed technique reduces torque ripple compared to PI Controller technique and results in low acoustic noise also increases the switching frequency of the inverter. Experimental results are reported using MATLAB/SIMULINK software.*

Keywords—DTC, Fuzzy Logic, PI,Torque Ripple, Two -Level Converter

1. INTRODUCTION

The principle is based on limit cycle control and it allows both quick torque response and efficiency operation [1]. In conventional DTC drive it contains a pair of hysteresis comparators, a torque and flux estimator and a space vector selection table. The torque and flux are controlled simultaneously by applying appropriate voltage vectors, and by limiting these quantities within their hysteresis bands, de - coupled control of torque and flux can be achieved. DTC control the torque and speed of the motor, which is directly based on the electromagnetic state of the motor.It only needs to know the stator resistance and terminal quantities (v and i) in order to perform the stator flux and torque estimations.

The time taken for the flux and torque to touch their upper and lower bands, depend on the operating condition (i.e., speed of rotor, stator flux and rotor fluxes, and DC link voltage). For the reason that device switching frequency of the VSI is at once related to switching terms of the torque and stator flux hysteresis comparators, it instruct that the device switching frequency depends on the operating conditions. The variable switching frequency, although may result in less irritating noise emissions, produces a wide band of harmonic spectra and is thus more likely to induce mechanical resonance. This, in turn, may result in higher noise emission. At low speed, the positive torque slope is large, which can cause torque overshoot, hence increasing the torque ripple. This is undesirable, especially for applications that require precise torque control. constant switching frequency[11]. Recent advance in DTC systems have contributed significantly to research new control method in the field of modern AC drive. It includes the use of predictive control scheme, space vector modulation (SVM) technique and fuzzy logic control[10]. This method can reduce effectively torque and current ripple, resulted in a constant switching frequency, but it requires solving a quadratic equation to obtain the desired voltage vectors. All of these methods have managed to fix the switching frequency and to some extent reduce the torque ripple; however, they require additional calculation and high-speed microprocessor, which outweigh the simple control structure of the DTC.

In recent years, the space vector pulse width modulation (SVPWM) technique demonstrated some improvement for both the output crest voltage and the harmonic copper loss. The maximum output voltage based on the space vector theory is 1.15 times as large as the conventional sinusoidal modulation. It makes it possible to feed the motor with a higher voltage than the easier sub-oscillation modulation method. This modulator enables higher torque at high speeds, and a higher efficiency.

during changes in the reference torque, it is possible to use a fuzzy-logic-based switching vector selection process. For this purpose a Mamdani-type fuzzy logic system will be used. The different output voltage states (active and zero states) are selected byusing three inputs: flux eö and torque eô errors and also the position of the stator flux linkage space vector us .For this purpose it is assumed that the stator flux linkage space vector can be located in any of twelve sectors each spanning over a 60 wide region. For every sector there are 15 rules.

2. THE CONVENTIONAL PI BASED DTC:

The basic configuration of the conventional DTC drive proposed by Takahashi is as shown in Fig. 1. It consists of a pair of hysteresis comparator, torque and flux estimators, voltage vector selector and a Voltage Source Inverter (VSI)

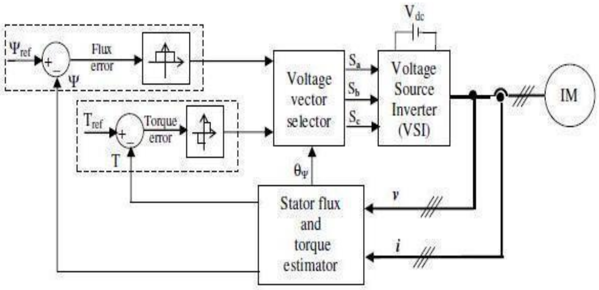

Figure1 Conventional PI based DTC drive configuration

According to the combination of the switching modes of VSI , the voltage vectors are specified for eight different voltage vectors. The switching vectors associated with DTC are shown in Fig. 2. There are six active voltage the origin.It can be shown that the voltage vector is given in Figure 2.

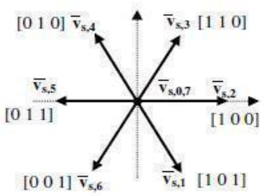

Figure 2 Voltage space vector

2.1 *Torque equation in DTC of induction motor*

The EM(electromagnetic torque) can be managed by controlling the amplitude and speed of the stator flux vector[4].To achieve the above phenomenon, appropriate voltage vectors are applied to the motor terminals. For counter-clockwise operation, if the actual torque is smaller than the reference value, then the voltage vectors that keeps the stator flux vector rotating in the same direction are selected. When the load angle, between increases the actual torque increases as well.

In case, the resistance term within the stator flux estimation among the set of rules is neglected,and the change in stator flux linkage(incremental flux expression vector)will only depend on the applied voltage vector.For a short interval of time,namely the sampling time,the stator flux linkage,position and amplitude can be changed incremently by applying the stator voltage,as discussed above,the position change of the stator flux linkage vector,will affect the torque.The stator flux linkage of an IM that is depicted in the stationary reference frame written.

Once the actual torque is greater than the reference value, the voltage vectors that keep stator flux vector rotating in the reverse direction are selected instead of the zero voltage vectors at the same time, the load angle decreases thus the torque decreases.

$$T_e = \frac{3P}{4} i_{qd} \times \lambda_{qd} \qquad (2.1)$$

Diffentiate equation (2.1),

$$\frac{d}{dt} T_e = \frac{3P}{4}\left(\frac{d}{dt} i_{qd} \times \lambda_{qd} + i_{qd} \times \frac{d}{dt} \lambda_{qd}\right) \qquad (2.2)$$

From eqs.(2.1)&(2.2) For A Non-Salient Motor

$$\frac{d}{dt} i_{qd}^r = \frac{1}{L_m}\left(v_{qd}^r - R_s i_{qd}^r - \mathrm{W}_r \begin{pmatrix} \lambda_d^r \\ -\lambda_q^r \end{pmatrix}\right) \qquad (2.3)$$

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$$\frac{d}{dt} T_e = \frac{3P}{4L_M}\left((v_q^r - \mathrm{W}_r \lambda_d^r)\,\lambda_m - \frac{4r_s}{3p} T_e\right) e_z \qquad (2.4)$$

For small TS

$$\frac{d}{dt} T_e \approx \frac{T_e[k+1] - T_e[k]}{T_s} \qquad (2.5)$$

Which gives

$$\Delta T_e[k] = \frac{3PT_s}{4L_M}\left((v_q^r[k] - \mathrm{W}_r \lambda_d^r[k])\,\lambda_m - \frac{4r_s}{3p} T_e[k]\right) \qquad (2.6)$$

2.2 *Stator Flux Equation*

Stator flux in the arbitrary qd frame from eq.(2.6)and rearranged, becomes

$$\frac{d}{dt}\Lambda_{qd} = v_{qd} - R_s i_{qd} - \mathrm{W}_r \begin{pmatrix} \lambda_m \\ -\lambda_m \end{pmatrix} \qquad (2.7)$$

For short sample periods

$$\frac{d}{dt}\Lambda_{qd} \approx \frac{\Lambda_{qd}[k+1] - \Lambda_{qd}[k]}{T_s} \qquad (2.8)$$

$$\lambda_q[k+1] = T_s(v_q[k] - r_s i_q[k] - \mathrm{W}_T \lambda_d[k]) + \lambda_d[k] \qquad (2.9)$$

$$\lambda_d[k+1] = T_s(v_d[k] - r_s i_d[k] + \mathrm{W}_T \lambda_q[k]) + \lambda_d[k] \qquad (2.10)$$

Or alternatively eq.(2.9) is rewritten

$$\lambda_q(t) = \int (v_q - r_s i_q - \mathrm{W}_T \lambda_d) dt \qquad (2.11)$$

$$\lambda_d(t) = \int (v_d - r_s i_d + \mathrm{W}_T \lambda_q) dt \qquad (2.12)$$

During a sufficiently short time interval, all variables on the right hand side may be approximated constant.

The field-oriented control of an induction machine is achieved on base of a measured shaft angle[2]. The measured value is used to easy the calculation of the rotating flux in the electrical machine. With the use of a

Motor control DSP,ultra-fast calculation can substitute (simply by adding a theoretical based sensorless algorithm) the measurement of the positionin the feedback and a competitive flux-controller can be implemented.The stator flux as illustrated in Figure 3

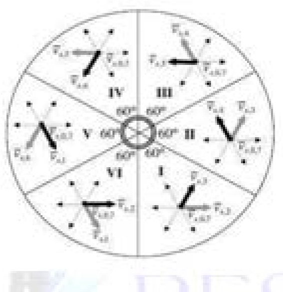


Figure 3 six equally sectors with different set of voltage vector

2.2.1 *Flux Estimator*

Now that the current, iqd, is known, the signal continues into the flux estimator. And the VSI voltage vector transformed, as the current, to the qd-stationary reference frame. The voltage, vqd, is calculated.

$$\Delta\lambda_q[k] = T_s(v_q[k] - r_s i_q[k] - W_T \lambda_d[k]) \quad (2.13)$$

This Formula is The foundation implemented directly, or approximated by various methods to avoid integrator drift.Estimated torque and flux are compared to their command values. The difference between command and estimated value is compared in the hysteresis comparators.

2.2.2 Torque Calculation

$$\Delta\lambda_d[k] = T_s(v_d[k] - r_s i_d[k] + W_T \lambda_q[k] \quad (2.14)$$

To calculate torque one has to substitute the corresponding, already, calculated fluxes and currents. Torque calculation is thus a simple operation. which is true for all qd-reference frames.

2.2.3 *Look-up Table*

The hysteresis comparator states, dT and dZ, together with the sector number, N, are now used by the Look-up Table block to chose an appropriate voltage vector.A table frequently used in DTC when controlling a Permanent Magnet motor is shown below,

Table 1 Look-Up Table

		N					
dλ	**dT**	**1**	**2**	**3**	**4**	**5**	**6**
-1	-1	u5	u6	u1	u2	u3	u4
	1	u3	u4	u5	u6	u1	u2
1	-1	u6	u1	u2	u3	u4	u5
	1	u2	u3	u4	u5	u6	u1

A high hysteresis state increases the corresponding quantity, and vice versa. The selected voltage vector is sent to the Voltage Source Inverter in, for the VSI, a suitable format and then synthesized.

2.2.4 *Voltage Source Inverter*

The VSI synthesizes the voltage vectors commanded by the Look-up Table block. In the case of DTC this task is quite simple since no pulse width modulation is used; the output devices stay in the same state during the entire sample period.

Torque Calcul Torque Calculation

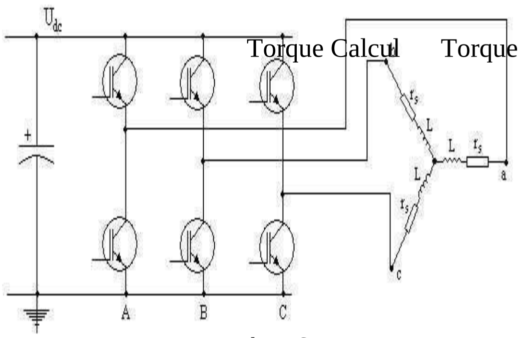


Figure 4 Voltage Source Inverter

2.3 Two Level Inverter

A voltage source inverter (VSI)[7] is used to convert a fixed DC voltage to three phase AC voltage. The circuit diagram for a two -level voltage source inverter for power applications is shown in Figure 5.

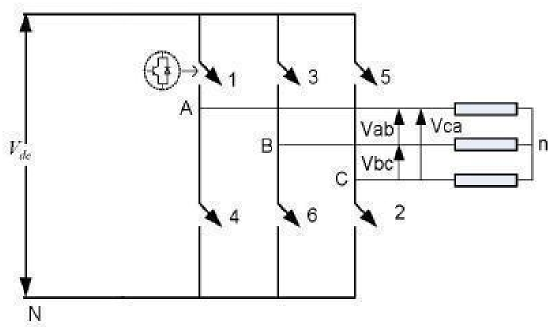


Figure 5 Two Level Inverter

The inverter is composed of six groups of active switches, S1 to S6. Depending on the DC operating voltage of the inverter, each switch is an IGBT switching device. This part focuses on pulse width modulation (PWM) schemes for two-level inverter and analysis on space vector modulation (SVM) algorithms [3,7]. Space Vector modulation (SVM) technique was originally developed as a vector approach to pulse-width modulation (PWM) for three-phase inverters. It is a more sophisticated technique for generating a sine wave that provides a higher voltage to the motor with lower total harmonic distortion. It confines space vectors to be applied according to the region where the output voltage vector is located. A different approach to Neuro-fuzzy control of PWM modulation is based on the space vector representation of voltage in the α, β plane [8]. The α, β components are found by transformations. The determination of the switching instant may be achieved using space vector modulation technique based on the representation of switching vectors in α, β plane. The Space Vector modulation technique is an advanced, computation intensive PWM technique and is possibly the best among all the PWM techniques for drives applications. Because of its superior performance characteristics.

3. PROPOSED FUZZY LOGIC TECHNIQUE

The steps of common observations about fuzzy logic technique are as follows,Fuzzy set is conceptually clean to manipulate:

The concept in the case of mathematical derivations about back of fuzzy reasoning is quite simple. Fuzzy logic set is a more intuitive method without the far-reaching complexity.

Fuzzy sets are more understandable:

Within many given system, it is simple to layer on more capability without beginning again from scratch.

Fuzzy logic system tolerant of vague data records:

The whole lot is imprecise in case look intently sufficient, however more than that, maximum things are imprecise even on cautious inspection. Fuzzy sets builds this expertise into the process as opposed to taking it onto the end.

Fuzzy inference system can version nonlinear capabilities of arbitrary complexity:

We may create a fuzzy sets to compare any set of input-output information. This process is made in particular easy by optimization techniques like adaptive Neuro -Fuzzy Inference System (ANFIS), which are to be had in Fuzzy Toolbox Software program.

Fuzzy logic sets may be built on experience of the experts:

In direct assessment to neuro-fuzzy networks, which take multi- data and generate optimized output, technical terms, neuro-fuzzy logic sets helps us to depend on the experience of those who recognize our system.

Fuzzy sets may be blended with convectional manipulate techniques:

Fuzzy systems do not always replace convectional control techniques,in lots of cases fuzzy inference systems increases output values and limits its implementation.

Fuzzy set is focused on natural language:

The nearest statement simplifies most critical one and discuss more about natural language, that's utilized by ordinary people on everyday basis, has been shaped via lots of years, however it is convenient and effient. Sentences written in common ordinary language represents a triumph of effient communication by using fuzzy sets.

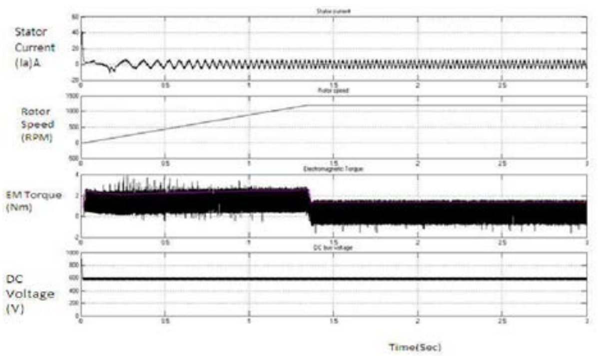
Fuzzy Sets:

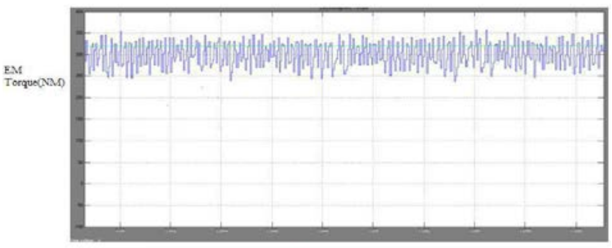
FL, unlike Boolean logic, deals with problems that have fuzziness or vagueness, as mentioned before. The classic set theory based on Boolean logic, where a particular object or variable is either a member of a given set(logic 1), or it is not (logic 0).on the other hand, in fuzzy set theory Based on FL, a particular object has a degree of Membership in a given set that may be anywhere in the range of 0(completely not in the set) to 1(completely in the set).For this reason, FL is often defined as muliti-valued logic(0 to 1),compared to bi-valued Boolean logic.it may be mentioned that although FL deals with imprecise

been finding wide spread application in recent years. The purpose of this chapter is to present the space vector modulation technique and then to simplify the explanation of how it can be implemented by using Matlab software packages (off time) and RT-LAB (real time) information [9], the information is processed in sound mathematical theory,which has been advanced in recent years.

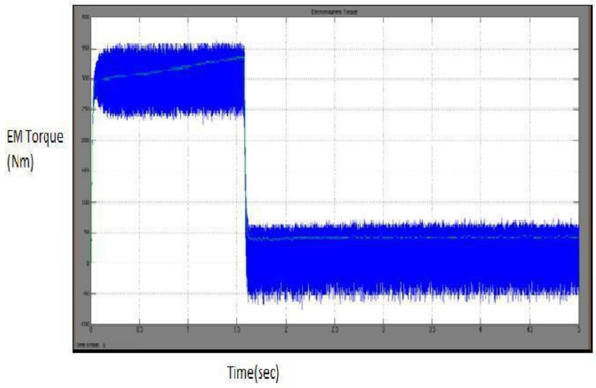
Before discussing the FL theory, it should be emphasized here that basically, a FL problem can be defined as an input/output, static, nonlinear mapping problem through a “black box,” as shown in figure 4.1 . All the input information is defined in the input space, it is processed in the black box, and the solution appears in the output space. In general,low speed performance and mapping can be static or dynamic, and the mapping characteristics are determined by the block box’s characteristics[12,13]. The black box cannot only be a fuzzy system, but also an Es,neural network, general mathematical system, such as differential equations, algebraic equations etc.., or anything else.

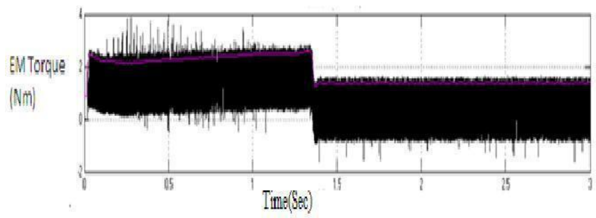
4. SIMULATION OUTPUT RESULT WAVEFORMS FOR THE PROPOSED FUZZY LOGIC SYSTEM





5. COMPARISION OF PI AND FUZZY LOGIC ELECTROMAGNETIC TORQUE WAVEFORM:





6. CONCLUSION

A new fuzzy logic direct torque control scheme based on PWM inverter technique has been presented in this paper. By analyzing the torque waveforms, it shows that torque ripples is reduced can be reduce by the fuzzy controller. Its control rules are established based on the prior experience. this approach provides more accurate selection of the inverter state. Simulations of the novel DTC scheme with a fuzzy logic control and two phase inverter shows a reduction in the torque ripple, stator flux and current distortion in both stator currents and voltages, when compared with conventional direct torque control. The simulation results verify that the proposed fuzzy based DTC approach achieved the reduction of torque ripple.

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