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A Modified Direct Torque Control of Induction Motor Using Space Vector Modulation Technique

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Abstract: A modified Direct Torque Control (DTC) scheme for an induction machine is investigated in this thesis which features very low flux and torque ripple and almost fixed switching frequency. It is based on the compensation of the error flux linkage vector by means of space vector modulation. In basic DTC, the flux linkage and electromagnetic torque are controlled directly by the selection of switching vector from a look-up table. This scheme shows that the flux and torque ripples are greatly reduced when compared with that of basic DTC. With the new scheme, very short sampling time is not essential. It retains all the advantages of the basic DTC, such as no coordinate transform, robust to parameter variation etc. In addition, fixed switching frequency at different operating conditions becomes possible. Computer simulation results confirm that the modified DTC has lower torque and flux ripples when compared with the modeling results of the basic DTC.

Key words: Induction-Motor Drives · Direct Torque Control · Space vector modulation

INTRODUCTION

Since Direct Torque Control of induction machine (DTC) was proposed in the middle of 1980's in [1-3], more than one decade has passed. The basic idea of DTC is slip control, which is based on the special relationship between the slip frequency and electromagnetic torque. If compared with Rotor Field Oriented Control, DTC has many advantages such as less machine parameter dependence, simpler implementation and quicker dynamic torque response. There is no current controller needed in DTC, because it selects the voltage space vectors according to the errors of flux linkage and torque. The most common way to carry out the DTC is to use switching table and hystersis controller, as reported in other papers. Fig. 1 is system diagram of a DTC induction machine drive system. It includes flux and torque estimators, flux and torque hystersis controller and a switching table. Usually a DC bus voltage sensor and two output current sensors are needed for the system. Speed sensor is not necessary for the torque and flux control. The switching state of the inverter is updated in each sampling interval [4].

Although DTC is getting more and more popular, it also has some drawbacks, such as the torque and flux ripple. Generally speaking, there are two methods to reduce the torque and flux ripple for the DTC drives. One is multi level inverter or multi cell inverter [5, 6]; the other is Space Vector Modulation (SVM) [7]. For the DTC scheme with the multi level or multi cell inverter, the cost

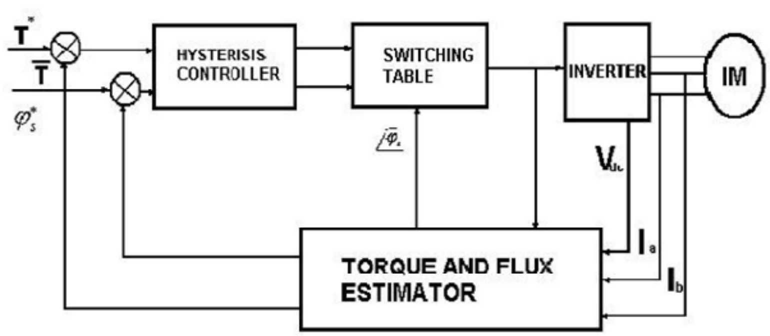

Fig. 1: Circuit diagram of Basic Direct Torque Control

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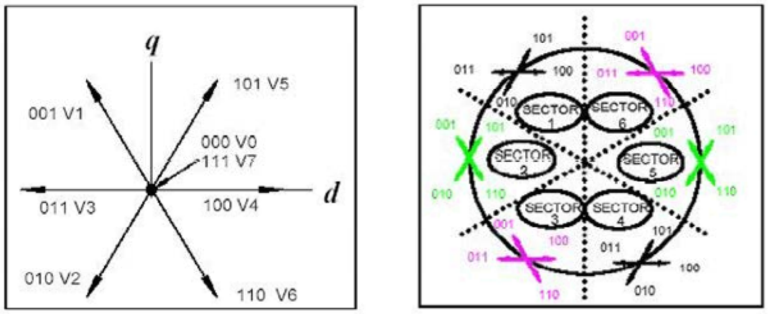

Fig. 2: and 3 Eight voltage space vectors generated by a 3 phase 2 level inverter

and complexity will be increased due to the fact that more power switches are used, they are mainly used for high voltage applications. For the SVM DTC method in [7] and [9], two controllers are used for the control of flux and torque; therefore, the parameters need to be tuned properly. In the SVM DTC scheme proposed in [8], the torque ripple and flux ripple can be reduced, however, the switching frequency still changes. In the SVM DTC scheme proposed in [8-10], a predictive flux controller is used with the SVM. It can work well with low sampling frequency and only one torque controller is used, which is better than the first SVM DTC scheme. However, it seems that the torque response under this scheme is slower than its counterparts.

Second problem for DTC is the changing switching frequency. Under the basic DTC, the inverter keeps the state until the output states of the hysteresis controller change. Therefore, the switching frequency is usually not fixed; it changes with the rotor speed, load and bandwidth of the flux and torque controllers. Although some researchers proposed a dithering signal method to fix the frequency in [4], their method requires very fast hardware.

In this paper, a different DTC algorithm proposed in [10-12] is investigated. It features low ripple in flux and torque and almost fixed switching frequency, in the mean time it still has a very fast dynamic torque response. There is only one control loop for the torque. All the calculations are done in stator reference frame and no machine parameter is used, except the stator resistance for estimation of the stator flux linkage. A Matlab/Simulink model is built to test the algorithm. Both simulation and experimental results show that ripples in torque and flux ripples are greatly reduced. And also the switching frequency remains fixed at a constant value. In the mean time, all the advantages of the basic DTC are still retained [13].

Idea of the Basic DTC: The key idea of the basic DTC is slip control, which is based on the fact that, under constant stator flux linkage, the change rate of torque is proportional to the instantaneous slip between the stator flux and rotor [3]. Therefore, torque control can be achieved by means of controlling the slip between the stator flux and rotor. There will be eight voltage vectors that can be used for torque and flux control as shown in Fig. 2. It is seen that there are 6 non-zero vector and 2 zero vectors [14].

Under the basic DTC, the flux and torque control are carried out by means of a switching table, as shown in Fig. 3 the flux plane is divided into 6 sectors. In each sector, there are four non-zero vectors and two zero vectors that are needed to control the flux and torque. Each vector has different effect on the torque and flux linkage. For example, if the flux linkage vector is in sector 1, voltage vector V3 (011) used to increase both the torque and the flux linkage. V4 (100) is used to decrease both the flux linkage and the torque. V2 (010) is used to increase torque and reduce the amplitude the flux linkage. V5 (101) is used to reduce the torque and increase the flux linkage [15].

If the voltage drop on the stator resistance is neglected, it can be assumed that the flux linkage is always following the direction of the voltage vector. And for each vector, there are two components, one for controlling torque and the other one for controlling the flux linkage. As shown in Fig. 4. It is seen that the torque component and the flux component are quite different at different position. It should also be noted that in each border of the 6 sectors, the ability of controlling the flux linkage is very weak sometime, as reported in [10].

Therefore, if more vectors are used in one sampling interval, maybe a better performance can be expected. And that is the basis of the modified DTC. Under the modified scheme, 3 vectors are used to control flux, such that the amplitude of flux and torque can be controlled [16-17].

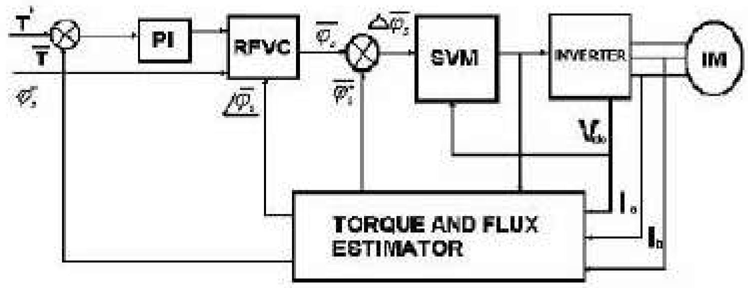

Fig. 4: Circuit diagram of Modified Direct Torque Control

Flux and Torque Control of the Modified Direct Torque Control Scheme: In the proposed system shown in Fig. 5, flux and torque estimators are also used. Instead of the switching table and hysteresis controllers, a Proportional Integral (PI) controller and reference flux vector calculator (RFVC) are used to determine reference stator flux linkage vector. Voltage space vectors and their duration are selected and calculated according to the error flux linkage vector, such that the error can be fully compensated.

From the system diagram of the proposed DTC, it is seen that the proposed scheme retains all the advantages of the basic DTC, such as no co-ordinate transformation, robust to machine parameters, no current control loop etc. However, a space vector modulator is used to generate the control signal for the inverter; therefore, the complexity is increased if compared with the basic DTC scheme.

The proposed DTC strategy can be further explained as: when the estimated torque is below the reference torque, the controller will force the stator flux to rotate at a higher speed to increase the slip frequency between the stator flux and rotor, such that the torque can be increased. The torque will be kept on increasing until error is zero. The RFVC is used to generate the reference flux vector according to the error in torque, which is based on the current estimated flux linkage vector.

The selection rule of voltage space vectors is also changed; it is not based on the region of flux linkage, but on the error vector, i.e. the error of the expected flux linkage vector and the estimated flux linkage vector. The switching frequency is around *2f/3*, *f* is the sampling frequency.

Simulation Result: The simulation results use a 3-Ph, 1500W, 380V Induction Motor parameter. The frequency used is 50Hz and the rated speed of the motor is 1460rpm. The simulation results of the torque, flux and current for basic DTC and modified DTC are shown in below figures.

Modified Direct Torque Control (Simulation Waveforms):

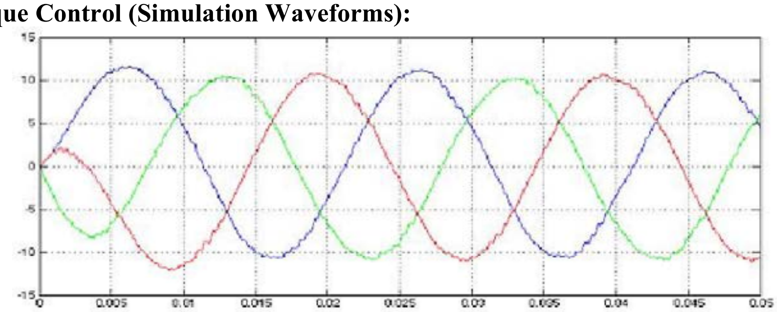

Fig. 5: Current response for Modified Direct Torque Control

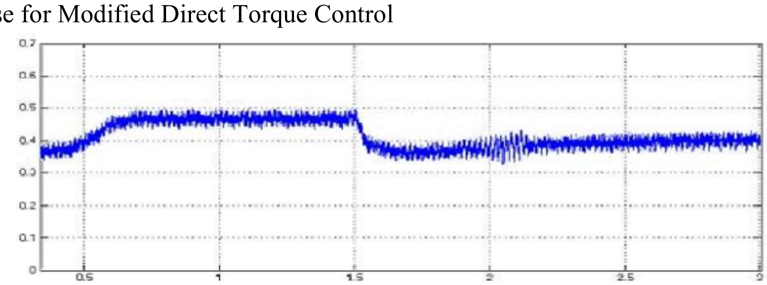

Fig. 6: Flux response for Modified Direct Torque Control

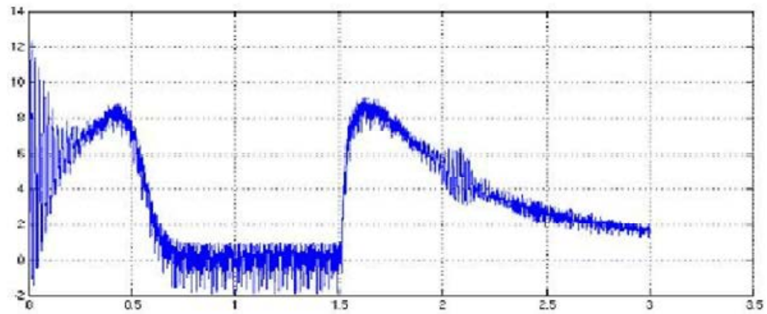

Fig. 7: Torque response for Modified Direct Torque Control

Basic Direct Torque Control (Simulation Waveforms):

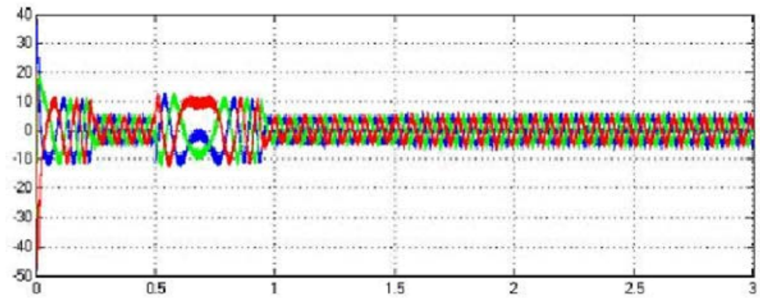

Fig. 8: Current response for Basic Direct Torque Control

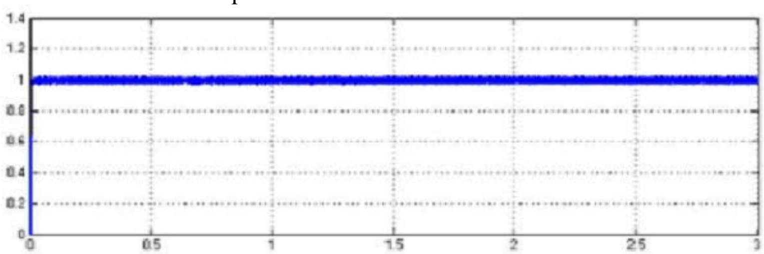

Fig. 9: Flux response for Basic Direct Torque Control

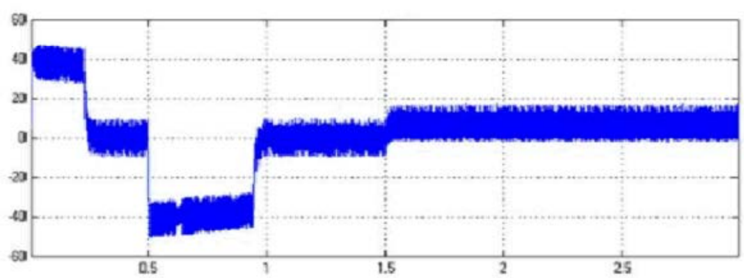

Fig. 10: Torque response for Basic Direct Torque Control

CONCLUSION

In this paper, a modified DTC scheme was investigated by experiment and modeling, it features in low torque ripple, low flux ripple and almost fixed switching frequency. It retains all the advantage of the basic DTC, such as no coordinate transform, robust to parameter variation etc.

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