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Comparison of Classical DTC Scheme and a Simplified DTC Scheme with Flux Optimization for an Induction Motor Drive

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Abstract - *Electric motor drives play a crucial role in industry automation. With the development of power electronics, Induction motors have replaced DC motors in various applications. The ease with which the machine can be controlled added to this trend. Various techniques were developed for induction motor control in the last two decades. The popular among them was the Direct Torque Control (DTC) due to its simple implementation and dynamic torque response. As the scheme relied on hysteresis controller for its operation, the varying switching frequency was a disadvantage. To overcome that, DTC using Space Vector Modulation (SVM) concept was put forward. Being a computationally complex technique, its implementation caused difficulties. A simplified scheme to implement DTC-SVM was then presented with the advantages of the scheme and reduced computations. Here a flux optimization algorithm is added to the system and the performance is compared with the classical DTC scheme. Simulation results in MATLAB/Simulink are presented.*

***Key Words*: Bandwidth, Flux optimization, Imaginary switching time, Offset time, Sampling times, Switching time.**

1.INTRODUCTION

The advantages of induction machines such as simple construction, low cost, robustness and reliability have made it popular as a suitable option for heavy industrial applications and for machine tools. With the advent in power electronic technologies it is possible to control the machine in order to attain desired performance. Among the various control techniques proposed for Induction Motors (IM), the Field Oriented Control (FOC) scheme and the DTC scheme attracted attention. For the control of flux and torque, the decoupling of stator current into direct and quadrature axis components is required in FOC scheme [1]. The scheme was also known as vector control as the current vector was controlled. The scheme required many transformations and hence was computationally complex.

A control strategy different from vector control is presented in [2]. The technique was based on the limit cycle control of torque and flux using optimum PWM voltage that gives quick torque response and is highly efficient. The varying nature of the bandwidth of the hysteresis controllers used results in varying switching frequency of the converter. To attain constant switching frequency, DTC with SVM technique is used. It is a predictive control scheme where a reference voltage vector needed to be calculated in each sampling period. The requirement for angle and sector identification made the method complex.

Operating the induction motors at their rated flux values gives higher torque per ampere for industrial applications. But at light load conditions this causes increased losses thereby reducing the efficiency. A flux optimization algorithm to overcome this is discussed in [5]. This concept is incorporated along with a simple DTC scheme presented in [7] and is compared with the classical DTC scheme in this paper.

2. CLASSICAL DIRECT TORQUE CONTROL

Direct torque control scheme is considered today as the world's most advanced ac drives control technology. It is a simple control technique that does not require any coordinate transformation, PI regulators, pulse width modulators and position encoders. The method results in direct control of torque and indirect control of flux by selecting optimum inverter voltage vectors. The optimum vector selection is made as to limit the torque and flux errors within fixed hysteresis bands. The stator flux linkage is estimated by integrating the stator voltages and the torque is estimated as the cross product of estimated stator flux linkage vector and measured motor current vector [4]. The implementation block diagram is shown in fig.1.

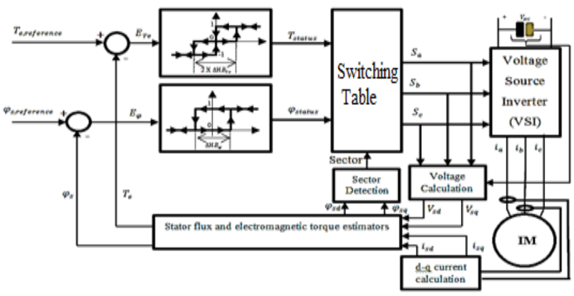


Fig.1 Classical DTC scheme implementation

The DTC scheme offers quick torque response in transient region and improves the steady state efficiency. The variation is the bandwidth of the hysteresis controller results in varying switching frequency of inverter. The scheme creates large amount of ripples in the torque and flux waveforms.

3. DIRECT TORQUE CONTROL WITH SPACE VECTOR MODULATION

To overcome the disadvantage of varying switching frequency in DTC scheme, SVM technique is used for operating the inverter. A reference voltage vector is synthesized in each sampling period in this predictive control scheme [3] so that the flux and torque values are controlled in a dead beat fashion. The voltage vector required is calculated based on the instantaneous current and voltage measurements. The calculated voltage is then synthesized using SVM. Using more than one voltage vector in one sampling period reduces the torque ripples. Though the method helps to attain constant switching frequency and reduced ripples, the basic advantage of DTC, which was simplicity, is lost. As SVM requires angle and sector identification and coordinate transformations, the DTC-SVM has a complex implementation. The generation of the reference voltage vector using adjacent vectors in sector 1 is shown in fig.2. For the generation of the reference vector, the adjacent vectors V_1 and V_2 can be used along with the zero vectors (V_0 or V_7). The time for which the various voltages are to be applied (T_1, T_2 and T_0) can be calculated using equations as detailed in [3].

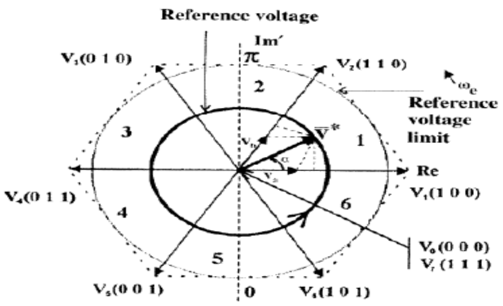


Fig.2. Space vector of two level inverter with reference vector in sector 1[8]

4. SIMPLIDIED DTC WITH FLUX OPTIMIZATION

The simplified algorithm for implementing DTC-SVM is based on imaginary switching time. The concept of imaginary switching time is derived from [6]. The time of application of the active voltage vectors is termed as the effective time. During this time power transfer takes place from the inverter to the machine. The algorithm for the implementation of the simplified DTC scheme is detailed in [7]. The method requires speed feedback from the machine. The error between the reference speed and the actual speed is termed as the slip speed. The torque error is proportional to the slip speed. Hence adding the slip speed obtained from torque error with the motor speed gives the synchronous speed. The synchronous speed is integrated to obtain the angle of the flux vector. There is no requirement of angle estimation and sector identification which makes the scheme computationally much simpler compared to DTC-SVM method.

The error between that reference and actual values of the direct and quadrature axis components of the stator flux vector is used to determine the imaginary times in d and q-axis. These are times are then transformed to obtain the three phase times as explained in [7]. The scheme gives results similar to DTC-SVM scheme. The torque and flux ripples can be reduced along with achieving simple implementation. Even though the scheme requires PI controllers and transformations, the performance is much better that the classical DTC scheme and the simplicity is maintained. The scheme can be easily implemented in industries using DSPs.

In industries, induction machines are operated at their rated flux value over the entire operating range. Under light load conditions, this may lead to increased core losses and ripples in torque. The flux optimization algorithm presented in [5] is used to improve the performance of the scheme along with reduction in torque ripple. The reference flux value is generated based on the machine output torque and is applied to the control loop.

5. RESULTS AND DISCUSSUION

A 2 HP, 4 pole inverter fed induction machine has been modeled in MATLAB/Simulink environment [9] and the two schemes were implemented to evaluate the performance. The classical DTC scheme and the simplified DTC scheme with flux optimization algorithm are compared based on the torque and speed response of the machine. The machine specifications are detailed in Table I.

Table I

3 Phase Induction Motor Specifications

Rated Power	2 HP
Rated Speed	1450 rpm
Frequency	50 Hz
Rotor Type	Squirrel Cage
Reference Frame	Stationary
Poles	4
R_s	0.435 Ω

R_r	0.816 Ω
$L_{ls} = L_{lr}$	2e-3 H
L_m	8e-3 H
J, Moment of inertia	0.089

The implementation of the conventional DTC scheme in MATLAB/Simulink is shown in fig.3 and the simplified scheme implementation with flux optimization is shown in fig.4. Classical DTC scheme includes flux and torque estimation, PI controller for regulating speed error, angle calculation and sector identification, hysterisis comparators for flux and torque and the voltage vector selection table. The switching vectors changes whenever the error value reaches the bandwidth limits of the comparator. Simplified DTC scheme comprises of the speed and torque control loop that provides the flux vector angle, time calculation block that gives actual gating times and the pulse generator block.

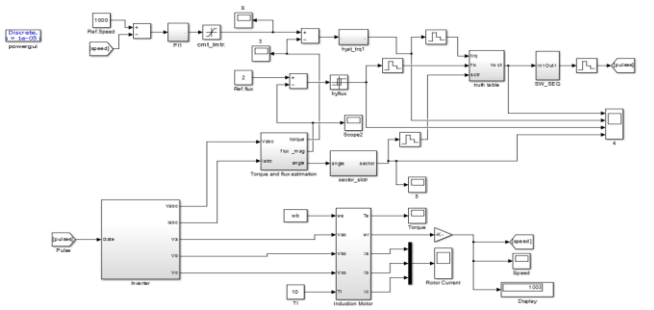


Fig.3 Implementation of conventional DTC scheme

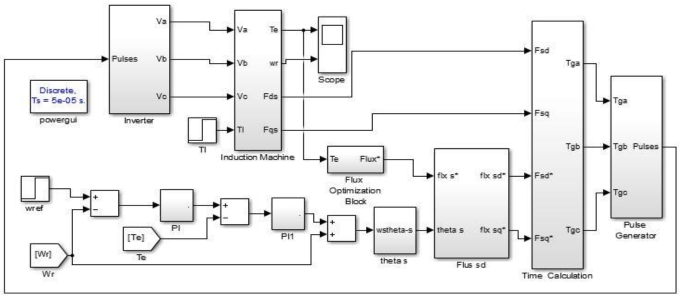


Fig.4 Implementation of simplified DTC scheme

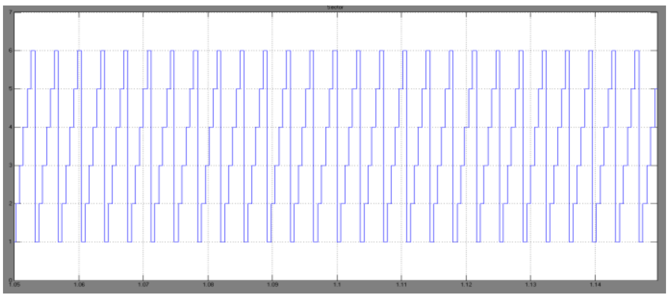


Fig.5 Sectors of operation in conventional DTC scheme

(x axis:0.01s/div, y axis:1sector/div)

The sectors of operation of the conventional scheme are shown in fig.5. The operation moves continuously from sector 1 to 6 and then repeats the cycle as the voltage vector completes one rotation. After each cycle the flux and torque errors are restored to their limits. The operating frequency varies with the bandwidth of the hysteresis controllers used.

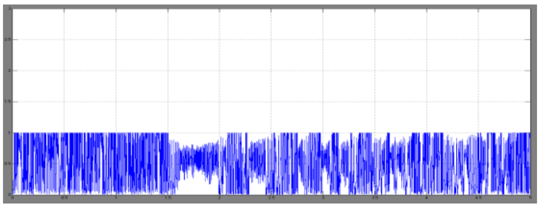
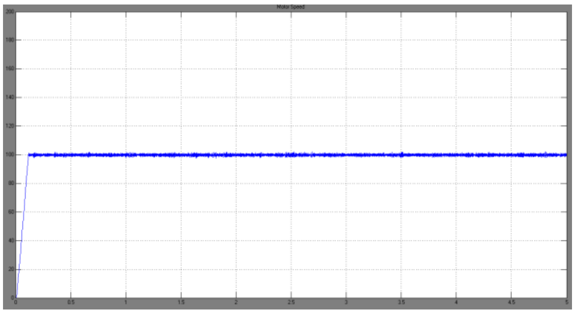


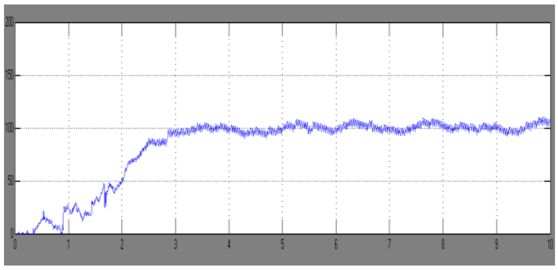
Fig.6 Flux reference for simplified DTC scheme with flux optimization

(x axis:0.5s/div, y axis:0.5 wb/div)



a. Speed response of conventional DTC scheme

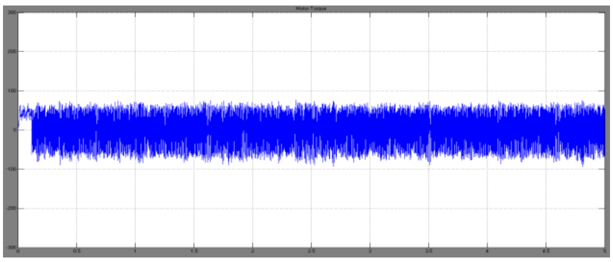
(x axis:0.5s/div, y axis:20 rad/s/div)



b. Speed response with Simplified DTC scheme

(x axis:1s/div, y axis:50 rad/s/div)

Fig.7 Speed response of the induction machine for a reference speed of 100 rad/s



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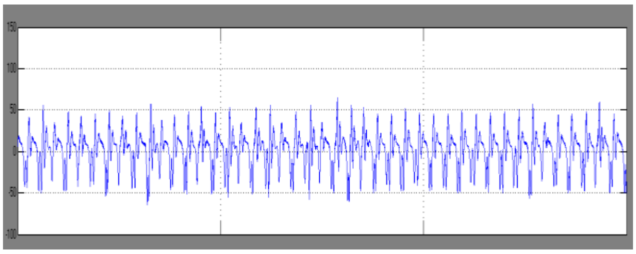
a. Torque response of Conventional DTC scheme

(x axis:0.5s/div, y axis:100 Nm/div)



b. Torque response with Simplified DTC scheme

(x axis:0.5s/div, y axis:50 Nm/div)

Fig.8 Torque response of the machine for a load torque of 2 Nm.

In the conventional scheme, a fixed torque reference value of 1wb is applied. In the simplified scheme the flux reference value varies according to the optimization algorithm. The reference value depends on the motor parameters and the developed electromechanical torque. The flux reference value with the optimization algorithm is shown in fig.6.

The speed responses of the machine are compared for a reference speed of 100 rad/s. The output speed with conventional and simplified DTC schemes are shown in fig.7 (a) and (b) respectively. The response with conventional scheme is smooth and faster compared to that with simplified scheme.

The torque responses with the two schemes for a load torque of 2 Nm are compared as shown in fig.8. The response with conventional DTC scheme is shown in fig.8 (a) and that with simplified scheme is depicted in fig.8 (b). It can be seen that the ripples are much reduced in the simplified scheme with flux optimization algorithm. This is owing to the fact that each time the flux reference value is adjusted according to the torque output of the machine. The torque reference generated from the speed error also varies accordingly to keep the speed and torque output at the reference values.

3. CONCLUSIONS AND FUTURE SCOPE

The paper presented a comparison between the conventional DTC scheme and a simplified DTC scheme with flux optimization algorithm for induction motor control. The speed response is superior with the conventional scheme according to the simulation results but the ripple in torque is high. With the flux optimization algorithm the torque ripples are considerably reduced and the simplified scheme reduces the computation requirements. The simplified scheme gives the same results as DTC-SVM without the need for angle calculation and sector identification.

For improving the performance of the scheme the algorithm can be improved by changing the offset times. This may cause variation in the operating frequency. Instead of a speed feedback loop, the torque control loop alone can be used where a torque reference can be directly given. The implementation of the scheme using advanced controllers like Field Programmable Gate Array (FPGA) can be considered for industrial implementations.

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