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Space Vector Modulation Based Direct Torque Control of Induction Motor with Super twisting speed controller and Loss Model Controller

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Abstract: The Space Vector Modulation based direct torque control is a common solution which is used to solve the conventional DTC's problems, such as high torque ripple and variable switching frequency. Moreover control performance is improved by replacing PI controller in the speed regulation loop by a higher order sliding mode controller. This controller is based on second order super twisting strategy. Furthermore, IM energy optimization is treated as the second objective of this paper. A proposed model based loss minimization strategy is presented for efficiency optimization. The strategy chooses an optimal flux magnitude for each applied load torque

Keywords: Induction motor, Direct Torque Control, Space Vector Modulation, Second order Sliding mode control, Loss minimization strategy

I. INTRODUCTION

The well, known major problems that are normally associated with conventional DTC utilizing hysteresis controllers are high torque ripples, flux ripples, and variable switching frequency. Problems have been addressed by various researchers and as a result several variations to the basic DTC structure have been proposed over the past few decades. Among them widely accepted methods are the one which are based on space vector modulation known as SVM-DTC. With SVM-DTC, voltage vector is generated within the sampling time, which is then synthesized using the space vector modulator. Thus hysteresis comparators are not needed for flux and torque control. Furthermore the SVM-DTC strategy can be enhanced by inserting robust controllers to improve the stability and robustness of the entire control scheme. Different nonlinear control techniques have been proposed for induction motor to improve the control performances, like fast dynamic response, good support for external load disturbance and rejection capabilities. The sliding mode control (SMC) method offers an excellent dynamic and high robustness of the IM drive. In addition, it has a simple software and hardware implementation. The higher order sliding mode control is presented in order to eliminate chattering phenomenon, which is the main problem of conventional SMC (First order SMC). For this, super twisting is a second order sliding mode control technique which is proposed to provide a continuous control, in order to reduce the effect of chattering while keeping the desirable properties of first order SMC (ie. fast response and high robustness).Another objective of this paper is that the DTC control scheme will be associated to an efficiency maximization strategy, based on loss minimization. To improve the motor efficiency, the generated magnetic flux should be reduced to an optimal level. Then the torque will be obtained with lower stator current and magnetic flux, resulting in lower ohmic and iron losses. Several efficiency improvement methods have been reported concerning the flux level control. In general they can be divided into two categories .The first category is termed as search controller(SC).This controller searches iteratively for the flux level until the electrical input power set to the lowest value for a given torque and speed. The second category is the Loss Model Controller (LMC). This approach consist of computing the losses by using induction motor model and selecting the flux level that minimizes the losses.

II. SVM BASED DIRECT TORQUE CONTROL

The main difference between classical and SVM based DTC strategies is that SVM DTC have replaced the switching table by SVM unit for switching signal calculation. The optimal selection of the space voltage vectors in each sampling period preserves a constant switching frequency which reduces considerably the noise.

Nomenclature

DTC –Direct torque Control SVM –Space Vector modulation

Isa, Isb- a and b components of stator currents. Vsa,Vsb –a and b components of stator voltage $\varphi_{s\alpha}$,$\varphi s\beta$ -alpha and beta components of stator flux Rs, Rr-Stator and rotor resistances

Ls,Lr –Stator and Rotor inductances

Msr-Stator and Rotor mutual inductances Te- Electromagnetic torque

p -Number of pole pairs

T1, T2- Reference voltage vectors durations Tz-sampling time

Vdc-DC link voltage Wr-Rotor speed

J-Inertia moment

f- Coefficient of friction TL-load torque

VSI- Voltage Source inverter SMC-Sliding Mode Control

STSC-Super Twisting Speed Control LMC-Loss Model Control

A. Induction Motor model

$$U_{s\alpha} = R_S I_{s\alpha} + \frac{d\varphi_{s\alpha}}{dt} \qquad (1)$$

$$U_{s\beta} = R_S I_{s\beta} + \frac{d\varphi_{s\beta}}{dt} \qquad (2)$$

$$0 = R_r I_{r\alpha} + \frac{d\varphi_{r\alpha}}{dt} - P_b \boldsymbol{\Omega}_m \varphi_{r\beta} \qquad (3)$$

$$0 = R_r I_{r\beta} + \frac{d\varphi_{r\beta}}{dt} - P_b \boldsymbol{\Omega}_m \varphi_{r\alpha} \qquad (4)$$

+

$$\varphi_{s\beta} = L_S I_{s\beta} \;\; L_M I_{r\beta} \qquad (5)$$

$$\varphi_{r\alpha} = L_r I_{r\alpha} + L_M I_{s\alpha} \qquad (6)$$

$$\varphi_{r\beta} = L_r I_{r\beta} + L_M I_{s\beta} \qquad (7)$$

$$\frac{d\Omega_m}{dt} = \frac{1}{J}\left[P_b \frac{m_s}{2}(\varphi_{s\alpha} I_{s\beta} - \varphi_{s\beta} I_{s\alpha}) - M_L\right] \qquad (8)$$

B. Load angle control

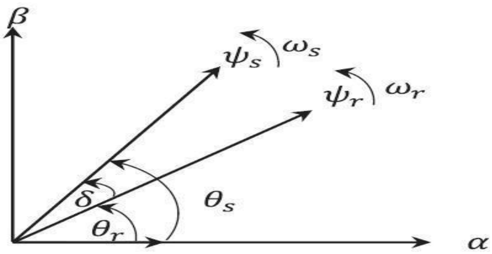

Fig.1 Load angle control

In this control scheme, the torque of the motor can be adjusted by changing the angle between stator and the rotor flux vectors which is called the load angle. The torque of induction motor can be expressed in terms of stator and rotor flux vectors as follows.

Te = pMsrσLsLrφs φr

= pMsrσLsLrIφs I Iφr Isin(δ) (9)

The main objective of this strategy is to select a reference voltage vector Vs, which changes stator flux, then modulate it by SVM technique. The produced change of load angle which produced by the PI controller is added to the actual angle of the rotor flux vector. Therefore, the reference stator flux vector can be computed by the following formula.

$$\varphi s\alpha = \varphi s * \cos(\delta + \theta r) \quad (10)$$

$$\varphi s\beta = \varphi s * \sin(\delta + \theta r) \quad (11)$$

C. *Space Vector Modulation*

The principle of SVM is to predict and calculate the voltage vector. It is based on each sector for two level inverter. The application time for each vector can be obtained by vector calculations and the rest of the time period will be spent by applying the null vector. For two level inverter, the space vector diagram is shown in fig2.

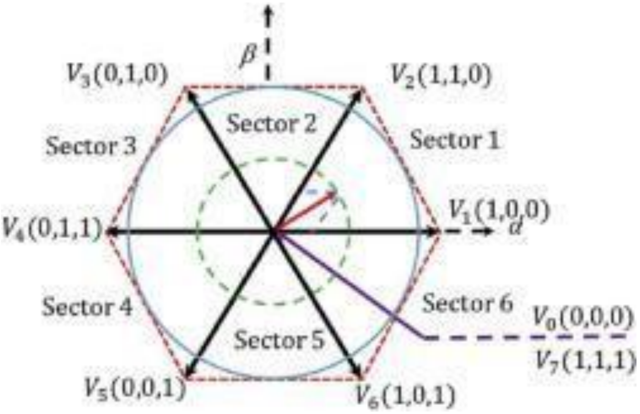

Fig.2.Space vector modulation

D. *Super Twisting Speed Controller*

The higher order sliding mode generalizes the idea of the first order by higher order derivatives of the sliding surface. The super twisting algorithm provides a continuous control by using only information about s and evaluating the sign of ṡ is not necessary. The convergence of this algorithm is described by the rotation around the origin of the phase diagram (s,ṡ). The super twisting control law is given by,

$$S = \omega ref - \omega \quad (12)$$

$$UST = u1(t) + u2(t) \quad (13)$$

$$u1(t) = -\lambda |s|^{\rho} \operatorname{sign}(s) + u_1 \quad (14)$$

$$u1. = -\beta \operatorname{sign}(s) \quad (15)$$

λ, β :are positive gains ,s is the sliding surface. The degree of nonlinearity can be adjusted by ρ value, which is defined by 0 < ρ≤ 0.5”, mostly it is fixed in “0.5” value.

E. Loss Model Control

The loss model control (LMC) strategy based on minimizing the motor losses in steady state by adjusting the rotor flux and stator flux to an optimal value to achieve the maximum efficiency and minimizes the total losses basically at low load values. In our case a simplification will be proposed by neglecting the core losses in the optimization. The total copper loss is given by,

$$Pc\ loss = Ps + Pr \quad (16)$$

$$\frac{\partial Pc\_loss}{\partial \varphi} = 0 \qquad (17)$$

$$\varphi_{r_{opt}} = \lambda_{opt}\sqrt{T_{e*}} \qquad (18)$$

$$\lambda_1 = \frac{Rs}{Msr} \qquad (19)$$

$$\lambda_2 = \frac{Rr}{p^2} + Rs\left(\frac{Lr}{pMsr}\right)^2 \qquad (20)$$

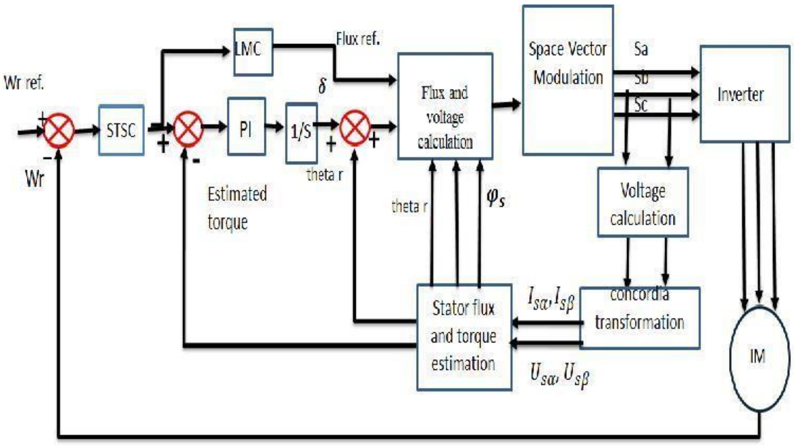

Fig.3.Block diagram of SVM DTC with STSC and LMC

Fig.3 shows the proposed control strategy of induction motor. Speed reference is compared with the measured speed. Based on the error, Super Twisting Speed Controller generate reference torque. It is compared with estimated torque value. Based on the error, pi controller in combination with integrator generate reference load angle. Using this controlled reference load angle stator flux angle is calculated by adding it with rotor flux angle. At the same time Loss Model Controller generate stator flux reference from the reference torque. Using the reference stator flux angle and stator flux reference, alpha beta components of stator flux reference is calculated using equation10-11. It is then compared with estimated stator flux. Based on the error, reference voltage space vector is calculated .Finally reference voltage space vector is realized using Space Vector Modulation unit.

III. SIMULATION RESULTS

The presented control algorithm has been simulated by matlab/simulink software .The simulation results were obtained for a three phase 1.5KW squirrel cage induction motor with characteristics given in the Appendix. The simulation results show firstly the comparative study of closed loop torque control (SVM-DTC) with constant flux reference (.9wb) and optimal flux reference which generated by LMC strategy. In the second phase the performance analysis of optimized SVM-DTC control scheme with various speed controllers is presented.

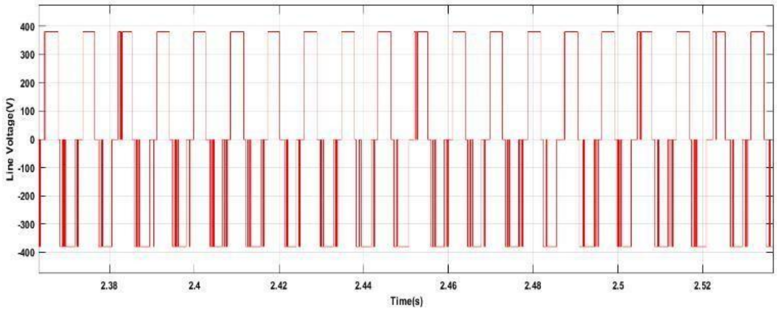

Fig.4 Line voltage

Figure 4.shows the line voltage of three phase inverter having two levels which are +vdc and –vdc, where vdc is the dc link voltage. The dc link voltage is given as 380 volt.

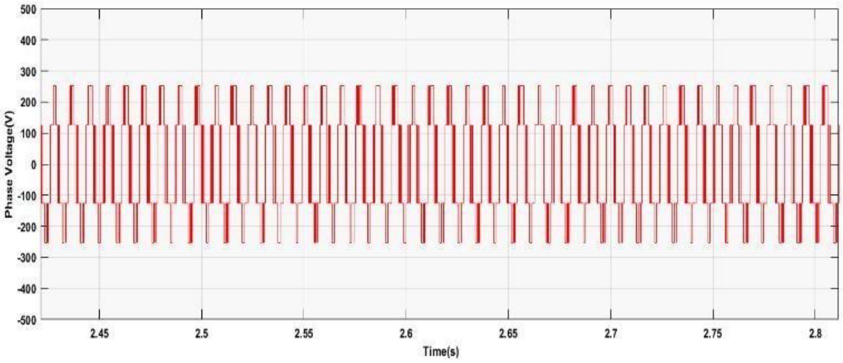

Fig.5 Phase voltage

Fig 5.shows the phase voltage of two level 3 phase inverter having levels 2vdc/3 and vdc/3 ie. 253 volt and 126.6 volt.

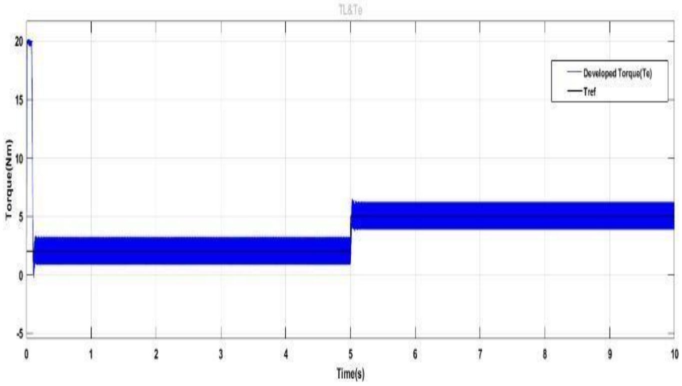

Fig.6.Torque response of basic DTC

Torque response of induction motor with conventional DTC is shown in figue.6.It can be see that load torque applied to induction motor is 3Nm up to 5s. Then after 5 seconds load torque is increased to 5Nm. The torque developed by the motor tracks the applied load torque with a ripple of 1Nm.

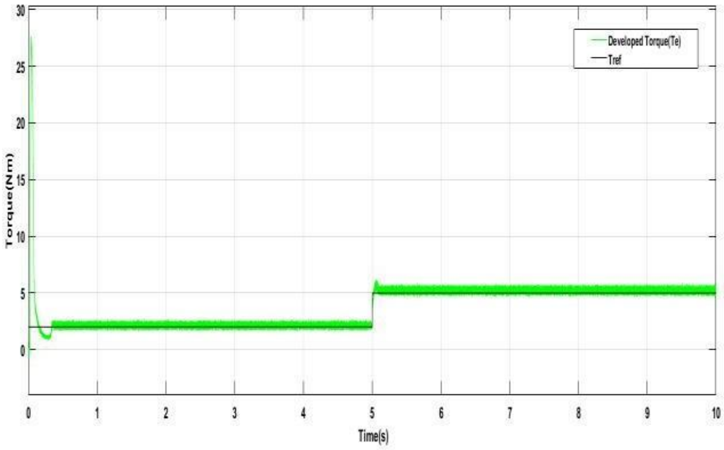

Fig.7 Torque response of SVM-DTC

Figure.7 shows the torque response of the system with SVM. The torque developed by the motor tracks the applied load torque with a torque ripple of .5Nm.

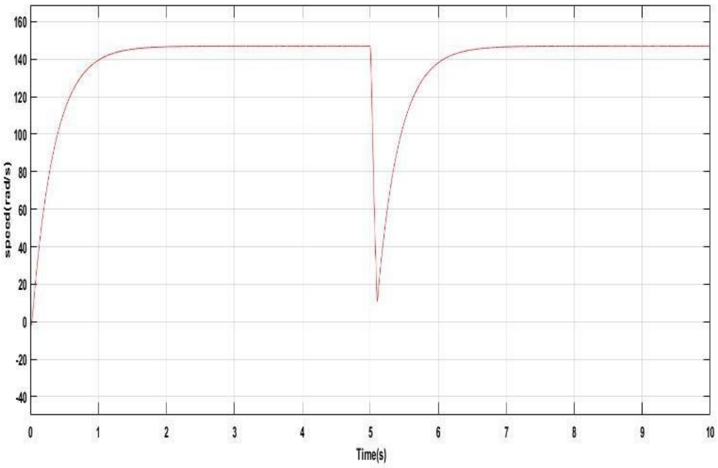

Fig.8. Speed response of SVM- DTC with PI controller

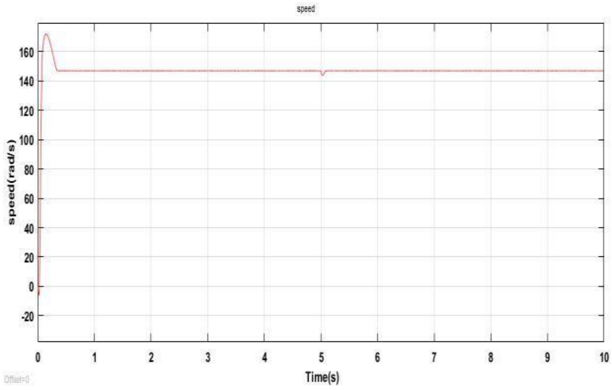

Fig.9 Speed response of SVM- DTC with STSC

In Figs.8-9, shows the speed response of the system with load disturbance introduction. Both controllers have fast response and good reference following, but we can notice that the STSC is more robust against the external disturbance.

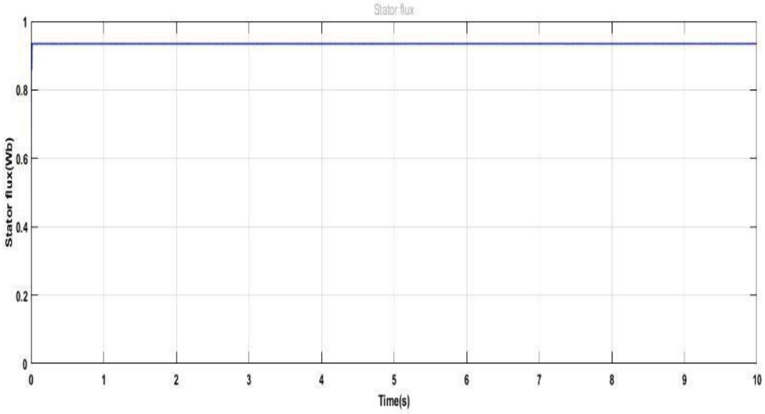

Fig.10 SVM DTC with constant flux reference

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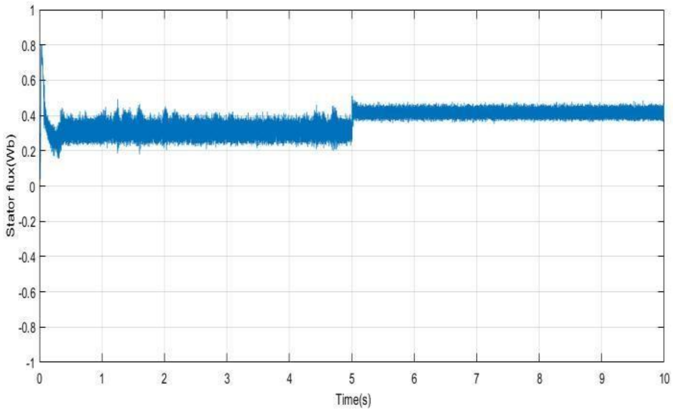

Fig.11 Stator flux variation with LMC

The proposed nonlinear SVM-DTC control strategy with LMC in **Figs.11** shows the optimal flux variation according to the load application contrary to the constant flux of ($0.9Wb$). We can see that after the transient state, the flux takes an optimal value in steady state in order to minimize the losses.

IV. CONCLUSION

The insertion of SVM in DTC control scheme solves the most common drawbacks (ie. high flux and torque ripple).Furthermore DTC achieves better dynamic control under different operating conditions ,such as load application, speed sense's reversing and low speed operation. In addition the design of second order sliding mode controller has improved comprehensively the control scheme performance and increased the algorithm robustness against external load and reference variation. Therefore, the coupling of SVM-DTC with robust control is a good solution for induction motor drive control. The effectiveness and the performances of LMC strategy which is based on the choosing of optimal flux reference has been verified and compared with basic technique which is based on constant flux references. The performed tests gives similar results. They show that LMC reduces losses and improve efficiency at zero and low load operations in steady state.

APPENDIX

1.5kW,1440 rpm,3 phase,415V,50 Hz,3A,4 pole, Rs=1.5Ω, Rr=6.21Ω, Ls=0.5192H, Lr=0.5192H, Msr= 0.4957 H, *f*=0.002 , J=0.01240 kg.m²,.8pf,

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