Speed Control of Vector Controlled Induction Motor using Sliding Mode Controller and Zeta Converter

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Abstract— Induction motors are used as the major workhorse in the industry due to its robustness, high efficiency and maintenance free nature. Owing to the fact that the induction motor models are highly non linear they are very difficult to control compared to DC motors. Also the time varying nature of parameters and variables which can be changed during the operation of the drive system makes the designing of the proper controller difficult. The best suggested solutions to solve these parametric variations and load torque variations would be a Sliding Mode Controller (SMC). But while using SMC in a vector controlled induction motor drive the Power Factor of the system is considerably reduced. A Zeta converter is incorporated in the system which will improve the power factor and thereby reduces the power quality issues. This paper presents the designing and the simulation of a vector controlled induction motor drive using sliding mode controller with zeta converter. The simulation is done using MATLAB/SIMULINK. The proposed control scheme can be implemented in real-time applications since it does not involve high computational cost.

Key words: PI Controller, Sliding Mode Controller, Zeta Conveter

I. INTRODUCTION

In high performance speed and position control applications only DC motors were used owing to their ability to control flux and torque independently and easily. However, existence of brushes and commutators are the basic drawbacks of a DC motor. Presence of brushes and commutators demands not only periodic maintenance but also difficulty to work in explosive and dirty environments. On the other hand induction motor is robust, simple in mechanical construction, low service requirements, reliable and lower costs with respect to DC motors. But compared to those of dc drives the control and estimation of ac drives in general are considerably more complex. The main reasons for this complexity are the machine parameter variations, the difficulties of processing feedback signals in the presence of harmonics, the need of variable frequency and the complex dynamics of ac machines. Scalar control, vector or field-oriented control, flux oriented control, direct torque control and adaptive control are the different control techniques of induction motor drives. Adaptive control includes self tuning control, Model Referencing Adaptive Control (MRAC), variable structure control or Sliding mode control, neural control, Fuzzy control, Expert system control. Even though a scalar controlled drives are easy to implement they give inferior performance in terms of coupling effect which results in instability of the system.

Over the past decade, vector control (VC) or field-oriented control (FOC) technique has been widely used in industry for high performance induction motor drive. Field oriented control guarantees the decoupling of the flux and the torque, so that the induction motor can be controlled just like a DC motor that is, independent control of torque and flux is made possible using field oriented control. Traditionally, to implement a vector controlled IM drive system two feedback loops are configured. The inner loop is a current regulation loop whereas the outer one is a speed or position regulation loop. Usually a PI controller is used for both inner and outer loop since the proportional plus integral (PI) controller is simple and very easy to design and implement. However, under external disturbances and machine parameter variations the performance of PI controller for position or speed regulation may not meet the concerned robustness for some applications. Also in order to obtain a desired response the gain of the PI controller has to be carefully selected. Hence For industrial variable speed drive applications where higher dynamic control performance with little overshoot and high efficiency is required traditional PI controller a poor choice. In order to preserve the performance under load torque variations and parameter variations various other control techniques such as non linear control, fuzzy control, neural control can be implemented. But all these controllers involve high computational cost and cannot be implemented over a low cost processor to perform real time control. These issues can be solved by using advanced control techniques such as sliding mode control (SMC).

Insensitivity to parametric variations, load torque variations fast dynamic response and good performance against unmodelled dynamics are some of the properties of SMC. These advantages of Sliding mode controller have been employed in the position and speed control of ac servo systems. The theory of SMC was introduced after by Utkin [8] A sliding motion has two phases namely sliding phase and reaching phase also known as non sliding phase. Once the sliding motion reaches the sliding phase the system response is independent of system dynamics and will only depend on the pre-designed sliding surface parameters. Chattering phenomenon is the major shortage of SMC. Also the power factor of the drive is reduced considerably when a sliding mode controller is employed. To improve the power factor of the system a zeta converter is used.

II. SLIDING MODE CONTROLLER

Sliding mode control approach has emerged because of its potential for circumventing parameter variation effects under dynamic conditions with a minimum implementation complexity. In electric drive systems the existence of parameter changes caused by, for instance converter switching effect, winding temperature variation, unknown loads, Saturation. Also sudden change in the load can affect the performance of the drive. Disturbance rejection, order reduction, strong robustness and simple implementation by means of power converters are some of the main features for Sliding mode control approach. Sliding mode control Techniques can be used for speed control, current control, observer design and sensor less control of electric drive systems.

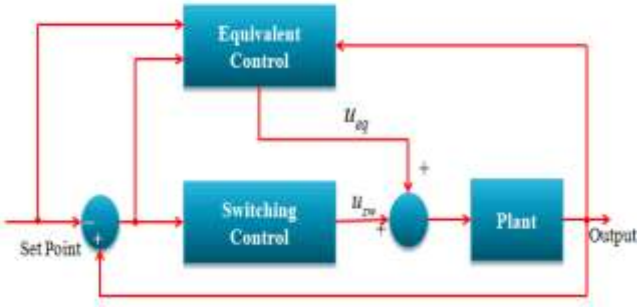


Fig. 1. Sliding Mode Controller

Conventional Sliding Mode control approach is usually design for first order systems. It contains two blocks namely switching control and equivalent control blocks. Designing of the switching control law which enforces the system to the sliding surface is the most important task. The dynamic performance of the system is directly dependent choosing an appropriate switching control law.

III. PROPOSED CONTROLLER DESIGN

Controller design consist of two phase, Reaching phase- the system response is forced to the sliding manifold and sliding Phase during sliding phase the system response is forced to slide along in the sliding manifold. The control law is proposed as:

$$u = u_{eq} + u_d \text{ ..... (1)}$$

Where u_{eq} is the equivalent control signal and u_d is the discontinuous control or switching control. Where u_d is defined as:

$$u_d = -K\,\mathrm{sgn}(s) \text{ .....(2)}$$

Where K is a positive constant, which is the gain of the sliding mode controller and s is the sliding surface or sliding variable which is usually a function of the tracking error which is the difference between the reference value and the actual measured value. Sliding surface is defined as:

$$s(t) = Ke(t) + \dot{e}(t) \text{ .....(3)}$$

Sgn term needs to be substituted by a saturation function to attenuate chattering for real time implementation

$$u_d = -K\,sat\left(\frac{s}{\varphi}\right) \text{ .....(4)}$$

φ is the width of the boundary layer. The control law is modified as:

$$u = u_q - K\,sat\left(\frac{s}{\varphi}\right) \text{ .....(5)}$$

u_{eq} is given as:

$$u_{eq} = \frac{1}{b}\left[a\dot{\omega}_m^* + \ddot{\omega}_m^* + f(t) - (k-a)\dot{e} - \hat{\beta}\gamma\, sgn(s)\right] \text{....(6)}$$

Where the terms a, b, f are:

$$a = \frac{B}{J}$$

$$b = \frac{K_t}{J}$$

$$F = \frac{T_L}{J}$$

Fig 2 shows the block diagram representation of a vector controlled induction motor with sliding mode controller; the speed is fed back and is compared to the reference value. The Sliding mode act such a way that the actual speed follows the reference speed value i.e., to minimize the error value. Here the output from the controller is the reference current and it is compared with the actual i_{qs} and the error from this is fed to a PI controller. PI controller will process the error and output from it will be such that it minimises the error between the currents. Output from the PI is used to generate the pulses for the motor.

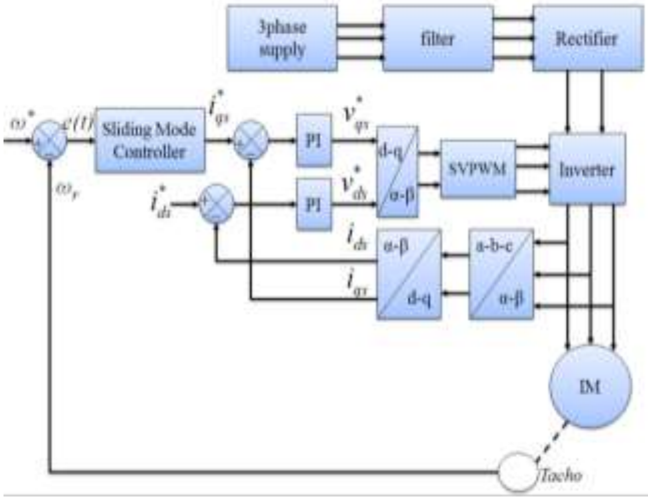


Fig. 2: Block Diagram of proposed sliding mode field oriented control

IV. ZETA CONVERTER

To improve the power factor and thereby to reduce the power quality issues a zeta converter is designed. Fig.3 shows the circuit diagram of the zeta converter. Where C_{in} and C_0 is the input and output capacitor, L_1 and L_2 is the coupled inductors, C_c is the AC coupling capacitor, Q_1 is a power mosfet and D_1 is a diode. The zeta converter will act like output voltage regulator. The voltage across the DC link capacitor is compared with reference voltage and the error signal thus obtained is given to a PI controller and necessary compensation is made by switching the zeta converter.

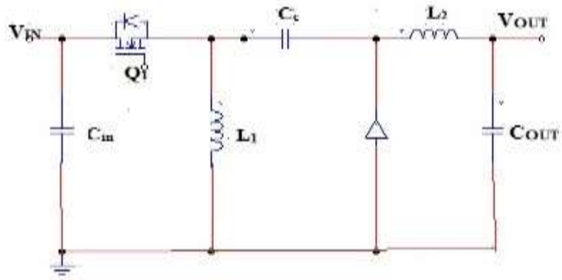
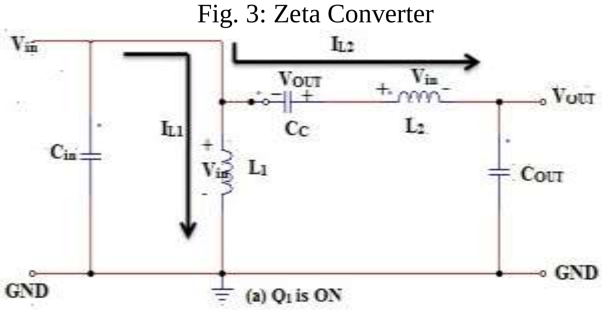


Fig. 3: Zeta Converter



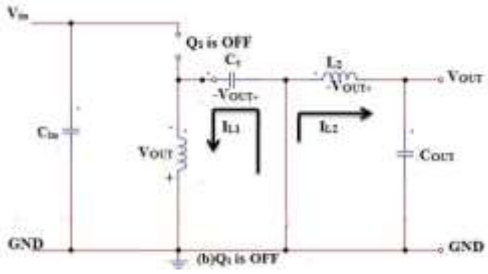


Fig. 4: Working principle of zeta converter

When both switches Q_1 and D_1 are at off condition and not switching, coupling capacitor C_c will be in parallel with C_{OUT}. So C_c is charged to the output voltage, V_{OUT}. When the Q_1 is turned ON, diode D will be reverse biased and inductor L_1 and L_2 and capacitor C_1 stores the energy from the input supply. When the Q_1 is turned OFF, Capacitor C_c is supplied from the energy stored in inductor L_1 and energy stored in L_2 is supplied to capacitor C_{OUT}. Diode D_F will be forward biased when Q_1 is turned off. Fig shows the schematic representation of the working of zeta when $Q_1$is turned on and turned off.

V. Simulation Results

The simulation work was done in MATLAB/SIMULINK. A 415V induction motor with rated speed 1440 rpm was used for the simulation. The overall simulation diagram for a vector controlled induction motor using sliding mode controller and zeta converter is shown in Fig 3. The output from the sliding mode controller is compared with the actual current from the motor and the error is fed to a PI controller.

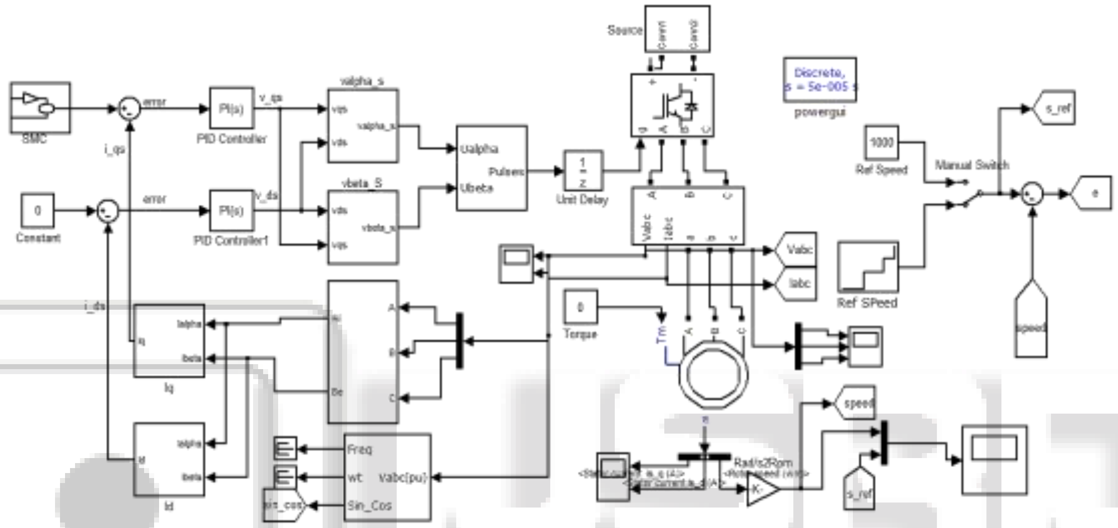


Fig. 5. Induction motor drive with sliding mode controller and zeta conveter design in simulink

Fig.5 shows the switching control law design in simulink/matlab. The sliding surface s is generated using the Eqn.3 and switchning law is generated using Eqn.4

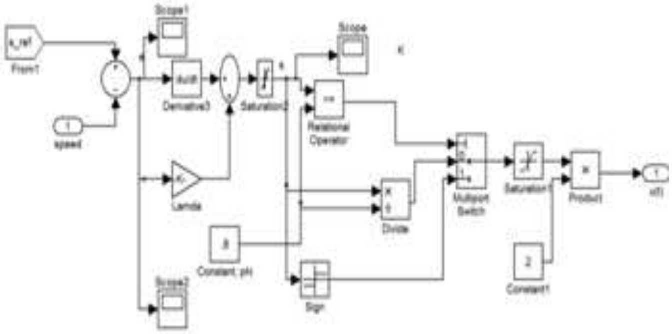


Fig. 6. Switching control law design in Simulink

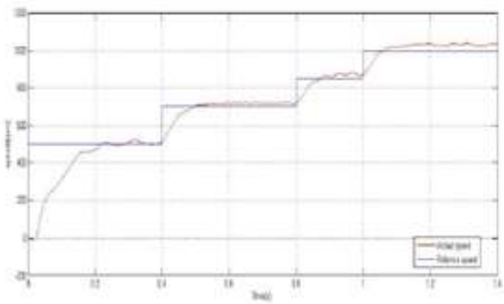


Fig. 7: Dynamic response of an induction motor drive using sliding mode controller

Fig.7 shows the speed response of a induction motor drive using SMC. Smooth speed control was possible from 300 rpm to 1450 rpm. Actual speed of the motor follows the reference speed with minimum overshoot. The reference speed was varied at intervals for example reference speed was varied from 450rpm to 550rpm at .4sec and the motor speed settles in 550 rpm at .5sec that is motor only takes less than .1 seconds to sense the change in speed and to settle in the new reference speed.

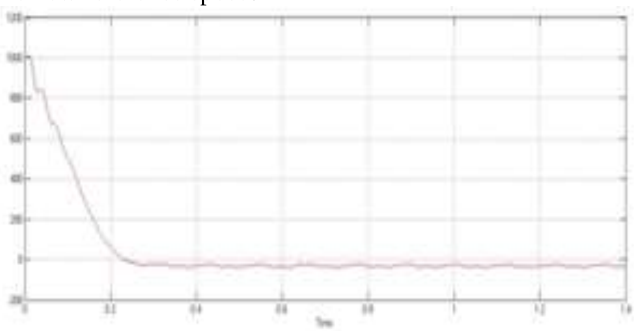


Fig. 8: Error waveform

Fig.8 shows the error waveform. That is the deviation between the actual speed and the reference speed and from the waveform it is clear that after .2 seconds the error is almost zero.

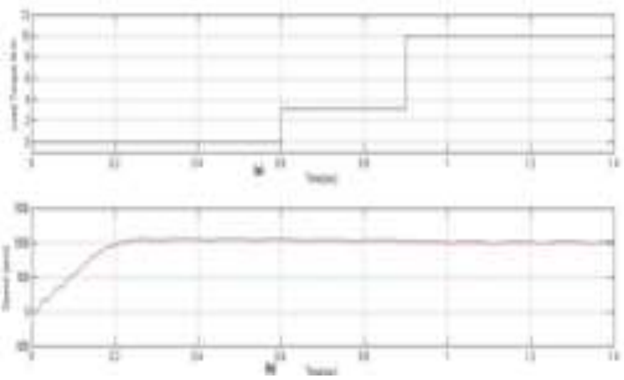


Fig. 9: (a) Applied load torque (b) Speed response

Fig.9 shows the speed response as the load torque applied changes. From the wave form its is clear that there is no significant change in the speed response eventhough the applied torque is varied at intervals. That is by using sliding mode controller the affect of load torque variations in the speed response is minimized here. Fig.10 shows the d and q axis current, which are in 90° phase shift.

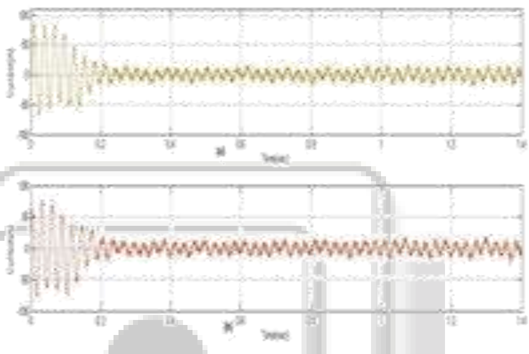


Fig. 10: d-q current waveform

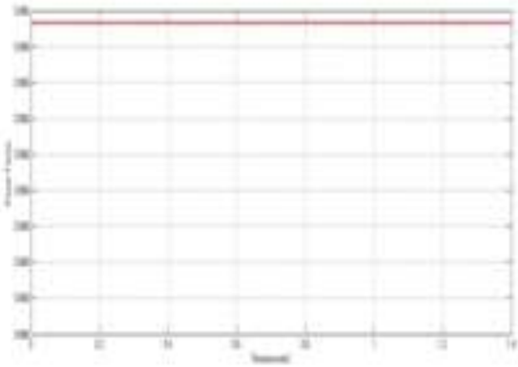


Fig. 11: Power factor of Induction motor drive with sliding mode controller

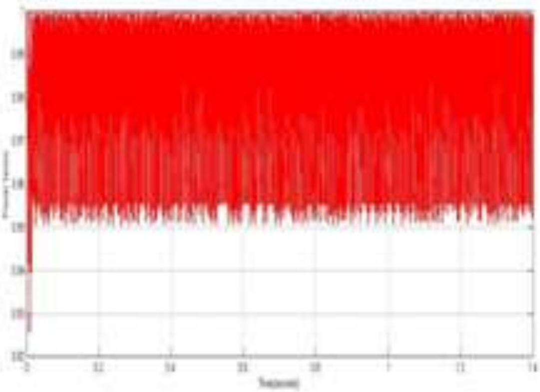


Fig. 12: Power factor of Induction motor drive with sliding mode controller and zeta converter

Fig.11 shows the power factor of a induction motor drive with sliding mode controller which is .86 and Fig.12 shows power factor of the drive with zeta converter. From the wave forms it is clear that by using a zeta converter power factor of the drive has increased to .96 to .99 from .86.

VI. CONCLUSION

Sliding Mode Control (SMC) is a robust control where in order to obtain a desired response the structure of the controller is changed in response to the changes in state of the system. The biggest advantage of this system is that even in the presence of large disturbance signals stabilizing properties of the system is preserved. The proposed controller is evaluated using SIMULINK/MATLAB. From the simulation results it is clear that there is no significant change in the speed response even though the applied torque of the system is changed at regular intervals, i.e., system will adapt itself with the help of control law. And also the motor tracks the reference speed, with less settling time and peak overshoot. It has been shown that the control scheme performs reasonably well in practice, and that the speed tracking objective is achieved under uncertainties in the parameters and load. One of the problems associated with implementation of SMC is Chattering which is essentially a high frequency switching of the control. Chattering can be minimized by smoothening of the discontinuity control and selection of proper control parameters. By using zeta converter a regulated DC voltage is obtained and also the power factor of the system is increased to almost unity and hence the related power quality issues are minimised.

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