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EFFICIENCY OPTIMIZED SENSORLESS SPEED AND INDIRECT VECTOR CONTROL OF INDUCTION MOTOR DRIVES

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***Abstract*—**Nowadays, Induction Motors are popular such that these motors must be compact, lightweight, less expensive and may be recycled very easily. Furthermore, without using the speed sensor we have increased the safety and reliability. Efficiency optimized speed sensorless control technique offers sufficiently high performance. In Indirect vector control the total rotor flux is aligned along the d-axis and the q-axis rotor flux is set to zero. The efficiency optimization is based on the measurement or estimation of the active power input to the machine and by utilizing the reactive power the speed sensorless algorithm is developed. Simulation results and experimental results are presented.

***Keywords*—**Indirect vector control, Efficiency optimization, Sensorless speed control, Induction motor drives.

I. INTRODUCTION

Due to the advancement in power electronics, vector controlled induction motor drives are used in industrial applications in place of DC machines. In Indirect vector control the total rotor flux is aligned along the d-axis and the q-axis rotor flux is set to zero. Due to this induction motor can be controlled like a separately excited DC machine. But the performance vector control under low speed operation is not satisfactory because of unbalances, drift problems etc. Most of the presented research papers discussed about performance of sensor less vector control with various observers but the performance of indirect vector control under low speed operation has not been presented[1].

Stability of the system during transient processes and a wide range of operation are assured through application of the vector-control. This paper also deals with the speed estimators for applications in sensorless induction motor drive with vector control. when these machines are used in large numbers, the recycling would be a big problem. On the other side, the IMs are less expensive, easily recyclable ,requires least maintenance and compact machines. However, the efficiency of the IM is low particularly at lower load. Thus, it is clear that if IMs to be used in EV applications the efficiency of the machine bas to be optimized. An induction motor is an asynchronous AC (alternating current) motor. The least expensive and most widely used induction motor is the squirrel cage motor. The interest in sensor less drives of induction motor (IM) has grown significantly over the past few years due to some of their advantages, such as mechanical robustness, simple construction, and less maintenance. These applications include pumps and fans, paper and textile mills, subway and locomotive propulsions, electric and hybrid vehicles, machine tools and robotics, home appliances, heat pumps and air conditioners, rolling mills, wind generation systems, etc. So, Induction motors have been used more in the industrial variable speed drive system with the development of the vector control technology. This method requires a speed sensor such as shaft encoder for speed control[2].

Vector control is a control strategy to decouple flux and torque from an induction motor in order to emulate a DC motor. The great advantage is that it can be controlled as easy as a DC motor and induction one with all of its advantages such as high efficiency, robustness, no maintenance and low cost. By using vector representation, it is possible to present the variables in an arbitrary coordinate system. If the coordinate system rotates together with a flux space vector, then we use different terminology: flux-oriented control. In this way, it was possible to represent he electromagnetic torque as a product of flux-producing current and a toque producing current [3].The concept of the low speed operation of sensor less vector control, various strategies have been developed and studied. In all these strategies, nonlinearities introduced by inverter and parameter variations are discussed. In order to reduce these problems and to obtain better performance various observers are placed in the sensor less vector control. Due to this circuit complexity is increased and the improvement in the performance is not satisfactory.

Speed sensorless estimation as its name implies, is the determination of speed signal from an IM drive system without using rotational sensors. It makes use the dynamic equations of the IM to estimate the rotor speed component for control purposes. Estimation is carried out using the terminal voltages and currents which are readily available using sensors. Sensor less vector control induction motor drive essentially means vector control without any speed sensor. An incremental shaft mounted speed encoder, usually an optical type is required for closed loop speed or position control in both vector control and scalar controlled drives. A speed signal is also required in indirect vector control in the whole speed range and in direct vector control for the low speed range, including the zero speed start up operation. Controlled induction motor drives without mechanical speed sensors at the motor shaft have the attractions of low cost and high reliability. Drives operating in hostile environments or in high speed drives speed sensors can't be mounted. To replace the sensor the information on the rotor speed is extracted from measured stator voltages and currents at the motor terminals.

Thus, it is understood that the motor drive should possess optimum efficiency, high performance and preferably should be without a speed sensor at the motor shaft to ensure a higher level of robustness. In this paper we propose a novel efficiency optimized, speed sensorless technique for the IM drive. The paper discusses the concept of the proposed efficiency optimized and speed-sensorless-control technique [4].

11. SENSORLESS SPEED CONTROL

The schematic diagram of control strategy of induction motor with sensorless control is shown in Fig 1. Sensor less control induction motor drive essentially means vector control without any speed sensor. The inherent coupling of motor is eliminated by controlling the motor by vector control, like in the case of as a separately excited motor. The inverter provides switching pulses for the control of the motor. The flux and speed estimators are used to estimate the flux and speed respectively. These signals then compared with reference values and controlled by using the PI controller.

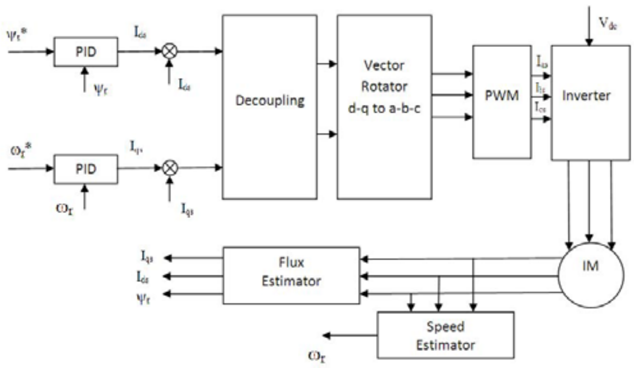

Figure 1: Basic block diagram of sensorless control of induction motor.

An incremental speed signal for an induction motor is essential for closed-loop speed control of scalar or vector drives. The signal is also needed for indirect vector control, and direct vector control if speed control is necessary from zero speed. A physical speed encoder mounted on the shaft adds cost and reliability problems to the drive, in addition to the need for a shaft extension for mounting it. In modern speed sensorless vector control, precision speed estimation from the machine terminal voltages and currents with the help of DSP is an important topic of research. The machine stationary frame (d-q) equations,

$$V_{ds} = R_s i_{ds} + K_1 i_{ds} + \frac{L_m}{L_r}\Psi - K_1 \omega_e i_{qs} - \omega_e \frac{L_m}{L_r}\Psi \quad (1)$$

$$V_{qs} = R_s i_{qs} + K_1 i_{qs} + \frac{L_m}{L_r}\Psi - K_1 \omega_e i_{dx} - \omega_e \frac{L_m}{L_r}\Psi \quad (2)$$

shown in Figure 2,contain speed (w_r) as a variable that can be solved from the known values of the simplified forms of equations that are actually solved in real time for speed estimation, essentially relate to voltage model rotor flux vector estimation, where, these equations are derived from the stator equations and express the rotor fluxes in terms of stator voltages and currents.

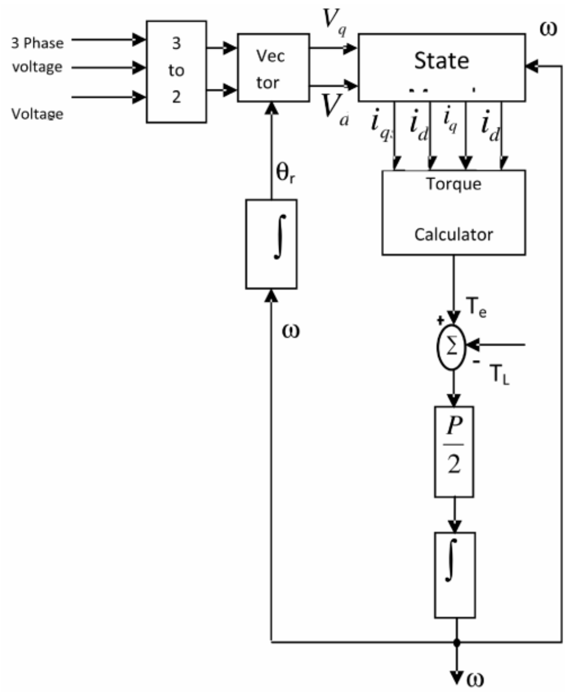

Figure 2: Block Diagram of Induction Machine Model with Input Voltage

111. OVERVIEW OF DIFFERENT CONTROLLING SCHEMES FOR SPEED CONTROL OF INDUCTION MOTOR

A. SPEED ESTIMATION METHOD

Scalar control as the name indicates, is due to magnitude variation of the control variable only, and disregards the coupling effect in machine. For example, the voltage of machine can be controlled to control the flux, and frequency or slip can be controlled to control the torque. However flux and torque are also function of voltage and frequency respectively. A scalar controlled drive gives somewhat inferior performance. Scalar control is easy to implement. Scalar controlled drives have been widely used in industry, but the inherent coupling effect (both torque and flux are function of voltage or current and frequency) gives sluggish response and system is easily prone to instability because of higher order (fifth order) system effect. To make it clearer, if torque is increased by incrementing the slip (the frequency), the flux tends to decrease .it has been noted that the flux variation is also sluggish. Decreases in flux then compensated by the sluggish flux control loop feeding an additional voltage.

This temporary dipping of flux reduces the torque sensitivity with slip and lengthens the response time. However, their importance has diminished recently because of the superior performance of vector or Field orientated control (FOC) drives. To improve speed control performance of the scalar control method, an encoder or speed tachometer is required to feedback the rotor angle or rotor speed signal and compensate the slip frequency. However, it is expensive and destroys the mechanical robustness of the induction motor. So these are the limitation of scalar control which is overcome by Field orientated control (FOC) for induction motor drive.

B. MRAS TECHNIQUE:

The speed can be calculated by the Model Referencing Adaptive System. The model reference approach (MRAS) makes use of redundancy of two machine model of different structures that estimate the same state variables. Both models are referred to in the stationary reference frame. As the name implies it consists of two models namely reference model and adaptive model, where the output of a reference model is compared with the output of an adjustable or adaptive model until the errors between the two models vanish to zero. With the correct value of rotor speed, the fluxes determined from the two models should match. An adaptation algorithm with P-I control can be used to tune the value until the two flux values match.

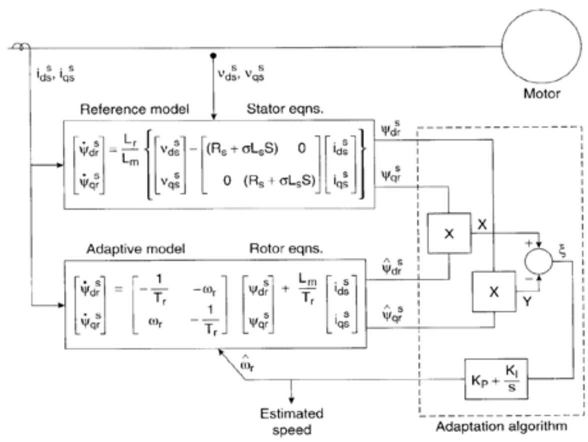

Fig 3.Basic block diagram of MRAS speed estimation

C.EFICIENCY OPTIMIZATION METHOD

Losses may be minimized by implementing a Loss Model Controller or a Search Controller or a Hybrid Controller. For the indirect vector controlled IM drive that is considered here, this may be implemented very easily by an additional loop to decide the optimum flux. Authors recently reported a hybrid technique for the loss minimization of the IM drives. The same technique may be added with the speed-sensorless control algorithm to develop the proposed system presented in the following section. Apart from efficiency optimization and sensorless control, EVs primarily require high performance control to enable fast control of the generated motor torque and speed to achieve increased stability and safety. Therefore vector control would be very suitable for such applications. We considered indirect vector control for the EV motors. As it is well known that such control is impossible without the information of the speed he it either from the speed encoder or an estimate of the same processing the voltage and/or current signals, we followed the MRAS based approach to estimate the speed, utilizing the reactive power. To make the efficiency maximum the flux or flux-producing current is adjusted by adding an outer loop through a search technique.

1V. PROPOSED METHOD

The motor is fed from a PWM-controlled l0 kHz IGBT inverter (the left IGBT converter works as a rectifier).The IM is coupled to a DC machine that is used to load the IM. The control part is implemented on a TMS320-C32 DSP board. It can he easily understood that in the indirect vector control environment the speed is estimated by the MRAS technique. The speed estimation algorithm is marked by shadow part and consists of three main blocks: “Reference Model”, “Adjustable Model”, and “Estimation Mechanism”. In addition, two other blocks “Flux Estimator” and **“**Flux tuning” which yield flux signals to the “Adjustable Model” are also included. The adaptation mechanism may be implemented by a PI controller. The physical reason of the integrator (in the PI controller) is that it ensures the error of the reactive power converging asymptotically to zero. That is, the estimated rotor speed converges asymptotically to the correct one.

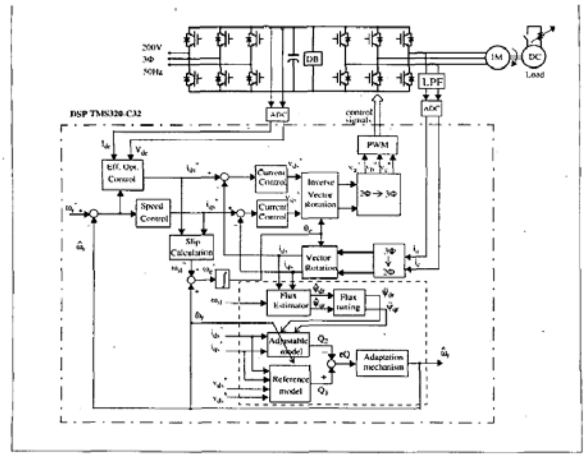

Fig 4.Proposed Method

The PI law of the adaptation mechanism satisfies the Popov integral inequality, our designed system is hyper stable. The efficiency optimization is included by an additional outer. loop to decide the optimum flux-producing-current. In case of sudden change of load or speed the efficiency optimization is bypassed and the rated rotor flux is restored. It is only during steady state the efficiency optimization algorithm is activated.

V. EXPERIMENTAL RESULT

A. Test with different speed commands

When a step speed command of lOOrad/s, 200rad/s and 100rads is set at 0s, 50s. and 10.0s respectively. This experiment is conducted to check the performance of the system at start with a step speed command and also to see the system behavior with a step increase and decrease of the speed. We can see excellent speed build up and very stable performance.

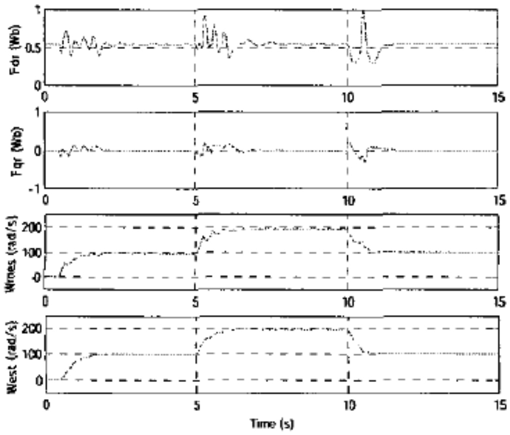

Fig.5. Performance at different speed commands (both increase and decrease)

A step speed command **of** +100rad/s, -1OOrad/s and +100rad/s is applied at 0 5 , 5.0s and 10.0s respectively. A very good agreement between experimentation is obtained.

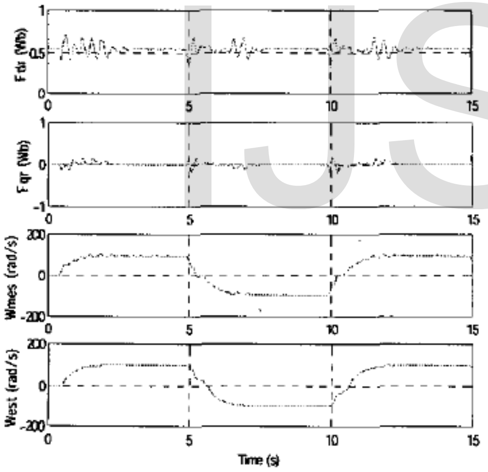

Fig.6. Performance at speed reversal.

C. Speed-Sensorless efficiency control

After the sensorless control scheme is found working satisfactorily the outer loop is activated to decide the optimum flux-producing current. The EOC is based on an approximate modeling of the machine. The optimum d-axis current is calculated and the same is set smoothly following a ramp in 0.5 sec. The quantities displayed in Fig.7 are motor speed, reference d-axis current, actual d-axis current, direct axis flux the quadrature axis flux and the power input to the machine. The drives is operated at a low load and the reduction of input power due to the efficiency optimization is evident. The input power can be seen to reach to the optimum value smoothly. It is important to note that the system maintains decoupling of the two axes fluxes.

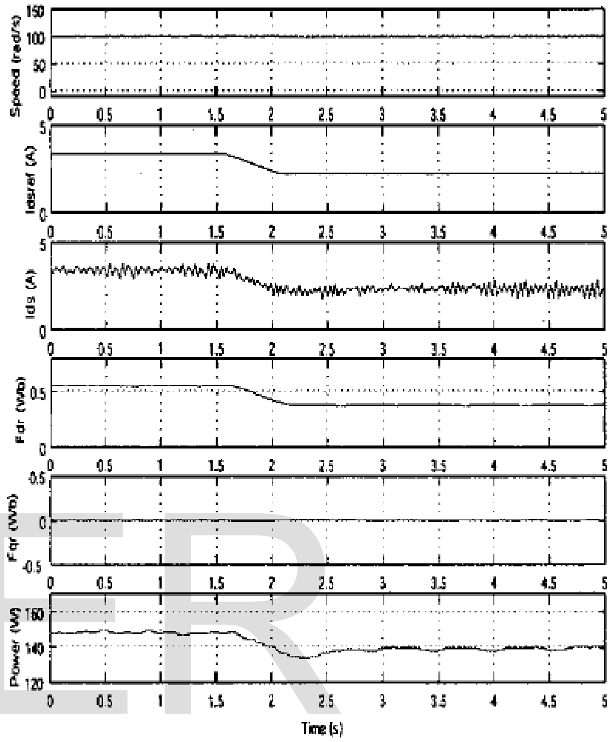

Fig 7.Performance of speed sensorless efficiency control.

VI. CONCLUSION

Electric Motors, those are used with the Electric Vehicles must have high efficiency for maximum utilization of the energy from the batteries and/or fuel cells. This paper presents one such control technique for the Induction Motor to make it suitable for the EV applications. The reactive power is utilized to develop an MRAS based algorithm for the speed estimation. The technique is sufficiently robust against load variation and also the variation of the stator resistance. The efficiency optimization is based on the measurement or estimation of the active power input to the machine while the speed sensorless algorithm is developed utilizing the reactive power. Experimental results are presented.

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