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OVERVIEW OF CONTROL METHODS FOR INDUCTION MOTOR DRIVES

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Abstract: The paper presents an analysis of the operation of asynchronous motor drive systems. The control method used is the vectorial one, being presented indirect and direct vector control, stator flux oriented direct vector control, and direct torque and flux control methods. The analysis of the operation of the electric drive systems is done by simulation with the help of the program package MATLAB-Simulink.

Keywords: vector control, direct torque, flux control, simulation, stator flux oriented control.

1. INTRODUCTION

The development of vector or field-oriented control, and the demonstration that ac motor can be controlled like a separately excited dc motor, brought renaissance in the high performance control of induction motor drives [1]. The advent of microprocessors made the vector control increasingly acceptable from the 1980's. In fact, with vector control, induction motor drive outperforms the dc drive because of higher transient current capability, increased speed range and lower rotor inertia. High performance adaptive and optimal control techniques can be easily applied on vector-controlled drives because of simple dc machine-like transient model [3], [8].

The advent of modern digital signal processors, powerful personal computers, user-friendly simulation and CAD tools, artificial intelligence (AI) techniques, and advancement of control and estimation theories are continuously extending the frontier of high performance AC drives, [9] [10].

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2. VECTOR OR FIELD-ORIENTED CONTROL

Vector control is the foundation of modern high performance drives. It is also known as decoupling, orthogonal, or transvector control [4].

Vector control techniques can be classified as indirect method, and direct method depending on the method of unit vector generation for vector transformation. There is also classification of control based on orientation with rotor flux (Ψr) or stator flux (Ψs) [2].

Fig. 1 shows the indirect vector control block diagram with rotor flux orientation. The synchronously rotating vector components of stator current iqs and ids are controlled independently to control the torque and rotor flux, respectively.

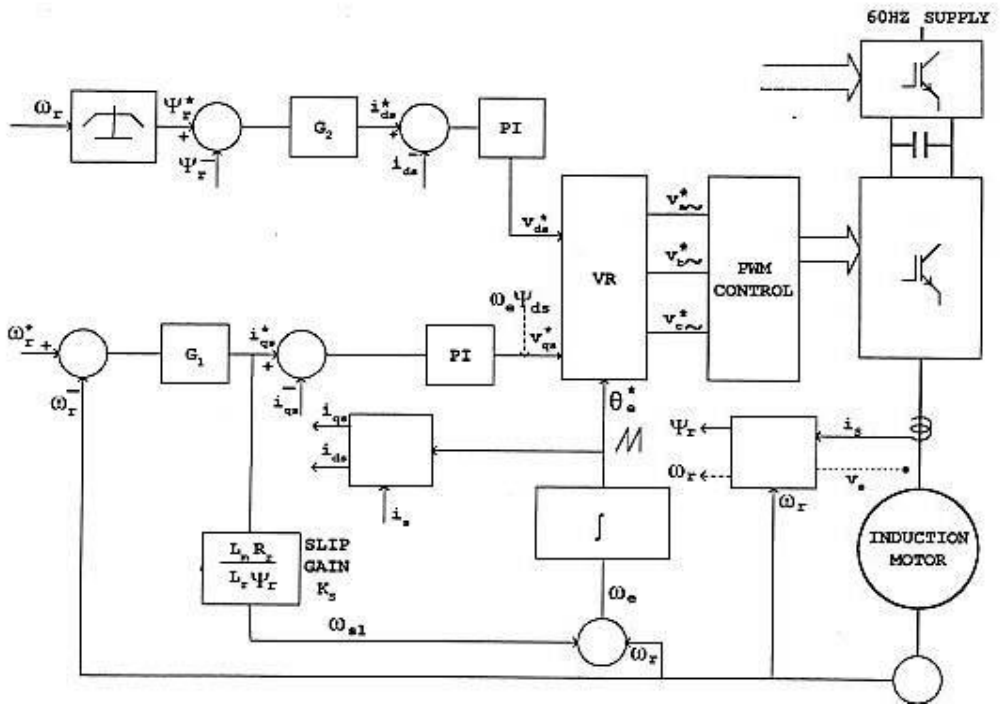

Fig. 1. Indirect vector control

It can be shown that rotor flux orientation (in contrast to stator flux orientation) tends to give true decoupling control. Within the synchronous current control loops, as shown, the respective counter emf (electromotive force) signals can be added (or subtracted) to enhance the current loop response [6], [11]. The unit vector signal θe that transforms the synchronously rotating stator voltages into stationary frame signals has been generated from the speed signal and slip signal which is a function of iqs*, as shown. The slip gain Ks is a function of machine parameters, which should track with the actual machine parameters to get true decoupling. The feedback flux can be estimated from machine terminal voltages and currents (voltage model), or from currents and speed (current model) [7]. The voltage model works well typically above 2% of base speed but the current model works from zero speed. Of course, the current model is more sensitive to machine parameter variation. The flux can also be simply controlled by open loop as a function of ids*. The drive can easily be operated from zero speed to constant power field-weakening region. It is the most popular vector control method in industry. However, the machine parameter variation affects the slip gain and correspondingly, both static and dynamic performances of the drive are affected [5]. The initial tuning of Ks can be done by automated parameter measurement with inverter-injected signals. The on-line tuning for parameter variation is more difficult.

Fig.2 shows the simulation waveforms for this method. The simulation was made by MATLAB-Simulink packages [12], [13].

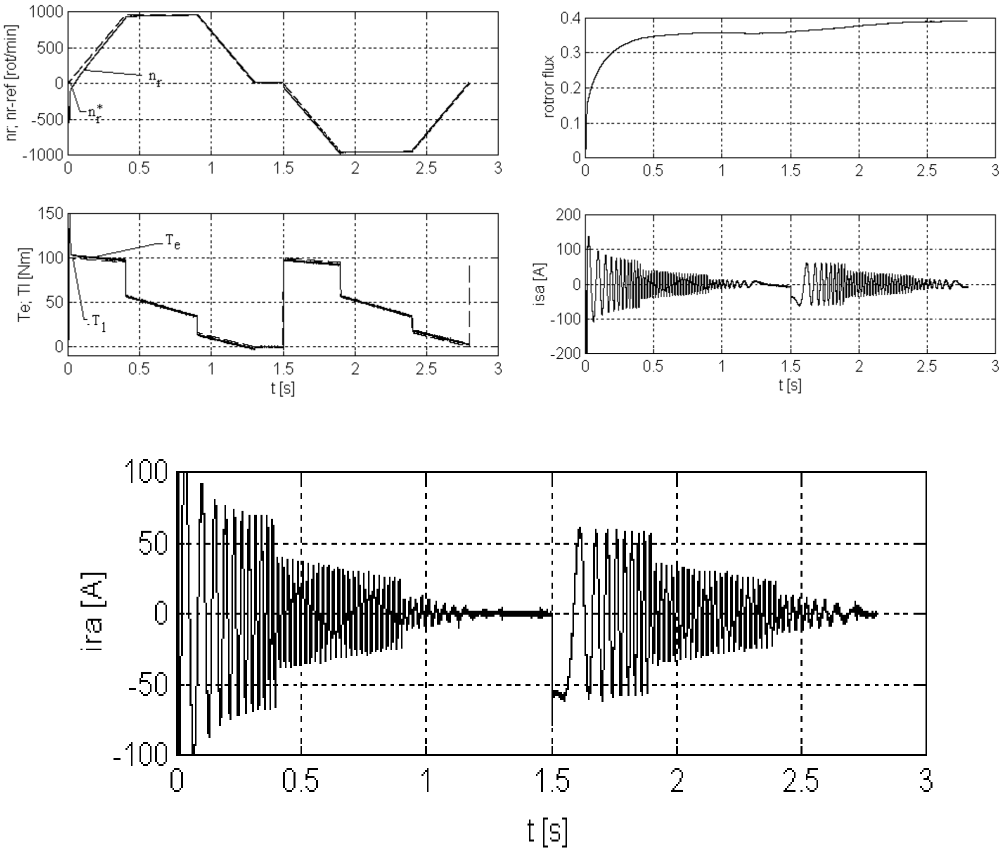

Fig.2. Simulation results for indirect vector control with rotor flux orientation

Fig. 3 shows the direct vector control based on rotor flux orientation.

All the basic elements of the control are essentially the same as indirect vector control except the unit vector signal θe which is derived from the flux vector that can be estimated either by voltage model, current model, or by close loop observer. It is also possible to estimate the speed signal from the voltage and current signals. The flux vector estimation with voltage model does not work near zero speed, but with current model it can be easily extended to zero, as indicated before [2].

Fig. 4 shows the stator flux oriented direct vector control method. It can be shown by analysis that stator flux oriented vector control introduces coupling effect that slows down the transient response, and therefore, decoupling compensation (idq) is required in the flux control loop. In spite of this drawback, the control has the advantage that the flux vector signal derived by integration of the voltage behind the stator resistance is sensitive to stator resistance only, and can be compensated somewhat easily. In fig.5 the authors present the simulation results for stator flux oriented vector control.

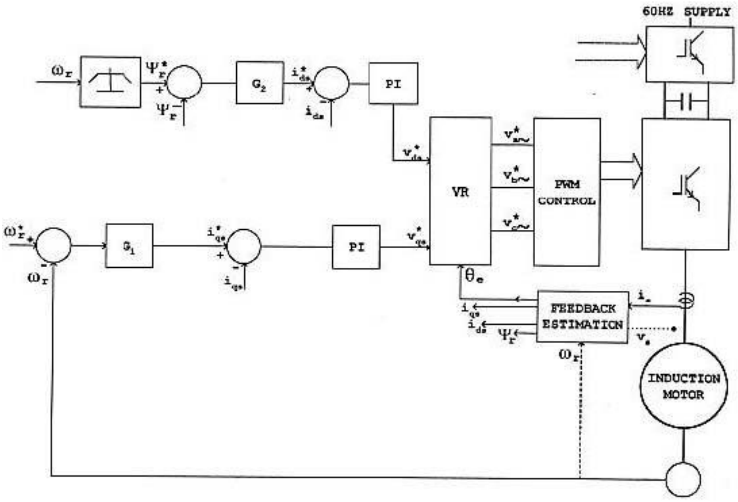

Fig. 3. Direct vector control

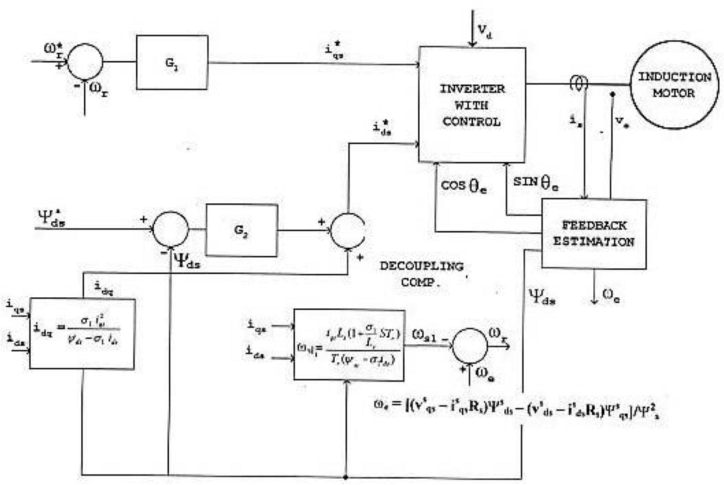

Fig. 4. Stator flux oriented direct vector control

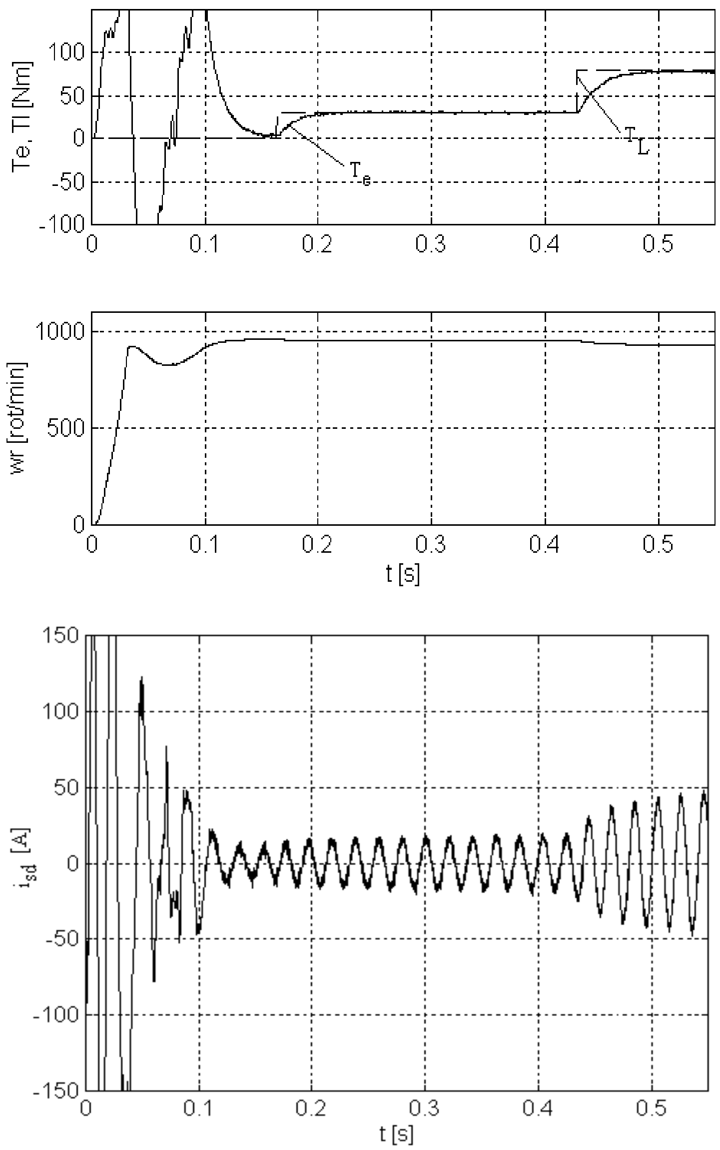

Fig.5. Simulation results for stator flux oriented vector control

3. DIRECT TORQUE AND FLUX CONTROL (DTFC)

The DTFC method, shown in Fig. 6, is basically a performance-enhanced scalar control method and is popularly known as direct torque control (DTC). It can be shown that the developed torque of a machine is proportional to the product of synchronously rotating stator flux (Ψs), rotor flux (Ψr) and the angle (δ) between them. In a PWM inverter-fed machine, Ψr vector is more filtered than Ψs, and therefore, Ψr vector rotates more smoothly. The motion of Ψs, dictated by the impressed voltage vector, is discontinuous, but its average velocity is same with Ψr in steady state. The Ψs magnitude is easily controlled within a hysteresis-band by limit cycle control [1].

Basically, DTC has torque and stator flux control in the outer loops, as indicated. The speed loop can be added on the torque loop with the speed encoder or estimated speed. The machine voltages and currents are sensed to estimate the torque and flux vector that gives information about Ψs location in one of the 60-degree sectors.

The control loop errors Es and ET generate the digital signals Ds and DT through the respective hysteresis-band comparators. A three-dimensional look-up table then selects the most appropriate voltage vector to satisfy the flux and torque demands. Since the feedback signals are being estimated from the machine terminal, the low-speed limitation and parameter variation problem are similar to Ψs-oriented direct vector control.

The drive has fast transient response, and has the simplicity of implementation due to absence of close loop current control, traditional PWM algorithm and vector transformation. However, the inherent limitations of limit cycle control, such as pulsating torque, pulsating flux and additional harmonic loss exist. Recently, a large number of papers are appearing in literature to improve the DTC control.

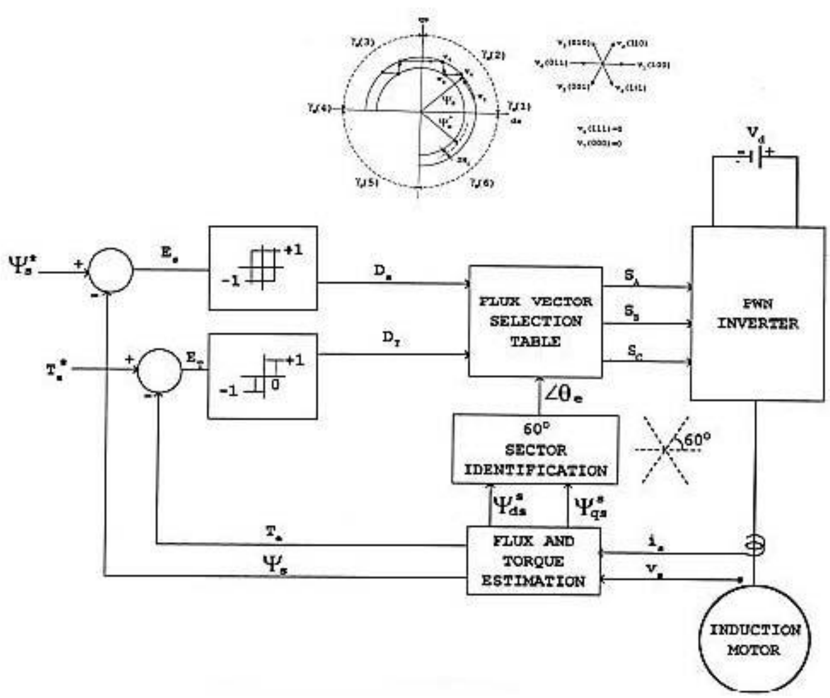

Fig. 6. Direct torque and flux control

Fig.7 shows the simulation waveforms for this method control of induction motor drive.

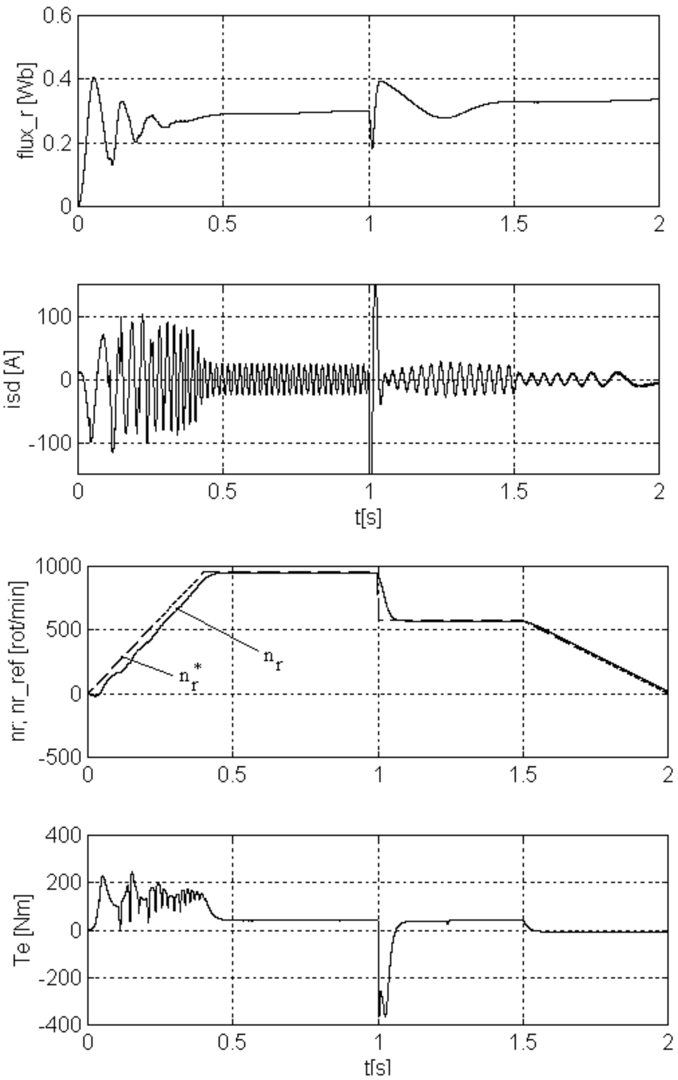

Fig.7. Simulation results for direct torque and flux control

4. CONCLUSIONS

From the analysis of the simulation results we can see that the indirect vector control and the direct torque and flux control methods offer the best transient performance, the response time being the fastest and the oscillations are minimal.

In the case of the stator flux oriented vector control method, the response time increases and the oscillations are more pronounced.

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