NOVEL DIRECT TORQUE CONTROL BASED ON SPACE VECTOR MODULATION WITH ADAPTIVE STATOR FLUX OBSERVER FOR INDUCTION MOTORS

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ABSTRACT

In this paper, we present a new approach to the Direct Torque Control (DTC) problem of three-phase induction motor drives. By observing that the DTC objectives, which require the controlled variables to remain within certain bounds, are related to feasibility rather than optimality, and by using a blocking control inputs regime for the whole prediction horizon we derive a low complexity controller. So that in this paper we describes a combination of direct torque control (DTC) and space vector modulation (SVM) for an adjustable speed sensorless induction motor (IM) drive. The motor drive is supplied by a two-level SVPWM inverter. The inverter reference voltage is obtained based on input-output feedback linearization control, and is compared with the stator D–Q axes reference frame components and this are given to SVPWM inverter. Here we use matlab/simulink for the simulation purpose. The proposed control algorithms are verified by extensive simulation results.

I. INTRODUCTION

Enabled by significant technological developments in the area of power electronics, variable speed induction motor drives have evolved to a state of the art technology within the last decades. The Adjustable Speed Drives (ADS) are generally used in industry. In most drives AC motors are applied. The standard in those drives are Induction Motors (IM) and recently also Permanent Magnet Synchronous Motors (PMSM) are offered. Variable speed drives are widely used in application such as pumps, fans, elevators, electrical vehicles, heating, ventilation and air-conditioning (HVAC), robotics, wind generation systems, ship propulsion, etc. These systems, in which DC-AC inverters are used to drive induction motors as variable frequency three-phase voltage or current sources, are used in a wide spectrum of industrial applications. One of the methods for controlling the induction motor’s torque and speed is Direct Torque Control (DTC) [2], which was first introduced in 1985 by Takahashi and Noguchi and is nowadays an industrial standard for induction motor drives. The basic characteristic of DTC is that the positions of the inverter switches are directly determined rather than indirectly, thus refraining from using a modulation technique like Pulse Width (PWM) or Space Vector (SVM) [1] modulation. In the generic scheme, the control objective is to keep the motor’s torque and the amplitude of the stator flux within pre-specified bounds. The inverter is triggered by hysteresis controllers to switch whenever these bounds are violated. Recently, we have proposed in a systematic procedure for the design of the DTC switching table by reformulating the control problem as an PI controller for a two- and a three-level inverter. We therefore propose an PI scheme based on feasibility with a prediction horizon N and an internal model of the DTC drive for the predictions. We propose to switch only at the current time-step and to disregard switching within the prediction horizon, which is equivalent to a move blocking strategy.

II. DESIGNING OF INDUCTION MOTOR

An induction motor (IM) is a type of asynchronous AC motor where power is supplied to the rotating device by means of electromagnetic induction. Other commonly used name is squirrel cage motor due to the fact that the rotor bars with short circuit rings resemble a squirrel cage (hamster wheel).An electric motor convert's electrical power to mechanical power in its rotor.

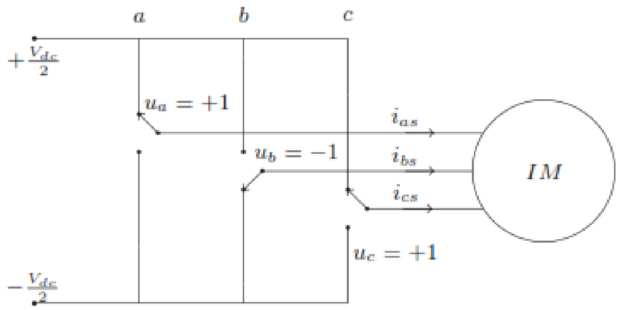

Fig: 1 The Equivalent Representation Of A Three Phase Two-Level Inverter Driving An Induction Motor

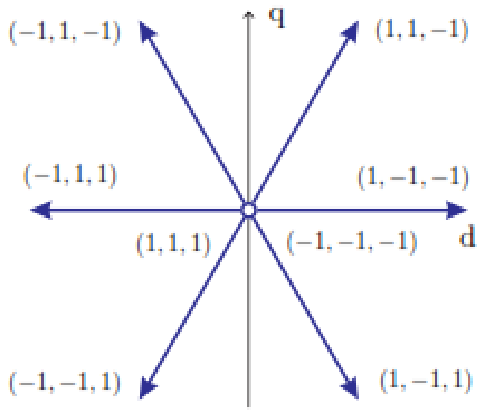

Fig: 2 The Voltage Vectors On The Dq Plane With Switch Positions

The ac induction motor is by far the most widely used motor in the industry. Traditionally, it has been used in constant and variable-speed drive applications that do not cater for fast dynamic processes. Because of the recent development of several new control technologies [5], such as vector and direct torque controls, this situation is changing rapidly. The underlying reason for this is the fact that the cage induction motor is much cheaper and more rugged than its competitor, the dc motor, in such applications. This section starts with induction motor drives that are based on the steady-state equivalent circuit of the motor, followed by vector-controlled drives that are based on its dynamic model as shown in the above figures 1 & 2.

III. MATHEMATICAL MODEL OF INDUCTION MOTOR

When describing a three-phase IM by a system of equations the following simplifying assumptions are made:

- The three-phase motor is symmetrical,
- Only the fundamental harmonic is considered, while the higher harmonics of the spatial field distribution and of the magneto motive force (MMF) in the air gap are disregarded,
- The spatially distributed stator and rotor windings are replaced by a specially formed, so-called concentrated coil,
- The effects of anisotropy, magnetic saturation, iron losses and eddy currents are neglected,
- The coil resistances and reactance are taken to be constant,
- In many cases, especially when considering steady state, the current and voltages are taken to be sinusoidal.

Taking into consideration the above stated assumptions the following equations of the instantaneous stator phase voltage values can be written:

$$Vqss = Rs\ iqss + d\psi qss/dt$$

$$Vdss = Rs\ idss + d\psi dss/dt$$

The development of torque by the interaction of air gap flux and rotor mmf was discussed earlier in this chapter. Hence it will be expressed in more general form, relating the d-q components [6] of variables. From equation

$$Te = (3/2)(p/2)\psi\hat{}mIrsin\delta,$$

the torque can be generally expressed in the vector form as

$$Te = (3/2)(p/2)\ (\psi dIq - \psi qId)$$

IV. DIRECT TORQUE CONTROL (DTC)

Direct Torque Control (DTC) is a method that has emerged to become one possible alternative to the well-known Vector Control of Induction Motors. This method provides a good performance with a simpler structure and control diagram. In DTC it is possible to control directly the stator flux and the torque by selecting the appropriate VSI state. A variety of techniques have been proposed to overcome some of the drawbacks present in DTC [2, 8]. Some solutions proposed are: DTC with Space Vector Modulation (SVM); the use of a duty--ratio controller to introduce a modulation between active vectors chosen from the look-up table and the zero vectors; use of artificial intelligence techniques. A different approach to improve DTC features is to employ different converter topologies from the standard two-level VSI. The major advantage of the three-level VSI topology when applied to DTC is the increase in the number of voltage vectors available. This means the number of possibilities in the vector selection process is greatly increased and may lead to a more accurate control system, which may result in a reduction in the torque and flux ripples.

In principle the DTC method selects one of the six nonzero and two zero voltage vectors of the inverter on the basis of the instantaneous errors in torque and stator flux magnitude.The block diagram of classical DTC proposed by I. Takahashi and T. Nogouchi is presented in Fig.

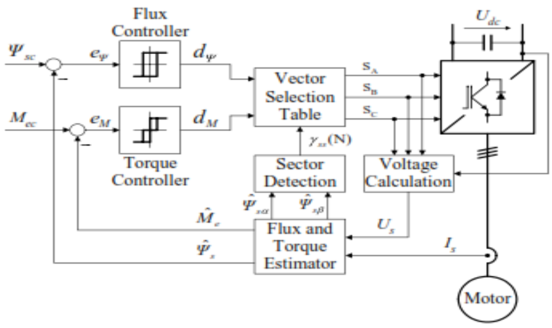

Fig:3 DTC control scheme

V. SPACE VECTOR PWM

The Space Vector PWM generation module accepts modulation index commands and generates the appropriate gate drive waveforms for each PWM cycle. This section describes the operation and configuration of the SVPWM module [7].

A three-phase 2-level inverter with dc link configuration can have eight possible switching states, which generates output voltage of the inverter. Each inverter switching state generates a voltage Space Vector (V1 to V6 active vectors, V7 and V8 zero voltage vectors) in the Space Vector plane (Figure: space vector diagram). The magnitude of each active vector (V1to V6) is 2/3 Vdc (dc bus voltage).

The Space Vector PWM (SVPWM) module inputs modulation index commands (U_Alpha and U_Beta) which are orthogonal signals (Alpha and Beta) as shown in Figure. The gain characteristic of the SVPWM module is given in Figure . The vertical axis of Figure represents the normalized peak motor phase voltage (V/Vdc) and the horizontal axis represents the normalized modulation index (M).

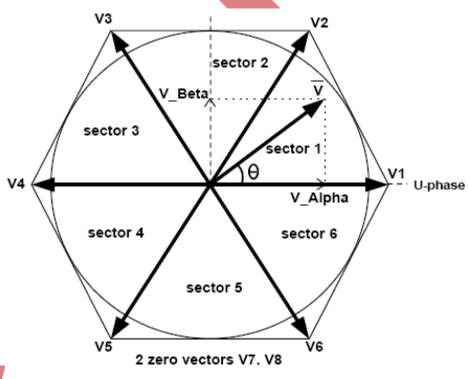

Fig:4 Space Vector Diagram

The inverter fundamental line-to-line Rms output voltage (Vline) can be approximated (linear range) by the following equation:

$$Vline = Umag * Mod\_Scl * Vdc / \sqrt{6} / 2^{25}$$

VI. CONTROLLER DESIGN

6.1 Pi Controller

PI control [3] With a view to have a self-regulated speed, the speed of induction is sensed and controlled by employing a suitable closed loop control. The speed of IM is sensed at a regular interval and is compared with its reference counterpart N*. The error signal is processed in a PI controller.

VII. SIMULATION

To verify the DTC-SVM scheme based on input-output linearization and adaptive observer, simulations are performed in this section. The block diagram of the proposed system is shown in Fig 3.

Case 1: The simulation results for the conventional DTC scheme.

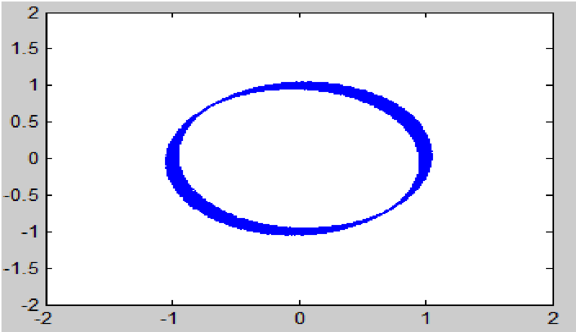

Fig: 6 Stator flux Trajectory Curve

Fig 6 Shows The Relation Between Stator Direct And Quadrature Axis Flux Linkages.

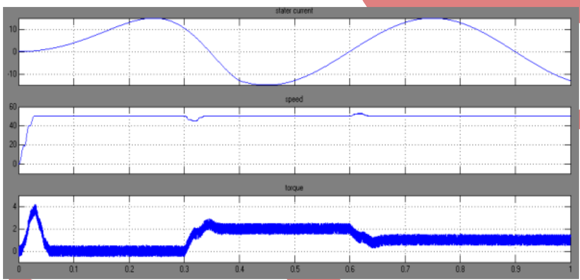

Fig: 7 Current, Speed And Torque Response for DTC Scheme.

Fig 7 Contains The Graphs For Stator Current, Rotor Speed And Torque Response For IM. In This The Torque Contains Ripples.

Case 2: The simulation results for the conventional DTC based SVM scheme.

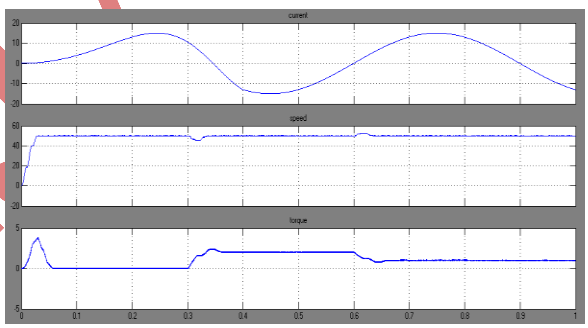

Fig: 8 Current, Speed And Torque Response For DTC - SVM Scheme

Fig 8 contains the graphs for stator current, rotor speed and torque response for IM. In this the torque ripples can be reduced by SVM modulation technique.

VIII. CONCLUSION

In this paper a novel DTC-SVM scheme has been developed for the IM drive system, which is on the basis of input-output linearization control. In this control method, a SVPWM inverter is used to feed the motor, the stator voltage vector is obtained to fully compensate the stator flux and torque errors. The stator flux and speed are estimated synchronously. By designing the constant observer gain matrix based on state feedback control theory, the robustness and stability of the observer systems is ensured. Therefore by this proposed converter, the drive system is steadily working, in very low speed, has much smaller torque ripple and exhibits good dynamic and steady-state performance.

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