Comparison of the Field Oriented and Direct Torque Control Methods for Induction Motors used in Electric Vehicles

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I. INTRODUCTION

In the last decade, the increasing restrictions imposed on the exhaust emissions from internal combustion engines and the traffic limitations in the urban areas have given a strong impulse toward the development of electrical propulsion systems for automotive applications. The goal of electrical and hybrid vehicles is the reduction of global emissions, which in turn leads to a decrease of fuel resources exploitation.

The major components of an electric vehicle system are motor, controller, power source, charger and drivetrain. The majority of electric vehicles (EV) developed so far are based on dc machines, induction machines or permanent magnet machines. The disadvantages of dc machines forced the EV developers to look into various types of ac machines. The power density of permanent magnet machines together with the high cost of permanent magnets makes these machines less attractive for EV applications. The maintenance-free and low-cost induction machines became an attractive alternative to many developers. However, high-speed operation of induction machines is only possible with a penalty in size and weight. Three-phase squirrel cage-rotor induction motors are best suited to electric vehicle drive applications. Induction motors are cost-effective, and are suitable in terms of size and weight, speed of rotation, efficiency, controllability and reliability. The durable rotor and high-speed operation under easily implemented field-weakening control enable the use of large reduction gear ratios that limit maximum torque requirements, allowing the incorporation of smaller motors driven by compact low-current inverters.

In this paper, two different control schemes are proposed and investigated to determine their suitability for electric vehicle application. A brief overview of the operation of each scheme is presented followed by results from Matlab-Simulink simulations. A comparison of the advantages and disadvantages of the two schemes is included.

II. CONTROL METHODS

Field Oriented Control (FOC) and Direct Torque Control (DTC) were chosen for simulation as they are standard induction motor control techniques [1-2]. The DTC technique is intrinsically sensorless. Therefore it is more suitable for the comparison to consider a direct field oriented control (DFOC) scheme, instead of a general FOC scheme.

Starting from this basis, the DTC scheme [3-5] is characterized (in comparison with the DFOC) by the absence of:
1) PI regulators;
2) coordinate transformations;
3) current regulators;
4) PWM signals generators (no timers).

So, only the control schemes, which meet all these requirements, should be considered as real DTC schemes. According to these considerations, the analysis is carried out with reference to a basic DTC scheme characterized by the above mentioned features. A block diagram of a basic DFOC scheme is presented in Fig. 1.

FOC [6] refers to induction motor operation in a synchronously rotating dq reference frame that is aligned with one of the motor fluxes, typically the rotor flux. In this mode of operation, control of the torque and flux is decoupled such that the d-axis component of the stator current controls the rotor flux magnitude and the q-axis component controls the output torque. A proportional-integral controller regulates the stator voltage to achieve the calculated stator current. The required voltage is then synthesised by the inverter using space vector modulation (SVM). During motor operation the actual rotor resistance
and inductance can vary, for example with temperature. The resulting errors between the values used and the actual parameters cause an incomplete decoupling between torque and flux.

In principle, the DTC method selects one of the inverter’s six voltage vectors and two zero vectors in order to keep the stator flux and torque within a hysteresis band around the demand flux and torque magnitudes. The torque produced by the induction motor can be expressed as:

$$T = \frac{3}{2} \left( \frac{P}{2} \right) L L L \left| \psi \right| \sin \psi$$

which shows the torque produced is dependent on the stator flux magnitude, rotor flux magnitude, and the phase angle between the stator and rotor flux vectors. The induction motor stator equation can be approximated as (2) over a short time period if the stator resistance is ignored.

$$\dot{\psi} = \frac{d\psi}{dt}$$

This means that the change in the stator flux vector is determined by the applied voltage vector. If a voltage vector is applied that changes the stator flux to increase the phase angle between the stator flux and rotor flux vectors, then the torque produced will increase.

Since a two-level inverter is only capable of producing six non-zero voltage vectors and two zero vectors, it is possible to create a table that determines the voltage vector to apply based on the position of the stator flux and the required changes in stator flux magnitude and torque. This is called the optimal vector selection table. It is possible to expand the optimal vector selection table to include the larger number of voltage vectors produced by a three-level inverter.

The estimated stator flux magnitude and torque output is compared to the demand values. A voltage vector is then selected that will drive the torque and flux towards the demanded values (see Fig.2).

Both control schemes described above have been simulated [7-8] using Matlab-Simulink. The first results show that the behaviour of DFOC scheme is characterized by lower values of the three-phase rms current ripple with respect to the DTC scheme (see Fig. 3). A disadvantage of DTC is its comparatively high current distortion and torque ripple.

Figure 2. Basic DTC scheme.

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References

[8] Siemens AG, “Highly dynamic and speed sensorless control of traction drives”.

Figure 3. Phase current (a) DFOC and (b) DTC.