PERFORMANCE IMPROVEMENT OF INDUCTION MOTOR CURRENT CONTROLLERS IN FIELD-WEAKENING REGION AND TORQUE IMPROVEMENT FOR ELECTRIC VEHICLES

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ABSTRACT- Because of variable parameters like high ratios of fundamental to sampling frequencies, interval delay caused by PWM etc. the effect of current control technologies are degraded, especially when motors work in field weakening region. Highly oscillatory or unstable response may occur if current regulators do not obtain proper current commands. Thus an expert current regulator, using fuzzy interference, is proposed to avoid unreasonable tuning. Use of fuzzy interference avoids robustness of current control. Again, it would be obvious to have a torque control in addition for an electric vehicle. Hence Direct Torque Control based on limit cycle is adopted. This gives us both quick torque response and efficiency operation.

I INTRODUCTION

Cage induction motors (IM) are widely accepted as the most promising candidate for the electric propulsion of hybrid electric vehicles (HEVs) and electric vehicles (EVs), due to their reliability, ruggedness, low maintenance, low cost, and ability to operate in the extended high speed. Fig. 1 shows the typical block diagram of IM drives based on indirect field oriented control (IFOC). Extended speed range operation beyond the base speed is accomplished by the flux weakening strategy. At present, most of the research on the current control in the flux weakening region is below 2 to 3 times of the base speed. Moreover, most of the existing research focuses on flux- weakening strategy optimization or current regulators design.

Hybrid electric vehicles (HEVs) are powered by an internal combustion engine or other propulsion source that can be run on conventional or alternative fuel and an electric motor that uses energy stored in a battery. HEVs combine the benefits of high fuel economy and low emissions with the power and range of conventional vehicles. There are a variety of HEV types, and the degree to which they function as EVs varies as well. The most common form of HEV is the hybrid electric car, although hybrid electric trucks (pickups and tractors) and buses also exist.

The control strategies now exist includes flux weakening system and an expert controller utilizing fuzzy inference mechanism are proposed to improve robustness of current control in the flux weakening region. Because of variable parameters, high ratios of fundamental to sampling frequencies and interval delay caused by pulse width modulation (PWM) and digital discrete, the effects of the current control technologies are degraded in the existing indirect field oriented control system. It is especially obvious when motors work in the weakening region. Highly oscillatory or unstable response may occur if current regulators do not obtain proper current commands. Thus, an expert controller changing current command before current regulators is proposed to avoid unreasonable tuning.

The superior control strategy is proposed in the modification with a DTC scheme to improve the torque control and thereby achieving a much improved speed response.

II SPEED CONTROL BY CHANGING APPLIED VOLTAGE

From the torque equation of the induction machine, we can see that the torque depends on the square of the applied voltage. The variation of speed torque curves with respect to the applied voltage is shown in Figure. 1.1. These curves show that the slip at maximum torque $\hat{s}$ remains same, while the value of stall torque comes down with decrease in applied voltage. The speed range for stable operation remains the same.

Further, we also note that the starting torque is also lower at lower voltages. Thus, even if a given voltage level is sufficient for achieving the running torque, the machine may not start. This method of trying to control the speed is best suited for loads that require very little starting torque, but their torque requirement may increase with speed.

Figure1.1 also shows a load torque characteristic — one that is typical of a fan type of load. In a fan (blower) type of load, the variation of torque with speed is such that $T \propto \omega^2$. Here one can see that it may be possible to run the motor to lower speeds within the range ns to $(1 - \hat{s})$ns. Further, since the load torque at zero speed is zero, the machine can start even at reduced voltages. This will not be possible with constant torque type of loads. One may note that if the applied voltage is reduced, the voltage across the magnetizing branch also comes down. This in turn means that the magnetizing current and hence flux level are reduced. Reduction in the flux level in the machine impairs torque production (recall explanations on torque production), which is primarily the explanation for Figure.1.

If, however, the machine is running under lightly loaded conditions, then operating under rated flux levels is not required. Under such conditions, reduction in magnetizing current improves the power factor of operation. Some amount of energy saving may also be achieved.

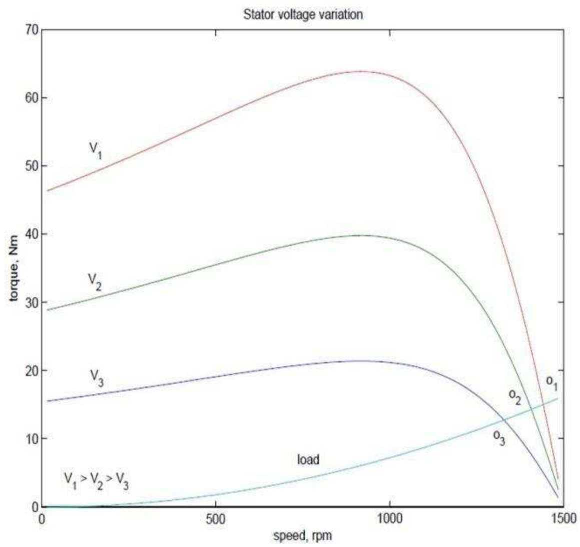


Figure1: Torque – Speed characteristics with reference to stator voltage

Voltage control may be achieved by adding series resistors (a lossy, inefficient proposition), or a series inductor / autotransformer (a bulky solution) or a more modern solution using semiconductor devices. A typical solid state circuit used for this purpose is the AC voltage controller or AC chopper. Another use of voltage control is in the so-called ‘soft-start’ of the machine.

III. PRINCIPLE ANALYSIS OF FLUX WEAKENING

Three phase full bridge circuit and its conduction principles used for the SDFDS motor drive is shown in Figure. 3.1, where the piecewise linear inductance model is utilized so as to make it easy to analyze the SDFDS motor drive. The voltage equation of the SDFDS motor is shown as follows:

Up = ipRp + ebp = ipRp + efp + er

Where, ebp = efp+ erp is the total back electromagnetic force. Up, ip, and Rp are phase voltage, phase current and winding resistance, respectively.

Lp, Lpf, and if are phase self-inductance of armature winding, mutual-inductance between armature winding and field winding, and field current, respectively. And ω and θ are rotor angular velocity and rotor position angle, respectively.

IV BLOCK DIAGRAM OF INDIRECT FIELD ORIENTED CONTROL WITH FLUX WEAKENING STRATEGY

The cage induction motors are widely accepted as the most promising candidate for the electric propulsion of hybrid electric vehicles and electric vehicles, due to their reliability, ruggedness, low maintenance, low cost, and ability to operate in the extended high speed.

Figure. 2 shows the typical block diagram of IM drives based on indirect field oriented control. Extended speed range operation beyond the base speed is accomplished by the flux weakening strategy. At present, most of the research on the current control in the flux weakening region is below 2 to 3 times of the base speed. Moreover, most of the existing research focuses on flux weakening strategy optimization or current regulators design.

In the following block diagram, the current ia, ib and ic are fed back and performed the clark’s transformations obtaining iαs and iβs. These two components along with θc are fed for park’s transformation, obtaining ids and iqs. These two components are fed to current PI regulator along with idsref and iqsref from flux PI regulator and speed PI regulator.

The current PI regulator outputs vds and vqs which are sent for inverse parks transfer, obtaining vαs and vβs which are given to space vector pulse width modulator, which in turn provides required triggering pulses for the 3 phase inverter for driving the motor.

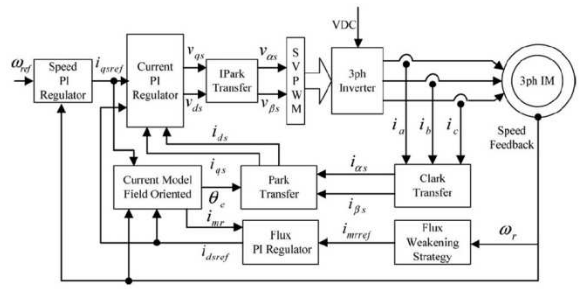


Figure 2: Scheme of IFOC including flux weakening strategy.

The current PI regulator outputs vds and vqs which are sent for inverse parks transfer, obtaining vαs and vβs which are given to space vector pulse width modulator, which in turn provides required triggering pulses for the 3 phase inverter for driving the motor.
A flux weakening strategy is used produce a reference current imrref from feedback speed Wr. This output and current imr from field oriented current control are fed to a flux PI regulator, which in turn produces current idsref.
The speed PI regulator on receiving feedback speed and reference speed produces a reference current iqsref. The iqsref, idsref and feedback speed Wr are used by field oriented current model circuit to produce imr and θc.
In the flux weakening region, the current distribution (ids and iqs) is absolutely important to the torque capability. There are two major flux weakening optimal strategies to achieve maximum torque capability. First, ids and iqs are calculated by IM parameters. Second, ids and iqs are selected by utilizing voltage regulators and flux regulator. These flux weakening strategies can achieve the optimization of maximum torque capability in theory. However, the first optimal algorithm relies on a good knowledge of several motor parameters and the actual dc busbar voltage. In view of temperature variable, magnetic hysteresis and some other reasons, parameters are variable. Therefore, it is difficult to achieve the desired optimal performance. The second optimal algorithm is robust to motor parameters. Although its realization is more complex because two or more regulators are needed, and fast response is affected, it is still the most attractive flux weakening optimal strategy till now.
In the IFOC system, the fundamental excitation signals are transformed into dc signals with a reference frame rotating synchronously with the fundamental excitation. Consequently, the current regulators forming the inner loop of the IFOC system are able to regulate ac current over a wide frequency range with high bandwidth and zero steady-state error by proportional-integral(PI) regulators.
However, there is cross coupling between ids and iqs that is proportional to the frequency of the fundamental excitation. As a result, the performance of the current regulator has been shown to degrade as the excitation frequency increase. To eliminate the cross-coupling influence, the complex vector synchronous frame—the PI current regulator was introduced in. A similar solution was proposed using an internal model control formulation and using the complex vector current control approach generalized with a transfer function matrix.
Although the complex vector synchronous frame—PI current regulator has concerned the cross coupling between ids and iqs, the bandwidth is degraded due to the variable motor parameters with the working situation such as temperature and magnetic hysteresis in the flux weakening region. Moreover, the digital implementation of continuous-time-derived current regulators can reduce bandwidth because of the interval delay when the drive needs to work at very high fundamental excitation frequencies relative to the sampling frequency. In addition, the use of PWM to drive the inverter forces additional interval delay between the sampling of signals and the application of the control response. Margin and phase errors exist between practical voltage vector and command voltage vector. The influence of PWM increases with the increase of the ratio of fundamental to sampling frequencies fb /fs . At the high fb/fs oscillatory response, even instability can occur if the current regulator design does not consider the effects of the discrete nature of the controller.
In recent years, discrete current regulators have been the subjects of significant research. But these schemes could not eliminate the influence of the interval delay caused by digital implementation and PWM. Thus, the performance of current regulators is degraded more or less in the deep flux weakening region.
In the high-speed flux weakening region, such as 5–6 times of base speed, current IFOC control system cannot reach the design performance because of variable parameter, interval delay, and critical voltage limitation, although there have been so many aforementioned approaches. What is worse is that current regulators are too unstable, and they even result in damage to insulation gate bipolar transistors (IGBTs) and drive equipment in some cases. Here the focuses are on how to improve stability of current control in high speed flux weakening.

V. PROPOSED SYSTEM

Considering the application being electric vehicle, the field weakening problem elimination is good for its smooth performance. But, a direct or instantaneous torque response is also essential for an induction machine, considering the application being electric vehicle.
The Direct Torque Control technique would do the job in a cost effective and efficient manner.

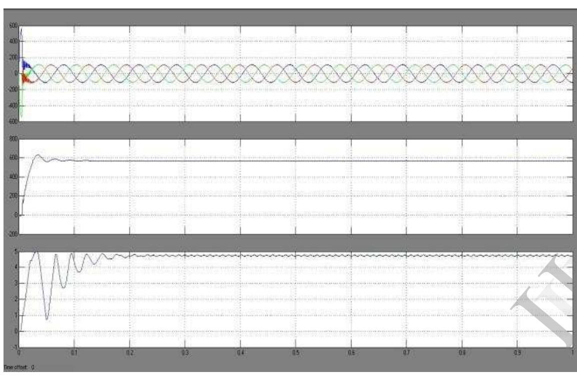
A. DIRECT TORQUE CONTROL

Direct torque control (DTC) is one method used in variable frequency drives to control the torque (and thus finally the speed) of three-phase AC electric motors. This involves calculating an estimate of the motor's magnetic flux and torque based on the measured voltage and current of the motor.

B. DTC control platform

Stator flux linkage is estimated by integrating the stator voltages. Torque is estimated as a cross product of estimated stator flux linkage vector and measured motor current vector. The estimated flux magnitude and torque are then compared with their reference values. If either the estimated flux or torque deviates from the reference more than allowed tolerance, the transistors of the variable frequency drive are turned off and on in such a way that the flux and torque errors will return in their tolerant bands as fast as possible. Thus direct torque control is one form of the hysteresis or bang-bang control.

VI. SIMULATION OUTPUT OF PROPOSED SYSTEM



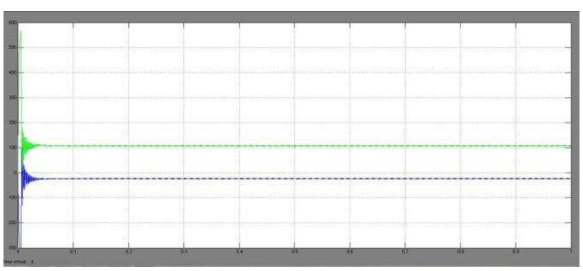


Figure 3: Simulation output of proposed system

VII. INFERENCE

•SMOOTH AND STEADY MOTOR TORQUE.

•21.28% IMPROVEMENT IN SPEED IS OBTAINED WITH THE DTC SCHEME (570 RPM).

•IMPROVED LOAD CAPABILITY AND SMOOTH ACCELERATION FOR THE VEHICLE DRIVE SYSTEM.

•IMPROVED EFFCIENCY AND TORQUE CHARACTERISTICS.

V. CONCLUSION

In this project, a simplified field weakening strategy along with a direct torque control is introduced. The field weakening strategy alone cannot optimize the torque capability, but the strategy can alone improve current control performance significantly even in too high flux level.
This project investigates the chances of introducing a control along with the field weakening strategy so as to optimize the torque capability too. The Direct Torque Control came feasible with its cost effective and efficient operation satisfying the requirement.
With the introduction of DTC scheme by simulation showed positive results, showing a 21.28% improved speed, that is from 470rpm to 570rpm and a smooth and steady torque
Hence, the project came to success satisfying its goal.

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