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INDIRECT CONTROL OF INDUCTION MOTOR IN FIELD – WEAKENING REGION FOR ELECTRIC VEHICLES

C. Asenshiya[1] (Asst. Prof), T. S. Joshuva[2] (B.E, M.E)
Department of Electrical and Electronics Engineering
Thangavelu Engineering College, Chennai, Tamil Nadu, India.

Abstract: In this project, a flux weakening strategy and an expert controller utilizing fuzzy inference mechanism has been used to improve robustness of current control in the flux weakening region. The existing Indirect Field Oriented Control system has been inefficient because of the variable parameters, high ratios of fundamental to sampling frequencies and interval delay caused by pulse width modulation (PWM) and digital discrete. When the current regulators do not receive proper commands there is a chance for highly oscillatory or unstable response. This will happen especially when the motor operates in the weakening region. To overcome this situation an expert controller has been proposed to change the current commands before current regulators to avoid unreasonable tuning. The expert controller could be triggered in parallel based on the simple and formal inference rules. Even in the case of invalid performance target, the sub optional parameter could be substituted. As a part of current control the flux weakening strategy proposed for engineering applications. Simulation results are provided to verify the stability of current control.

I. INTRODUCTION

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. Fig 1 shows the typical block diagram of Induction Motor 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 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. 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 bus bar 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 n.

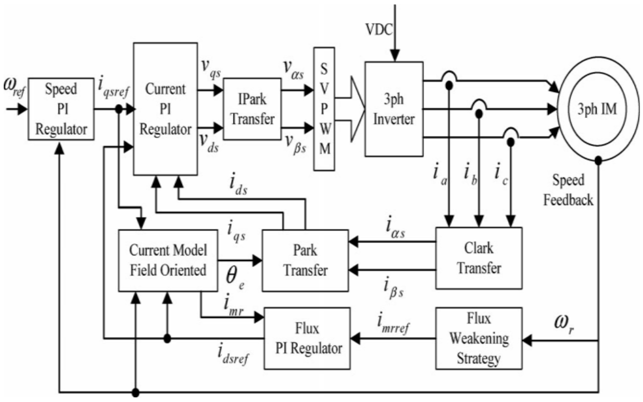

Fig. 1: IFOC

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 in using an internal model control formulation and in 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 applications 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 the fundamental to sampling frequencies fb/fs. At the high fb/f 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. This paper focuses on how to improve stability of current control in high speed flux weakening. The main contribution of this paper is the proposal of an expert controller before current regulators to process current command avoiding unreasonable fast tuning in high – speed flux weakening region so as to keep current command followed by actual current. However, a common expert controller may lead to tuning failure because of invalid performance target.. Thus,. A fuzzy inference expert controller is introduced. In tuning failure condition, a suboptimal current command can be fetched by fuzzy inference. In addition, a robust flux weakening optimal strategy easy to use in engineering application is included in this paper. Simulation results are to demonstrate the effectiveness of the proposed approaches.

II. FLUX WEAKENING STRATEGY

The basic flux weakening strategy is that magnetizing current ids is inversely proportional to speed. It is easy to implement in engineering application. And the flux level can be set artificially according to the working situation, so it is still the usual flux weakening scheme. However, this flux weakening strategy cannot optimize torque capability. When the selected flux level is so high that counter electromotive force (CEMF) occupies too much voltage, the efficiency will decrease and the motor will not develop enough torque to raise speed. The values of ids and iqs can be selected n voltage regulators. This flux weakening strategy can achieve maximum torque capability. The approach is robust to motor parameters.

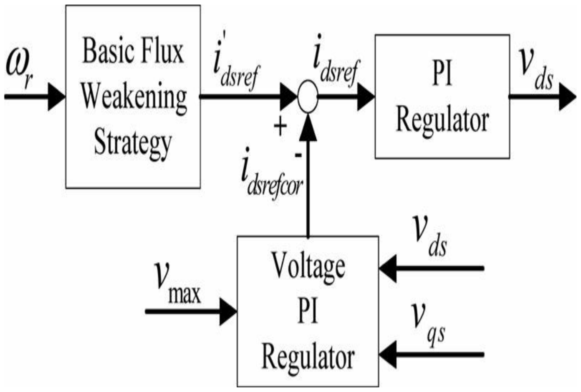

Fig. 2: Flux weakening strategy

However, it needs two more regulators. In engineering application, so many regulators increase complexity of the control system implementation. Fig 2 shows an advanced flux weakening strategy in which the magnetizing current is inversely proportional to the speed. Meanwhile the magnetizing current is corrected by one voltage regulator. Vmax is the limitation of current PI regulator. The approach just needs to add one regulator. What is more, it decreases CEMF when flux level is too high and improves iqs response to keep current regulators robust. However, this approach does not optimize maximum torque capability because it cannot modify iqs according to the voltage limitation. In most engineering application conditions, small integral parameters is enough for the added voltage regulator, Under the demand for both large torque at low speed and rapid response of iqs, the proportion and integral parameters are both needed. However, if the parameters, especially the integral parameter, are too large, the d – axis current could be unstable. Therefore, the parameters of PI regulators are selected base on the following tow rules:

- A small integral parameter is set first,
- If the response of iqs is not rapid enough, a small proportion parameters could be adopted.

III. FUZZY INFERENCE EXPERT CONTROLLER

A. Introduction

The stability of a current control depends on the bandwidth of current regulators and the voltage that can be utilized. As mentioned earlier, the bandwidth of current regulators is decreased and voltage is critically limited in high – speed flux weakening region. To improve current control stability in high – speed flux weakening region, a fuzzy inference expert controller is proposed to handle current commands before current regulators.

It is based on the consideration of the bandwidth decreasing and the critical voltage limitation. The controller has two purposes. First, it can avoid unreasonable fast tuning of current concerning the bandwidth of regulators. Second, it can limit the current margin concerning the valid voltage.

B. Structure

Fig 3 shows the current control structure including the proposed expert controller. Compared with the traditional current control in IFOC, an expert controller is added to preprocess current commands before the current regulators. The expert controller based on the fuzzy inference consists of the knowledge database, the fuzzy inference mechanism and the characteristics recognition.

The feature recognition records the waveform features of ids fed, iqs fed, vds and vqs. When a period of the tuning ends, it calculates the properties of the current control, such as the rise time, the ratio of attenuation and the oscillation period. The characteristics recognition provides references for the fuzzy inference.

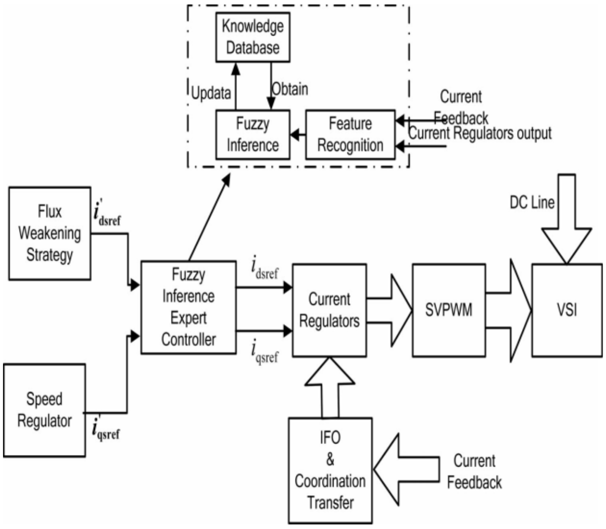

Fig 3: Block diagram

C. Character Recognition

The characteristic recognition is the foundation of the inference in the expert controller. Characteristic recognitions of certain subjects, such as rise time, ration of attenuation, oscillation period, etc., can be calculated with digital filter, statistics, zero point detection, and other algorithms.

D. Knowledge Database

The knowledge database is implemented to store the specialized knowledge of the expert controller including facts, feasible operation rules and so on. It describes the characteristics of the controller and plants. IF – THEN statements were used to explain the knowledge database of the proposed fuzzy inference expert controller.

E. Fuzzy Inference Mechanism

The inference machine provides the mechanism of triggering rules and implementation. The traditional inference method is that iqs ref, iqs ref if feature 1 > threshold 1 and feature 2 < 2. Iqs ref is a tuning value of q axis current command during the last period. Rigid rules are implemented in the traditional inference mechanism. As a result, the tuning may fail when an improper performance target and/or unreasonable triggering sequence is set. Moreover, the tuning oscillation easily appears when iqs is a constant. Concerning these situations, a fuzzy inference machine is proposed based on the rule triggering to make the expert controller work in parallel triggering.

IV. SIMULATION

A saber simulation environment has been designed for the three phase induction motor drive. The simulations have been done to prove the effectiveness of the proposed control scheme. Moreover, a high speed experiment setup and full digital drives have been designed for obtaining experimental results Fig 4.

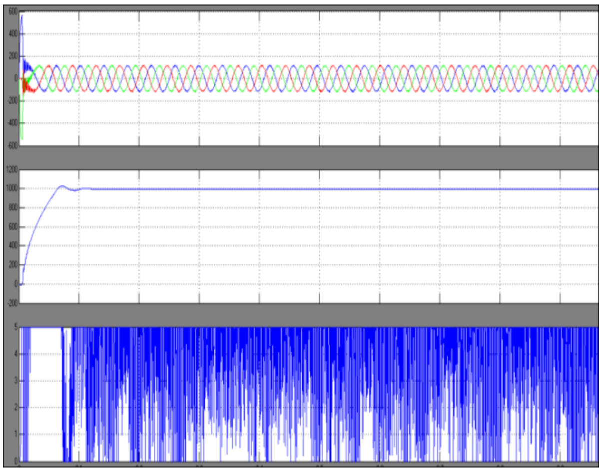

Fig. 4: Simulation results

Fig 5 shows the design of the overall circuit which consist of induction motor circuit, fuzzy inference controller circuit and PWM circuit model.

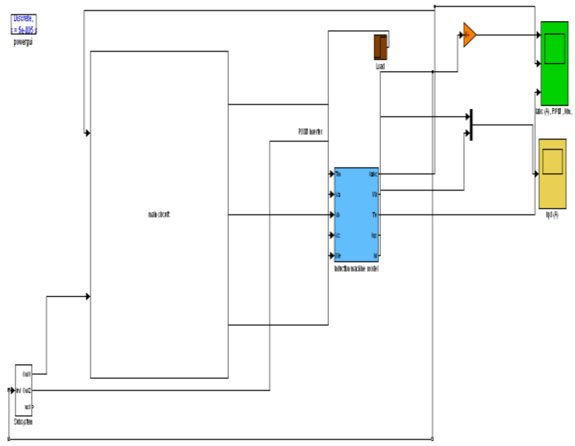

Fig. 5: Circuit design

Fig 6 shows the main circuit design which consists of the space vector pulse width modulation and voltage source inverter which is used to drive the induction motor by receiving pulses from the expert controller ie., fuzzy inference mechanism.

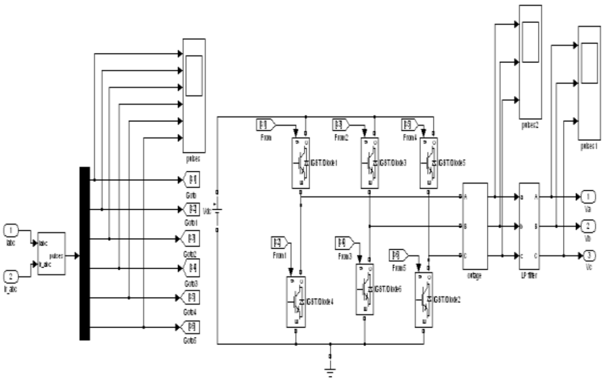

Fig. 6: Main circuit model

Fig 7 depicts control system; this control system is of fuzzy inference system, flux weakening strategy in which the entire current control is carried out.

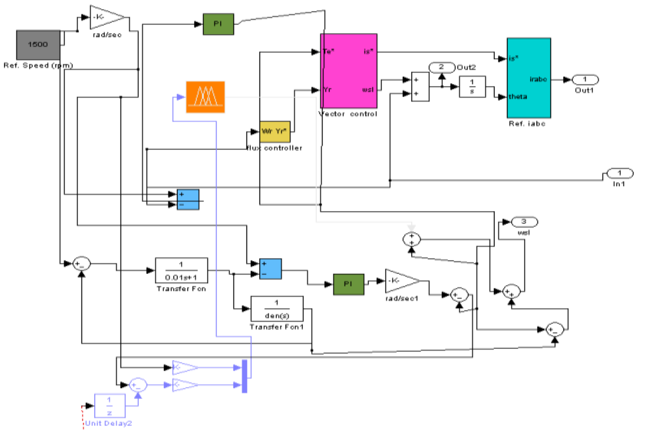

Fig. 7: Controller circuit

Fig 8 shows induction motor circuit in which the park transform and inverse park transform has been used for the running of induction motor and for getting feedback from the induction motor.

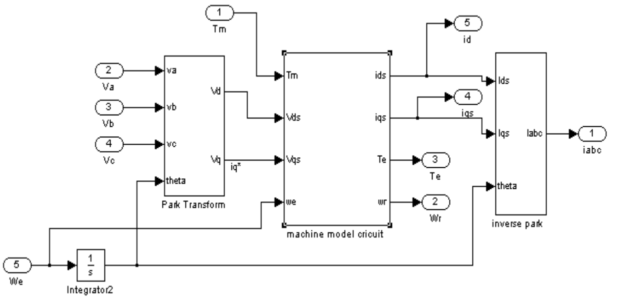

Fig. 8: Induction Motor model

The dc generator used in the setup provides load torque over base speed. Its maximum speed is 2000 r/min. The load instrument provides load torque under base speed. The dc generator and load instrument can be separated for different experiments. The experimental induction motor is a two pole pairs, 1.5 KW single phases AC induction motor.

V. CONCLUSION

In this paper, a simplified flux weakening strategy for engineering application is introduced. Though it cannot optimize the torque capability, the strategy can improve current control performance significantly even in too high flux level. Moreover, this paper investigates the influence of the rapid current regulation in the high speed flux weakening region. Too rapid current regulation is unavailable and degrades the robustness of current regulations considering the effect of variable parameters, high fundamental to sampling frequencies, inherent PWM and digital discrete interval time delay. Consequently, an expert controller based on the fuzzy inference has been proposed to self-tune the current commands in order to avoid the unreasonable variation of current commands. Extensive simulation and experiment have been performed and the results verify that the performance of current control has been improved and the scheme proposed in his paper is effective.

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