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Hybrid Fuzzy-PI controller and Novel Switching Functions Using Speed Control technology of Surface Mounted Permanent Magnet Synchronous Motor

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ABSTRACT:

Vector control is one of the standard techniques used for the control of a permanent magnet synchronous motor (PMSM). The outer speed loop in vector controlled PMSM drive greatly affects the drive performance. In order to combine the advantages of proportional plus integral (PI) and fuzzy controllers, hybrid fuzzy-PI controllers are used in which the output can either be the outputs of the two, i.e. the PI or fuzzy units being switched as per the predetermined speed errors or be a combination of the two outputs with separate weights assigned to them with online calculations for the weights from the speed errors. The former method based on switching often causes chattering effects, and later method demands larger execution time because of inclusion of separate switching algorithms. This paper reports the vector control of PMSM with hybrid fuzzy-PI speed controller with switching functions calculated based on the weightsfor both the controller outputs using the output of (a) only the fuzzy controller, (b) only the PI controller and (c) a combination of the outputs of both the controllers. These switching functions are very simple and effective and do not demand any extra computations to arrive at the hybrid fuzzy-PI controller outputs. These control algorithms have been simulated and also implemented on hardware with TMS320F2812 digital signal processor, and it is observed that the performance of the vector controlled PMSM drive with these hybrid fuzzy-PI speed controllers in terms of the response and torque ripples is very promising.

***Index Terms*—Fuzzy controller, hybrid fuzzy-PI controller, motor control, surface mounted permanent magnet synchronous motor, vector control.**

I. INTRODUCTION

Permanent magnet synchronous motors (PMSM) have advantages like high efficiency, high power factor, high power density and maintenance free operation, and these motors are nowadays preferred in a variety of applications. Vector controlled PMSM drive provides better dynamic response and lesser torque ripples, and necessitates only a constant switching frequency. The outer speed loop in vector control greatly affects the system performance. These problems can be overcome by the fuzzy logic controllers which do not require any mathematical model and are based on the linguistic rules obtained from the experience of the system operator. But the performance of the fuzzy controllers compared to the PI controller is superior only under transient conditions. A simple gain scheduled PI speed controller has been proposed in where the controller gains are varied with the input error signal. This controller suffers from the drawback that for its proper performance, the limits of the controller gains and the rate at which they would change have to be appropriately chosen. Fuzzy based gain scheduling of PI controller has been proposed in, but the limits of

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the gains have to be determined by the user manually. PI controller has superior performance as compared to the fuzzy controller under steady state conditions.

The advantages of the fuzzy and PI controllers can be obtained with a hybrid fuzzy-PI controller which can be implemented as a speed controller where the PI controller is active near and at steady state conditions and the fuzzy controller is active during transient conditions. Hybrid fuzzy-PI speed controller has been used for the control of the induction motor, where the fuzzy controller is active during speed overshoot or undershoots only. In a permanent magnet brushless dc (PMBLDC) motor with hybrid fuzzy-PI speed controller, the fuzzy logic controller is only activated under the condition of overshoot and oscillations; else the output of the fuzzy logic controller is null and hence inactive.

Here, the selection between the fuzzy and the PI speed controllers is based on a set of simple rules; oscillations have to be detected by comparing the sum of errors over a period of time with the sum of absolute errors over the same period. Keeping track of the oscillations by continuous monitoring of the speed errors necessitates more computation time. In a direct torque controlled PMSM drive with hybrid fuzzy-PI speed controller under the dynamic conditions, the weightage given for the fuzzy controller output is more than that of the PI controller output, and under the steady state conditions, the weightage given for the PI controller output is more than that of the fuzzy controller output; the combined weightage is decided by another fuzzy controller.

II. CONTROL SCHEME

A. Vector Control

The instantaneous position of voltage, current and flux space vectors are controlled, ideally providing a correct orientation both under steady-state and transient conditions. With the vector control scheme, the magnitude, phase and the frequency of the motor currents are controlled. The stator currents are resolved into torque producing and flux producing components with coordinate transformations, and are controlled independently. For operating under the constant torque region, the torque angle is maintained at 90, and for maximizing the torque per ampere, the d-axis current is set to zero. The schematic diagram of a vector controlled PMSM drive with hybrid fuzzy-PI speed controller in the outer loop and two PI current controllers in the inner loops. With the phased currents sensed at the instant of sampling, the torque and flux producing current components are obtained through the coordinate transformations.

The two currents are then compared with their respective reference values and the errors are Processed by the individual PI current controllers, which determine the voltage to be impressed at the motor terminals. The reference value of the d-axis current is set to zero for constant torque angle control. The actual motor speed is sensed and compared with the commanded reference value.The speed error is processed by the hybrid fuzzy-PI speed controller, which determines the reference value of the q-axis current.

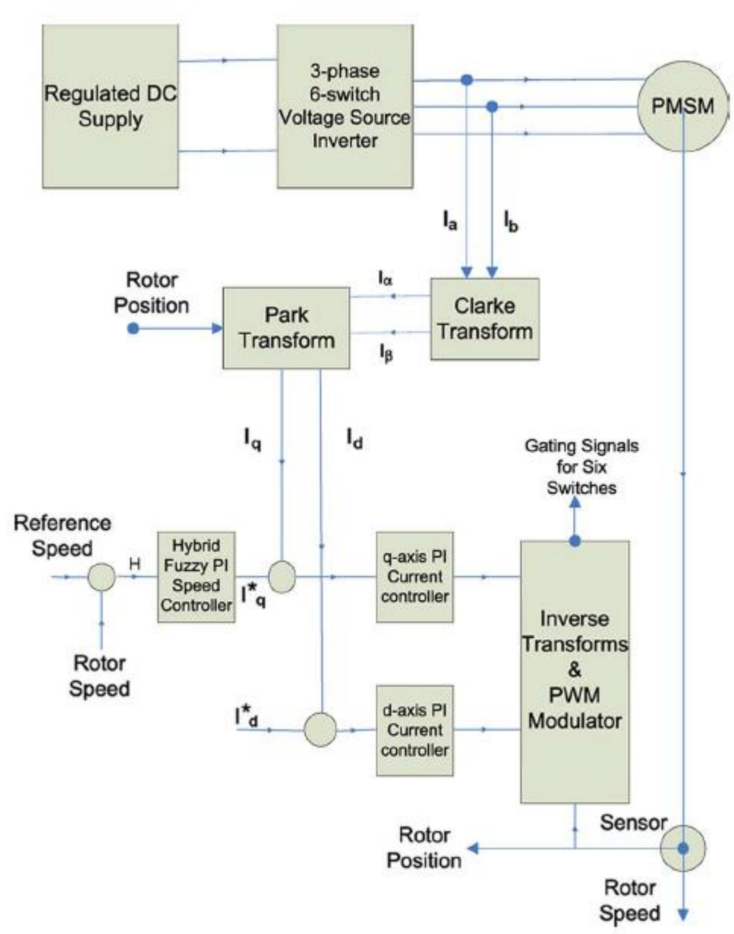

Fig.1. Schematic diagram of the vector control of PMSM with hybrid fuzzy-PI speed controller and PI current controllers.

B. Hybrid Fuzzy-PI Speed Controller

Hybrid fuzzy-PI speed controller combines the advantages ofPI controller and fuzzy controller. PI controller is active during and near the steady state conditions, whereas the fuzzy controller is active conditions.The main focus of the controller design is not only to improve the performance of the speed controller, but also to reduce the computational burden and thereby to reduce the algorithm execution time.

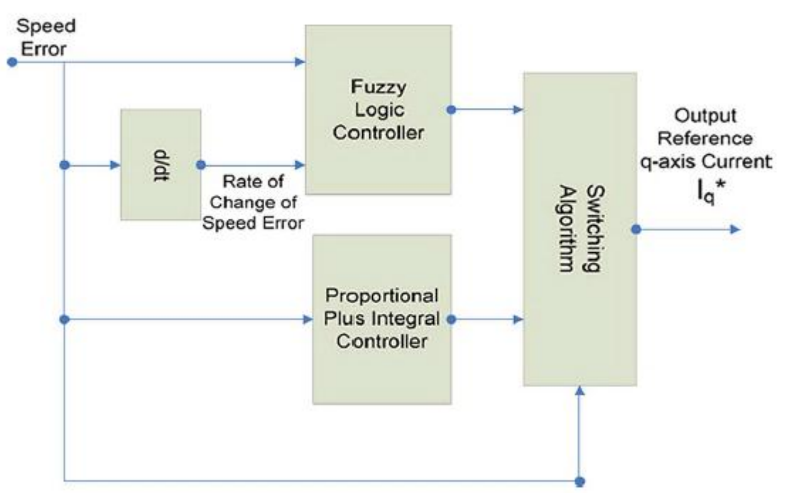

Fig.2.Schematic diagram of hybrid fuzzy-PI controller with switching function.

Various types of switching functions can be implemented to combine these two controller outputs to make a hybrid controller and based on the switching functions, the performance of the PMSM drive will vary. The main focus of the controller design is not only to improve the performance of the speed controller, but also to reduce the computational burden and thereby to reduce the algorithm execution time. As the fuzzy based switching function increases the computational burden, it is not advisable to use the same. In this paper, three different switching functions for the hybrid fuzzy-PI controllers have been analyzed, implemented on hardware and compared. Each switching function has its own rule for assigning the weights for both the fuzzy and PI controller outputs.

The first switching function uses only the output of the fuzzy controller to generate the weight; the second switching function uses only the output of the PI controller to generate the weight; and the third switching function uses a combination of the outputs of both the controllers to generate two separateweights.

While the relay switching function switches form fuzzy logic controller to PI controller when the transients die out, these three inherent switchingfunctions are based on one common rule, that during the transient conditions the output of the fuzzy logic controller has the prominent effect on the output of the hybrid controller and during the steady state conditions, the PI controller has the more prominent effect. The advantages of these switching functions are absence of chattering, less computational burden resulting in reduced torque ripples, and simple yet robust switching algorithm.The speed error is processed by the fuzzy algorithm, which has speed and rate of change of speed as inputs, and the PI controller. Depending on the switching function, appropriate weights are assigned to the output of the fuzzy and PI controllers to determine the hybrid fuzzy-PI controller output.

III. RESULTS

A. Simulation

Simulations have been carried out for the hybrid fuzzy-PI speed controller with all the three switching functions for the vector control on a 24 V, 100 W, 7 A, 4000 rpm PMSM withFuzzy-PI speed controller with the switching function calculated based on the weights for both the controller outputs using the output of only the fuzzy controller.

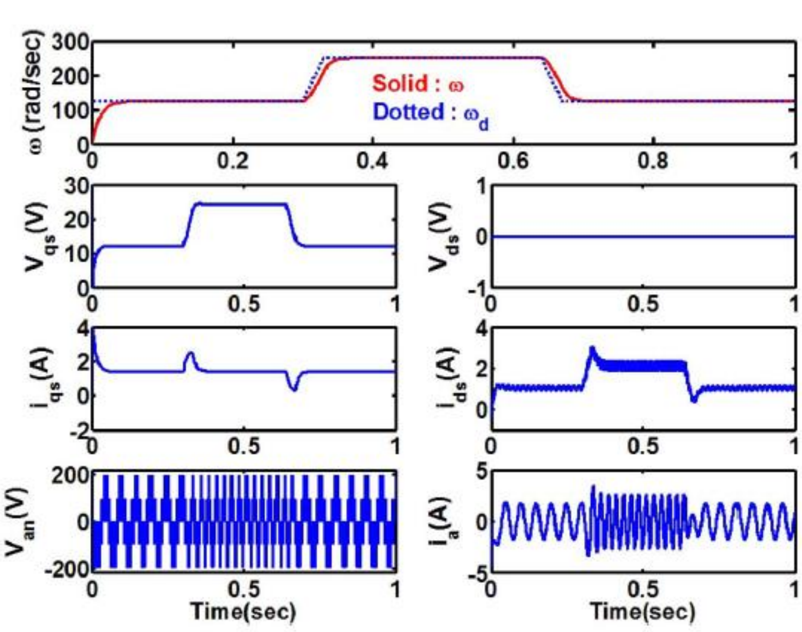

Fig3. Simulation results under no parameter variation.

It can be observed that the motor speed settles down at the reference value of 4000 rpm in 0.15 s without any oscillations, overshoots or dips. From the plot for the output of the speed controller it is observed that there exist sudden spikes and dips around the instant when the motor speed has reached its reference value.

The output of the hybrid controller is the maximum during the dynamic condition. And around the point when the motor speed attains its reference value, hybrid controller output oscillates randomly between the maximum values on the positive and negative sides. When the motor reaches the steady state condition, the controller output reduces rapidly.

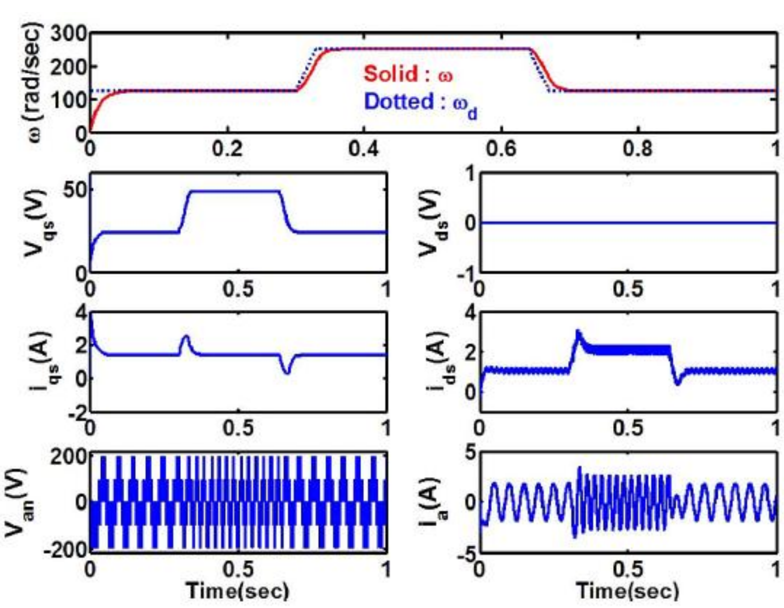

Fig. 4. Simulation results under 200% variations of some parameters (Rs, Ls, J, TL, and λm).

The line current is fairly sinusoidal as the maximum current being 3.26 A at starting. Simulation results for the hybrid fuzzy-PI speed controllerwith the switching function calculated based on the weights for both the controller outputs using the output of only the PI controllerfrom which it can be observed thatthere are no oscillations, overshoots or dips in the motor speed.The settling time is 0.26 s. It is also observed that thespeed controller output is smooth, with less number of spikes oflow magnitude.

The controller output reduces and settlesafter exhibiting less oscillations and spikes of far lesser magnitudethan the previous case. The maximum current at starting is 2.30 A only against the rated line current of 7 A, and is fairly sinusoidal.Thus the performance is better as compared to the previous case with respect to the quality of the controller output. As compared to the previous case, the settling time has increased, but the maximum current at starting has decreased.With the switching function calculated based on the weights of the combination of the outputs of both the controllers, the results of the simulation are shown in Fig. 5.

In this case too, there are no over or undershoots in speed. The settling time is 0.19 s. The speed controller output waveform is without any spikes or dips. The maximum line current at the starting is 2.62 A; and is fairly sinusoidal. As compared to the previous two cases, the settling time is higher and the starting current is the least. Table I gives a comparison of the results of the simulation of the entire three hybrid fuzzy-PI controller based vector controlled PMSM along with those obtained from the conventional.

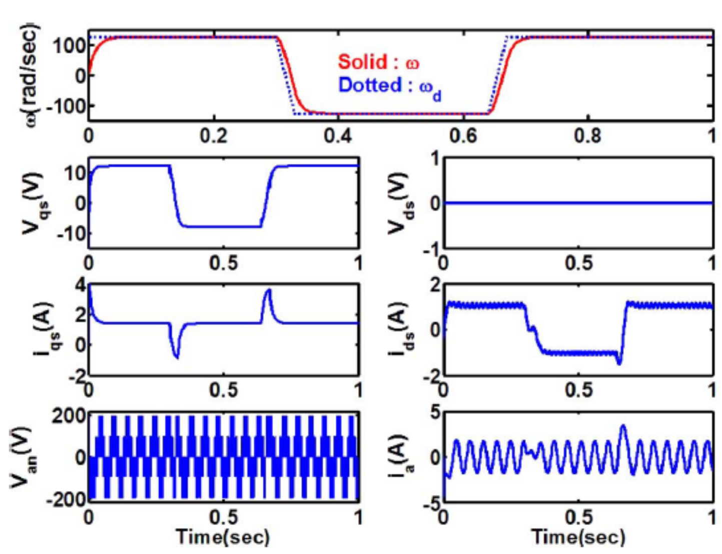

Fig 5. Simulation results under speed reverse case.

PI alone and fuzzy alone speed controllers. It can be observed from this table that the settling time is lower in case of all the three hybrid controllers, than the PI controller alone case and the starting currents are lower in case of all the three hybrid speed controllers than that of both the PI alone and fuzzy alone controllers. With the switching function calculated based on the weights for both the controller outputs using the output of only the fuzzy controller, the settling time is the least but the starting current is the maximum.

B. Hardware

Hybrid fuzzy-PI speed controller with different switching functions has been implemented on a 100 W, 7 A, PMSM with TMS320F2812 DSP to implement the control algorithm, at no load; a photograph of the test set the reference speed in each case is chosen to be 1500 rpm, with a regulated DC bus voltage of 15 V. The measured speed and line current for the vector control of the PMSM with hybrid fuzzy-PI speed controller with three switching functions calculated based on the weights for both the controller outputs using the output of only the fuzzy controller, only the PI controller and the combination of the outputs of both the controllers, have been obtained of both the controllers, are performing better than the PI alone and fuzzy alone speed controllers. With the switching function using the output of only the fuzzy controller, the settling time is the least but the starting current is the maximum.

With the switching function using the output of only the PI controller, the starting current is the least and the settling time is the maximum. The case with the switching function based on the weights of a combination of the outputs of both the controllers appears to the optimum. Appropriate switching function can be used for the PMSM drives used in various applications. 8 and 9 respectively. With these three switching functions, the motor attains the reference speed of 1500 rpm without any oscillations or overshoot.

The settling times are 0.042, 0.052 and 0.045 s, and the RMS values of line currents under steady state condition are 1.48, 1.4 and 1.4 A respectively for the three cases and they are in agreement with the trends observed in the simulated motor. The current is fairly sinusoidal in all the three cases. It may be noted these currents are observed when the motor is fed with 15 V instead of the simulated rated value of 24 V, and hence the increase in load currents of the motor is understandable. The total harmonic distortions in the line currents of the three cases are 4.3, 5.8 and 4.1% respectively, which are well below the acceptable limits; this implies reduced torque ripples too.

IV. CONCLUSION

The hybrid fuzzy-PI speed controllers with the three switching functions calculated based on the weights for both the controller outputs using the output of only the fuzzy controller, only the PI controller and the combination of the outputs.

The bounds of uncertainties needed for the sliding mode control are deduced and the robustness is achieved by using these bounds to generate the control inputs which compensate the parameter uncertainties and disturbances.We have presented two controllers for velocity regulation in PMSMs.

These controllers are the simplest controllers reported until now with a formal stability study. Since these controllers are very similar to those used in most commercial drives we think that tuning procedures given by the stability conditions in our study may be useful as tuning guidelines of commercial drives.

Moreover, we have presented a simulation study to compare responses with our proposal and with torque control or current control (common in commercial drives).We found the same velocity response with both controllers. Commercial torque control or current control, are not included in practice.

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