PMSM의 퍼지 로직 최적 효율 제어

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A Fuzzy Logical Optimal Efficiency Control of Permanent Magnet Synchronous Motor

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Abstract - This paper presents a fuzzy logical control method to implement an on-line optimum efficiency control for Permanent Magnet Synchronous Motor. This method real-timely adjusts the output voltage of the inverter system to achieve the optimum running efficiency of the whole system. At first, the input power is calculated during the steady state in the process of efficiency optimizing. To exactly estimate the steady state of the system, this section needs check up the speed setting on timely. The second section is to calculate input power of dc-bus. The exact measurement of the voltage and current is the vital point to acquire the input power. The third section is the fuzzy logic control unit, which is the key of the whole drive system. Based on the change of input power of dc-bus and output voltage, the variable of output voltage is gained by the fuzzy logical unit. With the on-line optimizing, the whole system can fulfill the minimum input power of dc-bus on the running state. The experimental result proves that the system applied the adjustable *V/f* control method and the efficiency-optimizing unit possesses optimum efficiency, and it is a better choice for simple variable speed applications such as fans and pump.

1. INTRODUCTION

The permanent magnet synchronous motor (PMSM) does not have the slip loss inherent in induction motor operation, and it have those attractive features such as high efficiency, high power factor and high power density. So the PMSM has emerged as an alternative to the induction motor when employed in adjustable speed driver, especially in drivers where overall efficiency is critical, especially in pump, compressor and fan drives.

When the general-purpose inverter drivers PMSM, a series of problems will appear, for instance, rotor temperature of rotor will rise, and the start-up *V/f* curve can't give the optimum steady running curve, and so on.

There are basically two approaches to realize the optimal efficiency control in electrical machine. By employing a loss model of the machine, the first method regulates the controlled quantities (voltages and current) to minimize the estimated loss. In paper [2] a novel algorithm is proposed to minimize the induction motor driver loss. The intention is to preserve the loss model based on controller benefits while insuring precise drive loss modeling by means of an on-line identification routine. On-line identification of the loss function parameters is made possible by measuring the input power of the driver.

The second approach of optimal efficiency control is to measure the power delivered to the drive and then use a search algorithm to adjust a control variable until it detects a minimum in the power. Many researchers have been pursuing their study in this field. Paper [3] describes a frequency-controlled induction motor drive that employs an adaptive control to find the maximum efficiency operating point at any speed and load. A similar control was described in [4] for optimal efficiency control of PMSM drive. The efficiency control operates by measuring the current on the dc link and adjusting the output voltage of the inverter to minimize the quantity. In this way the algorithm optimizes the whole system efficiency combined motor and inverter, not just the motor efficiency.

A novel efficiency-optimization control strategy is presented in [5]to meet the demand of rapidity after analyzing the defect of optimal efficiency control strategy of PMSM system with minimum input power in general applications. On the basis of general efficiency optimization control strategy with minimum input power, this paper adopts fuzzy logic control method and torque compensation strategy to accelerate convergence in process of optimizing controlled parameter.

It has been shown that the PMSM can be operated at its optimal efficiency for a given speed and torque by adjusting the amplitude of the voltage to minimize the total losses. This paper introduces a definite purpose driver about adjustable speed PMSM drives in fans and pumps applications.

2. THE PREPARE ITEMS BEFORE EFFICIENCY OPTIMAL

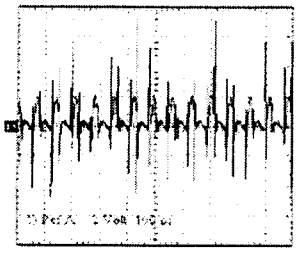
2.1 Exactly Estimate the Steady State of the System

The input power is calculated on the steady state in the process of efficiency optimizing. To exactly estimate the steady state of the system, the program would continuously judge the applied frequency three times. When the speed error $\omega(k)-\omega(k-1)$ of the system is less than the rated $\Delta\omega$, the system makes an adaptive adjustment of the output voltage V, where $\omega(k-1)$ is the last sample of the speed. $\omega(k)$ is the present sample of actual speed. $\Delta\omega$ is the rated error of speed.

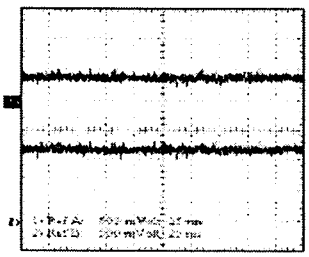
2.2 Measurement of the Dc-bus Input Power

The second section is the calculation of input power of Dc-bus. The exact measurement of the voltage and current of the Dc-bus is the vital step. Firstly the voltage and current signal pass through a two-step low-pass-filter on the hardware. Then they get across the digital filter, like glide

mean value method and preventing pulse disturb mean value method. Fig.2 is the actual current and voltage waveform, a) is the current waveform before hardware filter and b) is the voltage and current waveform after hardware filter.



a) current waveform before hardware filter



(b) voltage and current waveform after hardware filter

Fig.1 waveform of DC-bus

To insure the accuracy of the sampling, the program synthesizes the glide mean value method and preventing pulse disturb mean value method. This method not only fulfills the sampling speed, but also attains sampling precision. Firstly it deposits the (N-1) sample data in the RAM of the DSP, when the program gets a new datum, with the method the program acquires the arithmetic mean value of the N numbers according to the following formula.

$$x=\frac{1}{N-2}\left(\sum_{1}^{N}x_i-x_{\max}-x_{\min}\right) \qquad (1)$$

Where x is the arithmetic mean value of variables, N is the total number of the data, x_i is the actual sample value of the variable, and $x_{\max}$ is the maximum value of the whole numbers, and $x_{\min}$ is the minimum value of the whole numbers. After the above calculation, the lattermost of the data is gotten rid of.

3. Efficiency Optimize Unite

To reduce the time spending on the efficiency optimum, fuzzy logical controller is applied to self-adaptively adjust the step of output voltage ΔV. The output voltage ΔV is changed according to the variety of input power of Dc-bus $\Delta P(k)$ and the direction of last step of output voltage ΔV. Fig. 3 shows the membership function for the variables of efficiency-optimized unit $\Delta P(k), \Delta V(k-1)$ and $\Delta V(k)$.

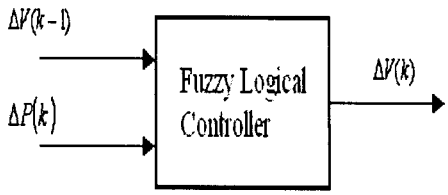
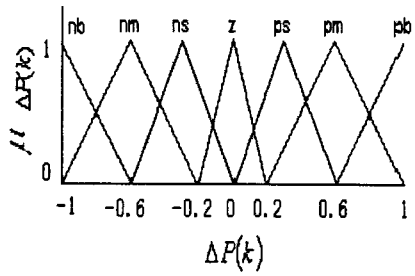
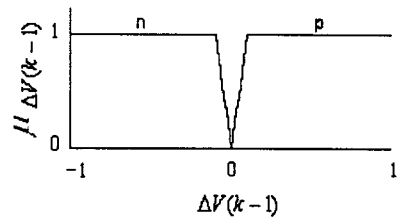


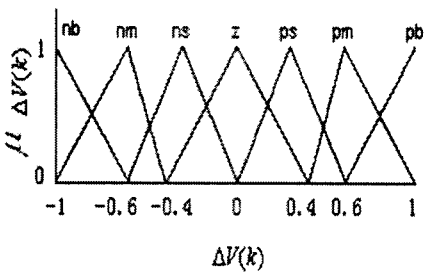
Fig.2 The control strategy of fuzzy logical controller



(a) The change of input power error



(b) The error of voltage before measure



(c) The error of voltage after measure

Fig.3 The membership function for various fuzzy sets

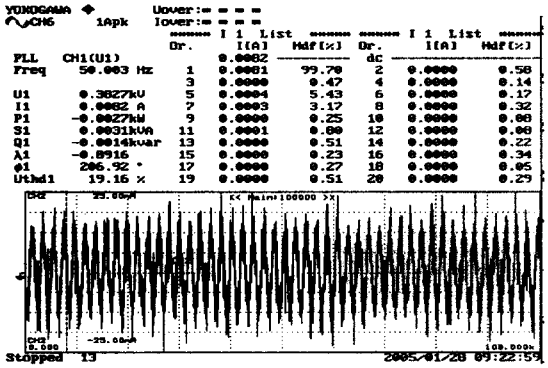
Based on the above rules, the fuzzy rule based matrix is shown in table 1.the values of the constants, membership function, fuzzy sets for the input and output variables and the rules used in this work are selected by trial and error to obtain the optimum efficiency.

TABLE 1: The fuzzy rules based matrix

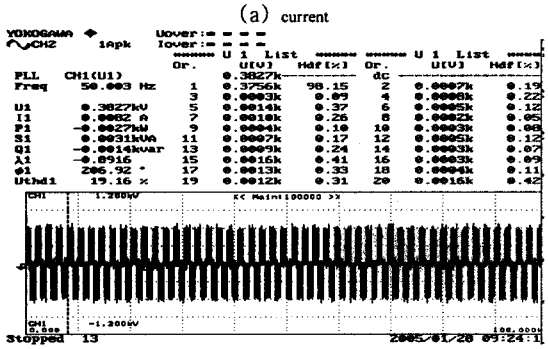
$\Delta V(k)$		$\Delta P(k)$						
		pb	pm	ps	z	ns	nm	nb
$\Delta V(k-1)$	p	nb	nm	ns	z	ps	pm	pb
	n	pb	pm	ps	z	ns	nm	nb

4. The Analysis Of The Examination Result

To verify the performance of the drive, a laboratory test system is developed. The control algorithm of the drive is implemented in a digital signal processor (DSP) (TMSLF2407A), which is controlled by an industrial computer. The actual current and voltage are fed back to the DSP board through A/D converters. Hall-effect transducers with a good frequency response obtain the actual current. The tested motor is an IPMSM (interior-mounted-type PMSM), which is 7.5kW, 3000r/min, 3 phases, 2 poles, 50Hz, 13 A and 380V. Figure.5 is the output current wave and frequency spectrum analysis. Figure.6 is the output voltage wave and frequency spectrum analysis. Figure.7 is the power factor of whole system. Figure.8 is the efficiency of motor before and after optimized, and the inverter.



(a) current



(b) voltage

Fig.4 The output current ,voltage waveform and their frequency spectra

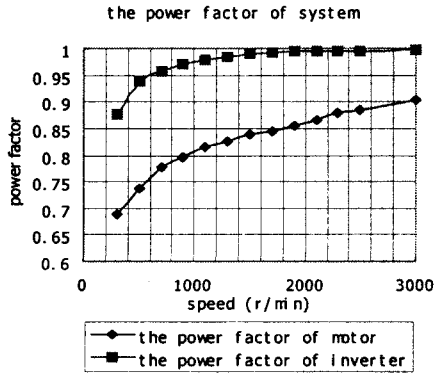


Fig.5 The power factor of whole system.

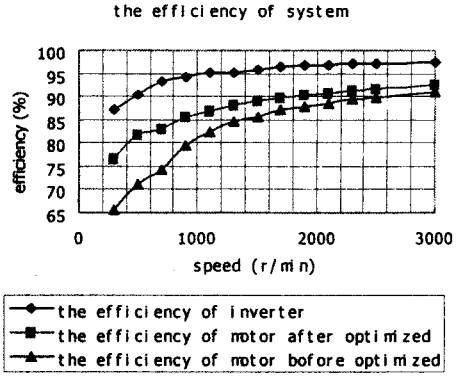


Fig.6 The efficiency of whole system

Numerous experiments have been performed to evaluate the performance of the whole system. Some sample results have been presented in this paper. Fig.4.gives the line current and voltage waveform when the system operating at 23.88 N.m. From the current waveform we can see the load current wave is approximate to the sinusoidal. Thus the harmonic losses are restrained to the minimal. Form the voltage waveform we can see the load voltage waveform is approximate sinusoidal. Thus the harmonic losses are restrained to the minimal, too. Fig.6 shows the efficiency of inverter, motor and the whole system, respectively. It can be seen that: the efficiency of the system increases evidently after the optimization. The whole system efficiency is more than 85% at the wide running scope, and the increased efficiency is up to 10% at the low speed running scopes.

5. CONCLUSION

This paper describes a fuzzy logical *V/f* Control Method for Permanent-Magnet Synchronous Motor drives. Through the efficiency-optimizing unit, the whole system is able to operate at optimum efficiency. The analysis of experiment result proves that the system possess optimum running performance. So the adjustable V/f control of PMSM, which is simple and has low cost, is more suitable for such applications as fans and pumps, and so on.

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[References]

[1] Tang Renyuan. "Modern permanent magnet machines –theory and design". Beijing: China Machine Press, 1996, pp. 310-312.

[2] Slobodan N. Vukosavic,Emil Levi, "Robust DSP-based efficiency optimization of a variable speed induction motor drive," IEEE Transactions On Industry Application, vol .50, no3,pp.560-568.

[3] D .S. Kirschen, D. W. Novomy, and T. A. Lipo, "On-line efficiency optimization of a variable frequency induction motor drives," in Conf. Rec.1984 IEEE-IAS Ann. Meeting, pp. 488-493.

[4] R. S. Colby and D. W. Novotny, "An efficiency-optimizing permanent magnet synchronous motor drive," IEEE Trans. Ind. Applicat., vol. 24,pp. 462-469, May/June 1988.

[5] Xu Jiaqun, "Study on permanent magnet synchronous motor drive system in electric vehicle application," PH. D. dissertation. Shenyang University of Technology, Mar. 2003.