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Fuzzy Logic Controller for PMSM

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Abstract - Dual motor drives designs are attractive for high power application because of their mechanical simplicity, traction and regenerative braking control on low friction surfaces. However, such configurations normally require two power inverters with coordinated control. The high cost and large size of packaging needs of the inverters make such dual inverter, dual motor drive configurations are economically less competitive. Therefore, the need for dual motor drives fed by single inverter rising consequently to reduce sizes and costs with respect to the single motor drives, either in industrial or in traction application. This paper aims to investigate the behavior of dual motor drives fed by single inverter using averaging technique MATLAB/Simulink has been chosen as the simulation tools.

Keywords - *Component; PMSM; Fuzzy Logic Controller.*

I. INTRODUCTION

For widespread industrial applications, such as high performance motor drives, accurate motor speed control is required in which regardless of sudden load changes and parameter variations . Hence, the control system must be design very carefully as it required to ensure the optimum speed operation under the environmental variations, load variations and structural perturbations. Alternative control strategies have been studied extensively in attempts to provide accurate control capability. Among many kinds of control schemes, fuzzy logic controller (FLC) is one of the superior schemes used for plants having difficulties in deriving mathematical models or having performance limitations with conventional linear control schemes . Reference also mentioned that the FL and neural network (NN) became a pleasing approach to high performance controllers for non linear systems and has been practical to electrical drives. The present paper presents a study of a DC motor with FL speed controller. Besides that, FLC is broadly used by numerous publications with diversity of industrial drive applications such as vector controlled induction motor permanent magnet synchronous motor brushless DC motor and switched reluctance motor .Theoretically; FL is based on human reasoning, providing algorithms which can convert a set of linguistic rules based on expert knowledge into an automatic control strategy. There is no need of mathematical models to deal with a problem, but skill is needed to create the rules in a particular FL controller. This point also being supported by which stated that a fuzzy control algorithm embeds the intuition and experience of an operator designer and researcher as the concept of FLC is to utilize the qualitative knowledge of a system to design a practical controller.Dual PMSM drives are at first modeled in MATLAB/Simulink program. As mentioned before, the standard controller is designed based on the common criteria of fuzzy speed controller that have been reviewed from various publications. This means 49 rules is a standard approach for the FL speed control with PMSM drive application. Meanwhile, the proposed controller consists of 9 rules which are formed by minimizing the number of membership function used. In this case, three rules for speed error and three rules for change in speed error is used, so that 3x3 = 9 rules are produced. The same PMSM drive model is being used for standard 49 rules and simplified 9 rules, so that a fair comparison is enabled. It has to be noted that 49 rules are represented by ‘standard design’ and the proposed controller are represented by ‘case design’. The results from both controllers are being compared and evaluated to show the appropriateness and effectiveness of the proposed controller which aims to achieve the following properties: robustness around the variety of operating conditions and invariant dynamic performance in presence load disturbance while maintaining the performance obtained by ‘standard design’ controller.

II. FUZZY LOGIC CONTROLLER

For widespread industrial applications, such as high performance motor drives, accurate motor speed control is required in which regardless of sudden load changes and parameter variations . Hence, the control system must be design very carefully as it required to ensure the optimum speed operation under the environmental variations, load variations and structural perturbations. Alternative control strategies have been studied extensively in attempts to provide accurate control capability. Among many kinds of control schemes, fuzzy logic controller (FLC) is one of the superior schemes used for plants having difficulties in deriving mathematical models or having performance limitations with conventional linear control schemes the FL and neural network (NN) became a pleasing approach to high performance controllers for non linear systems and has been practical to electrical drives. The present paper presents a study of a DC motor with FL speed controller. Besides that, FLC is broadly used by numerous publications with diversity of industrial drive applications such as vector controlled induction motor permanent magnet synchronous motor brushless DC motor and switched reluctance motor .

Theoretically, FL is based on human reasoning, providing algorithms which can convert a set of linguistic rules based on expert knowledge into an automatic control strategy. There is no need of mathematical models to deal with a problem, but skill is needed to create the rules in a particular FL controller [17]. This point also being supported by which stated that a fuzzy control algorithm embeds the intuition and experience of an operator designer and researcher as the concept of FLC is to utilize the qualitative knowledge of a system to design a practical controller. Dual PMSM drives are at first modeled in MATLAB/Simulink program. As mentioned before, the standard controller is designed based on the common criteria of fuzzy speed controller that have been reviewed from various publications. This means 49 rules is a standard approach for the FL speed control with PMSM drive application. Meanwhile, the proposed controller consists of 9 rules which are formed by minimizing the number of membership function used. In this case, three rules for speed error and three rules for change in speed error is used, so that 3x3 = 9 rules are produced. The same PMSM drive model is being used for standard 49 rules and simplified 9 rules, so that a fair comparison is enabled. It has to be noted that 49 rules are represented by 'standard design' and the proposed controller are represented by 'case design'.The results from both controllers are being compared and evaluated to show the appropriateness and effectiveness of the proposed controller which aims to achieve the following properties: robustness around the variety of operating conditions and invariant dynamic performance in presence load disturbance while maintaining the performance obtained by 'standard design' controller.

III. DUAL MOTOR DRIVES

In many applications, one motor is controlled by one converter. These systems are called SMSC, single machine single converter system . Multi machine systems (MMS) are more and more used for industry today. Those systems allow to extend the field of high power applications or to increase their flexibility, mechanical simplicity and safety operating. However, it includes a lot of power switches which are large in size, costly and bulky. The high cost and large size need of the inverter make such dual inverter, dual motor drive configurations economically less competitive. Therefore, the need for dual motor drives fed by single inverter is rising consequently to reduce sizes and cost with respect to the single motor drives, either in industrial or in traction application. But, the reduction number of power electronics switches and other components will results the paralleling of the drives systems. If the load torque for each motor is still the same, there is no speed changes will be encountered because every motor will have the same behavior . On the other hand, a mechanical perturbation on one of the motors will create perturbations on the electrical part and perhaps a malfunctioning of the system. For this type of disturbance, a control drive is needed to compensate the disturbance in order to make the system back to its origin. After several reading, an average technique has been selected to overcome the loss of adhere of the motor. The technique is average of the mean of phase current. Generally MMSC can be divided into two main categories, which are master-slave and mean control system . In Master-Slave scheme, one motor which is selected as the master is directly control. The motor with the highest load is set as the master motor and the other one is slave motor, which has the same applied voltage, same electric pulsation and also the same speed Then the behavior of slave motor will be ignored. In some conditions, the performance of slave motors may not acceptable whereas in mean control, there are several techniques have been applied. One of them is average of current. In this scheme, the control system is basically similar to that of a single machine. And the machine internal parameter such as flux, do not show desirable behavior. The second technique is averaging over the parameters of the equivalent circuit at steady state. But in the case of motor parameters are not similar, some of the results, may not be not acceptable. The other techniques are the averaging the voltage space vector . Through this technique, for each motor, a single motor controller was applied, and then a reference voltage is obtained for each machine. In view of the fact that an inverter can only provide one reference voltage vector, thus a vector average is taken over the motor reference voltages, and the result is generated by the inverter. Besides, there are other technique such as mean and differential torque and the Optimum torque over current ratio.

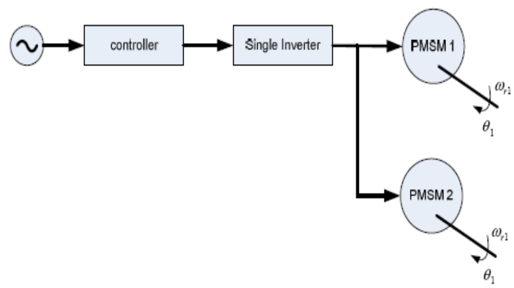


Fig. 1

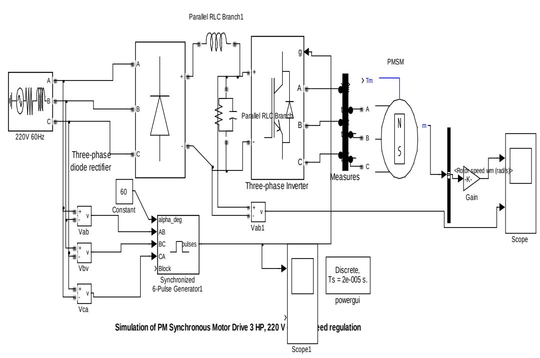


Fig. 2

A. Mathematical Equations

The simulated machines are smooth air gap PMSMs without any damping circuits in the rotor. The rotors fields are constant and created by permanent magnets and the e.m.f are considered as sinusoidal. The simplified electric equations for motor "1" can be presented as below.

$$v_1 - Ri_1 + L\frac{di_1}{dt} + jp\omega_{r,1}\psi_{r,1} \quad (1)$$

$$T_1 - T_{L,1} = J\frac{d\omega_{r,1}}{dt} \quad (2)$$

$$with\ T_1 = \frac{3}{2}p\Im m\{i_1\psi_{r,1}\}$$

$$\omega_{r,1} = \frac{d\theta_1}{dt} \quad (3)$$

ω_r = Motor angular velocity

T= Electrical Torque

T_L= Load torque

J= Moment of Inertia

The model of the motor "2" can be derived from (1) to (3) by changing the subscript "1" to "2". With the assumptions, motor "1" and motor "2" are equal in all parameters but have different loads. The space vectors of the rotor fluxes, *ψr,1* and *ψr,2* are equal in magnitude and its instantaneous position θ*1* and θ*2* respectively in the stationary frame. Consider a rotating reference frame d,q whose direct axis "d" is along the direction of (*ψr,1*+*ψr,2)/2* and its instantaneous angular position isθ=(θ*1*+ θ*2)/2.* Based on this reference, the electromagnetic torque of the motors "1" and "2" can be expressed as:

$$T_1 = \frac{3}{2}p.\psi_{r,1}.i_{q,1} \quad (4)$$

B. Controller for motor

The FLC, as illustrated in figure 2, is a standard structure with inputs of speed error, *e* and change in speed error, *ce* and output is change in q-axis reference current, *Δiqs** The membership function is used and the input and output scaling factors are determined. The FLC executes the rule base taking the fuzzy variables *e* and *ce* as the inputs and quantity of *Δiqs** as the output are processed in the defuzzification unit.

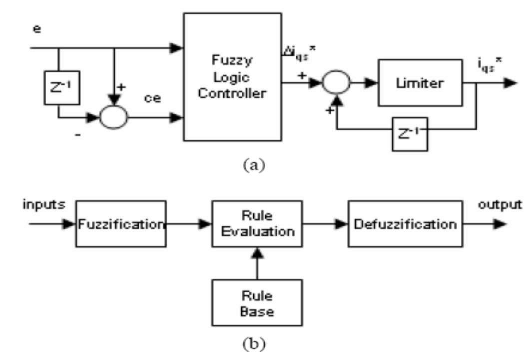


Fig. 3 (a) Fuzzy Logic Controller, (b) Internal Structure of FLC

C. Design of Fuzzy Logic Controller

The main goal of the control system is to determine the effectiveness of the 'case design' for high performance PMSM drive by comparing the speed response with 'standard design' obtained. The 'standard design' is designed first, on the basis of the speed response to the step rated speed command (209 rad/s) under no-load conditions with rated inertia. The design criteria are set in terms of a speed overshoot less than 0.1 rad/s and minimum rise time considering the limited current capability of the inverter. The scaling factors, *Ge, Gce* and *Gcu* are chosen for fuzzification, as well as for obtaining factors play a vital role for the FLC which effect the stability, oscillations and damping of the system, hence needs to be chosen with utmost care [11]. The factors *Ge*and *Gce* are chosen to normalize the speed error and the change in speed error respectively.

The factor *Gcu* is so chosen that one can get the rated current for rated conditions. Fine tuning to the specification is achieved by trial and error. Therefore, the constants are taken as *Ge* = 0.0003, *Gce* = 4 and *Gcu* = 3 in order to get optimum drive performances. For the next step, the membership functions of *e, ce* and *cu* are determined which perform important tasks of the FLC and being main focused in this paper. Two different fuzzy sets are designed as shown in Fig. 3 and Fig. 4 respectively. The shape of the fuzzy sets on the two extreme ends of the universe of discourse is taken as trapezoidal whereas all other intermediate fuzzy sets are triangular with overlap to each other as standard approach. The width of triangular membership function is divided equally in a range (Universe of Discourse) with overlap to each other. The fuzzy rule-base matrix for 'standard design' and 'case design' are shown in Table II and Table III respectively. As declared previously, the rules of the 'standard design' are determined by common criteria from many publications while the rules of the 'case design' parameters are determined by standard approach with reducing the number of fuzzy rule-base. The linguistic elements used are the same as those used in most publications . Fixed-step mode is selected for the computational time interval. Numerical method for solving differential equations is Dormand-Prince and Mamdani-type fuzzy inference is used. The value of constants, membership functions and fuzzy sets for input/output variables in this study are selected by trial

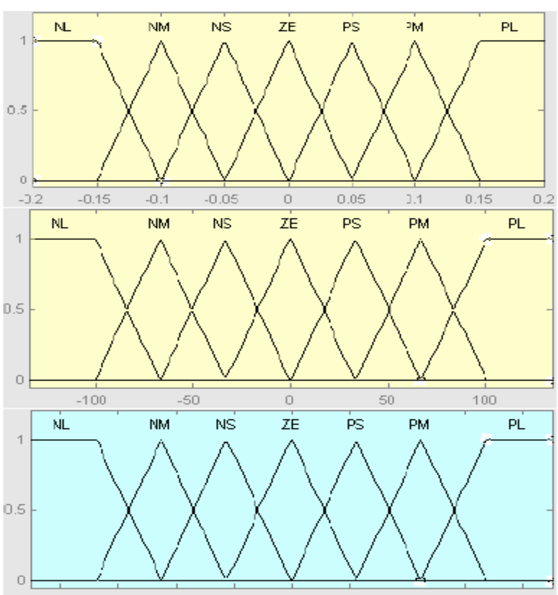


Fig. 3 : Membership functions of 'standard design' for speed error, change in speed error and q-axis command current.

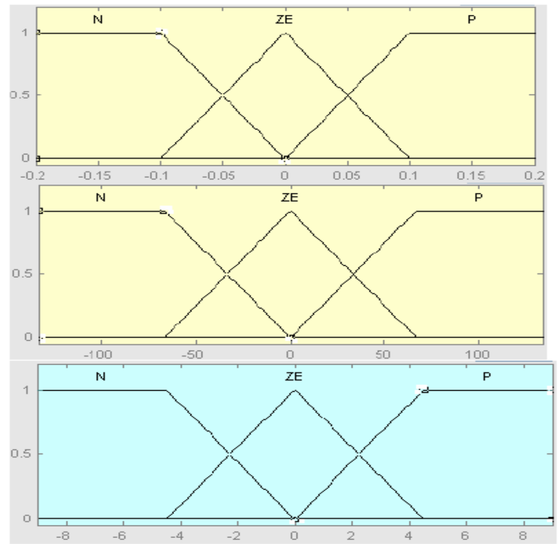


Fig. 5 : Membership functions of 'case design' for speed error, change in speed error and q-axis command current

TABLE I "Standard Design"

MATRIX OF 'STANDARD DESIGN'

Change in speed error, ce	Speed error, e: NL	NM	NS	ZE	PS	PM	PL
NL	NL	NL	NL	NL	NM	NS	ZE
NM	NL	NL	NL	NM	NS	ZE	PS
NS	NL	NL	NM	NS	ZE	PS	PM
ZE	NL	NM	NS	ZE	PS	PM	PL
PS	NM	NS	ZE	PS	PM	PL	PL
PM	NS	ZE	PS	PM	PL	PL	PL
PL	ZE	PS	PM	PL	PL	PL	PL

TABLE II "Matrix of reduced rules"

Change in speed error, ce	Speed error, e: N	ZE	P
N	N	N	ZE
ZE	N	ZE	P
P	ZE	P	P

Seven terms are assigned in Table I: NL, negative large; NM, negative medium; NS, negative small; ZE, zero; PS, positive small; PM, positive medium; and PL, positive large. Three terms are assigned in Table II: N, negative; ZE, zero; and P, positive. Each fuzzy variable is a member of the subsets with a degree of membership μ varying between 0 and 1. As mentioned before, for convenience, the rules have been written in matrix form and should be interpreted as (Refer to Table II): IF ‘speed error is NS’ AND ‘change in speed error is PS’ THEN ‘change in q-axis reference current is ZE’ .All the scaling factors, shape of membership function, method of fuzzification and method of defuzzification are predefined and kept constant during the research except the number of rules.

IV. RESULTS

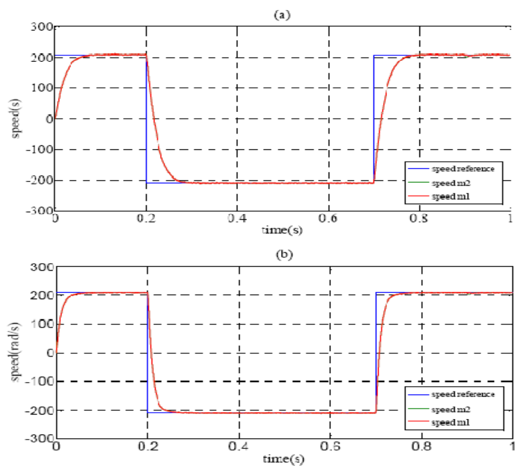
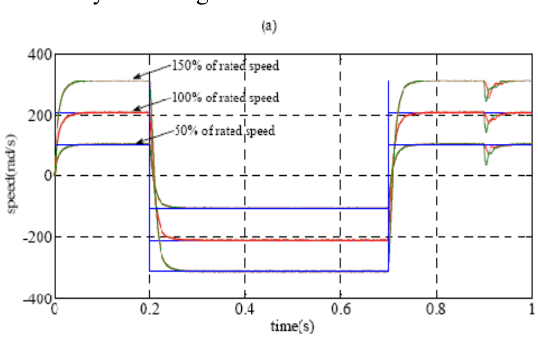
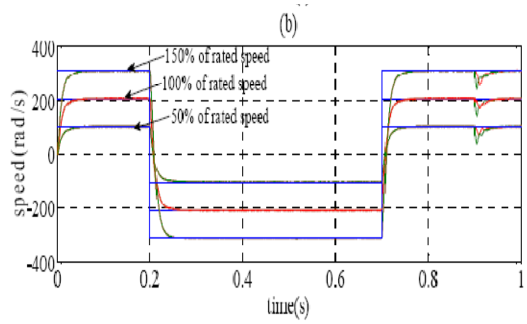


Fig. 6 : Speed response (a) Fuzzy logic using 49 rules, (b) Fuzzy logic using 9 rules for the case of TLm1=1Nm, TLm1=0.5Nm at t=0.9s

Fig.6. shows the speed response during start-up at t=0s, reverse operation at t=0.2s, then forward operation at t=0.5s for Fuzzy logic 49 rules and 9 rules respectively. Both cases are applied torque load changes at t=0.9s about 1Nm for motor “1” and 0.5Nm for motor “2”. For the case of low load, the motors are not too affected by the changes.





V. CONCLUSION

This paper presents the results of a detailed comparative study on Fuzzy logic speed controller in Dual PMSM drives. Two fuzzy speed controllers which are ‘standard design – 49 rules’ and ‘case design -9 rules’ are studied. Performance of both designs are compared for different type of load disturbance and for wide range of speed. The simulation study is realized in MATLAB/Simulink environment. Detailed comparison of performances over the several tests shows that both designs of controllers produce nearly identical performance, thus it is feasible to minimize the complexity of Fuzzy logic controller by reducing the number of fuzzy rule-basse from 49 rules to 9 rules especially for the case of dual PMSM drives.

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