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Effect of Different Defuzzification Methods on the Performance of Fuzzy Logic Controller for PMSM Drives

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***Abstract*— An electric drive performance is paramount for crucial motion application and greatly influenced by capabilities of controller. For high performance application, vector control technique is normally applied with the permanent magnet induction motor (PMSM) drive. Instead of conventional PID controller fuzzy logic controller (FLC) has been widely used for such application. A fuzzy system used number of methods for defuzzification when an output fuzzy set should mapped to a crisped value. In this paper two different defuzzification methods are used for the performance evaluation of vector controlled PMSM drives. The performance of the drive has been investigated for speed control at load and at no load. With center of gravity (COG) defuzzification method base the performance of drive system is found superior as compared to the mean of maximum (MOM) method.**

Keywords*— PMSM drives, vector control, Fuzzy logic controller, Defuzzification methods.

I. Introduction

Induction motor speed control despite of various advantages due to complex mathematical model, nonlinearities such as core saturation, unpredictable load disturbances and coupling of variables. For speed control application where high performance needed such as aircraft, surgical and robotics application sometimes these factors make the precious speed control impossible with the conventional controllers making them inefficient and inaccurate.

In recent years, for its superior performance in speed control application FLC is distinguished and captured the attention of researchers. FLC's have the advantage to handle the system nonlinearities, and its control performance is not much affected by system parameter variation.

Numerous researchers have proposed the different aspects of designing of FLC rule base. But in this paper give the attention on the fuzzy sets theory – the soft computing constituent, can be used in modeling information pervaded with imprecision and uncertainty. Those characteristics make fuzzy models useful in great variety of applications. Fuzzy systems [1], [2], [3] handle imprecise and uncertain information using the theory of fuzzy sets, [4]. The output of a fuzzy system is represented by an output fuzzy set. In applications it is often needed to map the output fuzzy set onto a crisp output value, what is done in a defuzzification process. Defuzzification is the procedure of determining the crisp value, which in some way is the best representation of the output fuzzy set viewed as an isolated entirety. In discussions on fuzzy systems, for example [2], defuzzification process often is not treated as much in details as the other processes in the system are. It seems that in the domain of defuzzification a designer has too wide possibilities of choices, so that some indicators in connection of defuzzification approach are welcome. The defuzzification technique selection essentially influences the output value determined by selected method, so it is important to use an appropriate technique.

The objective of this paper is providing a detailed comparative analysis of FLC with different defuzzification methods, employed in PMSM drives. For two different condition at no load and at full load performance evaluation was carried out through simulation result .The system is dynamically simulated using Simulink/MATLAB Software.

II. VECTOR CONTROL OF PMSM DRIVES

A. PMSM DRIVES

Permanent magnet induction motor is introduced in order to overcome the problem associated with synchronous motor. In PMSM a permanent magnet is used in place of excitation coil. The stator current of an IM contain magnetizing as well as torque producing component. The use of the permanent magnet in rotor of the PMSM makes it unnecessary to supply magnetizing current through the stator for constant air gap flux, the stator current need only to torque producing. At the higher power factor, the PMSM will be more efficient then the IM.

B. VECTOR CONTROL TECHNIQUE

For ac IM the most popular technique is vector control. In the special reference frames, the expression for the smooth-air -gap machine is similar to the expression for the torque of the separately excited DC machine. In case of IM, the reference frame (d-q) attached to the rotor flux space vector; the control is usually performed in this reference frame. That's why the implementation of vector control requires information on the module and the space angel of the rotor flux space vector. By utilizing transformation to the d-q coordinate system, the stator current of the IM are separated into flux and torque producing component, whose direct axis is aligned with the rotor flux space vector. That means the rotor flux q-axis component of space vector is always zero.

$$\Psi_{rq} = 0 \quad \text{and} \quad \frac{d}{dt}\psi_{rq} = 0 \tag{1}$$

The main objective of the vector control of IM is that, by using a d-q rotating reference frame synchronously with the rotor flux space vector is to independently control the flux and the torque. In ideally field-oriented control, the rotor flux linkage axis is forced to align with the d-axis. Applying the result of both, equation namely field-oriented control, the torque equation becomes analogous to the DC machine and can be described as follows,

$$T_e = \frac{3}{2}\frac{pL_m}{L_r}\psi_r i_{qs} \tag{2}$$

III. SYSTEM DISCRIPTION AND CONTROL

The Fig.1 shows the schematic diagram of FLC based IM drive system under analysis. The basic configuration of the drive consists of an IM fed by a current-controlled voltage-source inverter.

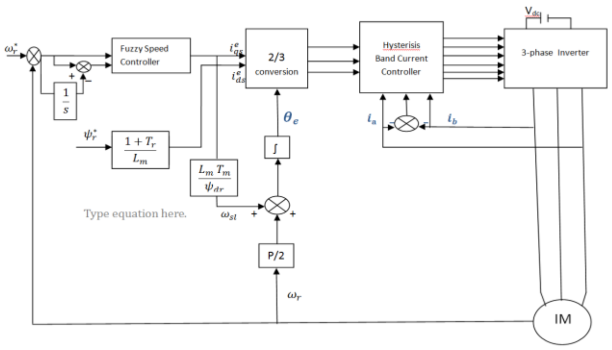

Fig.1 Schematic diagram of indirect vector control PMSM drive

In this work for high performance the indirect vector control technique is incorpirated. The actual rotor speed ω_r measuerd and compared with the ω_r^*. The reference torque T_r^* is calculated as the output, when the resulting error generated from the comperison of the two speeds processed in the controller. A limmiter is used to limit the reference torque T_r^* in order to generate the q-axis reference current i_{qs}^{e*}. The d-axis reference current set to zero. Both d-axis and q-axis stator current generate three phase reference current (i_a^*, i_b^* and i_c^*) through Park's Transformation. Which are compared with senced winding current (i_a, i_b and i_c) of the IM. The control signals genereted after the comparing the senced current and reference current willfire the power semiconductor devices of the three-phase voltage source inverter (VSI) to produce the actual voltage to be fed to the induction motor. In synchronously rotating reference frame the mathematical model for a three-phase y-connected squirrel-cage induction motor under steady state condition and load is given as [10-11].

$$\begin{bmatrix} I_{qs}^e \\ I_{ds}^e \\ I_{qr}^e \\ I_{dr}^e \end{bmatrix} = \begin{bmatrix} R_s & \omega_s L_s & 0 & \omega_s L_m \\ -\omega_s L_s & R_s & -\omega_s L_m & 0 \\ 0 & \omega_{sl} L_m & R_r & \omega_{sl} L_r \\ -\omega_{sl} L_m & 0 & -\omega_{sl} L_r & R_r \end{bmatrix} \begin{bmatrix} v_{qs}^e \\ v_{ds}^e \\ 0 \\ 0 \end{bmatrix} \tag{3}$$

$$T_e = \frac{3}{2}\frac{p}{2}L_m\left(i_{qs}^e i_{dr}^e - i_{ds}^e i_{qr}^e\right) \tag{4}$$

$$T_e - T_L = J\frac{d\omega_r}{dt} + B\omega_r \tag{5}$$

$$\frac{d\theta_r}{dt} = \omega_r \tag{6}$$

Where i_{ds}^e, i_{qs}^e are d,q-axis stator current respectively, are v_{ds}^e, v_{qs}^e are d,q-axis stator voltages respectively, i_{dr}^e, i_{qr}^e are d,q-axis rotor current respectively R_s, R_r are stator and rotor resistance per phase respectively, L_s, L_r are the self inductances of the stator and rotor respectively, L_m is the mutual inductance, ω_e is the speed of the rotating magnetic field , ω_r is the rotor speed, p is the number of poles, T_e is the developed electromagnetic torque, T_L is the load torque, J is the inertia, B is the rotor damping coefficient and θ_r is the rotor position. The key feature of the vector control is to keep the magetizing current at a constant rated value by setting i_{dr}^e =0. Thus, by adjustihg only the torque –producing current component the torque demand can be controlled. With this assumption , the mathematical formulation can be rewritten as

$$\omega_{sl} = \frac{R_r}{L_r}\frac{i_{qs}^e}{i_{ds}^e} \tag{7}$$

$$i_{qs}^e = \frac{L_m}{L_r} i_{qr}^e \tag{8}$$

$$T_e = \frac{3}{2}\frac{P}{2}\frac{L_m}{L_r}\psi_{dr}^e i_{qs}^e \tag{9}$$

Where ω_{sl} is the slip speed ψ_{dr}^e is the d-axis rotor flux linkage. The indirect vector controlled drive system with FLC assisted speed controller model is represented from equation (1) to equation (7).

IV. FLC DESIGNING

Fig.2 show the general block diagram of FLC. The main objective of the designed FLC is to maintain the performance obtained by 'standard design' while reducing the complexity of fuzzy rule base design . FLC has mainly four intrenal component from which input has to be processed to come out as output.

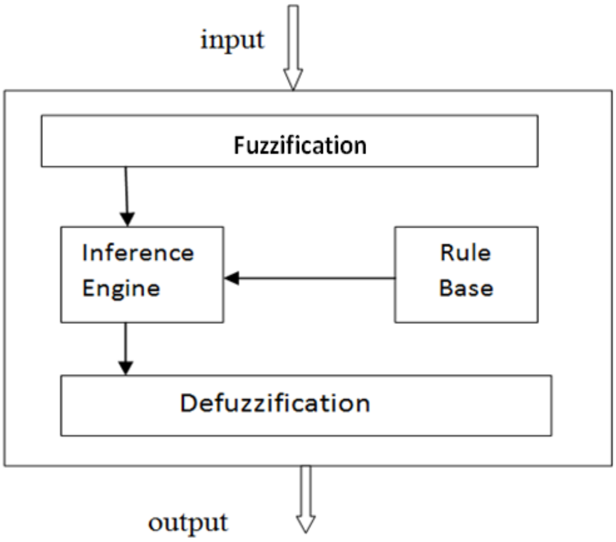

Fig.2 Block diagram of FLC

These component are –

Fuzzification- is the conversion of crisp numerical values into fuzzy linguistic quantifiers. Fuzzification is performed usin membership functions. Each membership function evaluates how will the linguistic variable may be described by a particular fuzzy qualifier.

Inference Engine- The inference engine uses the fuzzy vectors to evaluate the fuzzy rules and producing an output for each rule. Mandani type fuzzy inference engine is used for this particular work.

Defuzzification-in this process the combined output fuzzy set produced from the inference engine into a crisp output value of real-world meaning. Center of gravity and mean of maximum defuzzification technique is used in this paper

V. DFUZZIFICATION TECHNIQUE FEATURES

The following features are important: computational efficiency, defuzzification result continuity, design suitability, and compatibility with fuzzy system from an application point of view.

Under defuzzification result continuity is considered the following feature: small changes in membership values of the output fuzzy set should not give large changes in the results of defuzzification. This feature is important in the case of fuzzy controllers, which require input-output continuity: small changes of input parameters should give small changes of output values.

Computational efficiency depends mostly on a kind and a number of operations required for obtaining the result of defuzzification.

Design suitability expresses the impact of a defuzzification technique on a software or hardware implementation and tuning of fuzzy system.

Compatibility to the other operations used in a fuzzy system, like inference and composition, [3], may be important.

VI. THE OVERVIWE OF DEFUZZIFICATION TECHNIQUES

The most often used defuzzification techniques are grouped according to the basic methods used in them: a group is made of the basic technique and of the all techniques extended from that basic technique. Extended techniques differ from the basic ones by introduced additional parameters. A fuzzy system designer defines more precisely the defuzzification process by defining those additional parameters. In the general case, defuzzification techniques can be formulated in a discrete form (using Σ) or in a continuous form (using $\int$). For the sake of simplicity, only discrete form is considered in the paper. For each class of the techniques, the basic techniques are discussed having in mind the features given in Section IV.

(a) CENTER OF GRAVITY (COG) METHOD

The output fuzzy set membership function is treated as a distribution is the main characteristic of this method, for which the average value is evaluated. Due to that heuristic approach, the output has continuous and smooth change for the change of values of input variable in the universe of discourse. The *center- of gravity* technique, designated by COG and given by the following expression (10) , in the discrete form

$$y_0 = defuzzifier(B') = \frac{\sum_{i=1}^{N_q} B'(y_i) y_i}{\sum_{i=1}^{N_q} B'(y_i)} = cog(B') \qquad (10)$$

where: Nq is the number of quantizing samples yi, used in order to get the discrete form of the membership function $B'(y)$ of the output fuzzy set B'. The calculation of the value (1) requires $3 \cdot N$q -1 operations (the large number of multiplication and one division). This technique is less convenient for a hardware implementation, because it requires large number of multipliers, as well as it requires passing through the whole universe of discourse of the output variable. Nevertheless, due to continuity and, often, smoothness of changes of defuzzified values, this technique is used with fuzzy controllers.

(b) MEAM OF MAXIMUM

This method gives as a result of defuzzification an element from a fuzzy set core. A fuzzy set core (designated as *core*) consists of elements of a universe of discourse on which that set is defined with the highest degree of membership to the fuzzy set. As the basic representation is given by the expression (11):

$y0=\min core(B')=fom(B')$ (11)

Those techniques are convenient for the general fuzzy expert systems. They are computationally efficient: they require about 2· *N*q simple operations. Maxima techniques belong to the group of the fastest defuzzification techniques, because they require passing through values of the core, only.

VII. RESULT & DISCUSSION

The performance evaluation of the FLC based PMSM drives shown in Fig. 3 the results of two different dafuzzificetion methods. The output values obtained by the center-of gravity and by the mean-of-maxima defuzzification techniques were observed. The COG technique aggregates the influence of all rules in the result which is continually changing across the domain of the output variable, as the parameters of the model are changed. The MOM technique gives as the defuzzification value the point of the output domain with the maximum member-ship degree. It can be seen from figure that the defuzzification result obtained by the COG technique, is always sensitive to all rules, the change is smooth. When maxima technique is applied, there is the jump in the considered values.

Under consideration of discussed PMSM drives of the two FLC, the load rejection capability is shown in Fig.4 at rated speed 52.3 rad/sec. At time t=1 sec the step rated load is applied suddenly when the drive running at no load steadily. It is shown in the figures that the FLC with COG method gives the smooth output response as camper to MOM method.

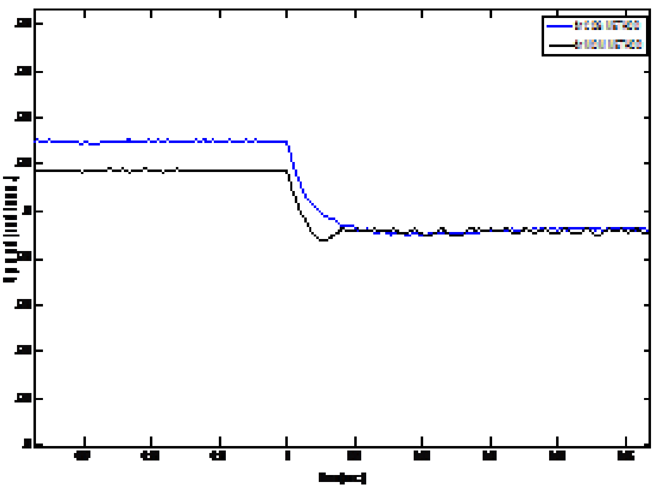

Fig.3. Load rejection capability of drive for two different defuzzification methods at speed of 52.3 rad/sec.

VIII. CONCLUSION

In this paper use two different defuzzification methods for compare the performance of indirect vector controlled technique for speed control of PMSM drives namely center of gravity (COG) and mean of maximum (MOM). The dynamic model of drive system has been developed in Simulink/MATLAB. It has been observed that the performance of drive system using COG method has been found excellent as far as performance indices have been concerned in comparison with the performance with MOM method. COG technique is less convenient for a hardware implementation, because it requires large number of multipliers, as well as it requires passing through the whole universe of discourse of the output variable. Nevertheless, due to continuity and, often, smoothness of changes of defuzzified values, this technique is used with fuzzy controllers.

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