International Journal of Technology and Engineering System (IJTES)
Vol 6. No.1 – Jan-March 2014 Pp. 21-26
©gopalax Journals, Singapore
available at : www.ijcns.com
ISSN: 0976-1345

# FUZZY LOGIC-BASED NONLINEAR SPEED CONTROL FOR PMSM SYSTEM USING SLIDING MODE CONTROL AND DISTURBANCE COMPENSATION TECHNIQUES

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## ABSTRACT

In order to optimize the speed-control performance of the permanent magnet synchronous motor (PMSM) system with different disturbances and uncertainties a nonlinear speed control algorithm for the PMSM servo systems using sliding mode control and disturbance compensation techniques is developed in this paper. The fuzzy logic controller is used to control a speed of motor for keeping the motor speed to be constant when the load varies. A reduced switch inverter topology is presented, which reduces the cost and complexity of switching logic. A sliding mode control method based on sliding mode reaching law (SMRL) is applied this SMRL can dynamically to the variations of the system controlled and chattering reduction control input. Then, an ESMDO is to compensate strong disturbances and achieve high servo precisions.

**Keywords**—Fuzzy sliding mode controller, Permanent magnet synchronous motor (PMSM), Sliding mode reaching law (SMRL), Reduced switch inverter.

## 1. INTRODUCTION

In the permanent magnet synchronous motor (PMSM) has been used widely in various industry fields and has advantages such as its high torque to inertia ratio high efficiency and superior power density. The proportional integral (PI) control technique based on the field-orientation control is very popular and useful for a PMSM control with a precise mathematical model. However it has unavoidable uncertainties caused by parametric variations and unstructured dynamics in a practical PMSM [12]. These uncertainties caused by parametric variations are more serious at high speed operation, since the variations of flux linkage and stator inductance are proportional to the product of operating speed and these parameters Moreover, the parametric variations under different temperature or operating conditions will also make a PMSM model inaccurate [1]. To obtain high performance and system robustness, advanced motor controllers are necessary. Sliding mode control (SMC) Systems are well known for their invariant properties to certain internal parameter variations and external disturbances, and have been successfully applied in many fields. In the performance of a sliding-mode controller is studied using a hybrid controller applied to induction motors via sampled closed representations [13], [5], [10]. The results were very conclusive regarding the effectiveness of the sliding mode approach. The proposed sliding mode fuzzy is used in the speed control design for PMSM Compared to the conventional PI controller the proposed sliding mode speed controller of PMSM based on the external sliding mode reaching law can improve the dynamic performances and robustness Characteristics of speed servo system and reduced switch inverter use. Fuzzy sliding mode controller (FSMC) is a nonlinear controller based on sliding mode method when fuzzy logic methodology applied to sliding mode controller to reduce the high frequency oscillation (chattering) and compensate the dynamic model of uncertainty based on nonlinear dynamic model .The SMC has a good condition but the main drawback compared to FSMC is calculation the value of sliding surface slope coefficient predefined very carefully and FSMC is more suitable for implementation the system stable condition and insensitive external disturbance reduced. The Controller is a device which

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can sense information from linear or nonlinear system to improve the systems performance [8]. The main targets in designing control system are stability and good disturbance rejection, and small tracking error. In order to solve the aforementioned problems, a novel reaching law, which is based on the choice of an exponential term that adapts to the variations of the sliding-mode surface and system states, is proposed in this paper [5], [9]. This reaching law is able to deal with the chattering and reaching time formulates based on the reaching law presented, a SM speed controller of PMSM is developed. Then to further improve the disturbance rejection performance of the SMC method and ESMDO [12]. Thus, a composite control method combining

An SMFC part and a feed forward compensation part based on ESMDO, called SMFC+ESMDO method, is developed. Finally, the (ESMDO) is proposed, and the estimated system disturbance is considered as the feed forward compensation part to compensate sliding-mode speed controller effectiveness of the proposed control approach was verified by simulation and experimental results. The FSTPI structure generates four active vectors in the plane, instead of six, as generated by the 6-Switch three phase inverter topology and reduced switch count voltage source inverter [four switch three phase voltage source inverter uses only two legs, with four switches. 2.1

The FSTPI structure regarding inverter performance and switching control this paper presents a general method to generate pulse width modulated (pwm) signals for control of four-switch, 3 phase voltage source inverters(VSI) When the voltage oscillations is across the two dc-link capacitors [11]. The method is based on the space vector modulation and includes the scalar version this permits to implement all alternative and thus allowing for a fair comparison of the different modulation techniques. The proposed method provides a simple way to select and the either three or four vectors to synthesize the desired output voltage during the switching level period. In the proposed approach, the selection between three or four vectors is parameterized by a single variable .

The influence of different switching patterns on output voltage symmetry current waveform and switching frequency and the common mode voltage is examined. The paper is also discusses how the use of wye and delta connections of the motor windings affects the implementation of the pulse width modulator. It is possible to solve this problem by combining fuzzy sliding mode controller and fuzzy rule base tuning the simulations and experimental results are presented to allow not in the method.

## 2. PMSM NONLINEAR MODELING

***Electrical System***

The permanent magnet synchronous motor is an AC sinusoidal back-EMF induced and the Compared to the BLDC motor. It has minimum torque ripple because the torque Pulsation associated with current communication do not exist. A carefully designed machine in combination with a good control technique can yield a low level of ripple (<2% rated), which is attractive for high- performance motor control applications such as machine tool and servo applications.

The electromagnetic torque can be written as

$$T_e = 3/2\ [\ P/2\ (\ \lambda'^{r}_{m}\ i^{r}_{qs} + (\ L_{ds} - L_{qs}\ )\ i_{qs}\ i_{ds}\ )\ ]........(1)$$

From (1), it can be seen that torque is related only to the d-axes and q-axes current. Since Lq ≥ Ld (for surface mount PMSM, both of inductances equal), the second item contributes a negative torque if the flux wekening contrl has been used. In order to achive the maximum torque/current ratio. The d-axis current is set to zero during the constant torque control so that the torque is propotional only to q-axis current. Hence, this results in the control of q-axis current for regulating the torque in rotor reference frame.

***2.2 Sliding Mode Design***

The controller design procedure consists of two stepladders, first a feedback control law u is select to verify sliding condition However, in order to account for the presence of modeling imprecision and of disturbances the control law has to be discontinuous across S (t). Since the implementation of the associated control switching is imperfect, this leads to chattering is an undesirable practice method since it involves high control activity and may excite high frequency dynamics neglected in the modeling. Thus, in a second step, the discontinuous control law u is suitably smoothed to achieve an optimal trade-off between control bandwidth and tracking precision. The first step achieves robustness for parametric uncertainty; the second step achieves robustness to high frequency un modeled dynamics. This section discusses the first step. Consider a simple second order system

$$\ddot{X}\ (t) = f(x, t) + u\ (t) \qquad ……………. (2)$$

Where f (x, t) is generally nonlinear and/or time varying and is estimated as u (t) is the control input, and x (t) is the state to be controlled so that it follows a desired trajectory xd (t).

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**Alternate approach**

In both of the examples, we use in the existing trajectories and the two original dynamics so that the goal is achieved. There is another approach to create new trajectories.

Consider the case

$$\psi = \begin{cases} +1 \\ -1 \end{cases} \quad \text{in different parts of state space}$$

and introduce the line $s = cx_1 + x_2 \quad \Rightarrow \quad 0 < c < 1$

Consider $cx_1 + x_2 = 0 \quad \Rightarrow \quad x_2 = -cx_1$
differential equation on $s = 0$ or $y = -cy$

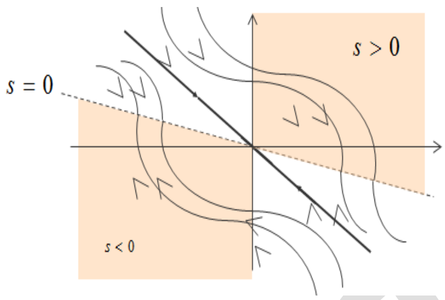


**Figure. 1**

*Variable structure control*

Than

$$\text{Choose} \quad \psi = \begin{cases} +1 & \text{if} \quad x_1 s > 0 \\ -1 & \text{if} \quad x_1 s < 0 \end{cases}$$

$(\alpha)$ for all initial conditions, the trajectories will reach $s = 0$

$(\beta)$ after reaching $s = 0$, the trajectory will slide away $s = 0$

according to $\dot{x}_1 = -cx_1$

To the equilibrium 0=> asymptotic stability since, the coefficient of the equation does not depend on the system parameter (or perturbation on, if any) the system invariant, not sensitive to parameter or perturbation.

2.2.3 Robustness and discontinuous Nonlinearity

- Robustness to uncertainties during reaching phase forcing trajectories toward sliding manifold maintaining them on the manifold.

This task is affected by matched and unmatched uncertainty $\dot{\eta} = f(\eta, \phi(\eta)) + \delta_\eta(\eta, \phi(\eta))$

During sliding phase:

- Discontinuous nonlinearity in SMC theoretical issue uniqueness & existence and practical issue chattering in due to imperfect switching devices and delay fig2.

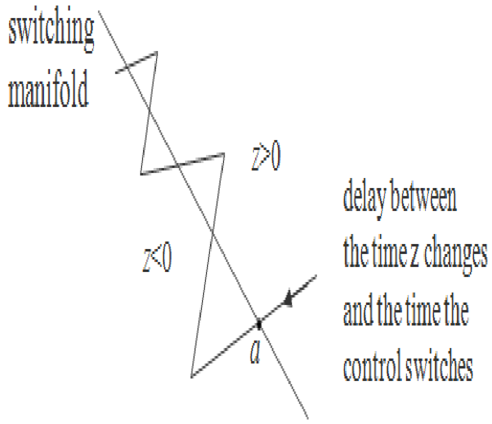


**Figure. 2**

***Chattering Effects***

Chattering $\rightarrow$ low control accuracy
high heat losses in electrical power circuits
high wear of mechanical parts

To eliminate, the $v$ will be

$$v_i = -\frac{\beta(\eta, \xi)}{1-k} \operatorname{sat}\left(\frac{z_i}{\varepsilon}\right) \qquad 1 \le i \le p \text{ and } \varepsilon > 0$$

where $\beta(\eta, \xi) \ge \rho(\eta, \xi) + b, \quad \forall(\eta, \xi) \in D$

$$\operatorname{sat}(y) = \begin{cases} y & \text{if } |y| \le 1 \\ \operatorname{sgn}(y) & \text{if } |y| > 1 \end{cases}$$

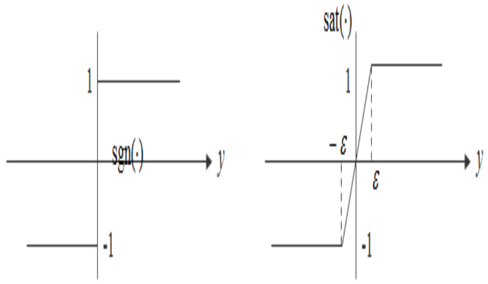


**Figure. 3**

***Fuzzy Logic Controller***

The point of fuzzy logic is to map an input space to an output space and the primary mechanism for the doing this is a list of if then statements called rules. A membership function (MF) is a curve that defines how each point in the input space is mapped to a membership value (or degree of membership) between 0 and 1.

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**Table 1 Fuzzy Function**

| e / Δe | NL | NS | ZE | PS | PL |
|---|---|---|---|---|---|
| NL | NL | NL | NM | NS | ZE |
| NS | NL | NM | NS | ZE | PS |
| ZE | NM | NS | ZE | PS | PM |
| PS | NS | ZE | PS | PM | PL |
| PL | ZE | PS | PM | PL | PL |

There are seven clusters in the membership functions, with seven linguistic variables defined as Negative low (NL), Negative Medium(NM) Negative small (NS), zero Enable (ZE), Positive Small (PS), Positive Medium(PM) , Positive Low (PL). Table1the process input state variables are chosen as the error signal e between the actual and the desired speed and the change in error signal (Δe). The fuzzy output variable is chosen as the corrective control signal uc. First, inputs and outputs of the fuzzy controller are determined. Here it has two inputs (e, e^ ) and one output ($V$f). The input $f$ is the error which measures the difference between desired and actual input the input fuction is the change in error and Second, an appropriate membership function (MF) should be selected. By using different MFs it was concluded that triangular MFshape has the best output response in this experiment. The membership function fig.4 of the two inputs and one output of the fuzzy controller.

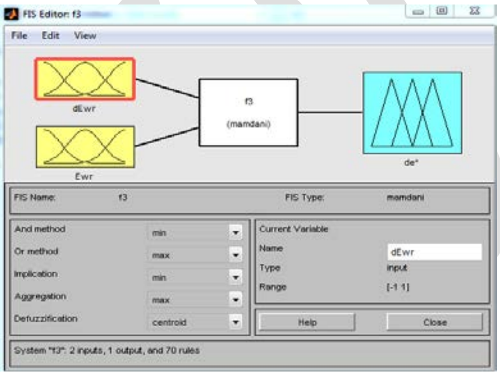


**Figure. 4 Fuzzy interface mamdani function**

### *Reduced Switch Inverter*

The PMSM has been utilized as a workhorse in the industry due to its easy and the high robustness, and generally developed efficiency. By tradition, 6 switch three phase inverters to have been widely used for variable speed PMSM drives. The last work on FSTPI for PMSM drives investigated the performance of a 4-switch, 3-phase inverter fed cost effective PMSM motor in a real time to has been implemented by vector control .

## 3. SIMULATION AND EXPERIMENTAL RESULTS

### *Parameter of PMSM*

The Permanent magnet synchronous motor consider the simulation value are following the fig.5

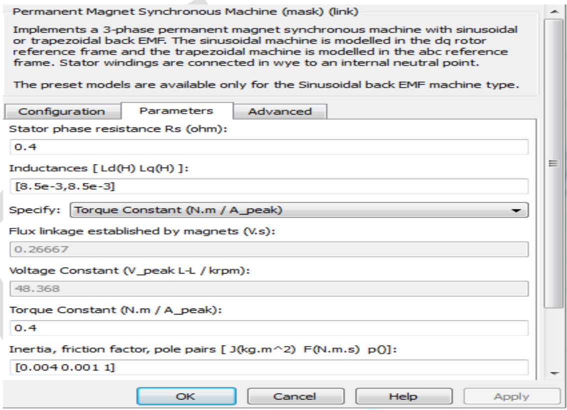


**Figure. 5 Simulate value of PMSM**

**Proposed Block Diagram**

The permanent magnet synchronous motor (PMSM) system with different disturbances and uncertainties a nonlinear speed-control algorithm for the PMSM servo systems using sliding-mode control and disturbance compensation techniques is developed in this paper. The fuzzy logic controller is used to control a speed of motor for keeping the motor speed to be constant when the load varies. A reduced switch inverter topology is presented, which reduces the cost and complexity of switching logic mention the fig.6

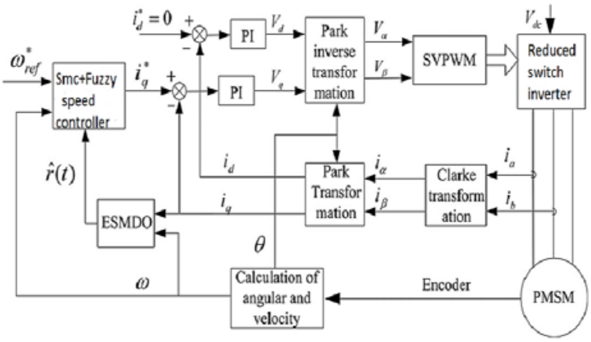


**Figure. 6 Proposed block diagram**

### *Simulation Diagram*

Fig.7 Shows the Matlab simulation diagram of the sliding mode Fuzzy logic controller and developed in

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the Matlab model is use to observe in the phase current waveforms, speed, torque and angular displacement.

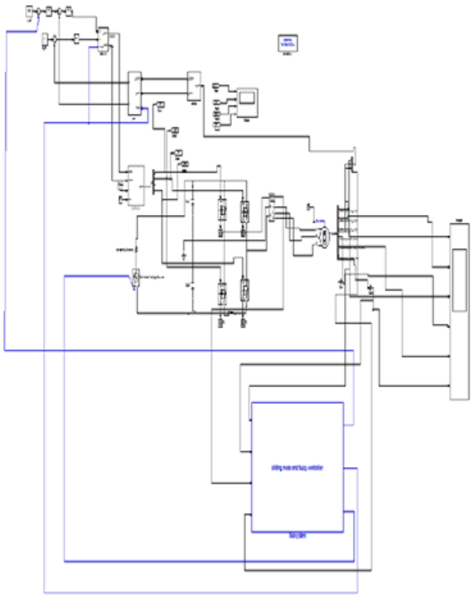

**Figure. 7 Matlab simulation diagram of smc + fuzzy logic controller**

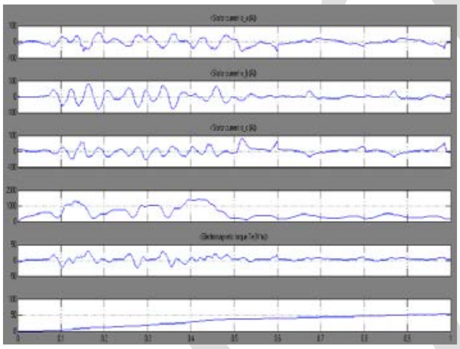

**Figure. 8 the stator current, speed, torque, displacement angle**

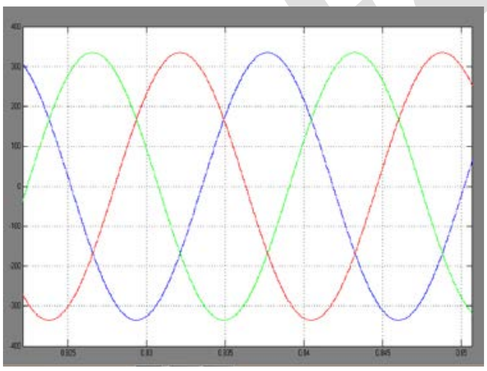

**Figure. 9 120 Phase sifting inverter voltage**

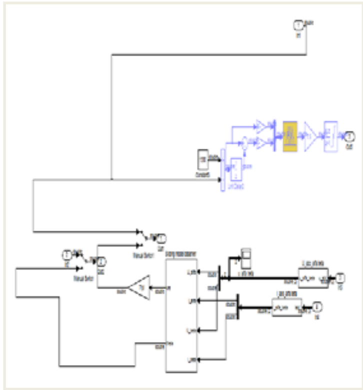

**Figure. 10 Interfacing circuit for sliding mode fuzzy logic control**

Fig.10 is respectively the tracking error curve and the control input curve when the classical sliding mode fuzzy logic control is used. Fig.11 and the represented waveform in alpha beta controller input.

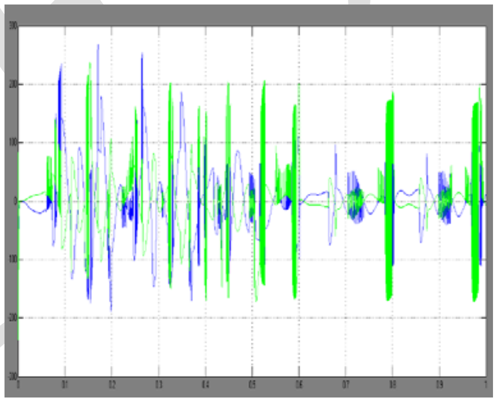

**Figure. 11 Simulate controller input voltage**

## 4. CONCLUSION

As a conclusion, the increasing demand for using sliding mode fuzzy logic as a controller for modern intelligent motion control of PMS motors, both simulation and experimental set-up have provided a good dynamic performance of the fuzzy logic controller system. The speed of the PMSM motor is detected by accurately instead of the usual, expensive and complicated encoder system. Besides, SMFC reasoning algorithm designed to control PMSM to get the optimum control under the unstable rotor turning situation or sudden load change, the proposed fuzzy logic controller system has a good and strong robustness whenever the system is disturbed. The proposed FSTP inverter fed PMSM drive is found acceptable considering its cost reduction and other advantageous features. The simulation model which is implemented in a

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ISSN: 0976-1345

modular manner under MATLAB environment allows dynamic characteristics and the mechanical torque, rotor speed, and phase currents to be effectively considered. The result paired with MATLAB/SIMULINK is a good simulation tool for modeling and analyzing sliding mode fuzzy logic controlled permanent magnet synchronous machine drives.

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