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An Adaptive Direct Torque Control of Permanent Magnet Synchronous Motor by using Fuzzy-Sliding Mode Control Method

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Abstract – **Permanent magnet synchronous motors (PMSMs) are recognized to be very efficient machines and replace induction machines in several applications slowly. PMSM are non-linear, consisting of time specific parameters with complicated dynamics of high order. High performance applications of PMSMs require their speed controllers to provide a fast response, precise tracking, small overshoot and strong disturbance rejection ability. Our goal is to emphasize different sliding surface designs and composite control designs for SMC execution with the objective of strengthening and/or reducing the chattering of the control system. This control technique includes super twisting algorithms, direct torque control and space vector modulation, which are aimed to address noticeable problems, such as the huge flux connection and torque in standard DTC, and typical sliding mode control. A type of Fuzzy sliding mode control (FSMC)-based torque control and speed controller has been devised to adjust the torque angle and speed, to increase the dynamic response period and boost the performance of the torque against external load disturbances and motor parameter change. The torque controller is designed based on a sliding mode controller with an asymmetric boundary layer to reduce the overshoot. The effect of the proposal DTC based FSMC approach has been validated by MATLAB/SIMULINK simulation results.**

Keywords – **PMSM, SMC, Fuzzy logic, SVM.**

I. INTRODUCTION

Permanent magnet synchronous machines (PMSMs) have wide range of industrial uses including hybrid power vehicles, robotics and wind turbines. This can be explained by desirable performance features including high power density, elastic load balancing rate, high reliability and good efficiency. In literature studies a number of PMSM control approaches have been established. There are two typical ways to implement the high-performance motor operating, the field-oriented control (FOC) and the direct torque control (DTC). In contrast to FOC, the typical DTC uses two regulators of hysteresis and a switching table directly for the management of the electromagnetic torque and stator flux connections. DTC technique therefore benefits from easy implementation, fast dynamic reaction and strong robustness against fluctuation of motor parameters and external disturbances. Although the PI controls remain a popular choice because they are simple and easy to use, disturbances and uncertainties do not take them into account, which contribute to poor performance.

In the past, due to their simple implementation, a proportional integral (PI) control technique based on the field orientation control is commonly utilized. In practice, however, the system faces inherent uncertainties due to parameter fluctuations, unstructured dynamics and load disturbances, which make the achievement of high-precision control requirements very challenging for the PI controller. Advanced motor controllers are therefore required to achieve high performance and system reliability. Method of Space Vector Modulation (SVM) to constantly reduce torque ripple with the inverter frequency. Instead of using a hysteresis regulator to manage stator flux and torque, this approach commonly uses PI regulators, although the selected regulator has a weak strength problem.

In order to increase the performance of PMSM drives, nonlinear and resilient control approaches with the ability to reject disruptions have been implemented. Sliding mode control (SMC) is one such way. SMC approach has also been widely used for its advantages of easy application, strong robustness and rapid reaction among these non-linear methods of control. The robustness of SMC can be achieved in true applications only by massive control gains; this, however, makes the inherent limitations of SMC worse, which affects the system performance significantly.

A study comparing conventional PI controller with design Fuzzy logic controller shows a strong performance from the fuzzy logic controller. The basic goal in these works is to smooth down the control over the sliding surface. This is done by replacing the PI speed controller with an SM controller to make the control of PMSM unlike the fluctuation of parameters. A Fuzzy logic algorithm, however, is used to modify the weight of the SM gain, in order to keep the SMC performance and to reduce the chattering impact in the constant state, it can be taken to substantially beyond the standard value in the transitional phase.

II. SYSTEM MODELING

In the d-q rotating reference frame, the dynamic model of the PMSG, the q-axis is 90 ahead of the d-axis in terms of rotary direction. In the d-q synchronous frame, the Electric PMSG model is provided by Voltage and Torque Equations:

$$v_d = R_s i_d + \frac{d\varphi_d}{dt} - \omega\varphi_q$$

$$v_q = R_s i_q + \frac{d\varphi_q}{dt} + \omega\varphi_d$$

$$\varphi_d = L_d i_d + \varphi_f$$

$$\varphi_q = L_q i_q$$

As the electromagnetic torque is indicated as:

$$T_e = \frac{3}{2} p\left[\varphi_f i_q + \left(L_d - L_q\right) i_d i_q\right]$$

Furthermore, the second Newton law permits the following mechanical equation to be derived:

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

The status equation of the synchronous permanent magnet motor is so as follows:

$$\frac{di_d}{dt} = -\frac{R_s}{L_d} i_d + \frac{pL_q}{L_d}\omega_r i_q + \frac{1}{L_d} v_d$$

$$\frac{di_q}{dt} = -\frac{R_s}{L_q} i_q - \frac{pL_d}{L_q}\omega_r i_d - \frac{p\varphi_f}{L_q}\omega_r + \frac{1}{L_q} v_q$$

$$\frac{d\omega_r}{dt} = \frac{3p}{2J}\left[\varphi_f i_q + \left(L_d - L_q\right) i_d i_q\right] - \frac{B}{J}\omega_r - \frac{T_L}{J}$$

Sliding mode control is an inherent robustness, flexibility of the layout, and relative ease of application in microprocessor systems make the non-linear control approach attractive. Control of the sliding mode uses a stop-control strategy, which shifts quickly from one continuous multiplier to the other, driving the system dynamics to a preset place in the state space called the sliding surface.

Consider the nonlinear system of switching:

$$\dot{x}(t) = g(x(t)) + h(x(t)) \cdot u(t)$$

Fig.1 shows the schematic diagram of the PMSM based on FSMC.

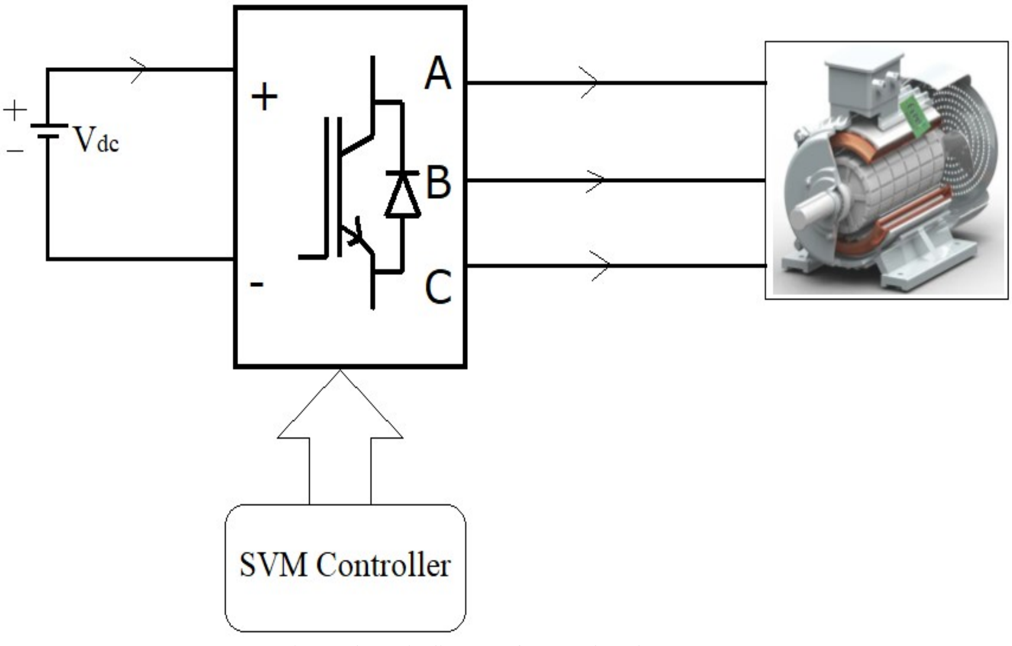

Fig.1: schematic diagram of PMSM based on FSMC.

Sliding mode control is simple to implement; it is based on state-space equations from the system examined and strong against external perturbations and changes in processes. The Variable Structure Controller (VSC) for Sliding Mode Control is also recognized because it is discontinuous. The objective at VSC is to provide a user-defined surface termed a sliding surface to the plant states.

The control law is therefore determined accordingly:

$$v_d^* = R_s i_d - pL_q\omega_r i_q - k\,sign\left(S\left(i_d\right)\right)$$

The control law includes a discontinuous period that guarantees the attraction of stability and sliding control. However, depending on the value of k it causes ripples. A fuzzy logic strategy is provided to reduce this gain. Fig.2 describes the PMSM's fuzzy sliding mode control system.

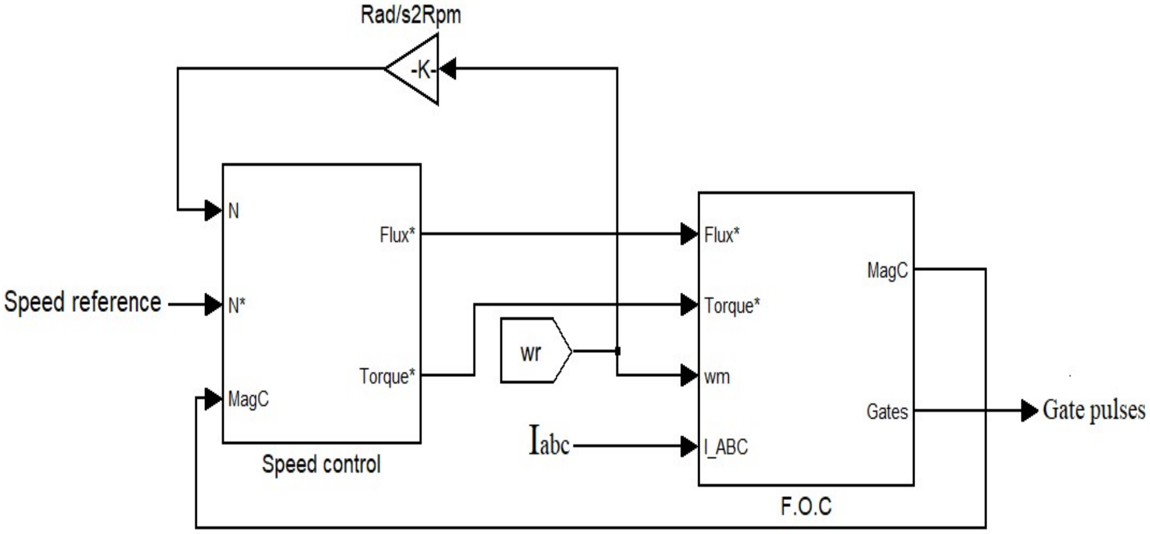

Fig.2: Control block diagram of PMSM based on FSMC.

III. SIMULATION RESULTS

Here we examine the control of PMSM by comparative analysis of DTC, DTC-SMC and FSMC methods by using MATLAB/SIMULINK simulation results. The motor parameters and the control time for all simulations are adjusted to the same in order to compare the performance of the proposed system with existing methods.

Table.1: Parameters of PMSM

Parameter	value
Pole Pairs(P)	4
Stator Phase Resistance(Rs)	1.2 Ω
Flux linkage	0.175 Wb
Friction Factor(F)	0.001 N.m.s
Moment of Inertia(J)	0.0008 kg.m^2

In all simulation conditions, we are taken as values about reference flux (0.3Wb) and reference speed (600 rad/s) and also the load torque is changes to T_L = 0 N.m to T_L = 1.5 N.m. The simulation waveforms represent the torque, rotor speed and flux linkage for different models are shown in figures. The total simulation time taken as 0.4 sec, as from 0 to 0.2 sec the system performance has a good dynamic response. When suddenly load torque changes to 1.5 N.m, the ripple of torque and flux in system is large. Here we can observe that the ripple of flux linkage and torque is lower when implemented proposed method with conventional methods and we get the good dynamic response.

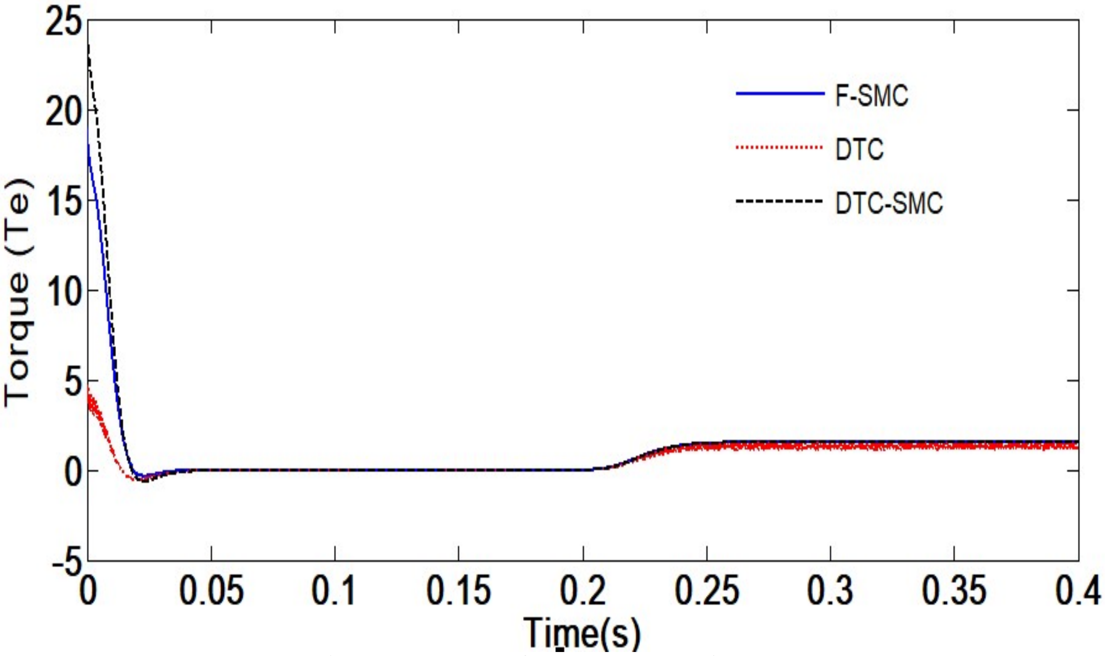

Fig.: Torque response of DTC, DTC-SMC and FSMC.

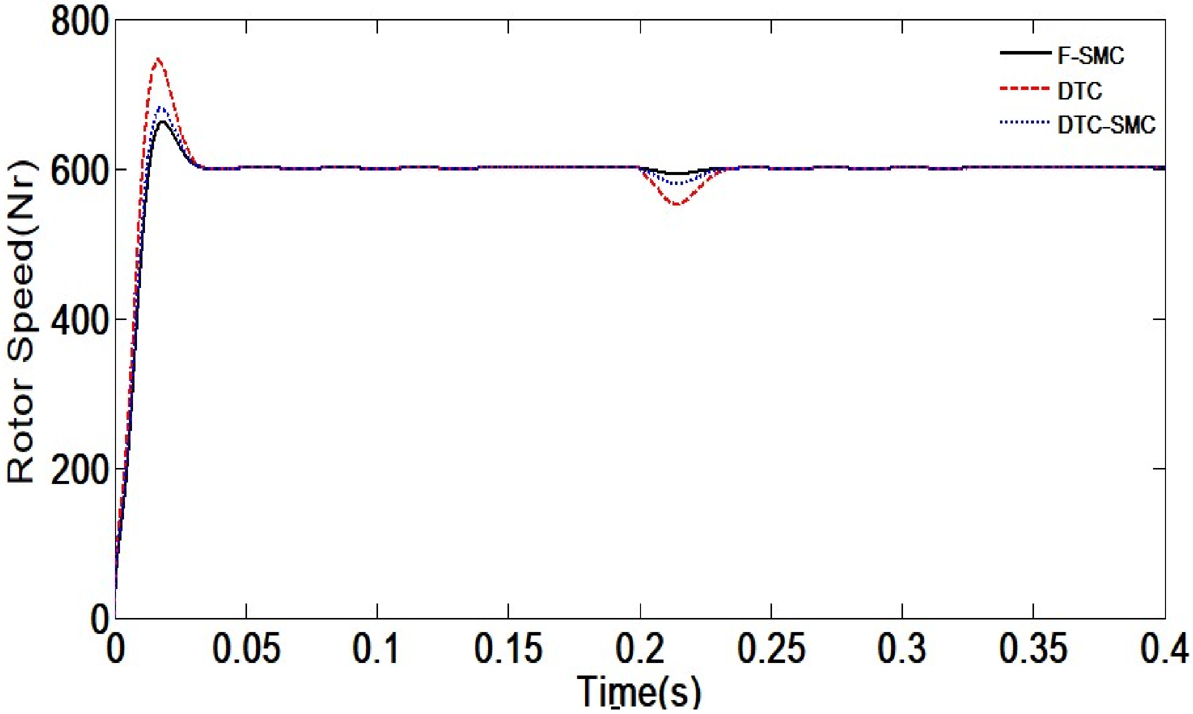

Fig.: Rotor speed response of DTC, DTC-SMC and FSMC.

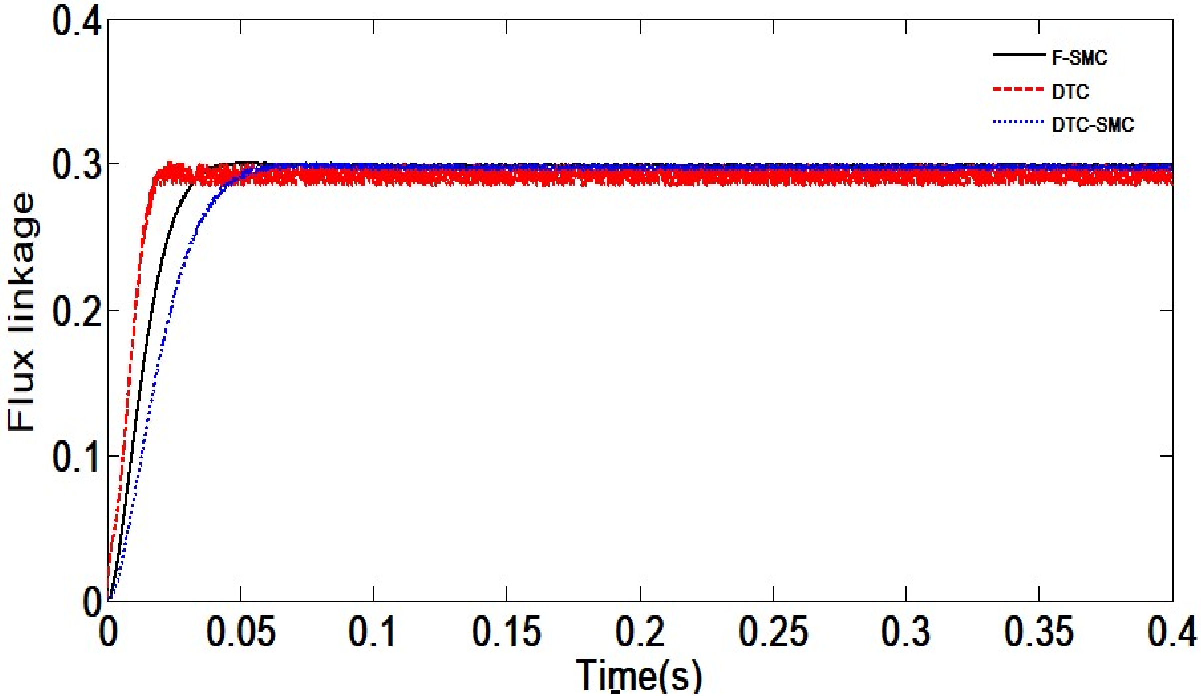

Fig.: Flux linkage response of DTC, DTC-SMC and FSMC.

CONCLUSION

The main characteristics required in PMSM speed control are load changes and sensitivity to mechanical motor parameters. It proposes the permanent magnet-synchronous motor control system based on FSMC to solve the weak limitations in the control of DTC-SVM and the chattering issues of the conventional SMC. The analysis reveals that the suggested technique minimizes the torque and flux linkage ripple, improves the response speed and has a very robust performance with regard to changes in system parameters.

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