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A second order sliding mode control design of a switched reluctance motor using super twisting algorithm

Muhammad Rafiq [a,*], Saeed-ur Rehman [b], Fazal-ur Rehman [a], Qarab Raza Butt [b], Irfan Awan [c]

[a] *Muhammad Ali Jinnah University, Islamabad, Pakistan*
[b] *Centre for Advanced Studies in Engineering (CASE), Islamabad, Pakistan*
[c] *School of Computing, Informatics and Media, University of Bradford, UK*

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ABSTRACT

A novel robust technique for speed control application of variable reluctance motor is proposed. The suggested scheme is model based and uses a mathematical model of an SR motor, and Second Order Sliding Mode Control (SOSMC) with Super-Twisting algorithm. Sliding mode controllers for SR motor were reported before but super twisting SOSMC have an added advantage of reduced chattering which is one of the main focuses of this work. The proposed controller gives fast dynamic response with no overshoot and nearly zero steady state error. The effectiveness of the proposed controller and its robustness to parameter variations is also confirmed by simulation results.

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1. Introduction

Switched Reluctance Motors (SRMs) have gained considerable attention due to its robust, and simple mechanical construction, high efficiency, and ease to maintain a high torque at low speed. Due to its mechanical design structure an SR motor is very suitable for operations at high speed [1]. SRMs are typically operated in magnetic saturation and phase torque is a highly nonlinear function of phase current and rotor position. Many nonlinear control techniques have been proposed for the control of SRMs. Sliding mode is one of these techniques and has gained much popularity in such applications due to its simple structure, intrinsic robustness and potential to control nonlinear systems [2]. This technique has been applied on various engineering problems (for example [3]). In [4,5], sliding mode control was reported for SR motor to regulate its speed but their research did not cater for magnetic saturation.

SR motor has inherently a problem of torque ripples particularly in variable speed application. Sliding mode technique has provided ripple free torque for SR motor (see for example [6–8]). Ref. [9] designed flux linkage controller for SR motor to reduce torque ripple. The proposed controller was based on integral sliding mode technique. Both the properties of PI and sliding mode controls were incorporated in the controller and better results were reported. A similar attempt was also made in [10] to minimize torque ripples in SR motor. The controller was designed to remove the low frequency oscillations and further it was applied for speed regulation problems and was shown to be more efficient and robust than conventional controllers. Ref. [11] used the idea of dynamic sliding mode technique for speed regulation of SR motor. The performance of the designed controller was shown to have chattering reduction in output.

* Corresponding author. Tel.: +447438577950.
E-mail addresses: rafiq_mufti@yahoo.com (M. Rafiq), I.U.Awan@Bradford.ac.uk (I. Awan).

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The conventional sliding-mode control experiences inherent problem of chattering. A number of techniques have been introduced in the literature for chattering reduction, i.e. one of the techniques is the use of Fuzzy Sliding Mode Control (FSMC) [12]. Another popular technique for the chattering reduction is the use of Higher Order Sliding Mode (HOSM) control [13]. HOSM has been used for a number of engineering problems [14–18]. Ref. [19] investigated HOSM technique and employed it on DC motors having less data about system parameters showing its better performance. Ref. [20] proposed HOSM controller for a class of MIMO nonlinear uncertain systems. The effectiveness of the proposed controller was shown through experimental results. Ref. [21] used the same system and designed HOSM observer to suppress chattering inherent in conventional sliding mode technique. Application of HOSM control on induction motor was also reported in [22–24] for various purposes. In [23,24], HOSM based observer was used for speed tracking problems. The system parameters like magnetic flux, angular velocity, stator phase current and load torque were estimated by the observer by eliminating the need of mechanical sensors.

The paper is organized as follows: In next section, control oriented mathematical model of the SR motor is described along with commutation scheme. Higher order sliding mode is briefly explained in Section 3, with brief details of super twisting controller design algorithm. Second order super twisting controller design for both regulation and tracking controls is proposed in Section 4. Simulation results are discussed in Section 5, and Section 6 concludes the work presented in this paper.

2. Mathematical model of SR motor

In order to study the dynamics of SR motor and to synthesize its controllers, a mathematical model of the system is required. A lot of work has been done on modeling and design of SR motor. Several numbers of techniques have been found in literature for estimating the motor parameters [25–28]. The mathematical model used in our work is a specific 3-phase commercial SR motor whose parameters are listed in Section 5. This model has been taken from [29]. The model consists of electrical and mechanical dynamical subsystems which is given in state space form as:

$$\frac{d\theta}{dt} = \omega \tag{1}$$

$$\frac{d\omega}{dt} = \frac{1}{J}(T_e - B\omega - T_L) \tag{2}$$

$$\frac{di_j}{dt} = \left(\frac{\partial\lambda_j(\theta, \mathbf{i}_j)}{\partial i_j}\right)^{-1}\left(u_j - \mathrm{R}i_j - \omega\frac{\partial\lambda_j(\theta, \mathbf{i}_j)}{\partial\theta}\right) \tag{3}$$

where j = 1, 2, 3 represent the phase number and

θ	Rotor position
J	Moment of inertia (rotor)
B	Coefficient of friction
i_j	Current in the jth phase
u_j	Voltages of jth phase = $[u_1 \quad u_2 \quad u_3]^T$
T_e	Total electromagnetic torque = $\sum_{j=1}^{3} T_j(\theta, \mathbf{i}_j)$
ω	Angular velocity of rotor
T_j	Electromagnetic torque of the jth phase
T_L	Load torque
λ_j	Flux linkages in jth phase
R_j	Resistance to the jth phase = R

2.1. Commutation scheme

The mathematical model of a three phase 6-Stator and 8-Rotor poles Switched Reluctance (SR) motor is used. In this configuration, an electrical angle of 2π radians is equivalent to $\pi/4$ radians rotation of mechanical angle. This mechanical angle of $\pi/4$ radians is further divided into 12 regions ranging from R1 to R12 as explained above. In region R1, positive torque is produced via phase B, while phase C and phase A provide negative torques. Similar phases are energized for region R2. In R3, phases B and C provide positive torque while negative torque is produced by phase A. So if the positive torque is required, only the phases B and C should be energized that may give higher net torque instead of energizing all phases which will collectively give less net torque due to the counter effect of negative torque produced by phase A in this region. On the other hand, if only negative torque is required, only phase A should be energized. There is no need to energize phases B and C due to their positive torques in the region, which will ultimately increase the net torque. A similar pattern is adapted in remaining regions and only one or at the most two phases of desired polarity are energized. From the above discussion it is clear that torque depends upon the rotor position. Ultimately the proposed scheme will save net power, which will increase the system efficiency.

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