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Design and Development of Sensorless Vector Control of Switched Reluctance Motor using Fuzzy Logic Controller

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Switched reluctance motor (SRM) drive has gained popularity in high-performance motion control applications where high speeds and soft torque are required. Nevertheless, presence of flux harmonics in the air gap results in unattractive torque ripples. The torque ripples deteriorate the performance of the high-performance drive applications. In this paper the speed of the SRM drive is controlled by using sensorless vector control. Flux in the motor is estimated by an estimator and the switching of the inverter is modulated by the vector control. To reduce the ripples in the torque, fuzzy logic controller is used. Rule based fuzzy controller is developed by considering error and change in error as inputs. The proposed system is validated by changing the load of the drive. Results obtained are found be acceptable and torque ripples are minimized significantly.

Keywords: Fuzzy controller, Load, Torque ripples

Introduction

In recent years, the Switched reluctance motor (SRM) has been a rejuvenated intriguing research subject. The SRM has a precise mechanical structure and is robust in nature. It suits in cases for high temperature and high speed. The rotor circuit is opened with the end goal of SRM flux linkage is legitimately corresponding to stator current. Consequently, the motor torque is constrained via altering the flux.[1,2] In any case, the fundamental drawback of this motor is the parasitic torque ripple.[3–5] These torque ripples are for the most part brought about by cogging, current scaling, harmonics and current offset. Nearness of these torque ripples brings abrupt torque which intermittently varies based on position of the rotor. These ripples are indicated in the motor speed as periodic motions, especially at nominal speed movement.

Switched Reluctance Motor

At higher driving velocities, torque ripples are commonly filtered due to inertia of rotor and load and in this way, are not indicated back in the motor speed.[7] Be that as it may, direct-drive servos without mechanical gears, the motor drive demands to function at low speeds. Furthermore, these speed motions severely impede the operation of the servo especially in sharp precision studies. Additionally, the mechanical vibrations are produced by the oscillations on the load side.[6–9]

In SRM, the ripples in torque are the main source for the generation of harmonics in air gap flux. In genuine SRM, it is difficult to analyse the distribution of flux in the air gap and expose to assembling resiliencies. These outcomes in a rudimentary sinusoidal flux concentration distribution appropriation, when it interfaces with the absolutely sinusoidal stator flows offers ascend to intermittent torque swells.[10–12] The cogging torque in addition becomes another cause of torque ripples. The variable magnetic hesitance between the rotor and stator slots causes cogging torque essentially. Also, due to current estimation errors the torque ripples increases (offset and scaling errors).[10–14]

Lately, there are basically two essential methodologies for reducing the torque ripples: One approach is by enhancement of seductive motor design and alternatively by employing improved electronic control circuit. Machine designer can change the stator and pole structures to reduce, yet just to the detriment of motor performance. The electronic procedure depends on deciding the working parameters in an ideal blend, which incorporate the

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voltage input, edged on and off cycles, current magnitude and shaft load. It is noticed that normal torque reduces because of reduced torque ripples. The motor competencies based of rotor position have been not used effectively. When all is said in done, it tends to be expressed that torque improvement and ripple minimization can't be accomplished at the same time by electronic control.[8]

This analysis suggests a different control design which aims of limiting intermittent speed ripples started by torque ripples to achieve the steady state quickly. In a prior paper[9,10], of SRM drive the writers have just detailed the prolific utilization of the fuzzy logic for control of torque. Whereas this paper discusses about the external loop speed control using fuzzy controller, in the interior control loops conventional PIC controllers are adopted to generate control voltages.

SRM Drive

The SRM is an electrical machine which has stator and rotor. Stator is wounded with multiple windings; number of windings in SRM depends on the type of supply. Unlike induction motor, rotor in SRM is a laminated salient pole structure. When stator is energized the magnetic flux produced reacts with the rotor. Rotor is attracting to the energized stator pole. The attraction force between magnetic field generated in the stator and rotor causes torque.

Magnetic circuit is shaped with rotor and the invigorated stator post. In the magnetic circuit, reluctance diminishes as the rotor lines up with the stator poles. The profile of inductance SRM is triangular in shape, with most extreme inductance when it is in an adjusted position and least inductance when unaligned. At the point when the voltage is applied to the stator stage, the motor produces torque toward the increasing inductance. At the point when the phase is re-energized in its least inductance position, the rotor moves to the anticipated situation of most extreme inductance. The shape of the magnetization characteristics together with the phase current, characterizes the generated torque and accordingly the speed of the motor.

The necessity of unipolar current have particular bit of leeway in that because for control of current in phase winding one semiconductor switch is sufficient. Such an attribute enormously lessens the quantity of converter switches which marks the SRM drive conventional. The rotor can be turned around by altering the excitation sequence of stator. Torque and speed control is accomplished with converter control. A controlled converter is required by this machine for its activity and does not work legitimately from three phase power supply.

The scientific model of a SRM in d-q synchronous frame can be communicated as[1–6], the instantaneous voltage applied to the progressing phase of motor as in Eq. (1),

$$V_i = Ri_i + \frac{d\psi_i(\theta,i_i)}{dt}, \text{ i = \{1,2,3,4\}} \qquad \dots (1)$$

In SRM, magnetic saturation is effected due to double salience way of construction; due to this the flux related in phases changes as the function of phase current and position of rotor.

The equation is rewritten as:

$$V = Ri + \frac{d\psi}{di}\frac{di}{dt} + \frac{d\psi}{d\theta}\frac{d\theta}{dt} \qquad \dots (2)$$

And $\partial\psi/\partial i$ is the instantaneous inductance L (θ, I). The third term in LHS of Eq. 2 represents instantaneous back EMF.

Torque equation is obtained by partial differentiation of total energy equation with respect to the rotor position. The correlation between magnetic torque and space distribution of inductance can be obtained as Eq. 3.

$$T = \frac{1}{2}\left(\frac{\partial L}{\partial\theta} i_a^2 + \frac{\partial L}{\partial\theta} i_b^2 + \frac{\partial L}{\partial\theta} i_c^2\right) \qquad \dots (3)$$

Experimental Details

Proposed System

In this paper, an 8/6 SRM motor is used. The SRM is fed by an asymmetric H Bridge inverter. Inverter is supplied from a DC source. Speed and flux of the SRM is estimated by speed estimator. With the resultant speed and flux motor using vector control the gate pulses are given to the converter. The proposed 8/6 SRM needs 4 phase supply; this is supplied by an asymmetric H bridge inverter. Each phase has 2 insulated gate bipolar transistors (IGBT) with an inductor in between them and two diodes are linked with inductor both sides and input supply. The switching pulses to the inverter are given by proposed switching strategy for the SRM is proposed.

In SRM the number of switches needed in inverter is same as that of synchronous drive. Nevertheless, the structure differs completely. It can still be observed that when the resistance of the coil restricts the current, there are less chances of input source being short circuited.

Fuzzy Logic Controller (FLC)

Fuzzy logic (FL) has defining the controlling laws of several processes since morphological explanation. The control scheme can be framed in the form of rules. The FLC constitutes of an input, inference, output phase and it is a controller which operates on rule basis. The crisp values obtained from the controller are converted in to membership functions based on their properties. Similarly the output is also converted in to membership functions. In FL, control rules are framed based on the experience. The input or fuzzification stage maps input variables e and Δe. Input and output variable involves seven membership functions which are to positive big (PB), positive Small (PS), positive medium (PM), zero (ZR), negative small (NS), negative medium (NM) and negative big (NB). This fuzzy controller uses morphological information, which has the advantages of robust performance with good strength, and satisfies the approximation theorem using the algorithm developed using rule basis.

The crisp inputs achieved are the estimates of nearer values of individual universes of dissertation. Therefore, singleton fuzzy set illustrates the fuzzified inputs

Here, the phase plan is utilized for the controller design. In each fuzzy sets merger the control input 'u' is framed using 'e' and 'Δe'. From Table 1, rate of change in error 'e' is represented in rows; change in error, i.e error change 'Δe' is represented in columns. Combination of 'e' and 'Δe' determines the corresponding output u. The levels of output from negative big (NB) to positive big (PB), the intermediary values are positive small (PS), positive medium (PM), zero (ZR), negative small (NS) and negative medium (NM).

For the desired performance of FLC, it is necessary for continuity mapping of $V_{fuzzy}(e, \Delta e^{\cdot})$ is with membership functions of input, method of reasoning and defuzzification. The membership functions adopted in the control method are incessant. Triangular and trapezoidal are the membership functions used in this controller, for fuzzification max min method is adopted. In defuzzification method, centre of gravity method is employed. For developing the set theory, Mamdani rule is applied as primary objective. The proposed FLC configuration along with fuzzy set and its respective membership functions are presented in Fig. 1.

Results and Discussion

The validation of the effectiveness of the suggested control algorithm, simulations has been done using MATLAB/Simulink. The SRM drive system with control unit depicted in Fig. 2 is simulated. The simulation results are carried out in two cases. In case 1 the SRM Drive without load and in case 2: with Load. The simulation results are depicted in Fig. 3.

Table 1 — Rules base for speed control

E Δe	**NL**	**NM**	**NS**	**EZ**	**PS**	**PM**	**PL**
NL	NL	NL	NL	NL	NM	NS	EZ
NM	NL	NL	NL	NM	NS	EZ	PS
NS	NL	NL	NS	NM	EZ	PS	PM
EZ	NL	NM	NS	EZ	PS	PM	PL
PS	NM	NS	EZ	PS	PM	PL	PL
PM	NM	EZ	PS	PM	PL	PL	PL
PL	NL	NM	NS	EZ	PS	PM	PL

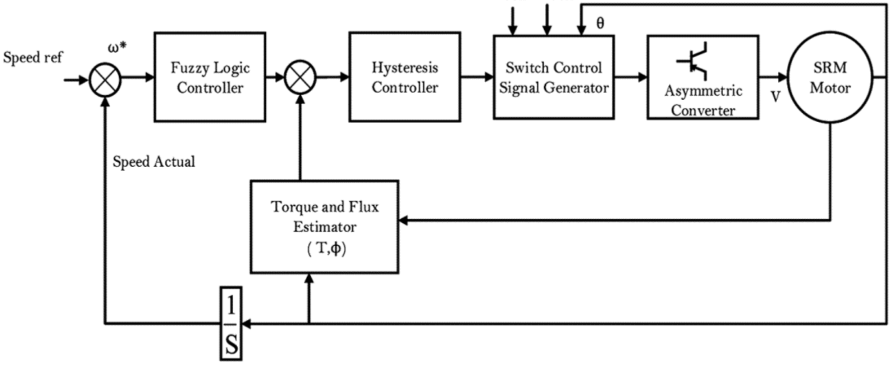

Fig. 1 — The FLC structure and Input membership functions

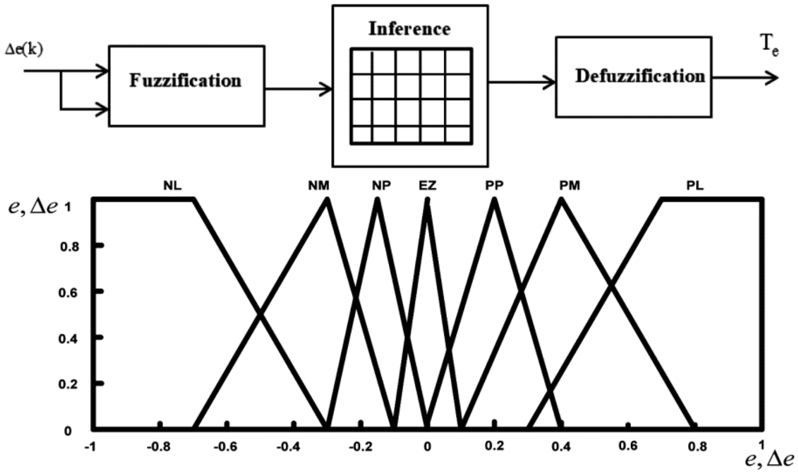

Fig. 2 — Fuzzy Logic controlled SRM Drive

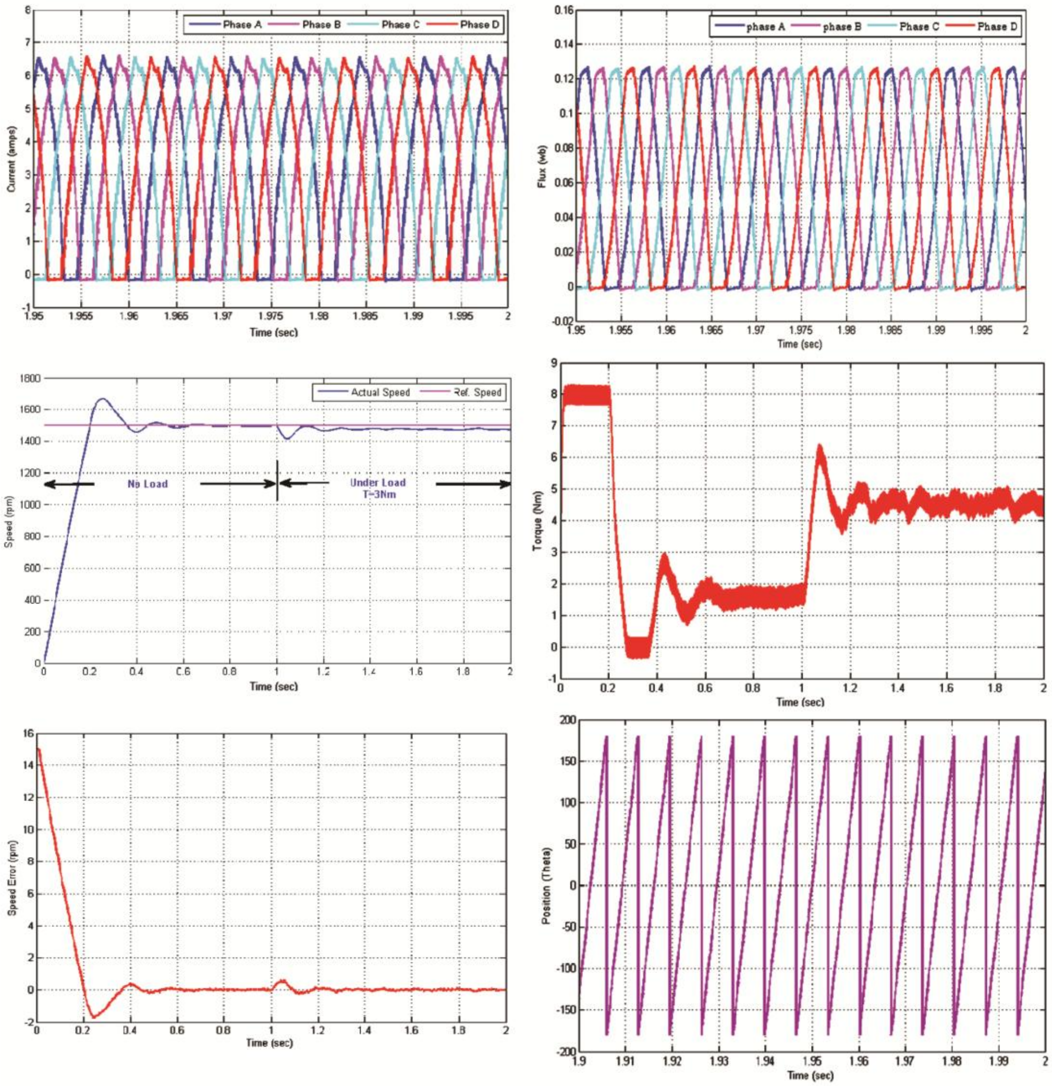

Fig. 3 — Simulation Results of Current, flux, speed, torque, speed error and rotor position

From the results it can be observed that the phase current of motor is 6 A and flux is 12.5 mwb. We can observe that the current and flux are unipolar and the overshoots of current is within the limit. The shape of phase current is uniform for all phases.

From Simulations results can be contingent that using FLC, under load, the speed of SRM congregates to the mentioned value rapidly withzilch steady state error. The fluctuations in speed are minimal and it congregates to the mentioned value without any overshoot under loading condition. Change in torque is similar to that of speed but the ripples are within the limit. We can also observe that the speed error settles to zero at quickly under no load and load. Form the simulation results we can infer that the suggested FLC controlled drive is competent in after the reference speed with good response time with steady state error at zero and relatively no overshoot.

Conclusions

This paper investigates Fuzzy based sensorless vector control of switched reluctance motor and detailed discussion of the simulation of sensorless vector control of SRM. Working of SRM drive is presented. Process of framing fuzzy rules with input and out is presented. The influence of fuzzy controller in speed control and torque minimization is investigated. Performance of fuzzy logic controller under no load and load is analysed. From simulation results it is observed that the fuzzy controller is effective in speed control and smooth operation of drive system. Finally, it can be concluded that for nonlinear and complicated systems, dynamic properties can be enhanced by fuzzy logic.

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