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Sensorless Rotor Position Estimation of Switched Reluctance Motor Drive Using Computational Intelligence Techniques

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Abstract*—This paper deals with an accurate method to detect the rotor position, which is used for high performance operation of Switched Reluctance Motor (SRM). Earlier, a several type of position sensors were used to detect the rotor position but this has many disadvantages like additional cost, electrical connections, mechanical alignment problems, and unreliability. To overcome these disadvantages several sensor less schemes were proposed for the SR Motor in the recent years, there by facilitating the elimination of the rotor position sensor. Here, the sensor fewer schemes is proposed based on fuzzy technique and also using adaptive Neuro fuzzy inference system (ANFIS) which it overcomes the disadvantages of sensor scheme and also it does not require any mathematical models and large lookup tables to predict the position angle. Then position estimation based on fuzzy and ANFIS are compared. In this paper, the rotor position or angle is estimated by using the relationship between flux linkage and phase current based on fuzzy rule base. ANFIS-based model reference system is continuously tuned by using Back Propagation method with actual value of SRM. The simulation results for novel sensorless schemes is described and developed in MATLAB and shown the effectiveness of this sensor less Scheme.

Keywords*—ANFIS, SRM, Sensorless Rotor Position Scheme, Fuzzy Logic Estimator.

I. INTRODUCTION

The Switched Reluctance motor (SRM) drives are very attractive and more usage in variable speed drives. SRM drives are now used in various sectors of industry such as aerospace, automotive industries, and home appliances. It's simple construction, due to the absence of magnets, rotor conductors, brushes it improves the system efficiency over a wide speed range and makes the SRM drive an interesting alternative to use for other commercially available drives. The accurate knowledge for rotor position estimation is needed for the good performance of SRM.Many literatures and journals establish the several methods to develop the sensorless scheme. Earlier hall shaft position sensor, encoders are employed for determining the rotor position. Due to these discrete position sensors it adds complexity, additional cost and reduces the reliability of the drive. So, to overcome these drawbacks, in recent years the extensive research leads to indirect method of determining the rotor position. Several methods have been patented and reported in many literatures but all has some merits and demerits depending on their principle of operation.

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The basic principle have been used in indirect position estimation is the extraction of rotor position information from stator circuit measurements or from their derived parameters. Compared to other types of electric machines, it is an advantage for an SRM not to have a rotor field disturbing the stator field. The other method used is the nonlinear relationship between the electrical and mechanical terminals of the machine that makes analytic calculation of rotor position, that is impossible for a given flux linkage and current value. Moreover, accurate measurement is much more difficult if more than one phase winding carries current simultaneously and the mutual coupling is not negligible. These are disadvantageous because of demand for fast real time applications and it is not suitable for all motor drives .So this makes the previous schemes to be difficult to implement SRM which operates under the magnetic saturation, thus for an accurate rotor position estimation is described by non-linear model. Ideally it is desirable to have a sensor less scheme which uses only terminal parameters and hardware is not required.

Recently new techniques are developed to estimate the rotor speed and position estimation that is advanced adaptive estimation techniques based on FLC and ANN. The main idea proposed here for the sensor less rotor position detection is to use the unique relationship between the flux linkage and current. The SRM is modeled by the equation of flux, torque, speed and inductance can be predicted directly from the measurement of SRM. Here we use the concept of fuzzy logic and ANFIS technique to estimate the position. Here the ANFIS is used to map the relationship between rotor position, flux linkage and phase current. After the model based on ANFIS established, the measured phase current and calculated flux linkage are input to the ANFIS to estimate the rotor position. An advantage of this method is that error will not be accumulating for the flux linkage returns to zero at each cycle allowing the integrator to be reset.

The ANFIS has the advantage of high accuracy and fast computational speed. It also shows robust characteristics. The application of ANFIS to estimate the rotor position of SRM can present a good performance. The speed control range will be extended. It increases the reliability and robustness of this approach.

II. PRINCIPLE OF OPERATION OF SWITCHED RELUCTANCE MOTOR

SR machine is an energy converter thatconverts an electrical energy to mechanical energy in motoring operation, and vice versa in generating operation. When the rotor isout of alignment, the inductance is very low, and the current will increase rapidly. When the rotor is aligned with the stator, the inductance will be very large. In a magnetic circuit, the rotor always prefers to come to the minimum reluctance position during excitation. The torque produced in an SR machine when a phase is excited by applying a voltage, then the current in the coil produces a magnetic flux through its stator poles. This flux flows through the pair of nearest rotor poles and there exists magnetic reluctance. The reluctance of the flux path is at itsminimum in the aligned position and maximum in the unaligned position. The variable reluctance Principle is the tendency of the rotor to align itself to the minimum reluctance position. When a phase is excited, the pair of nearest rotor poles is attracted to align themselves to the excited stator poles. Thus, torque is produced.Note that the rotor poles of an SR machine do not require magnetic poles to produce torque, the radial magnetic attraction in SR machine becomes ten times larger than the circumference forces produced by an induction machine position. However, as soon as the rotor is displaced to either side of the unaligned position, there appears a torque and attracts towards the next aligned position.The torque is proportional to the square of the current; hence the current can be unipolar to produce unidirectional torque. The direction of rotation can be reversed by changing the sequence of stator excitation which is a simple operation .Torque and speed control is achieved with converter control.

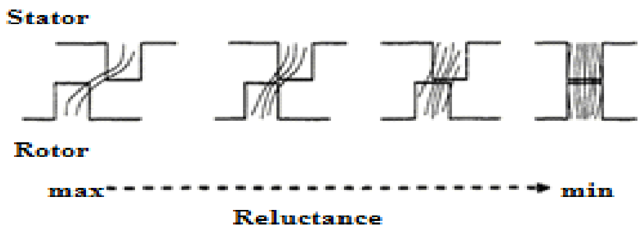

Fig.1 Variation of Reluctance with respect to Rotor Position

III. PRINCIPLE OF OPERATION OF THE PROPOSED SRM SENSORLESS SCHEME

The fundamental principle of operation of a SRM is based on the variation in flux linkage with the change in the angular position of the rotor and phase current. The proposed sensor less scheme based on the fuzzy based rotorposition estimator model of the SRM drive. The block diagram of the proposed sensor less scheme isshown in Fig.2.

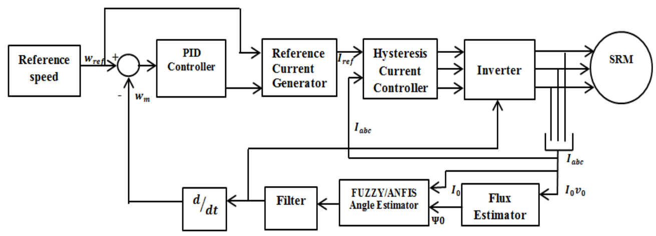

Fig.2 Block Diagram of Sensorless Control of SRM with Fuzzy/ANFIS Rotor Position Estimator

It consists of PID controller, Inverter, Flux Angle Estimator. The measured current and voltage of SRM is used in Flux Estimator to produce flux linkage. The phase current and flux linkage is used as the input for fuzzy angle estimator that produces the estimated angle. In ANFIS, the data's are trained and tested with actual value and error is calculated. Then it is given to the fuzzy. Then estimated angle is obtained in MATLAB scope. This angle is refined by using the low pass filter. The estimated angle is given to the inverter for the operation of SRM simultaneously the speed is compared with the reference speed. This fuzzy based model is implemented in MATLAB. Then the simulated result is compared with the experimental results to verify the effectiveness of the proposed scheme.

A. Rotor Position Estimation Using Flux Linkage Calculation

The flux linkage estimator plays a vital role for rotor position estimation. The quantity flux is generated by flux linkage estimator block, which calculates flux linkage based on the phase voltage and current in the active phase winding. The flux-linkage of any phase is computed by using Faraday's law from

$$\psi = \int (V - IR)\, dt \quad (1)$$

The calculation of flux linkages by equation, helpful in computing estimated angle for the operation of sensor less SRM drive.

IV. ROTOR POSITION ESTIMATION OF SRM USING FUZZY

To model a fuzzy rotor position estimator for SRM, the SRM magnetization curve (Flux linkage-current-rotor position) termed a fuzzy rule base where the several rotor position data's are stored in fuzzy rule-base tables, the position information can be taken from the rule base tables during operation. This rule base table provides several values of rotor position from the inputs of the fuzzy model. The generated fuzzy rule base is used for mapping the input values of flux linkage and current to output value of rotor position in terms of an angle. A variable in fuzzy logic has sets of values, which are characterized by linguistic labels, such as SMALL, MEDIUM, and LARGE etc. These labels are represented numerically by fuzzy sets. Each set is again characterized by membership function varies from 0 to 1. Thus fuzzy sets can be viewed as mathematical representation of linguistic values. Crisp value is the member of a fuzzy set, with a degree of membership varying from 0 (non-member) to 1 (full member). Fuzzy logic system can be simply represented into four parts: the fuzzifier, the rule base, the interference engine and the defuzzifier. During simulation estimated angle is compared with measured angle produces angle error and then fuzzy rule base has been updated according to error.In this case, the input domains are flux linkage and current are defined to have a domain of 0–1 and 0–20 A respectively. Similarly, the domain of the angle is defined as 0–30 degrees. Here the fuzzy sets were chosen to be isosceles triangular shapes.

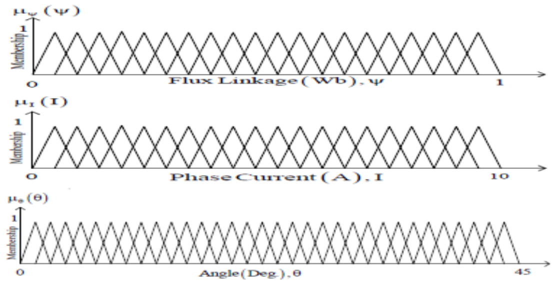

Fig.3Membership functions for Ψ, I and θ

A. Results of Position Estimation Using Fuzzy

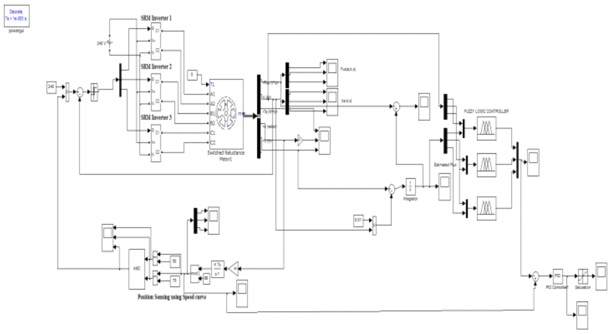

Fig.4 SIMULINK model of rotor position Estimation of SRM using Fuzzy

Experimental results of SRM drive using fuzzy are discussed in this section. The results show that the proposed fuzzy based sensor less scheme is estimating the rotor position with low error. In simulation model of sensor less scheme inverter is used and given to the SRM for the operation. The torque, speed, phase current and voltage are taken from the measured value of SRM. From the measured value of speed we calculate the actual angle. By taking the current and voltage by using the fuzzy estimator we calculate the flux linkage. Using the input of flux linkage and current given to the fuzzy angle estimator and estimated angle is calculated. Then the estimated angle and actual angle is compared and then error is saturated. The simulation results are scoped. Finally, the results are matched with experimental results. Simulated and experimental results have been verified successfully at low and high speed operations.

B. Performance of sensor less scheme at high speed= 4000 rpm

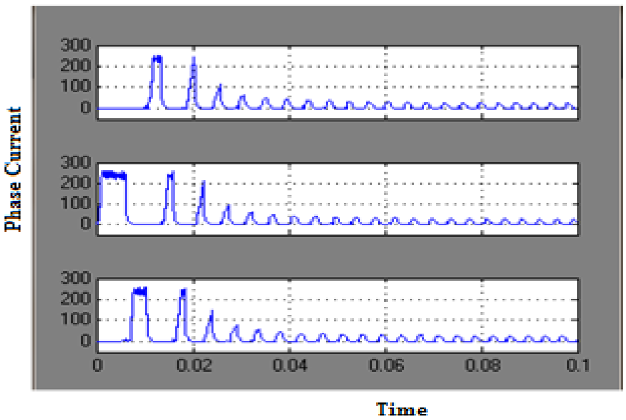

Fig.5 Phase Current vs. Time

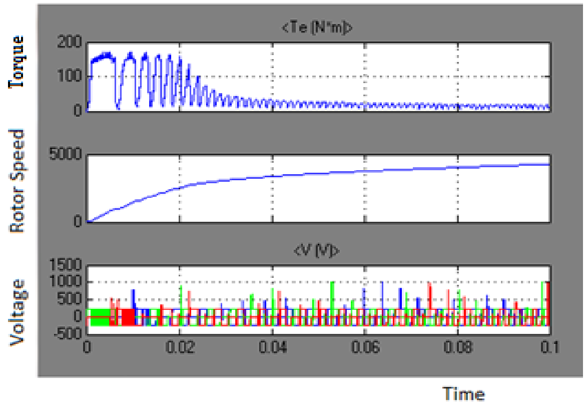

Fig.6Torque, Rotor Speed and Voltage vs. Time

V. ROTOR POSITION ESTIMATION OF SRM USING ANFIS

The ANFIS is a Sugeno adaptive network based fuzzy inference system. There are two-input flux linkage, current and one-output rotor position. Three membership functions are given for each input.. Then the rule base contains 9 fuzzy if-then rules of Sugeno's type. The ANFIS architecture is shown in Fig. 7. The ANFIS network has five layers. ANFIS implements Takagi – Sugeno fuzzy rules in a five layer network. Fuzzy membership functions are represented by first layer of ANFIS. The second layer and third layers contains nodes that form the antecedent parts in each rule. The fourth layer calculates the sugeno rules for each fuzzy rule. The fifth layer is the output layer which calculates the weighted output of the system. The back propagation algorithm is used to modify the membership functions. Many rules can be extracted from a trained ANFIS as there is pre-defined number of rule nodes.
Two sets of fuzzy rules learned by ANFIS model are :

Rule 1: If x is A_1 and y isB_1, then f_1= P_1x+q_1x +r_1
Rule 2: If x is A_2 and y is B_2, then f_2= P_2x+q_2y+r_2

Where x and y are input variables,,, and are the membership functions; f is the output; and p, q, and r are theparameters of the output. ANFIS has multiple iteration and has a fast convergence due to back propagation method. It does not require preselecting of the hidden nodes; i.e., the number of combinations between the fuzzy input membership functions.

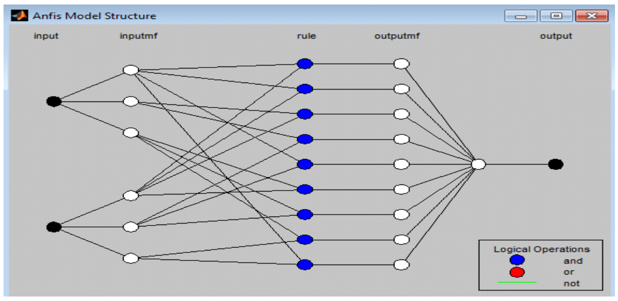

Fig.7 ANFIS structure

Due to the nature of fuzzy rules only one output from ANFIS. Thus ANFIS can be applied to tasks such as approximation of non-linear

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functions where there is only one output.

The SIMULINK model for Position Estimation of SRM is modeled for ANFIS using MATLAB. The data's for current, flux and rotor angles are continuously trained and tested in ANFIS GUI and FIS file has been generated. This FIS file is given to the Fuzzy and results are taken. The obtained results are matched with Fuzzy output.

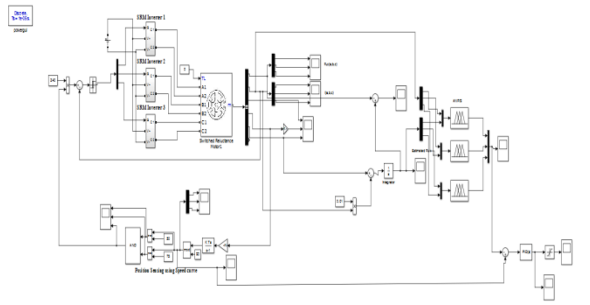


Fig.8 SIMULINK model of Rotor Position Estimation of SRM using ANFIS

VI. SIMULATION RESULTS

A. Comparison of Simulation Results of Fuzzy and ANFIS

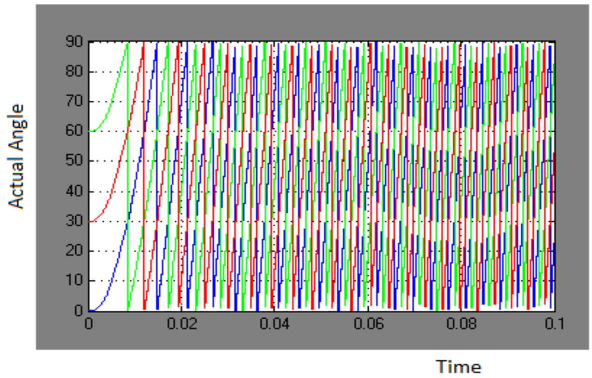
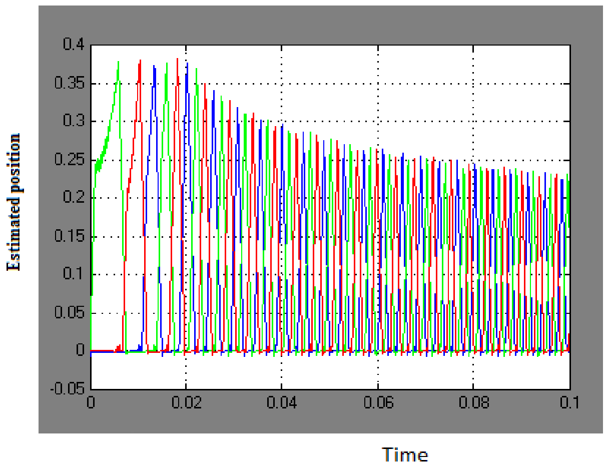
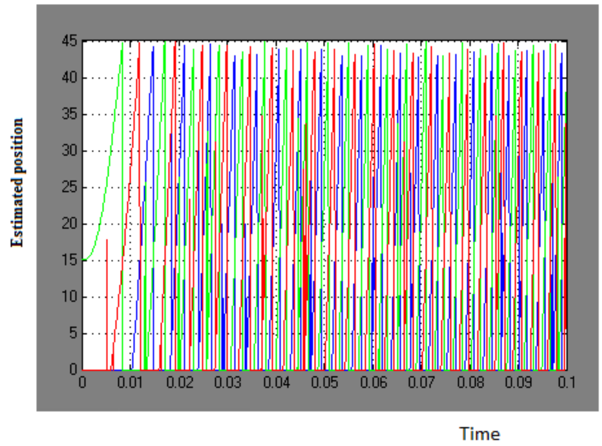


Fig.9 Actual Position Angle vs. Time

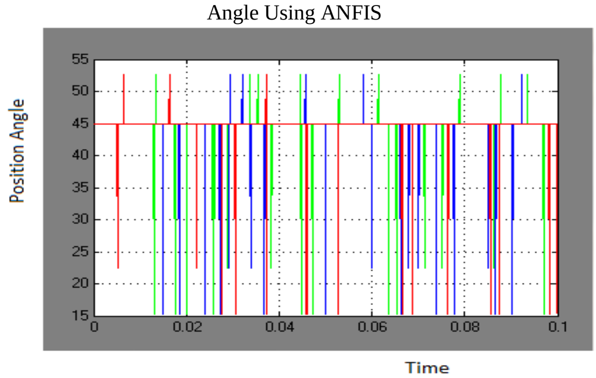


(a)

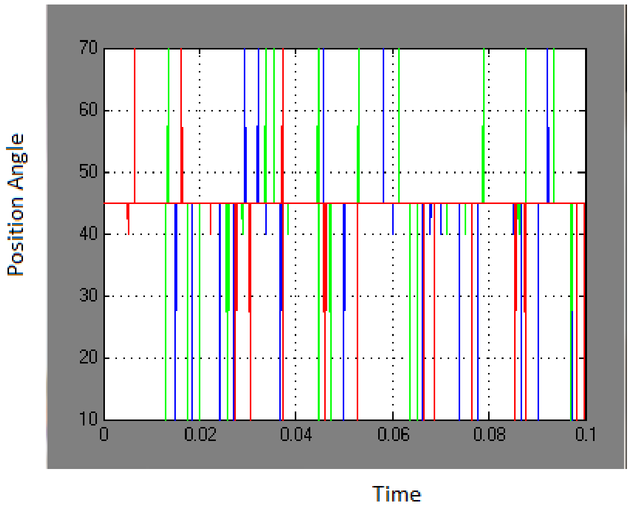


(b)

Fig.10 (a) Estimated Position Angle Using Fuzzy, (b) Estimated Position Angle Using ANFIS



(a)



(b)

Fig.11 (a) Position Angle using Fuzzy, (b) Position Angle using ANFIS

VII. CONCLUSION

This paper discussed about rotor position Estimation using computational techniques i.e., fuzzy and ANFIS. Both the techniques were model free and high reliability at various operating conditions. Here we used the relationship of flux linkage and rotor position characteristics to estimate the rotor position. Both these techniques are verified and position is estimated successfully in MATLAB.

In ANFIS the accurate position is estimated than using fuzzy. This paper proved that proper designed Fuzzy and ANFIS based rotor position estimation of SRM operates within acceptable limits. We conclude that this proposed technique control of SRM drive is suitable for real world problems.

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