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An Improved Direct Torque Control Using Intelligent Technique for Switched Reluctance Motor Drive

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Abstract

In the direct torque control of switched reluctance motor, flux and torque are controlled directly by the selection of switching vector. However, the selected vector is not always the best one. In this paper Fuzzy logic approach is used to select the switching vector hence the torque and flux ripple is reduced and also no flux dropping caused by sector changes. This new technique implemented in real time with low cost DSP controller can give fast torque response.

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Keywords: Direct torque control, Flux control, Fuzzy control, Switched Reluctance Motor.
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I. INTRODUCTION

Switched reluctance motor, the doubly salient, singly excited motor has simple and robust construction. Although, the induction motor is still the workhorse of the industries, the promising feature of the high torque to mass ratio, high torque to inertia ratio, low maintenance, high specific output and excellent overall performance of SRM make it an efficient competitor for ac drives. The simplified converter topology and switching algorithm due to the unipolar operation avoiding shoot through faults makes SRM advantageous in applications of aerospace, which require high reliability. Also it finds wide application in automotive industries, direct drive machine tools etc [1].

However, significant torque ripple, vibration and acoustic noise are the main drawbacks of SRM to achieve high performance. As the control of SR motor is being the recent trend of research, schemes were developed involving linear and non-linear models to control torque ripple [2], [12]. But due to inaccuracy in linear models and complexity involved in non-linear control, the Direct Torque Control (DTC) was proposed which provided simple solution to control the motor torque and speed and minimized torque ripple.

There are two types of instantaneous electromagnetic torque-controlled drives used for high performance applications namely, vector and Direct Torque Control (DTC) drives [3], [10]. In vector controllers, there are two independent control loops for controlling both the torque and the flux. The most spread controllers were the ones that use vector transform. The main disadvantages in vector control are the huge computational capability required and the compulsorygood identification of the motor parameters. However, in DTC it is possible to control directly the stator flux and the torque by selecting the appropriate inverter state. This method proves advantageous due to the absence of co-ordinate transform, the absence of voltage modulator block, as well as other controllers such as PID for both motor flux and torque regulations. Also, its torque response time is so good, even better than vector controllers. Nowadays, it is considered to be the best controller. Although DTC has proved to be a simplified control method then vector controlled drive an improvement is still needed because of disadvantages caused by hysteresis comparator and switching tables.[4] [5] [6]. Also, DTC has some disadvantages like problems during starting, the compulsory requirement of torque and flux estimators, and an inherent torque and flux ripples.

In DTC SRM [10] drive there are torque and flux ripples because none of the converter states is able to generate the exact voltage value required to make zero both the torque electromagnetic error and the stator flux error. Thus, it is believed that by using a fuzzy-logic-based DTC system it is possible to perform a fuzzy-logic-based control during zero error. This paper is focused on trying to overcome all the previous disadvantages mainly eliminating hysteresis comparator and specially reducing the torque ripple.This Paper Is Organized As Follows: In Chapter II describes The Classical DTC Scheme for SRM Chapter III refers Voltage Vectors for SRM. The Proposed Fuzzy Logic Approach is covered in Chapter IV and Simulation Result is covered in Chapter V. Finally the Conclusion and future scope are explained in Chapter VI.

II. THE CLASSICAL DTC SCHEME FOR SRM

DTC is based on theories of field oriented (FOC) control and torque vector control. Field Oriented Control uses space vector theory to optimally control magnetic field orientation. The DTC principle is to select stator voltage vectors according to the differences between the reference torque and stator flux linkage with exact value.Voltage vector are so chosen to limit the torque and flux errors within hysteresis bands. The required optimal voltage vectors are obtained from the position of the stator flux linkagespace vector, the available switching vectors and the required torque and flux linkage [7],[8].

To drive the control scheme for the SR motor, the non-uniform torque characteristics will firstly be examined. The motor torque output can be found using the motors electromagnetic Eq

$$v = Ri + \frac{d\psi(\theta, i)}{dt} \tag{1}$$

The energy equation is

$$dW_e = dW_m + dW_f \tag{2}$$

Where $dW_{m=}$differential mechanical energy

$$dW_e = eidt \quad (3)$$

$$dW_f = \frac{\partial W_f}{\partial i} di \Big|_{\theta = const} + \frac{\partial W_f}{\partial \theta} d\theta \Big|_{i = const} \quad (4)$$

The instantaneous torque expression is

$$T = \frac{dW_m}{d\theta} \quad (5)$$

Hence by substitution torqe expreesion is derived consideration the varatuion of magnetic co energy and is given by

$$T \approx i \frac{d\psi(\theta, i)}{d\theta} \quad (6)$$

This approximate equation is sufficient for control purpose as it controls the general characteristics of torque production and not the magnitude of torque. The current is always positive as SRM is a unipolar drive. Hence, the sign of torque is directly related to the sign of $\partial\psi/\partial\theta$. The increase of stator flux amplitude with respect to rotor position (positive value of $\partial\psi/\partial\theta$) produce a positive torque and is called “flux acceleration”. Whereas a negative value of $\partial\psi/\partial\theta$ called “flux deceleration” produce a negative torque. As this is held for both directions of rotation a four quadrant operation is achieved using unipolar currents.

The DTC technique can be defined as follows.

a) The stator flux linkage vector of the motor is kept at constant amplitude.

Torque is controlled by accelerating or decelerating the stator flux vector.

III. VOLTAGE VECTORS FOR SRM

Similar to the AC drives, equivalent space vectors can be defined for SRM. The voltage space vector (Fig. 1) for each phase is defined as lying on the center axis of the stator pole because the flux linkage for a current and voltage applied to the motor phase will have phasor direction in line with the centre of the pole axis. This does not need any change in physical winding topology.

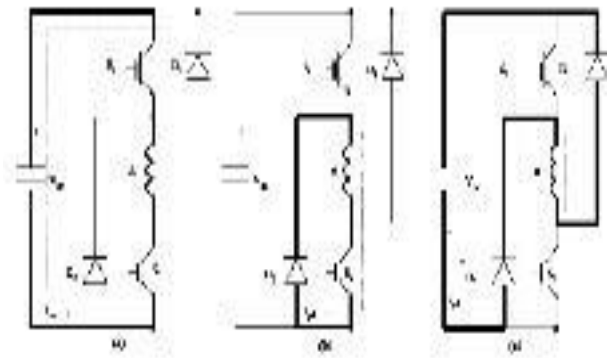


Fig. 1 SR motor phase voltage states.

In SRM, each motor phase can have three possible voltage

(2) states (Sq) for a unidirectional current.

i. When both devices are ON and positive voltage is

energy,

applied Sq=1.

ii. For Sq=0, one device is turned OFF and a zero voltage

loop occurs.

(3) iii. For negative state Sq=-1, both devices are OFF. The freewheeling current flows through$_{(3)}$ the diodes.

So with each phase having three possible states (0, 1,-1)

(4) unlike conventional DTC for ac drives with two states, a total of 27 possible configuration is possible

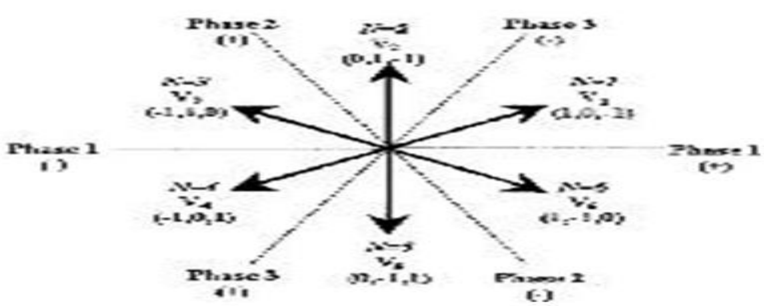


Fig 2. Definition of SR motor voltage vectors for DTC

Fig 2. shows only six equal magnitude voltage vectors separated by π/6 radians is considered as DTC allows no other states to be chosen by the controller. One out of the six states is chosen to keep torque and flux within the hysteresis bands. Let the stator flux vector be located in the Kth sector (K=1,2,3,4,5,6). In order to increase the amplitude of the stator flux, the voltage vector V_K,V_{K+1},V_{K-1} can be applied and V_{K+2},V_{K+3}, V_{K-2}, can be applied to decrease the flux. V_K and V_{K+3} are zero space vectors. The control scheme of SRM is based on the results as follows.

a) The motor is solicited only through the converter component of voltage space vectors along the same flux.

b) The motor torque is affected by the component of the voltage space vector orthogonal to the stator flux.

The zero space vectors do not affect the space vector of the stator flux. So the stator flux when increased by V_{K+1} and V_{K-1} vectorsand decreased by V_{K+2} and V_{K-2} affect the torque. As V_{K+1} and V_{K+2} vector advance the stator flux linkage in the direction of rotation they tend to increase the torque. But V_{K-1} and V_{K-2} decelerate the flux in opposite direction and decrease the torque. So the switching table becomes as Table. I

Table I

T↑ **ψ↑**	**T↑** **ψ↓**	**T↓** **ψ↑**	**T↓** **ψ↓**
V_{K+1}	V_{K+2}	V_{K-1}	V_{K-2}

Stator flux and torque variations due to applied inverter voltage space vector.

IV. THE PROPOSED FUZZY LOGIC APPROACH

During recent years, fuzzy logic has been intensively used in a lot of domains and in particular in control applications and has obtained very attractive performance. Fuzzy logic is well suited for dealing with ill-defined and uncertain systems. Fuzzy interface system is employing fuzzy ***if-then*** rules, which are very familiar to human thinking method. It is possible to build complete control system without using any precise quantitative analyses. However, to conceive a fuzzy controller, it is necessary to choose a lot of parameters, like number of membership functions in each of input and output, shape of these functions, fuzzy rules, and other. Fuzzy logic allows to achieve better features. Human expert knowledge can be used to build initial structure of the regulator

A fuzzy interface system is as shown in Fig.3**.** It contains rule base and data base (as a knowledge base), fuzzification and defuzzification unit and decision-making unit.

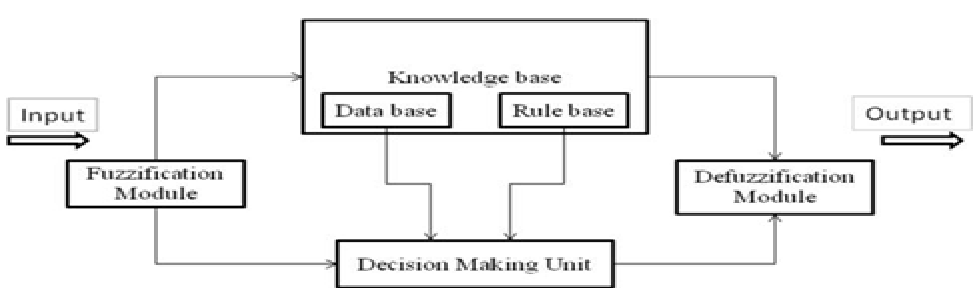


Fig.3 Fuzzy Logic Controller

In this paper, the fuzzy logic controller is so designed to select a single preferable voltage space vector based on three inputs- torque error, flux error and sector information . Triangular membership function (Fig.4) is used for errors with Mandami implication.

1) Fuzzy Membership Function

The flux errors (Fe) use three linguistic values: positive error (PE), zero error (ZE) and negative error (NE) with universe of discourse [-0.01 0.01]. For the torque error (Te) the universe of discourse is [-0.1 0.1] with three fuzzy aggregations positive (P), negative (N) and zero(Z) (Table.II). The flux linkage angle θ is divided into sixaggregations of 60˚ each. The output control variable is the state space vector V_i (1~6).

Fig.4. Triangular Membership Function for toque and flux error

Table II. Variables for Toque and Flux Error

Flux error	P			Z			N		
Torque error	P	Z	N	P	Z	N	P	Z	N

2) Fuzzy Rules

The rule base for control is designed with ***if-then*** rules having Te, Fe and θ as the rule antecedent and voltage vector

(V_i) as rule consequent. The ith rule R_i in rule base is denoted as

If Te is A_i and Fe is B_i and θ is $θ_i$, then vector is V_i

where A_i, B_i, $θ_i$ denote fuzzy aggregation. So with three aggregation for both torque and flux error and six aggregations for angle a total of 54 control rules are defined.

3) Fuzzy Reasoning

The fuzzy reasoning adapts mamdani minimum operation and the output space vector is chosen by max~min composition as:

$\mu V(n)=max\ [min(min(\mu A_i(Te),\mu B_i(Fe),\mu\theta_i(\theta)),\mu V_i(n))]$

where μA, μB, $\mu\theta$ and μV are the membership function of sets.

The defuzzification is done by centroid method to give signals to the inverter section of SRM. The fuzzy logic controller controls the switching of the converter switches based on inputs. The voltage space vectors are chosen by means of FLC with P,N,Z errors for torque and flux and a detail of six sector details giving a surface viewer as in Fig.6

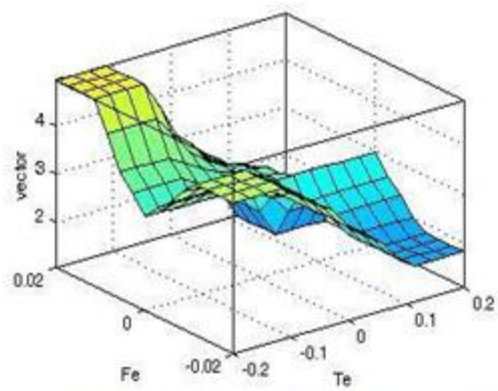


Fig.5 Fuzzy logic interference system

V. SIMULATION RESULT

To simulate the system a Matlab/ Simulink model was constructed shown in Fig.6. In this simulation test, the motor command flux was maintained a constant 0.3wb and a motor torque reference of 5Nm was used. The speed of the motor in this test was a constant 2800rpm.The hysteresis bands were defined to be of ±0.01Wb and ±0.1Nm for the flux linkages and torque respectively. The result of the torque and flux control can be seen in Fig.7.

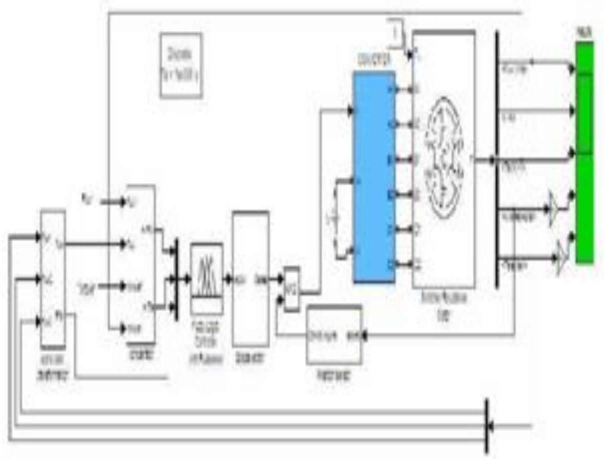


Fig. 6. Block Diagram of Fuzzy Logic Controller Based DTC Algorithm

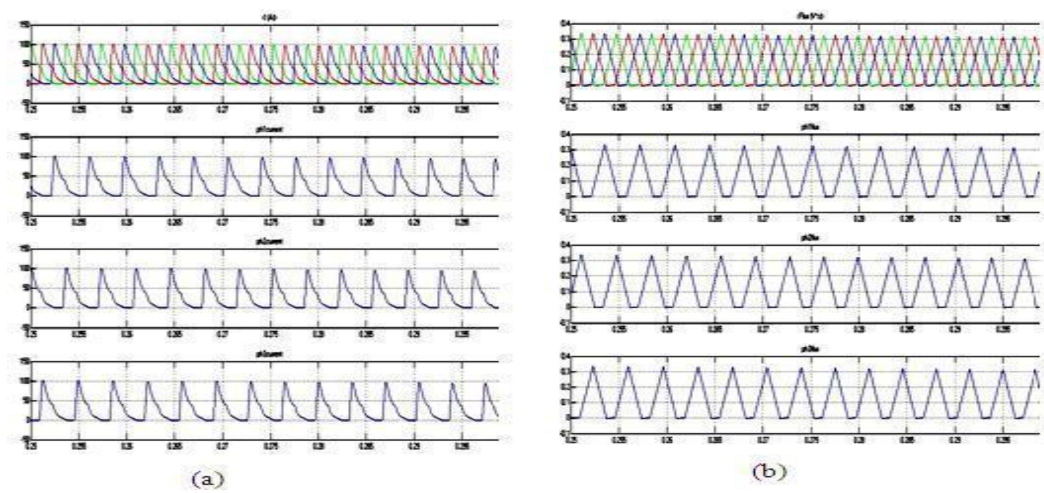
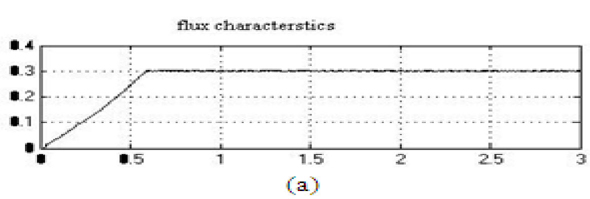
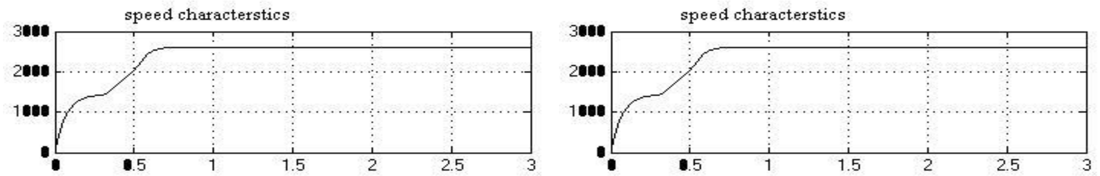


Fig. 7. Simulation results for (a) Phase current (b) Phase flux





VI. CONCLUSION

In this paper, a novel control methodology for the SR motor was derived from combination of direct torque control and Fuzzy logic. The analysis in based on non-uniform torque characteristics of the motor. In the method, torque and torque ripple is directly controlled through the control of the magnitude of the flux linkage and the change in speed of the stator flux vector. Based on the difference between the reference and actual value of flux and torque values voltages space vectors are chosen with fuzzy for accurate control. Furthermore, the scheme is not dependent on the accuracy of the estimated model parameters, as no model calculation is required during operation. The advantages of the proposed fuzzy logic based DTC control technique is very low torque and current distortion, no flux dropping caused by sector change, very fast torque and flux response and lower sampling time with higher accuracy of control.

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