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A Novel Fuzzy Based Single Switch Converter For High Speed Srm Drive Applications

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Abstract- The design of the fuzzy logic controller is the voltage control action as feedback for significantly improving the dynamic performance of converter. The switches pertaining in Switched reluctance motor (SRM) drive is receiving increasing attentions from various researchers as well as viable candidate for adjustable speed and servo applications. Switched Reluctance Motors have a simple structure and inherent mechanical strength without rotor winding. A new converter for SRM which uses only one switch per phase consisting an important characteristic "fast phase current commutation" is used to improve dynamic performance, Speed Range and efficiency. Recently, the demand of high speed drives has been increased due to its mechanical advantages. High speed drive systems are widely used in the industrial applications such as blowers, compressors, pumps and spindles due to the compact size and high efficiency. This paper presents a new fuzzy controller design for a switched reluctance motor drive system. The simulation results based on Matlab/Simulink are discussed in detail.

Keywords- **Fuzzy Logic Controller, PI Controller, Switched Reluctance Motor Drive.**

I.INTRODUCTION

Switched reluctance machines (SRM's) are considered to be mechanically robust. This is by virtue of their simple structure. The stator and rotor typically comprise of a lamination stack displaying appropriate magnetic saliency. The rotor has no windings and stator coils are mounted on individual poles with no overhang thus reducing as far as possible end-winding inductance. For high-speed operation, motors with low pole numbers are preferred. This reduces hysteresis and eddy current losses by minimizing the magnetic core pulsations per rotor revolution. In recent years, the switched reluctance motor (SRM) has received considerable attention for variable-speed drive applications. It's simple construction, due to the absence of magnets, rotor conductors, and brushes, and high system efficiency over a wide speed range make the SRM drive an interesting alternative to compete with permanent magnet (PM) brushless dc motor and induction motor drives.

SRM is the simplest of all electrical machines in Construction. Only the stator has windings, Where as the rotor contains no conductors or permanent magnets. It consists simply of steel laminations stacked onto a shaft. It is because of this simple mechanical construction that SRMs carry the promise of low cost, which in turn has motivated a large amount of research on SRMs in the last decade. Like the brushless DC motor, SRM cannot run directly from a DC bus or an AC line, but must always be electronically commutated. Also, the saliency of the stator and rotor, necessary for the machine to produce reluctance torque, causes strong non-linear magnetic characteristics, complicating the analysis and control of the SRM

This is due to a combination of perceived difficulties with the SRM, the lack of commercially available electronics with which to operate them, and the entrenchment of traditional AC and DC machines in the market place. However, SRM's offer some advantages along with potential low cost. For example, they can be very reliable machines since each phase of the SRM is largely independent physically, magnetically, and electrically from the other motor phases. Also, because of the lack of conductors or magnets on the rotor, very high speeds can be achieved, relative to comparable motors.

Switched reluctance machines are used in electric vehicles, washers, dryers and aerospace applications as the machine is brushless, fault tolerant, maintenance free and rugged and simple in construction. However, some of its limitations are noise, torque ripple and low torque to volume. Noise and low torque to volume have been addressed in the segmented switched reluctance machine (SSRM). SSRM has full-pitched winding while concentrated winding is used in variable reluctance switched reluctance machine (VSRM). The geometry of VSRM is shown in Fig. 1. This change in winding arrangement in SSRM reduces length of flux paths as compared to those in VSRM. It is shown there that SSRM can give double torque than SRM for the same frame size. This increase in torque is because of the increase in aligned flux, while the torque of SSRM increases with the use of full pitch winding, the end winding volume of the motor also increases by a factor which depends on the ratio of motor air gap diameter (D) to stack length (L). For higher values of D/L ratio, as required in in-wheel electric vehicle (EV) or in fans, the copper loss and end winding volume become significantly higher than those corresponding to concentric winding. This arrangement is particularly more effective for machines with D/L ratio equal to and greater than 2.

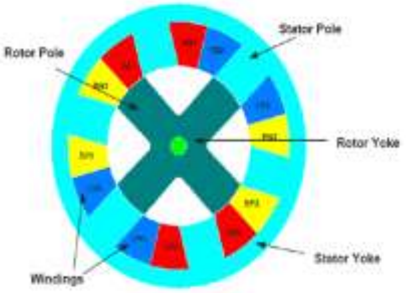


Fig. 1,VSRM

II. PROPOSED SRM DRIVE CONVERTER

A. Converter Topology

The converter operation is simple with only one switch per phase Such that it can perform phase current commutation quickly. Regarding the number of switches used, the converter is similar to the R-dump converter, and it functions like the C-dump converter since the phase inductance energy is recovered. In fact, in addition to its simple structure, this converter has higher efficiency than the R-dump converter and a simpler structure and quicker phase current commutation than the C-dump converter. Fig. (2) Shows the per phase structure of the proposed SRM drive topology.

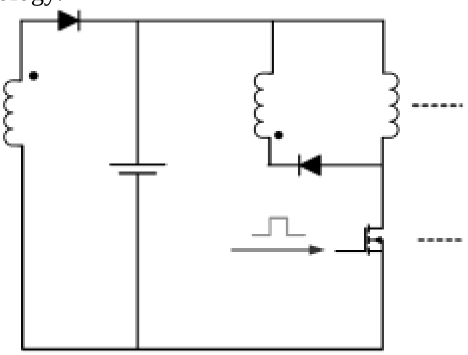


Fig. 2. Proposed SRM per phase converter

Fig. (3) shows the operating modes of this converter for 2 phase SRM. As shown in Fig. (3-a), in the magnetization mode, the switch T1 turns on in order to magnetize phase 'a'. As T1 turns on, the energy is transferred from the source to phase winding and the current through phase inductance increases. Also, in this mode if the magnetizing inductance of coupled inductors is not reset yet, diode D1 would conduct the magnetizing inductance current of the coupled inductors and the input voltage would reset this inductor. When the phase current reaches the reference, T1 is turned off and demagnetization starts. When the magnetizing inductance of coupled inductors is reset, Diode D1 turns off. The reset of coupled inductors magnetizing inductance is similar for other phases. This mode of demagnetization is shown in Fig. (3-b). Since the voltage across phase winding is reversed, diode D1 turns on in this mode. When D1 turns on, Db1 turns on and a negative voltage is placed across the phase winding in proportion to the coupling ratio which accelerates phase current commutation. Fig. (3-c) and Fig. (3-d) shows two overlapping modes of stator phase currents. In the first mode, the phase inductance 'a' is being demagnetized and phase 'b' is being magnetized. In the second mode, both 'a' and 'b' phases are being demagnetized. As it can be observed, this converter has the ability to separately control phase currents. Also, It is important to notice that the snubber circuit of each switch will absorb the voltage spikes across the switches that otherwise would occur due to leakage inductance of coupled inductors.

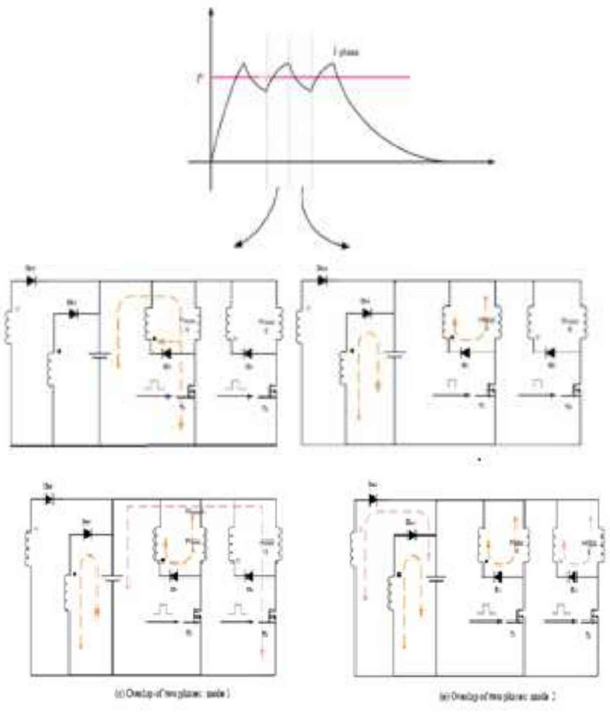


Fig. 3. Operating modes of the proposed converter

B. Design Considerations

For designing this converter, the coupled inductors ratio has to be determined considering the performing speed of the drive. If the phase current does not reach zero fast enough during the commutation, the phase current continues to exist in the negative torque production area and the phase torque becomes negative. This negative torque will cause large ripples in the torque generated by the motor. This is especially important at higher speeds, because higher speed requires faster commutation. So, each SRM drive can function to an extent of speed with regard to its converters structure. The maximum SRM drive speed depends on the type of converter used and is illustrated by the following equation.

$$T_f = T_a \ln[1 + \frac{R_s I p}{V c}] \quad (1)$$

where T_f is the time needed for the current to reach from reference value to zero, Ta is the electrical time constant of machine phases, Rs is the resistance of each phase winding, V_c is the reverse voltage applied to the phase inductance during commutation. The electrical time constant equation of the machine is as follows

$$T_a = \frac{L_a}{R_s} \quad (2)$$

The phase inductance at the current commutation area equals to aligned inductance, thus L and τ would take an "a" subscript. Current drop angle at speed ω is calculated as follows.

$$\theta_f = \omega_m T_f = [\omega_m \tau_a] ln\left[1 + \frac{R_s I_p}{V_c}\right] \quad (3)$$

As it can be observed from (3), when speed increases, θf becomes larger resulting in a larger negative torque and, consequently, more torque ripples. Therefore, it is needed to look for a way to reduce θf at higher speeds. As it can be observed from (3), commutation can be carried out faster by increasing Vc. In the proposed converter, the reverse voltage across the phase winding can be increased for faster commutation purposes by increasing the coupled inductors L1 and L2 turns ratio. Also it is important to notice that Vc is constant in most of the converters introduced so far. But in this converter, Vc can be designed by changing the coupled inductors turns ratio considering the maximum SRM drive functioning speed.

III. PROPOSED FUZZY CONTROLLER

Fuzzy set theory has been widely used in many control areas. A simple fuzzy logic control is built up by a group of rules based on the human knowledge of system behavior. Matlab/Simulink simulation model is built to study the dynamic behavior of single switch based converter which is used for SRM drive. L. A. Zadeh presented the first paper on fuzzy set theory in 1965. Since then, a new language was developed to describe the fuzzy properties of reality, which are very difficult and sometime even impossible to be described using conventional methods Furthermore, design of fuzzy logic controller can provide desirable both small signal and large signal dynamic performance at same time, which is not possible with linear control technique. Thus, fuzzy logic controller has been potential ability to improve the robustness of used converter circuit. The basic scheme of a fuzzy logic controller is shown in Fig.5. It consists of four principal components such as: a fuzzification interface, which converts input data into suitable linguistic values; a knowledge base, which consists of a data base with the necessary linguistic definitions and the control rule set a decision-making logic which, simulating a human decision process, infer the fuzzy control action from the knowledge of the control rules and linguistic variable definitions; a de-fuzzification interface which yields non fuzzy control action from an inferred fuzzy control action [10].

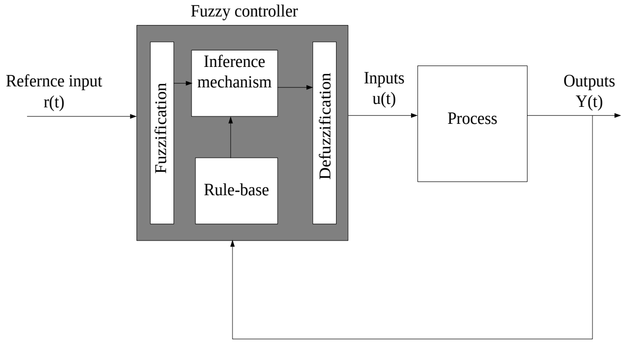


Fig. 4. General Structure of the fuzzy logic controller on closed-loop system

The fuzzy control systems are based on expert knowledge that converts the human linguistic concepts into an automatic control strategy without any complicated mathematical model [10].

A. Fuzzy Logic Membership Functions:

The Fuzzy controllers do not require an exact mathematical model. Instead, they are designed based on general knowledge of the plant. Fuzzy controllers are designed to adapt to varying operating points. Fuzzy Logic Controller is designed to control the output of converter using Mamdani style fuzzy inference system. Two input variables, error (e) and change of error (de) are used in this fuzzy logic system. The single output variable (u) is PWM generation of the converter to control the output.

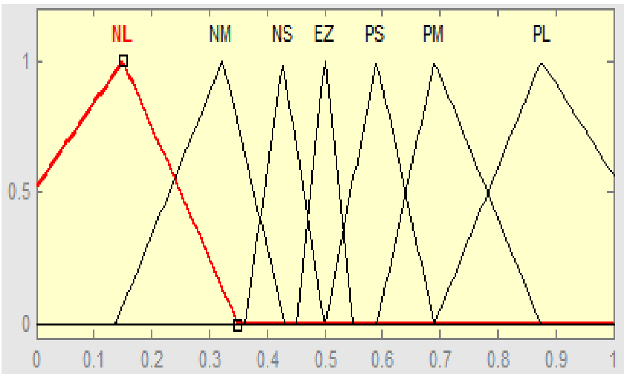


Fig.5 Membership function for error, Change in error, Output.

B. Fuzzy Logic Rules:

The objective of this dissertation is to control the output voltage of the converter circuit. The error and change of error of the output voltage will be the inputs of fuzzy logic controller. These 2 inputs are divided into seven groups; NL: Negative Large, NM: Negative Medium NS: Negative Small, EZ: Equal to Zero, PS: Positive small PM: Positive Medium and PL: Positive Large and its parameter. These fuzzy control rules for error and change of error can be referred in the table that is shown in Table I as per below:

Table I
Table rules for error and change in error

Δe \ e	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	NM	NS	EZ	PS	PM
EZ	NL	NM	NS	EZ	PS	PM	PL
PS	NM	NS	EZ	PS	PM	PL	PL
PM	NS	EZ	PS	PM	PL	PL	PL
PL	NL	NM	NS	EZ	PS	PM	PL

IV.MATLAB MODELING AND SIMULATION RESULTS

Here simulation is carried out in different cases, the simulation results of SRM drive using the proposed converter is compared to the results of a SRM drive operated under fuzzy logic control technique.

Case 1: Performance of Proposed Converter Fed SRM Drive under Open-Loop Condition.

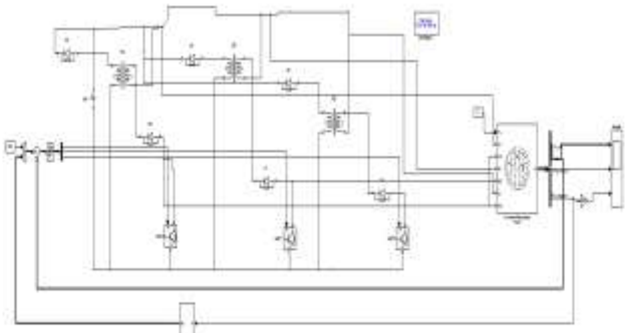
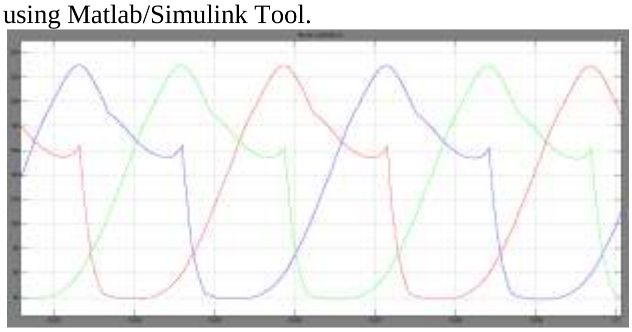
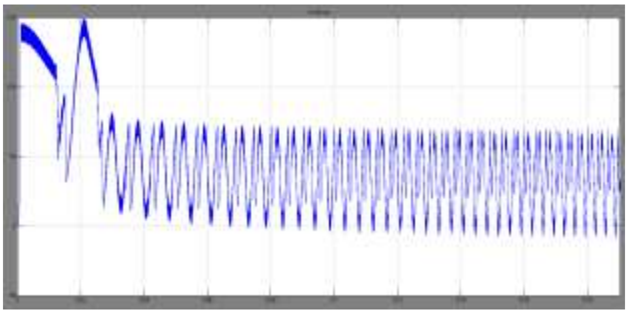


Fig. 6 Matlab/Simulink Model of Proposed Converter Fed SRM Drive under Open-Loop Condition

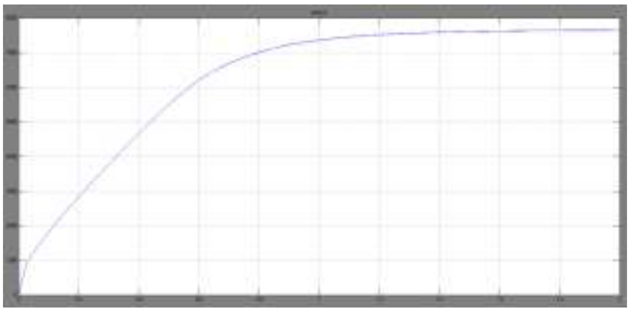
Fig.6 shows the Matlab/Simulink Model of Proposed Converter Fed SRM Drive under Open-Loop Condition using Matlab/Simulink Tool.



(a) Phase Currents



(b)Electro-Magnetic Torque



(c)Speed

Fig.7 Phase Currents, Electromagnetic Torque, Speed of the SR drive, when operating under open loop condition, the SR drive need 1.2 sec to settle down the steady state condition.

Case 2: Performance of Proposed Converter Fed SRM Drive under Closed-Loop Condition

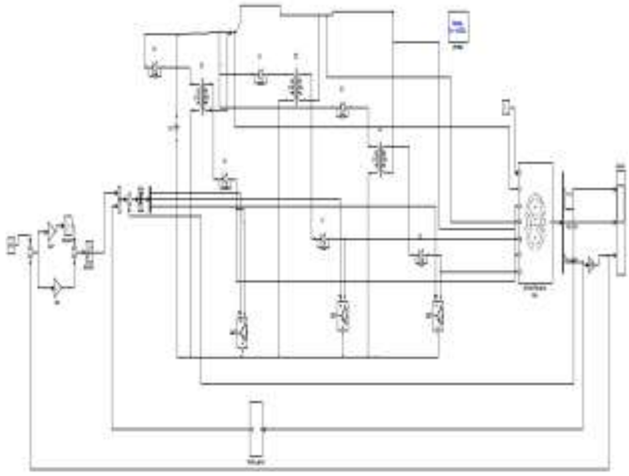
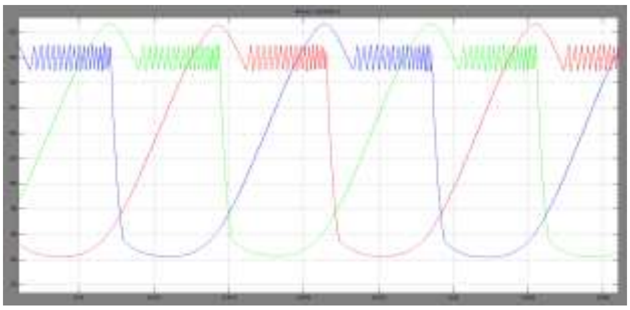
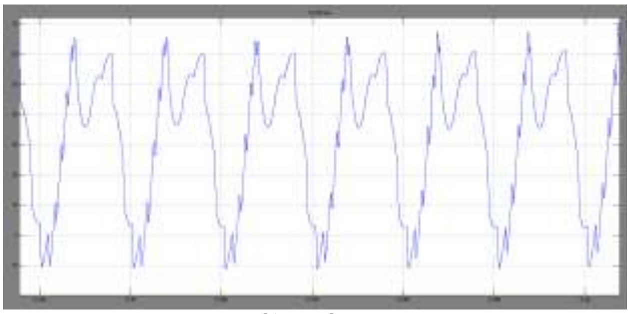


Fig.8 Matlab/Simulink Model of Proposed Converter Fed SRM Drive under Closed-Loop Condition

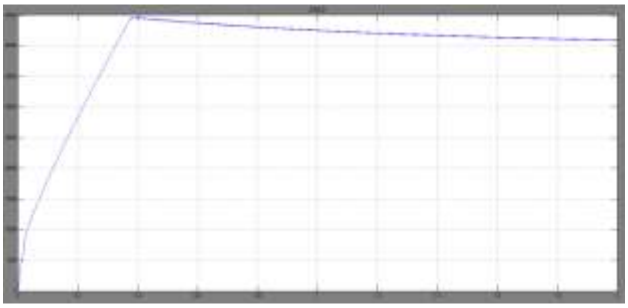
Fig.8 shows the Matlab/Simulink Model of Proposed Converter Fed SRM Drive under Closed-Loop Condition using Matlab/Simulink Tool.



(a)Phase Currents



(b) Electromagnetic Torque



(c) Speed

Fig.9 Phase Currents, Electromagnetic Torque, Speed of the SR drive, when operating under closed loop condition, the SR drive need 0.4 sec to settle down the steady state condition.

Case 3: Performance of Proposed Converter Fed SRM Drive under Closed-Loop Fuzzy Controller.

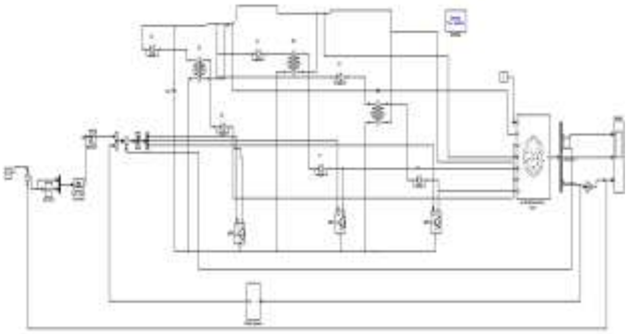
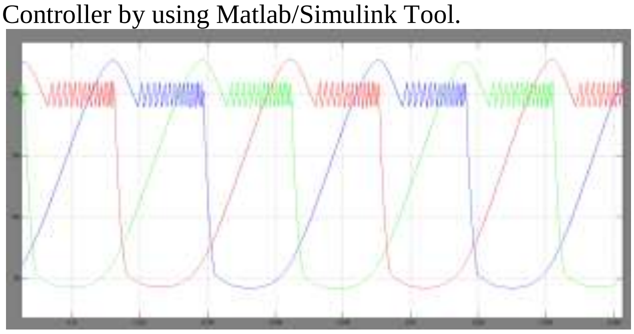
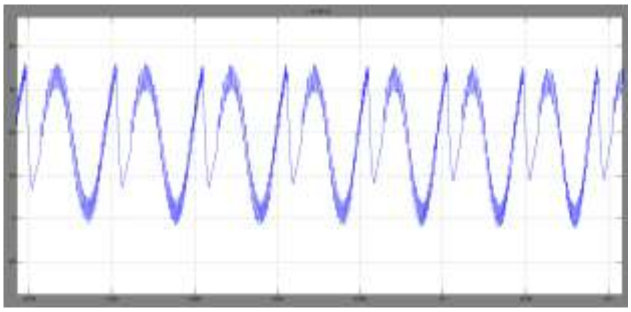


Fig.10 Matlab/Simulink Model of Proposed Converter Fed SRM Drive under Closed-Loop with Fuzzy Logic Controller

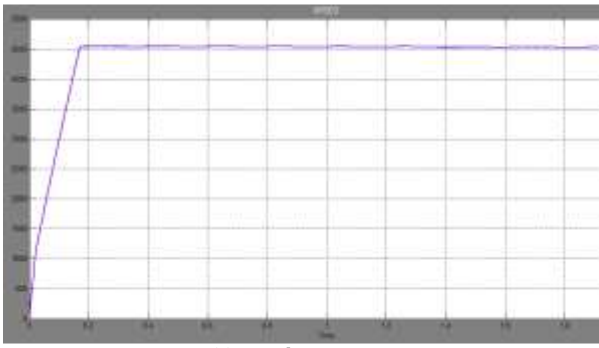
Fig.10 shows the Matlab/Simulink Model of Proposed Converter Fed SRM Drive under Closed-Loop Fuzzy Controller by using Matlab/Simulink Tool.



(a) Phase Currents



(b) Electromagnetic Torque



(c) Speed

Fig.11 Phase Currents, Electromagnetic Torque, Speed of the SR drive, when operating under closed loop fuzzy control condition, the SR drive need 0.17 sec to settle down the steady state condition.

V.CONCLUSION

This proposed model is implemented using Matlab Simulink software and the obtained resultant waveforms were evaluated and the effectiveness of the system stability and performance of converter have been established. In this paper a new SRM drive is introduced. The proposed converter is analyzed and its operating modes are discussed. The proposed converter only uses one switch for each motor phase. Also, in the proposed converter the phase inductance energy is recovered to achieve high efficiency. Simulation results are presented to justify the validity of the theoretical analysis. Without using any dedicated converter, one converter can be used to attain low steady state error values, maintain high stability factor.

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