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COMPARATIVE STUDY OF DIFFERENT TYPES OF CONVERTERS FOR SWITCHED RELUCTANCE MOTOR DRIVE

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ABSTRACT

Switched Reluctance Motor (SRM) is a competition for many applications of electric drive system due to its simple construction and robustness. This paper presents a comparison between different types of conventional converters with a new Bridgeless SEPIC converter. The conventional converter topologies employed for SRM drive are R-dump, C- dump, H-bridge, series and parallel type converters. The SRM with 6/4 pole is analyzed with a Bridgeless SEPIC converter by using Matlab/Simulink packages and operating principles of various converters also described. This paper provides the results of Bridgeless SEPIC converter yields reduced current, torque ripples with a constant speed used in medical application particularly for Sleep Apnea Treatment.

Index Terms - Switched Reluctance Motor (SRM), Single Ended Primary Inductor Converter (SEPIC), R-dump, C- dump, H-bridge, series and parallel converter.

I. INTRODUCTION

Switched Reluctance Motor is a doubly salient machine in which the electromagnetic torque is developed owing to reluctance principle. The stator and rotor has salient poles but only stator carries windings and rotor does not have any attached coils or magnets. Due to the presence of independent SRM phases the failure of one winding does not affect the continuous operation of the drive, but power output from the drive is reduced. The various drawbacks of SRM drive are acoustic noise, torque ripples and position sensing. The Bridgeless Single Ended Primary Inductor Converter (SEPIC) with open and closed loop is proposed to overcome these drawbacks. The advantages of proposed converter are continuous output current, reduced switching stress and smaller voltage ripples compared to conven-tional converters.

The proposed converter has three identical ind-uctors which are coupled to the circuit for reducing the ripples and it can operate as capacitor diode voltage multiplier. The controller gives command to power converter unit to activate the phases of drive. The regulation of phase current and performance of motor is achieved by the controller to meet the spe-cific requirements of drive. The drive system for three phase 6/4 pole SRM with H- bridge converter is shown in Fig.1.

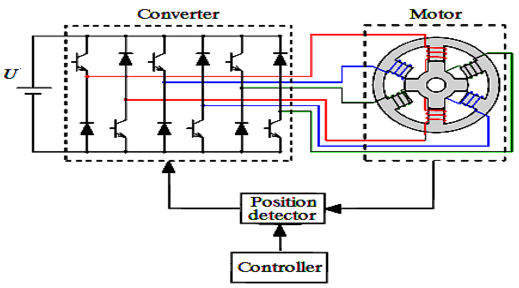

Fig.1 Basic configuration of three phase 6/4 SRM with drive system

The continuous torque can be obtained by synchronizing excitation phases with rotor position. The current flowing through the windings of SRM drive is controlled by power electronic switches. Power converter is the most important part of drive [1]. Based on the selection of converter type, the performance, cost and size of the drive gets varied. The identification of best drive for motor perfor-mance is obtained by comparison of converters. The basic requirements of SRM drive converters are as follows [3];

- The converter should be able to excite the phases before it enters into generating or demagnetization region.
- Each phase of motor has at least one switch to conduct independently

II.TYPES OF SRM CONVERTERS

The fixed DC link voltage for SRM drive is obtained by using AC/DC converter. Based on the performance and application, the suitable type of power converter and control scheme is selected. Some of the features of SRM drive are summarized as follows [3];

- The maximum torque is accomplished during energizing of motor phase.
- The magnetic energy stored during commutation period should be free wheeled or returned to source.
- The supply of current to phase is made only at positive gradient duration of inductance profile.

A.R-Dump Converter

The R- dump converter is shown in Fig.2. It consists of one switch and one diode per phase. The power dissipation and switching voltage is determined by the value of resistance R. The change in value of R should be done to achieve both stress on the switch and fall time of the current. When the switch T_1 is turned off, the current freewheels through diode D_1, charging capacitor C and external resistor R. This resistor dissipates the stored energy in energized phase [3]. The drawback of this conver-ter is that current in any phase will take longer time to extinguish. It reduces overall efficiency of the motor and dissipates more energy in a resistor [5].

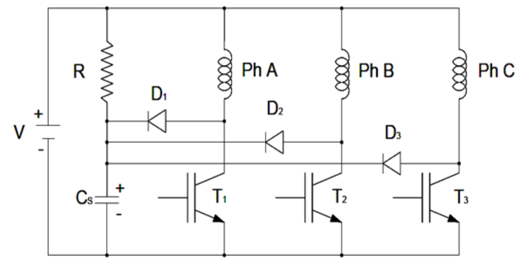

Fig.2 Circuit Diagram of R-dump Converter

B.C-Dump Converter

The C-dump converter is shown in Fig.3. It consists of one switch and one diode per phase and has one additional dump capacitor to dissipate the stored energy back to the supply. The phase A is energized when the switch T_1 is turned on. When the switch T_1 is turned off, the phase current i_a exceeds the reference value. Due to this the diode D_1 is forward biased and current path closed through dump capacitor C_d to achieve fast demagnetization. The dump switch T_1 operates at higher frequency compared to other phase switches.

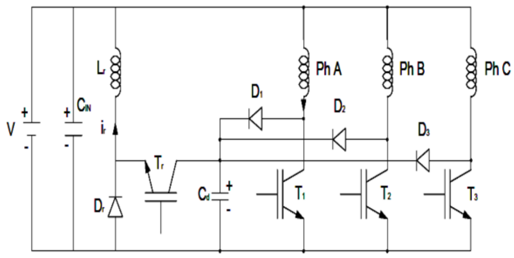

Fig. 3 Circuit Diagram of C-dump Converter

The advantages of C-dump converter are reduced number of switching devices, independent phase current control, regenerative capability and fast winding demagnetization. The major drawback of this converter is use of capacitor and an inductor in the dump circuit which increases the voltage to twice the bus voltage [5]. The efficiency of the drive gets decreased due to energy circulation between dump capacitor and dc link voltage which also results in additional losses.

C.H-Bridge converter

The H- bridge converter is shown in Fig.4. It consists of two switches and two diodes per phase to achieve unipolar strategy. The unipolar switching strategy is used to obtain less current ripple and better frequency response. In each phase, PWM switching control is performed by upper switches such as T_1, T_3 and T_5 and charge of commutation by lower switches such as T_2, T_4 and T_6. The three modes of operation of this converter are magne-tization, freewheeling and demagnetization mode [5,10].

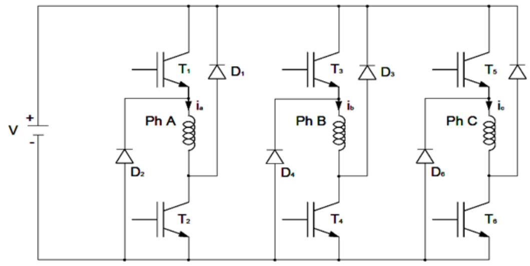

Fig.4 Circuit Diagram of H-bridge converter

By using H-bridge converter, the SRM is contro-lled either by voltage control or current control. Compared to voltage control, current control is advantageous because it provides possibility of reduction in torque ripples and noise [14]. The advantageous of this converter is that it provides greater flexibility in controlling the machine current. The major drawback of this converter is that two devices are always in series with the motor winding which leads to increase the conduction losses as well as size and cost of the drive gets increased.

D. Series Converter

The series converter is shown in Fig.5. The series converter is modified from the H-bridge converter by adding one diode and boosting capacitor in series with the phase windings of SRM to achieve voltage boosting capability [7]. The three modes of operation are magnetization, freewheeling and demagnetization mode. In magnetization mode T_1 and T_2 are turned on and phase winding A is energized with the current flow through the path of V, D_a, T_1, L_1, T_2 and V. In free wheeling mode when the winding current exceeds the reference value, either T_1 or T_2 is turned off.

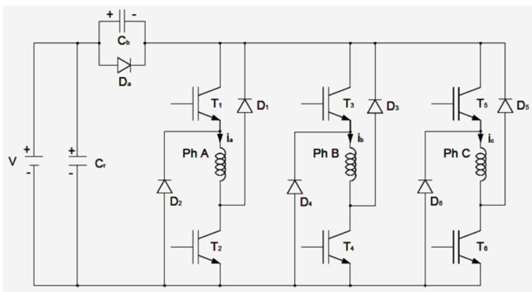

Fig.5 Circuit Diagram of series converter

The flow of current in winding is freewheeling in one path L1, D_1, and T_1 or the path of L_1, T_2 and D_2. In the demagnetization mode the incoming phase winding is charged by stored magnetic energy of energized winding [2]. The advantages of this con-verter are higher efficiency and simple control. The major drawback is that the torque per ampere is medium.

E. Parallel Converter

The parallel type of converter is shown in Fig.6. The parallel type converter is modified from H-bridge converter by adding one boost capacitor in parallel with phase windings to achieve voltage boosting capability [6]. The three modes of operation are magnetization, demagnetization and freewheeling mode. In magnetization mode T_1 and T_2 are turned on and phase A winding is energized with current flow through the path of V, D_a, T_1, L_1,, T_2 and V. In freewheeling mode, when the winding current exceeds the reference value either T_1 or T_2 is turned off..

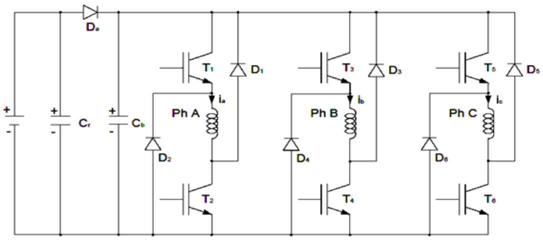

Fig.6 Circuit Diagram of Parallel converter

The flow of current in winding is freewheeling in one path L_1, D_1 and T_1 or with the path of L_1, T_2 and D_2. In demagnetization mode the incoming phase winding is charged by the stored magnetic energy of energized winding [3]. The major advantages of this converter are high reliability and better performance

F. Bridgeless SEPIC Converter

The circuit diagram of bridgeless SEPIC converter is shown in Fig.7. The auxiliary circuit includes an additional winding Ns of input inductor L_c, auxiliary inductor L_s and a capacitor C_a. The coupled inductor L_c can be modeled as a magnetizing inductance L_m and an ideal transformer which has a turns ratio of 1:n(n= N_s/N_p) . The leakage inductance of the coupled inductor L_c is included in auxiliary inductor L_s. The capacitance C_a is considered as a voltage source V_s during a switching period. By volt-second balance law, the average input voltage should be zero and average capacitor voltage V_{ca} is equal to the input voltage V_m during a switching period under steady state [13]. Likewise average capacitor voltage V_{c1} is equal to the input voltage V_{in}. The diodes D_1 and D_2 are input rectifiers. The intrinsic body diodes D_{s1} and D_{s2} are switches of s_1 and S_2 which operated by gate signals.

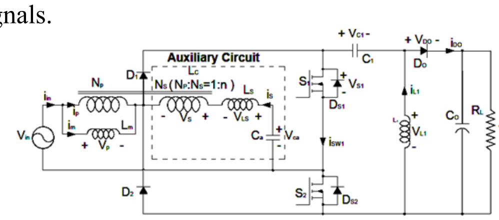

Fig.7 Circuit Diagram of Bridgeless SEPIC converter.

The operation of proposed converter is symmetrical in both half cycles of input voltage. So, the converter operation is analyzed during the positive half-line cycle of input voltage [12]. The output diode D_o is turned off before the main switch gets turned on [15]. The gate driving signals for the proposed converter is shown in Fig.8.

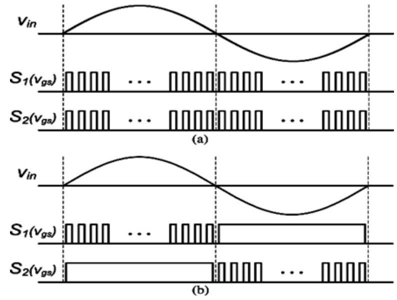

Fig.8 Gate driving signals a). Conventional gate signals for S_1 and S_2. B). Proposed gate signals for S_1 and S_2.

III.. BRIDGELESS SEPIC CONVERTER – MODES OF OPERATION

Mode 1 $[t_0,t_1]$ In Fig. 9, at the time instant t_0, the switch S_1 is turned on and switch S_2 is conducting.

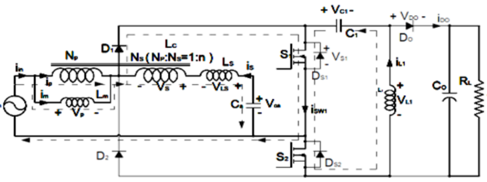

Fig.9 Operation of mode 1

The magnetizing current i_m increases from its minimum value of i_{m2} linearly with a slope of V_m/I_m due to the voltage V_p across magnetizing inductance L_m is (1-n)V_{in}. The voltage V_{LS} across L_s is V_{in} and therefore current i_s increases from its minimum value of L_2 linearly with a slope of (1-n) V_{in}/L_s. Mode 2 $[t_1,t_2]$ In Fig.10, at the time instant t_1, the switch S_1 is turned on and switch S_2 is conducting.

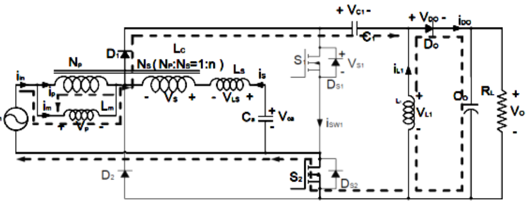

Fig.10 Operation of mode 2

The voltage V_p across magnetizing inductance L_m is –V_o. The magnetizing current i_m decreases from its minimum value of L_{m1} linearly with a slope of -V_m/L_m. The voltage V_{ls} across L_s is –(1-n)V_0 and the current i_s decreases from maximum value L_{s1} linearly with a slope of –(1-n) V_{in}/L_s.

Mode 3 $[t_2,t_0]$ In Fig.11, at the time instant t_o diode D_0 is turned off and current i_{do} becomes zero. The freewheeling currents i_{s2} and i_{l2} makes the sum of input current i_{in}. The input current is given as $i_m = i_m$-nis = i_s-i_{l1}.

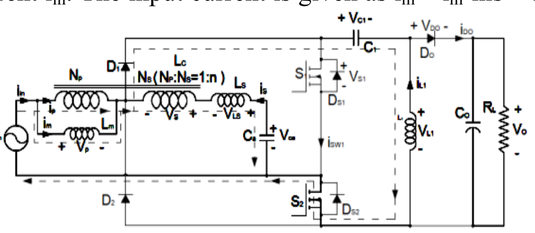

Fig.11 Operation of mode 3

IV. SIMULATION RESULTS AND DISCUSSION

A. Results R-Dump Converter

The simulation model using R-dump converter is shown in Fig.12. The output parameters such as flux, current, torque and speed are shown in Fig.13. During steady state operation, the flux is 1.5 Wb, maximum phase current is 300A. The torque developed by motor is 250 N-m with a speed of 3000 rpm.

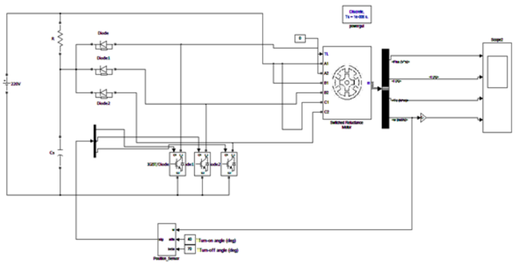

Fig.12 Simulink model of 3-phase, 6/4 SRM using R-dump converter

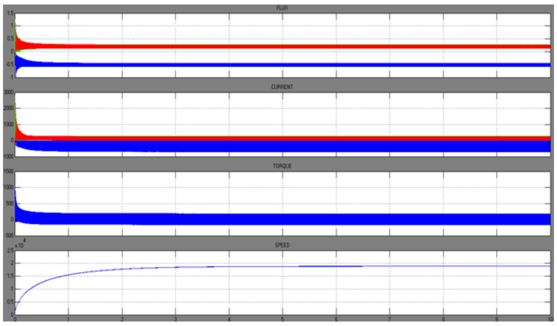

Fig.13 Simulation Results of R-dump converter. a).Flux, b).Current, c).Torque, d).Speed

B. Results for C-Dump Converter

The complete simulation model using C-dump converter is shown in Fig.14. The output parameters of SRM such as flux, current, torque and speed is shown in Fig.15.

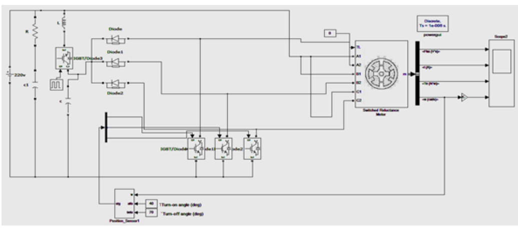

Fig.14 Simulink model of 3-phase 6/4 SRM using C-dump converter

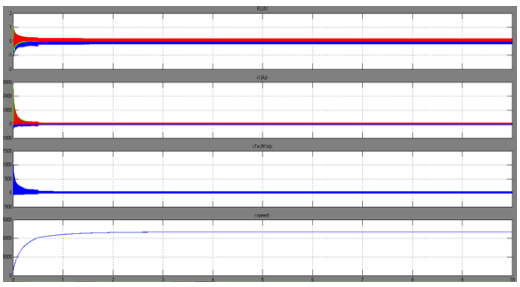

Fig.15 Simulation results of C-dump converter a). Flux, b).Current, c).Torque, d) Speed

During steady state operation, the flux obtained is 0.7 Wb, the maximum phase current is 500A. The torque developed by a motor is 270 N-m with speed of 4000 rpm.

C. Results for H- Bridge Converter

The complete simulation model using H-bridge converter is shown in Fig.16. The simulink results of SRM with flux, current, torque and speed are shown in Fig.17. During steady state operation, the maximum current is 400A with flux 0.5 Wb. The torque developed by motor is 300 N-m with a speed of 5000 rpm..

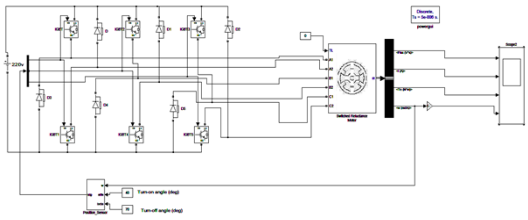

Fig.16 Simulink model of 3-phase 6/4 SRM using H-bridge converter

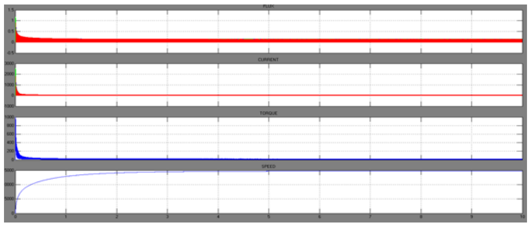

Fig.17 Simulation results of H-bridge Converter, a).Flux, b).Current, c).Torque, d).Speed

D. Results for Series Converter

The complete simulation model of series converter is shown in Fig.18.

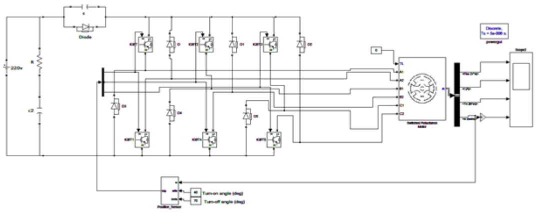

Fig.18 Simulink model of 3-phase 6/4 SRM using Series Converter

The variations of flux, current, torque and speed are shown in Fig.19. During steady state operation, flux obtained is 0.5 Wb with maximum phase current of 350A. The torque developed by motor is 250 N-m with speed of 4500 rpm.

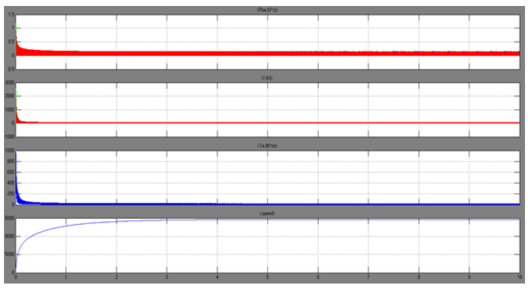

Fig.19 Simulation results of Series Converter a).Flux, b).Current, c). Torque, d).Speed

E. Results for Parallel Converter

The complete simulation model of parallel converter is shown in Fig.20. The simulation results of flux, current, torque and speed are shown in Fig.21. During steady state operation,, the flux is 0.5 Wb, the maximum phase current is 300A. The torque developed is 250 N-m with a speed of 4500 rpm.

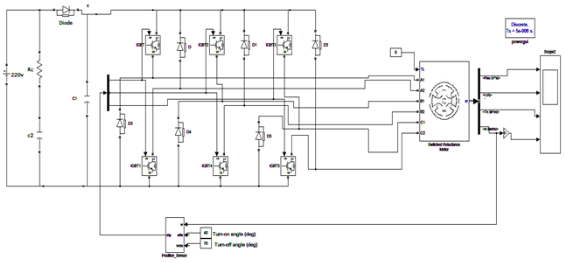

Fig.20 Simulink model of 3 phase 6/4 SRM using Parallel Converter

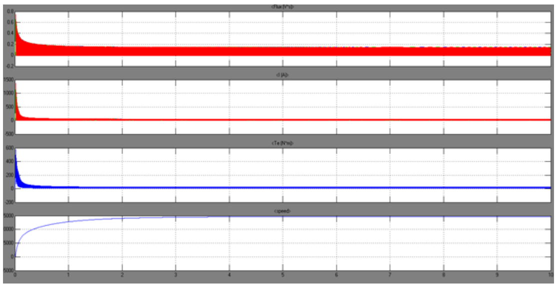

Fig.21 Simulation results of Parallel Converter a).Flux, b).Current, c).Torque, d).Speed

F. Results for Bridgeless SEPIC Converter

- Open loop SRM
- Closed loop SRM

(i). Open loop Bridgeless SEPIC Converter fed SRM Drive

The complete simulation model of open loop Bridgeless SEPIC converter fed SRM drive is shown in Fig.22. The variations of flux, current, torque and speed is shown in Fig.23. During steady state operation, the flux obtained is 0.4 Wb, the maximum phase current is 50A. The torque developed by motor is 25 N-m with a speed of 2000 rpm.

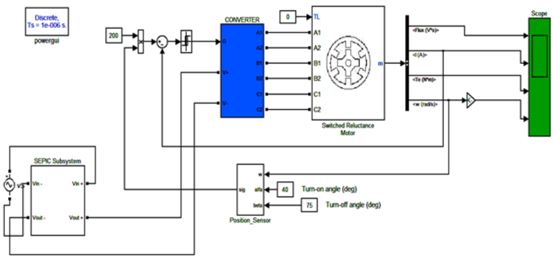

Fig.22 Simulation model of 3 phase 6/4 pole SRM using open loop Bridgeless SEPIC Converter

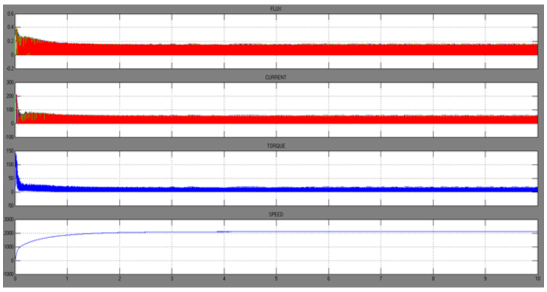

Fig.23 Simulation results of Open loop Bridgeless SEPIC Converter fed SRM drive a).Flux, b).Current, c).Torque, d).Speed

(ii). Closed loop Bridgeless SEPIC Converter fed SRM Drive

The complete simulation model using closed loop Bridgeless SEPIC converter fed SRM drive is shown in Fig.24.

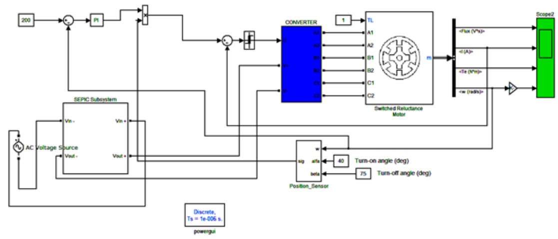

Fig.24 Simulation model of 3 phase 6/4 pole SRM using Closed loop Bridgeless SEPIC Converter

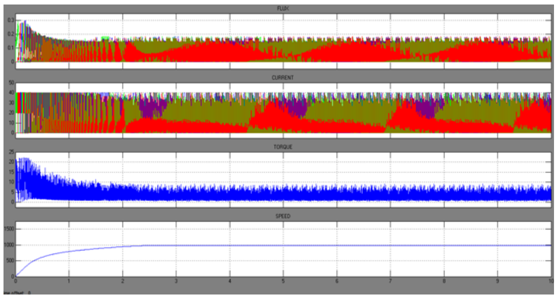

Fig.25 Simulation results of closed loop Bridgeless SEPIC Converter a).Flux, b).Current, c).Torque, d).Speed

The output parameters of flux, current, torque and speed are shown in Fig.25. During steady state operation, the flux is 0.3 Wb with maximum current of 40A. The torque developed by motor is 20 N-m with a speed of 1400 rpm

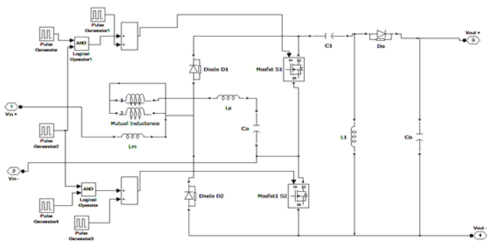

Fig.26 Subsystem model of Bridgeless SEPIC Converter for 3 phase 6/4 pole SRM

TABLE 1.COMPARISON OF SIMULATION RESULTS OF SRM CONVERTERS

Converter	Parameters			
	Flux (weber	*Curren (A)*	*Torque (N-m)*	*Speed (rpm)*
R-dump	1.5	300	250	3000
C-dump	0.7	500	270	4000
H=bridge	0.5	400	300	5000
Series	0.5	350	250	4500
Parallel	0.5	300	250	4500
Open loop Bridgeless SEPIC	0.4	50	25	2000
Closed loop Bridge-Less SEPIC	0.3	40	20	1400

The comparison of various converters such as R-dump, C-dump, H-bridge, series, parallel and Bridge-less SEPIC converter with Open loop and Closed loop topologies for SRM drive is represented in Table 1. The comparison of various parameters such as flux, current, torque and speed shows that Bridgeless SEPIC Converter with closed loop produces better results with reduced current and torque ripples

V. CONCLUSION

The most flexible and versatile converter for SRM drive is Bridgeless SEPIC converter with closed loop which produces reduced current and torque ripples compared to conventional converters employed for SRM drive. By comparing various converter topologies from table 1, it is found that Bridgeless SEPIC converter with closed loop produces better results and performance. The Bridgeless SEPIC Converter topology is more beneficial in low-voltage high-current applications. Thus the simulation and its output have a tendency of improved performance with reduced current and torque ripples throughout the operation.

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