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Modified SEPIC Converter Using Fuzzy Logic Controller Based Torque Ripple Reduction in Brushless DC Motor

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Abstract: This paper proposes a novel converter topology to reduce the commutation torque ripple in brushless DC (BLDC) motor drives. The modified SEPIC (single-ended primary inductor converter) DC-DC converters, and a commutation voltage selection circuit. The torque ripple appears due to stator winding inductance during phase commutation, which prevents the use of BLDC motor in high performance applications due to undesirable vibration and acoustic noise. To weaken the torque ripple during the commutation period, two modified SEPIC converters are used to adjust the DC bus voltage to the desired value depending upon the BLDC motor rotational speed. A metal oxide semiconductor field effect transistor (MOSFET)-based commutation voltage selection circuit is used to apply the regulated DC bus voltage during the commutation period. Finally, simulation results show that torque ripple can be significantly reduced by the proposed modified SEPIC DC-DC converters and commutation voltage selection circuit.A modified version of the bridgeless single-ended primary inductance converter (BL-SEPIC) as preferred to varying thespeed of BLDC motor is presented in this paper. The conduction losses and ripple current in the input side of conventional SEPICconverter can be overcome by bridgeless SEPIC converter with auxiliary circuit. The proposed concept can be implemented to Communication Torque Ripple Reduction in Brushless DC Motor using current control technique by using Matlab/Simulink software.

Keywords: BLDC Motor, Modified SEPIC Converter, Commutation Torque Ripple, Dc Link Voltage Control.

I. INTRODUCTION

The Brushless DC (BLDC) motor is rapidly gaining popularity by its utilization in various industries, such as appliances, automotive, aerospace, consumer, medical, industrial automation equipment and instrumentation. A BLDC motor is known as a―synchronous‖ type because the magnetic field generated by the stator and the rotor revolve at the same frequency. One benefit of this arrangement is that BLDC motors do not experience the ―slip‖ typical of induction motors. While the motors can come in one, two, or three phase types. As the name implies, the BLDC motors do not use brushes for commutation; instead they are electronically commuted [1]. BLDC motors have many advantages over brushed DC motors and induction motors, a few of these are,

- Better speed Vs torque characteristics
- High dynamic response
- High efficiency
- Long operating life
- Noiseless operation

Fig.1 shows the typical driving circuit for BLDC motor. The input circuit consists of a half wave or full wave bridge rectifier followed by a capacitor capable of maintaining a voltage of approximately the peak voltage of input sine wave until [2] the next peakcome along to recharge the capacitor. So the power factor will decrease. In such cases, active or passive power factor [3-6] correction maybe used to counteract the distortion and raise the power factor. Passive PFC uses a capacitive filter at the AC input to correct poor power factor. Passive PFC may be affected when environmental vibration occurs. Passive PFC requires that the AC input voltage beset manually [7-9]. Passive PFC does not use the full energy potential of the AC line.

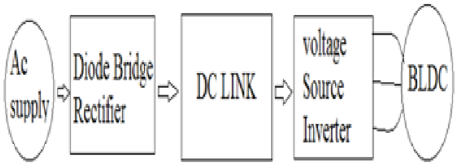


Fig.1. Typical driving circuit for BLDC motor.

Many types of active power factor correction circuits are there buck converter, boost converter, buck-boost converter, conventional SEPIC converter [10-12], etc. Since, the input current of the PFC buck converter has dead angles during the time intervals when the input voltage is lower than the output voltage, there is a strong tradeoff between power factor and output voltage selection. On the other hand, a SEPIC PFC converter can provide a high power factor regardless its output voltage due to its step up/down function. Several bridgeless single-ended primary inductor converters (SEPICs) [13] were proposed. The efficiency of these converters is improved by removing the input bridge diode. However, bulk input inductor or another LC filter is required to suppress the input current ripple. In this paper, a Modified SEPIC (MSEPIC) converter is proposed as a step-up and step -down [14] converter having high power conversion efficiency and minimized voltage and current stress than the classical SEPIC topology. The idea of this proposed work is to drive phase currents to increase and decrease in the identical slope [15], resulting in the reduction of pulsated commutation torque ripple. Simulation results prove that the torque ripple is reduced [16] when compared with the conventional method.

II. COMMUTATION TORQUE RIPPLE IN BLDCM

Ideally, the current drawn by the BLDCM, with trapezoidal back EMF, takes the form of rectangular waveform [8] as shown in Fig.2. This kind of current waveform will produce a constant torque.

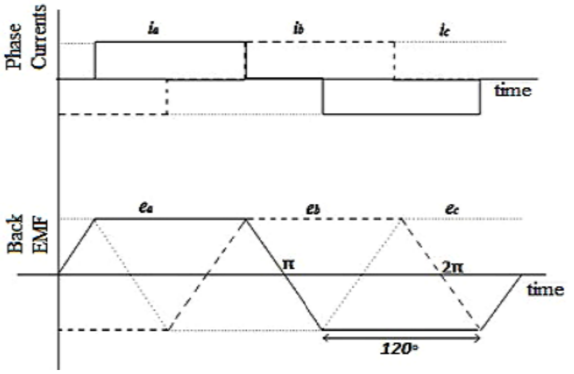


Fig.2. Ideal Current and back emf waveform.

Practically, the smoothness in torque waveform is not observed and torque ripple is prevalent. Various non – linearity in the machine will result in the disruption of the ideal rectangular current waveform thereby resulting in torque ripple. The excitation current waveforms do not change instantaneously and a variable commutation time for different speeds is observed as shown in Fig.3.

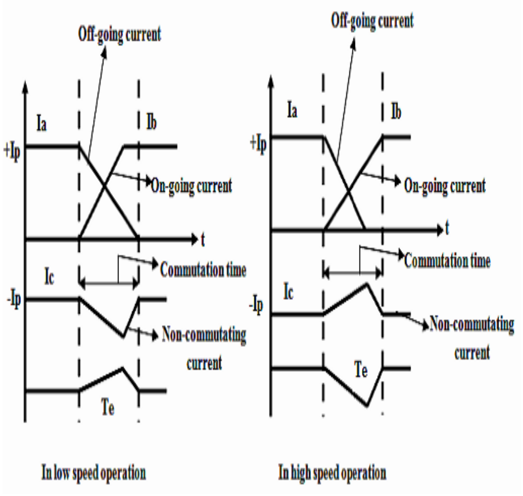


Fig.3. Commutation Currents and Torques.

During this commutation time, Torque ripple occurs due to the difference between the time taken by the ongoing phase 'b' current to reach the saturation value and the time taken by the off going phase 'a' current decay to zero. In order to eliminate the dip in the Torque waveform, the difference in the commutation time for ongoing and off going phase currents should be made zero as shown in Fig.4. This torque dips can be reduced by suitable dc link voltage control method during the commutation time. This can be achieved by using proposed MSEPIC in BLDCM drives.

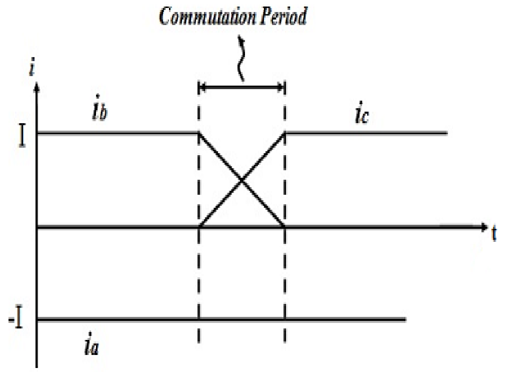


Fig.4. Current waveform for the torque ripple compensation.

III. MODIFIED SEPIC CONVERTER

The circuit topology of the conventional SEPIC Converter is presented in Fig.5

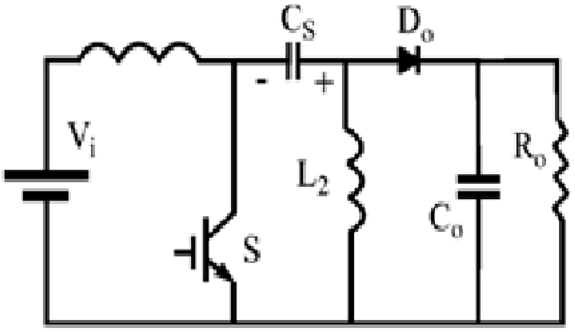


Fig.5. Conventional SEPIC Converter.

The wide range of input voltages can be realized because of the step-up and step down static gains of SEPIC converter. However, SEPIC converter suffers from higher voltage and current stress. This disadvantage can be eliminated by using the proposed M-SEPIC converter circuit. Here, the modification of the SEPIC converter is accomplished by including diode Dm and capacitor Cm as shown in Fig.6.

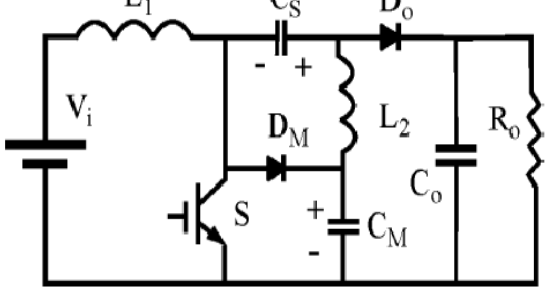
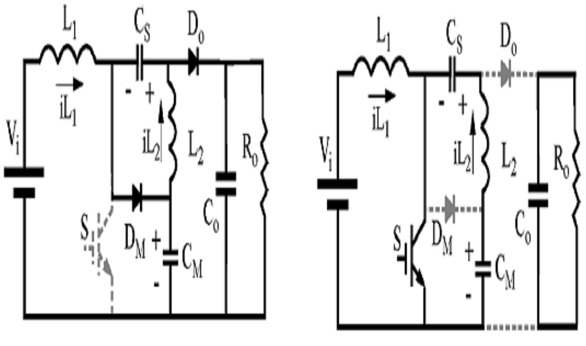


Fig.6. Modified SEPIC Converter.

A multiplier cell (C_m and D) reduces the switch stress in the proposed converter. The capacitor $C_m$is charged with the output voltage of the classical boost converter. Hence, the voltage applied to the inductor L_2 during conduction is higher compared with the classical SEPIC, thereby increasing the static gain.



(a) Mode 1 (b) Mode 2

Fig.7. MSEPIC modes of operation.

The continuous conduction- mode (CCM) operation of the MSEPIC converter presents the following two modes.

Mode 1: In this mode the switch S is turned-off as shown in Fig.7(a) and the energy stored in the input inductor L_1 is transferred to the output through the capacitor C_s and output diode D_o, and also to the capacitor C_m through the diode D_m. Therefore, the switch voltage is equal to the capacitor C_m voltage. The energy stored in t he inductor L_2 is transferred to the output through the diode D_o.

Mode 2: In this mode the s witch S is turned-on and the diodes D_m and D_o are blocked as shown in Fig.7(b), and the inductors L_1 and L_2 store energy. The input voltage is applied to the input inductor L_1 and the voltage ($V_{cs} – V_{cm}$) is applied to the inductor L_2. The voltage V_{cm} is higher than the voltage Vcs. The inductor L1 current is equal to the input current and the inductor L2 current is equal to the output current.

IV. PROPOSED TORQUE RIPPLE MINIMIZ ATION TOPOLOGY FOR BLDCM

A Modified SEPIC Converter with a switch over IGBT for implementing the dc link voltage adjustment is shown in Fig.8.

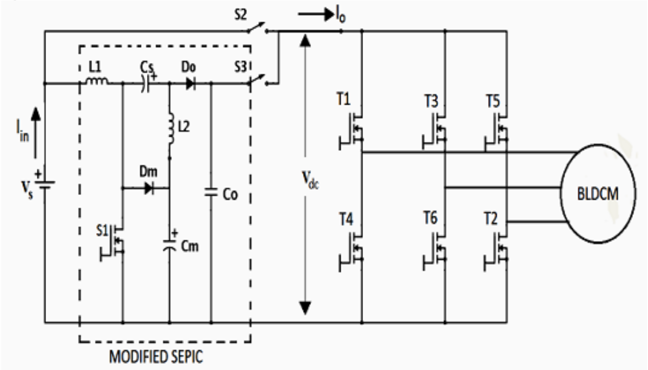


Fig.8. Configuration of BLDCM driving system with MSEPIC Converter.

In Fig.8, S_1, S_2, S_3 are power MOSFET s. By operating S_1 appropriately, the energy storage components L_1, L_2, C_s, C_0 and C_m of the M-SEPIC can be adjusted to get the desired voltage. S_2 and S_3 are switched over power MOSFETs used for choosing between the inputs of the inverter V_s and the output voltage of the MSEPIC V_o. V_o can be calculated as

$$V_o = \frac{1+D}{1-D} * V_s \tag{1}$$

Where, D is the Duty ratio. Em is proportional to speed, i.e.,

$$E_m = K_e \omega \tag{2}$$

Where Ke is the back EMF co-efficient and ω is the speed of the machine. Then, the duty ratio of S1 forsatisfying Vo = 4Em from [14] can be calculated by

$$D = \frac{4K_e\omega - V_s}{V_s + 4K_e\omega} \tag{3}$$

According to above equation, the duty ratio of S_1 corresponding to the desired dc link voltage can be estimated by measuring the motor speed. The relationship between the duty ratio and speed is shown in Fig.9. The duty ratio calculations are done by assuming the input voltageV_s as 200V.

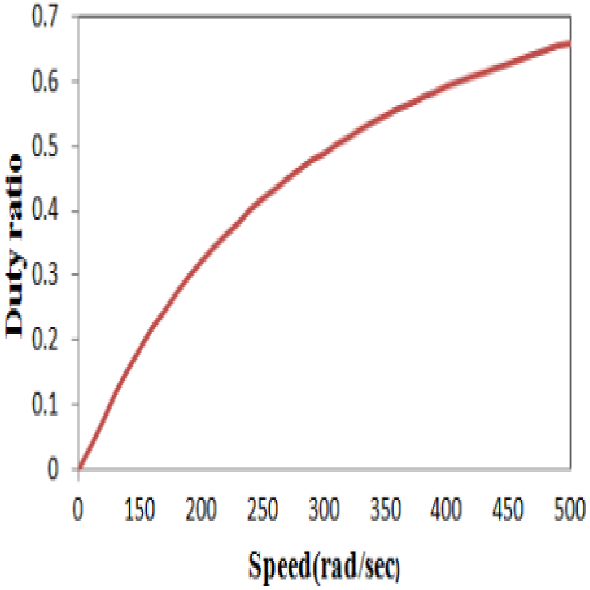


Fig.9. Duty ratio with respect to speed.

To achieve an immediate change of the input voltage of inverter, S2 and S3 should be complementary to each other. At the beginning of every commutation, S2 is switched OFF and S3 is switched ON. The MSEP IC converter stops adjusting, and the output voltage remains constant. Once commutation is over, S2 is switched ON and S3 is switched OFF. The MSEPIC converter will start regulating again, and its output voltage will reach the expected value before the next commutation. The flowchart for the proposed method is clearly indicated in Fig.10.

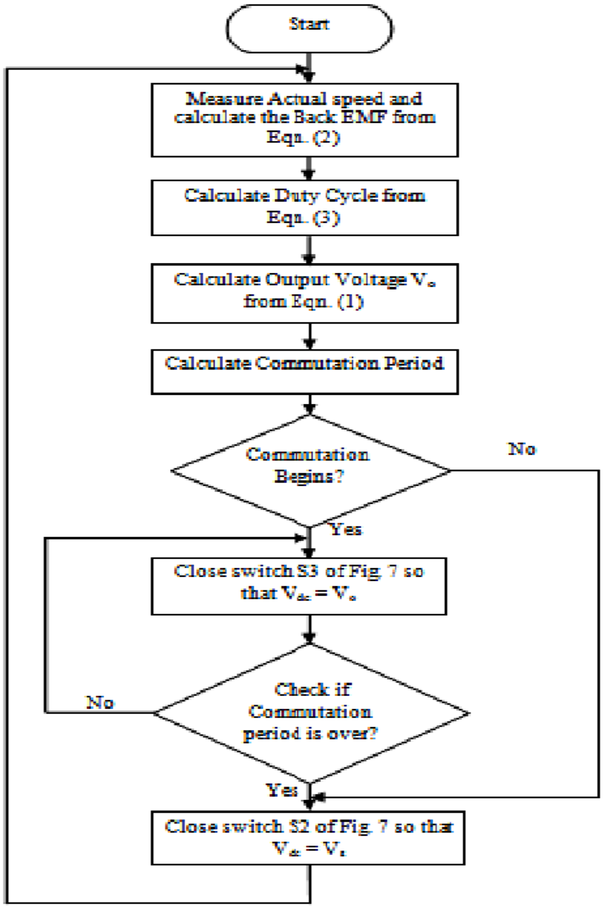


Fig.10. Flowchart of the proposed method for one electrical cycle.

V. FUZZY LOGIC CONTROLLER

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. Fuzzy set theory has been widely used in the control area with some application to dc-to-dc converter system. 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 dc-to-dc converter and performance of proposed controllers. 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 dc-to-dc converters. The basic scheme of a fuzzy logic controller is shown in Fig.11 and consists of four principal components such as: a fuzzy fiction 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]. 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]. Simulation is performed in buck converter to verify the proposed fuzzy logic controllers as shown in Fig.12.

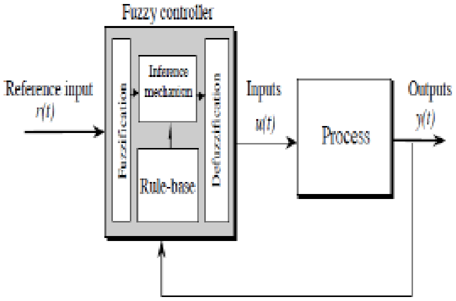


Fig.11. General Structure of the fuzzy logic controller on closed-loop system.

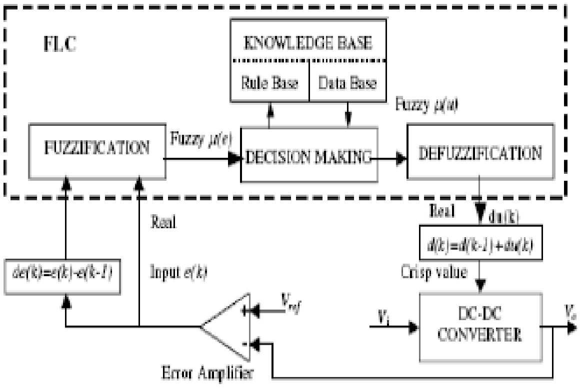


Fig.12. Block diagram of the Fuzzy Logic Controller (FLC) for dc-dc converters.

Fuzzy Logic Membership Functions: The dc-dc converter is a nonlinear function of the duty cycle because of the small signal model and its control method was applied to the control of boost converters. 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 boost dc-dc 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 duty cycle of PWM output as shown in Figs.13 to 15.

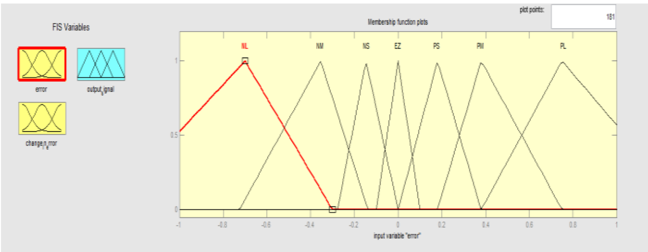


Fig. 13.The Membership Function plots of error.

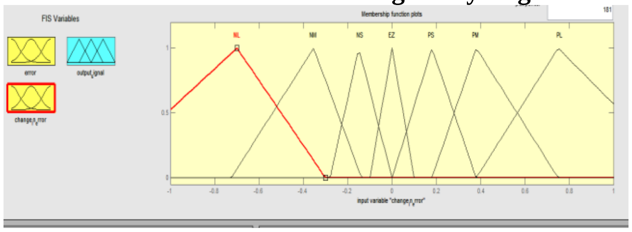


Fig.14.The Membership Function plots of change error.

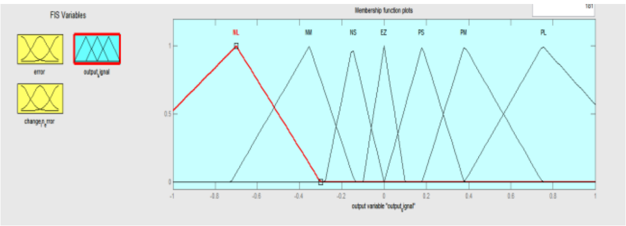


Fig.15. the Membership Function plots of duty ratio.

Fuzzy Logic Rules: The objective of this dissertation is to control the output voltage of the boost converter. 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: Zero Area, PS: Positive small and PM: Positive medium PL: Positive Large and its parameter [10]. These fuzzy control rules for error and change of error can be referred in the table that is shown in Table as per below:

TABLE I: Table Rules For Error and Change of Error

De \ 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	EZ	PS	PM	PL	PL	PL	PL

VI. SIMULATION RESULTS

Simulation results of this paper is as shown in bellow Figs.16 to 24.

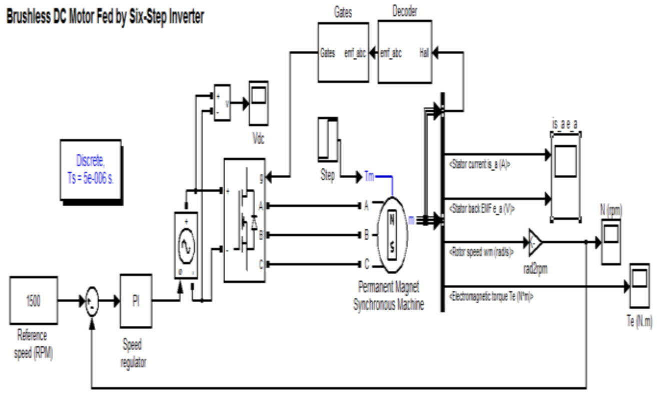


Fig.16. Matlab/simulation circuit of conventional for reducing commutation torque ripple in BLDCM drive.

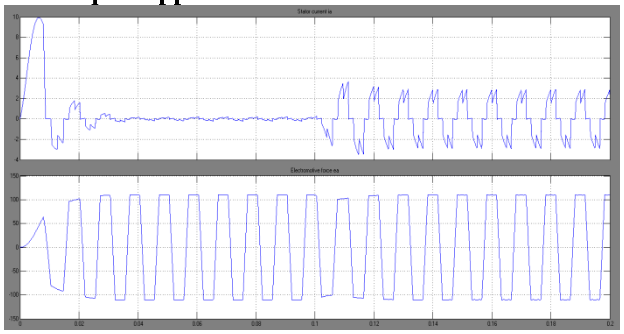


Fig.17.Matlab/simulation circuit of conventional for reducing commutation torque ripple in BLDCM wave form of current and electromagnetic force.

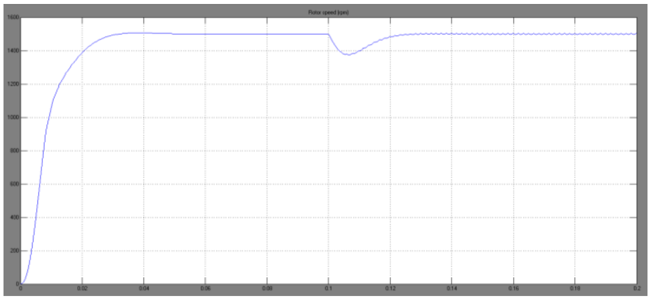


Fig.18.Matlab/simulation circuit of conventional for reducing commutation torque ripple in BLDCM wave form of speed.

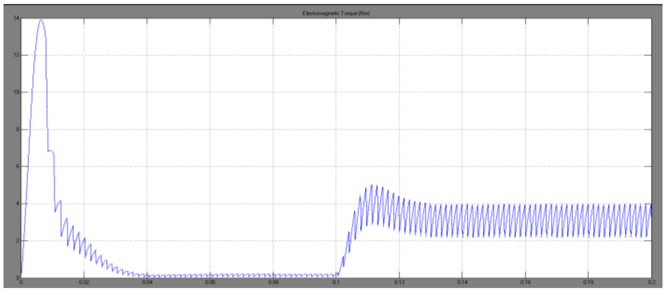


Fig.19.Matlab/simulation circuit of conventional for reducing commutation torque ripple in BLDCM wave form of torque.

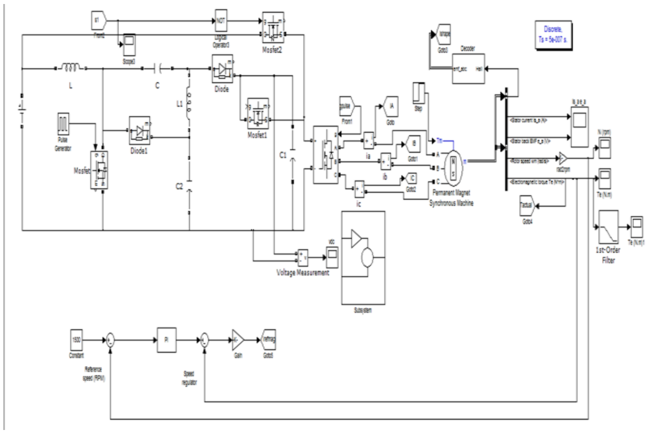


Fig.20.Matlab/simulation circuit of conventional for SEPIC converter reducing commutation torque ripple in BLDCM drive.

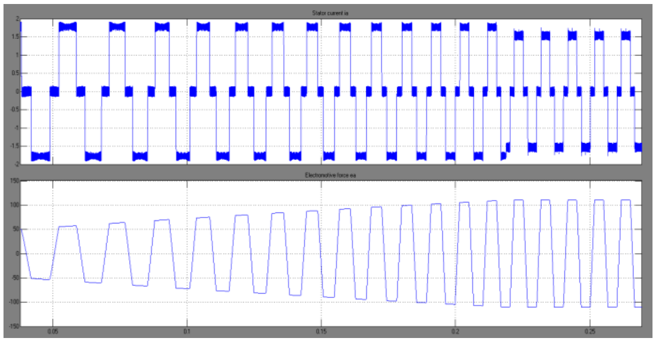


Fig.21.Matlab/simulation circuit of conventional for SEPIC converter reducing commutation torque ripple in BLDCM wave form of current and electromagnetic force.

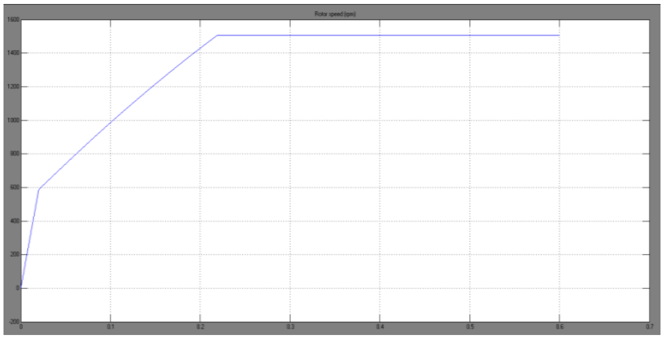


Fig.22.Matlab/simulation circuit of conventional SEPIC converter for reducing commutation torque ripple in BLDCM wave form of speed.

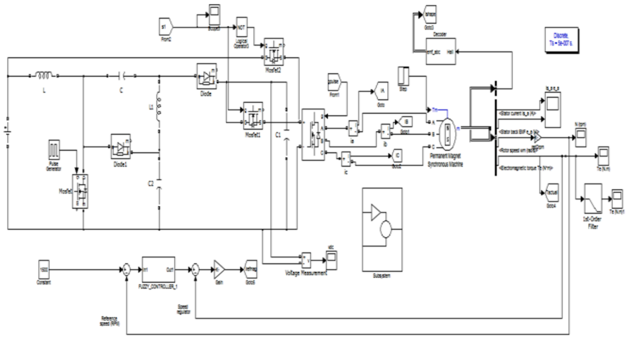


Fig.23. Matlab/simulation circuit of proposed method for SEPIC converter reducing commutation torque ripple in BLDCM drive with fuzzy logic.

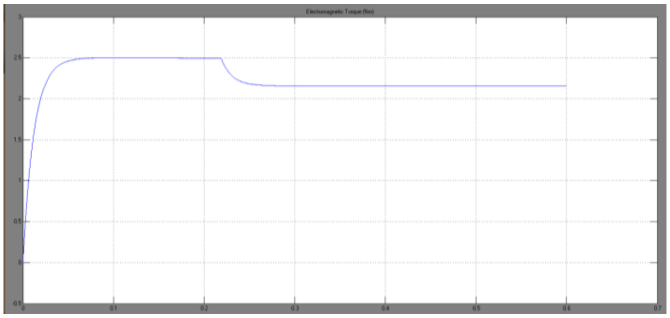


Fig.24. Matlab/simulation circuit of proposed method for SEPIC converter reducing commutation torque ripple in BLDCM drive torque with fuzzy logic.

VII. CONCLUSION

The conduction losses in the conventional SEPIC converter is high, this can be overcome by bridgeless SEPIC converter. The ripple current in the input side can reduce by bridgeless SEPIC converter. The final efficiency of PMBLDC can increase by using this converter and power factor can also increase. In this project a fuzzy logic topology based on Modified SEPIC converter is analyzed for reducing commutation torque ripple in BLDCM drives. Fuzzy logic implementation of BLDCM drive with conventional control is done using FPGA. The close correlations between simulation results illustrate the relevance of the topology for torque ripple minimization.

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