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Performance Comparison between Conventional Cuk Converter and Bridgeless Cuk Converter Fed PMBLDC Motor Drive

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ABSTRACT: Permanent Magnet Brushless Direct Current (PMBLDC) motors are widely accepted for their high efficiency, reliability, good dynamic response and low maintenance. This paper proposes an effective speed control of PMBLDC motor drive using conventional Cuk converter and bridgeless Cuk converter. Further a performance comparison is made using PI and fuzzy controllers for the speed control of PMBLDC motor drive in both the converters. The simulation and performance comparison is analysed using MATLAB/SIMULINK software.

KEYWORDS: Cuk converter, Bridgeless Cuk converter, PMBLDC, PI, Fuzzy.

I.INTRODUCTION

PMBLDC motors are recommended for many low- and medium-power drives applications because of their high efficiency, high flux density per unit volume, low maintenance requirement, low electromagnetic interference (EMI) problems, high ruggedness, and a wide range of speed Control. A brushless DC motor is similar to brushed DC motor in that it has an internal shaft position feedback. The internal feedback is accomplished in a brush type DC motor with the mechanical commutator and the mechanical brush through which the current is fed into the commutator bars and switched sequentially into the appropriate winding in the armature. In a BLDC motor, the internal feedback is accomplished by Hall sensors which give the required shaft position information to the drive electronics. The drive electronics in turn switches on the appropriate windings exactly at the right moment. The Hall Effect position sensors, Hall_A, Hall_B, and Hall_C, each having a lag of 120 degrees are used to determine the position of the rotor field. These particular Hall position sensors, based on Hall Effect principle, generate a TTL compatible output. In the motor which is being used, when the phase Back-EMF starts rising, the corresponding hall sensor generates a logic high signal and goes low when the corresponding Back-EMF starts falling and remains low till that Back-EMF starts rising. This implies that for the given motor, Hall sensor outputs lead the corresponding Back-EMF by 30 degree. The logic high of a Hall position sensor is maintained for 180 degree. This can be a significant disadvantage, since timers may have to be used in order to reduce the switching times to 120 degree. Single and two-phase BLDC motors are usually in the fractional horsepower category, where cost is a major factor: a reduction in the number of phases implies a reduction in cost.

In this paper, the speed of the PMBLDC motor drive is controlled using conventional Cuk converter and bridgeless Cuk converter. Normally the speed control operation is carried out either by voltage follower approach or by current multiplier approach. The voltage follower approach is employed in Discontinuous Conduction Mode (DCM) of operation whereas, the current multiplier approach is employed in Continuous Conduction Mode (CCM) of operation. For low cost applications voltage follower approach is well suited because the number of sensors required in current multiplier approach is more. And also the voltage follower approach has better performance results compared to current multiplier approach.

II.CUK CONVERTER

The Cuk converter shown in fig.1 is a step-down/step-up converter based on a switching boost-buck topology [4]. By controlling the duty cycle of the switch, the output voltage can be controlled and the output voltage can be higher or lower than the input voltage [5].The voltage ratio of a Cuk converter is the same as that of a buck-boost converter, but its main advantage over other converters is that the input and output inductors result in a filtered current on both sides

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of the converter, while buck, boost, and buck-boost converters have a pulsating current that occurs on at least one side of the circuit i.e. either on input side or output side [6]. This pulsation will increase the ripple in the circuit and due to this ripple, the efficiency of battery gets lowered. To ensure good efficiency ripple should be reduced [10].

L_1= 2.5mH, C_1 = 0.66µF, L_o = 70µH, C_d = 2200µF.

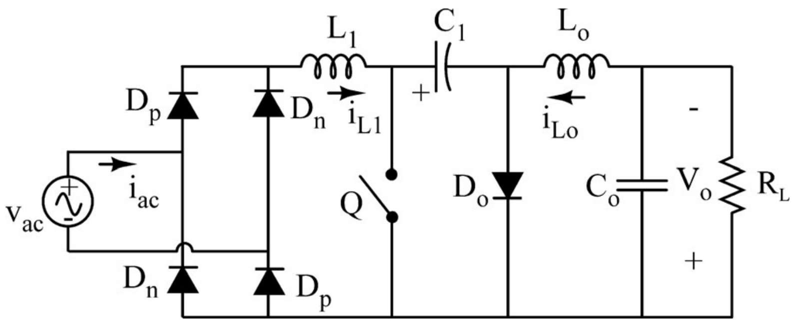

Fig.1 Conventional Cuk converter

III.BRIDGELESS CUK CONVERTER

Bridgeless Cuk converter topology shown in fig.2 is formed by connecting two dc–dc Cuk converters, one for each half-line period (T/2) of the input voltage [1]. By using lesser numbers of semiconductor switches, the losses due to current stresses in the switches arereduced and the circuit efficiency is improved compared to the conventional Cuk Rectifiers. The operation of the circuit will be described by assuming that the three inductors are operating in DCM [9].The power switches are turned ON at zero current, and the output diodes (D01 and D02) are turned OFF at zero current. Thus, the losses due to the turn ON switching and the reverse recovery of the output diodes are considerably reduced [11]. By operating in DCM power factor can be maintained near to unity.

L_1= 1 mH,L_2= 1 mH, L_{01}= 22 µH, L_{02}= 22 µH, C_1= 1 µh, C_2= 1 µh, C_0= 12 mF.

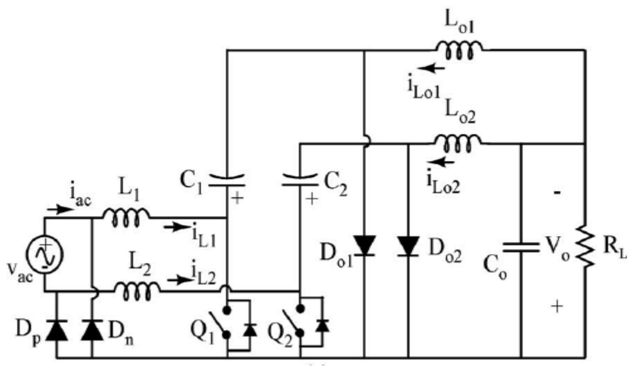

Fig.2 Bridgeless Cuk converter

IV. VOLTAGE FOLLOWER APPROACH

The voltage follower approach is shown in fig.3. In this approach, a reference voltage **Vref** corresponding to particular reference speed **ω*** is generated [3]. Now this reference voltage is compared with sensed dc-link voltage **Vdc** to generate a voltage error **Ve**. The voltage error is given to the controller to generate a controlled output **Vcd**. Finally, the controlled output **Vcd** is compared with the high frequency saw tooth waveform to generate the PWM signal to be given to the Conventional Cuk converter's switch.

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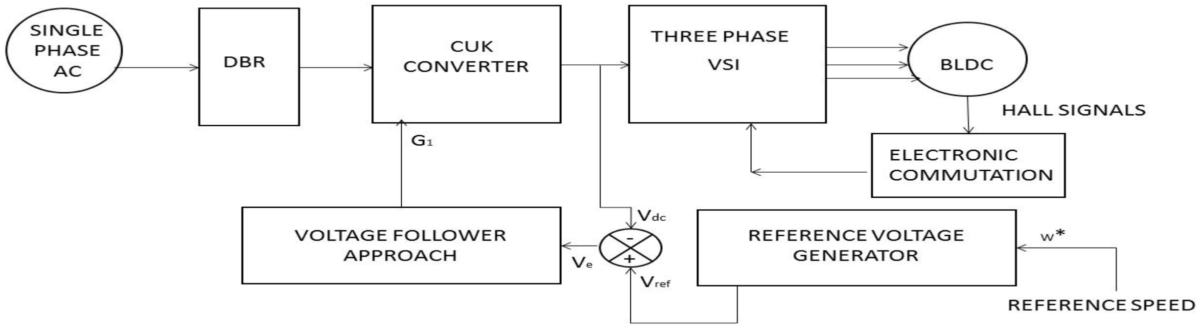

Fig.3 Block diagram of Voltage Follower Approach

A. PI CONTROLLER

A Proportional Integral-Derivative (PID) is a control loop feedback mechanism used in industrial control system. In industrial process a PI controller attempts to correct the error between a measured process variable and desired set point by and then provides the corrective action that can adjust the process accordingly [2]. The PI controller calculation involves two separate modes the proportional mode and the integral mode. The proportional mode determines the reaction to the current error and the integral mode determines the reaction based on the recent error. The weighted sum of the two modes provides a corrective action to the control element. PI controller is widely used in industry due to its ease in design and simple structure. PI controller algorithm can be implemented as

$$u(t) = Kp \, . \, e(t) + Ki \int e(t) \, dt$$

Kp - Proportional gain, Ki - Integral gain, Where e (t) = Set reference value – Actual value.

The MATLAB simulations of the closed loop operation of PMBLDC motor drive fed by conventional Cuk converter and bridgeless Cuk converter using PI controller in voltage follower approach are shown in fig.4&5. The MATLAB simulation of voltage follower block is shown in fig.6. The simulation is carried out based on the following motor parameters shown in Table.1.

S. No.	*Parameters*	*Values*
1.	No. of Poles (P)	4 Poles
2.	Rated Power (P_{rated})	251.32W
3.	Rated DC link Voltage (V_{rated})	200V
4.	Rated Torque (T_{rated})	1.2Nm
5.	Rated Speed (ω_{rated})	2000rpm
6.	Back EMF Constant (K_b)	78V/krpm
7.	Torque Constant (K_t)	0.74Nm/A
8.	Phase Resistance (R_{ph})	14.56Ω,
9.	Phase Inductance (L_{ph})	25.71mH
10.	Moment of Inertia (J)	$1.3x10^{-4}Nm/s^2$

Table.1 Motor Parameters

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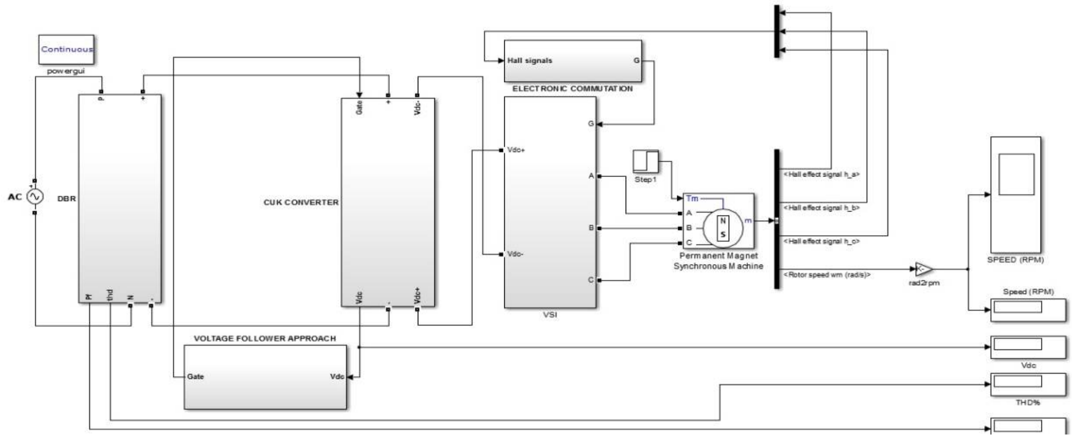

Fig.4 MATLAB simulation of conventional Cuk converter fed PMBLDC motor drive using PI controller.

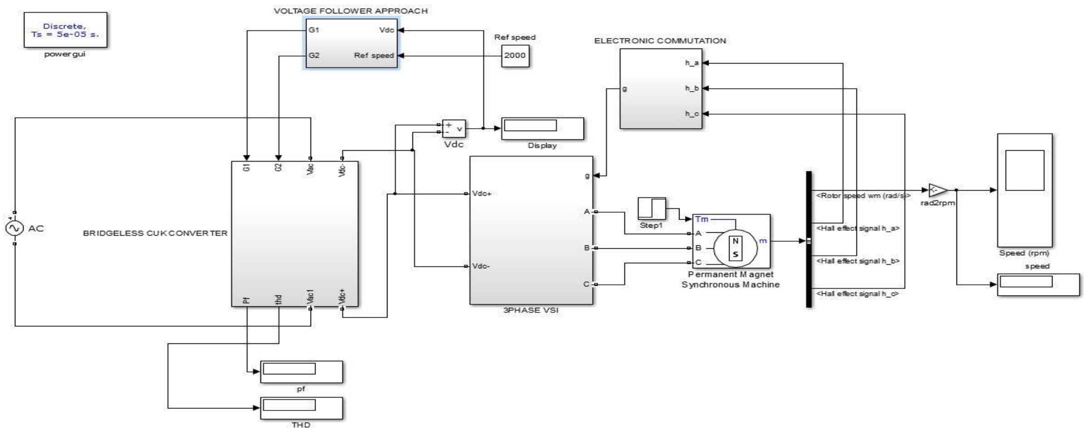

Fig.5 MATLAB simulation of bridgeless Cuk converter fed PMBLDC motor drive using PI controller.

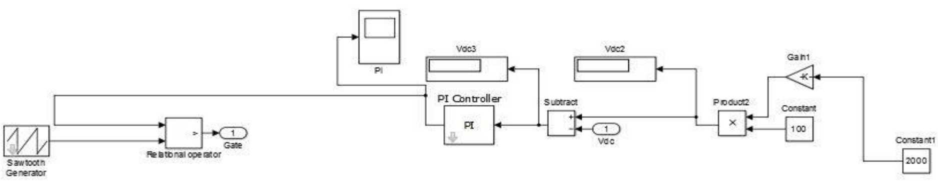

Fig.6 Voltage FollowerApproach block.

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B. FUZZY CONTROLLER

Fuzzy Logic (FL) is a convenient way to map an input space to an output space [7]. FL controller is beneficial compared to other classical controllers because of its simplicity in control, low cost and the possibility to design without knowing the exact mathematical model of the process. Fuzzy logic also allows modeling complex systems using higher level of abstraction originating from the knowledge and experience.In this approach, a reference voltage **Vref** corresponding to a particular reference speed **ω*** is generated. Now this reference voltage is compared with the sensed dc-link voltage **Vdc** to generate a voltage error **Ve**. The voltage error is given to the Fuzzy controller to generate a controlled output **Vcd**[8].Finally, the controlled output **Vcd** is compared with high frequency saw tooth waveform to generate the PWM signal to be given to the Conventional Cuk converter's switch.

NB- Negative Big	Vs- Very Small
NM- Negative Medium	S- Small
Z- Zero	B- Big
PB- Positive Big	VB- Very Big
PM- Positive Medium	

The fuzzy rules table is shown in Table.2. The MATLAB simulation of PMBLDC motor drive fed by conventional Cuk converter and bridgeless Cuk converter using fuzzy controller in voltage follower approach is shown in fig.8&9. The fuzzy controller block is shown in fig.7.

Control Rules	
Error	**Output**
NB	VS
NM	S
Z	Z
PM	B
PB	VB

Table.2 Fuzzy Control Rules

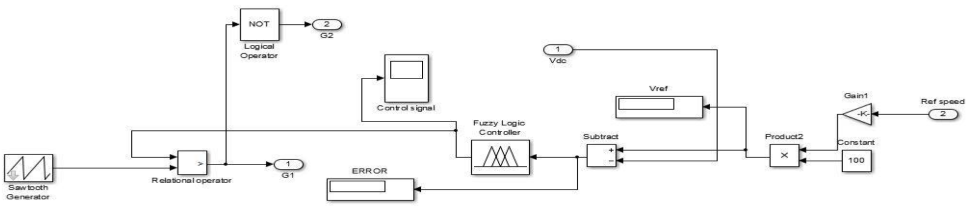

Fig.7 Fuzzy controller block.

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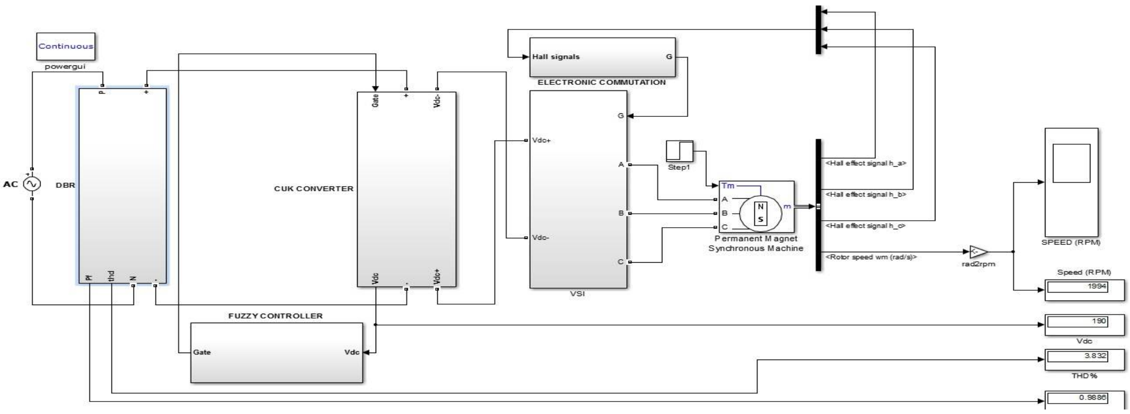

Fig.8 MATLAB simulation of conventional Cuk converter fed PMBLDC drive using Fuzzy controller

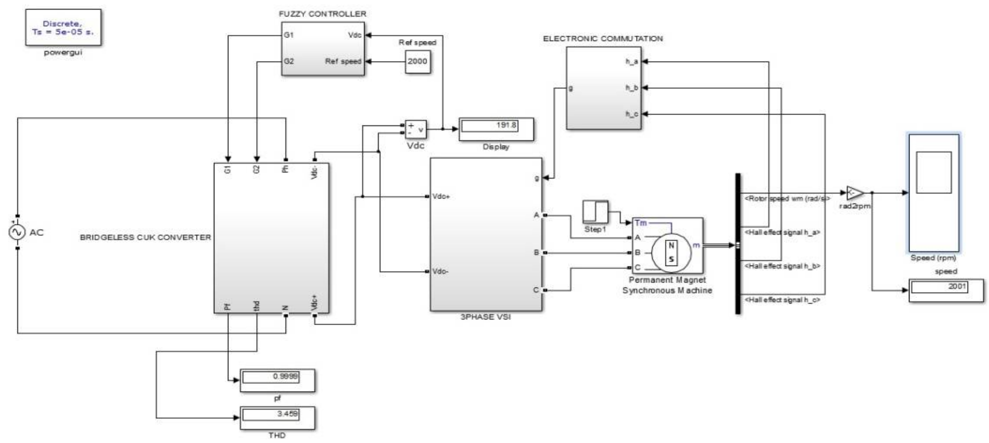

Fig.9MATLAB simulation of bridgeless Cuk converter fed PMBLDC drive using Fuzzy controller

V. SIMULATION RESULTS

A) Conventional Cuk converter fed PMBLDC motor drive using PI controller

The simulation outputs of conventional Cuk converter fed PMBLDC motor drive using PI controller are as follows.

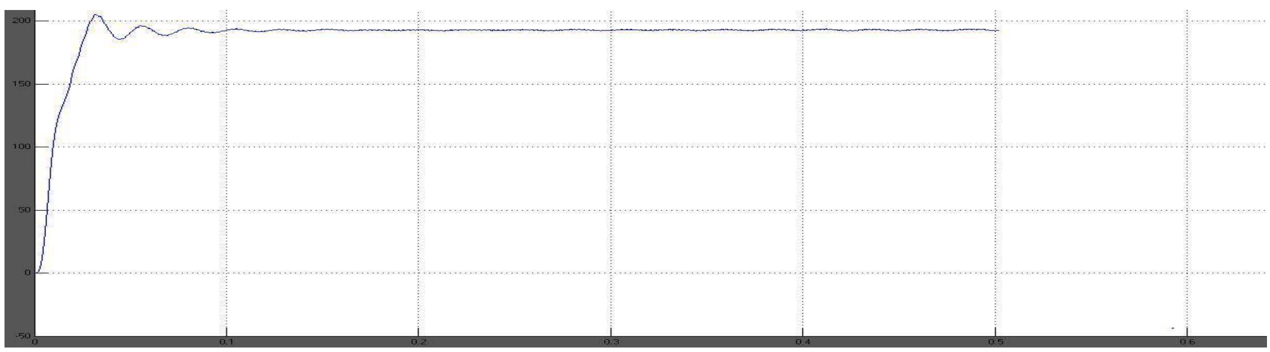

Fig.10 Shows theOutput voltage Vdc (V) of Cuk converter vs. Time (sec), where the rated DC link voltage is 200 V.

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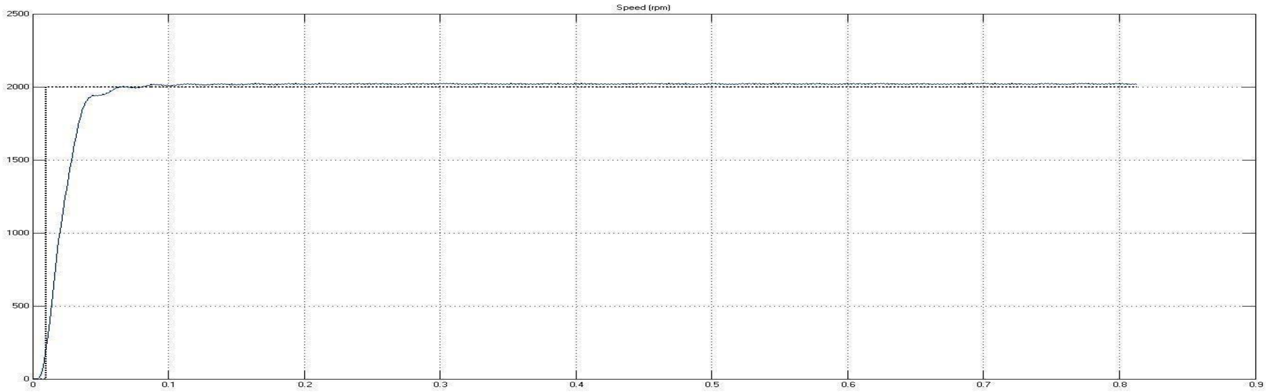

Fig.11 Shows theSpeed (rpm) of the PMBLDC motor vs. Time (sec) where, the rated speed is 2000 rpm is attained with minimum ripples.

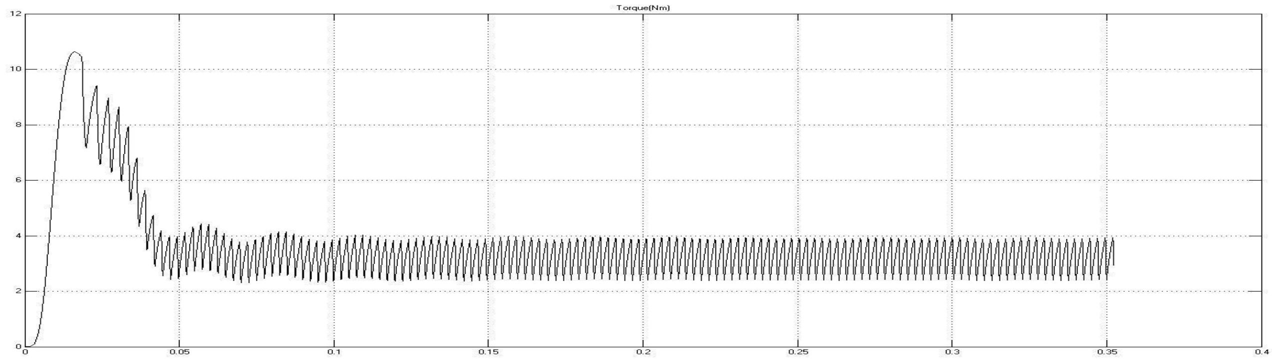

Fig.12 Shows the Torque (Nm) vs. Time (sec) where, the rated torque of the PMBLDC motor is1.2 Nm is achieved with maximum ripples.

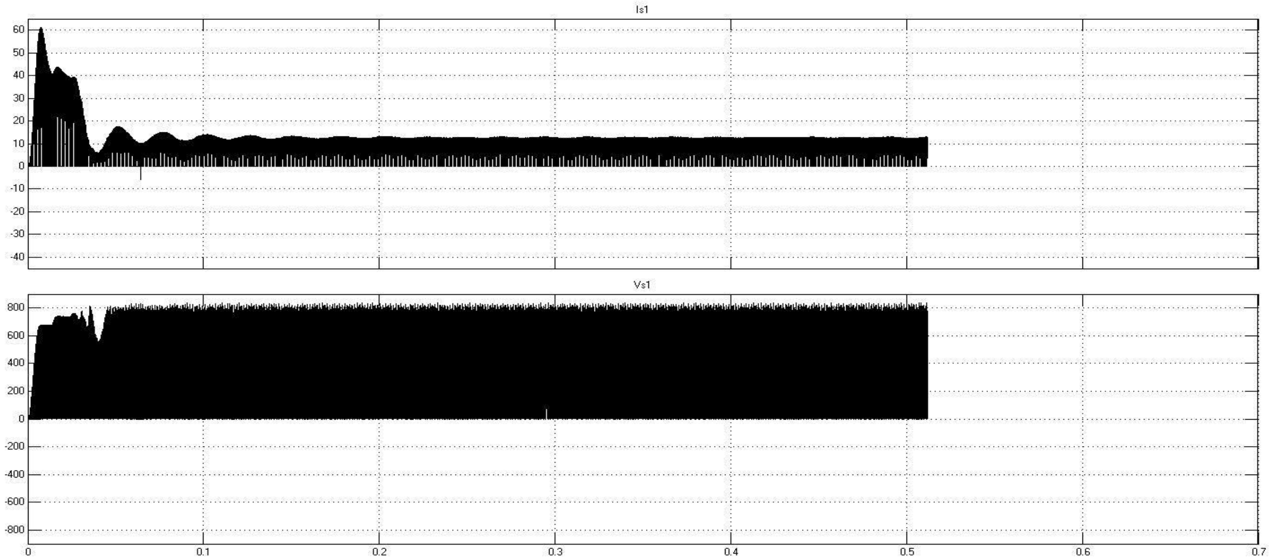

Fig.13 Shows the Switch current (A) vs. Time (sec) and Switch Voltage (V) vs. Time (sec), represents the current and voltage stresses experienced by the switch.

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B) Conventional Cuk converter fed PMBLDC motor drive using fuzzy controller

The simulation outputs of conventional Cuk converter fed PMBLDC motor drive using fuzzy controller are as follows.

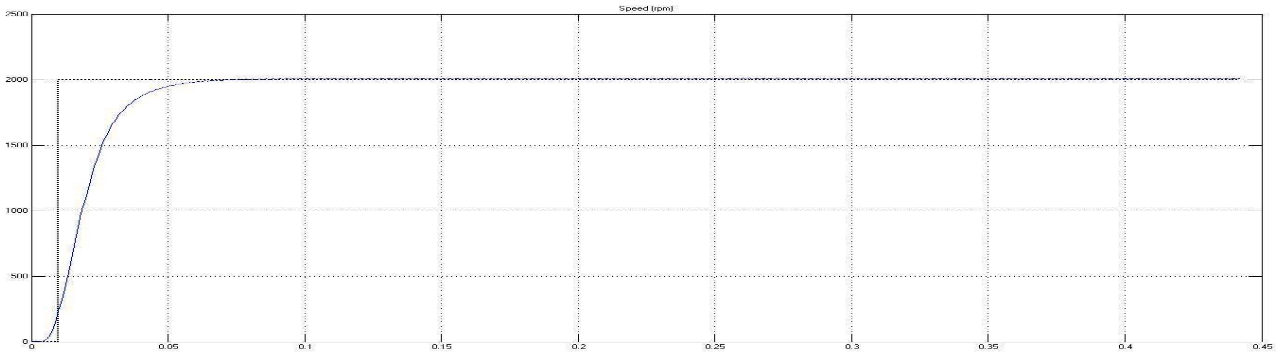

Fig.14Shows the Speed (rpm) of the PMBLDC motor vs. Time (sec) where, the rated speed is 2000 rpm is attained without any ripples and the settling time is faster (0.065 msec) compared to other speed responses.

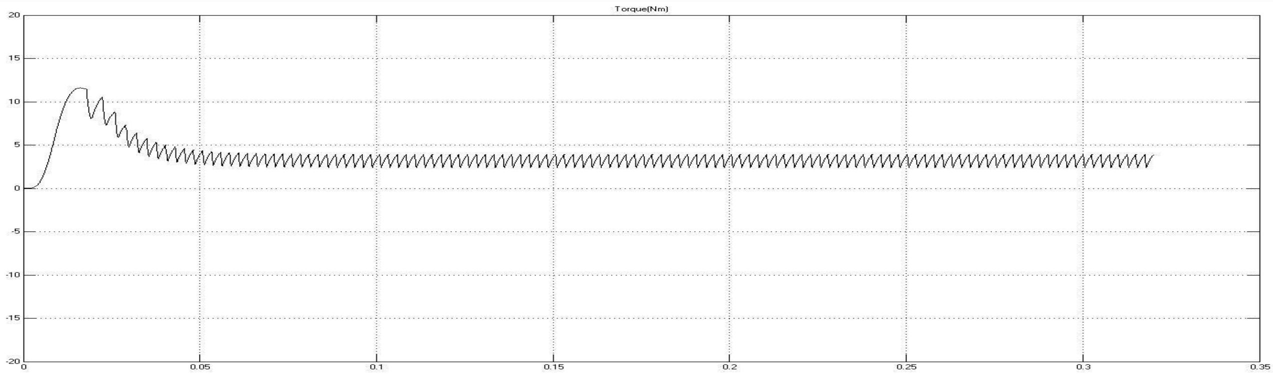

Fig.15Shows the Torque (Nm) vs. Time (sec) where, the rated torque of the PMBLDC motor is 1.2 Nm is achieved with minimum ripples.

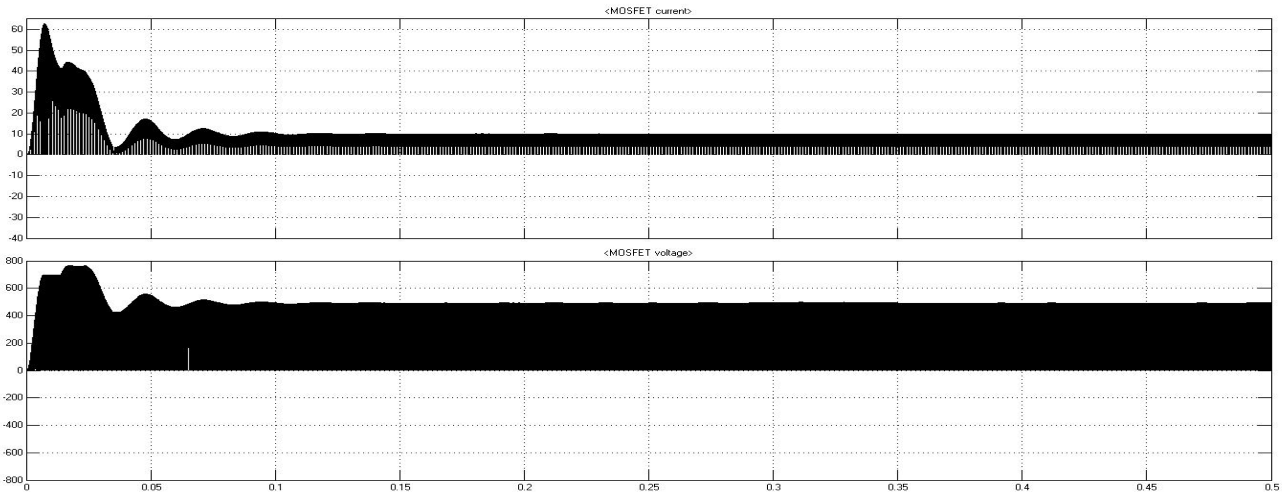

Fig.16Shows the Switch current (A) vs. Time (sec) and Switch Voltage (V) vs. Time (sec), represents the current and voltage stresses experienced by the switch.

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C) Bridgeless Cuk converter fed PMBLDC motor drive using PI controller

The simulation outputs of bridgeless Cuk converter fed PMBLDC motor drive using PI controller are as follows.

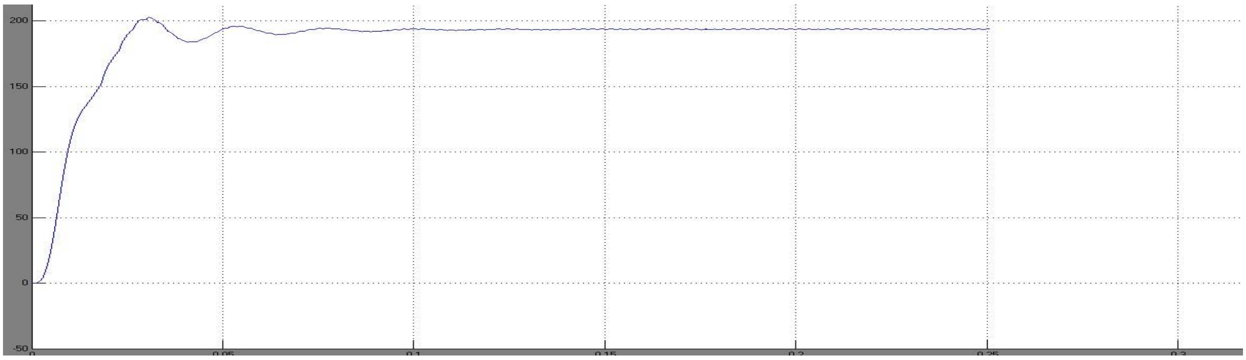

Fig.17 Shows the Output voltage Vdc (V) of Cuk converter vs. Time (sec), where the rated DC link voltage is 200 V is attained with maximum ripples.

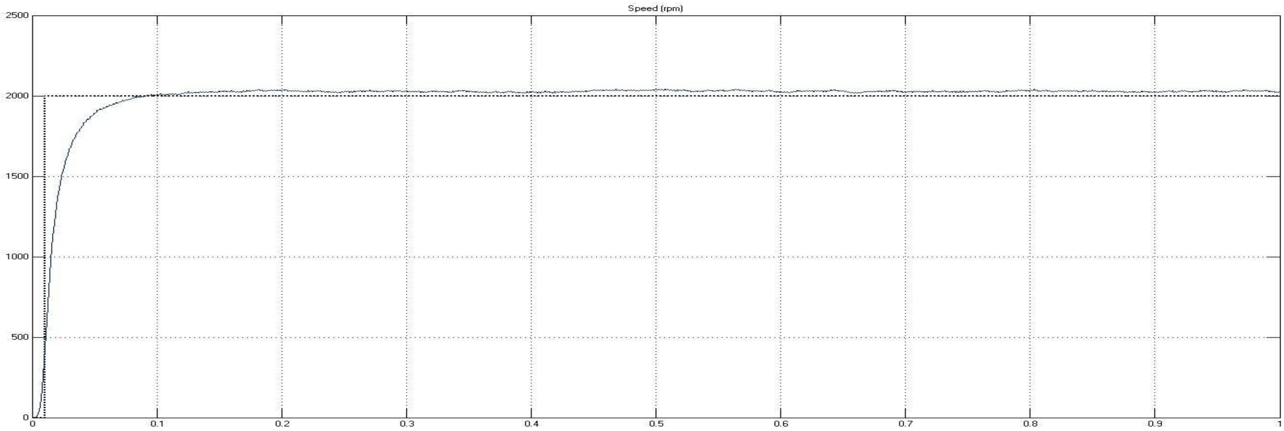

Fig.18Shows the Speed (rpm) of the PMBLDC motor vs. Time (sec) where, the rated speed is 2000 rpm is attained with minimum ripples and the settling time is more (0.1 msec) when compared to other speed responses.

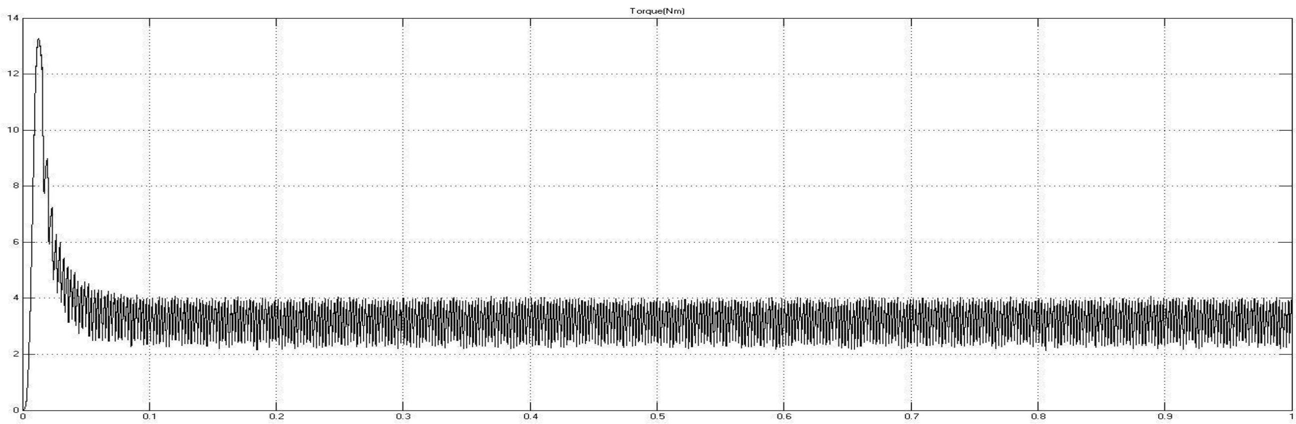

Fig.19Shows the Torque (Nm) vs. Time (sec) where, the rated torque of the PMBLDC motor is 1.2 Nm is achieved with maximum ripples.

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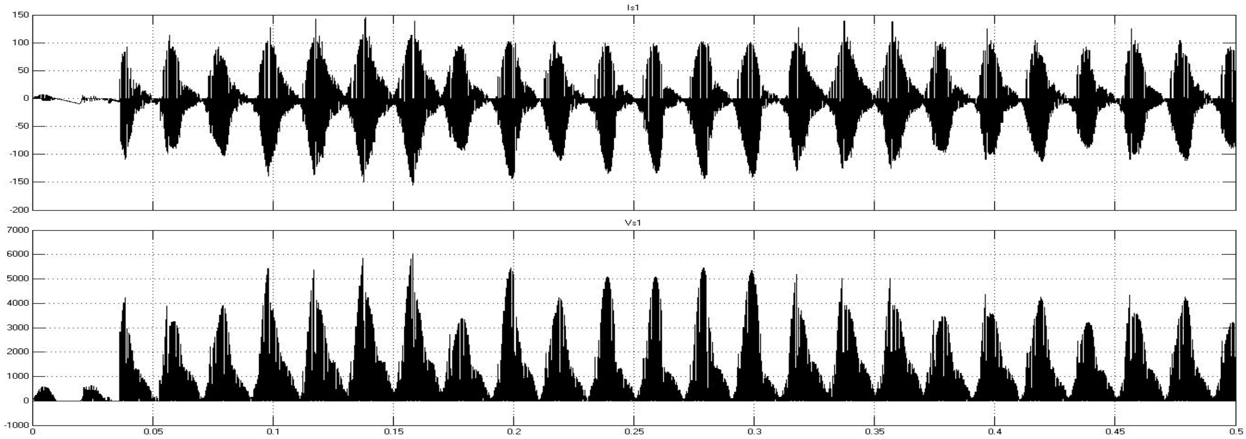

Fig.20 Shows the switch current Is1 (A) vs. Time (sec) and switch Voltage Vs1 (V) vs. Time (sec),represents the current and voltage stresses experienced by the switch.

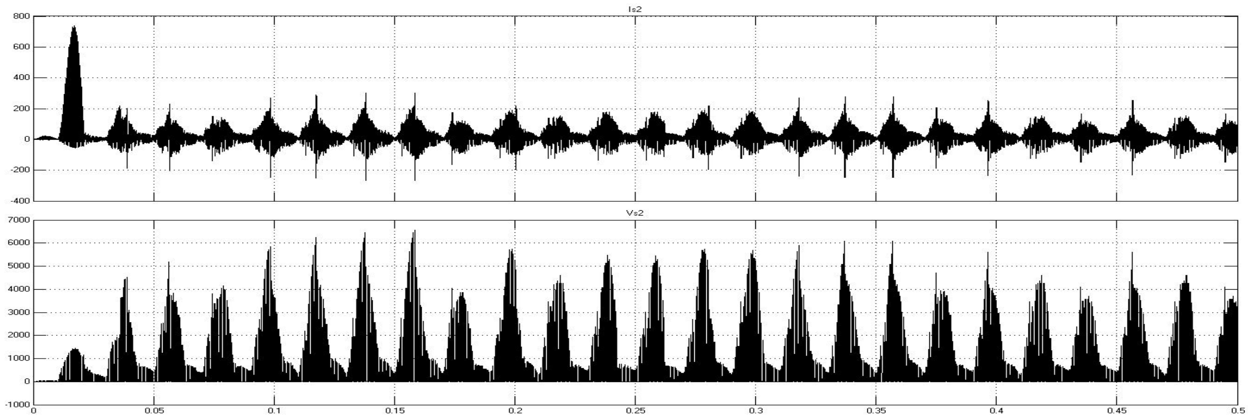

Fig.21 Shows the switch current Is2 (A) vs. Time (sec) and switch Voltage Vs2 (V) vs. Time (sec), represents the current and voltage stresses experienced by the switch.

D) Bridgeless Cuk converter fed PMBLDC motor drive using fuzzy controller

The simulation outputs of bridgeless Cuk converter fed PMBLDC motor drive using fuzzy controller are as follows.

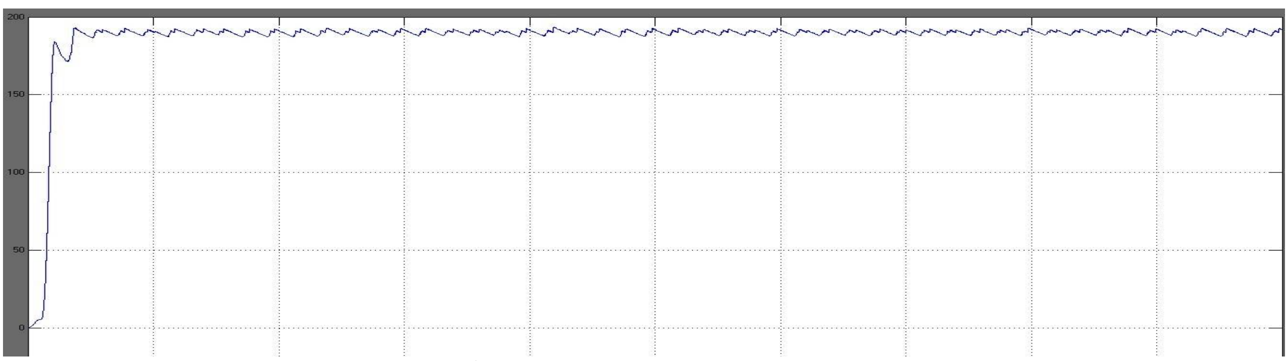

Fig.22Shows theOutput voltage Vdc (V) of Cuk converter vs. Time (sec), where the rated DC link voltage is 200 V is attained with maximum ripples.

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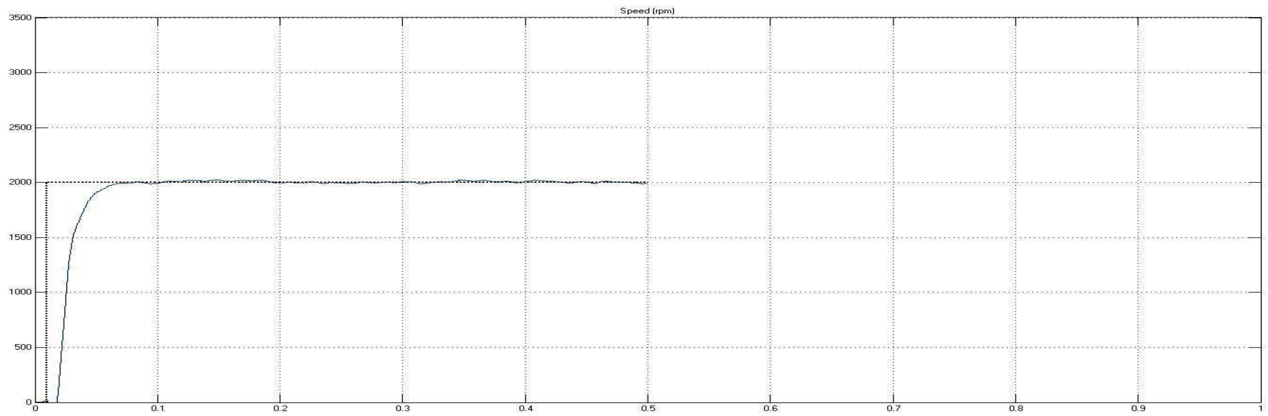

Fig.23Shows the Speed (rpm) of the PMBLDC motor vs. Time (sec) where, the rated speed is 2000 rpm is attained with minimum ripples and the settling time is more (0.1 msec) when compared to other speed responses.

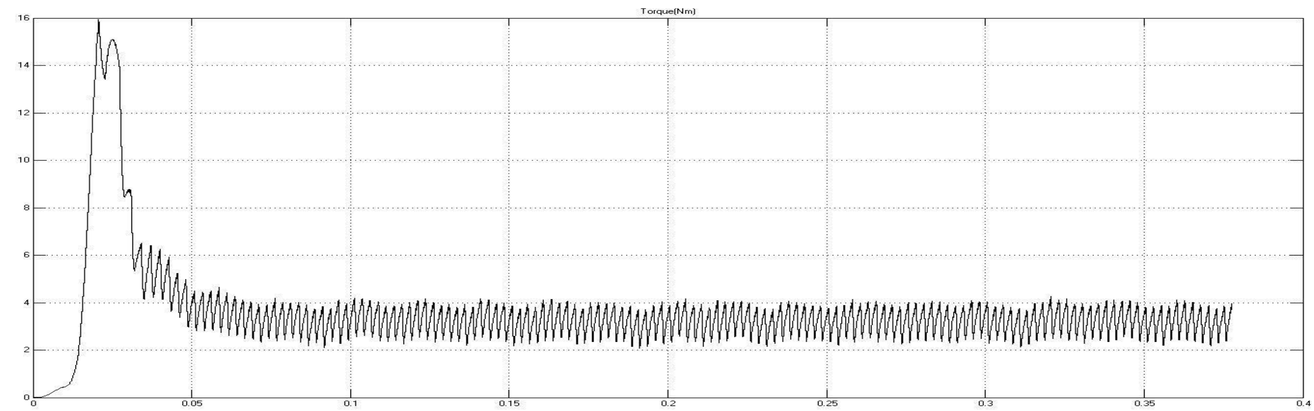

Fig.24 Shows the Torque (Nm) vs. Time (sec) where, the rated torque of the PMBLDC motor is 1.2 Nm is achieved with maximum ripples.

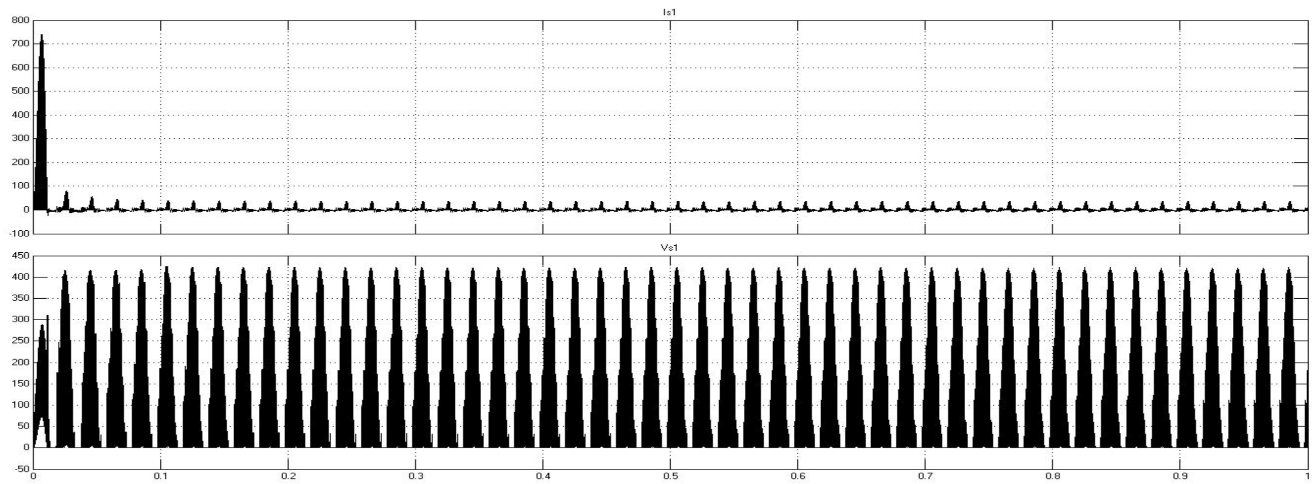

Fig.25Shows the switch current Is1 (A) vs. Time (sec) and switch Voltage Vs1 (V) vs. Time (sec), represents the current and voltage stresses experienced by the switch.

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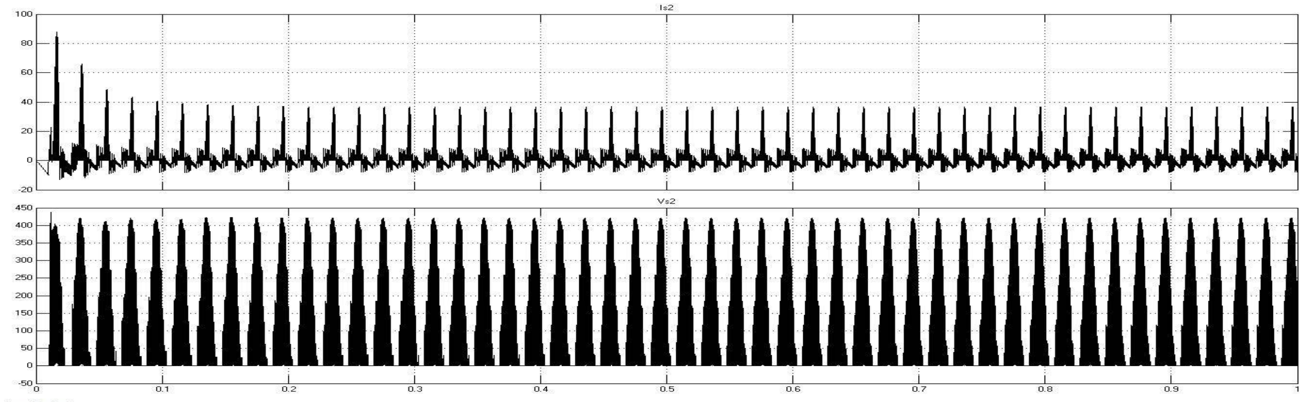

Fig.26Shows the switch current Is2 (A) vs. Time (sec) and switch Voltage Vs2 (V) vs. Time (sec), represents the current and voltage stresses experienced by the switch.

Based on the simulation results a performance comparison is made between the converters as shown in Table.3.

CONTROLLERS	PARAMETERS	CONVERTERS	
		CONVENTIONAL CUK IN DCM	BRIDGELESS CUK
FUZZY	Input voltage (v)	Single phase AC supply	
	Output voltage (v)	191.7	194.6
	Speed (rpm)	2006	1996
	Speed Settling time (msec)	0.065	0.12
	Power factor	0.99	1
	THD of Is (%)	3.82	2.94
PI	Kp	0.9	0.97
	Ki	0.001	0.00001
	Input voltage (v)	Single phase AC supply	
	Outputvoltage (v)	191	202
	Speed (rpm)	2007	1998
	Speed Settling time (msec)	0.1	0.13
	Power factor	0.99	1
	THD of Is (%)	3.61	3.25

Table.3 Comparison Table

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VI. CONCLUSION

As a result of comparing the performances of the conventional Cuk converter operating in DCM and the bridgeless Cuk converter, the conventional Cuk converter operating in DCM using Fuzzy approach provides cost effective solution and has simple control techniques. Moreover the speed settling time in conventional Cuk converter fed PMBLDC motor drive is 0.065 msec which is very less compared the bridgeless Cuk converter configuration. And based on the simulation results the switching losses is lesser in conventional Cuk converter operating in DCM using fuzzy approach. So it is proposed that the conventional Cuk converter operating in DCM using Fuzzy approach is best suited for the speed control operation of PMBLDC motor drive for low power applications.

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