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Design and Implementation of Bridgeless Cuk Converter for Controlled BLDC Motor

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ABSTRACT

This study determines speed control of BLDC motor using a Bridgeless CukConverter (BCC) which enhance low conduction loss as well as lesser number of heat sink. Ascheme in which controlling voltage at output of BCC the variation in the speed of the drive is attained.Operation of cuk converter is carried out discontinuous inductor current mode at output inductance and continuous mode at input inductance and intermediate capacitors for better power factor and good power quality at AC supply mains for various speeds. On eliminating distorted currents at AC mains using filter technique to a BCC thereby improving PQ over suitable limits by IEC 61000-3-2. In this setup,supply ac mains is given to power converter. Power converter consists of BCC and VSI, voltage is varied from DC link and speed of the motor is regulated accordingly.Diode bridge rectifier(DBR) requirement is eliminated to obtain reduced conduction losses. Finally proposed system is validated in simulation and test results are obtained to get PFC at AC mains as well as operation of drive is smooth developing PQ for various range of speeds.

Keywords: Bridgeless Cuk Converter (BCC), Brushless DC Motor (BLDC), Low conduction losses, Power Factor Correction (PFC), DBR (Diode Bridge Rectifier)

I. INTRODUCTION

Basically we refer to variable speed motor drive machines over constant speed drive. The reason for choosing such a drive has three major advantage – position control, energy saving and improvement in the transients [1]. Torque is known from the current and voltage determines speed of the motor drive.With torque to inertia high accelerationdeceleration of speed is easy, initial torque high, excellent efficiency and low maintenance [2]; BLDC motor turns out to be a popular for various application medical equipment's,industrial tools, HVAC system, washing machine, refrigerators etc. BLDC motor has PM on the rotor and stator consists of coil winding [3]. BLDC name signifies no need of brushes rather we utilize an electronic commutation. This technique comprises of hall sensors wherein to know the rotor positioning [4].

Development of such motor drive rules out following disadvantages such as problem of mechanical commutation noise problem, brushes wear & tear and also eliminate magnetic interference issue.

BLDC motor drive for dc supply of 6v,12v,24v from rectified AC or battery, torque will producedin magnetic flux due PM and rotor current carrying conductor [5]. Advantage of having such drive is good characteristics of speed and torque,long operating life, noise less operation and high efficiency [6].

Bridgeless Cuk Converter has unique advantage of eliminating DBR at the input side this will reduce the setup being bulky. Input voltage of 12V AC is given to the circuit through a setup down transformer [7]. Output voltage of this converter is fed to a VSI which is input to the BLDC drive.

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II. PROPOSED TOPOLOGY

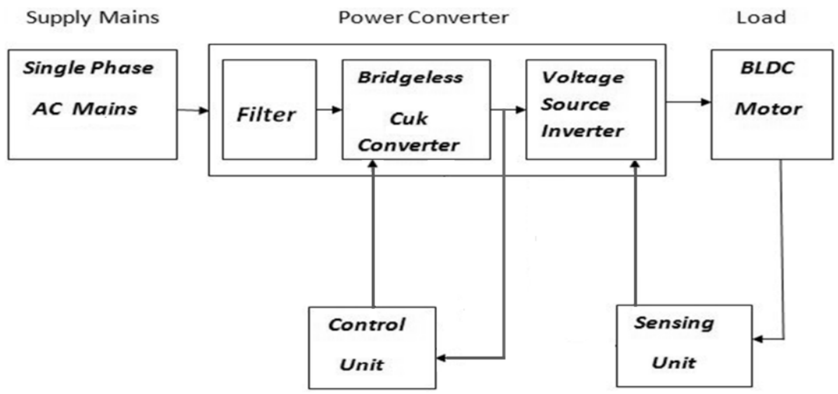

Figure 1: Block Diagram for Proposed Controlled BLDC Motor

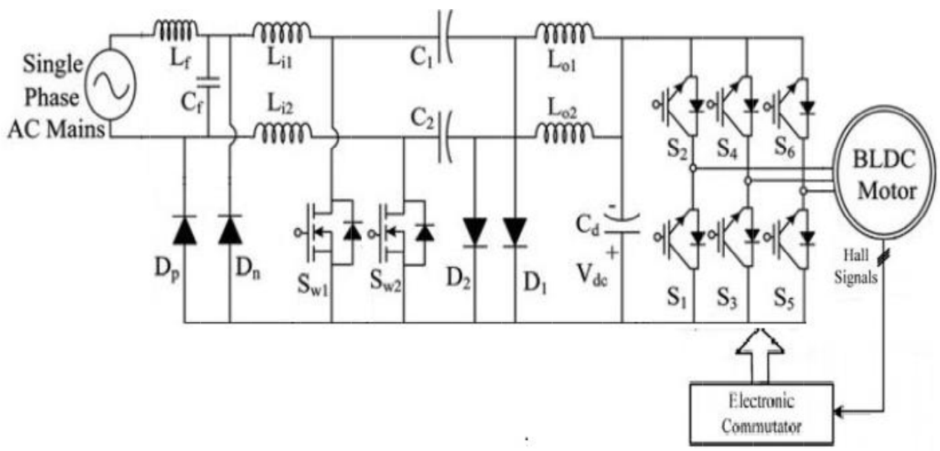

Figure 2 Topology for BLCC fed to BLDC Motor

Analysis of Converter

Later on, inverter setup is used which is operated at line frequency. This will reduce leakage current as well as switching losses, overall improvement in efficiency of the system [8]. These topology operational modes are similar to that of regular DC-DC converter. It consists of 3 modes of operation in which initial starting setup runs which store energy and in second mode same elements release energy.So there is a need to limit the THD and to increase the source power factor, for this purpose a power factor correction converter is necessary.

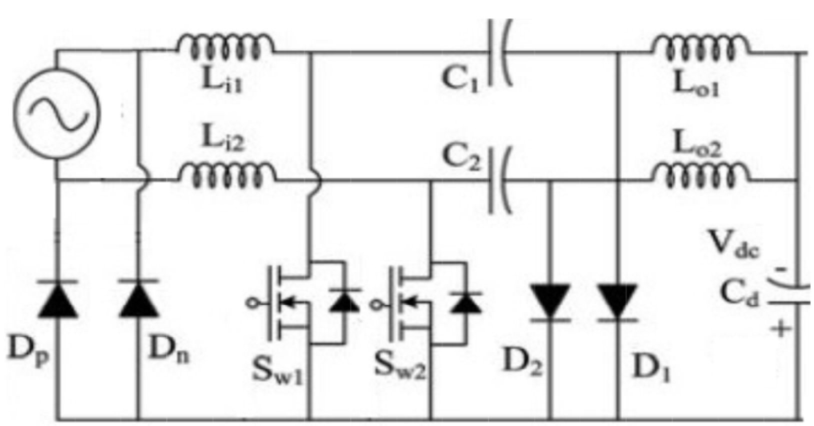

Figure 3: Bridgeless Cuk Converter

IV. MODES OF OPERATION

Mode 1 : Switch S_{w1} is turned ON,inductor current increases.energy from Capacitor C_1 will discharge in the Capacitor C_d output inductor current increase and capacitor C_d voltage increases. Inductor are charging and capacitor are discharging

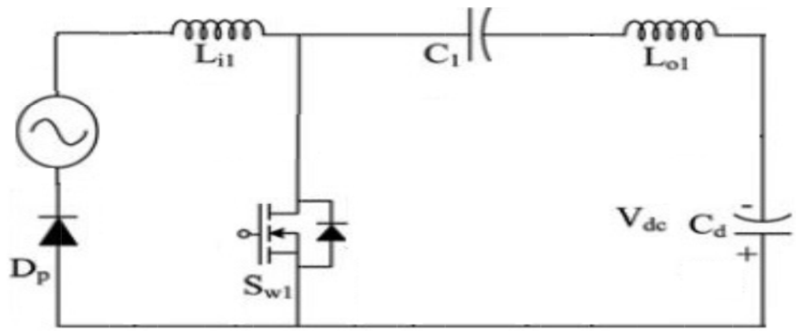

Figure 4(a): Mode 1 positive half cycle operation of the circuit

In negative half cycle, Current pass through inductor L_{i2} and switch S_{w2} and covers the loop through D_n diode. Intermediate capacitor C_2 discharge and inductor L_{o2} gets charged. Therefore DC link voltage increase and intermediate capacitor voltage decreases.

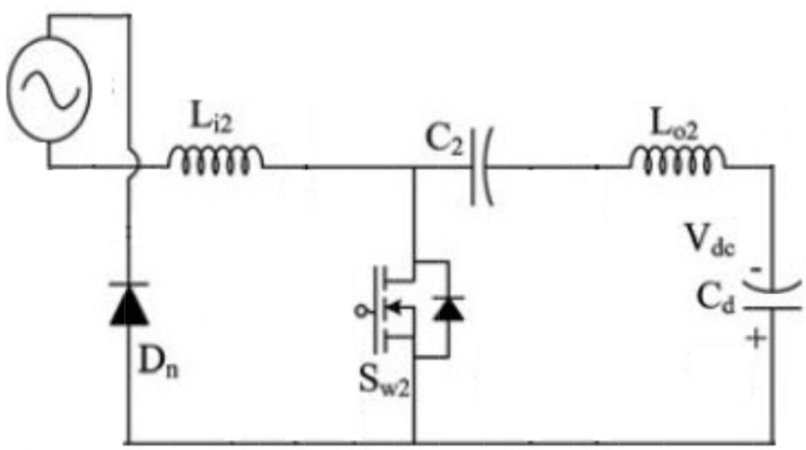

Figure 4(b): Mode 1 negative half cycle operation of the circuit

Mode 2: In this mode of operation, Switch is OFF. The inductors are discharging and capacitors are charged. Here diodes are forward biased. The inductor L_{i1} is discharging current enters the intermediate capacitor C_1.Inductor L_{o1} discharge, the current pass through diode and charge the DC link capacitor. The voltage across the capacitor increases.

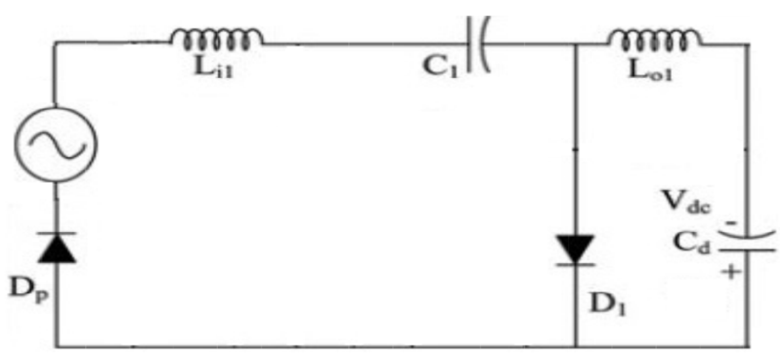

Figure 5(a): Mode 2 positive half cycle operation of the circuit

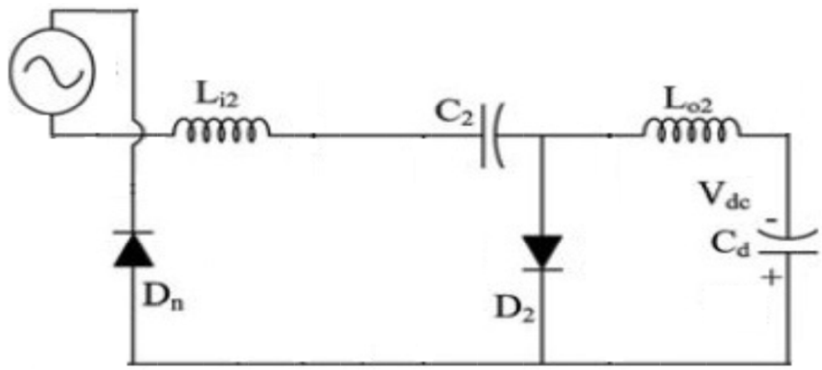

Figure 5(b): Mode 2 negative half cycle operation of the circuit

In this negative half cycle, current pass through inductor L_{i2} to intermediate capacitor C_2 and by pass through diode D_2.Inductor L_{o2} discharge its stored energy and charge the DC link capacitor. Voltage across DC link capacitor increases

Therefore, switch is OFFL_{i2} L_{o2}inductor discharge its stored energy. Current in input and output inductor will decrease and transfer energy to DC link capacitor

Mode 3: No energy is present in the output inductor,voltage in intermediate capacitor and input side inductor current increase this will continue until again switch is turned ON.

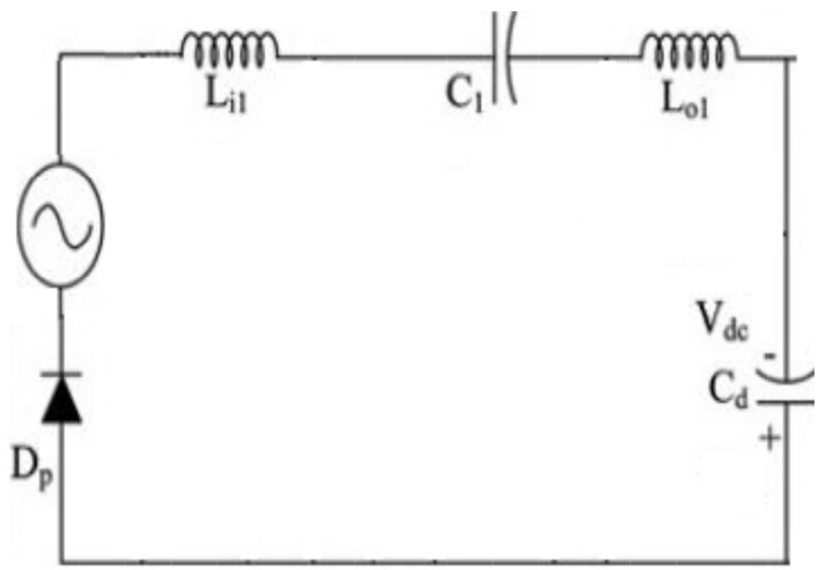

Figure 6(a): Mode 3 positive half cycle operation of the circuit

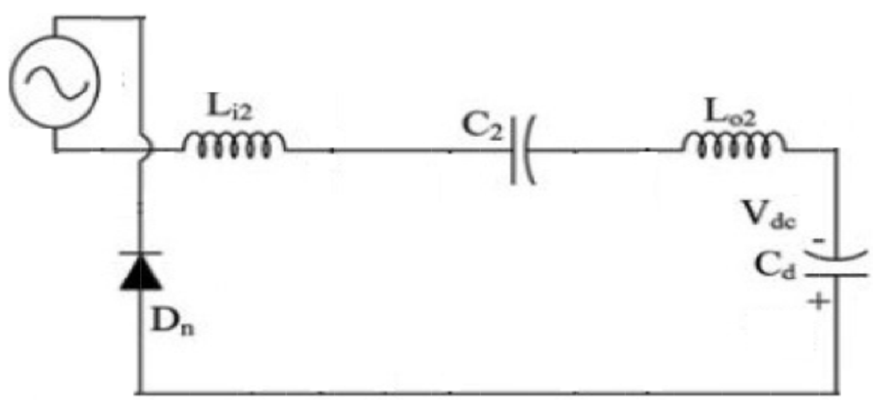

Figure 6(b): Mode 1 negative half cycle operation of the circuit

Input inductor L_{i1} L_{i2} gets charged through input voltage, Intermediate capacitor C_1 C_2 is also getting charged. Output inductor completely discharge its energy to the DC link capacitor.

V. DESIGN OF CONVERTER

Design values of BCCwhich is operating in DICM mode to get regulated with wide range of voltage ratio. In this continuous conduction is carried out by input side inductor (L_{i1} and L_{i2}) and capacitors (C_1 and C_2). On the hand the output inductor (L_{o1} and L_{o2}) under discontinuous mode throughout one switching period.For a source voltage of 12V AC the average input voltage is obtained from equation as follows [1]

$$V_{in} = \frac{2\sqrt{2}\,V_S}{\pi} = \frac{2\sqrt{2}\,80}{\pi} = 72.02 \tag{1}$$

Where

V_{in} =Input average voltage

V_s = Supply voltage

The regulated PFC for designed DC link voltage ranges from 4V (V_{dcmin}) to 33(V_{dcmax}) with nominal voltage of $18V_{dcdes}$. The duty ratio can be calculated as follows[1]

$$d = \frac{V_{dc}}{V_{in} + V_{dc}} = 54\% \tag{2}$$

Where

d = duty ratio

V_{dc} = DC link voltage

From the duty ratio values for DICM to have better efficient control the input inductance can be calculated as follows[1]

$$L_{i1} = L_{i2} = \left(\frac{V_m d_{nom} T_S}{\Delta i_{L1}}\right) = \left(\frac{16.97 \times 0.4 \times \frac{1}{10 \times 10^3}}{1.767}\right) = 1234.8\mu H \tag{3}$$

Where,

V_m = maximum value of supply voltage (i.e 12 $\sqrt{2}$)

T_s = Switching period

Critical Conduction K_{cric}

Where n = isolated converter turns ratio usually for anon isolated kind converter value will be n=1.Hence conduction value can be calculated as follows[1]

$$K_{acrit} = \left(\frac{1}{2(M+n)^2}\right) = \left(\frac{1}{2\left(\left(\frac{V_{dcdes}}{V_m}\right) + n\right)^2}\right) = 0.166 \tag{4}$$

After knowing conduction parameter value now know the equivalent inductance it is calculated using equation 5

Equivalent Inductance $L_{eq} = \left(\frac{R_O T_s K_a}{2}\right) = \left(\frac{\left(\frac{V^2{}_{dcdes}}{P}\right) T_S K_a}{2}\right)$

$$= \left(\frac{(24^2/100 \times \frac{1}{10 \times 10^2} \times 0.111}{2}\right) = 15.99\,\mu H \tag{5}$$

Here K_a is take $\frac{2_{rd}}{3}$ value or the K_{cric} Therefore K_a= 0.111

R_o refers to load resistance

Now the output Inductance can be calculated as follows[1]

$$L_{o1} = L_{o2} = \left(\frac{L_i L_{eq}}{L_i - L_{eq}}\right) = 161.90\mu H \tag{6}$$

Where,

L_{eq}= equivalent inductance

L_i=input side inductance

Transferring Energy Capacitors

$$\begin{aligned} C_1 = C_2 &= \frac{1}{\omega_r{}^2 (L_i + L_o)} \\ &= \frac{1}{(2 \times \pi \times 5000)^2 (192.076 + 157.44) \times 10^{-6}} \\ &= 1.30\,\mu F \end{aligned} \tag{7}$$

DC link Value of Capacitor

$$C_d = \frac{I_{dc}}{2\omega \Delta V_{dc}} = \left(\frac{P_i}{V_{dc}}\right) \frac{1}{2\omega k V_{dc}} = 3502.46\mu F \tag{8}$$

Filter: For the filters we use following formulas

$$L_f = \frac{1}{4\pi^2 f_c^2 C_f} = 8.65mH \tag{9}$$

$$C_f = \frac{I_{peak}}{\omega_L V_{peak}} = 1906.41nF \tag{10}$$

As per the attained values using above formulas the cuk converter is designed. In this converter both buck and boost operation is possible. The switches which present in converter are having 180^0 phase shift. First switch S_{w1} for positive half cycle and switch S_{w2} for the negative half cycle. The simulation results and hardware results are shown in the figure [7-19].

Table 1
Switching Sequences of the VSI

Θ (in degrees)	*Switching States*					
	S_1	S_2	S_3	S_4	S_5	S_6
0-60	1	0	0	0	0	1
60-120	0	1	1	0	0	0
120-180	0	0	1	0	0	1
180-240	0	0	0	1	1	0
240-300	1	0	0	1	0	0
300-360	0	1	0	0	1	0

Simulation parameters Under Ideal Conditions

a) Input Voltage (V_{in})=80V AC
b) Duty cycle & corresponding dc output voltage

Duty Cycle	DC Voltage
32.1%	40V
49.51%	70.7V
61.10%	113.13V

c) Power (P_o)= 200W
d) R_{Load}=22&!
e) $L_{i1} = L_{i2}$ = 1234.8µH,20A
f) $C_1 = C_2$= 4.835µF,300V
g) $L_{01} = L_{02}$ = 161.90µH,20A
h) C_d = 3502.46µF,220V

VI. RESULTS AND DISCUSSION

For PF Correction using BCC fed to BLDC motor is achieved. Acceptable THD is obtained according to the IEC 61000-3-2 standards. Variation in the speed for minimal change in the input current is within allowable limit. Bridgeless cuk converter is efficient than conventional cuk converter

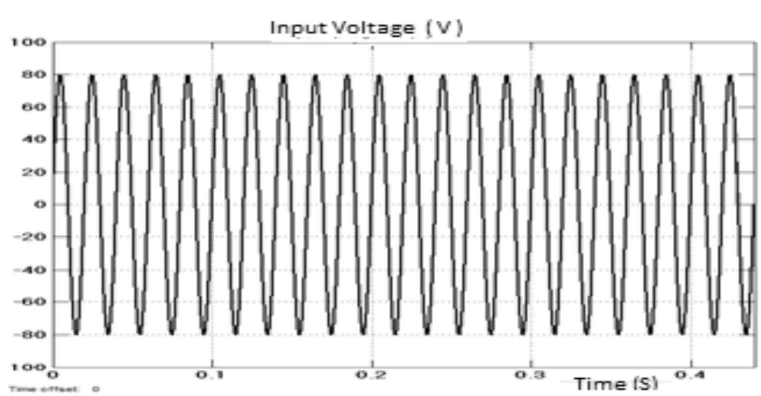

Figure 7: Input Voltage of Converter

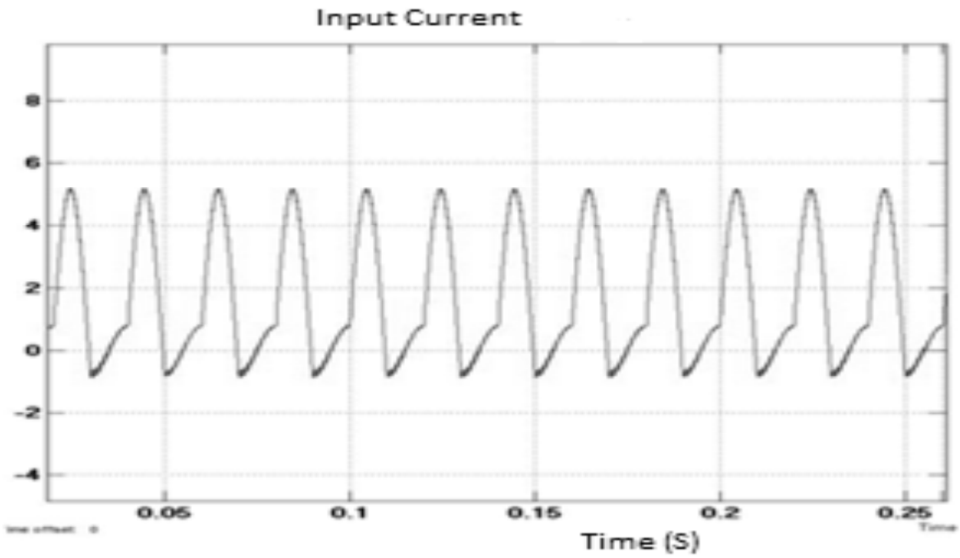

Figure 8: Input Current of the Converter

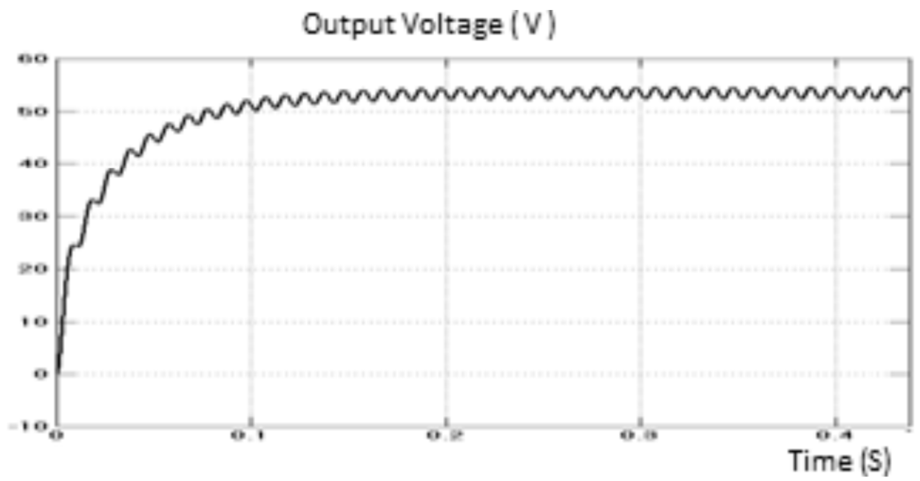

Figure 9: Output Voltage of the Converter

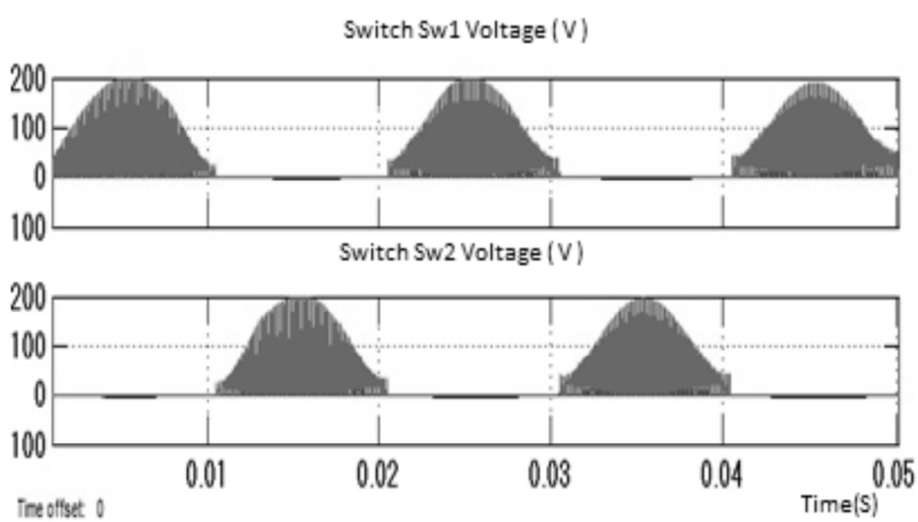

Figure 10: Switch voltage of the Converter

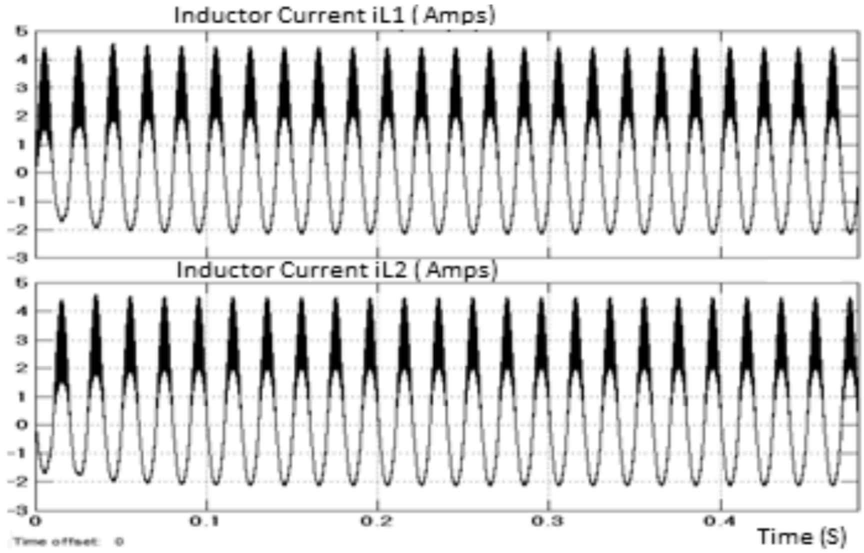

Figure 11: Inductor Current

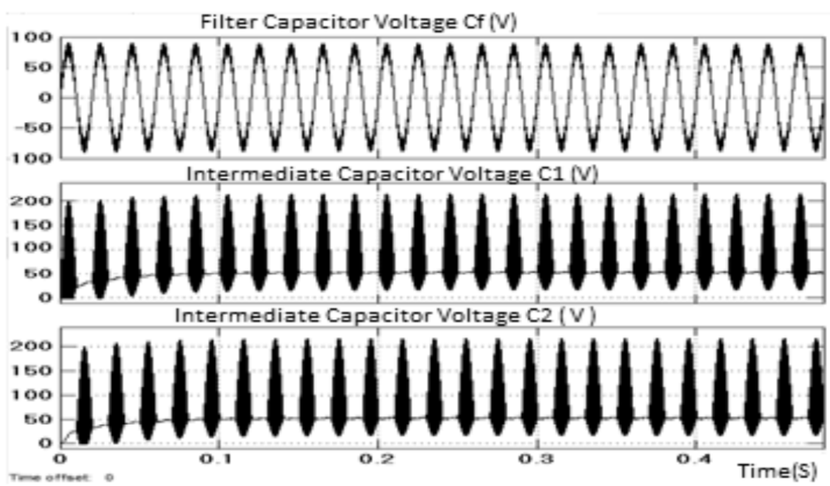

Figure 12: Capacitor Voltages

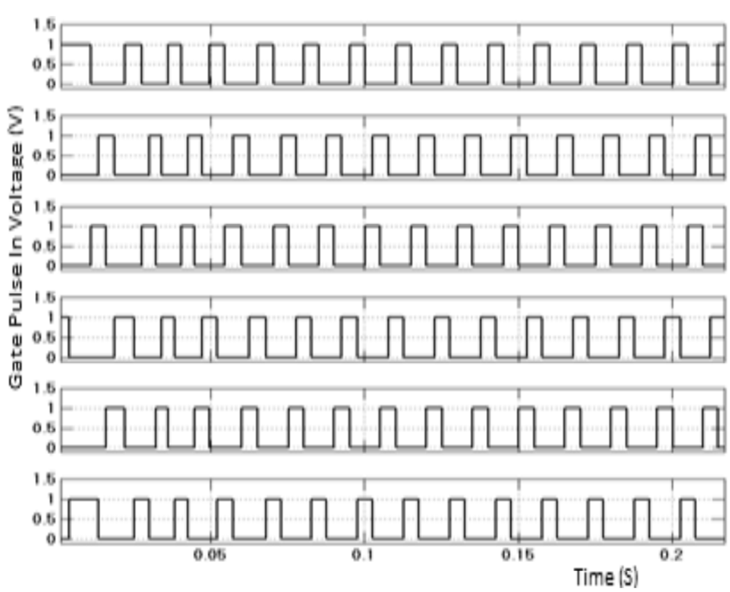

Figure 13: Gate Pulses of the Inverter

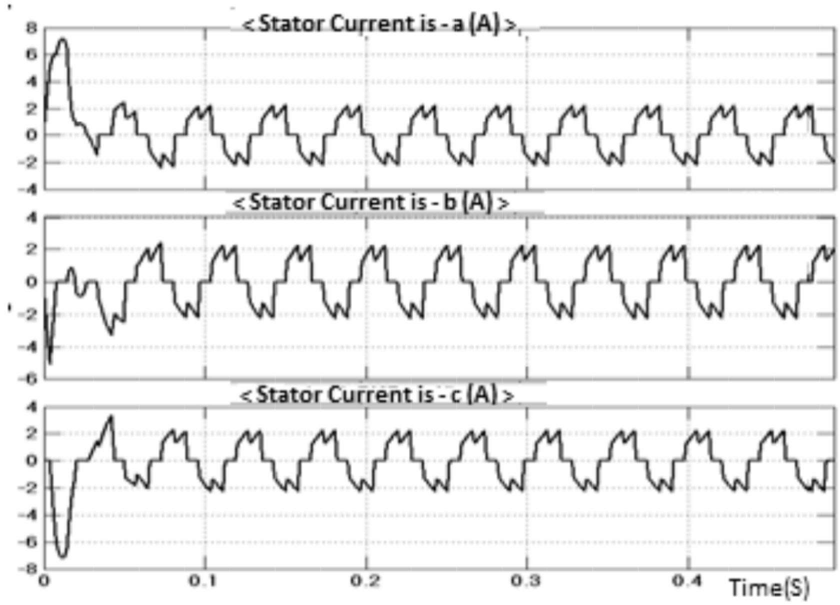

Figure 14: Stator Currents of the BLDC Motor

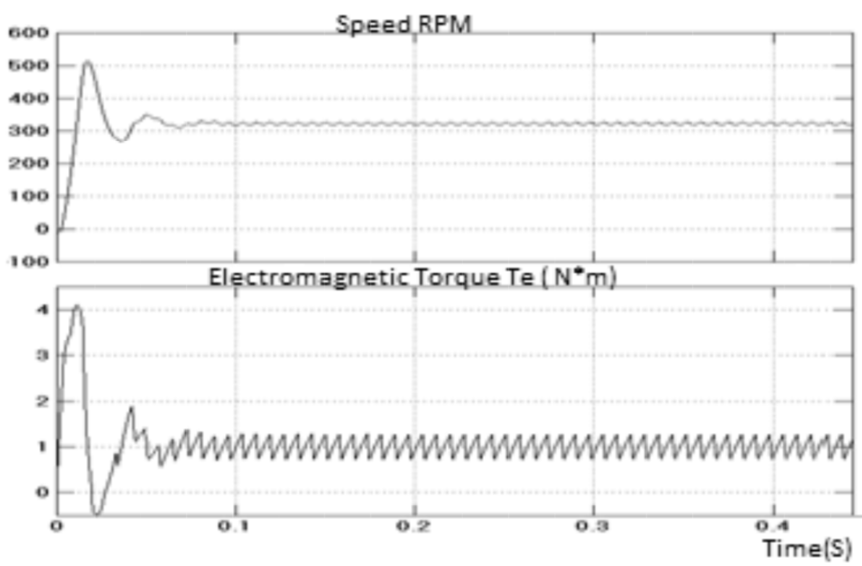

Figure 15: Speed and Electromagnetic Torque of the BLDC Motor

VII. HARDWARE

Design of an prototype converter as been built and photograph of the hardware setup is shown in the figure 16. For the designed values and relative parameters the switched selected is IRF250 and diodes based on current finalized is MUR1660. Relevant experimental results are shown in the figure 17-19.Gate pulse given to the switches for duty cycle of 32.1% and switching frequency of 10kHZ as shown in the figure 18. For 80V AC input the output voltage is 40V as shown in figure 19.

VIII. CONCLUSION

For PFC of a BCC by boosting the inputDC voltagewith help of only two switches. Circuit can be controlled with ease of only two switches to buck and boost the voltage.Simulation of is done in MATLAB/Simulink.A scheme of controlling the speed by control of voltage at DC link.Proposed system for cost effective motor drive is designed. At theinput side PFC correction is observed. Stress on VSI switches is less. Simulation

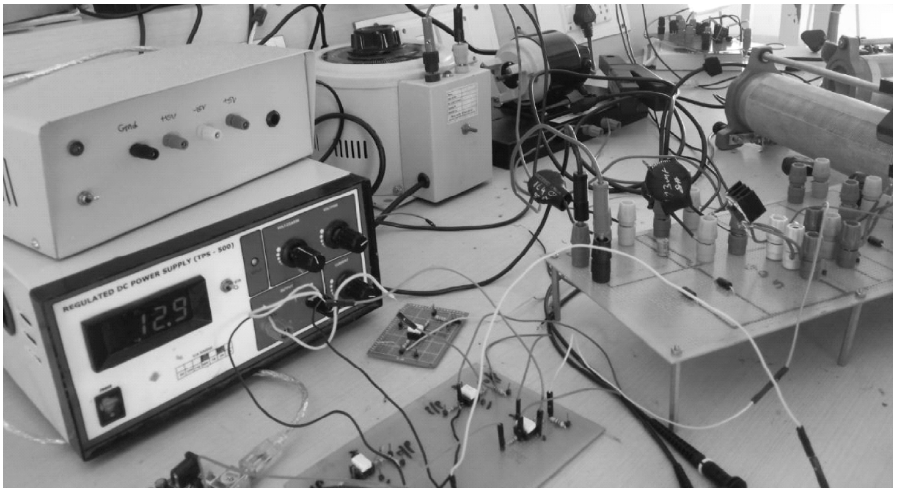

Figure 16: Experimental Prototype

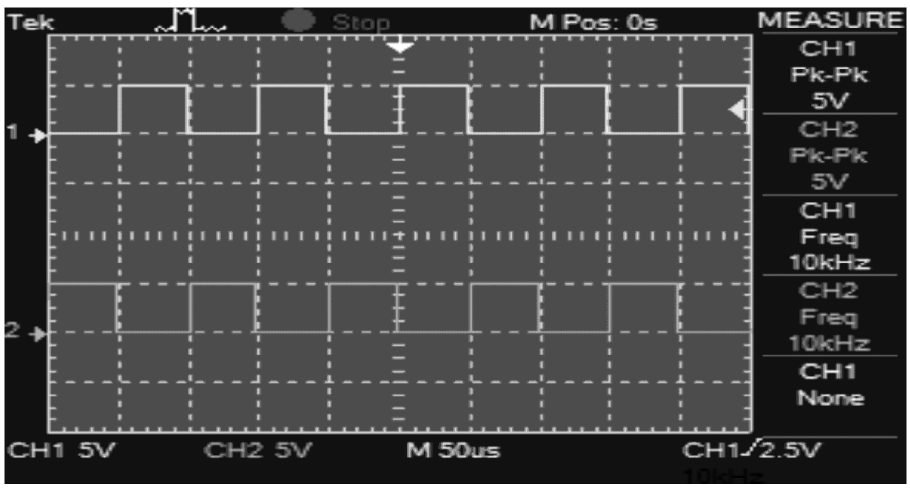

Figure 17: Gate Pulse of two switches

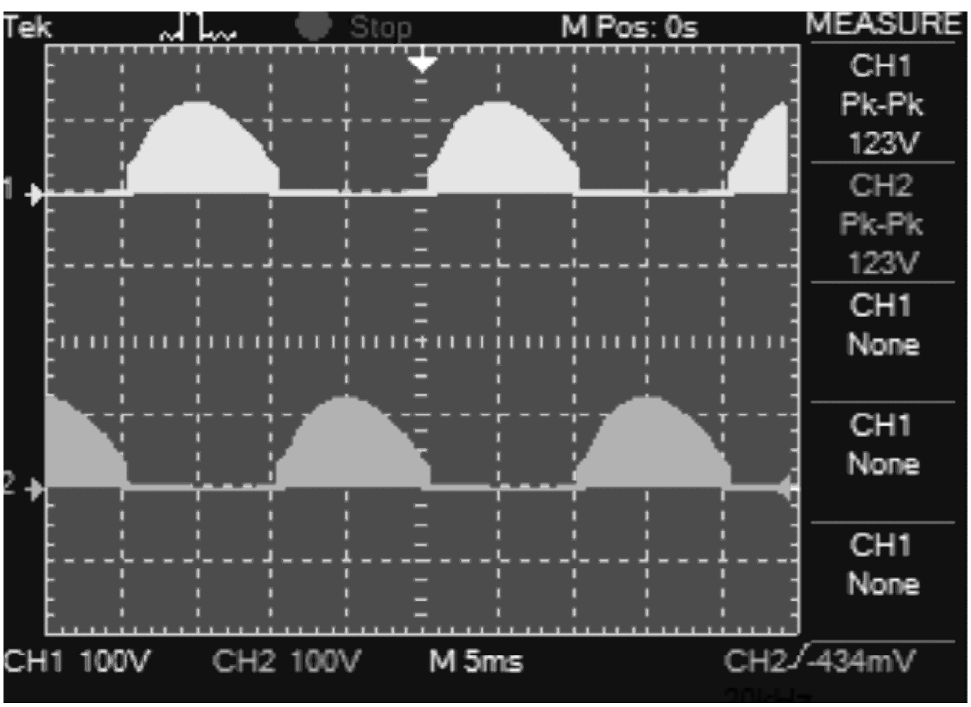

Figure 18: Intermediate Capacitor Voltage

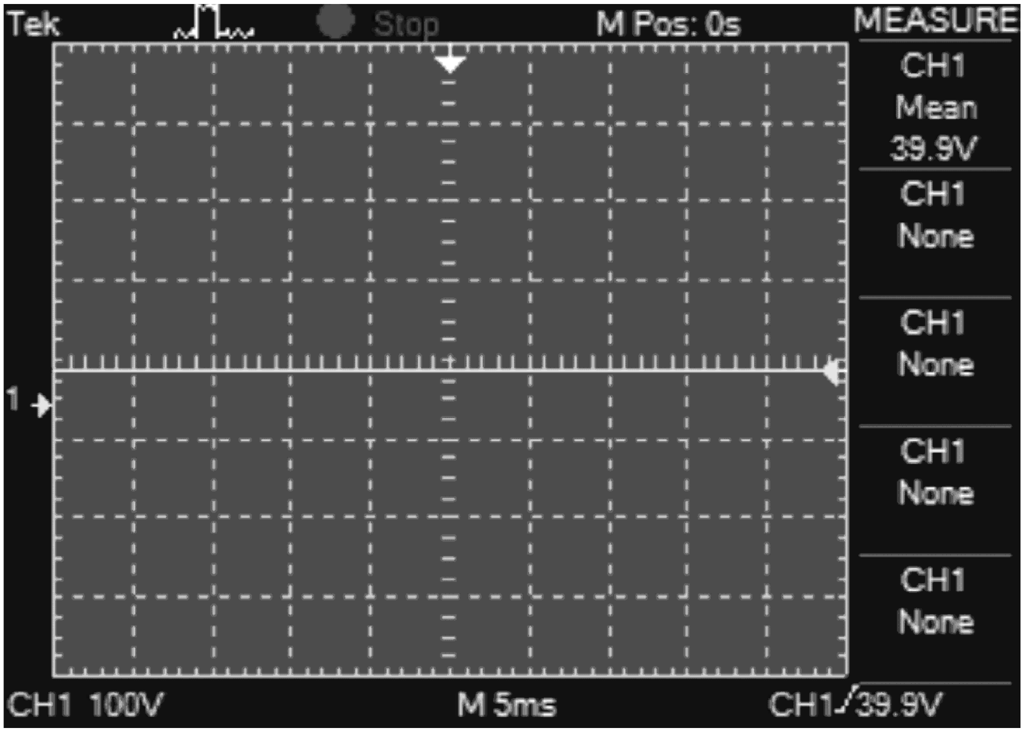

Figure 19: Output Voltage of the Converter

results are obtained as shown in the figure. The experimental and simulation results validate the analysis of the converter proposed.

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