Advanced Research in Electrical and Electronic Engineering
p-ISSN: 2349-5804; e-ISSN: 2349-5812 Volume 5, Issue 2 April-June, 2018, pp. 134-140

http://www.krishisanskriti.org/Publication.html

Design of Cuk Converter for Power Factor Correction of PMBLDC Motor Drive

Shaik Fareed Ahmed[1] and Syed Shajih Uddin Ahmed[2]

[1,2]Assistant Professor, ISL Engineering College
E-mail: [1]selectsfa@gmail.com, [2]shajihroyal@gmail.com

Abstract—*To have a good power factor correction at AC mains quality analysis is needed for better performance of any power electronics application. A PMBLDC motor needs distortion less controlled DC voltage fed to VSI. Electronic commutation technique is used for BLDC motor drive. Work dealing in this includes quality performance of BLDC motor. Mainly overcoming, the problem related of poor power factor in AC supply input and eliminating current harmonics at input supply by utilizing closed loop technique. For power factor correction DC-DC converter is used i.e cuk converter. DBR is employed for AC-DC conversion. Quality analysis on each parameter is done using MATLAB/Simulink and hardware waveforms are also captured for verification of the analysis.*

Keywords*: Permanent Magnet Brush Less DC (PMBLDC motor), Cuk converter, V.S.I, Diode Bridge Rectifier(DBR).*

1. INTRODUCTION

Now a days BLDC motor is having wide range of application. Whether it is related to railway fans, medical appliances new technology wherein motor of synchronous speed is required. Basically a BLDC motor is a synchronous motor, the only difference is the rotor will have permanent magnet and stator with phase windings. BLDC motor can only be worked on closed loop because it is enhanced and will only work using electronic commutation. Switching of VSI gate pulse will be decoded by electronic commutation by knowing the rotor position using hall sensor effect. If we utilize such technique then noise from motor will be less and low maintenance of motor. Therefore, BLDC motor has numerous advantages due to its wide range of application usage.

BLDC is a three phase motor, the entire proposed system consists of single phase AC supply, power modulator block, load which is BLDC motor, sensing unit and a control unit as shown in the figure 1. The power modulator includes a diode bridge rectifier, DC-DC converter and three phase voltage source inverter. Sensing unit consists of electronic commutation to know the rotor positioning enclosed in the BLDC casing. Here hall effect sensors are used. This will again decoded and given to VSI in the form of gate input signals. It concludes the closed loop block system.

Power modulator consists of DC-DC converter i.e here cuk converter is employed to reduce the increased harmonics at AC mains. Also cuk converter will suppress the improper charging of DC link capacitor. Hence good power factor correction can also be done in closed loop system of the converter. Cuk converter is only chosen because it has advantage of continuous input current and output current. Wide range of output voltage as well. As it is known that cuk can perform both buck and boost operation based on the duty cycle settings. It has both step up and step down the voltage. Moreover cuk converter is a forth order circuit, because it has 2 inductors and 2 capacitors for storing energy. Perhaps the total energy is going to be delivered to main DC link capacitor of the converter.

By employing closed loop operation for this cuk converter we can improve the power quality as per IEC61000-3-2 standards. Power factor increase will obviously boost the utilization of the system. If power factor is less, then it will indicate the system ineffectively used. Motor produces back emf opposite to that of supply voltage. This causes voltage leading and the current is lagging which results low power factor for this purpose we need to design closed loop control unit in order to have power factor correction.

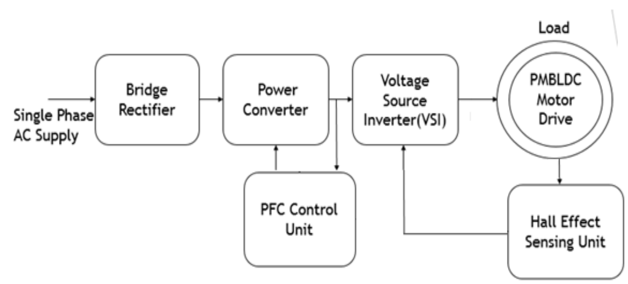

Figure 1: Block diagram of proposed system

Cuk converter has three modes of operation. Input inductor has continuous flow of current. Output side inductor will also have continuous flow of current. Voltage source inverter is for 60 degree phase shift. The frequency of VSI will be the line frequency fed to BLDC motor as shown in the figure 2. Cuk converter has three modes of operation.

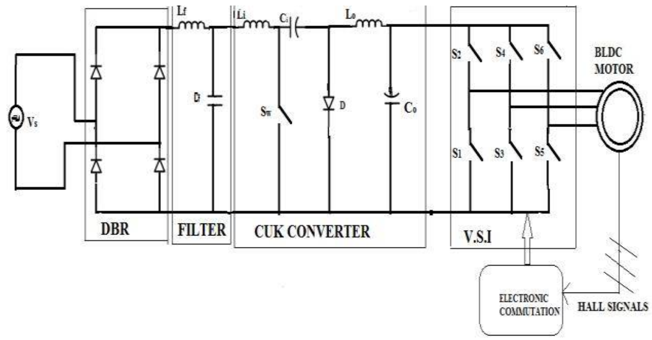

Figure 2: Circuit diagram of proposed system

Mode 1: The switch SW is ON. Inductor current i_L rises and flows through the switch. The voltage across capacitor C_1 will reverse bias the diode D. Further, Capacitor C_1 will discharge or transfer the stored energy to the load. It is observed the output voltage polarity and the load current have reversed as shown in the figure 3a.

Mode 2: This mode starts when the switch S is turned off. The inductor current i_{L1} begins to decrees through C_1 and D. Capacitor C_1 charges from the supply voltage V_s. During this mode also the output voltage polarity is opposite to that of conventional case as shown in figure 3b.

Mode 3: Both the switch and diode are OFF. The inductor stored energy is utilised to charge the output Capacitor C_2 as shown in the figure 3c.

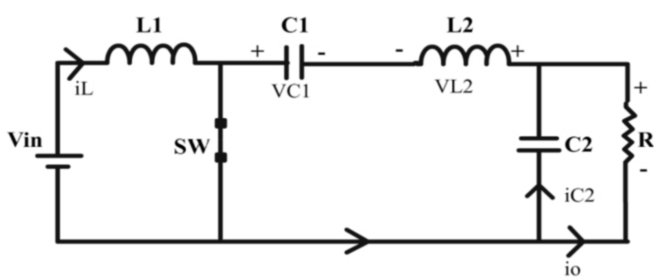

Figure 3a Mode 1 operation of cuk converter

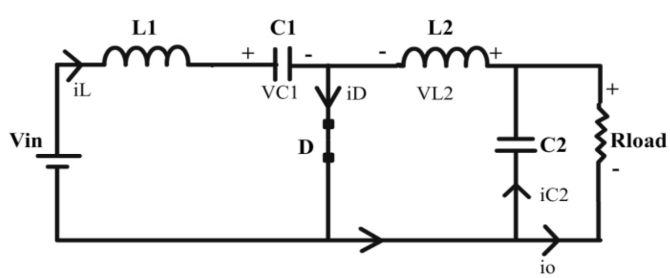

Figure 3b Mode 2 operation of cuk converter

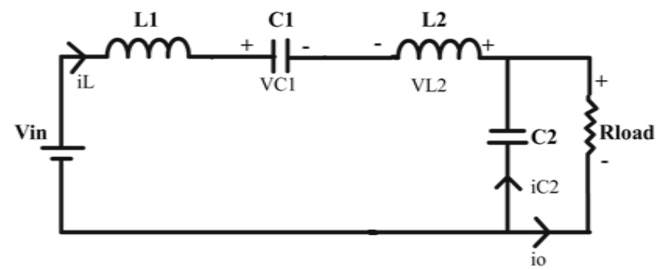

Figure 3c Mode 3 operation of cuk converter

2. DESIGN OF CUK CONVERTER

The Average input voltage at the ac mains is

$$V_{in} = \frac{2\sqrt{2}\,V_s}{\pi} \quad (1)$$

The Duty Ratio D is determined by the input voltage and the dc output voltage of the converter

$$\frac{V_o}{V_s} = \frac{D}{1-D} \quad (2)$$

Input inductor

$$L_i = \frac{DV_{in}}{\Delta L_i f_s} \quad (3)$$

Output inductor

$$L_o = \frac{(1-D)V_{dc}}{\Delta I_{Lo} f_s} \quad (4)$$

Intermediate capacitor

$$C_i = \frac{DI_{dc}}{\Delta V_{c1} f_s} \quad (5)$$

DC-Link capacitor

$$C_d = \frac{I_{dc}}{\omega \Delta V_{cd}} \quad (6)$$

R- Load

R_L = Load resistance, ohms.

$$R_L = \frac{V_{dc}^2}{P_i} \quad (7)$$

Table 1: Design values of cuk converter

Parameter	Rating
Supply voltage (V_S)	48 V
DC link voltage (V_{dc})	24V
Switching frequency (f_s)	40 kHz
Output current (I_o)	4.166 A
Input inductor current ripple (I_{Li})	2.15 A
Output inductor current ripple(I_{LO})	50% of I_O
Intermediate capacitor voltage ripple (V_{ci})	3.5% of V_{dc}
Output capacitor voltage ripple (V_{cd})	1.14% of V_{dc}

Table 2: Cuk converter design specification

Parameter	Specifications
Supply voltage (V_S)	48V
DC link voltage (V_{dc})	24V
Switching frequency (f_S)	40KHZ
Inductor (L_i)	1mH
Capacitor (C_i)	45µF
Inductor (L_o)	185µH
Capacitor (C_0)	6000µF

3. MATLAB SIMULINK & RESULTS

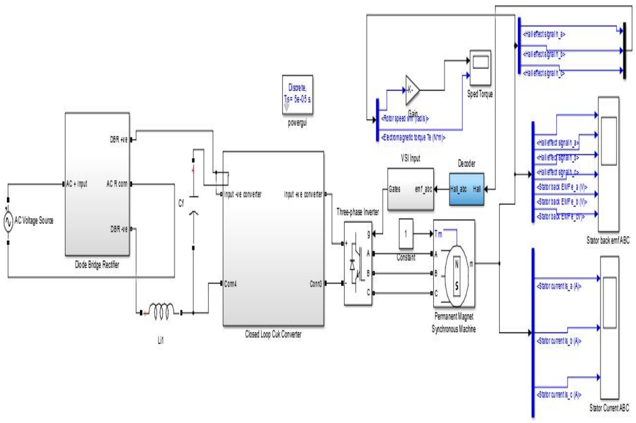

Figure 4 Closed Loop Simulation of proposed system

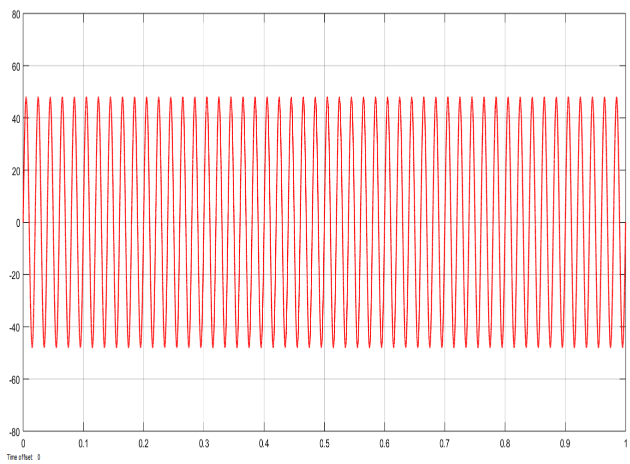

Figure 5 AC input voltage

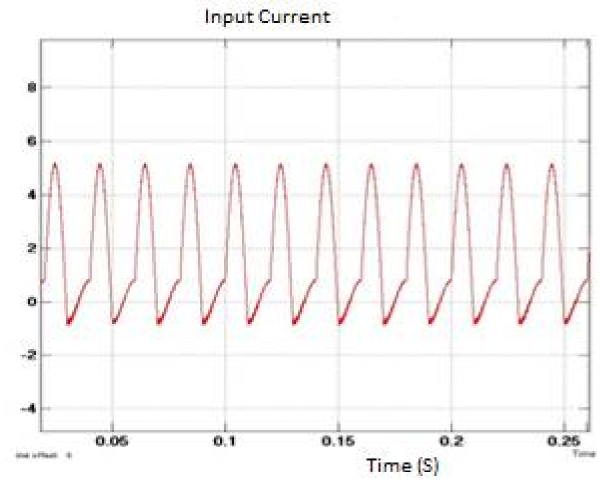

Figure 6 Input current

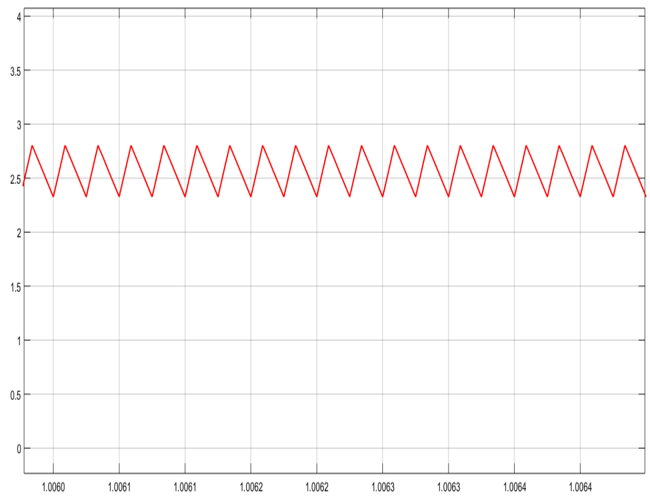

Figure 7 Input Inductor current

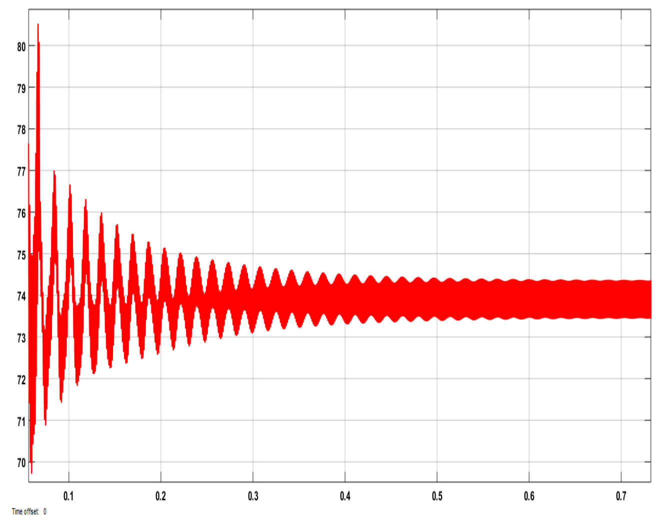

Figure 8 Intermediate Capacitor voltage

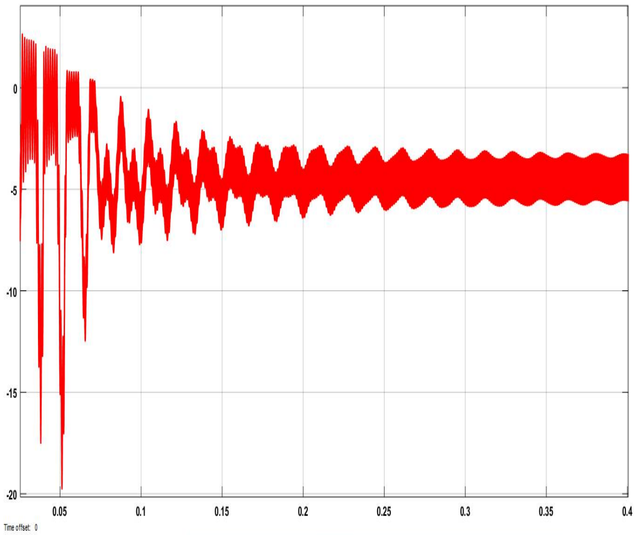

Figure 9 Output Inductor current

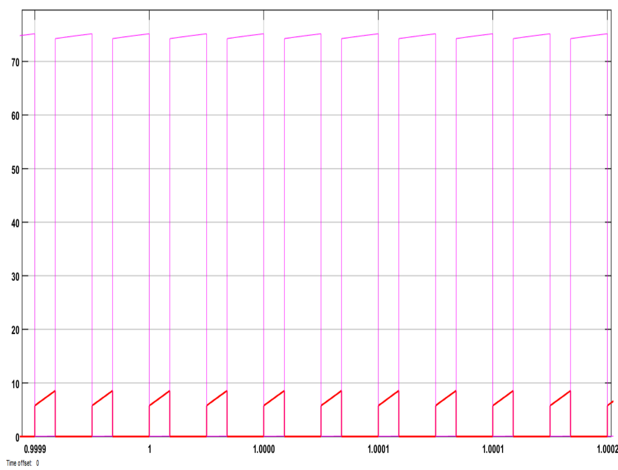

Figure 10 Switch Voltage and Current

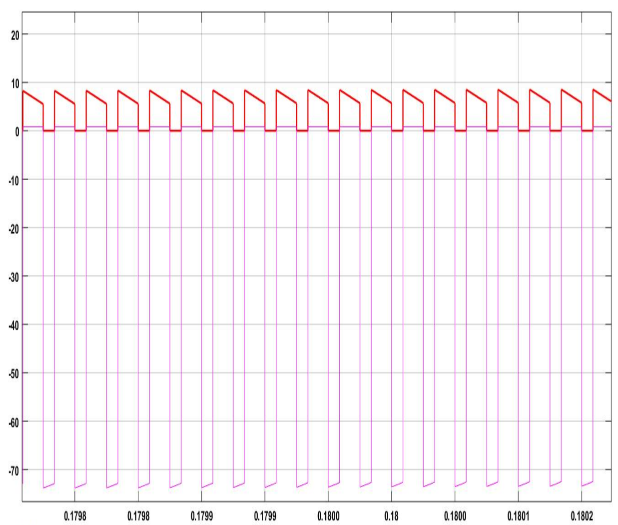

Figure 11 Diode Voltage and Current

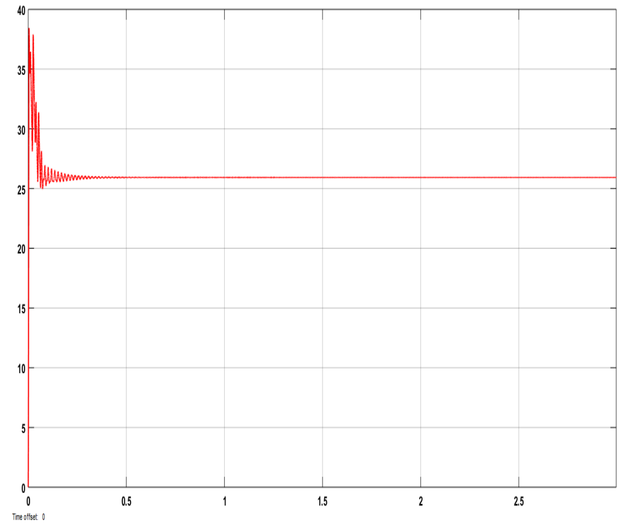

Figure 12 DC Link – Output Voltage

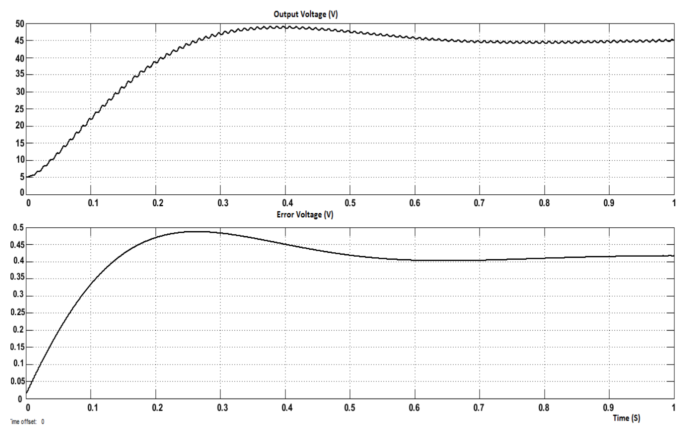

Figure 13 Closed Loop DC Voltage

Proposed system for BLDC is implemented in MATLAB/ Simulink. Initially cuk converter been simulated with obtained values from formulas. Calculated for P = 120W rating of the converter as shown in Table 1. The corresponding values of each value are obtained for cuk converter they are tabulated in Table 2.

Cuk converter along with DBR and AC supply voltage is seen in the figure 4. A fourier block is also used to check the power factor at AC mains. Whose angle is 25.69 degrees. Power factor near to 0.91 is obtained. Voltage reference closed loop is implemented for the converter. The AC supply voltage is plotted in the graph as shown in figure 5. Similarly the input current of 1.45Amps is shown in the figure 6.

Input inductor is carrying an average current of 2.5 amperes as shown in the figure 7. Due to high storing capacity of intermediate capacitor the voltage is around 72 volts as shown in the figure 8. The charging and discharging is clearly seen in the graph with respect to time in seconds. The output inductor is carrying very less amount of current shown in the figure 9.

The switch voltage and current behavior is also captured to know which MOSFET switch is suitable for current voltage and current behavior in the circuit. The graph is shown in the figure 10. Similarly, the diode voltage and current are also captured as shown in the figure 11.

The output voltage of open loop cuk converter is shown in the figure 12. After applying control unit to the cuk converter the error voltage happens to be settled after 0.6 seconds getting a constant DC voltage after saturating as shown in the figure 13.

Voltage source inverter is using electronic commutation technique for gate pulse. The decoder will sense the hall effect and know the switching sequence accordingly for the line frequency of 50Hz. The switching sequence of VSI is shown in the tabular column where in the phase shift is 60 degrees. 50Hz line frequency is nothing but in one cycle of time period 0.02 seconds all the switches should turn on and turn off. This is done for BLDC applications. The back emf is developed which will oppose the supply voltage. For BLDC motor the back emf will be trapezoidal in nature as shown in figure 15. The decoder will sense the hall effect signals and gives as input to the inverter i.e the required gate pulses as shown in the figure 14.

TABLE 3: Switching sequence of 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

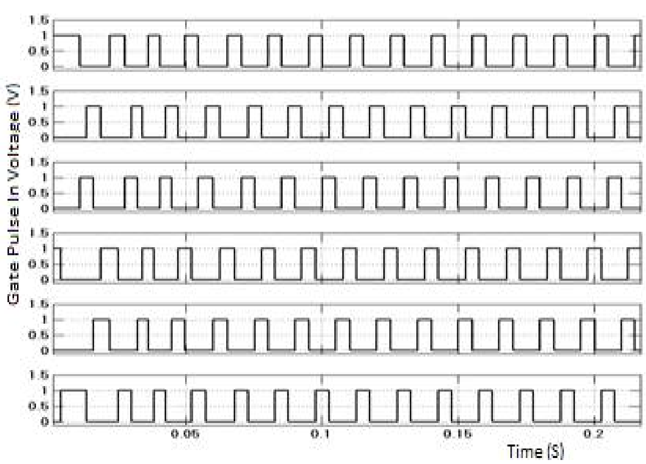

Figure 14 Gate pulse to the inverter

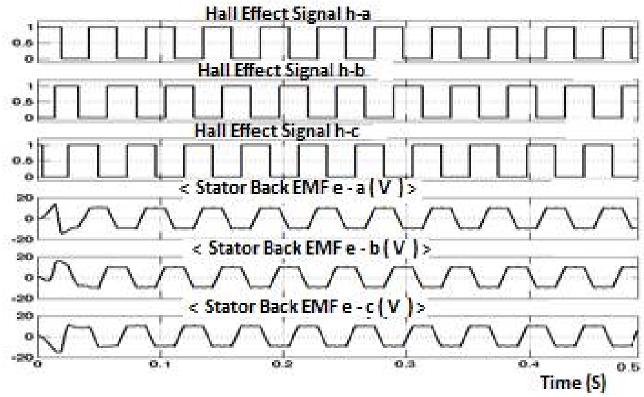

Figure 15 Hall Effect signals and Back EMF

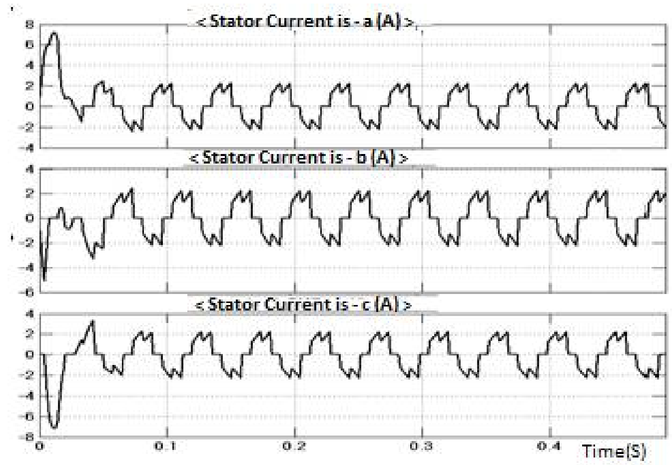

Figure 16 Stator Current

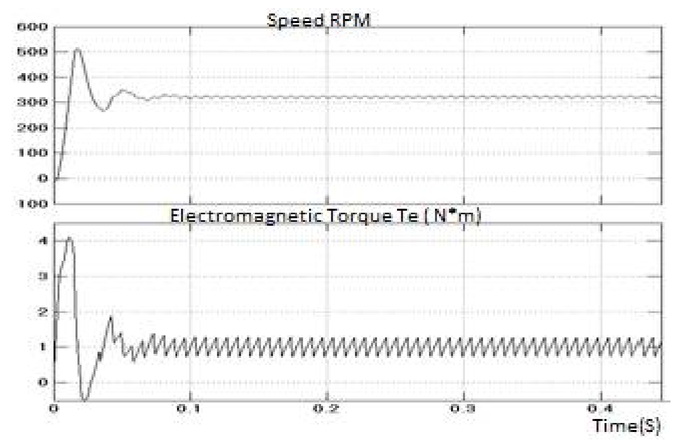

Figure 17 Speed (RPM) & Torque(N-m)

Stator current is also captured in the simulation and is shown in the figure 16. We know that, the speed and torque will be inversely proportional to each other. The variation is shown satisfactorily in the figure 17.

4. HARDWARE & RESULTS

Table 2: Hardware specification

Parameter	Specifications
Diode MUR 1640	300V,16A
MOSFET IRF250N	200V, 30A
Switching frequency (f_S)	40KHZ
Inductor (L_i)	1mH, 10A
Capacitor (C_i)	45µF, 100V
Inductor (L_o)	185µH, 8A
Capacitor (C_0)	6000µF, 63V

Hardware Implementation of PFC cuk converter

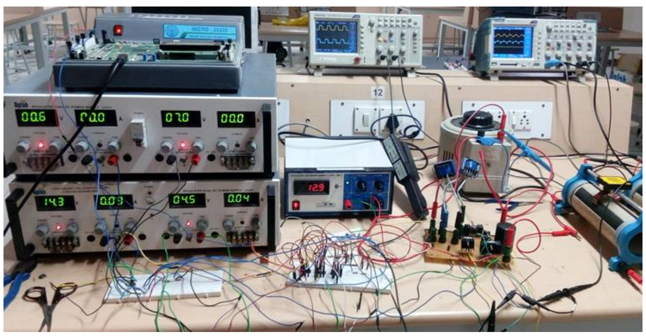

Figure 18: Experimental Setup of Cuk converter

Figure 18 represents the proposed converter closed loop setup working on power factor correction. with diode rectifier at its input. AC Variable voltage is supplied through variac. Solid state DBR is used for AC-DC conversion and given as input to the cuk converter.

The arduino Uno is used for giving gate pulses to the MOSFET IRF250N. The switching frequency is 40kHz as shown in the figure 20 with corresponding calculated duty cycle of 34.5%. For closed loop operation of the converter special IC IR1150S is used the connections of it is shown in the figure 18 hardware setup. IC connections are shown in figure 19.

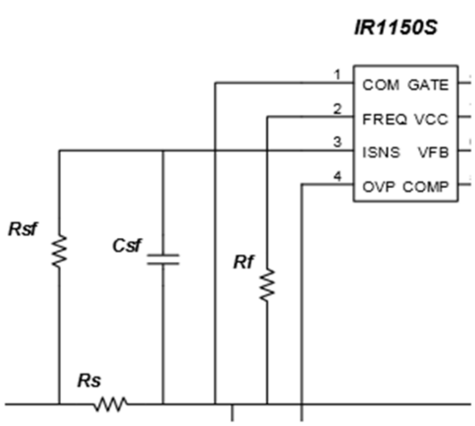

Figure 19 Closed Loop Used IC IR1150S

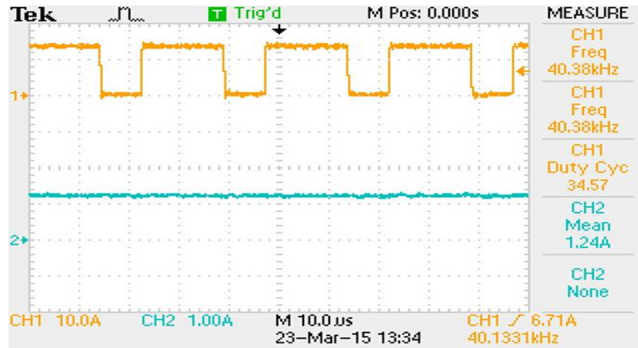

Figure 20 Gate pulse

In the figure 20 shows the gate pulse, the duty cycle is 34.5%. The gate pulse is given to the MOSFET Gate terminal of switch in the cuk converter.

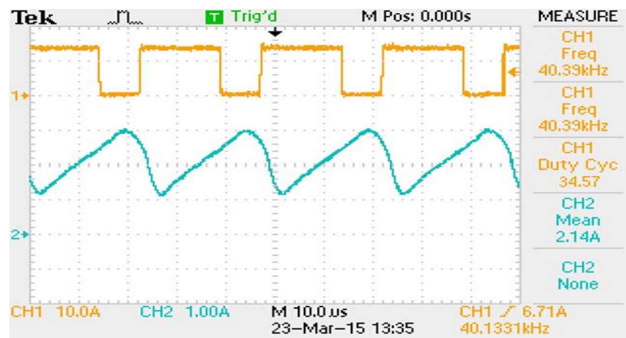

Figure 21 Input Inductor Current

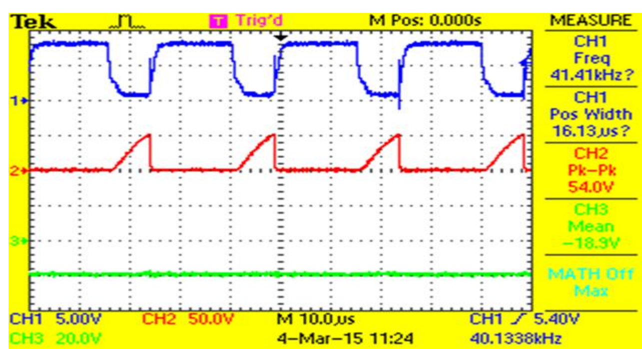

Figure 22 Switch Voltage

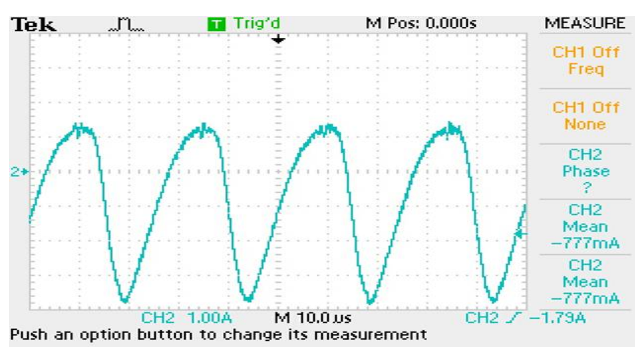

Figure 23 Output Inductor Current

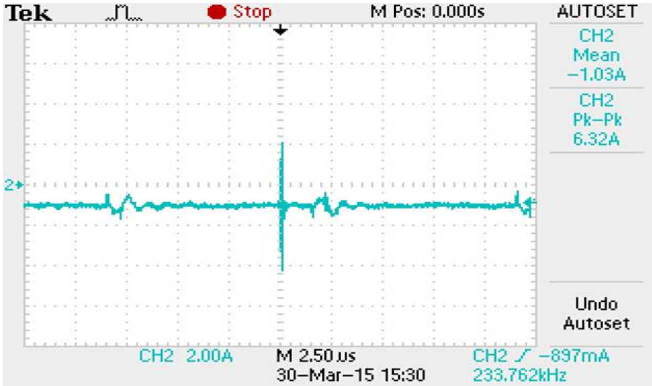

Figure 24 Output Current of the Cuk converter

Figure 19 shows the input inductor current i.e 2.14A linearly increasing and decreasing i.e charging and discharging. Figure 22 represents the switch voltage for starting voltage given by the variac AC supply. Figure 23 represents the inductor current. Figure 24 represents the output current if the cuk converter. A PFC closed loop operation is done, following waveform at input AC unit been captured in DSO as shown in the figure 25. Figure 26 represents the VSI fed to BLDC motor of 100W rating. The wattage rating of VSI is 105W switching at line frequency 50Hz.

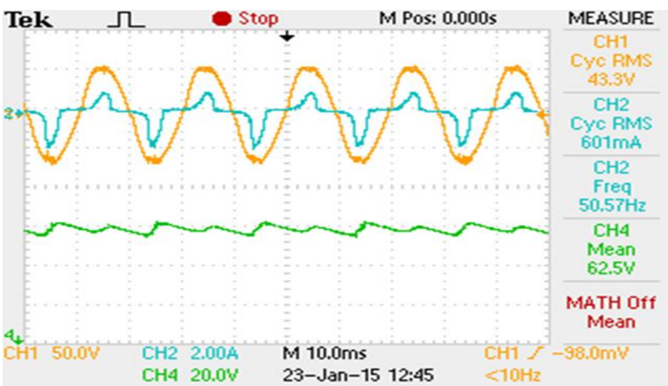

Figure 25 Closed Loop PFC at line frequency 50Hz

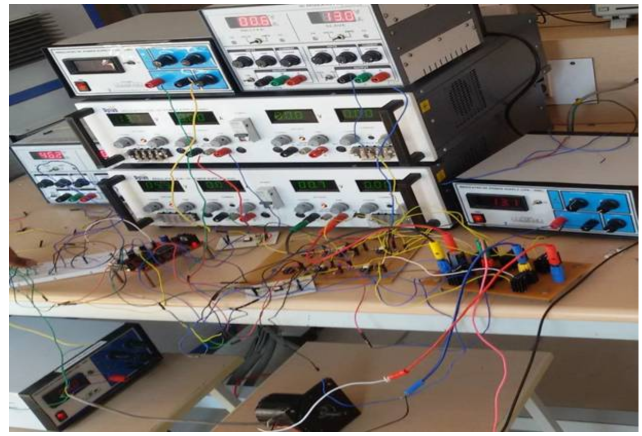

Figure 26 VSI Fed to BLDC Motor Drive

5. CONCLUSION

The cuk converter is designed and tested successfully. For designed converter 92% is the efficiency. Three phase VSI of 50Hz is also shown in figure 27.Proposed system as shown high power factor. Hardware of proposed system has shown satisfactory results.

REFERENCES

[1] Vashist bist, Bhim Singh,“PFC cuk converter-Fed BLDC motor dive,” in *Proc.IEEE Trans on power electronics,* vol 30 no 2 *Feb 2014.*

[2] C.L.Xia, *Permanent Magnet Brushless DC Motor Drivers and Controls*. Beijing, China: Wiley, 2012.

[3] T.Kenjo and S.Nagamori, *Permanent Magnet Brushless DC Motors*. Oxford, U.K.: Clarendon Press, 1985.

[4] H. Y. Kanaan and K. Al-Haddad, “A unified approach for tanalysisof single-phase power factor correction converters,” in *Proc. 37th Annu.Conf. IEEE Ind. Electron. Soc.*, Nov. 7–10, 2011,pp.1167–1172.

[5] J.R.Handershot and T.J.E.Miller, *Design of Brushless Permanent Magnet Motors*,Oxford, U.K.: Clarendon Press, 2010.

[6] V.Vlatkovic, D.Borojevic, and F.C.lee, “Input filter design for power factor correction circuits,” in *Proc.IEEE Trans on power electronics,* vol 11 no 1 *jan 1996.*

[7] P.Alaeinovin , J.Jatskevich, “ Filtering of hall-sensor signals for improved operation of brushless DC motor,” in *Proc. IEEE Trans.Energy Convers.*,vol 27 no2 pp 547-549, Jun.2012.