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An Improved Power Quality Based Sensorless Control of BLDC Motor

Antony Dominic[1], Caroline Ann Sam[2]

PG Scholar [Industrial Drives and Control], Dept. of EEE, Rajagiri School of Engineering and Technology, Kochi, Kerala, India[1]

Asst. Professor, Dept. of EEE, Rajagiri School of Engineering and Technology, Kochi, Kerala, India[2]

ABSTRACT: The use of a permanent magnet brushless DC motor in low power appliances is increasing because of its features of high efficiency, wide speed range, and low maintenance. The international Power Quality standard IEC 61000-3-2 recommends a high power factor and low total harmonic distortion of ac mains current for Class-A applications, which includes many household equipments. The conventional scheme of a brushless DC motor fed by a diode bridge rectifier with a high value of dc-link capacitor draws a non sinusoidal current from AC mains which are rich in harmonics causing the distortion of supply current to be high, which results in low power factor. The Improved Power quality based sensorless control of brushless DC motor drive uses a power factor correction based Cuk converter to feed the brushless dc motor drive. The prime advantage of making the BLDC motor sensorless is that the weight mounted on the rotor shaft can be drastically reduced. The susceptibility of the sensors to external environment factors and consequent variations in the machine performance can also be avoided. Also there is reduction in the cost of the overall system due to the absence of sensors. The entire performance has been evaluated using MATLAB/SIMULINK.

KEYWORDS: Brushless DC Motor (BLDC), Total Harmonic Distortion (THD), Variable Frequency Drive(VFD), Cuk Converter, Discontinuous Conduction Mode (DCM), Power Factor Correction (PFC), Power Quality (PQ) .

I. INTRODUCTION

The rapid developments in power electronics, power semiconductor technologies has lead to brushless DC motors to be used in various areas such as automotive, computer, industrial, and household products, and its market is rapidly growing. This is mainly due to its features of small size, good performance, simple structure, high reliability and large output torque. The BLDC motors have attracted increasing attention. The international PQ standard IEC 61000-3-2 which recommends a high power factor and low total harmonic distortion of ac mains current for Class-A applications (<600 W, <16 A) which includes many household equipments [2].

The conventional scheme of a BLDC motor fed by a diode bridge rectifier and a high value of dc-link capacitor draws a non sinusoidal current, from ac mains which is rich in harmonics such that the THD of supply current is as high as 65%, which results in PF as low as 0.8 [3]. These types of PQ indices cannot comply with the international PQ standards such as IEC 61000-3-2 [2]. Hence, single-phase power factor correction converters are used to attain a unity PF at ac mains [5]. Conventional schemes of PFC converter-fed BLDC motor drive utilize an approach of constant dc-link voltage of the VSI and controlling the speed by controlling the duty ratio of high frequency pulse width modulation (PWM) signals [6]. The losses of VSI in such type of configuration are considerable since switching losses depend on the square of switching frequency. The cascaded buck–boost converter-fed BLDC motor drive, which utilizes two, switches for PFC operation. This causes high switching losses in the front-end converter due to double switch and reduces the efficiency of the overall system. The single-ended primary inductance converter (SEPIC) as a front-end converter for PFC with a dc-link voltage control approach, but utilizes a PWM switching of VSI which has high switching losses[6].

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Bridgeless configurations of PFC buck–boost [7], Cuk, SEPIC, and Zeta converters have been proposed in [8]. These configurations offer reduced losses in the front-end converter but at the cost of high number of passive and active components. The proposed power factor correction based Cuk converter-fed sensorless control of brushless dc motor drive is a cost effective solution for low-power applications. The speed of the BLDC motor is controlled by varying the dc-bus voltage of a voltage source inverter which uses a low frequency switching of VSI for low switching losses. A diode bridge rectifier followed by a Cuk converter working in a discontinuous conduction mode is used for control of DC-link voltage with unity power factor at ac mains.

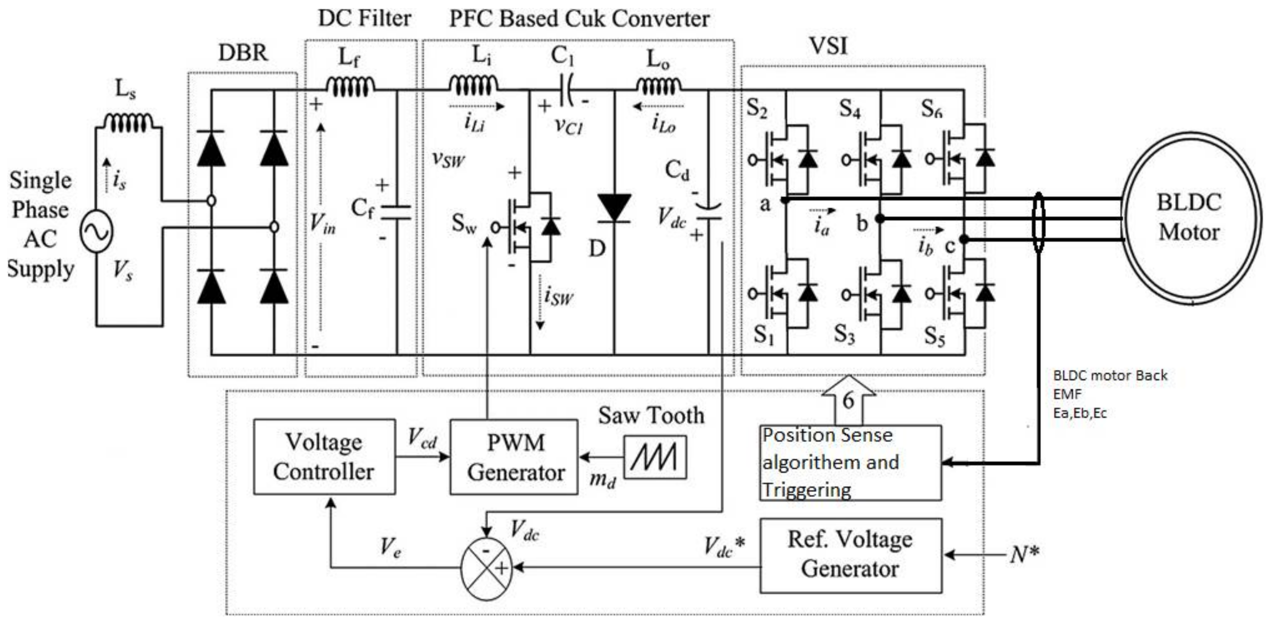

Fig. 1 Proposed Sensorless Control of BLDC motor

The Fig 1 shows the proposed sensorless control of BLDC motor. The input of single phase AC supply is given to the diode bridge rectifier. A high frequency metal oxide semiconductor field effect transistor is used in the Cuk converter for power factor correction and voltage control[1]. The MOSFET switches are used in the Voltage Source Inverter. The back EMF of the BLDC motor is a function of rotor position and velocity. Thus the information from the back EMF can be used to operate the MOSFET switches of the BLDC motor thus the use of Hall Sensors can be eliminated. The prime advantage of making the system sensorless is that the efficiency and reliability of the motor can be improved[10]. The susceptibility of the sensors to external environment factors and consequent variations in the machine performance can also be avoided. Also there is reduction in the cost of the overall system due to the absence of sensors. The Cuk converter is operated in Discontinuous Conduction Mode to achieve improved power quality in terms of Power factor[9] and harmonic distortion in the AC mains. In this mode of operation the current flowing in the output inductor becomes discontinuous.

II. OPERATING PRINCIPLE OF CUK CONVERTER

The PFC Cuk converter is operated in discontinuous inductor current mode (DICM) in this mode the current flowing in the inductor L_i or L_o becomes discontinuous in their respective mode of operation. The improved power quality in terms of power factor and harmonic distortion in the input side is obtained by operating the Cuk converter in DICM (L_o) mode. The operation of Cuk converter in DICM (L_o) mode is described as follows Fig3(a)-(c) shows the operation of Cuk converter in three different intervals of a switching period and Fig 4 shows the associated waveforms in a switching period.

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Interval I: In Fig. 3(a), when switch S_w in turned ON, inductor L_i stores energy while capacitor C_1 discharges through switch S_w to transfer its energy to the dc-link capacitor C_d.

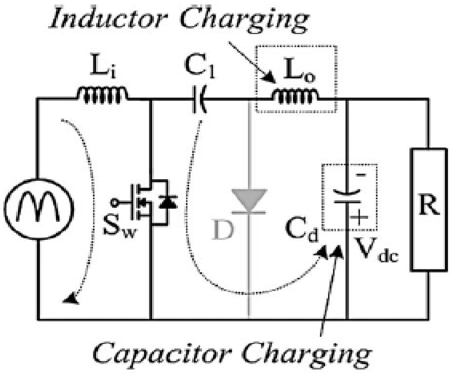

Fig. 3 (a) Interval I: Capacitor and Inductor Charging Mode

Interval II: When switch S_w is turned OFF, the energy stored in inductor L_i and L_o is transferred to intermediate capacitor C_1 and dc-link capacitor C_d , respectively.

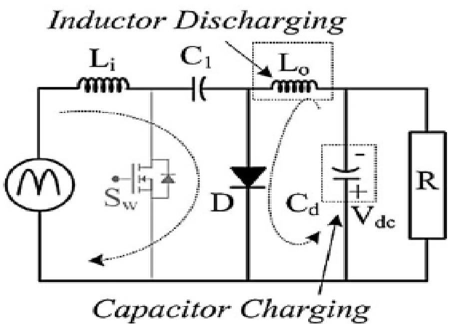

Fig. 3(b) Interval II: Capacitor Charging and Inductor Discharging Mode

Interval III: In this mode of operation, the output inductor L_o is completely discharged; hence, its current i_{Lo} becomes zero. An inductor L_i operates in continuous conduction to transfer its energy to the intermediate capacitor C_1 via diode D.

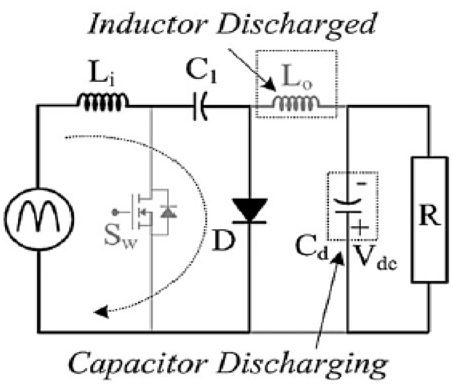

Fig. 3 (c) Interval III:Capacitor and Inductor Discharging Mode

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The Fig 4 shows the associated waveforms in a switching period.

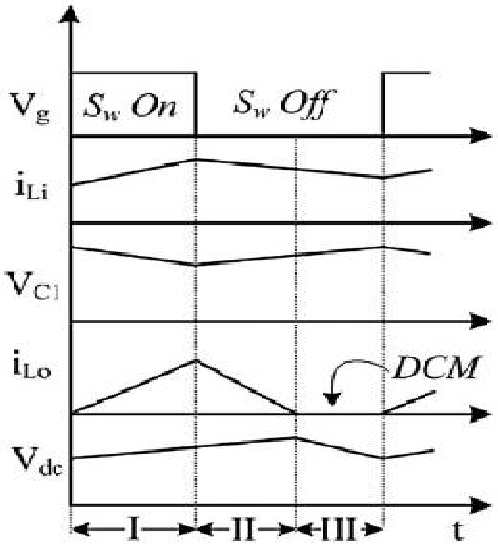

Fig. 4 Waveforms (a) Voltage across S_w (b) Current through L_i (c) Voltage across V_{c1} (d) Current through L_o (e) Cuk converter output voltage

III. SIMULATION

The PFC Cuk converter fed sensorless control of BLDC motor is simulated using MATLAB/ SIMULINK. The input voltage given to the diode bridge rectifier is 12V, 50 Hz single phase AC supply .The Cuk converter is designed to operate in DICM (L_o) mode with a maximum DC output voltage of 24V.

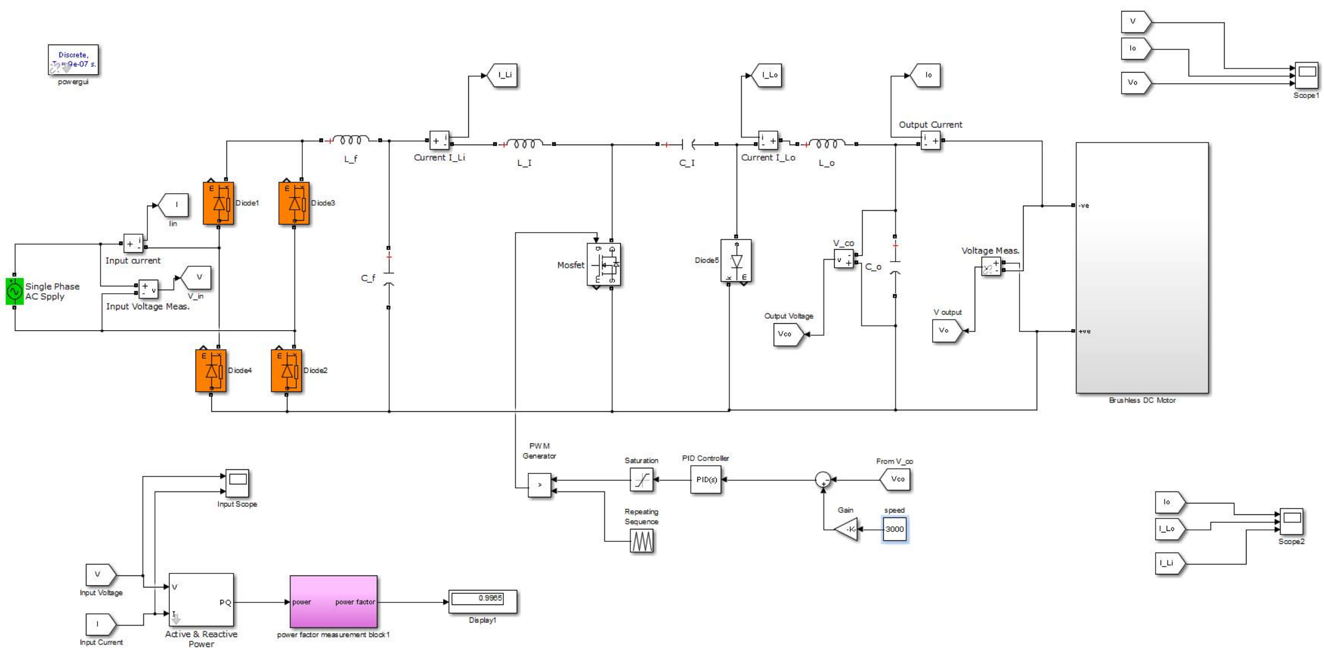

Fig. 5 Simulation Model of Cuk converter fed Sensorless control of BLDC

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The switching frequency of the MOSFET switch in the Cuk converter is set at 20 kHz. The Cuk converter fed BLDC motor drive operating in discontinuous conduction mode using a voltage follower approach is implemented in the Simuink model. The Fig6 shows the sensorless based control of BLDC motor. The BLDC motor has a rated voltage of 24V and a rated speed of 4000RPM. The signal block is used to provide the initial starting pulse to the switches so as to make the motor self starting.

The speed command of 4000RPM is given to rotate the motor at the rated speed. The Fig: 6 shows the sensorless based control of the BLDC motor. The back EMF of the motor is used to estimate the current position of the rotor and to commutate the required switches of the VSI.

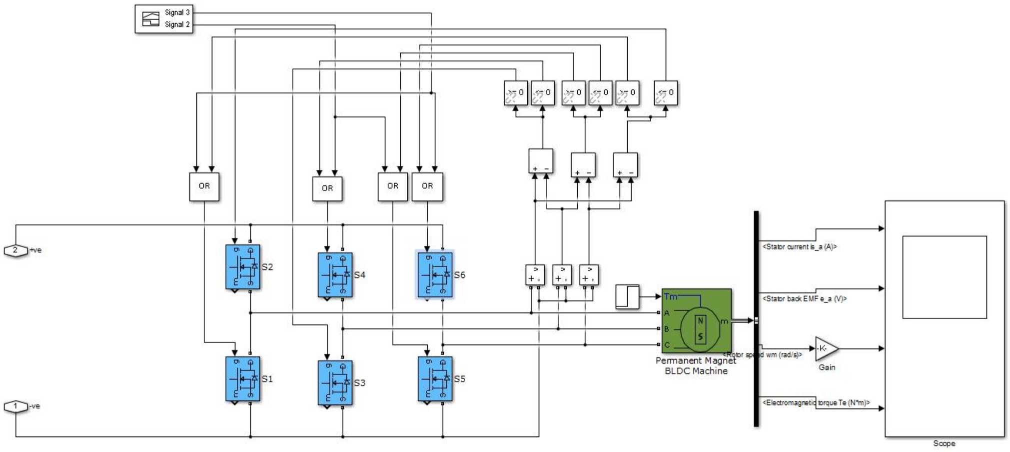

Fig 6: BLDC motor Subsystem

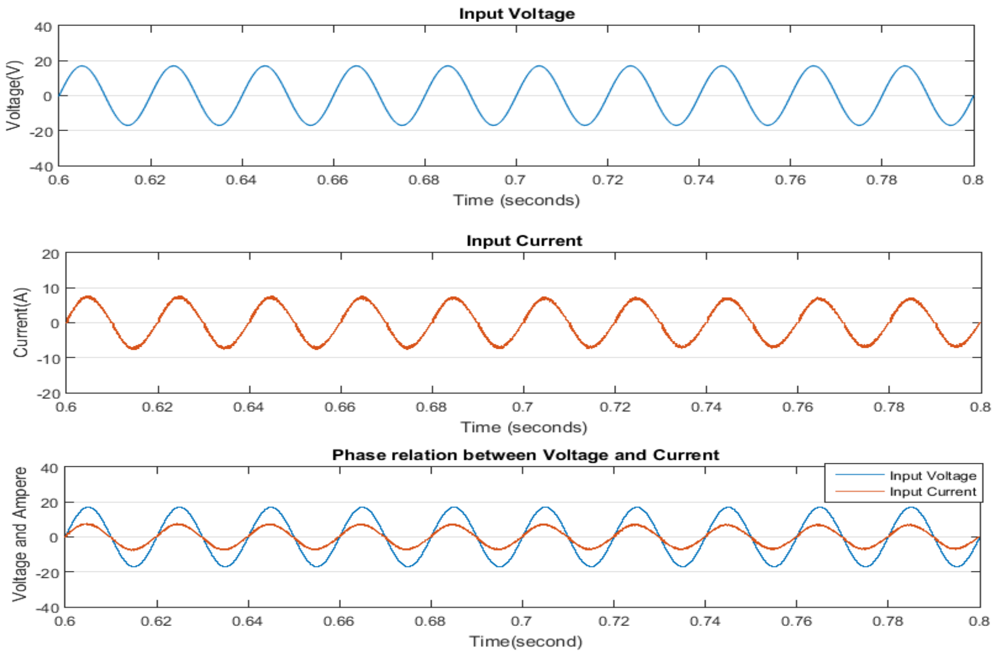

Fig 7 (a) Input Voltage (b) Input Current (c) Phase relation between input Voltage and current

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The input power factor is obtained as 0.996.The input current and input voltages are obtained to be in phase. Thus almost unity power factor operation is obtained using the Cuk converter.

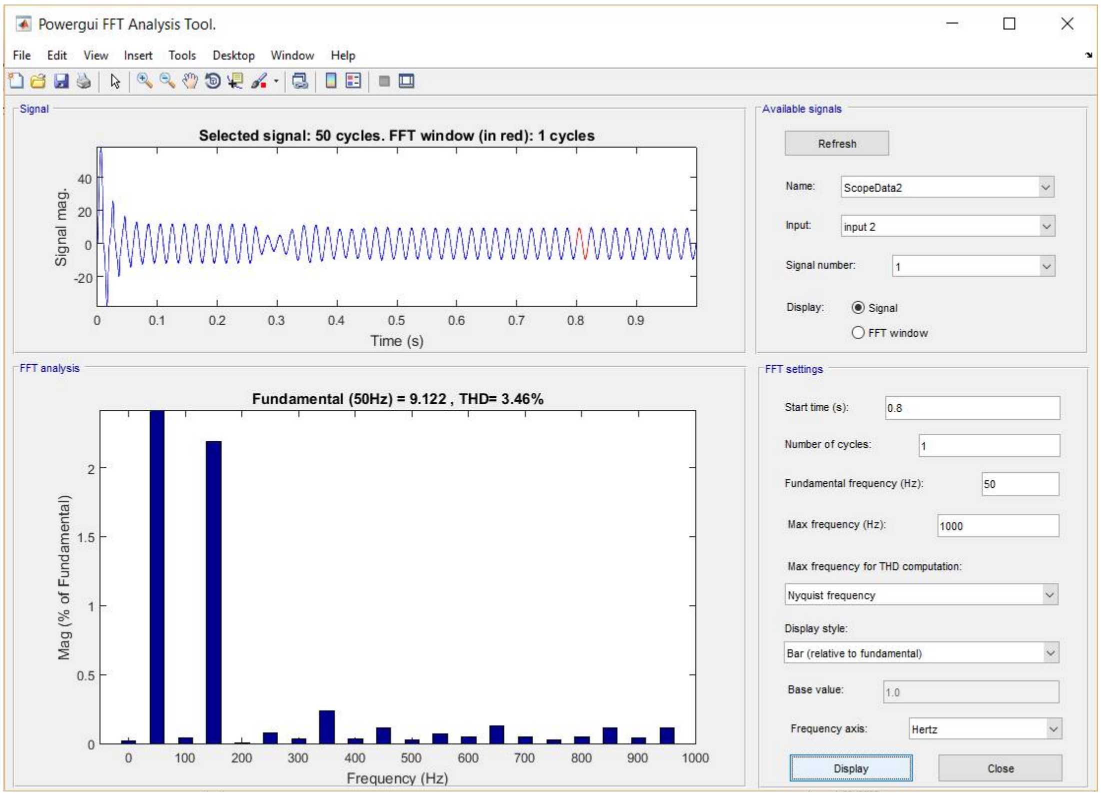

Fig 8 FFT analysis of input current

The input current waveform shown in Fig 7(b) is analyzed by Fast Fourier Transform. The third harmonic component of current is about 2.5% of fundamental component. The fifth and seventh component is 0.10% and 0.20% of fundamental component. The input current THD obtained is about 3.46 %.

The parameters selected for this converter to operate in the DICM (L_o) mode are as follows: input inductor L_i = 200µH, output inductor L_o = 15µH, Intermediate capacitor C_1 =30µF and DC-link capacitor C_d = 2000 µF. The Fig. 9 shows the performance of the proposed BLDC motor drive fed by a PFC Cuk converter operating in the DICM (*Lo*).
A discontinuous output inductor current i_{Lo} is obtained while the input inductor current i_{Li} remain in continuous conduction operation.

The Fig 10 shows the performance waveform of the BLDC motor. Fig 10(a) shows the output voltage of cuk converter which is set at 24V. The rise time of the output voltage is 0.08 sec and a speed of 4000RPM is obtained for the BLDC motor. The electromagnetic torque is set at 0.085Nm and a trapezoidal back EMF waveform is obtained.

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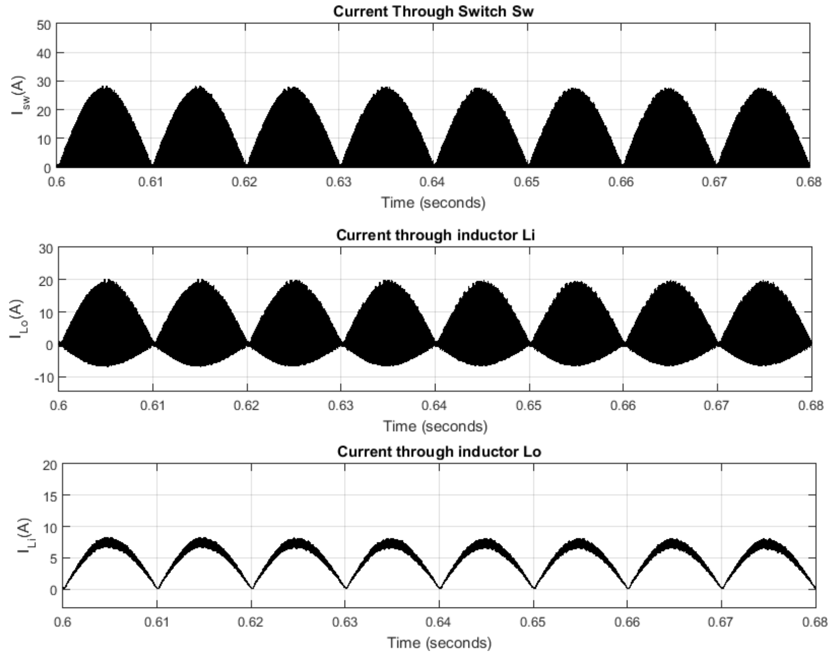

Fig 9 (a) Current through S_w (b) Current through L_o (c) Current through L_i

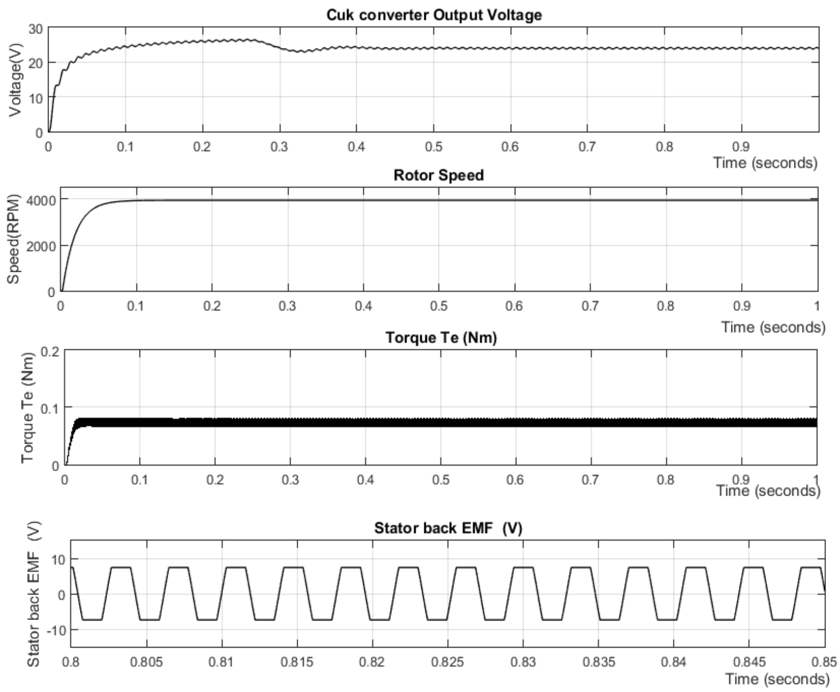

Fig 10 (a) Cuk converter output voltage (b) Rotor Speed (c) Electromagnetic torque (d) Stator back EMF.

V. CONCLUSION

The speed of the BLDC motor drive has been controlled by varying the dc-link voltage of VSI. The MOSFET switching frequency was 20 kHz. Throughout the simulation near unity power factor was achieved for Cuk Converter.

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The Input current and voltage waveforms are found to be in phase and near unity power factor was obtained. The THD was observed to be 3.46% when operated at rated speed. The proposed design of Cuk converter fed sensorless control of BLDC motor gives superior power quality in terms of high power factor and low harmonic distortion.

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