An Openloop of Power Factor Correction using CUK Converter Fed BLDC Motor

N. Janaki[a]

[a]*Assistant Professor Department of Electrical and Electronics Engineering, Vels University, Pallavaram, Chennai. Email: janaki.se@velsuniv.ac.in*

Abstract: A power factor correction (PFC)-based Cuk converter-fed brushless dc motor (BLDC) drive as 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 (VSI) which uses a low frequency switching of VSI (electronic commutation of the BLDC motor) for low switching losses. Conventionally, the Brushless direct current motor is fed by a diode bridge rectifier which results in poor power factor and highly distorted supply current with high total harmonic distortion. To overcome such problems a Power factor correction (PFC) Cuk converter is proposed for improving power quality at the AC mains of an inverter fed BLDC motor drive. The drive is implemented to achieve unity power factor at AC mains for a wide range of speed control and reduce supply voltage fluctuations. The proposed Power factor correction Cuk converter topology is modeled and its performance is simulated in Matlab-Simulink environment.

Keywords: Brushless dc (BLDC) motor, Cuk converter, Discontinuous conduction mode (DCM), power factor correction (PFC), Total Harmonic Distortion (THD), Power Factor (PF), power quality (PQ).

1. INTRODUCTION

Brushless dc (BLDC) 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. Due to these advantages, they find applications in numerous areas such as household application, transportation (hybrid vehicle), aerospace, heating, ventilation and air conditioning, motion control and robotics, renewable energy applications, etc. The BLDC motor is a three-phase synchronous motor consisting of a stator having a three-phase concentrated windings and a rotor having permanent magnets. It does not have mechanical brushes and commutator assembly; hence, wear and tear of the brushes and sparking issues as in case of conventional dc machines are eliminated in BLDC motor and thus it has low EMI problems. This motor is also referred as an electronically commutated motor since an electronic commutation based on the Hall-effect rotor position signals is used rather than a mechanical commutation.

There is a requirement of an improved power quality (PQ) as per the international PQ standard IEC 61000-3-2 which recommends a high power factor and low total harmonic distortion (THD) of ac mains current for Class-A applications (<600 W, <16 A) which includes many household equipments. The conventional scheme of a BLDC motor fed by a diode bridge rectifier (DBR) 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. These types of PQ indices cannot comply with the international PQ standards such as IEC 61000-3-2. Hence, single-phase power factor correction (PFC) converters are used to attain a unity PF at ac mains. These converters have gained attention due to single-stage requirement for dc-link voltage control with unity PF at ac mains. It also has low component count as compared to a multistage converter and therefore offers reduced losses. 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. The losses of VSI in such type of configuration are considerable since switching losses depend on the square of switching frequency (*P*sw loss α*f*2*S*). Ozturk *et. al.*, have proposed a boost PFC converter-based direct torque controlled (DTC) BLDC motor drive. They have the disadvantages of using a complex control which requires large amount of sensors and higher end digital signal processor (DSP) for attaining a DTC operation with PFC at ac mains. Hence, this scheme is not suited for low-cost applications. Ho *et. al.,* have proposed an active power factor correction scheme which uses a PWM switching of VSI and hence has high switching losses. Gopalarathnam *et. al.*, have proposed a 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. Bridgeless configurations of PFC buck–boost, Cuk, SEPIC, and Zeta converters have been proposed. These configurations offer reduced losses in the front-end converter but at the cost of high number of passive and active components.

Selection of operating mode of the front-end converter is a trade-off between the allowed stresses on PFC switch and cost of the overall system. Continuous conduction mode (CCM) and discontinuous conduction mode (DCM) are the two different modes of operation in which a front-end converter is designed to operate. Continuous conduction mode (CCM) and discontinuous conduction mode (DCM) are the two different modes of operation in which a front-end converter is designed to operate. A voltage follower approach is one of the control techniques which is used for a PFC converter operating in the DCM. This voltage follower technique requires a single voltage sensor for controlling the dc-link voltage with a unity PF. Therefore, voltage follower control has an advantage over a current multiplier control of requiring a single voltage sensor. This makes the control of voltage follower a simple way to achieve PFC and dc-link voltage control, but at the cost of high stress on PFC converter switch. On the other hand, the current multiplier approach offers low stresses on the PFC switch, but requires three sensors for PFC and dc-link voltage control .Depending on the design parameters; either approach may force the converter to operate in the DCM or CCM. The DCM is preferred over other modes for having some added advantages like natural near-unity power factor, the power switches are turned ON at zero current, and the output diodes are turned OFF at zero current.

A PMBLDCM has developed torque proportional to its phase current and its back electromotive force (EMF), which is proportional to the speed. Therefore, a constant torque is maintained in its stator windings. VSI is used for electronic commutation based on the rotor position signals of the PMBLDC motor. The PMBLDCM drive is fed from a single phase ac supply through a diode bridge rectifier (DBR) followed by a capacitor at dc link. Due to an uncontrolled charging of the capacitor at dc link, draws a pulsed current. With a peak higher than the amplitude of the fundamental input current at ac mains. This results in poor power quality (PQ) at ac mains in terms of poor power factor (PF), high total harmonic distortion (THD) and high crest

factor (CF). Therefore, for PMBLDCMD a PF correction (PFC) converter among various available converter topologies is used. The Cuk dc–dc converter is used as a PFC Converter. The main advantages of using a Cuk dc–dc converter compared to other single switch converters are: continuous input and output currents, small output filter, wide output voltage range, almost near unity power factor with simple control and small size.

2. PROPOSED CONTROL SCHEME

Figure 1 shows the proposed speed control scheme is based on the control of the dc link voltage reference as a comparable to the reference speed. The rotor position signals established by Hall-effect sensors are used by an electronic commutator to generate switching sequence for the VSI which in turns feeds the PMBLDC motor. Therefore, rotor position is necessary only at the commutation point. The dc link voltage is controlled by Cuk dc-dc converter by making use of capacitive energy transfer which result is non-pulsating input and output currents.
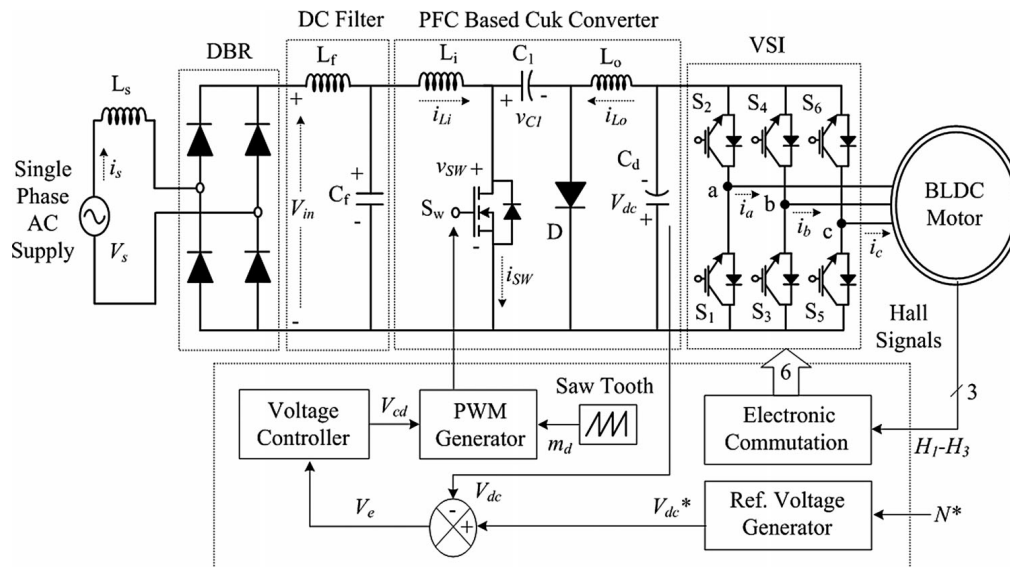

Figure 1: BLDC motor drive fed by a PFC Cuk converter

The suggested PFC converter is operated in high switching frequency for fast and effective control. It uses metal-dioxide semiconductor field effect transistor (MOSFET) for high-frequency operation. A current multiplier is used in PFC control scheme with a current control loop within the speed control loop for continuous-conduction-mode operation. By comparing sensed dc link voltage (V_{dc}) and a voltage (V_{dc}^*) equivalent to the reference speed, voltage error (V_r) is obtained, The control loop begins with the processing of voltage error (V_r), through a proportional (PID) controller to give the modulating control signal (I_c). The reference dc current ($I \times d$) is obtained multiplying signal (I_c) with a unit template of input ac voltage. It is then compared with the dc current (Id) sensed after the DBR. The resultant current error (I_e) is amplified and compared with a saw tooth carrier wave of fixed frequency (f_s) to generate the pulse width modulation (PWM) pulse for the Cuk converter. Its duty ratio (D) controls the dc link voltage at the desired value.

3. CONTROL OF CUK CONVERTER FED BLDC MOTOR DRIVE

The PFC converter and the sensor less BLDC motor drive are modelled for the proposed drive scheme. The control scheme of the PFC converter consists of following three blocks.

Reference Voltage Generator

The speed of BLDC motor is proportional to the DC link voltage of the VSI, hence a reference voltage generator is required to produces an equivalent voltage corresponding to the particular reference speed of the BLDC motor. The reference voltage generator produces a voltage by multiplying the speed with a constant value known as the voltage constant (K_b) of the BLDC motor.

Speed Controller

An error of the V_{dc}^* and V_{dc} is given to a PI (Proportional Integral) speed controller which generates a controlled output corresponding to the error signal. The error voltage V_e at any instant of time *k* is as;

$$V_e(k) = V_{dc}^*(k) - V_{dc}(k)$$

and the output $V_c(k)$ of the PI controller is given by,

$$V_c(k) = V_c(k-1) + K_p \cdot (V_e(k) - V_e(k-1)) + K_i \cdot V_e(k)$$

where, K_p is the proportional gain and K_i is the integral gain constant.

PWM Generator

The output of the PI controller V_c is given to the PWM generator which produces a PWM signal of fixed frequency and varying duty ratio. A saw tooth waveform is compared with the output of PI controller PWM is generated as;

If $m_d(t) < V_c(t)$ then S = 1 else S = 0

Where S denotes the switching signals as 1 and 0 for MOSFET to switch on and off respectively. L_2, and the diode, D, have been swapped so that the output polarity is the same as the input polarity.

4. MATLAB/SIMULINK MODELING AND SIMULATION RESULS

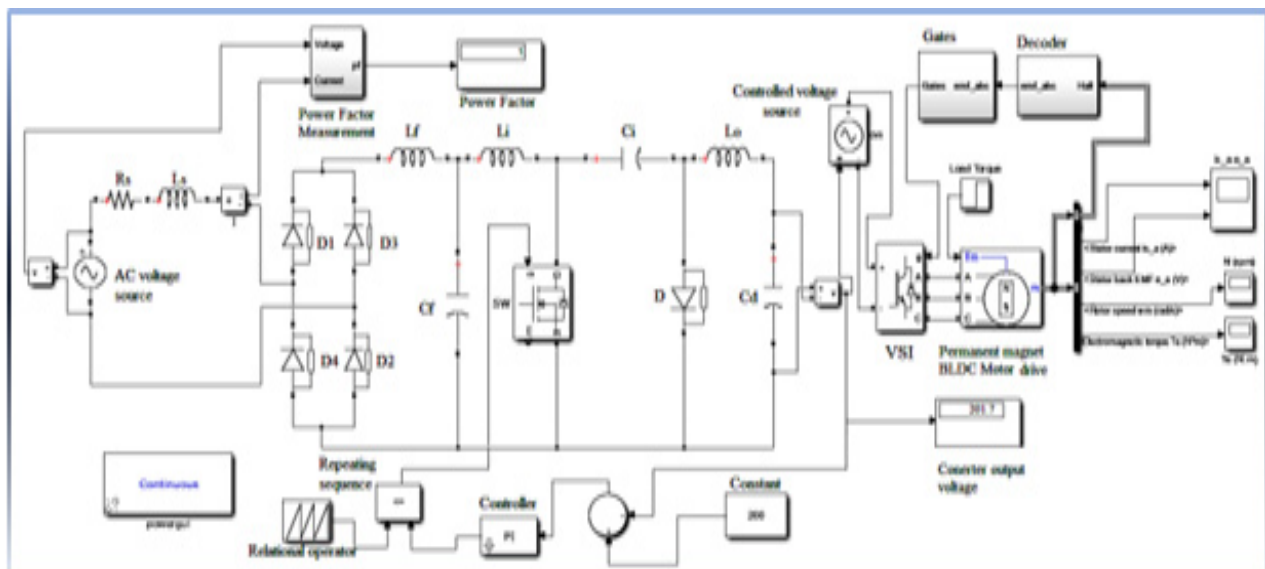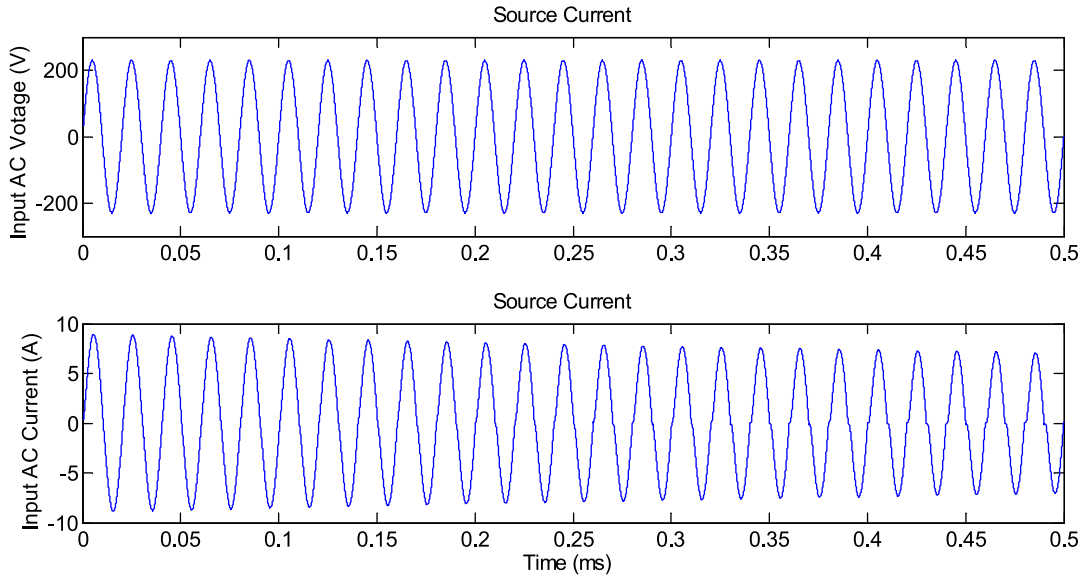The performance of the Cuk converter-fed BLDC motor drive is simulated in MATLAB/Simulink environment.

Figure 2: Simulink model of single phase PFC cuk converter fed BLDC motor

Source Current

Figure 3: waveforms of supply voltage and supply current

The simulated waveforms shows the input source voltage of 230V and by using the cuk converter topology the supply current becomes sinusoidal with reduced distortion. A sinusoidal supply current in phase with supply voltage is obtained, which shows a unity power factor with DC link voltage of 200V.

Converter output voltage
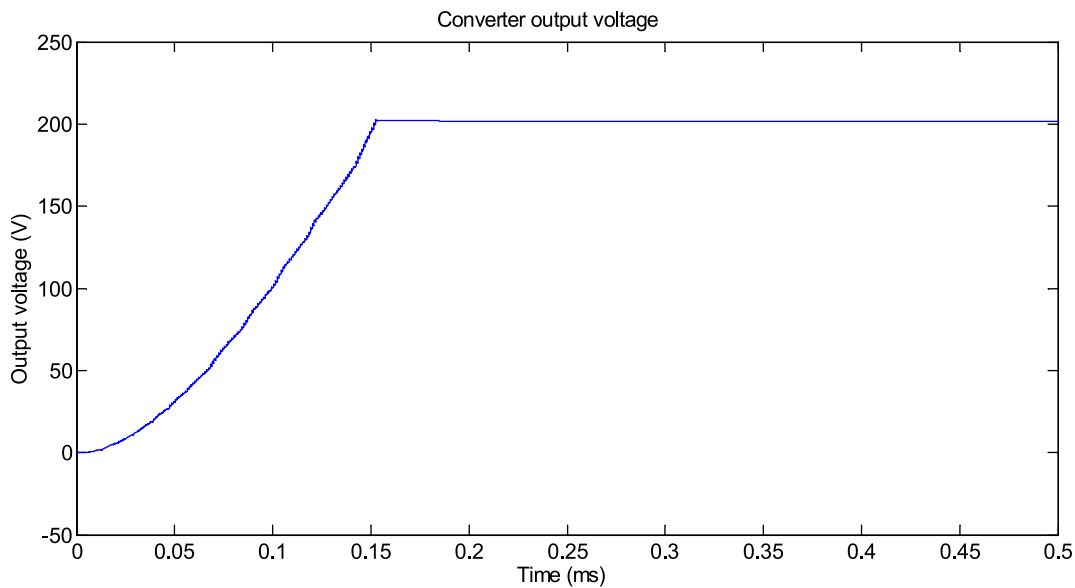
Figure 4: Waveform of DC-DC converter output voltage

The line voltages obtained from three phase VSI are $V_{ab} = 67.88V$, $V_{bc} = -133.9$ V, $V_{ac} = 201.7$ V. the stator current and back emf of cuk converter fed BLDC drive at 2000 RPM Under steady state condition the stator current is 0.428 A. Back emf is 97.53 V. Rotor speed is 2000 rpm and electromagnetic torque is 0.3 Nm. Each phase currents will be 120 degree shifted. The back EMF of BLDC motor is in trapezoidal in shape.
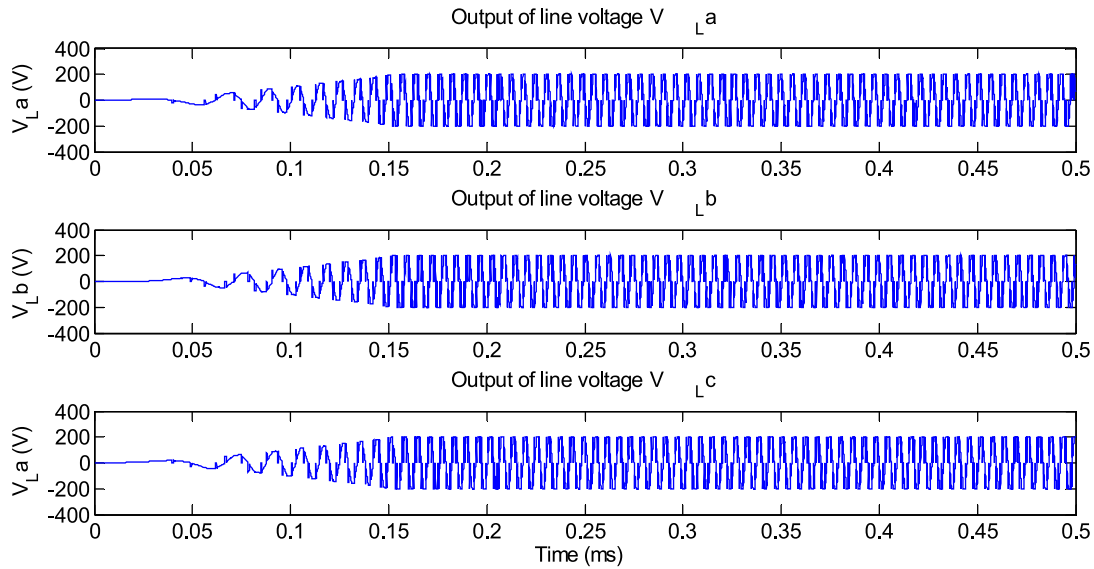
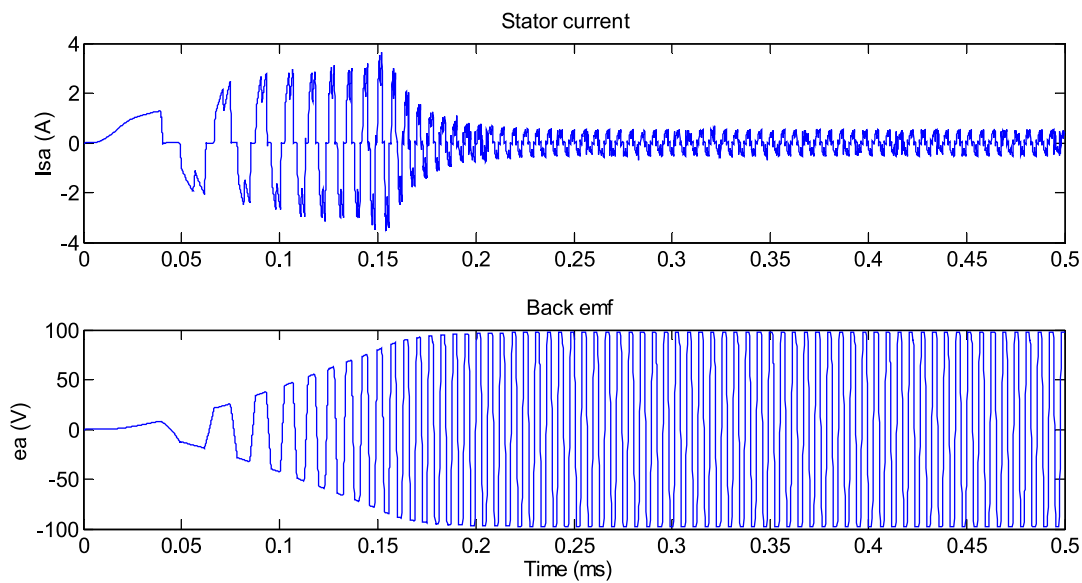**Figure 5: Waveforms of three phase Line voltages of VSI**

Figure 6: Waveforms of stator current and back emf of BLDC motor

5. CONCLUSION

A Cuk converter for VSI-fed BLDC motor drive has been designed for achieving a unity PF at ac mains for the development of the low-cost PFC motor for numerous low-power equipment's such fans, blowers, water pumps, etc. The speed of the BLDC motor has been controlled by varying the dc-link voltage of VSI, which allows the VSI to operate in the fundamental frequency switching mode for reduced switching losses. Discontinuous mode has been explored for the development ofthe BLDC motor drive with unity PF at ac mains. The power quality indices for the speed control and supply voltage variation have been obtained within the limits by International power quality standard IEC 61000-3-2.

REFERENCES

[1] Bist V and Singh B (2014). "An adjustable speed PFC bridgeless buck-boost converter fed BLDC motor drive," *IEEE Trans. Ind. Electron.*, Vol. 61, No. 6, pp. 2665–2677.

[2] Brekken T.K., et. al., (2010). "Machines and drives comparison for low-power renewable energy and oscillating applications," *IEEE Trans. Energy Convers.*, Vol. 25, No. 4, pp. 1162–1170.

[3] Chen Y, Chiu C, Jhang Y (2003). "A driver for the single phase brushless DC fan motor with hybrid winding structure," *IEEE Trans. Ind. Electron.*, Vol. 60, No. 10, pp. 4369–4375.

[4] Cui W, Gong Y, and Xu M.H. (2012). "A PMBLDC motor with bifilar winding for automotive engine cooling application," *IEEE Trans. Magn.*, Vol. 48, No. 11, pp. 3348–3351.

[5] Gieras J F and Wing M (2002). *Permanent Magnet Motor Technology—Design and Application*. New York, Inc.

[6] Gopalarathnam T and Toliyat H.A. (2003). "A new topology for unipolar brushless DC motor drive with high power factor," *IEEE Trans. Power Electron.*, Vol. 18, No. 6, pp. 1397–1404.

[7] Huang X, et. al., (2012). "A single sided matrix converter drive for a brushless DC motor in aerospace applications," *IEEE Trans. Ind. Electron.*, Vol. 59, No. 9, pp. 3542–3552.

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

[9] Nikam S, et. al., (2012). "A high torque density permanent magnet free motor for in-wheel electric vehicle application," *IEEE Trans. Ind. Appl.*, Vol. 48, No. 6, pp. 2287–2295.

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

[11] Milivojevic N, et. al., (2011). "Theory and implementation of a simple digital control strategy for brushless DC generators," *IEEE Trans. Power Electron.*, Vol. 26, No. 11, pp. 3345–3356.

[12] Mohan N, Undeland T.M, and W.P. Robbin (2009). *Power Electronics: Converters, Applications and Design*. New York, NY, USA: Wiley.

[13] Ozturk S.B. and H.A. Toliyat H.A. (2007). "Power factor correction of direct torque controlled brushless DC motor drive," in *Proc. 42nd IEEEIAS Annu. Meeting*, Sep. 23–27, pp. 297–304.

[14] Sokira T J and Jaffe W (1989). *Brushless DCMotors: Electronics Commutation and Controls*. Blue Ridge Summit, PA, USA: Tab Books.

[15] Singh B, Singh B Nand Chandra A (2003). "A review of single-phase improved power quality AC-DC converters," *IEEE Trans. Ind. Electron.*, Vol. 50, No. 5, pp. 962–981.

[16] Singh B and Chandra A (2011). "Comprehensive study of single-phase AC-DC power factor corrected converters with high frequency isolation," *IEEE Trans. Ind. Inf.*, Vol. 7, No. 4, pp. 540–556.

[17] Toliyat H A and Campbell S (2004). *DSP-Based Electromechanical Motion Control*. New York, NY, USA:CRC Press.

[18] Wu C.H. and Tzou Y.Y. (2009). "Digital control strategy for efficiency optimization of a BLDC motor driver with VOPFC," in *Proc. IEEE Energy Convers. Congr. Expo.*, Sep. 20–24, pp. 2528–2534.