ISSN: 2278 – 7798
International Journal of Science, Engineering and Technology Research (IJSETR)
Volume 5, Issue 8, August 2016

A Voltage-Controlled Switched Boost Inverter-Based PMBLDCM Drive for Air Conditioners

K Sabarinath [*], P RamaKrishna [**]

[*] Department of EEE, Amrita Sai Institute of Science & Technology, Paritala, Krishna Dt, A.P, India
[**] Department of EEE, Amrita Sai Institute of Science & Technology, Paritala, Krishna Dt, A.P, India

Abstract- This paper deals with a switched boost inverter as a single-stage power-factor-correction converter for a permanent magnet (PM) brushless dc motor (PMBLDCM) fed through a diode bridge rectifier from a single-phase ac mains. A three-phase voltage-source inverter is used as an electronic commutator to operate the PMBLDCM driving an air-conditioner compressor. The speed of the compressor is controlled to achieve optimum air-conditioning using a concept of the voltage control at dc link proportional to the desired speed of the PMBLDCM. The stator currents of the PMBLDCM during step change in the reference speed are controlled within the specified limits by an addition of a rate limiter in the reference dc link voltage. The proposed PMBLDCM drive (PMBLDCMD) is designed and modelled, and its performance is evaluated in Matlab–Simulink environment. Simulated results are presented to demonstrate an improved power quality at ac mains of the PMBLDCMD system in a wide range of speed and input ac voltage. Test results of a developed controller are also presented to validate the design and model of the drive.

Index Terms- DC-link voltage balance, PMBLDCM, power quality (PQ), Air conditioner (AC).

I. INTRODUCTION

Air-conditioners (Air-Cons) constitute a considerable amount of load in AC distribution system. However, most of the existing air-conditioners are not energy efficient and thereby, provide a scope for energy conservation. Air-Cons in domestic sector are usually driven by a single-phase induction motor; the temperature in the air conditioned zone is regulated over a hysteresis band through the ‘on/off’ control of the compressor motor. Therefore, the motor is operated only at full load (compressor ‘on’) at nearly constant speed, i.e., rated speed, [1] because these motors achieve maximum efficiency near the rated load only. The ‘on/off’ control provides inefficient temperature control with increased losses in the motor during frequent ‘on/off’ operation. Efforts to improve the efficiency of the existing air-con system using new mechanical and electronic system designs have resulted in marginal improvement in system efficiency; however, the variable speed operation of the air conditioner significantly improves system efficiency [2]. Moreover, the compressor driven by a motor with speed control delivers the desired cooling capacity and maintains the room temperature effectively and efficiently. Permanent magnet brushless DC motor (PMBLDCM) drives are being employed in many variable speed applications due to their high efficiency, silent operation, compact size, high reliability, ease of control, and low maintenance requirements. It is a good option for an air conditioner compressor. PMBLDCM is operated through a three-phase voltage source inverter (VSI), which is fed from single phase AC supply using a diode bridge rectifier (DBR), followed by a smoothening DC link capacitor. PMBLDCM is supplied by three-phase rectangular current blocks of 120° duration, in phase with the constant part of the back EMF waveform. These motors need rotor-position information only at the commutation points, e.g., every 60°electrical in the three-phase, requiring a simple controller for commutation [3-7].The PMBLDC motor is operated at a constant torque(i.e., rated torque) with speed control to improve energy efficiency [8]. In fact, the back-EMF of the PMBLDCM is proportional to the motor speed and the developed torque is proportional to its phase current [3-6]; therefore, a constant torque is maintained by a constant current in the stator winding of the PMBLDCM, whereas the speed can be controlled by varying the terminal voltage of the motor. A new speed control scheme that uses DC link voltage proportional to the desired speed of the PMBLDC motor is used in this work. VSI control is based on the rotor position signals and used only for electronic commutation of the PMBLDC motor.

The most commonly used topology for PMBLDCM Drive fed from single-phase AC mains uses a diode bridge rectifier (DBR) followed by a smoothening DC capacitor. It draws a pulsed current with a peak higher than the amplitude of the fundamental input current at ac mains due to an uncontrolled charging of the dc link capacitor. This results in poor power quality (PQ) at ac mains in terms of poor power factor (PF) of the order of 0.728, high total harmonic distortion (THD) of ac mains current at the value of 81.54%, and high crest factor (CF) of the order of 2.28 with 67% efficiency of the drive. Therefore, many Power Quality (PQ) problems arise at input AC mains including poor power factor, increased Total Harmonic Distortion (THD) and high Crest Factor (CF) of AC mains current etc. These PQ problems as addressed in IEC 61000-3-2especially in low power appliances become severe for the utility when many such drives are employed simultaneously at nearby locations[9].Therefore, PMBLDCM drives having inherent Power Factor Correction (PFC) become the preferred choice for the Air-Cons. The PFC converter draws sinusoidal current from AC mains in phase with its voltage.

II. PFC SWITCHED BOOST INVERTER FED PMBLDCMD

Fig. 1 shows voltage controlled PFC switched boost inverter fed permanent magnet brushless dc motor. The single phase AC mains supply is rectified into dc by the single phase bridge rectifier and rectified dc is controlled by switched boost inverter.

ISSN: 2278 – 7798
International Journal of Science, Engineering and Technology Research (IJSETR)
Volume 5, Issue 8, August 2016

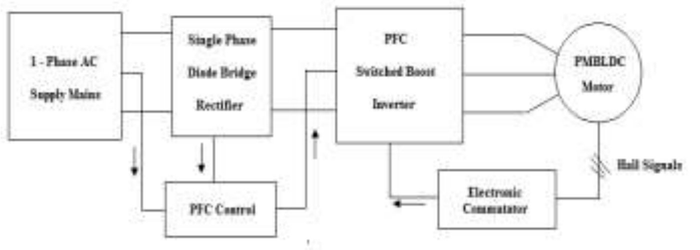


Fig 1. Schematic diagram of PFC Switched boost inverter fed PMBLDC Motor

A. Design of PFC Switched Boost Inverter

Switched boost converter (SBC) is able to buck or boost the input voltage in a single stage to get the desired output voltage. Fig.1 shows the schematic of a three phase SBI in which a switched boost network comprising of one active switch (S), two diodes (Da, Db), one inductor (L) and a capacitor (C) is connected between voltage source Vg and inverter bridge. Similar to ZSI, the SBI utilizes the shoot-through state of the H-bridge inverter (both switches in one leg of the inverter are turned on simultaneously) to boost the input voltage Vg to Vc. To explain the steady-state operation of the SBI, assume that the inverter is in shoot-through zero state for duration D.TS in a switching cycle TS. The switch S is also turned on during this interval. As shown in the equivalent circuit of Fig. 4(a), the inverter bridge is represented by a short circuit during this interval. The diodes Da and Db are reverse biased (as VC >Vg), and the capacitor C charges the inductor L through switch S and the inverter bridge. The inductor current in this interval equals the capacitor discharging current. For the remaining duration in the switching cycle (1 − D).TS, the inverter is in non-shoot through state, and the switch *S* is turned off. The inverter bridge is represented by a current source in this interval as shown in the equivalent circuit of Fig.4 (b).

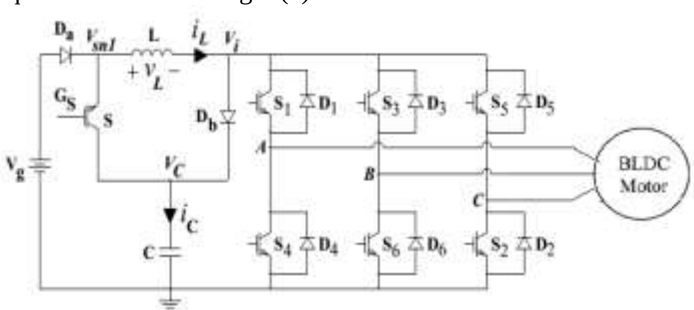
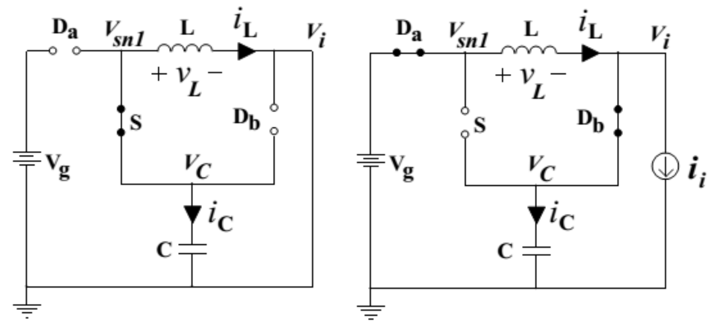


Fig 2. Circuit diagram of a three-phase Switched Boost Inverter.

Now, the voltage source Vg and inductor L together will supply power to the inverter and the capacitor through diodes Da and Db. The inductor current in this interval equals the capacitor charging current added to the inverter input current. Note that the inductor current is assumed to be sufficient enough for the continuous conduction of diodes Da and Db for the entire interval $(1 - D)T_S$.



(a) (b)

Fig.3. (a) Equivalent circuit diagram of SBI during the interval DTs (b) Equivalent circuit diagram of SBI during the interval (1 - D)Ts.

Under steady-state, the average voltage across the inductor and the average current through the capacitor in one switching cycle should be zero.

Using volt–second balance, we have

$$V_C D + (V_g - V_C)(1 - D) = 0$$

$$\frac{V_C}{V_g} = \frac{(1 - D)}{(1 - 2D)}$$

The average dc link voltage Vi can be calculated as

$$V_i = 0.D + V_C(1 - D)$$

The peak output AC line voltage is given by,

$$V_{om} = MV_C$$

$$V_{om} = \frac{(1-D)MV_g}{(1-2d)}$$

It is observed from equation (3) and (5) that VC can be boosted and V_{om} can be bucked or boosted based on the shoot-through duty ratio D and modulation index M.

B. Control Strategy for SBI fed PMBLDC Motor

The BLDC motor provides an attractive candidate for sensor less operation because the nature of its excitation inherently offers a low-cost way to extract rotor position information from motor terminal voltages. A Permanent Magnet brushless drive that does not require position sensors but only electrical measurements is called a sensor less drive [15]. For three-phase BLDC motor at one time instant, only two out of three phases are conducting current and the no conducting phase carries the back-EMF. If the zero crossing of the phase back EMF can be measured, we can know when to commutate the current. Sensing methods for the PMBLDC motors and generators are classified in two categories; direct and indirect back-EMF detection [15]. Direct back-EMF detection methods: the back- EMF of floating phase is sensed and its zero crossing is detected by comparing it with neutral point voltage. The methods can be classified as:

Direct back-EMF detection methods are

ISSN: 2278 – 7798
International Journal of Science, Engineering and Technology Research (IJSETR)
Volume 5, Issue 8, August 2016

- Back-EMF Zero Crossing Detection (ZCD) or Terminal Voltage Sensing and PWM strategies. [14]

Indirect back-EMF detection methods:

- Back-EMF Integration, Third Harmonic Voltage Integration and Free-wheeling Diode Conduction or Terminal Current Sensing [15].

Here position of the BLDC motor is obtained by employing zero crossing back emf detection method and thus eliminating position sensor requirement [8].

The PMBLDCMD consists of an electronic commutator, a SBI, and a PMBLDCM.

C. Mathematical Modelling of PMBLDC Motor Drive

The modelling of PMBLDCM drive involves modelling of the PFC converter and PMBLDCM drive. These components are modelled in the form of mathematical equations and the complete drive is represented as a combination of these models.

A. PFC Converter

The PFC converter consists of a DBR at front end and a buck or boost mechanism with Voltage source inverter. The PFC converter modelling consists of the modelling of a speed controller, a reference current generator, and a PWM controller as given below.

1) Speed Controller: The Speed Controller is a PI controller which closely monitors the speed error as an equivalent voltage error and generates control signal (Ic) to minimize the error. If at kth instant of time, V*dc(k) is reference DC link voltage, Vdc(k) is sensed dc link voltage then the voltage error Ve(k) is calculated as,

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

The output of the controller Ic(k) at kth instant is given as,

$$I_c(k) = I_c(k-1 + K_{pv}\{V_e(k) - V_e(k-1)\} + K_{iv}V_e(k)$$

Where, K_{pv} and K_{iv} are the proportional and integral gains of the voltage PI controller.

2) Reference Current Generator: The reference current at the input of the Cuk converter is,

$$i_d^* = I_c(k)u_d$$

where *ud* is the unit template of the ac mains voltage, calculated as,

$$u_d = {v_d}/{V_{sm}}\;; \qquad v_d = |V_s| \quad ; \qquad V_s = V_{sm}\sin \omega t$$

3) PWM Controller:

The reference input current of the Cuk converter (i*d) is compared with its current (id) sensed after DBR to generate the current error Δi. This current error is amplified by gain kd and compared with fixed frequency (fs) sawtooth carrier waveform md(t) to get the switching signal for the MOSFET of the Cuk converter as,

$$\begin{aligned} &if \qquad k_d\Delta i_d > md(t) \qquad then \qquad S = 1 \\ &if \qquad k_d\Delta i_d < md(t) \qquad then \qquad S = 0 \end{aligned}$$

where *S* denotes the switching of the MOSFET of the Cuk converter representing „ON" position with S=1 and its „OFF" position with S=0.

B. The PMBLDC Motor Drive

The PMBLDCM drive has an electronic commutator, a voltage source inverter and a PMBLDC motor as the main components.

1) Electronic Commutator:

The Electronic commutator uses signals from Hall-effect position sensors to generate the switching sequence for the VSI.

2) Voltage Source Inverter:

Fig.4 shows the PMBLDC Motor Drive system.

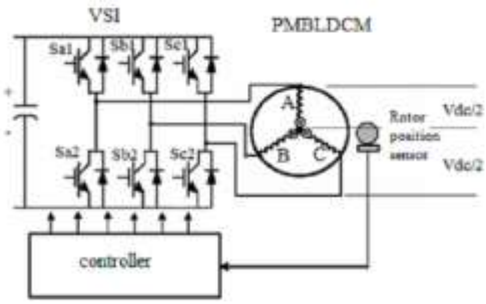


Fig.4 Brushless dc motor drive system

The output of VSI to be fed to phase „A" of the PMBLDC motor is given as,

$$\begin{aligned} &Vao = {V_{dc}}/{2} \qquad for \qquad Sa1 = 1 \\ &Vao = -{V_{dc}}/{2} \qquad for \qquad Sa2 = 1 \\ &Vao = 0 \qquad for \qquad Sa1 = Sa2 = 0 \\ &Van = Vao - Vno \end{aligned}$$

Where Vao, and Vno are voltages of phase A and neutral terminal with respect to virtual mid-point of the dc link. Using similar logic Vbo, Vco, Vbn, Vcn are generated for other two phases of the VSI feeding PMBLDC motor. The voltages Van, Vbn, and Vcn are voltages of three-phases with respect to the motor neutral terminal (n).

3) PMBLDC Motor:

The PMBLDCM is represented in the form of a set of differential equations given as,

$$V_a = i_a R_a + L\frac{di_a}{dt} + e_a$$

$$V_b = i_b R_b + L\frac{di_b}{dt} + e_b$$

$$V_c = i_c R_c + L\frac{di_c}{dt} + e_c$$

In these equations, ia, ib, and ic are currents, and ea, eb, and ec are the back EMFs of PMBLDCM, in respective phases; R is the resistance of motor windings/phase and L is the inductance. The developed torque Te in the PMBLDCM is given as,

$$T_e = \frac{\left(e_a i_a + e\, i_b + e_c i_c\right)}{\omega_r}$$

The mechanical torque equation of motion is given by,

$$T_e - T_l = \frac{P}{2}\left(Jp\omega_r + B\omega_r\right)$$

Where ω_r is the derivative of rotor position θ, *P* is the number of poles, T_l is the load torque in Newton meters, J is the moment of inertia in kilogram square meters, and B is the friction coefficient in Newton meter seconds per radian. The derivative of rotor position is given as,

$$p\theta = \omega_r$$

These equations represent the dynamic model of the PMBLDC motor.

III. SIMULATION RESULTS

The proposed PFC Switched boost inverter fed PMBLDC motor performance is studied in MATLAB/SIMULINK platform. The fig 5(a), (b) shows the simulated circuit of voltage controlled PFC Switched boost inverter fed PMBLDC drive system, control circuit for PFC converter. The switched boost inverter output line to line voltage and current, stator current and back EMF of motor, speed and torque of motor are presented .it is observed that the inverter output and currents are having the THD of 1.92%.the speed of the PMBLDC controlled by controlling dc bus voltage. The time delay of 0.1sec is allowed in the simulation to study the starting characteristics of the PMBLDC Motor.

Table: 1 Hall Signals

Hall Signals			Switching Signals					
H_a	H_b	H_c	S_{a1}	S_{a2}	S_{b1}	S_{b2}	S_{c1}	S_{c2}
0	0	0	0	0	0	0	0	0
0	0	1	0	0	0	1	1	0
0	1	0	0	1	1	0	0	0
0	1	1	0	1	0	0	1	0
1	0	0	1	0	0	0	0	1
1	0	1	1	0	0	1	0	0
1	1	0	0	0	1	0	0	1
1	1	1	0	0	0	0	0	0

A. Simulation circuit of Proposed PFC PMBLDCM Drive

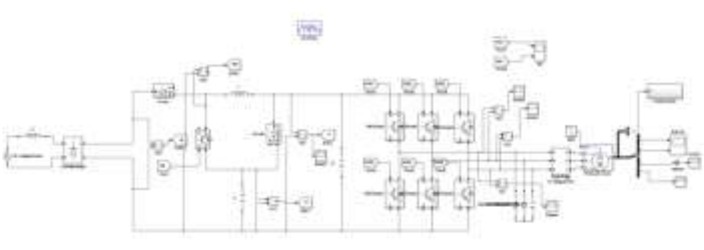


Fig 5(a)

B. Simulation Circuit of Control mechanism

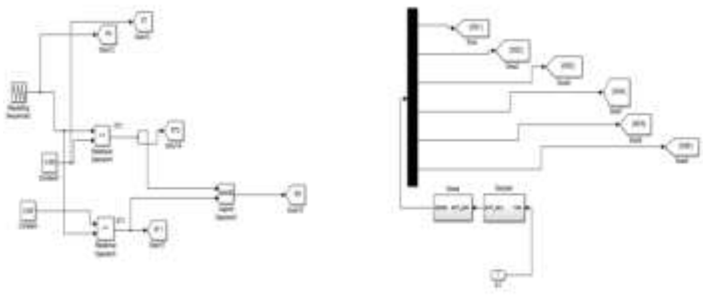


Fig 5(b)

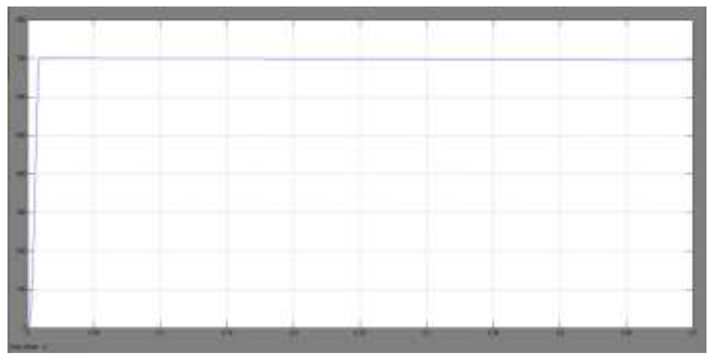


Fig 6 DC link Voltage

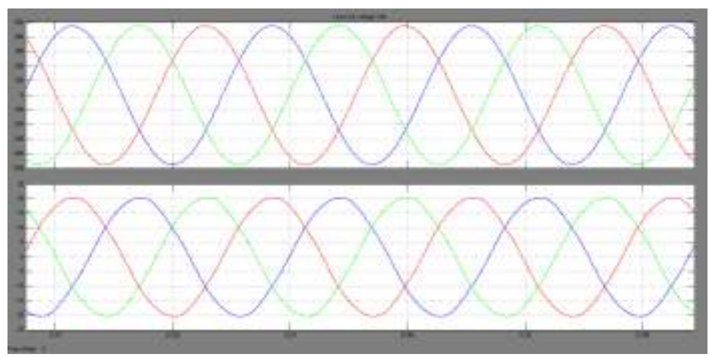


Fig 7 SBI output Voltages and currents

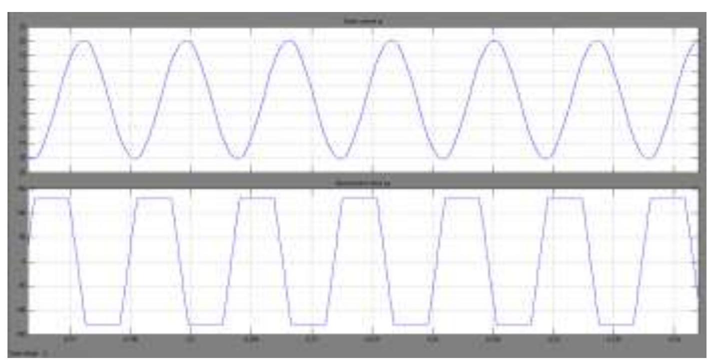


Fig 8 PMBLDC Motor Stator current and back emf

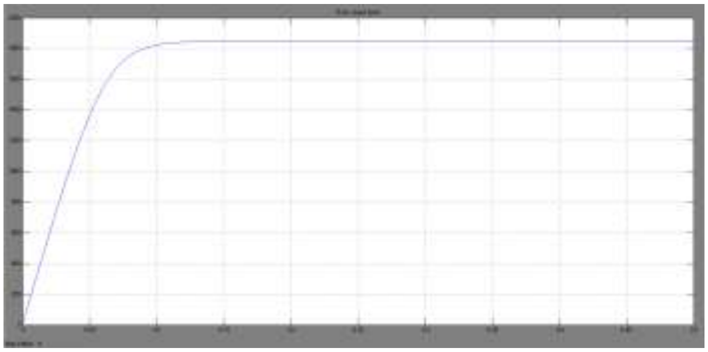


Fig 9. PMBLDC Motor Speed

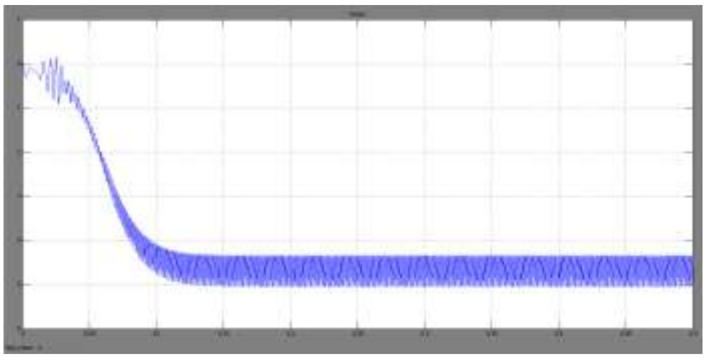


Fig 10. PMBLDC Motor Torque

IV. CONCLUSION

The permant magnet brush less DC Motor is suitable drive for compressor of air-conditioner. Since the characteristics of PMBLDC motor with power factor corrected switched boost inverter are better than the characteristics of the single phase motors used for air conditioners. These motors suffer from the power factor and harmonic currents but the proposed voltage controlled power factor corrected switched boost inverter fed PMBLDC motor has less harmonic distortion and high power factor.

REFERENCES

[1] Ravindranath Adda, Avinash Joshi, and Santanu Mishra, "Pulse Width Modulation of Three-Phase Switched Boost Inverter" 978-1-4799-0336-8/13/$31.00 ©2013 IEEE.

[2] S. Mishra, A. Ravindranath, and A. Joshi, "Switched-boost Inverter based on Inverse Watkins-Johnson Topology," in *Proc. 3rd IEEE Energy Conversion Congress and Exposition (ECCE),* Phoenix, 2011, pp. 4208–4211.

[3] Sanjeev Singh and Bhim Singh, "A Voltage-Controlled PFC Cuk Converter-Based PMBLDCM Drive for Air-Conditioners" IEEE Transactions on Industrial Applications, Vol: 48 No:2, March/April 2012.

[4] A. Ravindranath, S. Mishra, and A. Joshi, "A PWM control strategy for switched boost inverter," in *Proc. 3rd IEEE Energy Conversion Congress and Exposition (ECCE),* Phoenix, 2011, pp. 4208–4211.

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

[6] T. J. Sokira and W. Jaffe, *Brushless DC Motors: Electronic Commutation and Control*. New York: Tab, 1989.

[7] J. R. Hendershort and T. J. E. Miller, *Design of Brushless PermanentMagnet Motors*. Oxford, U.K.: Clarendon, 1994.

[8] J. F. Gieras and M. Wing, *Permanent Magnet Motor Technology—Design and Application*. New York: Marcel Dekker, 2002.

[9] B. Singh, B. N. Singh, A. Chandra, K. Al Haddad, A. Pandey, and D. P. Kothari, "A review of single-phase improved power quality ac–dc converters," *IEEE Trans. Ind. Electron.*, vol. 50, no. 5, pp. 962–981, Oct. 2003.

[10] N. Mohan, M. Undeland, and W. P. Robbins, *Power Electronics: Converters, Applications and Design*. Hoboken, NJ: Wiley, 1995.

[11] *Limits for Harmonic Current Emissions (Equipment Input Current ≤ 16 A Per Phase)*, Int. Std. IEC 61000-3-2, 2000.

[12] S. Cuk and R. D. Middlebrook, "Advances in switched-mode power conversion Part-I," *IEEE Trans. Ind. Electron.*, vol. IE-30, no. 1, pp. 10–19, Feb. 1983.

[13] C. J. Tseng and C. L. Chen, "A novel ZVT PWM Cuk power factor corrector," *IEEE Trans. Ind. Electron.*, vol. 46, no. 4, pp. 780–787, Aug. 1999.

[14] B. Singh and G. D. Chaturvedi, "Analysis, design and development of single switch Cuk ac–dc converter for low power battery charging application," in *Proc. IEEE PEDES*, 2006, pp. 1–6.

[15] C. L. Puttaswamy, B. Singh, and B. P. Singh, "Investigations on dynamic behavior of permanent magnet brushless dc motor drive," *Elect. Power Compon. Syst.*, vol. 23, no. 6, pp. 689–701, Nov. 1995.

[16] A. Ravindranath, S. Mishra, and A. Joshi, "Analysis and PWM Control of Switched Boost Inverter," Accepted for publication in *IEEE Trans. Ind. Electron.*, 2013.

[17] F. Z. Peng, "Z-source inverter," *IEEE Trans. Ind. Appl.*, vol. 39, no. 2, pp. 504–510, Mar./Apr. 2003.

[18] Y. Zhou, and W. Huang, "Single-stage boost inverter with coupled inductor," *IEEE Trans. Power Electron.*, vol. 27, no. 4, pp. 1066– 1070, Apr. 2012.

[19] S. Mishra, A. Ravindranath, and A. Joshi, "Inverse Watkins-Johnson topology based inverter," *IEEE Trans. Power Electron.*, vol. 27, no. 3, pp. 1066–1070, Mar. 2012.
.

AUTHORS

First Author – K.Sabarinath, he received his B.Tech degree in Electrical and Electronics Engineering from Gandhiji Institute of Science and Technology in 2013. He is currently pursuing M.Tech Power Electronics in Amrita Sai Institute of Science and Technology, Paritala, A.P, India. His interested research areas are Power Electronic Applications to ASDs.

Second Author – P Rama Krishna, he received his B.Tech degree in Electrical and Electronics Engineering from Nalanda Institute of Engineering and Technology, Sattenapalli (A.P), India, in 2012. M.Tech degree in Power Electronics from Mother Theresa Institute of Science and Technology, Sattupalli (Telangana), India, in 2014. He is currently working as a Assistant Professor in Amrita Sai Institute of Science and Technology, Paritala, A.P, India. His interested research areas are Power Electronics & Drives and Power System.