SVPWM Based BLDC Motor Drive Using Modified Zeta Converterfor Power Factor Correction

MUHAMMAD HAMID RAZA*, SYED ABDUL RAHMAN KASHIF*, MUHAMMAD AWAIS*, ALI AHMAD, NOOR-UL-AIN*, AND SALMAN FAKHAR***

* Department of Electrical Engineering, University of Engineering & Technology, Lahore, Pakistan.
** Department of Electrical Engineering, University of Central Punjab, Lahore, Pakistan.
Authors E-Mail: (hamidrazarana@hotmail.com, abdulrahman@uet.edu.pk, muhammadawais20@gmail.com, a.ahmad@ucp.edu.pk, noorulain0412@gmail.com, salmanfakhar.uet@gmail.com)

ABSTRACT

Electric motor is an essential part of any electric system. Control of a motor improves its dynamic performance. Exesting motors are mostly conventionally used AC (Alternating Current) and DC (Direct Current). BLDC (Brushless DC) motors are more efficient than conventional motors and wide range of speed control applications. Due to these features it attracts attention of industrial, commercial and domestic consumers. This study describes SVPWM controlled BLDC motor drive for the improvement of PF (Power Factor) using modified zeta converter. The design comprises of AC voltage source connected to a full BR (Bridge Rectifier) feeding DC supply to modified zeta converter whose output voltage is controlled through PWM (Pulse Width Modulation) technique. The zeta converter is modified into DICM (Discontinuous Inductor Current Mode) converter. The voltage follower control is engaged for voltage control of the modified zeta converter. The modified zeta converter improves PF upto 0.85 when controlled by PWM. The controlled output of modified zeta converter is served to a VSI (Voltage Source Inverter) which provides supply to a BLDC motor. The speed of BLDC is controlled through SVPWM (Space Vector Pulse Width Modulation) technique. The proposed scheme is designed and evaluated for improved speed control using MATLAB/Simulink platform.

Key Words: Diode Bridge Rectifier, Voltage Source Inverter, Brushless DC Motor, Discontinuous Inductor Current Mode, Pulse Width Modulation, Space Vector Pulse Width Modulation.

1. INTRODUCTION

Electric motor is an essential part of any industrial application. It is the integral part of power system. Recent researches indicated that BLDC is highly efficient machine [1-2]. It is known for its high torque to inertia ratio, reliability, robustness, speed bandwidth, less electromagnetic interferences and minimum maintenance cost [3-4]. It has compact rugged and versatile structure. It also gives substantial current savings. It is used in low power adjustable rpm (revolution per minuite) inverter fed AC drive for industrial and residential applications. For low power applications single phase induction motor and brushed DC motor are less efficient due to ohmic losses and high maintenance cost respectively. It has also proved itself to be a strong competitor to induction motor in servo applications. Its applications also lie in medical, aerospace, electric vehicles and water pumping [5-6]. For low power applications BLDC has higher efficiency and PF compared to induction motor. The major advantage of BLDC motor drive over brush type is that there is no limitation of maximum rpm and overcurrent because of mechanical commutation and brushes. As no brushes are required for BLDC, it shows no sparking. BLDC has a back emf of trapezoidal shape instead of sinusoidal as it is for PMSM. To produce constant torque in BLDC an alternating rectangular stator current is needed. It has a three phase winding on stator side while the rotor is permanent magnet. Due to this construction it has analogous torque - speed characteristics of a conventional DC motor .All industrial drives comprise of rectifiers and inverters. A diode bridge rectifier first converts an AC source into DC. Output of this rectifier is fed to an inverter while controlling the switching frequency of the inverter gives a controlled output voltage. The rectification process induces many power quality problems including low PF less than 0.8, and a significant harmonic distortion of the order of 80% because of increased harmonic contents in current and also a high value for crest factor of order of 3-5. Heating losses and voltage distortions are increased by these current harmonics circulating in power system. To avoid these losses number of arrangementsof different invertersare already been designed for power factor correction.

These converters are classified based on operation into two categories. One is CCM (Continuous Conduction Mode) which requires separate current and voltage control loops to maintain the output voltage. CCM has complex control consisting three sensors but exerts less stress on semiconductor switches of converter used for PFC (Power Factor Correction). Second mode of operation is DCM (Discontinuous Conduction Mode). This requires only one unity feedback control loop with only one voltage sensor. Its control is simple but it has higher stress on switches [7].

SVPWM based speed control is considered as having lower switching losses, lower torque ripple and harmonic distortion in current. The pulses are generated on the bases of reference voltage vector rotating in space divided into six sectors as shown in Fig. 1 [8].

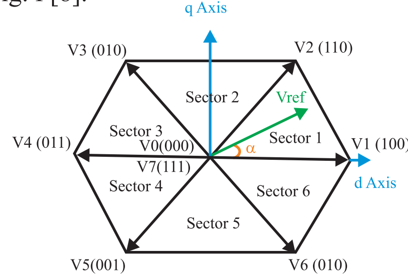

FIG. 1. SVPWM SWITCHING SECTORS

The literature survey provides numerous arrangements designed for PF improvement. Boost power factor correction AC-DC converter is the most commonly used arrangement. It has constant DC voltage across VSI and SVPWM pulses are used for rpm control. Its switching frequency is very high which leads to high switching losses.

A four switch arrangement instead for six switches for VSI is also proposed [9]. Although it has less cost but still its switching is PWM based which demands high switching frequency and results in large amount of switching losses. Cheng [10], silicon controlled rectifier is feeding DC supply to VSI for BLDC motor. It has a very complex control consisting of many sensors which makes the design costly.The speed control of BLDC motor using variable DC voltage is proposed [11]. PFC based front end cuk converter utilizes CCM including three sensor based complex arrangement [12]. It is mostly applicable for high power system. For PF pre-regulation a zeta converter is also suggested in the literature [13]. It is highly recommended for small power and cheaper power system applications. CCM consists ofdouble control loops and three sensors, making it complex, is used. Zeta configuration is very attractive as it can boost and buck the voltage level on the same time. It has certainly isolated form of structure. A generalized canonical switching cell based DC-DC converter is proposed [14]. A modified zeta converter for PF improvement and its demonstration for designing of SVPWM based BLDC motor drive is explored.

2. SVPWM CONTROLLED BLDC MOTOR DRIVE USING MODIFIED ZETA CONVERTER

The proposed design of SVPWM based modified zeta converter controlled for BLDC motor drive for PFC is given in Fig. 2. Fig. 3 shows VSI controlled BLDC motor circuit arrangement. SVPWM switching based VSI is arranged for speed control of BLDC motor. This control contains a distinctive speed sensor which compares the reference voltage of speed controller. Based on the reference output voltage of the speed controller, SVPWM generator produces pulse for switching of VSI. By controlling VSI pulses, the current supplied to BLDC motor is controlled which results in speed control. The modified zeta converter is organised to work in DICM. PWM based control is used to maintain the constant output voltage of modified zeta converter. The simple voltage follower control is utilized consisting of only one single voltage sensor. This arrangement perform both PFC and control of DC voltage. To verifiy the proposed arrangement, the concept is modelled in the sphere of MATLAB/Simulink. The MATLAB simulation findings prove robust control for wide speed bandwidth and improved power quality.

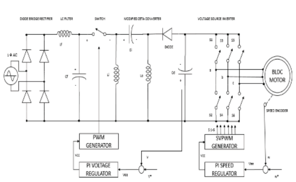

FIG. 2. MODIFIED ZETA CONVERTER BASED SVPWM CONTROLLED BLDC MOTOR DRIVING CIRCUIT

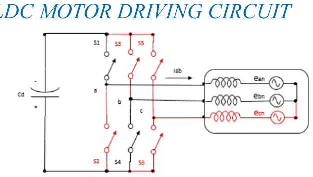

FIG. 3. VSI CIRCUIT ARRANGEMENT FOR BLDC MOTOR

3. FUNCTIONING OF MODIFIED ZETA CONVERTER

The modified Zeta converter is configured to function in DICM. Fig. 4(a-d) represents the functioning of modified Zeta Converter and Fig. 5 represents waveforms regarding all four mode of operations

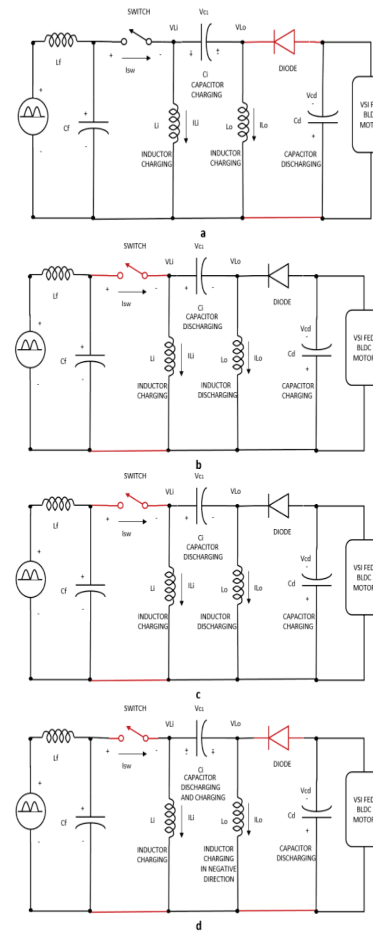

FIG. 4(a-d). MODIFIED ZETA CONVERTER OPERATING MODES

3.1 Mode-A

Fig. 4(a) shows mode A which shows that after turning the switch on, charge starts building up across connected middle capacitor, input inductor (Li) and output inductor (Lo) start charging. The voltage across middle capacitor rises. Initially the capacitor was negatively charged and when voltage rises enough it reverses its polarity and starts charging in positive direction. The currents starts increasing in both input and output inductors in this mode. During this mode the diode is reverse biased forcing DC capacitor to discharge through load attached. Therefore, during this interval, voltage of DC capacitor decreases. This mode lasts for 15%-20% of the switching period. It depends on duty cycle of the pulse generator.

3.2 Mode-B

Fig. 4(b) shows the Mode-B operation for modified zeta converter. This mode starts from the off state of switch. During that mode voltage of middle capacitor decreases while discharging viamiddle capacitor, which causes in increasing current of inductor connected at input. Thus current of inductor connected at output also decreases. DC capacitor is charging and diode is forward biased in this working mode, which results in rise of the DC capacitor voltage. The diode current equals algebraic sum of both output and input inductor currents. This mode stops when DC capacitor voltage and voltage across middle capacitor becomes equal.

3.3 Mode-C

This mode starts when voltage across the DC capacitor becomes bigger than the middle capacitor voltage. In this case, DC capacitor is charged by inductor connected at inpout and output both and the middle capacitor. Therefore, currentof inductor connected at input continues to rise up and through output inductor decreases down. This mode ends, as current of output inductor becomes minimum (zero) showing complete discharge of output inductor. 20-30% of the total switching time is required for Mode-B and Mode-C.

3.4 Mode-D

For proper operation of modified Zeta converter in discontinuous inductor current mode, the amount of inductance of inductorconnected at output is set very small than the inductor connected at input. This will discharge the output inductor completely in given switching duration. The current passing through inductor connected at input continue to grow till voltage across middle capacitor reduces to zero. Then input inductor discharges and starts charging middle capacitor in reverse direction. The diode is reverse biased here as a consequence load is supplied by DC capacitor resulting decrease in output voltages.

The wave forms of all the four operating modes; A, B, C and D are shown in Fig. 5. Fig. 5 clearly show the voltages and currents of each and every component of the circuit shown in Fig. 4(a-d).

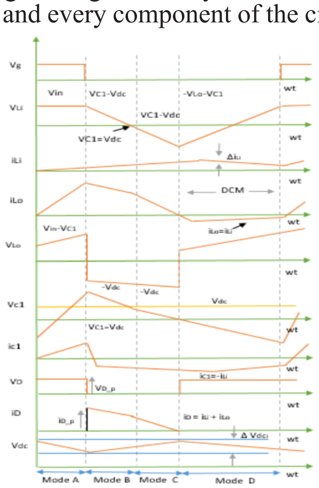

FIG. 5. WAVEFORMS OF MODIFIED ZETA CONVERTER

4. CONTROL OF BLDC MOTOR DRIVE BASED ON MODIFIED ZETA CONVERTER

The claimed BLDC motor drive includes modified zeta converter's output voltage control for PFC and for rpm control of BLDC motoris based on switching control of VSI.

4.1 Voltage Follower Control of Modified Zeta Converter

PWM pulses are used to control the modified Zeta converter for PF. The error signal is computed as:

$$V\_e(t)=V^{*}(t)-V(t)$$

where t is respective sampling time.

This error signal is supplied to PI (Proportional-Integral) controller. PI controller produces a controlled output signal to control voltage as follows:

$$V\_cc(t)=[[V]\_cc(t-1)+kp\{V\_e(t)-V\_e(t-1)\}+ki\,V\_e(t)]$$

Where in this equation kp is the proportional gain and ki is the integral gain of PI controller. This control signal is compared with saw tooth signal of PWM generator

$$\text{if } m\_d(t) < V\_cc(t) \text{ then } S\_sw=ON$$
$$\text{if } m\_d(t) \geq V\_cc(t) \text{ then } S\_sw=OFF$$

Where Ssw represents switching pulses used for switching of modified Zeta converter for PFC.

4.2 BLDC Motor Speed Control

SVPWM pulses are provided to VSI for rpm control of BLDC motor drive. The set rpm is compared with real speed of the motor which provides error signal. A PI controller acts as a speed controller. Proportional controller meets the settling time requirement whereas integral controller minimize the steady state error. Based on that error signal, the speed controller produces a controlled signal. This controlled signal perform as a reference voltage for the SVPWM generation. SVPWM generate pulses according to that reference voltage. Six pulses are generated by SVPWM which are fed to respective six switches of VSI. Fine speen control of BLDC motor is achieved by controlling stator current of motortrough appropriate switching of VSI.

5. SIMULATION RESULTS

MATLAB/Simulink platform is used to check the performance of recommended BLDC motor drive. Fig. 6 shows various voltage parameters including input voltage (Vac), voltage across full bridge rectifier (Vbr), voltage across middle capacitor (VC1),voltage across output inductor (VLo), voltage across input inductor (VLi), DC voltage (VCdc) and phase voltage (Vph).

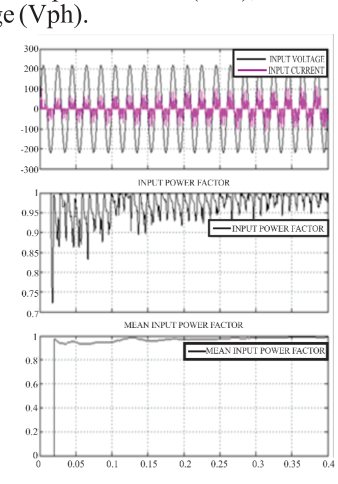

FIG. 6. INPUT SUPPLY WAVEFORM AND POWER FACTOR

Fig. 7 shows waveforms of voltage, input currents and PF. The input PF is unity. Fig. 8 explains the execution of recommended BLDC motor drive showing stator current (is), actual and reference value of rotor rpm (w), output PF and electromagnetic torque (Te). The PF is improved upto 0.85. Fig. 9 shows simulation diagram of proposed drive. The simulation results shows working of recommended BLDC motor drive with better power quality and rpm control.

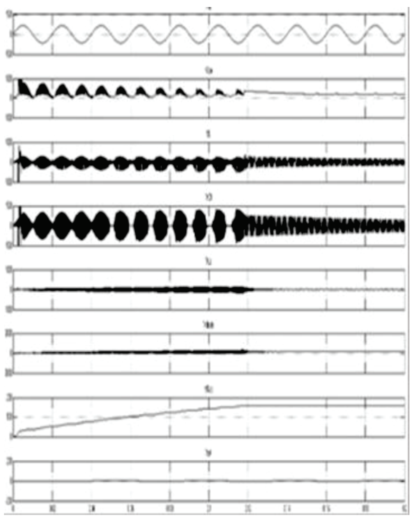

FIG. 7. VOLTAGE WAVEFORMS OF PROPOSED BLDC MOTOR DRIVE

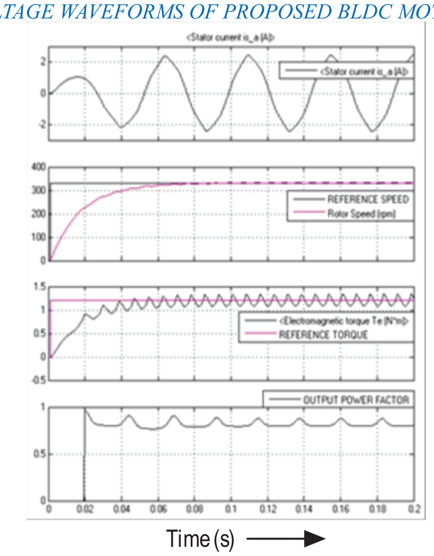

FIG. 8. EXECUTION OF RECOMMENDED BLDC MOTOR DRIVE

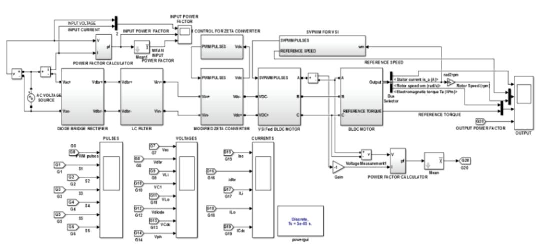

FIG. 9. SIMULATION OF RECOMMENDED BLDC MOTOR DRIVE

6. CONCLUSION

A SVPWM controlled BLDC motor drive is recommended by modified zeta converter that offers PF correction to the system. The recommended BLDC motor drive is devised to provide SVPWM based rpm control for broad span. The rpm is controlled by adjusting the switching of SVPWM generator in a closed loop control. The pulses are provided to VSI which feed current to stator of BLDC motor. The modified Zeta converter is constructed to provide PF correction which grants better power quality. The constructed modified Zeta converter is used in DICM mode of operation providing single closed loop control of voltage. The suggested modified design of Zeta converter operates as a PF pre-regulator. The suggested drive appears to be appropriate contender for low power appliances.

ACKNOWLEDGEMENT

This research was supported by University of Engineering & Technology, Lahore, and University of Central Punjab, Lahore, Pakistan, for providing facilities to conduct this research paper.

REFERENCES

[1] Miyamasu, M., and Akatsu, K., “Efficiency Comparison between Brushless DC Motor and Brushless AC Motor Considering Driving Method and Machine Design”, EEJ Journal of Industry Application, Volume 2, No. 1, pp. 79-86, [DOI: 10.1541/ieejjia.2.79], 2013.

[2] Lee, Y., and Kim, J., “Analysis of the Three-Phase Inverter Power Efficiency of a BLDC Motor Drive Using Conventional Six-Step and Inverted Pulsewidth Modulation Driving Schemes”, Canadian Journal of Electrical and Computer Engineering, Volume 42, No. 1, pp. 34–40, [DOI: 10.1109/CJECE.2018.2885351], 2019.

[3] Singh, B., and Bist, V., “Reduced Sensor Configuration of Brushless DC Motor Drive Using a Power Factor Correction-Based Modified-Zeta Converter”, IET Power Electronics, Volume 7, No. 9, pp. 2322-2335, [DOI: 10.1049/iet-pel.2013.0177], September, 2014.

[4] Xia, C.-L., "Permanent Magnet Brushless DC Motor Drives and Controls", John Wiley & Sons, Singapore, 2012.

[5] Milivojevic, N., Krishnamurthy, M., Gurkaynak, Y., Sathyan, A., Lee, Y.-J., and Emadi, A., “Stability Analysis of FPGA-Based Control of Brushless DC Motors and Generators Using Digital PWM Technique”, IEEE Transactions on Industrial Electronics, Volume 59, No. 1, pp. 343–351, [DOI: 10.1109/TIE.2011.2146220], January, 2012.

[6] Kumar, R., and Singh, B., “Grid Interactive Solar PV-Based Water Pumping Using BLDC Motor Drive”, IEEE Transactions on Industry Applications, Volume 55, No. 5, pp. 5153–5165, [DOI: 10.1109/TIA.2019.2928286], 2019.

[7] Singh, B., Singh, S., Chandra, A., and Al-Haddad, K., “Comprehensive Study of Single-Phase AC-DC Power Factor Corrected Converters With High-Frequency Isolation”, IEEE Transactions on Industrial Informatics, Volume 7, No. 4, pp. 540–556, [DOI: 10.1109/TII.2011.2166798], November, 2011.

[8] Nguyen, T.H., Chan, P.K.W., Shrivastava, Y., and Hui, S.Y.R., “A Three-Dimensional Space Vector Modulation Scheme for Three-Level Three-Wired Neutral Point Clamped Converters”, IEEE 36th Conference on Power Electronics Specialists, pp. 2307–2314, [DIO: 10.1109/PESC.2005.1581954], 2005.

[9] Madani, S.M., Hao, L., and Toliyat, H.A., “A Low-Cost Four-Switch BLDC Motor Drive with Active Power Factor Correction”, IEEE 28th Annual Conference of the Industrial Electronics Society, Volume 1, pp. 579–584, [DOI: 10.1109/IECON.2002.1187572], 2002.

[10] Cheng, L., “DSP-Based Variable Speed Motor Drive with Power Factor Correction and Current Harmonics Compensation”, 35th Intersociety Energy Conversion Engineering Conference and Exhibit Collection of Technical Papers, Volume 2, pp. 1394-1399, [DOI: 10.1109/IECEC.2000.870956], 2000.

[11] Gopalarathnam, T., and Toliyat, H.A., “A New Topology for Unipolar Brushless DC Motor Drive with High Power Factor”, IEEE Transactions on Power Electron, Volume 18, No. 6, pp. 1397-1404, [DOI: 10.1109/TPEL.2003.818873], November, 2003.

[12] Singh, S., and Singh, B., “A Voltage-Controlled PFC Cuk Converter-Based PMBLDCM Drive for Air-Conditioners”, IEEE Transactions on Industry Applications, Volume 48, No. 2, pp. 832-838, [DOI: 10.1109/TIA.2011.2182329], March, 2012.

[13] Singh, S., and Singh, B., “Voltage Controlled PFC Zeta Converter Based PMBLDCM Drive for an Air-Conditioner”, 5th International Conference on Computer Science, pp. 550–555, 2010.

[14] Williams, B.W., “Generation and Analysis of Canonical Switching Cell DC-to-DC Converters”, IEEE Transactions on Industrial Electronics, Volume 61, No. 1, pp. 329-346, [DOI: 10.1109/TIE.2013.2240633], January, 2014.