

A Review On - PMBLDC Motor Drive with Power Factor correction Controller

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Abstract - The review on the different developments in power factor correction techniques of BLDC motor is done in this paper. The different techniques like SEPIC converter, Isolated-Zeta converter, Boost converter, four quadrant operation of BLDC motor, Landsman converter, BL-CSC converter are discussed. For choosing the proper converter for BLDC motor drive for power factor correction the corresponding simulation results for the converters operating in particular mode of operation are observed for various speeds. The comparison of the results like percentage THD and power factor for these methods is compared.

Key Words: BLDC motor, PFC controller, THD

1. INTRODUCTION

In various industries such as medical, automotive, appliances, aerospace, etc. the BLDC motors are used due to their high efficiency, compact size, noiseless operation, low maintenance, high power density, etc. There are no commutators in BLDC motors hence the external means for commutation is needed. Therefore the BLDC motor is powered from a single phase supply through a diode bridge rectifier and three phase voltage source inverter. The Hall effect sensors are used for sensing the position of the rotor which are placed at 120° electrical degrees for three phase motor. According to this rotor position the switches are controlled using PI controller. There are six states of 60° rotation in electrical cycles and for each state, one of the Hall effect sensor shifts its state. In each state, out of three terminals two are connected to positive and negative terminal and one is left as a floating terminal.

Due to distortion in supply current drawn by the diode bridge rectifier, the percentage THD is high and hence the power factor is poor which is not acceptable. So a controller is needed to improve the THD and power factor. There are different topologies like SEPIC converter, Boost converter, Bridgeless converter, etc. these methods are discussed here.

The various considerations also has to be taken into account while choosing the correct PFC converter for the system such as cost, mode of operation etc. The cost of the sensors such as Hall effect sensors increases the overall cost of the drive which again depends on the mode of the PFC converter. The PFC converters which operates in continuous conduction mode of operation requires more number of sensors for sensing supply voltage, supply current and dc link voltage whereas those which operate in discontinuous mode of operation requires only one sensor for dc link voltage. But the stress on the switches in CCM is less than that in DCM. So DCM mode of operation can be used in low power application only. This paper presents different PFC techniques to improve the power factor and hence the power quality.

The control algorithms of BLDC motor are become advanced which make them suitable for applications where precision is important such as position control in machine tools, robotics, high precision servos etc. Due to its features like high power density, reduced volume, high torque, easy control, simple hardware and software and low maintenance BLDC motors can be used in EVs/HEVs also.

2. RECENT DEVELOPMENTS IN BLDC MOTOR DRIVES

2.1 Sensor-less BLDC control

Ganesh M. Kachare & Juber A. Shaikh [1] says overall cost of the drive is increased due to the Hall sensors and they cannot withstand the temperature variation. Due to increased hardware they also decrease the reliability of the system. To determine the voltage regulation without the Hall sensor various methods have been introduced. In this concept a bridgeless configuration of buck boost converter using Fuzzy logic controller is proposed which offers the elimination of diode bridge rectifier and resulting in conduction losses associated with it. The back EMF is used in fuzzy logic proposed system to determine the rotor position. Stability also increases due to this system. This system is applicable for low power BLDC motor.

2.2 Bridgeless Dual Buck-Boost Converter Fed BLDC Motor Drive

Mr. Sreekumar M B, Ms. Divya Sivan[2] presents different topologies for feeding the BLDC motor drives using various converter. In this a bridgeless configuration of buck boost converter is proposing. This converter offers good power quality at the AC mains with a filter performing the power factor correction. By electronic commutation of the inverter switches the speed control of the motor drive is performed.

For reducing the switching stress the converter is operating in discontinuous inductor current mode. To improve the power quality an L filter is used at the input. A dual buck boost converter used in both positive and negative cycle in which, one is operating at positive half cycle and the other operating during the negative half cycle. To provide alternating stator current to the motor drive a voltage source inverter is used. By the voltage feedback control of the converter along with the filter operation the power factor correction is done.

2.3 Isolated Zeta Converter

The power factor correction for BLDC motor achieved by using Isolated-Zeta converter and can be used only for low power applications. For electronic commutation of BLDC motor, voltage source inverter (VSI) is used which is operated in low frequency switching in order to reduce the switching losses. The drive is proposed for wide speed control range to achieve a unity power factor. Vashist Bist and Bhim Singh[3] presents that by varying the dc link voltage of VSI, speed can be controlled which reduces the switching losses. Also the current sensors required for PWM based current control can be eliminated. Isolated Zeta converter which is used as power factor corrector is designed to operate in DCM which has advantage over CCM that it requires single voltage sensor for control of dc link voltage, but the converter switches are subjected to high stress. The duty ratio of PWM pulses of isolated Zeta converter switch is changed to control the dc link voltage of VSI. BLDC motor drive is feed through a three phase VSI using the combination of diode bridge rectifier and PFC converter. The control of isolated -Zeta converter is achieved by using voltage follower approach which consist of reference voltage generator, voltage error generator, voltage controller and PWM generator. The rate of change of duty ratio of PWM pulses is limited by rate limiter and given to PFC converter switch. A Hall effect sensor is used for rotor position sensing.

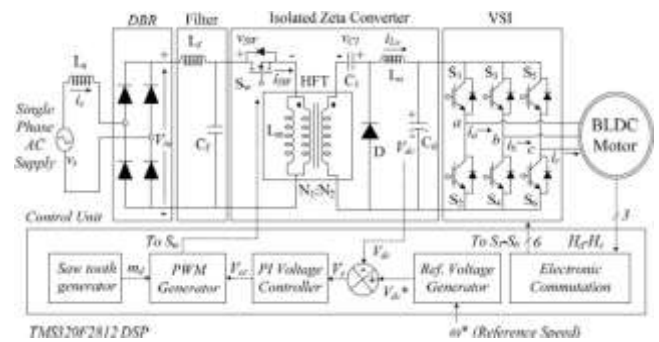


Fig-1: Simulation Model [3]

Table -1: Speed of BLDC Motor with Changing DC Link Voltage [3]

Sr. No.	Ref.DC Link Voltage(Vdc) (v)	Voltage at ADC of DSP (Vdc) (v)	Speed of BLDC Motor (w) (rpm)
1.	50	0.428	530
2.	60	0.514	660
3.	70	0.6	780
4.	80	0.686	890
5.	90	0.771	1000
6.	100	0.857	1110
7.	110	0.943	1220
8.	120	1.028	1330
9.	130	1.114	1400

2.4 Landsman Converter

Banu S, Geetha V, Samadharmi U, Indumathy M[4] says BLDC motor is highly reliable electrical drive if we use it for power factor correction. This motor is fed by voltage source with DC-DC converter. The PID logic controller is used as intelligent controller for BLDC motor. In this method low cost arrangement is used from this we can get reliable operation, speed regulation and we can achieve unity power factor. By using designed PFC converter improve the power quality at AC supply so it gives wide range of speed control. The commutator which is electronic commutator fed by VSI for PMBLDCM. The efficiency of the single phase IM is in between 70-80%. In regular on-off control for temperature control is not energy efficient and have many disturbances in distribution system. So it can increases the wear and tear and reducing the power factor. By using the PMBLDC for drive gives results in improvement of energy efficiency. In this for power factor improvement landsman converter is used.

It gives smooth start up for the air conditioning system. Avoiding any disturbances in input Ac supply voltage from this method gets the study and smooth speed control. It also gives the low harmonics and higher efficiency due to continuous switching. This motor is used in aerospace,

aircraft and mining applications. For speed control NFSS is used and landsman converter is used for power factor improvement. It provide the better power quality.

2.5 Direct Torque Controlled Brushless DC Motor Drive

Salih Baris Ozturk, Oh Yang, Hamid A. Toliyat[5] presents the different methods for correction of power factor of direct torque controlled BLDC motor. The quasi square wave current is obtained by selecting the inverter voltage space vectors properly from a simple look up table which helps to achieve faster torque response. There is a control algorithm for controlling the duty ratio of the boost converter. Boost PFC with average current control is used. Digital controllers have advantages over conventional analog controllers such as have high reliability, better performance, less number of components for control. At every sampling period, the instantaneous analog signals are sensed and using the ADC channels these signals are fed back to the DSP. For simplification of the calculations per unit system is used. With constant amplitude and increasing rotational speed of the stator flux linkage, the torque can be changed which allows fast torque response. The low ripple torque control can be achieved by mounting three Hall Effect sensors on stator at 120° electrical degree apart. The look up table with precision can be created by using the values of $\alpha\beta$ -axes motor back EMFs vs. electrical position so as to obtain a good torque estimation and accurate $\alpha\beta$ -axes back EMF values. Under no-load and at steady state the THD is 5.45% and 3.45% for input line current and voltage respectively and power factor is 0.9997. For the load of 0.371 Nm THD is 5.05% and 3.43% for input line current and voltage respectively.

2.6 Four Quadrant Operation And Active Power Factor Correction

Dhaneesh Krishnan, Samskriti, Dr. K. P. Vittal[6] proposes the study of four quadrant operation and active power factor correction of BLDC motor is done using the simulation in MATLAB/Simulink. The review of different developments in the BLDC motor drive such as sensor less control, fuzzy logic control and direct torque control is also given. If the direction of the current is within the motor, then the modes are forward motoring and reverse braking modes whereas it is forward braking and reverse motoring mode if the direction of the current is opposite. The braking torque is experienced by the current caused by the back EMF is flowing from motor to resistive load. So by changing the resistor value, braking time can be changed. The sign change of reference speed is continuously monitored by the controller which is basically a PI controller. The trial and error method is generally used for tuning of PI controller. The boost converter topology is used for the active power factor correction operating in CCM mode. There are two controllers' viz. voltage controller and current controller. Both these controllers are also PI

controllers. The duty ratio is determined by PI controllers. With increase in load, the power factor is improved.

2.7 A BL-CSC Converter

Bridgeless canonical switching cell converter by using power factor correction method to drive BLDC motor. In this to achieve a unity power factor, BL-CSC converter operates at a discontinuous inductor current mode by using single voltage sensor. L. Pattathurani, Rajat Kumar Dwibedi, Dr. P. Sivachidambaranathan [7] presents In this speed of BLDC motor controlled by varying Dc bus voltage through PFC converter which is fed by VSI to the BLDC motor. In the BLDC motor by using electronically commutated switch the switching losses are reduced. Due to elimination of Diode Bridge rectifier conduction losses are low. With a proper designing of PFC converter the combination of canonical switching cell with inductor and capacitor is used to achieve power factor correction operation.

BL-CSC converter provide the VSI to BLDC motor drive. A diode bridge rectifier introduces disadvantages such as injecting high amount of harmonics in supply and draw peak current from supply. Therefore PFC converter is used to improve the power factor quality. To operate PFC converter in a discontinuous conduction mode a current multiplier approach is used to reduce low stresses. For this required three sensors. Where a single voltage sensor is required for PFC converter which is operating the discontinuous conduction mode.

2.8 Boost Converter

Boost converter is a DC-DC converter which is used to step up the output voltage. It can be used as a power factor correction controller as if construction and working is simple which allows the simple control to keep the dc link voltage constant which is feed to the PMBLDC motor. Ms. Snehal Manik Kulkarni, Mr. P. M. Pujari, Dr. A. M. Mulla[8] presents the model of PMBLDC motor drive using MATLAB/Simulink for power factor correction. The system consist of PMBLDC motor, VSI, boost converter, DBR, Hall Effect sensors. The model for low- power adjustable speed drives with single phase supply is powered through diode bridge rectifier with smoothing capacitor and VSI is done in Simulink. The THD for this model is 63.89%. For PFC topology boost converter is used to boost the voltage supplied to the VSI. Using this topology the power factor is improved to 0.9994 and THD gets reduced to 1.08%. Using the FFT analysis of source current under steady state condition, the power quality is monitored. PI controller is used for the control of voltage and speed. So this paper presents the PFC technique with related circuit diagrams and simulation models. Also the waveforms for different parameters are shown such as input source voltage and input source current, rotor speed, torque, stator current. The conclusion is made that the PF can be made unity or can be improved by reducing the THD content of the system. BY varying the DC link voltage of the VSI, the speed of

the BLDC motor drive has been controlled. The rotor position feedback is used for the commutation of PMBLDC motor drive.

Gishin Jacob George, Rakesh R, N. Arun [9] proposes the power factor correction for PMBLDC motor drive using the boost converter topology which is assumed to be operated in CCM mode. There are two controllers used for PMBLDC drive and boost converter which are speed and voltage controllers respectively and are realized from PI controller. The VSI is used for the electronic commutation. Hall Effect sensors are used for sensing the rotor position at the commutation points which is needed for the control of VSI. The modeling of the speed controller, reference current generator, current controller and PMBLDC motor are important in the modeling of PMBLDC motor drive. The complete model is simulated in MATLAB/Simulink software and the results are compared for model with and without PFC controller. The THD percentage without PFC is about 71.97% at rated torque and by using PFC, the THD is reduced to 1.51%. Also the power factor is improved and it is 0.991. From the results it is shown that the dc link voltage changes with variations in speed and torque.

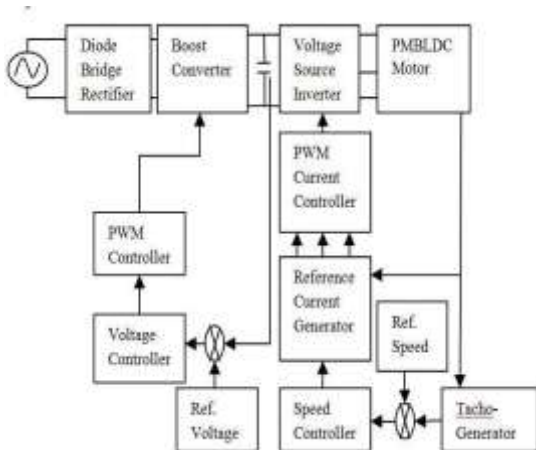


Fig.2: PMBLDC motor drive using Boost converter [10]

Ganesh M. Kachare & Juber A. Shaikh [10] proposes boost converter configuration in permanent magnet brushless DC motor drive to is used to overcome power quality problems at utility of ac mains. The DC-DC boost converter is used nearly for unity power factor and reduction of AC mains current harmonics. Voltage controller is employed in input side to provide controlled DC link voltage which is applied to BLDC motor through voltage source inverter. By using speed controller the speed control of PMBLDC motor with maximum torque is to be achieved. In variable speed application this is great significance. By using PI controller both voltage controller and speed controller is to be realized.

In this to boost the input voltage at appropriate voltage level which is fed to the voltage source inverter the boost converter is used. Through the boost converter and voltage source inverter the voltage supply is given to the BLDC

motor. At the input side for the control of voltage, voltage error is produced when the dc link voltage is sensed and compared with reference voltage.

The performance of PMBLDCM drive with PFC converter shows that boost PFC topology used in proposed work is best option for applications having rated voltage is higher than single phase supply RMS voltage.

2.9 Single Current Sensor PMBLDC Motor Drive

The single ended primary inductor converter (SEPIC) has many advantages like non-inverting output, good efficiency and low current ripple. This converter also can improve the power quality at AC mains. Also it provide a desire DC link voltage to PMBLDC motor. EMI generated by the SEPIC is less than EMI generated by boost converter for the same value of input inductor. Kanwar Pal, Saurabh Shukla, Sanjeev Singh [11] presents PMBLDC motor drive with single current sensor for variable speed variable torque using SEPIC i.e. single- ended primary inductor converter as a power quality controller. Ratings of the motor are 1.1 kW, 1400rpm, 7.4 Nm and related converters and controllers are designed according to these ratings. Effectiveness of the proposed system is demonstrated in Matlab/Simulink under steady state and transient conditions. A three phase voltage source inverter is used to accomplish the operation of the PMBLDC motor and rotor position information through Hall sensors is used for the commutation of three phase VSI. 71.56% of THD is present in current at AC mains due to the filter capacitor. SEPIC is a one of the DC-DC converter having the advantages like non- inverting output, low current ripple and better efficiency which is used for controlling the power quality. Also, the EMI generated by SEPIC for same inductor input value is less than that of the boost converter. This paper presents the continuous conduction mode of operation of SEPIC with low current ratings of switches. The shaft torque and speed of PMBLDC motor can be controlled by phase current and terminal voltage respectively. PI controller is used for minimizing the error between reference voltage and actual voltage. The switching devices used in converter as well as VSI is MOSFET due to its property of operating in wide switching frequency range in low power applications. When the simulation is run, the speed increases to rated value from 700 rpm then decreased to 800 rpm, so the torque changes accordingly. THD_i reduces and it is 5% whereas THD_v is 2% and the power factor is 0.9991 at 2.2Nm which is improved from 0.9656 at 0.5Nm. During steady state condition THD_i for speed 1000 rpm, 1200 rpm and 1400 rpm are 4.21%, 2.57% and 2.35% respectively. Power factor is improved from 0.9975 to 0.9995. During input voltage variation THD_i improves from 3.64% to 2.31% as the voltage on rated speed and torque increased from 150 V to 270V. The power factor is 0.9994 for voltage from 170 to 270V. Crest factor is 1.41 which is almost constant for all conditions.

2.10 Cuk Converter using SPWM Technique

C. Kowsalya, A. Nathiya, S. Shalini & S. Sheela[12] proposes PFC based Cuk converter fed BLDC motor drive. BLDCM drive acts as cost effective solution for low power application. For the power factor correction an improved power quality at the AC mains for a wide range of speed control a Cuk converter is operate in DICM. For giving the input pulses to the switches in converter and inverter the SPWM technique is used. A discontinuous output inductor current is obtained. When input inductor current and intermediate capacitor voltage remain in continuous conduction operation. For the complete range of speed control an improve PQ operation is achieved.

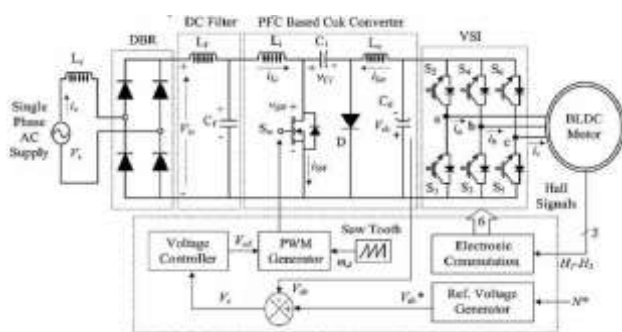


Fig-3: Simulation model using Cuk converter[12]

Table- 2: Comparison Of Different Output [12]

Vd (V)	Speed (rpm)	THD of Is (%)	DPF	PF	Is(A)
40	320	5.89	0.9959	0.9942	0.446
60	530	5.69	0.9965	0.9949	0.581
80	740	4.98	0.9971	0.9959	0.719
100	940	4.52	0.9978	0.9968	0.855
120	1150	4.11	0.9985	0.9977	0.993
140	1360	3.62	0.9992	0.9985	0.128
160	1560	2.85	0.9998	0.9994	0.265
180	1770	2.25	0.9999	0.9996	1.403
200	1980	1.81	0.9999	0.9997	1.537

2.11 Luo Converter

In this the bridgeless Luo converter is used for power factor correction based BLDC motor drive by Amruta Shivaji Anuse [13]. For the speed control of BLDC motor a voltage sensor is used this power factor correction is implemented at AC mains. For reducing the switching losses electronic commutation is used. For wide range of speed control proposed BLDC motor drive is designed. Due to high switching frequency of PWM pulses for VSI the conventional boost PFC for feeding a BLDC drive suffers from high switching losses and which results in reduction of efficiency of overall system. In this circuit consist of single phase

supply with BL-Luo converter and filter. BL-Luo converter is used to feed voltage source inverter driving a BLDC motor. BL-Luo converter act as a power factor pre regulator.

2.12 Isolated-Zeta converter

Chandru K, Mariaraja P, Kuppuswamy A [14] designed the power factor correction converter which is the isolated Zeta converter. To drive the compressor of conventional Air Conditioner uses single phase Induction Motor and it also provides inefficient temperature control operation. Due to the operation, efficiency, ease of control maintenance and size nowadays PMBLDCM drive is used.

In this proposed work single stage isolated Zeta converter is used to avoid the complexity and cost. An isolated Zeta converter inherits continuous conduction mode of operation and therefore this converter is proposed for PFC in a PMBLDCM drive. To reduce the switching stress and to operate at low switching frequency the IGBTs are used in n Voltage source inverter to provide the isolation between the input and output stages the high frequency transformer are used and it also provides flexibility for use of large voltage ratio. By using equiva lent reference voltage at DC Link a single stage Zeta converter is recommended for speed control of system.

2.13 Voltage Control

Balahemalatha.R ,Sarmila Har Beagam. K ,Srinivas. K. N[15] presents a paper in which SEPIC DC to DC converter is used as PFC converter for PMBLDCM. It is fed through diode bridge rectifier from a single phase AC mains to operate the PMBLDCM as an electronic commutator a 3 Phase VSI is used. PMBLDCM has developed the torque which is proportion to the phase current and its back EMF which also proportion to the speed PMBLDC Drive consist of VSI and PMBLDCM.

Due to the continuous input and output currents, small output filter and wide output voltage range as compared to other single switch converters a SEPIC DC to DC converter is used as PFC convert is used. By using the capacitive energy transfer the SEPIC DC to DC converter controls the dc link voltage and this results in non-pulsating input and output current.

The PFC converter is operated as high switching frequency for effective and fast control. This PFC converter has anadvantage of a small size filter. For the high frequency operation a MOSFET is used and IGBT are used in the VSI Bridge feeding the PMBLDC due to its low frequency operation as compared to PFC converter.

2.14 Landsman Converter

Y.Sree Harsha , R. Hariharan [16] proposed a paper in which utilizing just a single controller the Landsman Converter performs power factor correction and DC voltage control in single stage. If the PFC is planned properly it not

only enhances the power quality at AC mains but also gives variety of speed control. The cost effective solution for low power applications is PFC based on CUK converter. By changing the DC transport voltage of a VSI the speed of the BLDC motor can be changed. It gives better power quality. The comparison between speed and power factor is explained here.

Table-3: Speed V/S Power Factor [16]

SPEED IN RPM	POWER FACTOR
1200	0.975
1100	0.97
1000	0.965
900	0.955

3. CONCLUSIONS

The different developments in the BLDC motor drive are discussed. From the discussion it is concluded that by keeping the dc link voltage constant, the speed of the BLDC motor can be controlled. The Isolated -Zeta converter operated in discontinuous conduction mode of operation hence it is advantageous from the cost point of view as it requires less number of sensors. But the converter switches are subjected to high stresses hence can be used for low power applications only. For the fast control of speed and torque, the direct torque control method is advantageous but it is quite difficult to design. The fuzzy logic controller technique can be used for the fast response which does not require the plant mathematical model for the system control. Sensor less control can decrease the cost but the transient conditions can be deteriorated by the phase shifter. Also the dynamic performance may get affected due to nonlinearity and dependence of it on rotor position. The boost converter operated in the continuous conduction mode of operation is the effective method for power factor correction. Boost converter can be used for the applications where the voltage ratings are higher than the RMS value of the supply voltage. Also the converter operate in continuous conduction mode (CCM) allows it to operate for high power applications as there are less stresses on the converter switches.

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