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A BRIDGELESS ZETA CONVERTER BASED SENSORLESS BLDC MOTOR DRIVE WITH PFC

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Abstract

This paper describes a sensorless control of bldc motor drive using a bridgeless zeta converter with power factor correction. Brushless DC (BLDC) motor drives are becoming more popular in industrial and traction application.Sensorless method is used to reduce the cost and complexity of the system. The Sensor less control would need estimation of rotor position from the voltage and current signals, which are easily sensed. In this proposed method the switching loss of VSI is less.The bridgeless zeta converter is used to reduce the diode bridge rectifier conduction losses. The power factor correction is used to achieve high power factor.The proposed method is to be designed for high efficiency and wide range of speed control using model predictive control based speed controller eliminate torque ripples and provides fast speed response.

Keywords: BLDC motor, Bridgeless zeta converter, PFC, Sensorless control.

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1. Introduction

Now a days, a brushless dc (BLDC) motor drives have been widely used in aeronautics, electric vehicles,robotics, and food and chemical industries. A use of BLDC motor (Brushless DC Motor) in these applications is becoming very common due to features of high efficiency, high flux density per unit volume, low maintenance requirements and low EMI (Electro-Magnetic Interference) problems. A BLDC motor has three phase windings on the stator and permanent magnets on the rotor**.**

Single stage PFC converters have gained importance due to simplicity in design and low amount of losses due less count of components. Single stage isolated PFC converters use high frequency isolation transformer which is compact in size and thus reducing the space requirement of the PFC converter and provides isolation between input and output.

Sensorless control is achieved by the back-EMF of the motor to estimate the rotor position,it eliminates the need for Hall Effect sensor. Sensorless control is need for applications of low-cost variable speed motor drives like fans and pumps.

A bridgeless Zeta converter operating in Continuous Conduction Mode or Discontinuous Conduction Mode is used for PFC applications.Discontinuous Conduction Mode is preferred for low and medium power applications because it utilizes an approach of voltage follower which requires a single voltage sensor. Power factor correction is particularly important for dc drives because phasing back of the switches results in relatively poor power factor,especially when the motor is at reduced speeds. Additional transformer capacity is required to handle the poor power factor conditions (and the harmonics) and more utilities are charging a power factor penalty that can significantly impact the total bill for the facility.

II.SENSORLESS CONTROL OF BLDC MOTOR

The sensorless control method is based on the fact that the rotor position can be detected by using a trapezoidal back-EMF of BLDC motors.Normally, the back EMF voltage is measured by using neutral point of motor. The back EMF can be obtained by comparing the terminal voltage to the neutral point as shown in Fig 1.Otherwise the virtual neutral point is used to obtain back EMF if neutral point is not available in motor. The resistors are used to built virtual neutral, which is shown in Fig 2.The neutral point causes problems in the motor sensorless control.The proposed direct back EMF detection is eliminate the neutral point voltage. The back EMF voltage is to be measured by directly from the motor terminal voltage to the ground as shown in Fig 3.

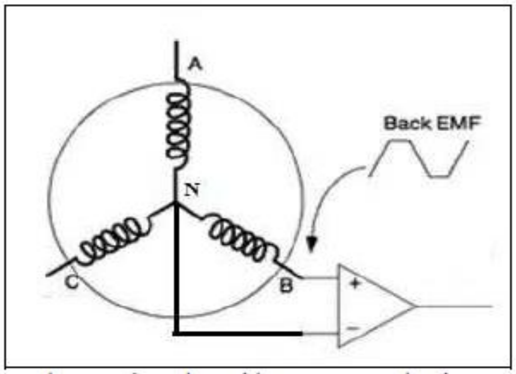

Fig.1-Back EMF detection with motor neutral point

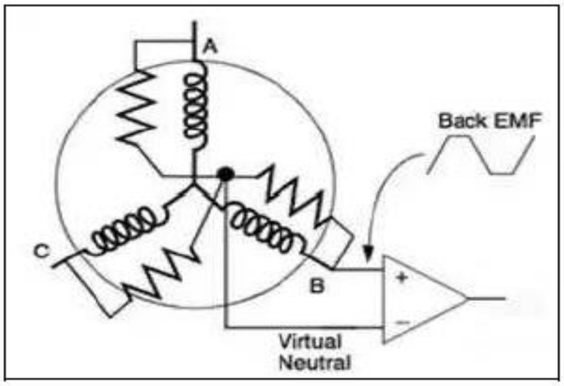

Fig.2- Back EMF detection with virtual neutral point.

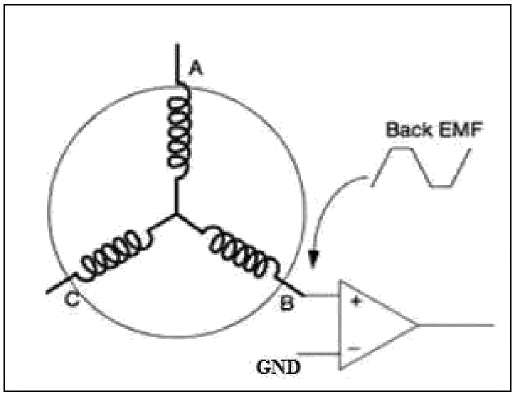

Fig.3-Direct back EMF detection.

The terminal voltage of the phase is directly proportional to the back EMF voltage.The ground is to be used instead of neutral point.This back EMF is to be measure by PWM signal. The PWM signal is to be apply only on high side switches.During the Off time of PWM, then the back EMF is to be measured.The Back-EMF sensing technique enables a sensorless detection of the rotor position, however the drive must be first started without this feedback. It is caused by the fact that the amplitude of the induced voltage is proportional to the motor speed. Hence, the Back-EMF cannot be sensed at a very low speed and a special start-up algorithm must be performed. In order to start the BLDC motor, the adequate torque must be generated.The motor torque is proportional to the multiplication of the stator magnetic flux, the rotor magnetic flux and the sine of angle between both magnetic fluxes.

III. PROPOSED BRIDGELESS ZETA CONVERTER FED BLDC MOTOR DRIVE

Proposed sensorless control of bridgeless Zeta converter based BLDC motor drive with power factor correction show fig. 4. A single stage, bridgeless Zeta converter is used for the DC link voltage control and PFC operation. The BLDC motor speed is controlled by DC link voltage control of VSI using a bridgeless zeta converter. This reduces the switching losses in VSI due to low frequency operation of VSI for sensorless operation of BLDC motor. Moreover, the conduction losses of the DBR are reduced to half by using a bridgeless topology which also offers improved thermal utilization of the converter’s switches. The front end Zeta DC-DC converte maintains the DC link voltage to a set reference value.Switch of the Zeta converter is to be operated at high switching frequency for effective control and small size of components like inductors. A high frequency MOSFET of suitable rating is used in the front end converter for its high frequency operation whereas an IGBT’s (Insulated Gate Bipolar Transistor) are used in the VSI for low frequency operation. PWM has been widely used in power converter control. PWM control is the most power full technique that offer a simple method for controlling of analog system with processors digital output. PWM frequency depends on the target device speed and duty cycle resolution requirement.BLDC motor drive controlled using microcontroller with model prective control technique.

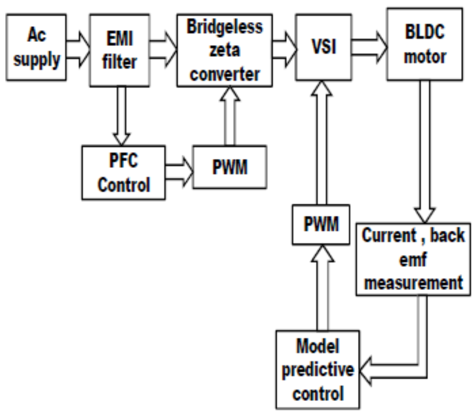

Fig.4-Block diagram of proposed bridgeless zeta converter fed BLDC motor drive

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IV.OPERATION OF BRIDGELESS ZETA CONVERTER

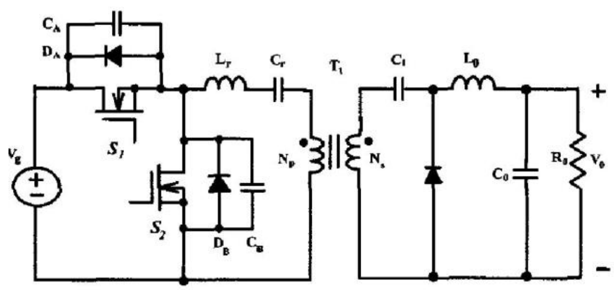

Fig.5-Bridgeless zeta converter

In the proposed configuration of bridgeless zeta converter has the minimum number of components and least number of conduction devices during each half cycle of supply voltage which governs the choice of BL zeta converter for this application. The operation of the PFC bridgeless zeta converter is classified into two parts which include the operation during the positive and negative half cycles of supply voltage and during the complete switching cycle.

A.Operation During Positive and Negative Half Cycle of Supply Voltage

Fig.5 shows the operation of bridgeless Zeta converter for a positive and negative half cycle of the supply voltage respectively. As shown in Fig. 5 switch S1 and diode D1 conduct for the positive half cycle of the supply voltage and diode D2 remains reversed biased during this period. Similarly for the negative half cycle of the supply voltage, switch S2 and diode D2 conduct and no current flows through switch S1 and diode D1.The energy is transferred through HFT (High Frequency Transformer) which turns ratio is

given as N1:N1:N2. The magnetizing inductance (Lm) is designed to operate in DCM such that a discontinuous conduction is achieved for a wide range of DC link voltage control to achieve an inherent power factor correction.

B. Operation during Complete Switching Cycle

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Three different modes of operation during a complete switching cycle for positive half cycle of supply voltage. When switch Sw1 is on, the energy is stored in the HFT, intermediate capacitor C1 and inductor L; whereas DC link capacitor Cd supplies the required energy to the load. When switch is turned off , the HFT discharges through Diode D and inductor Lo supplies the required energy to the DC link capacitor. In the DCM mode of operation, the HFT is completely discharged, whereas inductor Lo continues to supply the required energy to

the DC link capacitor. Variation of different parameters such as HFT current (iLm), inductor current (iLo), intermediate capacitor's voltage (VC1) and DC link voltage (Vdc).

The duty ratio D for the Zeta converter is given as

$$D = \frac{V_{dc}}{(V_{dc}+V_{in})} \quad \text{---(1)}$$

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

A. Reference Voltage Generator

A reference DC link voltage Vdc* is required to compare it with the sensed DC link voltage Vdc to

generate a voltage error signal. Reference DC link voltage Vdc* is generated from the reference speed N* by multiplying it with the motor's voltage constant kv as,

$$V_{dc}^{*} = k_v . N^{*} \qquad \text{---(2)}$$

B.Speed Controller

An error of the Vdc* and Vdc is given to a PI (Proportional Integral) speed controller which generates a controlled output corresponding to the error signal. The error voltage Ve at any instant of time k is as,

$$V_e(k)= V_{dc}^{*}(k)- V_{dc}(k) \qquad \text{---(3)}$$

And the output of the PI controller is given by,

$$V_c(k)= V_c(k-1)+k_p(V_e(k)-V_c(k-1)+k_i.V(k)) \qquad \text{---(4)}$$

Where, Kp is the proportional gain and Ki the integral gain constant.

C.PWM generator

The dynamic modeling of the BLDC motor is governed by the following equations given as

$$V_{an}=R_a i_a+p\lambda_a+e_{an} \qquad \text{---(5)}$$

$$V_{bn}=R_b i_b+p\lambda_b+e_{bn} \qquad \text{---(6)}$$

$$V_{cn}=R_c i_c+p\lambda_c+e_{cn} \qquad \text{---(7)}$$

Where, p represents the differential operator, V_{an} , V_{bn} and V_{cn} are the per phase voltages. e_{an} , e_{bn} and e_{cn} represents back EMF and λ_a, λ_b and λ_c represents flux linkages,where V_{ao}, V_{bo}, V_{co} are the three phase voltages and V_{no} is the neutral voltage referred to the zero reference potential.The flux linkages are given as,

$$\lambda_a=L_s i_a-M(i_a+i_c) \qquad \text{---(8)}$$

$$\lambda_b=L_s i_b-M(i_a+i_c) \qquad \text{---(9)}$$

$$\lambda_c=L_s i_c-M(i_a+i_c) \qquad \text{---(10)}$$

Where, Ls is the self inductance per phase and M is the mutual inductance of the windings. Moreover for star connected three phase windings of the stator,

$$i_a+i_b+i_c=0 \qquad \text{---(11)}$$

The equation for torque is expressed as

$$T_e= \frac{(e_{an}\, i_a+e_{bn}\, i_b+e_{cn}\, i_c)}{\omega_r} \qquad \text{---(12)}$$

Where, ω is the rotor speed in electrical rad/sec. **D.** Model Predictive Control Algorithm

Model predictive control (MPC) is an advanced method of process control that has been in use in the process industries in chemical plants and oil refineries since the 1980s. In recent years it has also been used in power system balancing models. Model predictive controllers rely on dynamic models of the process, most often linear empirical models obtained by system identification. The main advantage of MPC is the fact that it allows the current timeslot to be optimized, while keeping future timeslots in account. This is achieved by optimizing a finite time-horizon, but only implementing the current timeslot. MPC has the ability to anticipate future events and can take control actions accordingly. PID and LQR controllers do not have this predictive ability. MPC is nearly universally implemented as a digital control, although there is research into achieving faster response times with specially designed analog circuitry.

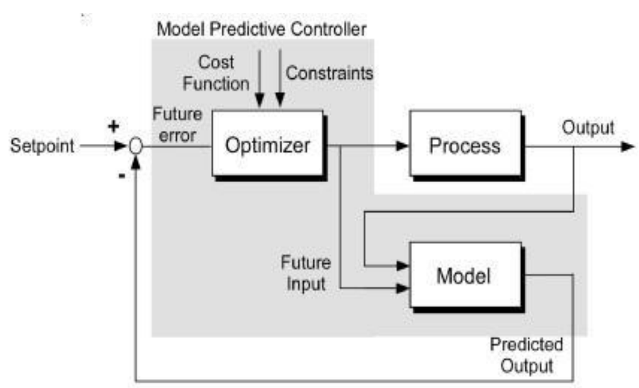

Fig 6 Block diagram of model predictive controller

V.EXPERIMENTAL SETUP

The Hardware experimental setup of a three level voltage source inverter fed PMBLDC motor with PFC zeta converter is shown in Fig. 7. This is a closed loop control circuit using back EMF. MOSFETs are used as switching devices here. To control the speed of the motor the output frequency of the inverter is varied.

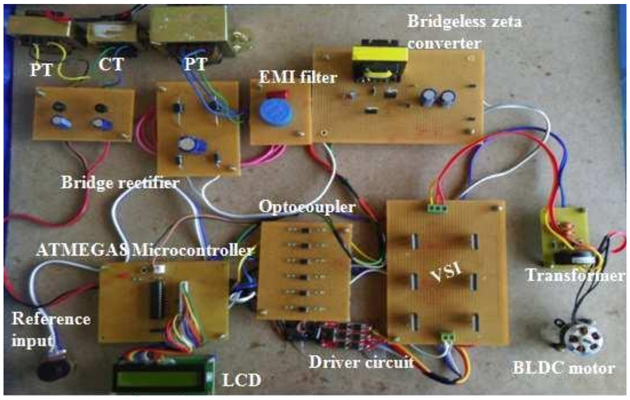

Fig.7- Hardware setup of Bridgeless Zeta Converter fed BLDC motor.

To maintain the flux constant the applied voltage is varied in linear proportion to the frequencyBy this the variation of the motor voltage can be achieved easily by changing the duty cycle of the PWM signal. In this method the actual voltage is measured and is compared with the set voltage value and the error signal is generated. This error signal is amplified by the microcontroller and hence the PWM duty cycle can be adjusted dynamically to maintain the voltage constant.When using PWM outputs from the microcontroller is used to control the switches of VSI, variation of the motor voltage can be achieved easily by changing the duty cycle of the PWM signal. In this method the actual speed of the motor is calculated using model predictive control by sensing the back EMF. The error is to be calculated by reference speed and actual speed of the motor. A microcontroller is used to detect the speed error and automatically to adjust the duty cycle of PWM.

VI.RESULTS AND DISCUSSION

The ATmega8 microcontroller is a low-power CMOS 8-bit microcontroller based on the AVR RISC architecture. By executing powerful instructions in a single clock cycle, the ATmega8 achieves throughputs approaching 1MIPS per MHz, allowing the system designed to optimize power consumption versus processing speed. The hardware implementation of the project is shown in Fig 7. In this project the sensorless control of bldc motor was done with back EMF method and the power factor was corrected. The bldc motor was controlled using six switch voltage source inverter. This proposed method 97% efficiency at low speed and 99% efficiency at high speed were achieved. The hardware implementation was done with bridgeless zeta converter and the ATMEGA 8 microcontroller.

The results the output response for different motor speed and their power factor is shown in Fig 8 , Fig 9 and Fig 10. The motor is achieved high power factor at low speed. From the medium speed to high speed the power factor is to be very high. And also the deviation of the set speed and the
actual speed is very low in all three different motor speed. So, the efficiency is very high in this method.

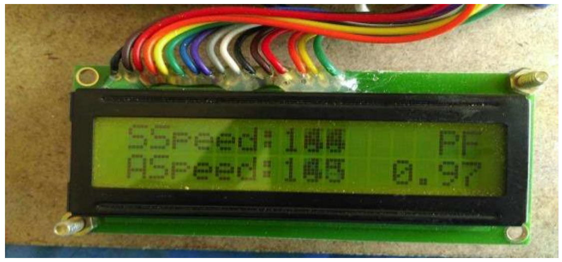

Fig 8 Power Factor at low speed

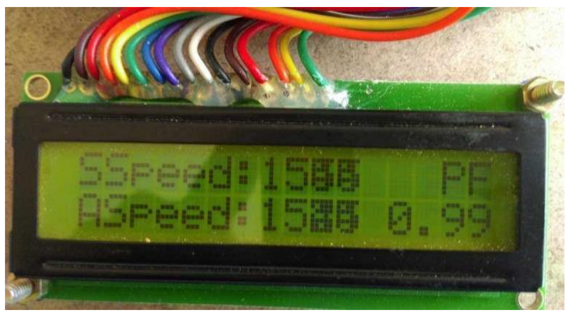

Fig 9 Power Factor at medium speed

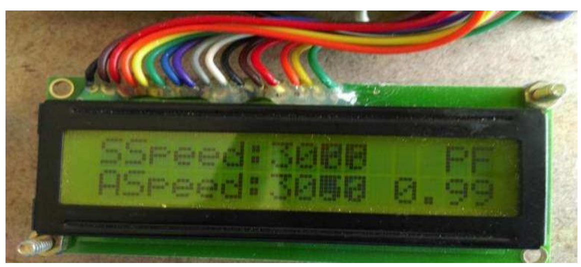

Fig 10 Power Factor at high speed

A bridgeless Zeta converter based VSI fed BLDC motor drive with power factor correction has been proposed with sensorless configuration. A bridgeless configuration of a Zeta converter has been explored to feed a BLDC motor drive via a VSI. A sensorless control of the BLDC motor has been used, which utilizes a fundamental frequency switching of the VSI for reduced switching losses. Moreover, a bridgeless configuration of Zeta converter has been used which eliminates the Diode Bridge Rectifier and thus reduces the conduction losses in it.

VII.CONCLUSION

In this paper, a comparative study of MPC Logic based sensorless speed control of BLDC motor drive fed with conventional Voltage source inverter is done. From the results we can conclude that as the voltage level increases the performance characteristics of the BLDC drive has been improved and the harmonics in the output voltages and currents has been reduced. Also the speed and torque characteristics of BLDC drive are having good transient and steady state response. The advantages of the Model predictive controller are that it reduces computational time, learns faster and produces lower errors than other method.

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