

## **An Isolated Two Stage Pfc Converter Fed Bldc Motor Drive**

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**Abstract**--This paper presents an Isolated Two Stage Power Factor Corrected (PFC) Converter as a cost-effective solution for low-power BLDC motor drive applications. An approach of speed control of the BLDC motor by controlling the dc link voltage of the voltage source inverter (VSI) is used by the proposed PFC converter. The first stage consists of a canonical switching cell converter which is an ac-dc converter. The second stage consists of a flyback converter which provides isolation for the drive. A two stage PFC converter is designed to operate in discontinuous inductor current mode (DICM) to provide an inherent PFC at ac mains. An open loop control method using PIC microcontroller and 555 timer is used here for the control action of the converter. The performance of the proposed drive is evaluated over a wide range of DC link voltage with improved power quality at ac mains. The performance of the proposed drive is simulated in MATLAB/Simulink environment.

**Keywords**— BLDC motor, Canonical switching cell converter, Continuous conduction mode, discontinuous inductor current mode (DICM), Flyback converter, power factor corrected (PFC)

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### **I. INTRODUCTION**

Efficiency and cost are the major concerns in the development of low-power motor drives targeting household applications such as fans, water pumps, blowers, mixers, etc.[1] The use of the brushless direct current (BLDC) 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 electromagnetic-interference problems. These BLDC motors are not limited to household applications, but these are suitable for other applications such as medical equipment, transportation, HVAC, motion control, and many industrial tools.

Power quality problems have become important issues to be considered due to the recommended limits of harmonic standards such as the International Electro technical Commission (IEC) 61000-3-2.[2] For class-A equipment (< 600 W, 16 A per phase) which includes household equipment, IEC 61000-3-2 restricts the harmonic current of different order such that the total harmonic distortion (THD) of the supply current should be below 19%. A BLDC motor when fed by a diode bridge rectifier (DBR) with a high value of dc link capacitor draws peaky current which can lead to a THD of supply current of the order of 65% and power factor as low as 0.8. Hence, a DBR followed by a power factor corrected (PFC) converter is utilized for improving the power quality at ac mains.[3] Many topologies of the single-stage PFC converter are reported in the literature[5]—[11] which has gained importance because of high efficiency as compared to two-stage PFC converters due to low component count and a single switch for dc link voltage control and PFC operation.

The choice of mode of operation of a PFC converter is a critical issue because it directly affects the cost and rating of the components used in the PFC converter[12]. The continuous conduction mode (CCM) and discontinuous conduction mode (DCM) are the two modes of operation in which a PFC converter is designed to operate. In CCM, the current in the inductor or the voltage across the intermediate capacitor remains continuous, but it requires the sensing of two voltages (dc link voltage and supply voltage) and input side current for PFC operation, which is not cost-effective. On the other hand, DCM requires a single voltage sensor for dc link voltage control, and inherent PFC is achieved at the ac mains, but at the cost of higher stresses on the PFC converter switch; hence, DCM is preferred for low-power applications.

The conventional PFC scheme of the BLDC motor drive utilizes a pulse width- modulated voltage source inverter (PWM-VSI) for speed control with a constant dc link voltage. This offers higher switching losses in VSI as the switching losses increase as a square function of switching frequency. As the speed of the BLDC motor is directly proportional to the applied dc link voltage, hence, the speed control is achieved by the variable dc link voltage of VSI. This allows the fundamental frequency switching of VSI (i.e., electronic commutation) and offers reduced switching losses.

Different AC-DC PFC converters are reported for the DC link voltage control. [2],[3],[5],[8],[11].In some cases a two stage converter is used for increasing the efficiency. Some particular applications like air compressors require some isolated converter for DC link voltage control. These can be achieved by some isolated converters. So here it is tried to design and implement an isolated two stage PFC converter fed BLDC motor drive. In this the front end converter consists of two stages. One is a canonical switching cell converter and the second one is a Fly back converter. The fly back converter provides a high frequency isolation called galvanic isolation.[4]

## II. BLDC MOTOR DRIVE

The proposed BLDC motor drive consists of two stages in its PFC converter. First stage consists of a canonical switching cell converter which provides a variable dc output voltage from the available single phase ac voltage. Canonical switching cell converter is a power factor correction converter which keeps the input ac source power factor as high as near to unity. Second stage consists of a Fly Back converter in which a high frequency transformer is used for providing the galvanic isolation. Some applications like compressors require this galvanic isolation for safe working. For providing isolation, Fly back converter is more suitable as it has only a few no of components during each cycle of switching. The dc link output voltage across capacitor (C2) is considered as source for the flyback converter. It is required to obtain the output voltage of Fly back converter as equal to its input. The proposed BLDC motor drive is shown in Fig 1.

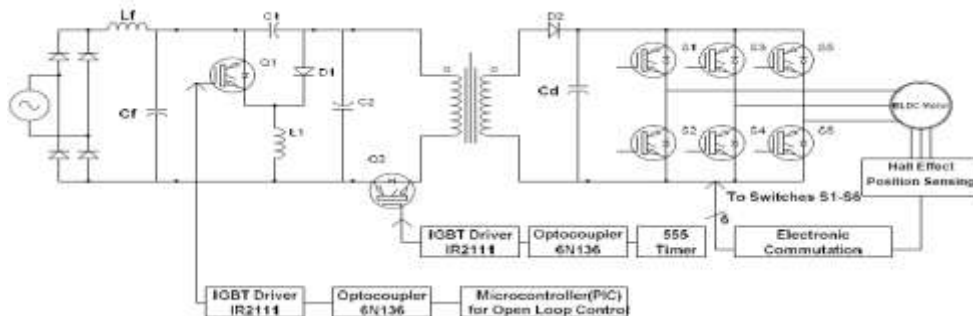


Fig 1: Proposed Isolated two stage converter control fed BLDC motor drive

A variable dc-bus voltage of the VSI is used for controlling the speed of the BLDCM. This operates the VSI in low-frequency switching by electronically commutating the BLDCM for reducing the switching losses in six insulated gate bipolar transistor's (IGBT's) of VSI which share the major portion of overall losses in the BLDCM drive. The front-end CSC converter is designed and its parameters are selected to operate in a DICM for obtaining a high-power factor at wide range of speed control.

## III. OPERATION OF THE PROPOSED DRIVE

### STAGE I: CSC CONVERTER

The proposed BLDCM drive uses a CSC converter operating in DICM. In DICM, the current in inductor L1 becomes discontinuous in a switching period ( $T_s$ ). Three states of CSC converter are shown in Fig.2-4. Waveforms of inductor current and intermediate capacitor's voltage for a complete cycle of line frequency are shown in Fig. 5(a), whereas Fig. 5(b) shows the variation in different variables of CSC converter such as switch gate voltage ( $V_G$ ), inductor current ( $i_{L1}$ ), intermediate capacitor's voltage ( $V_{c1}$ ), and dc-link voltage ( $V_{dc}$ ) in a complete switching period. Three modes of operation are described as follows.

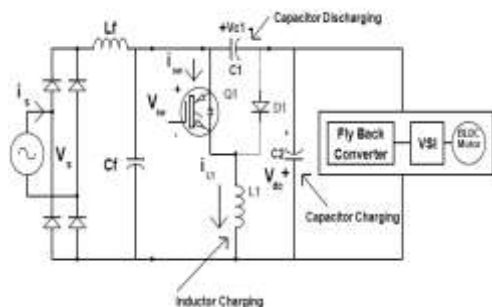


Fig 2: Mode I operation of BLDC motor Drive

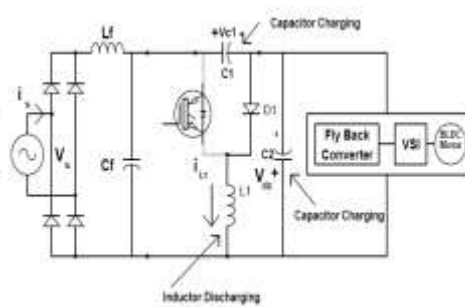


Fig 3: Mode II operation of BLDC motor Drive

**Mode I:** As shown in Fig. 2, when switch is turned ON, the energy from the supply and stored energy in the intermediate capacitor are transferred to inductor. In this process, the voltage across the intermediate capacitor reduces, while inductor current and dc-link voltage are increased as shown in Fig. 5(b). The designed value of intermediate capacitor is large enough to hold enough energy such that the voltage across it does not become discontinuous.

**Mode II:** The switch is turned OFF in this mode of operation as shown in Fig. 3. The intermediate capacitor is charged through the supply current while inductor starts discharging hence voltage starts increasing, while current decreases in this mode of operation as shown in Fig. 5(b). Moreover, the voltage across the dc-link capacitor continues to increase due to discharging of inductor.

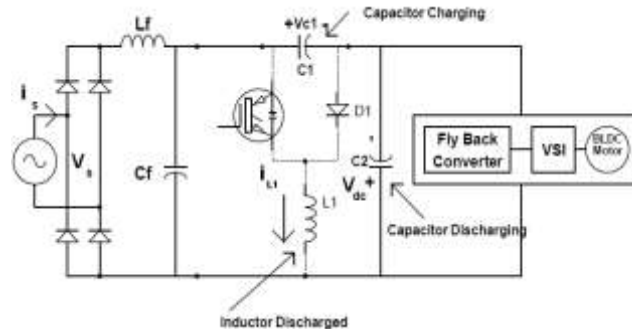


Fig 4: Mode III operation of BLDC motor Drive

**Mode III:** This is the discontinuous conduction mode of operation as inductor is completely discharged and current becomes zero as shown in Fig. 4. The voltage across intermediate capacitor continues to increase, while dc-link capacitor supplies the required energy to the load, hence starts decreasing as shown in Fig. 5(b).

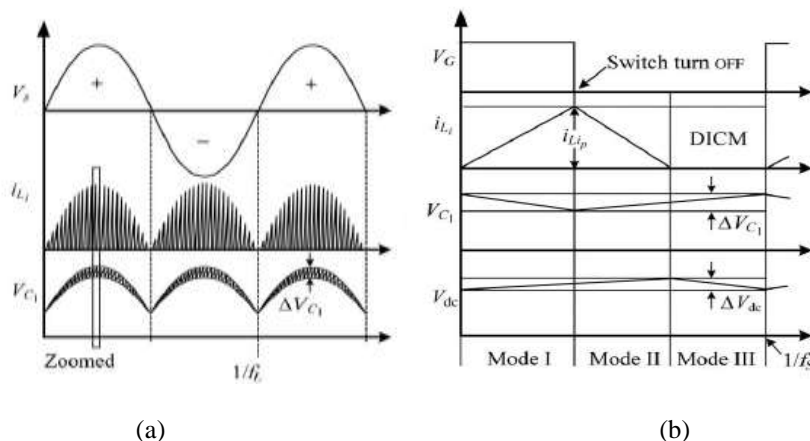


Fig 5: Waveforms during complete (a) Line cycle and (b) switching cycle

## STAGE II FLYBACK CONVERTER

The output voltage of CSC converter is a variable one for controlling the speed of BLDC motor. This variable voltage is given to the Flyback converter. Flyback converter has two modes of operation depending on the state of switch Q2 which is shown in Fig 4.1.6 and Fig 7.

**Mode I ( $0 < t < t_{onQ1}$ ):** When the switch Q2 is turn ON, the primary winding of the isolation transformer is get energized. Then as per the polarity of the transformer the diode on the secondary side of the transformer us in the reverse biased condition. So during this mode the output Capacitor does not get energy from the source and it drives the motor with its stored energy.

**Mode II ( $\text{ton}Q1 < t < T$ ):** At the instant when the switch Q2 is turn OFF the polarity of the secondary winding is reversed. Now the diode is forward biased and the energy stored in the inductance of the transformer is used for charging the capacitor Cd. Now the voltage across Cd is slightly increases and capacitor drives the BLDC motor with its stored energy.

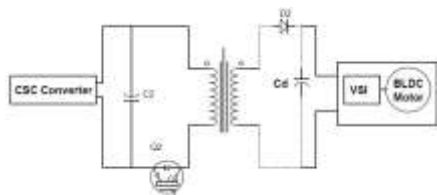


Fig 6: Mode I operation of Flyback converter

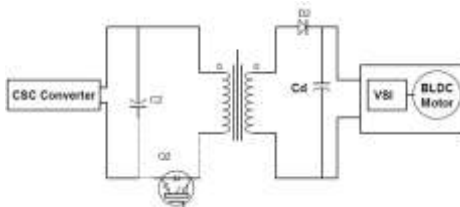


Fig 7: Mode II operation of Flyback converter

#### CONTROL OF THE PFC CONVERTER

The BLDC motor fed from the two stage PFC converter is controlled in an open loop manner. There is one controllable switch (IGBT) in the CSC converter and another switch in the Flyback converter. The Flyback converter is used to provide isolation and so its IGBT is designed to controlling constant duty ratio. The operating frequency of the switch Q2 in flyback converter is 100 KHz with Duty ratio 0.5. A 555 Timer is used for this control. The dc output voltage of the two stage converter is to be varied for speed control of the BLDC motor. This can be achieved by controlling the duty ratio (ON time) of switch Q1 in the CSC converter. This is achieved in an open loop manner by PIC microcontroller. The diagram for the control circuit of two stage converter is shown in Fig: 4.1.8. There is two push buttons were used each for increment and decrement of duty ratio of switch Q1. Thus the voltage output of CSC converter and there by the input voltage of VSI is varied

#### IV. CONTROL OF THE VSI FED BLDC MOTOR

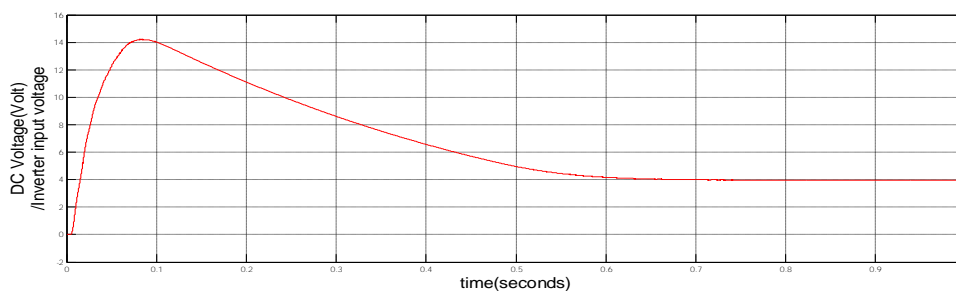
The variable DC voltage is given as input to voltage Source Inverter which consists of six IGBTs as controllable switch. This Hall signal output is corresponds to the rotor position of the BLDC motor and so it is used for controlling the VSI. Depending on three phase VSI to be controlled for controlling the speed of BLDC motor. BLDC motor has its Hall Effect sensors installed in its stator frame. The the different Hall signal combinations two IGBTs from any two legs need to conduct. This can be achieved by using a PIC microcontroller.

#### V. RESULTS AND DISCUSSION

##### SIMULATION RESULTS

The BLDC motor speed is controlled by dc link voltage control. The dc link voltage is controlled by controlling the duty ratio of switch Q1. A reference voltage is compared with the actual dc link voltage. The corresponding PWM switching signals will be generated. The following table gives the values of parameters for simulation.

The proposed drive gives a dc link voltage with minimum fluctuations and correspondingly the speed of the motor will stay on the reference speed corresponds to the reference voltage itself. This can be viewed in Fig.8. Here the reference voltage is 42V and the motor achieves the corresponding speed with minimum fluctuations.



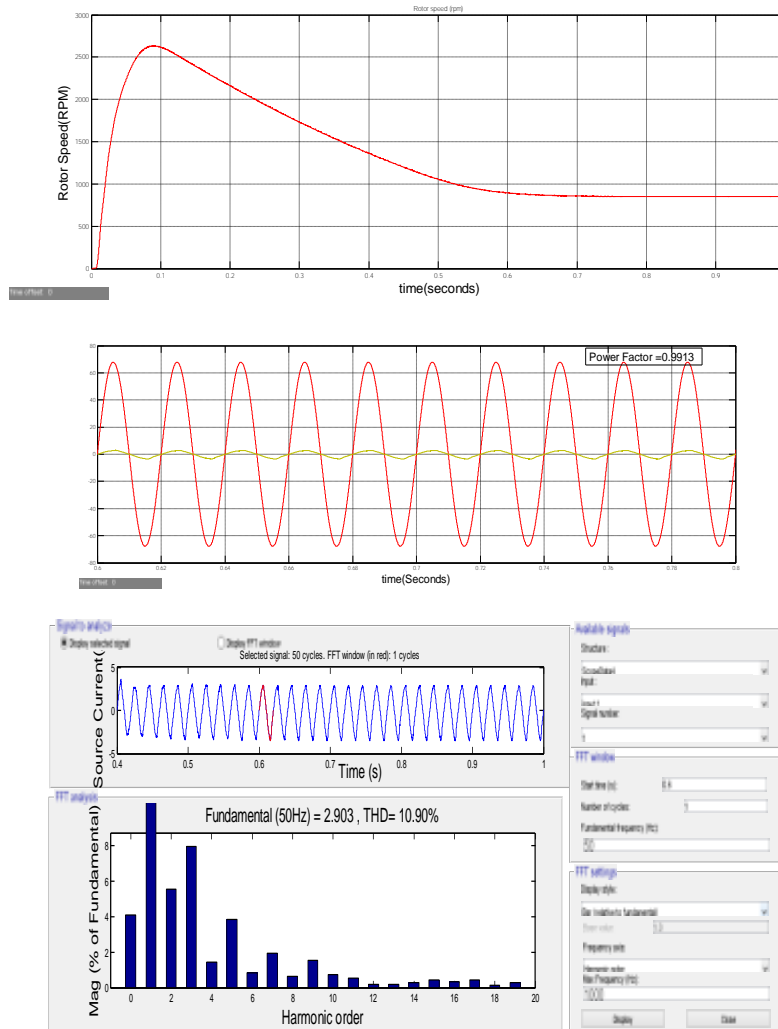


Fig 8 Different waveforms Of the proposed drive.

**EXPERIMENTAL RESULTS**

A two stage PFC converter is designed and set up for feeding a BLDC motor. The first stage is an ac-dc converter stage which uses a canonical switching cell and a diode bridge rectifier. The single switch IGBT is controlled in an open loop manner by using the gate pulses generated from a microcontroller PIC 16F877A. Two push buttons in controller board is used for increment/decrement the duty ratio of the IGBT in CSC converter. The gate pulses thus generated is given to an optocoupler and then to an IGBT driver IC.



Fig 9 Experimental Prototype

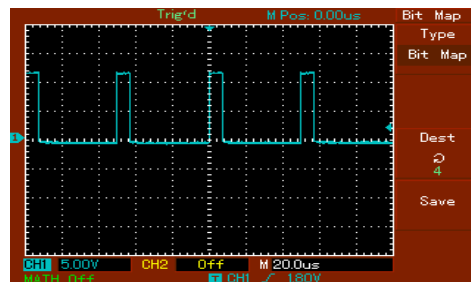


Fig 10 Gate signal for CSC converter switch

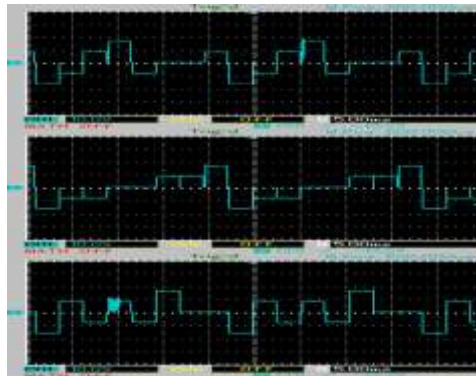


Fig 11 Input line voltages of BLDC motor

## VI. CONCLUSION & FUTURE SCOPE

### CONCLUSION

BLDC motor found wide applications nowadays. It has wide range of speed control and also its size is less compared to induction machines. These BLDC motors so can be used in the refrigerators and washing machines where size is the major concern. In the applications where reduced fire chance is compulsory there these BLDC motor found its place. Such a BLDC motor require a controlled DC voltage for the speed control by which the power saving can be achieved. From the available single phase ac supply the DC voltage is to be derived. This is done by a two stage PFC converter. Here the stage 1 provides a controlled voltage and the stage2 gives isolation between the device and converter. Such a drive is designed and set up by using PIC microcontroller. A 24V 4000 RPM BLDC motor is used. Advanced Digital signal Processors can give better performance.

### FUTURE SCOPE

Even if the Canonical Switching Converter (CSC) fed BLDC motor drive give better performance in the sense of THD and power factor, it is found that the replacement of the front end Diode Bridge Rectifier (DBR) can give better performance. In small capacity industrial tools, domestic appliances, Air conditioners etc the wide range of speed control is an added advantage .For this BLDC motor can be used which has wide range of speed control is possible. For these applications it is better to design and implement a new bridgeless Isolated PFC converter fed BLDC motor drive using canonical switching cell.

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