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DISCONTINUOUS INDUCTOR MODE OPERATING PFC BASED BRIDGLESS ISOLATED CUK CONVERTER FED BLDC MOTOR DRIVE

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ABSTRACT

The bridgeless isolated-Cuk converter fed BLDC motor drive has been proposed for low power household appliances. A three-phase voltage-source inverter is used as an electronic commutator to operate the PMBLDCM driving an air-conditioning system. The speed control of BLDC motor has been achieved by controlling the DC link voltage of VSI feeding BLDC motor. The front end PFC bridgeless cuk converters operating in DICM has been used for dual operation of PFC and DC link voltage control. The bridgeless converter topology is designed for obtaining the low conduction losses. The simulation of the proposed system has been implemented in Matlab / Simulink.

Index Terms— BLDC Motor, Bridgeless Isolated Cuk Converter, Discontinuous Inductor Current Mode, Power Factor Correction, Power Quality, Voltage Source Inverter.

INTRODUCTION:

The use of a permanent-magnet brushless dc motor (PMBLDCM) is used in low and medium power applications because of their high efficiency, wide speed range, high energy density ,high torque/inertia ratio, low maintenance and wide range of speed control. The bridgeless PFC cuk converter fed PMBLDC motor drive system has been proposed for house hold systems. A three-phase voltage source inverter (VSI) is used for achieving an electronic commutation of the BLDC motor based on the rotor position as sensed by Hall-Effect position sensors. The speed of the BLDC motor is controlled by varying the DC link voltage of the VSI.

A VSI fed BLDC motor drive is generally supplied by a combination of a diode bridge rectifier (DBR) with a high value of smoothening DC link capacitor. This combination of DBR and DC link capacitor draws current only for a small duration when the instantaneous value of supply voltage is higher than the DC link voltage. Therefore, a peaky current is drawn from the AC mains, which has very high value of harmonic contents. This total harmonic distortion (THD) of such current leads to a very poor factor (PF) at AC mains. A Power factor correction (PFC) converter is used to avoid power quality problems at the AC mains.In this project, a new configuration of bridgeless isolated-Cuk converter fed BLDC motor drive has been proposed for low power household appliances. The speed control of BLDC motor has been achieved by controlling the DC link voltage of VSI feeding BLDC motor. This bridgeless isolated-Cuk converter has been designed for the elimination of diode bridge rectifier at the front-end for reducing the conduction losses in the front-end converter. This PFC converter has been operated in DICM for DC link voltage control and inherent power factor correction is achieved at the AC mains.

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The BLDC motor has advantages such as high efficiency, high torque/inertia ratio, speed control and low noise and electro-magnetic interference (EMI) make brushless DC (BLDC) motor an ideal choice in many applications [1]. The BLDC motor finds applications in many household appliances, industrial tools, medical equipments, precise motion control and automation and transportation [1-5]. The BLDC motor is made of three phase concentrated windings on the stator and permanent magnets on the rotor [1]. A three-phase voltage source inverter (VSI) is used to achieve an electronic commutation of the BLDC motor [6]. A VSI fed BLDC motor drive is provided by a combination of a diode bridge rectifier (DBR) and a high value of smoothening DC link capacitor [7]. This combination of DBR and DC link capacitor draws current only for a small duration when the instantaneous value of supply voltage is higher than the DC link voltage [8]. Peaky current is drawn from the AC mains, which has very high value of harmonic contents [8]. The total harmonic distortion (THD) of current is in the order of 60-80 % which leads to a very poor factor (PF) [9]. The current sensors are required for achieving the pulse width modulation (PWM) based current control of BLDC motor for speed control [6, 7]. Moreover, such BLDC motor drives suffer from high losses in VSI due to high switching frequency. These losses are reduced by operating the VSI in low frequency switching by electronically commutating the BLDC motor. Moreover, the speed of the BLDC motor is controlled by varying the DC link voltage of the VSI [7].

Power factor correction (PFC) converters avoid power quality problems at the AC mains and to meet the prescribed guidelines of IEC 61000-3-2 [10, 11]. The PFC converter plays major role in deciding the cost of overall system. The number of sensors for a PFC converter is primarily decided by mode of operation of the PFC converter. Continuous inductor current mode (CICM) and discontinuous inductor current mode (DICM) are two modes of operation of the PFC converter. In CICM, or
continuous conduction mode (CCM), the current in inductor remains continuous in a switching period, whereas the current becomes discontinuous in a switching period for a PFC converter operating in DICM. The PFC converter operating in CICM uses a current multiplier approach for voltage control and power factor correction. It induces lower current stress on the PFC converter switch and needs three sensors (2-V, 1-C) for its operation. A single voltage sensor is used for a PFC converter operating in DICM using voltage follower approach, but at the cost of high current stress on the PFC converter switches [12]. This mode of operation is suited for low power applications.

II. PROPOSED PFC BRIDGELESS ISOLATED-CUK CONVERTER FED BLDC MOTOR DRIVE

Fig. 1 shows the proposed PFC bridgeless isolated-Cuk converter fed BLDC motor drive. A single-phase supply is followed by a LC-filter to feed a bridgeless isolated- Cuk converter. The Converter maintains the required DC link voltage of the VSI and provides power factor correction at AC mains. The proposed PFC converter is operated in DICM to behave as an inherent power factor corrector. The DC link voltage of the VSI is controlled for varying the speed of the BLDC motor. The BLDC motor is operated in a low frequency switching to achieve an electronic commutation of BLDC motor. The single voltage sensor controls the DC link voltage to achieve speed control of BLDC motor. The proposed drive is designed and its performance is validated on a developed prototype for improved power quality at AC mains for a speed control with different supply voltages.

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III. OPERATION OF PFC BASED BRIDGELESS ISOLATED-CUK CONVERTER

The proposed PFC converter operation is classified into two different sections such as a line cycle and a switching cycle. Fig. 2 shows six different modes of operation.

A. Line Cycle operation mode

The proposed bridgeless isolated-Cuk converter is designed with two switches *Sw1* and *Sw2* that conducts for positive and negative half cycles of supply voltage respectively. In positive half cycle of supply voltage, switch *Sw1*, inductors *Li1* and *Lo1*, intermediate capacitors *C11* and *C21* and diodes *D1* and *Dp* are in state of conduction and vice-versa for negative half cycle of supply voltage as shown in Figs. 2 (a-f).

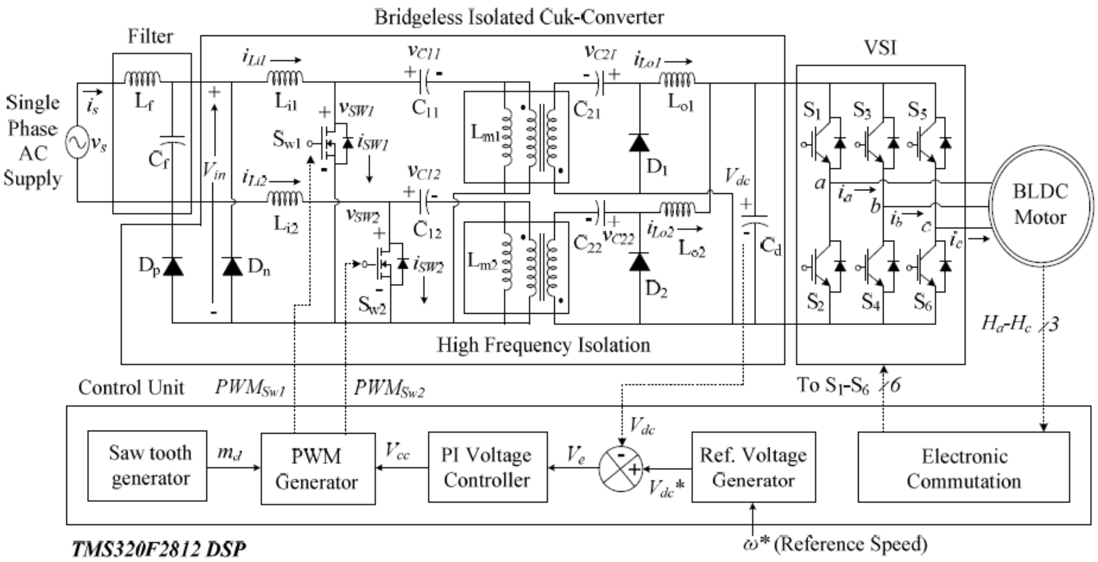

Fig. 1. Proposed configuration of a bridgeless isolated Cuk converter feeding BLDC motor drive.

During the DICM operation, the current of output inductors (*Lo1* and *Lo2*) becomes discontinuous in a switching period. Therefore, the current flowing in input and magnetizing inductance of HFT (*Li1*, *Li2*, *Lm1* and *Lm2*) and voltage across the intermediate capacitor (*C11*, *C12*, *C21* and *C22*) remain continuous in a complete switching period.

B. Switching Cycle operation mode

Figs. 2 (a-c) shows three modes of operation Cuk converter in a switching period for positive half cycle of supply voltage.

P-I mode: In PI mode, the switch (*Sw1*) is turned-on, and the input inductor (*Li1*), output inductor (*Lo1*) and magnetizing inductance of high frequency transformer (HFT) (*Lm1*) are charged as shown in Fig. 2 (a). The input side intermediate capacitor (*C11*) supply energy to the HFT and output side intermediate capacitor (*C21*) supply the energy to the DC link capacitor.

P-II mode: In this mode switch (*Sw1*) is turned-off, input inductor (*Li1*), output inductor (*Lo1*) and magnetizing inductance of HFT (*Lm1*) starts discharging. The intermediate capacitors (*C11* and *C21*) charge and the DC link capacitor (*Cd*) also discharges in this interval.

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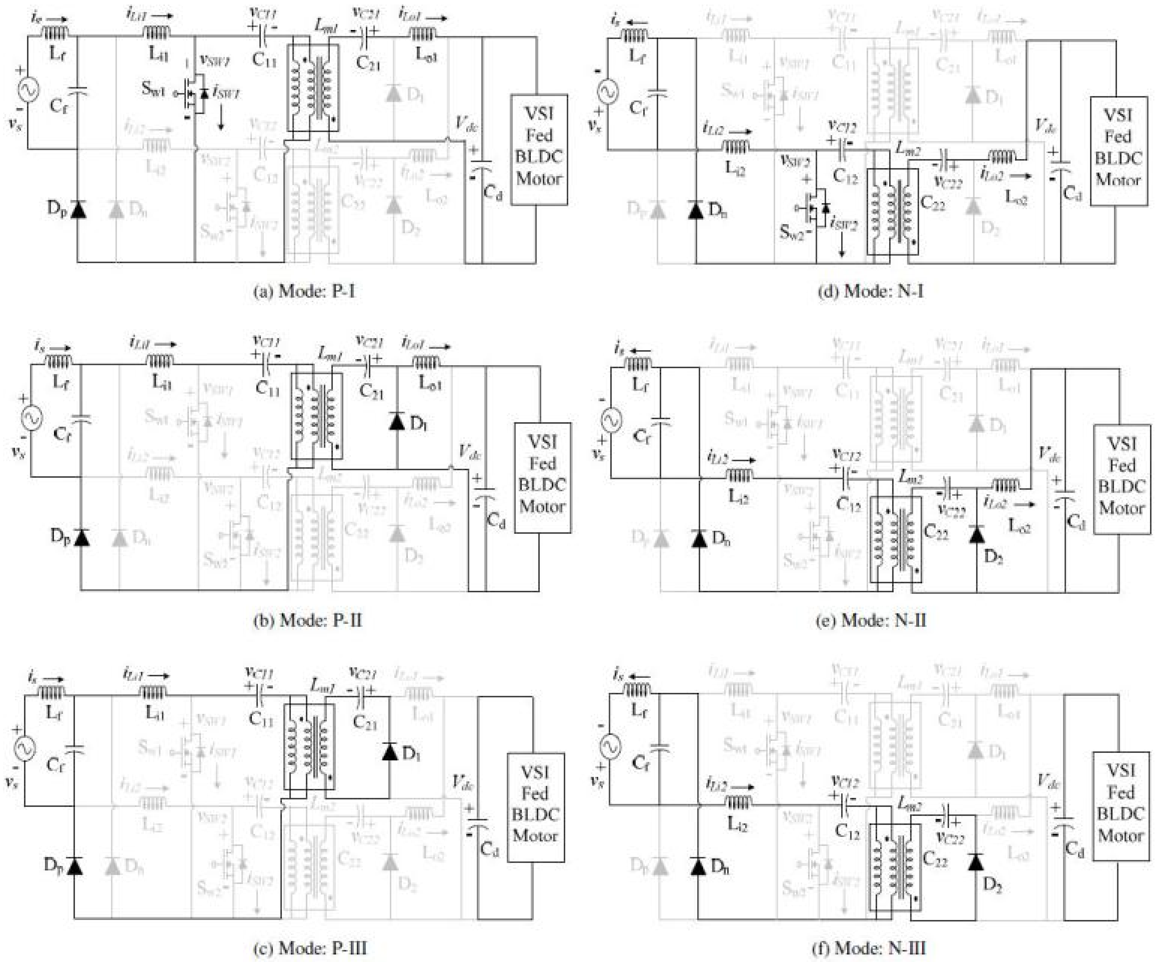

Fig. 2. Different modes of operation of bridgeless isolated Cuk converter during positive (a-c) and negative (d-f) half cycle of supply voltage.

P-III mode: In this mode, the input inductor (*Li1*) and magnetizing inductance of HFT (*Lm1*) continue to discharge and the output side inductor (*Lo1*) is completely discharged. The output side intermediate capacitor (*C21*) continues charging and the DC link capacitor (*Cd*) supply the energy to BLDCM. The operation for the negative half cycle of the supply voltage is realized in the similar way.

The intermediate capacitors (*C11*, *C12*, *C21* and *C22*) are completely discharged and are charged during the operation of the PFC converter initially. The voltage across the input side intermediate capacitors (*C11* and *C12*) depend upon the instantaneous input voltage; hence, the initial charging voltage of *C11* and *C12* is zero. However, the output side intermediate capacitors (*C21* and *C22*) are not completely discharged in a switching period or a half line cycle of supply voltage due to the voltage maintained at the DC link capacitor (*Cd*). Moreover, during the operation of PFC converter in positive half cycle; the energy storage components on the primary side of the HFT (i.e. *Li2*, *C12* and *Lm2*) remain in non-conducting state and are completely discharged. The energy storage components on the secondary side of HFT (i.e. *C22*) remain charged at its full voltage due to the unavailability of discharging path and the presence of DC link capacitor (*Cd*).

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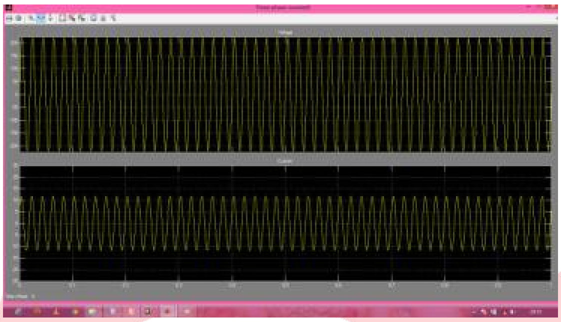
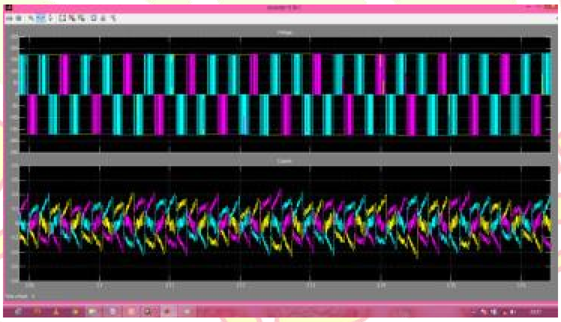
IV SIMULATION RESULTS

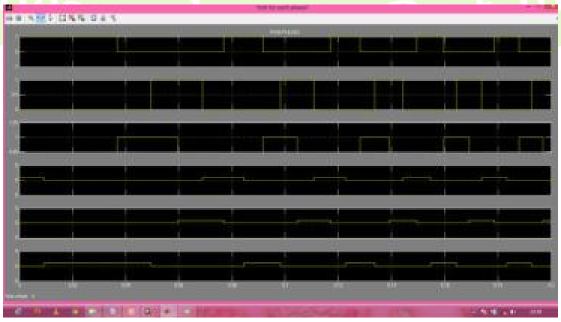


Input Voltage

DC Link Voltage



Inverter Voltage and Current



Phase Voltage

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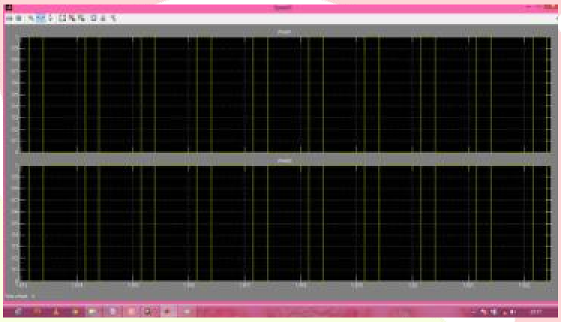
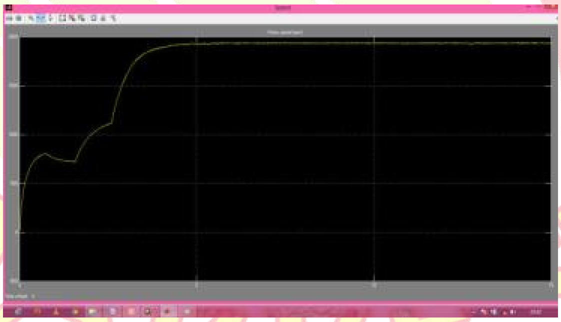
Phase current



Pulse width Modulation Output



Rotor speed

Stator Current

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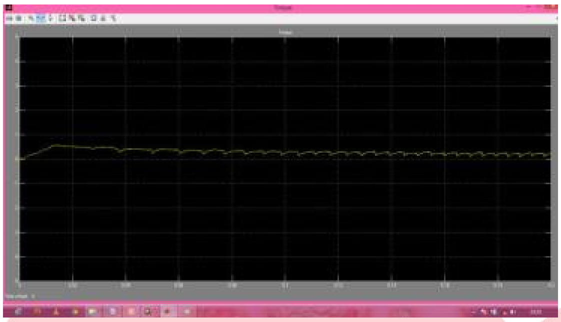

Torque

RESULTS AND DISCUSSION

A new configuration of bridgeless Cuk converter fed BLDC motor drive has been proposed for low power household appliances. The speed control of BLDC motor has been achieved by controlling the DC link voltage of VSI feeding BLDC motor. This has facilitated the operation of VSI in low frequency switching mode for reducing the switching losses associated with it. This bridgeless Cuk converter has been designed for the elimination of diode bridge rectifier at the front-end for reducing the conduction losses in the front-end converter. This PFC converter has been operated in DICM for DC link voltage control and inherent power factor correction is achieved at the AC mains. A prototype of proposed drive has been implemented using a DSP. Satisfactory test results for proposed bridgeless isolated-Cuk-converter fed BLDC motor has been evaluated for its operation over complete speed range. Moreover, the performance of proposed drive is also evaluated for operation at wide range of supply voltages. The obtained power quality indices have been found within limits of power quality standards as IEC61000-3-2.

The proposed work realizes achievement of unity power factor operating the bridgeless cuk converter in the DICM mode. The future work implements hardware configuration of the BLDC with Bridgeless cuk converter.

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