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Power Factor Correction using Zeta Converter for SMPS and BLDC Motor drive Applications

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Abstract- BRUSHLESS dc (BLDC) motors have become increasingly popular in the past decade due to the advantages such as high efficiency, high power density, compact size, high ruggedness, low maintenance requirements, and their immunity to electromagnetic interference (EMI) problems. Switched Mode Power Supply (SMPS) is an integral part of the computer that converts ac to multiple numbers of suitable dc voltages to impart power to different parts of the PC. It contains a diode bridge rectifier (DBR) with a capacitor filter followed by an isolated dc-dc converter to achieve multiple dc output voltages of different ratings. In this paper, a non-isolated power factor corrected (PFC) converter is being proposed to be used at the front end to improve the power quality of an SMPS for a PC. The front-end converter is able to reduce the 100-Hz ripple in its output that is being fed to the second stage isolated converter. The performance of the front-end Zeta converter is evaluated in three different operating conditions to select the best operating condition for the proposed SMPS system. The uncontrolled charging and discharging of the capacitor result in a highly distorted, high crest factor, periodically dense input current at the single phase ac mains; this violates the limits of international power quality (PQ) standards. The proposed concept is implemented with both BLDC and SMPS applications and This can be applied for BLDC motor application, i.e. Power Factor Correction using Zeta Converter for SMPS feeding Motor load results are verified using Matlab/Simulink software.

Index Terms—multiple outputs, power factor correctedZeta converter, power quality, switched mode power supply (SMPS), unity power factor.

I. INTRODUCTION

In electrical engineering, power conversion has a more specific meaning, namely converting electric power from one form to another. Some of these converters have found places in industry for a variety of applications.Practical electronic converters use switching techniques. Switched-mode DC-DC converters convert one DC voltage level to another, which may be higher or lower, by storing the input energy temporarily and then releasing that energy to the output at a different voltage [1-2]. The storage may be in either magnetic field storage components (inductors, transformers) or electric field storage components (capacitors). There are also devices and methods to convert between power systems designed for single and three-phase operation. One way of classifying power conversion systems is according to whether the input and output are Alternating Current (AC) or Direct Current (DC).Now here comes the problem: In an alternating current (AC) electrical supply, a mysterious thing called "Power Factor" comes into play. Power Factor is simply the measure of the efficiency of the power being used, so, a power factor of 1 would mean 100% of the supply is being used efficiently. A power factor of 0.5 means the use of the power is very inefficient or wasteful [3-8].So what causes Power Factor to change? In the real world of industry and commerce, a power factor of 1 is not obtainable because equipment such as electric motors, welding sets, fluorescent and high bay

lighting create what is called an "inductive load" which in turn causes the amps in the supply to lag the volts. The resulting lag is called Power Factor [9].

The permanent magnet brushless dc motor is rapidly gaining the popularity because of its performance, reliability, efficiency, wide speed control and also suitable for low power applications. The improved power quality converters required for many applications involving power converters [10].DC diode bridge rectifier and a smoothening DC link capacitor, which results pulsed currents from AC mains and various power quality disturbances such as poor power factor, total harmonic distortion, and high crest factor of current [11].Moreover, various international PQ standards for low power applications such as IEC 61000-3-2 emphasize on low THD of AC mains current and power factor is near unity, and therefore various PFC converter topology for DCM drive is essential [12].The air-conditioner uses single phase induction motor which is an intensive energy application, efficiency of these motor is between 70-80% in the low power range which can be improved by replacing the PMBLDCM drive. The air-conditioner compressor load drives by PMBLDCM and the efficiency are improved.

II. PROPOSEDPFC ZETACONVERTERBASED SMPS CONFIGURATION

Fig.1 shows the system configuration of a PFC Zeta converter based multi-output SMPS topology. At the input, a DBR with filter is connected to a non-isolated

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Zeta converter. It consists of two inductorsLz1andLz2, one intermediate capacitor C1, one high frequency switch S and one diode D. This PFC converter regulates the output dc voltage and draws a sinusoidal current from the ac mains at unity PF. Three different DCM conditions (i.e., input inductor DCM, intermediate capacitor DCM and output inductor DCM) are considered here to choose the best operating condition of the front-end PFC converter. In the DCM operation, the current becomes zero either in the input inductor or output inductor, or the voltage across the intermediate capacitor becomes zero for some duration in one switching cycle. The output dc voltage is regulated using a Proportional–Integral (PI) voltage controller.

The regulated output dc voltage is connected to an isolated converter for achieving multiple dc voltages at the output. The isolated converter consists of two equal valued input capacitors, two switches, one high frequency transformer (HFT) and filters. The filters are used in each output winding to reduce the output voltage and current ripples. Only one of the output voltages is directly sensed and the other output voltages are controlled by the duty cycle of the isolated converter. The winding that is selected for control action is of the largest power rating among all the outputs. Further, to reduce the component stresses, the isolated converter is designed in CCM. Another voltage PI controller is used here to regulate the output voltage. The performance of the proposed PFC Zeta converter based SMPS is demonstrated for a wide variation in the input voltages from 170 to 260 V and loads with the input power quality indices recorded for each of these operating conditions.

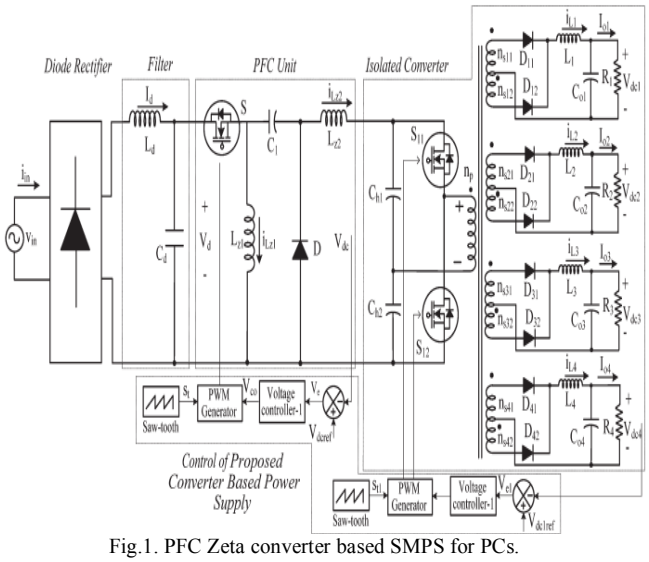


Fig.1. PFC Zeta converter based SMPS for PCs.

III. OPERATINGPRINCIPLE OF THE PROPOSED SMPS

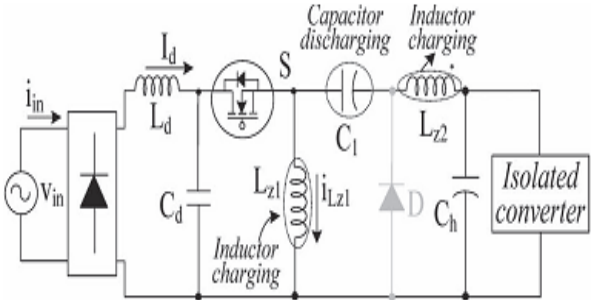
The operation of the proposed SMPS is studied to analyse its behaviour in one switching cycle. Three different conditions (input inductor in DCM, intermediate capacitor in DCM, output inductor in DCM) have been considered for the PFC Zeta converter to select the best operating condition.

A. PFC Converter Operation When Input Inductor is in DCM

Fig.2 shows the operation of a PFC Zeta converter when the input inductor is in DCM. The current in the input inductor remains zero for some time in one switching cycle while the current in the output inductor and voltage across the intermediate capacitor remain non-zero.

1) Mode I:

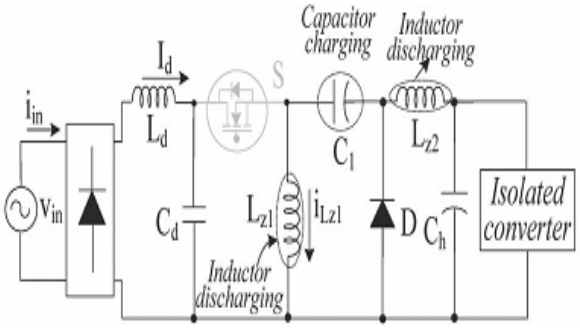
When the PFC switch S turns on, the current in the input inductor $L_{z1}$and output inductor L_{z2} start increasing and the voltage across the capacitor starts decreasing.



(a)

2) Mode II:

When S is turned off, diode D starts conducting as shown in Fig.2 (b). The stored energy in L_{z1} starts decreasing and continues until the current i_{Lz2} equals the negative of the current i_{Lz1}. The voltage across the intermediate capacitor C_1 starts increasing.



(b)

3) Mode III:

Both switch S and diode D are off in this period of one switching cycle as shown in Fig.2 (c). This state lasts until the start of the next PWM cycle. The input inductor current i_{Lz1}remains zero ensuring the DCM condition.

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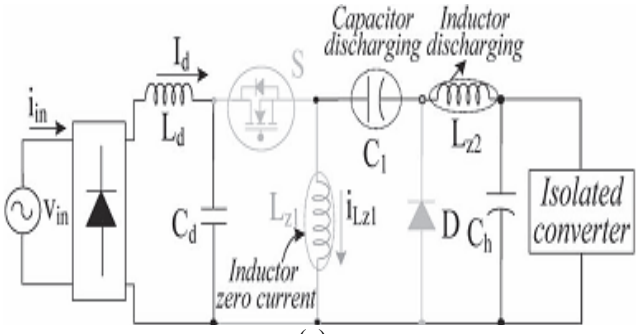
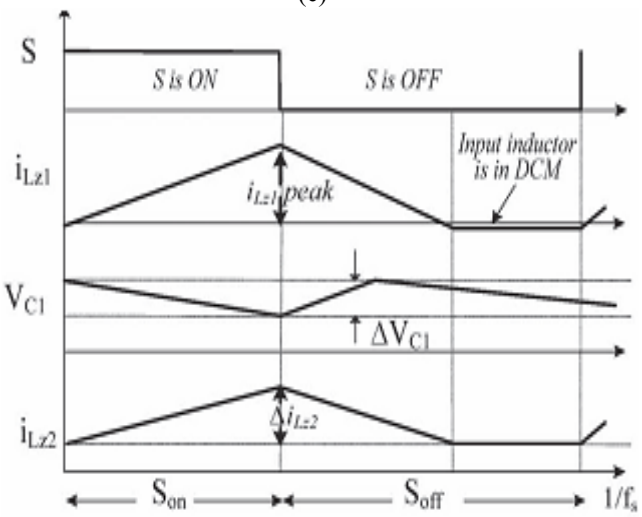


(c)



(d)

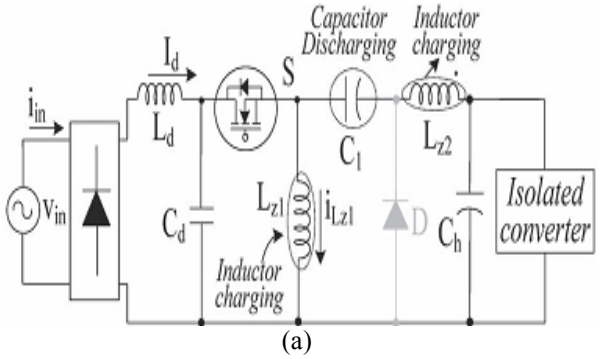
Fig.2. Operating modes of the PFC Zeta converter in one switching cycle when $L_{z1}$is in DCM (a) when input inductor is charging, (b) when input inductor is discharging, and (c) when input inductor is in zero current mode. (d) Waveforms of various components in one switching cycle.

B. PFC Converter with Intermediate Capacitor in DCM

The operation of a PFC Zeta converter, when the intermediate capacitor is operating in DCM, is shown in Fig.3.The three switching states are described as follows:

1) Mode I:

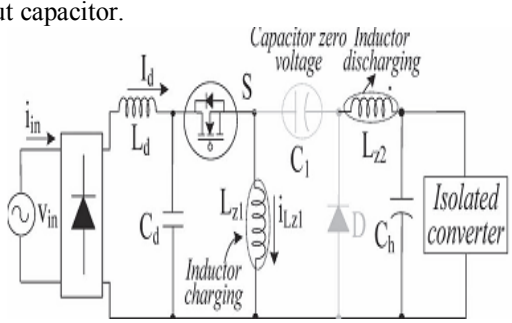
When switch S turns on, the currents in inductors $L_{z1}$and L_{z2} are increasing while the intermediate capacitor discharges through the output inductor L_{z2}; the voltage across the output capacitor increases.



(a)

2) Mode II:

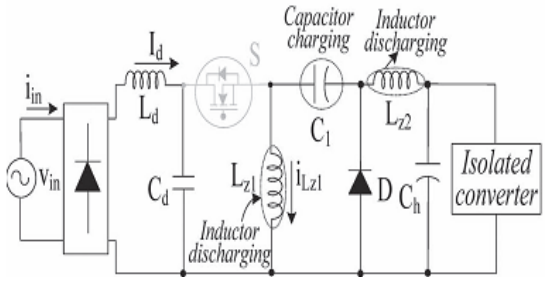
In this mode, switch S is in conduction state but the intermediate capacitor C_1 is completely discharged and the voltage across C_1 becomes zero. In this condition, output inductor L_{z2} continues to supply energy to the output capacitor.



(b)

3) Mode III:

Switch S now turns off, input inductor L_{z1} is discharging through the intermediate capacitor. The output inductor L_{z2} is discharging through the isolated converter while maintaining continuous conduction.



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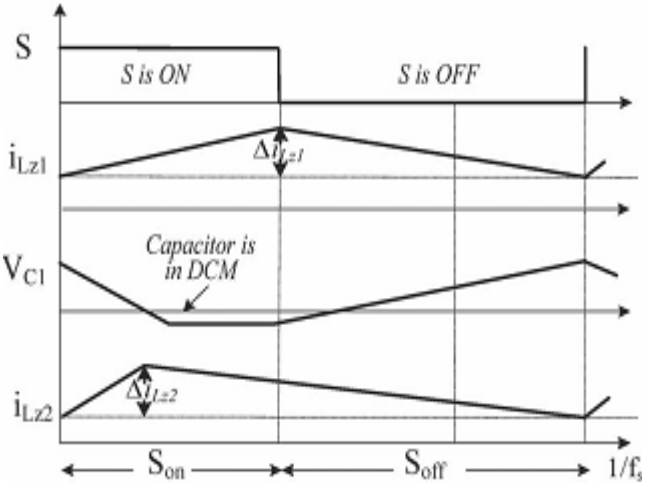

(d)

Fig.3. Operating modes of the PFC Zeta converter in one switching cycle when $C_1$is in DCM (a) when capacitor is discharging, (b) when capacitor is in zero voltage mode, and (c) when capacitor is charging. (d) Waveforms of various components in one switching cycle.

C. PFC Converter with Output Inductor in DCM

The DCM operation of the output inductor in one switching cycle is shown in Fig.4. The output inductor is designed in DCM and therefore, the current in the output inductor remains zero for a certain time period in one

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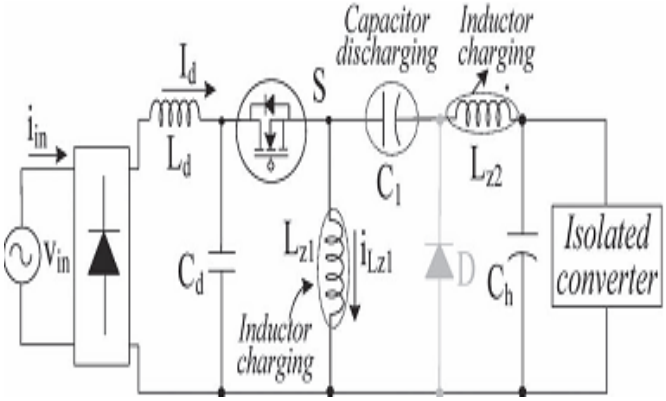
switching cycle. The different modes of conduction in one switching cycle are described as follows.

1) Mode I:

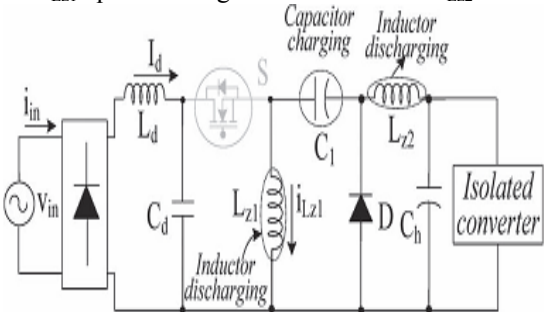
The PFC switch S turns on; the input voltage supplies energy to inductor L_{z1}. The intermediate capacitor discharges through the output inductor L_{z2}. The currents in L_{z1} and the output inductor increase linearly.



(a)

2) Mode II:

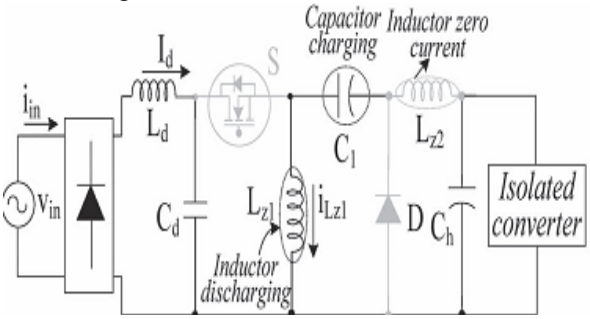
The switch S turns off and diode D turns on as shown in Fig.4 (b). The stored energy in $L_{z1}$is transferred to the capacitor C_1; the output inductor energy is fed to the isolated converter. This stage continues until the current i_{Lz1}equals the negative of the current i_{Lz2}.



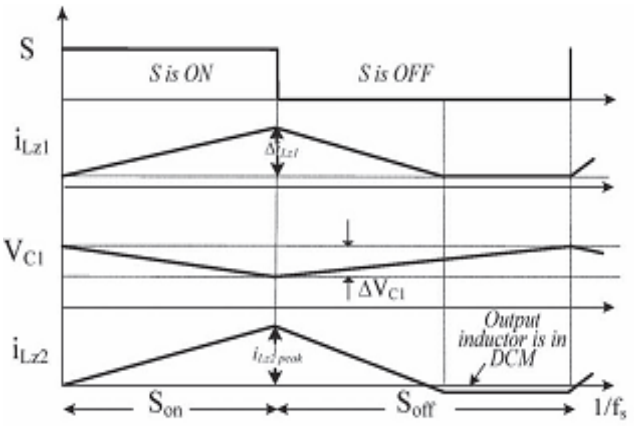
(b)

3) Mode III:

The switch and diode both are off in this duration of one switching cycle as shown in Fig.4 (c). This state lasts until the start of the next PWM cycle. The output inductor current remains zero in the remaining time ensuring the DCM condition.



(c)



(d)

Fig.4. Operating modes of the PFC Zeta converter in one switching cycle when L_{z2} is in DCM (a) when output inductor is charging, (b) when output inductor is discharging, (c) and when output inductor is in zero current mode. (d) Waveforms of various components in one switching cycle.

D. Isolated Converter

The operation of the isolated half-bridge converter working in CCM is described in two states during one half of the switching cycle (Fig.5) where the upper switch is involved. In the second half of one switching cycle, the same procedure repeats with the involvement of the lower switch.

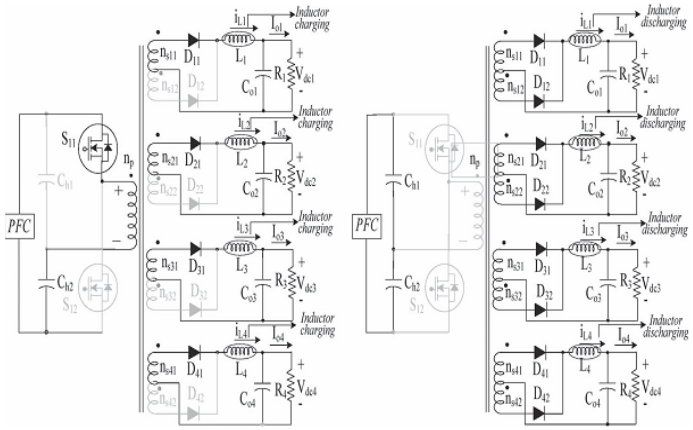


Fig.5. Operating modes of the isolated converter in one half of the switching cycle.

1) Inductor Charging:

The output voltage of the PFC Zeta converter is connected to one end of the primary winding of the HFT through switch S_{11}. Diodes D_1, D_3, D_5, D_7 start conducting. So, the output currents i_{Lo1}, i_{Lo2}, i_{Lo3}, and i_{Lo4} in inductors increase. When the inductor current reaches its maximum value, $S_{11}$is turned off.

2) Inductor Discharging:

The output inductor current in each secondary winding freewheels through corresponding diodes (D_1–D_8). The current in each winding cancels the flux until the voltages across all windings are reduced to zero.

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The same inductor charging and discharging take place in the next half of the switching cycle when the lower switch turns on and then turned off subsequently.

IV. DESIGN OF THEPROPOSEDPFC ZETA CONVERTERBASEDSMPS

The design of PFC Zeta converter based SMPS is carried out in this section. The design is based on the change in the inductor current during the switch on and off period. The diodes and switches are considered ideal. The switching frequency considered is high as compared to the line frequency; so, average magnitudes (of currents and voltages) within a PWM period are considered for analysis.

The relation between output voltage, V_{dc} and input voltage V_d of the Zeta buck-boost converter is expressed as

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

Therefore, the instantaneous value of duty ratio, D (t) is expressed as

$$D(t) = \frac{V_{dc}}{V_{in}(t) + V_{dc}} \quad (2)$$

A.Output Capacitor Selection

The input capacitor(s) of the isolated converter also works as the output capacitor of the Zeta converter. It is selected such that it eliminates the second order harmonic voltage introduced due to the single phase ac mains. The output capacitor value is selected as

$$C_h = \frac{I_{dc}}{2\omega\Delta V_{dc}} \quad (3)$$

The estimated output capacitors are calculated as 400µFfor a 9V ripple. The selected value of output capacitors $C_{h1} = C_{h2}$ are taken as 330µF in hardware.

B.Filter Design

The input filter design is very important for maintaining low harmonic distortion at the input ac mains. The maximum filter capacitance is expressed as

$$C_{max} = \frac{I_p \tan\theta}{2 * \pi * f * V_p} \quad (4)$$

Where V_p and I_p are the peak input voltage and current and θ is considered 1◦ for maintaining high PF. The maximum capacitance C_{max} is estimated as 0.4µF and the selected value C_d in hardware is 330 nF.

TABLE I
Selected values for the PFC converter for the power supply

Component	Calculated	Selected	Experimental
Input inductor L_{z1}	4.6mH	5mH	5mH
Input inductor L_{z2}	1.15mH	0.7mH	0.7mH
Capacitor C_1	0.062µF	66nF	66nF
Filter capacitor C_d	400nF	330nF	330nF
Filter inductor L_d	3.1mH	3mH	3mH
Capacitor C_{h1} and C_{h2}	630µF	660µF	660µF

The filter inductor to maintain low ripple is calculated as

$$L_d = \frac{1}{4 * \pi^2 * f_c^2 * C_d} \quad (5)$$

Where f_c is the cut off frequency which is selected such that it is more than the fundamental frequency (f = 50Hz) and less than switching frequency f_s (20 kHz). Therefore, it is taken as 2 kHz here. L_d from the above equation is calculated as 3.1 mH and the selected value in hardware is 3 mH. The selected component values are tabulated in Table. I.

IV. CONTROL OF THEPROPOSEDPC SMPS

Two independent controllers are used to control the dc output voltages of the PFC converter and the isolated converter. The front-end converter is controlled using voltage follower approach while the isolated converter utilizes average current control.

A. Control of PFC Converter

The control of the front-end PFC converter generates pulses according to the output voltage error, which is the voltage difference between the desired voltage and sensed voltage. The voltage error signal (V_e) at nth instant is

$$V_e(n) = V_{dcref}(n) - V_{dc}(n) \quad (6)$$

V_e is fed to the proportional–integral (PI) controller to generate a controlled output voltage (V_{co})

$$V_{co}(n) = V_{co}(n-1) + k_p V_e(n) - V_e(n-1) + k_i V_e(n) \quad (7)$$

Where k_p and k_i are the proportional and integral gains of the PI controller.

The output of the PI controller is compared with a high frequency saw-tooth signal (S_t) to generate the PWM pulses.

If $S_t < V_{co}$, then S=ON, else S=OFF where, S represents the switching signals for the PFC converter device. If the output voltage varies, the control output voltage Vco changes to vary the duty cycle. Hence, the width of PWM pulses changes accordingly to maintain the dc output voltage as a constant.

B. Control of Isolated Converter

To control the multiple dc output voltages of the isolated converter, average current control scheme is

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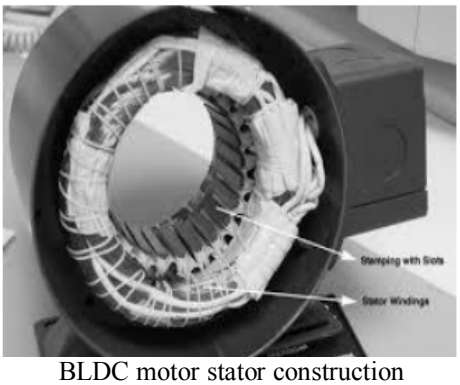
used. Only one winding's output voltage which is having the highest power rating is controlled. The other windings' output voltages are controlled by the duty cycle of the converter as a common core is used for all secondary windings. The responses of the other windings are slow as compared to the output whose voltage is sensed. For control, output voltageVdc1is sensed and compared with the corresponding reference voltage to produce voltage error which is the input to the PI controller. The output of this PI controller is compared with a saw-tooth wave to generate the switching pulses for both the switches $S_1$and S_2.

Both the switches are switched on and off alternately in each half cycle of one PWM period with sufficient dead time to avoid shoot-through. The width of the pulses varies according to the voltage error. Thus, the control of isolated converter is able to take care of the impact of other output voltage variations (due to load changes in these outputs) by modifying the duty ratio. If any winding undergoes a load change, the duty ratio changes according to the impact felt on the sensed output to maintain voltage regulation on all the outputs.

BLDC MOTOR

BLDC engine comprises of the perpetual magnet rotor and an injury stator. The brushless engines are controlled utilizing a three stage inverter. The engine obliges a rotor position sensor for beginning and for giving legitimate compensation arrangement to turn on the force gadgets in the inverter extension. In light of the rotor position, the force gadgets are commutated consecutively every 60 degrees. The electronic compensation takes out the issues connected with the brush and the commutator plan, in particular starting and destroying of the commutator brush course of action, along these lines, making a BLDC engine more rough contrasted with a dc engine. Fig.4 demonstrates the stator of the BLDC engine and fig.5 shows rotor magnet plans.



BLDC motor stator construction


BLDC motor Rotor construction.

The brush less dc engine comprise of four fundamental parts Power converter, changeless magnet brushless DC Motor (BLDCM), sensors and control calculation. The force converter changes power from the source to the BLDCM which thus changes over electrical vitality to mechanical vitality. One of the remarkable highlights of the brush less dc engine is the rotor position sensors, in view of the rotor position and order signals which may be a torque charge, voltage summon, rate order etc; the control calculation s focus the entryway sign to every semiconductor in the force electronic converter.

The structure of the control calculations decides the sort of the brush less dc engine of which there are two principle classes voltage source based drives and current source based drives. Both voltage source and current source based commute utilized for perpetual magnet brushless DC machine. The back emf waveform of the engine is demonstrated in the fig. 6. Be that as it may, machine with a non sinusoidal back emf brings about diminishment in the inverter size and lessens misfortunes for the same influence level.

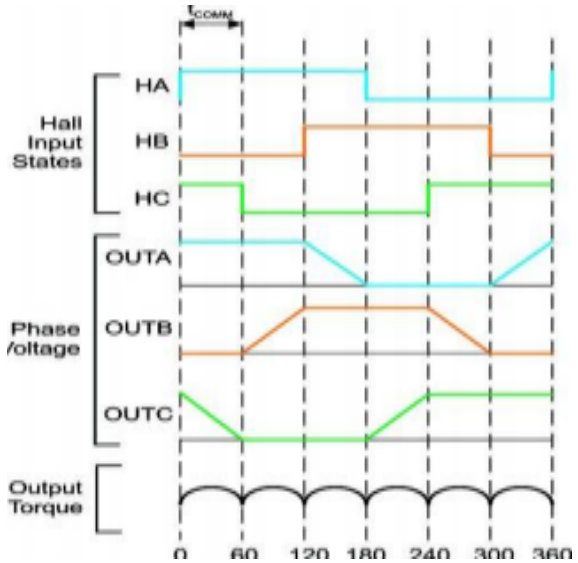


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Fig.6. Hall signals & Stator voltages.

V.MATLAB/SIMULATION RESULTS

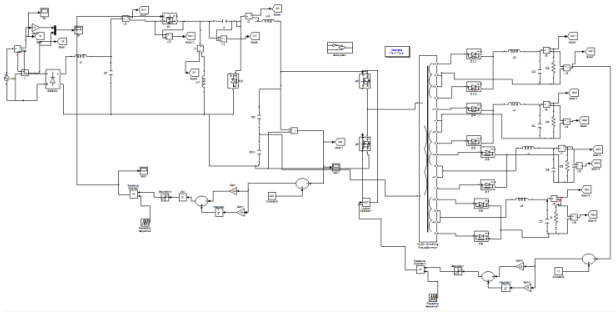

Fig 7 Matlab/simulation circuit of when Vdc=300v when Lz1 in DCM mode

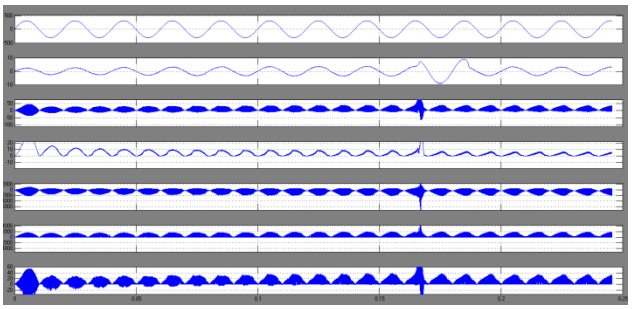

Fig 8 Simulation waveforms of vin, iin, iLz1, iLz2, VC1, VS, IS when Lz1 is in DCM

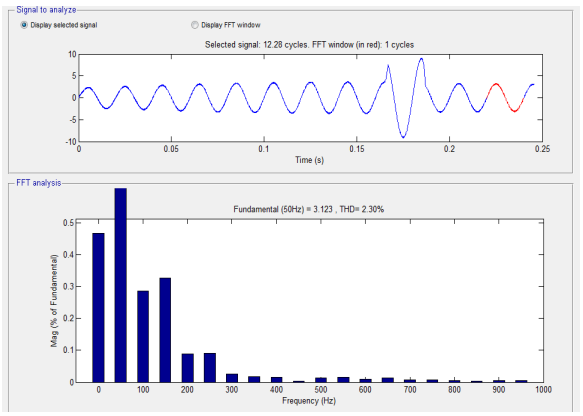

Fig 9 simulation THD analysis when Lz1 is in DCM mode

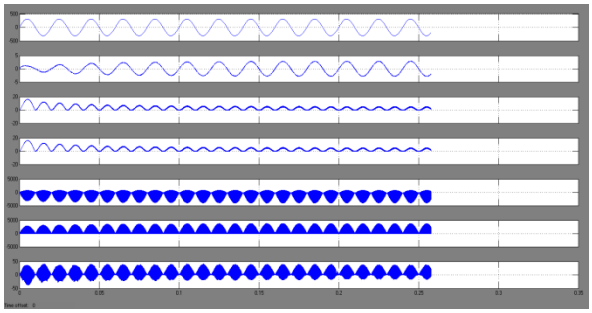

Fig 10 Waveforms of PFC converter when C1 is operating in DCM.
(a) Waveforms of vin, iin, iLz1, iLz2, VC1, VS, IS

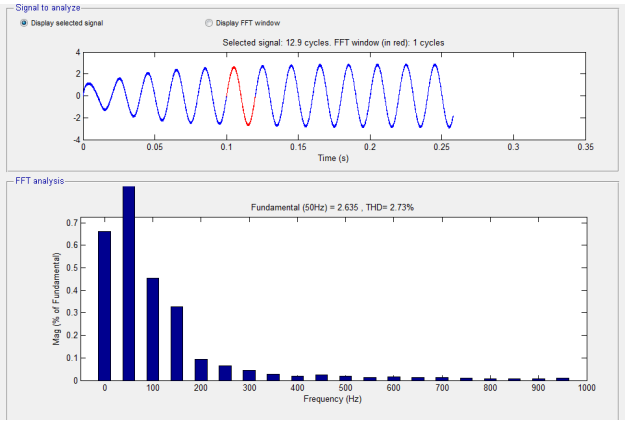

Fig 11 simulation THD analysis when C1 is DCM mode

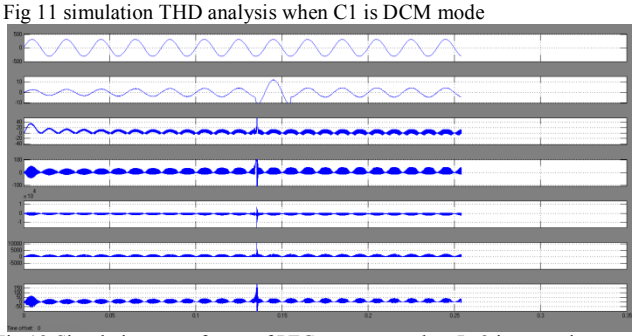

Fig 12 Simulation waveforms of PFC converter when Lz2 is operating in DCM. Waveforms of vin, iin, iLz1, iLz2, VC1, VS, IS

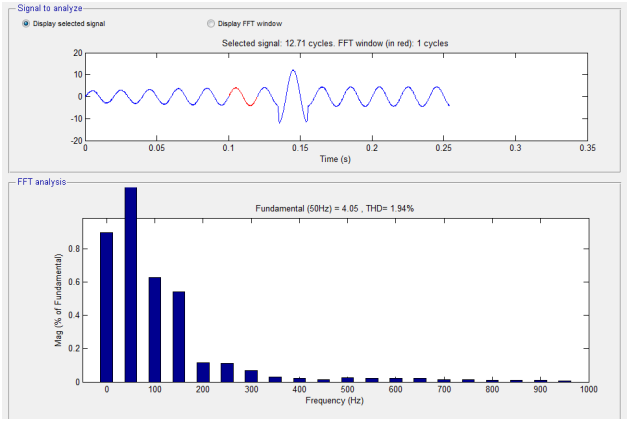

Fig 13 simulation THD analysis when Lz2 in DCM mode

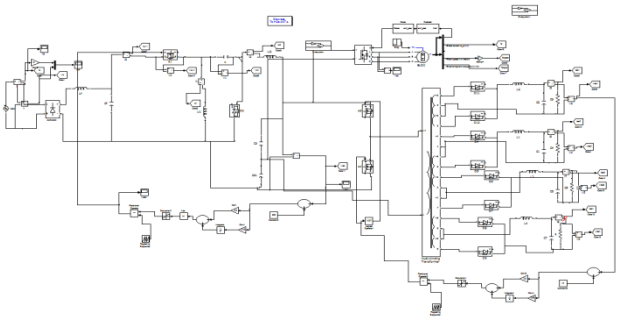

Fig 14 Matlab/simulation circuit of when Vdc=300v when Lz1 in DCM mode with BLDC motor drive

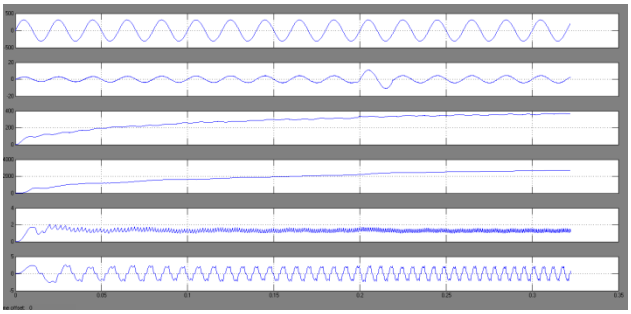

Fig 15 simulation wave form BLDC motor characteristics of stator current, EMF, speed and electromagnetic torque

VI.CONCLUSION

A Zeta converter for VSI-fed DC motor drive has been designed for achieving a unity PF at ac mains for the development of the low-cost PFC motor for numerous low-power equipment's such fans, blowers, water pumps, etc. The speed of the DC motor drive has been low-power renewable energy and oscillating controlled by varying the dc-link voltage of VSI, switching mode for reduced switching losses. Three different intervals of operation for the Zeta converter operating in the DICM have been explored for the of a simple digital control strategy for brushless development of the DC motor drive with PF near to DC generatorssatisfactory results in all aspects and is a recommended solution for low-power BLDC motor drives and study the characteristics of BLDC motor drive

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