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# Study on DC-DC Converters for a Pfc BLDC Motor Drive

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***Abstract:*** *Motors are an essential components that drives almost every systems in motion around us. There are several classification of motors depending on the construction and type of electrical input power. A brief comparison about the several classifications of motor is done. From the comparative study the benefits of BLDC motor in low and medium power applications than the induction motors are clearly identified. And these permanent magnet (PM) brushless dc motor (PMBLDCM) is fed from a single-phase ac mains as a source of energy. Instead of conventional brush type commutation in induction motor, a three-phase voltage-source inverter is used as an electronic commutator to operate the PMBLDC Motor in the motor drive. The comparative study of DC-DC converters is presented which includes the SEPIC, Cuk, ZETA and Luo converters derived from the fundamental buck, boost and buck boost converters which all are mainly used in BLDC motor drives. All these DCDC converter functions as a single-stage power-factor-correction converter for a permanent magnet (PM) brushless dc motor (PMBLDCM) fed from a single-phase ac mains. A hall effect sensor and single voltage sensor is used for the speed control of the BLDC motor .From the comparative study carried down among the different derived converters it is inferred that BLDC drive system fed with Luo converter have the least ripple characteristics and so Luo converter fed PFC BLDC Motor drive can be used for low power application with best performance standards. [1]*

***Keywords:*** *BLDC motor, PMBLDCM, Luo converter, ripple, PFC, Motor drive.*

## I. Introduction

Every day we see systems in motion all around us. What makes them move? On the outset, it may be due to wheels as in the case of an automobile. What actually drives these movements are motors. Additionally, many household appliances such as refrigerators, air-conditioners, ventilation fans, washers, driers and so many others all require electric motors. One can see that motors are part of our day-to-day life. Power electronics have a great roles among the various components and requirements in motor drives through applications that we use and encounter in household and industrial environments. While considering another important application called solar power energy system. To achieve the objective of having the maximum efficiency of the solar panels, the load must be connected to the solar panel through a power electronic DC-DC converter. The topologies and the operation of these converters are mentioned in the literature. There are five classical or traditional converters classification: (1) fundamental converters, (2) transformer-type converters, (3) developed converters, (4) voltage-lift converters, and (5) super-lift converters. The developed converters we are discussing in this literature are SEPIC (Single Ended Primary Inductance Converter) topology, Cuk converter topology, Luo converter topology and ZETA converter topology. The developed-type converters are derived from fundamental converters by addition of a low-pass filter in addition to the converter system. [2]

Motors are an essential components that drives almost every systems in motion around us. There are several classification of motors depending on the construction and type of electrical input power. Many household appliances such as refrigerators, air conditioners, ventilation fans, washers, driers and so many others all require electric motors. One can see that motors are part of our day-to-day life. Power electronics have a great roles among the various components and requirements in motor drives through applications that we use and encounter in household and industrial environments. The Brushless DC (BLDC) motors have become increasingly popular than other types of motor especially in low power and medium power applications 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 electro-magnetic interference (EMI) problems. A BLDC motor has many advantages over a brushed DC motor and an AC induction motor: It is easily controlled with position feedback sensors and generally performs well, especially in speed/torque. With these advantages, BLDC motor will spread to more applications. Moreover, with the development of sensor less technology, BLDC motor will become convenient or indispensable in applications with environmental limitations. The conventional BLDC motor drive using a front-end diode bridge rectifier (DBR) and a high value of DC link capacitor draws highly distorted peaky current which is rich in harmonics. Such configuration leads to a very low power factor of the order of 0.72 and high total harmonic distortion (THD) of supply current at AC mains. Such power quality indices are not acceptable under the limits of international power quality standards such as IEC 61000-3-2. Moreover, such power quality indices also increase the EMI in the PFC converter. These EMI's are classified into two categories as conducted and radiated EMI, respectively. At lower frequencies, the EMI is primarily caused by the conduction and at higher frequencies; the EMI is caused by the radiation. Such EMI causes problems such as skin effect, high overshoot transients, hysteresis loss, eddy current loss and voltage drop which affect the overall efficiency and performance of the system. Therefore, improved power quality converters are used for improving the power quality at AC mains which also reduce such EMI problems. An improved power quality converters can be designed to operate in either continuous conduction mode or discontinuous conduction mode of operation. A continuous conduction mode offers an advantage of lower stress on a Power factor corrector converter switch, but requires a two control loops (i.e. voltage and current control loops) for achieving a DC link voltage control with PFC at AC mains. This requires three sensors for the operation, which is a costly option, and hence preferred for high power ratings (1kW). Whereas, the converter operating in DCM acts as an inherent power factor corrector and hence requires a single voltage control loop (i.e. single voltage sensor) for DC link voltage control. However, a higher stress on PFC converter switch is obtained in a PFC converter operating in discontinuous inductor current mode (DICM); hence this mode is preferred for low power applications. A boost-PFC converter fed BLDC motor drive has been the most widely used configuration but it utilizes a constant DC link voltage with PWM (Pulse Width Modulation) based VSI for speed control. The conventional boost-PFC for feeding a BLDC motor drive suffers from high switching loss on account of high switching frequency of PWM pulses for VSI which drastically reduces the efficiency of overall system. Moreover, it also requires high number of sensors and complex control for its operation. A SEPIC (Single Ended Primary Inductance Converter) for feeding a BLDC motor drive. It uses a bifilar winding which uses a PWM based control of VSI and have high switching losses. A PFC Cuk converter fed BLDC motor drive using the control of variable DC link voltage. This utilizes a Cuk converter operating in Continuous Conduction Mode; hence requires three sensors and is preferred for higher power rating.

Bridgeless converter configurations have gained importance in the past decade due to their high efficiency. The front end DBR is eliminated in these configurations which reduce the conduction losses associated in them. The bridgeless buck and boost converters have been reported in and respectively. They suffer from a limited voltage conversion ratio (1 for boost converter) which limit its application for a wide range of speed control by varying DC link voltage. The bridgeless Cuk and SEPIC converters have also gained popularity due to a wide voltage conversion ratio. A Luo converter has been widely used due to its inherent characteristics of voltage lifting. Many versions of Luo converter voltage lifting technique such as re-lift. Super-lift and ultra-lift have been reported in the literature. The use of Luo converter as a PFC has been explored in. Inheriting the advantages of the Luo converter, a bridgeless configuration of the Luo converter is explored in this paper for feeding a BLDC motor as a low cost solution for low power applications to achieve the main research objective of finding out and an appropriate energy-effective drive unit by incorporating the best regulators, converters and inverters in electric motor fed from a renewable energy source.

## II. Motor Drive

### 2.1 Motor Drive System

An electric motor is a device that converts electrical energy to mechanical energy. It also can be viewed as a device that transfers energy from an electrical source to a mechanical load. The system in which the motor is located and makes it spin is called the drive, also referred to as the electric drive or motor drive. The function of the motor drive is to draw electrical energy from the electrical source and supply electrical energy to the motor, such that the desired mechanical output is achieved. Typically, this is the speed of the motor, torque, and the position of the motor shaft. Figure 2.1 shows the block diagram of a motor drive.

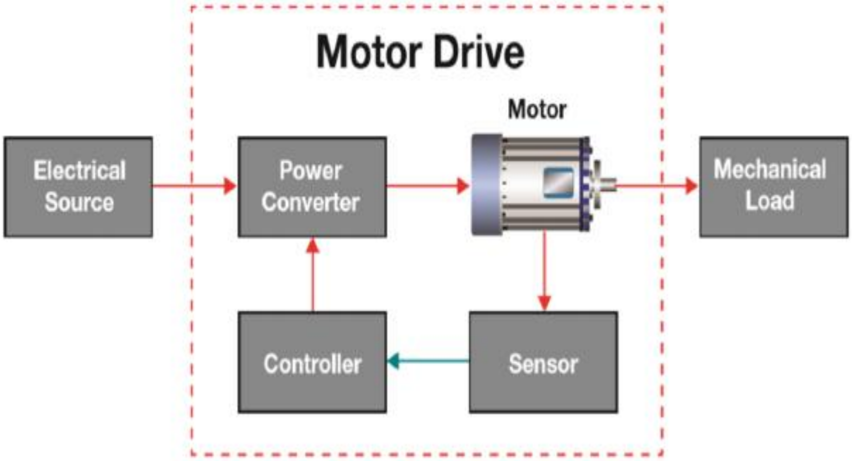


**Fig.2.1** Block diagram of a motor drive system

The functions of the power converter circuit in the motor drive are: Transfer electrical energy from a source that could be of a given voltage, current at a certain frequency and phase as the input to an electrical output of desired voltage, current, frequency and phase to the motor such that the required mechanical output of the motor is achieved to drive the load Controller regulates energy through feedback coming from the sensor block Signals measured by sensors from the motor are low-power, which are then sent to the controller [5] Controller tells the converter what it needs to be doing. A closed-loop feedback system is the method of comparing what is actually happening to what the motor should be outputting, then adjusting the output accordingly to maintain the target output.

### 2.2 Motor Drive Efficiency

Electric motors represent 45 percent of all electrical energy consumption across all applications. Increasing the efficiency of motor-drive systems could potentially result in a significant reduction in global electricity consumption. With increasing demand of electricity along with industrialization and urbanization across the globe, the ability to supply energy is becoming even more challenging. As part of a global effort to reduce energy consumption and carbon emissions on the environment, various regulations across many countries have put forth and are continually working on governmental mandates to improve motor drive efficiency. All these requirements make it compelling to have an efficient power converter system using switched mode power supplies (SMPS).

The SMPS uses semiconductor power switches (also called power electronic switches) in a switch mode and on and off states only, that yields 100 percent efficiency in an ideal situation. Power electronics systems are primarily designed using silicon-based power management with power semiconductor switches. These switches are power MOSFETs, bipolar junction transistors (BJTs), and isolated gate bipolar transistors (IGBTs) that have made significant improvements in their performances. [6] Examples include lower on-state resistance, increased blocking voltage, and higher drive currents.

### 2.3 Motor Drive Classifications

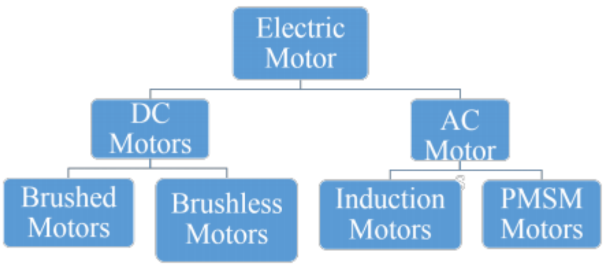


**Fig.2.2** Basic classification of motors

### 2.1.1 Comparison of various motor types

**Table 2.1** Comparison between BLDC motor and brushed DC motor

| Feature | BLDC Motor | Brushed DC Motor | Actual Advantage |
|---|---|---|---|
| Commutation | Electronic commutation based on rotor position information | Mechanical brushes and commutator | Electronic switches replace the mechanical devices |
| Efficiency | High | Moderate | Voltage drop on electronic device is smaller than that on brushes |
| Maintenance | Little/None | Periodic | No brushes/commutator maintenance. |
| Thermal performance | Better | Poor | Only the armature windings generate heat, which is the stator and is connected to the outside case of the BLDC-The case dissipates heat better than a rotor located inside of brushed DC motor. |
| Output Power/Frame Size (Ratio) | High | Moderate/Low | Modern permanent magnet and no rotor losses. |
| Speed/Torque Characteristics | Flat | Moderately flat | No brush friction to reduce useful torque. |
| Dynamic Response | Fast | Slow | Lower rotor inertia because of permanent magnets. |
| Speed Range | High | Low | No mechanical limitation imposed by brushes or commutator |
| Electric Noise | Low | High | No arcs from brushes to generate noise, causing EMI problems. |
| Lifetime | Long | Short | No brushes and commutator |

The BLDC motor has several advantages over other motors. Table 2.1 and Table 2.2 summarize the advantages of the BLDC motor when compared against a brushed DC motor and an AC induction motor. This application note introduces the motor fundamentals, with special attention to BLDC motors. As described in this document, a BLDC motor has many advantages over a brushed DC motor and an AC induction motor: It is easily controlled with position feedback sensors and generally performs well, especially in speed/torque. With these advantages, BLDC motor will spread to more applications. Moreover, with the development of sensor less technology, BLDC motor will become convenient or indispensable in applications with environmental limitations. [7]

**Table 2.2** Comparison between BLDC Motor and AC Induction Motor

| Feature | BLDC motor | AC induction motor | Actual Advantage |
|---|---|---|---|
| Speed/Torque Characteristics | Flat | Nonlinear — lower torque at lower speeds | Permanent magnet design with rotor position feedback gives BLDC higher starting and low-speed torque |
| Output Power/Frame Size (Ratio) | High | Moderate | Both stator and rotor have windings for induction motor |
| Dynamic Response | Fast | Low | Lower rotor inertia because of permanent Magnet |
| Slip Between Stator And Rotor Frequency | No | Yes; rotor runs at a lower frequency than stator by slip frequency and slip increases with load on the motor | BLDC is a synchronous motor, induction motor is an asynchronous motor |

### 2.4 Conventional BLDC Motor Drive

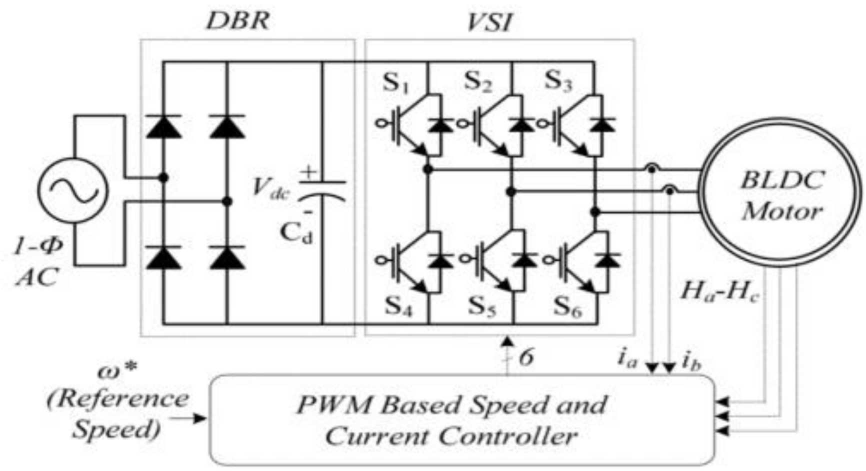


**Fig.2.3** Brush less DC Motor Drive with DBR

A conventional BLDC motor drive using a front-end diode bridge rectifier (DBR) and a high value of DC link capacitor draws highly distorted peaky current which is rich in harmonics. Fig. 3 shows the conventional scheme of BLDC motor drive fed by a pulse width modulation (PWM) based VSI for speed control. Such configuration leads to a very low power factor of the order of 0.72 and high total harmonic distortion (THD) of supply current at AC mains. Such power quality indices are not acceptable under the limits of international power quality standards such as IEC 61000-3-2. Moreover, such power quality indices also increase the EMI in the PFC converter. These EMIs are classified into two categories as conducted and radiated EMI, respectively. At lower frequencies, the EMI is primarily caused by the conduction and at higher frequencies; the EMI is caused by the radiation. Such EMI causes problems such as skin effect, high overshoot transients, hysteresis loss, eddy current loss and voltage drop which affect the overall efficiency and performance of the system. Therefore, improved power quality converters (IPQC) are used for improving the power quality at AC mains which also reduce such EMI problems. [2]

## III. Dc-Dc Converters

### 3.1 Fundamental DC-DC Converters

From the viewpoint of input and output voltages V 1 and V 0, the fundamental converters are:
a. Step-down or buck converters
b. Step-up or boost converters
c. Step down/up or buck-boost converters.

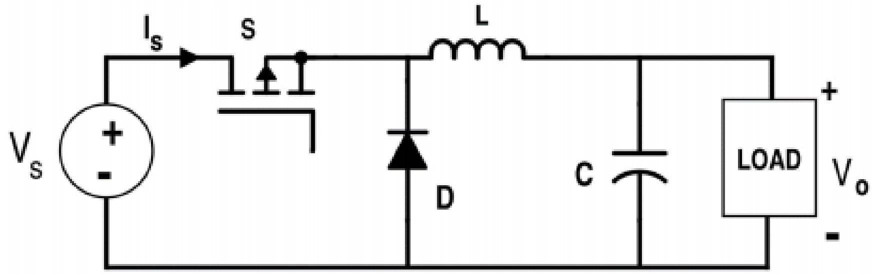


**Fig.3.1** Circuit Diagram of Buck converter

Figure 3.1, Figure 3.2 and Figure 3.3 shows the principle diagrams of these topologies. [6] In ideal operating conditions (no voltage loss on the switch S, the average voltage across inductors L at steady state zero, no current loss on capacitors C, and no voltage loss on diode at forward conduction) the equations of ratio V 0/V 1 are:

1. for the buck converter
V 0/V 1 = D (3.1)
where, D is the duty cycle of PWM signal of switch S.
2. for the boost converter
V 0/V 1 = 1/(1 − D) (3.2)
where, D is the duty cycle of PWM signal of switch S.
3. for the buck-boost converter
V 0/V 1 = D/(1 − D) (3.3)
where, D is the duty cycle of PWM signal of switch S.
D = ton/T (3.4)
where, ton is the conduction time of switch S and T is the period of PWM signal.

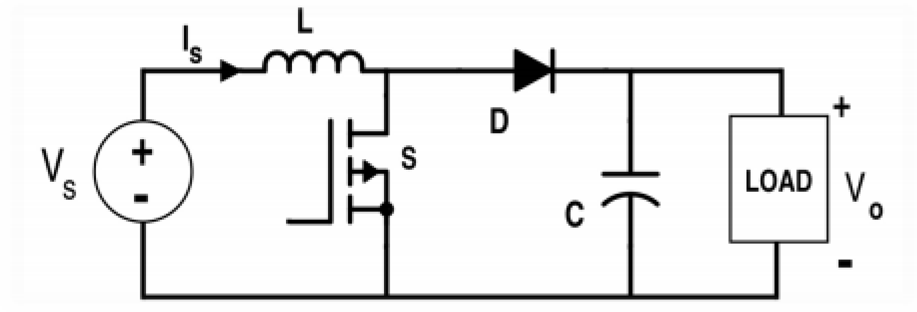


**Fig.3.2** Circuit Diagram of Boost converter

In all these equations the internal resistance of power supply V1 was considered zero.

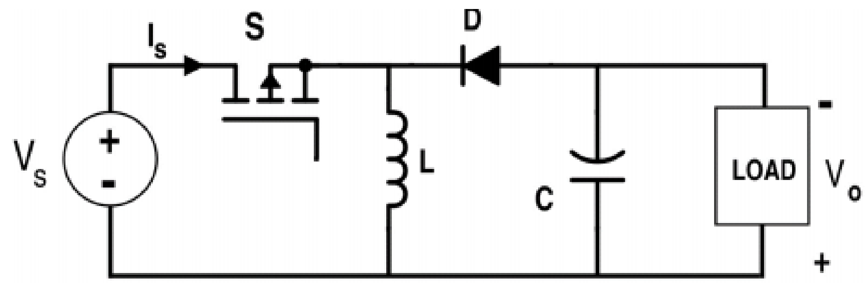


**Fig.3.3** Circuit Diagram of Buck-Boost converter

## 3.2 Developed DC-DC Converters

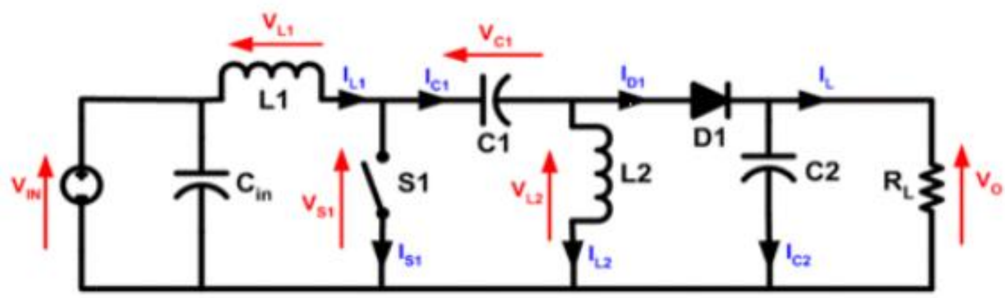


**Fig.3.4** Circuit Diagram of SEPIC converter

Figure 3.4, Figure 3.5, Figure 3.6 shows the topologies of developed DC-DC converters. [6] These converters are used in different applications, such as with solar panels, in systems supplied with electrical energy where the output voltage V 0 of converter can be superior or inferior of the input voltage V 1 of converter. The fundamental converters don't accept this situation. The capacitor C assures the galvanic insulation between input and output. The short circuits or others breakdown of the load don't affect the power supply. The output voltage becomes zero if the PWM control signal of switch S is missing. The diode D can be replaced by a transistor switched synchronized with the main switch in the synchronous converters. The differences between these topologies are: SEPIC and Cuk converters are formed from the boost converter, and ZETA and Luo converter are formed from the buck-boost converter. The ripple current in the load is greater for Cuk and ZETA converters than SEPIC, because the SEPIC converter has an inductor L2 that smooth the current spikes. The switch S of SEPIC and Cuk converters is an N channel MOS transistor that needs a Low Side driver, when the ZETA converter has a P channel MOS transistor that needs a High Side driver. LUO converter based PV power generation along with the incremental conductance is more efficient with reduced voltage ripple. Among the many configurations of PFC converter feeding a BLDC motor drive. A boost-PFC converter fed

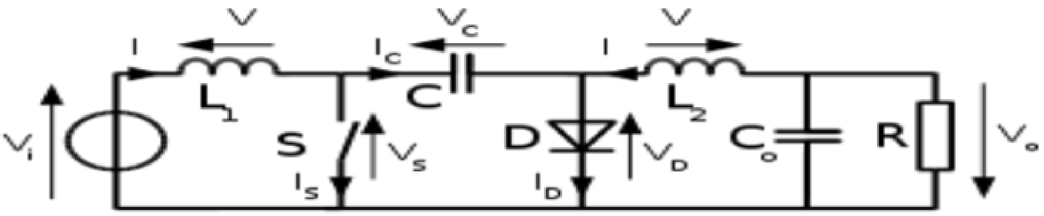


**Fig.3.5** Circuit Diagram of Cuk converter

BLDC motor drive has been the most widely used configuration but it utilizes a constant DC link voltage with PWM (Pulse Width Modulation) based VSI for speed control. This scheme suffers from high switching loss on account of high switching frequency of PWM pulses for VSI which drastically reduces the efficiency of overall system. Moreover, it also requires high number of sensors and complex control for its operation. A concept of variable DC link voltage for speed control of BLDC motor uses the concept of using converters like a SEPIC (Single Ended Primary Inductance Converter) for feeding a BLDC motor drive. It uses a bifilar winding which uses a PWM based control of VSI and have high switching losses and a PFC Cuk converter fed BLDC motor drive using the control of variable DC link voltage. This utilizes a Cuk converter operating in CCM; hence requires three sensors and is preferred for higher power rating. Bridge-less converter configurations have gained importance in the past decade due to their high efficiency. The front end DBR is eliminated in these configurations which reduce the conduction losses associated in them. The bridge-less buck and boost converters suffer from a limited voltage conversion ratio (<1 for buck and >1 for boost converter) which limit its application for a wide range of speed control by varying DC link voltage. The bridge-less Cuk and SEPIC converters have also gained popularity due to a wide voltage conversion ratio. A Luo converter has been widely used due to its inherent characteristics of voltage lifting. Many versions of Luo converter voltage lifting technique such as re-lift, super-lift and ultra-lift are there. A bridge-less configuration of the Luo converter can be used for feeding a BLDC motor as a low cost solution for low power applications.

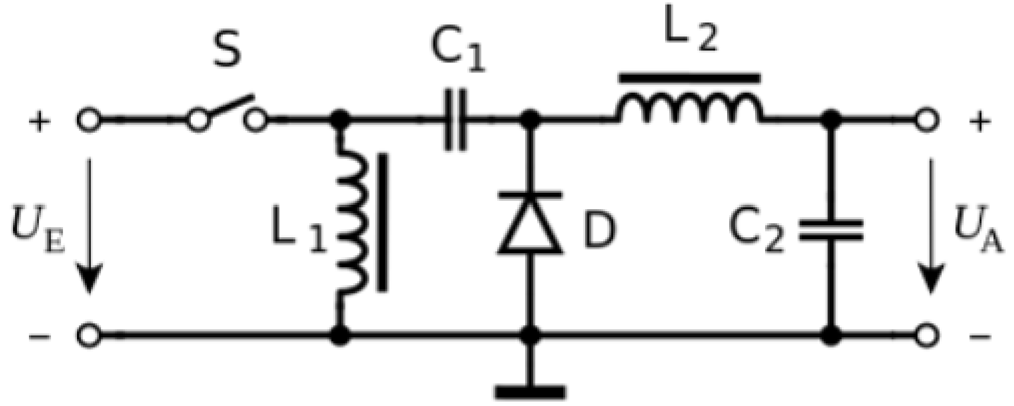


**Fig.3.6** Circuit Diagram of Zeta converter

## IV. PFC Based BLDC Motor Drive

In the PFC based BL-Luo converter fed BLDC motor drive. A single phase supply followed by filter and a BL-Luo converter is used to feed a VSI driving a BLDC motor. The BL-Luo converter is designed to operate in DICM to act as an inherent power factor pre-regulator. The speed of the BLDC motor is controlled by adjusting the DC link voltage of VSI using a single voltage sensor. This allows VSI to operate at fundamental frequency switching (i.e. electronic commutation of BLDC motor) and hence has low switching losses in it;

which are considerably high in PWM based VSI feeding a BLDC motor. [5] The proposed scheme is designed and its performance is simulated for achieving an improved power quality at AC mains for a wide range of speed control and supply voltage variations.

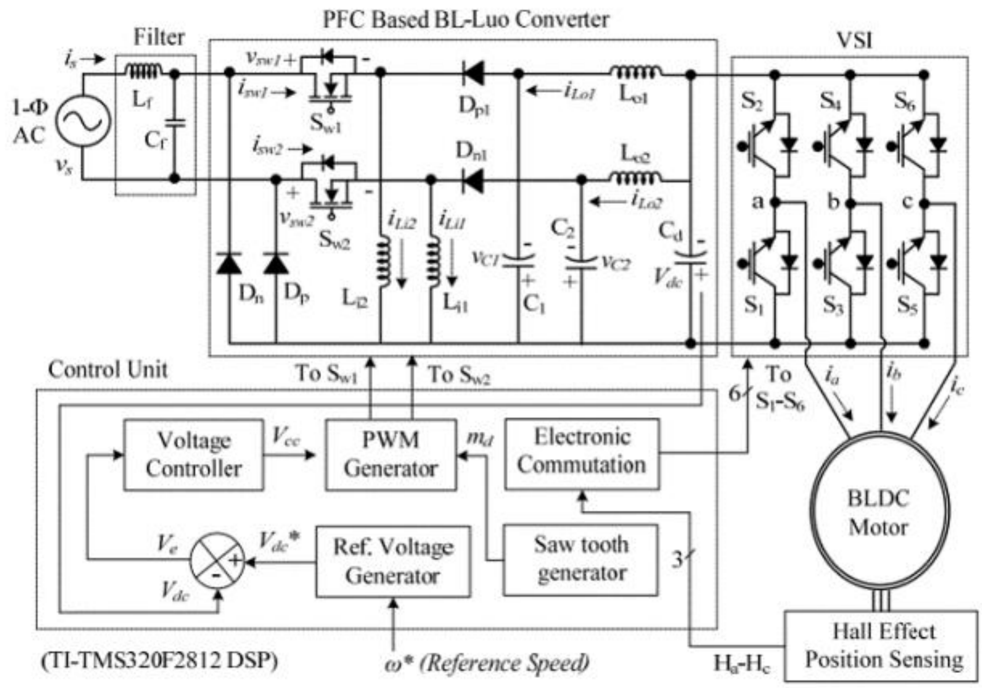


**Fig.4.1** PFC based BL-Luo converter fed BLDC motor drive

## V. Conclusion

PFC BL-Luo Converter fed BLDC motor drive system after comparing with all fundamental and derived converters is found to be highly efficient system which requires only a single voltage sensor. It also possess a simple control loop for DC link voltage control with very lower losses. Advantages like Requirement of minimum amount of sensing, simple approach of speed control, Power factor correction at AC mains etc. [1] Make the BLDC drive a good solution for low power application in present scenario in which there is huge need of eco-friendly low power consuming highly efficient devices.

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