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A Cuk Converter Based Four Quadrant Operation of BLDC Motor

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Abstract*— A Cuk Converter for attaining unity power factor at ac mains based BLDC Motor drive with a rechargable battery for energy conservation is described in this paper. BLDC Motor is commutated electronically based on Hall position sensors with the help of Voltage Source Inverter (VSI). Currrent Multiplier and Voltage Follower are the two methods used in PFC Cuk Converter based BLDC Motor Drive. DC link voltage is controlled by the speed of BLDC Motor Drive. This causes VSI to operate in fundamental frequency switching mode. So switching losses will be reduced. In this BLDC Motor Drive regenerative braking occurs and the energy is stored back into the battery.

***Index Terms*—Brushless Direct Current (BLDC) Motor, Cuk Converter, Power Factor Correction (PFC), Voltage Source Inverter (VSI).**

I. INTRODUCTION

High efficiency, high torque/inertia ratio, high power density, wide range of speed control, low noise and electro-magnetic interference (EMI) are the main features of a BLDC Motor. Rocket applications (brush less),Car power window, Fuel pump, Electric train, Hill train ,Coolant applications are some of applications of BLDC Motor .BLDC motor has no brushes for commutation. In BLDC motor electronic commutation is possible. Electronic commutation is obtained when the Hall sensors sense the rotor position signals and it is done with the help of a Voltage Source Inverter. A Cuk Converter is used for power factor Correction. Usually there is mismatch between power supplied and power utilized at the consumer end which is the main reason for Total Harmonic Distortion. So power factor correction circuits are necessary. For power factor correction in Discontinuous Conduction Mode a voltage follower is essential. Four Quadrants of Operation is possible in BLDC Motors. The operation is done without loss of power. And also during regeneration period energy is conserved.

II. SYSTEM CONFIGURATION

A. Current Multiplier Approach

Stresses on PFC converter switch are low. But this method requires three sensors. Fig.1 illustrates BLDC Motor drive fed by a PFC Cuk converter operating in CCM using current multiplier. The parameters which remain continuous in a switching period are current through input and output inductors and voltage across intermediate capacitor. As the speed of a BLDC motor is proportional to dc link voltage of VSI reference voltage corresponding to reference speed is generated by reference voltage generator. The reference speed is multiplied with voltage constant of BLDC Motor (K_b) to generate reference voltage. Voltage error is obtained as the result of comparison between reference voltage and dc link voltage. The controller accepts the error as its input and controlled output is the result. The controller output multiplied with unit template of supply voltage gives reference current. Current error is obtained by comparison of sensed input current and reference current. Controlled output is obtained when current error is given to current controller and PWM (Pulse Width Modulated) signal is obtained when the controller output is compared with high frequency saw tooth waveform. Fig.1shows BLDC motor drive fed by a PFC Cuk converter using Current Multiplier approach.

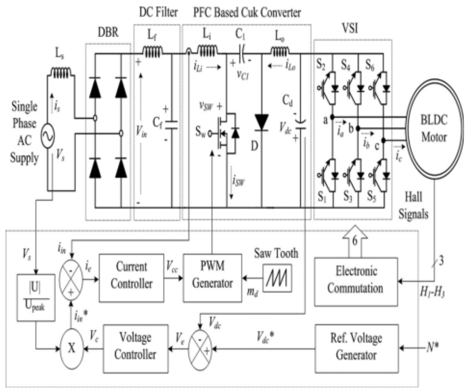

Fig 1. BLDC motor drive fed by a PFC Cuk converter using Current Multiplier approach

B. Voltage follower Approach

Voltage follower approach needs a single voltage sensor. But a stress on PFC converter switch is high. Fig.2 shows BLDC motor drive fed by a PFC Cuk converter using a Voltage follower approach [1]. A reference voltage generator generates a reference dc voltage. An error signal is generated when reference signal is compared with dc link voltage. Then error signal is given to speed controller. The Reference speed is multiplied with voltage constant of BLDC Motor (K_b) to generate reference voltage. Controlled output is obtained when voltage error is given to voltage PI controller. Finally PWM signal generated when the controller output is compared with high frequency sawtooth waveform. Fig.2 shows BLDC motor drive fed by a PFC Cuk converter using Voltage follower approach.

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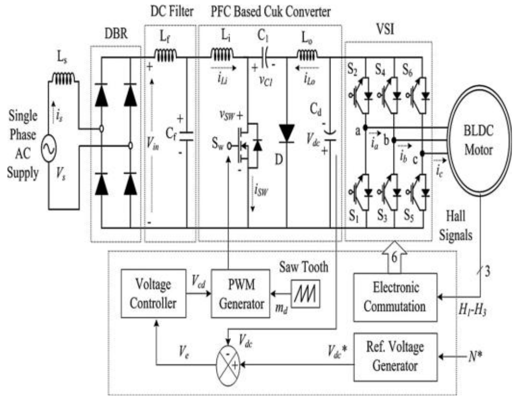

Fig 2. BLDC motor drive fed by a PFC Cuk converter using Voltage follower approach

C .Operation of Cuk converter in different modes

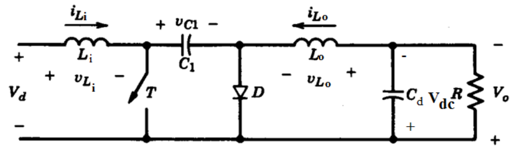

Fig 3.Cuk Converter

Cuk is a type of DC/DC converter that has an output voltage magnitude that is either greater than or less than the input voltage magnitude. Actually it is a combination of a boost converter followed by a buck converter with a capacitor to couple the energy. Four different modes of Continuous Current Conduction (CCM) and Discontinuous Current Conduction (DCM) are available in the working of Cuk converter. Current in inductors (Li and Lo) and voltage across intermediate capacitor C1 become continuous in Current Conduction Mode. In Discontinuous Conduction Mode DICM (Discontinuous Inductor Current Mode)and DCVM (Discontinuous Capacitor Voltage Mode) are the main modes of operation. The current in inductors become discontinuous in DICM (Discontinuous Inductor Current Mode). The voltage across intermediate capacitor C_1 remains discontinuous in capacitor voltage mode. Fig.3 shows basic circuit of a cuk converter.

III. DESIGN OF CUK CONVERTER

Cuk Converter consists of many energy storage elements. Diode Bridge Rectifier is fed by input supply voltage. The input inductor, output inductor, intermediate capacitance and dc link capacitor are designed.

Input voltage

$$v_{s(t)} = V_m \operatorname{Sin}(2\pi f_L t) \quad (1)$$

where V_m = the peak input voltage

V_s = rms value of supply voltage

f_L = line frequency

$$V_{in(t)} = | V_m \operatorname{Sin}(\omega t) | \quad (2)$$

where || = moduls function

$V_{in(t)}$ = Instantaneous Voltage after Diode Bridge Rectifier

$$V_{dc} = \frac{D}{1-D} V_{in(t)} \quad (3)$$

where D = dutyratio

$$D(t) = \frac{V_{dc}}{\left(V_{dc}+V_{in(t)}\right)} \quad (4)$$

$$\text{Value of Input Inductor},L_{ic} = \frac{1}{2f_S}\frac{V_S^2}{P_i}\frac{V_{dc}}{\left(V_{dc}+V_{in(t)}\right)} \quad (5)$$

where P_i = Instantaneous Power

$$\text{Value of Output Inductor},L_{oc} = \frac{V_S^2}{P_i}\frac{V_{dc}}{2V_{in(t)}f_s}\frac{V_{dc}}{\left(V_{dc}+V_{in(t)}\right)} \quad (6)$$

$$\text{Value of intermediate capacitance},C_1 = \frac{V_{dc}D(t)}{2V_{c_1(t)}f_s R_L} \quad (7)$$

Vc1 = Intermediate capacitor Voltage

fs = Switching Frequency

$$\text{Value of dc link capacitor},C_d = \frac{P_i}{2\omega\delta V_{dc}^2} \quad (8)$$

δ = Permitted ripple in dc link voltage

IV. FOUR QUADRANT OPERATION OF BLDC MOTOR

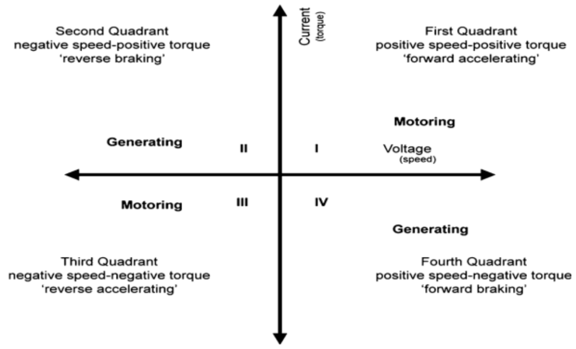

Fig 4.Four Quadrant Operation of a BLDC Motor

In forward and reverse motoring modes the supply voltage is greater than back emf and the direction of current flow is different. In that case motor is operating in first and third quadrant respectively [2]. In second quadrant (forward braking mode) and fourth quadrant (reverse braking mode) back emf is greater than supply voltage. The speed of rotating machines decreases on application of brakes. Applying brakes is called as braking. It is the process of reducing speed of any rotating machine.

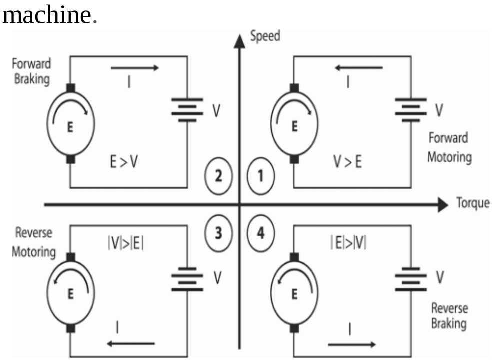

Fig 5.Operatingg modes of BLDC Motor

In case of first quadrant both torque and speed are positive. So they are called as forward torque and forward Speed. Taking the case of third quadrant speed and torque are negative. This mode is named as reverse motoring. For the second quadrant speed is negative and torque is positive. And the motor is running in reverse direction. Speed is positive and torque is negative in fourth quadrant. In Regenerative braking the motor acts as a generator, redirecting the current flow into the battery. Almost all electric vehicles employ regenerative braking. When the motor runs in one direction conversion of energy is from electrical energy into mechanical energy. For opposite direction motor is acting as generator. Whenever there is a reversal of direction of rotation there is a change in the quadrant. In motoring mode when the motor runs in clockwise direction one of the breaker is normally open and the second one will be closed. But when braking is applied the kinetic energy which will be wasted as heat energy is now converted into electric energy which is rectified and stored in a chargeable battery.

V. CONCLUSION

BLDC motor drives are becoming more popular in many industrial applications like traction. This makes the control of BLDC Motor in all the four quadrants very vital. Cuk converters can be used for either stepping-down or stepping-up the voltage level.Single-phase power factor correction (PFC) converters gives unity PF at ac mains.In this paper a Cuk Converter is used for PFC. The motor operation is possible in all the four quadrants without any loss of power. In fact energy is conserved during the regenerative period.

VI. ACKNOWLEDGMENT

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