PFC Cuk Converter-Fed BLDC Motor Drive

Submitted by

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1 Introduction

Brushless DC (BLDC) motors are recommended for many low- and medium-power drives applications because of their high efficiency, high flux density per unit volume, low maintenance requirement, low electromagnetic interference(EMI) problems, high ruggedness, and a wide range of speed control. Due to these advantages, they find applications in numerous areas such as household application, transportation (hybrid vehicle), aerospace, heating, ventilation and air conditioning, motion control and robotics, renewable energy applications etc.

The BLDC motor is a three-phase synchronous motor consisting of a stator having a three-phase concentrated windings and a rotor having permanent magnets. It does not have mechanical brushes and commutator assembly hence, wear and tear of the brushes and sparking issues as in case of conventional dc machines are eliminated in BLDC motor and thus it has low EMI problems. This motor is also referred as an electronically commutated motor since an electronic commutation based on the Hall-effect rotor position signals is used rather than a mechanical commutation.

The conventional scheme of a BLDC motor fed by a diode bridge rectifier (DBR) and a high value of dc-link capacitor draws a nonsinusoidal current, from ac mains which is rich in harmonics such that the THD of supply current is as high as 65%, which results in PF as low as 0.8. Hence, single-phase power factor correction (PFC) converters are used to attain a unity PF at ac mains.

Conventional schemes of PFC converter-fed BLDC motor drive utilize an approach of constant dc-link voltage of the VSI and controlling the speed by controlling the duty ratio of high frequency pulse width modulation (PWM) signals. A PFC cuk converter operated generally preferred in DICM and CCM topology. It's required three sensors of a dc-link voltage control as well as PFC operation, hence this topology is fit for a high-power applications. But only the CCM topology is prefer for improving the PF at ac mains.

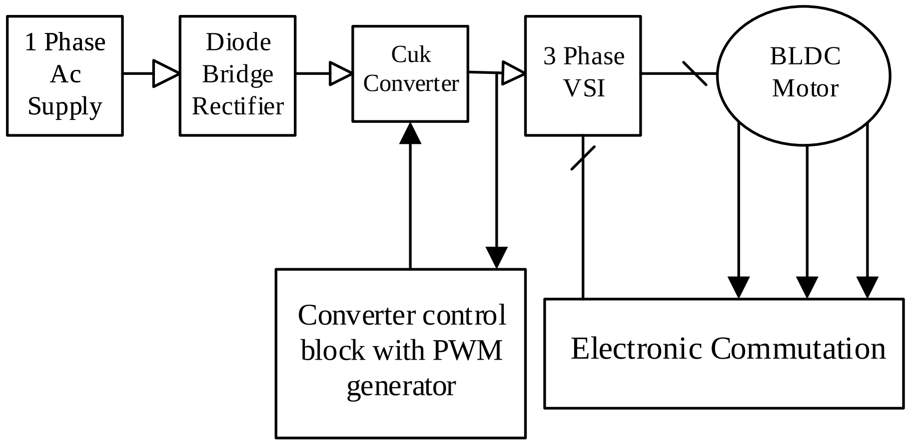

Fig. 1: Proposed scheme of Cuk converter fed BLDC motor drive

2 Significance of Power Factor

PFC is the technique to make the line current sinusoidal and in phase with line voltage with reduced input current harmonics in order to meet the standard. Also, it can be said that PFC is a procedure of neutralizing the unwanted effects of electric loads that create below unity power factor (PF ¡ 1). When PF is under unity value, the apparent power delivered to the load is more than the real power that the load absorbs.

Ideally, PF is cos ϕ, that is for sinusoidal source voltage and source current. But in actual practice, the presence of nonlinear load makes the source current non-sinusoidal and hence, mathematically PF is:

$$PF = K_p cos\phi \tag{1}$$

where cosϕ is the displacement factor of line voltage and current. And Kp = $\frac{I_{1rms}}{I_{rms}}$ is named as distortion factor, describes the harmonic limit of the current referred to fundamental. Again, the distortion factor is related to THD and is mathematically:

$$Kp = \frac{1}{\sqrt{1 + (THD)^2}} \tag{2}$$

where THD is the total harmonic distortion.

3 Technique of PFC Scheme

The general approaches to improve power factor can be widely classifieds as passive and active approaches. The passive approaches use capacitive inductive filters to achieve PCF, while the active approaches use a switched- mode power supply to shape the input current.

3.1 Passive Approaches

In the passive approaches, a full bridge rectifier with an LC filter is used to reduce the line current harmonic limits. Generally the LC filter can be placed in either the AC-side or the DC-side of the rectifier. Placing the LC filter in the AC-side will result in more pure sinusoidal input current. Passive PFC can meet the regulation with high efficiency, superior reliability, low cost, and low EM1.

On the other hand, the filter capacitor voltage vanes with the line voltage, which bas a detrimental effect on the performance and efficiency of the DC-DC converter. When considering a hold-up time for the power supply, the bulk capacitance has to be increased and becomes very bulky compared to what it would be without this varying voltage. As a result, the passive approaches seem to be more attractive in low-power applications, up to 300Watts, and are more suitable for narrow line voltage range. Other drawbacks are the size and weight of the filter choke inductor. However, the majority of power supplies manufactured in low-power and cost-sensitive applications have adopted the passive PFC approaches.

3.2 Active Approaches

In active PFC approaches, a switched mode converter is employed to overcome the limitations of the passive approaches. Assuming unity power factor, the line current should be sinusoidal and in phase with the line voltage. That will result in pulsating output power than contains - in addition to the real (average power) - an alternating component with double-line frequency. Since the power demanded by most loads is constant, an energy storage element is needed. Since the inductor-stored energy cannot match this excessive energy, another storage component is needed.

4 Cuk converter Design

4.1 Design parameter of cuk converter

Given design parameter for cuk converter is listed out in below table:

Sl. No.	Parameter	Value
1	Supply Voltage (V)	Rated: 220 V
2	DC-link Voltage (V)	Rated: 200 V
3	Power (P)	Rated: 350 W
4	Switching frequency (f_s)	Rated: 20kHz
5	Inductor current ripple	10%
6	Capacitor voltage ripple	10%

By using above given specification, the value of both inductor and capacitor for CCM operation are calculated as follow:

- Inductor (L_i) = 2.5 mH
- Inductor (L_0) = 4.3 mH
- Capacitor (C_1) = 0.66 uF
- Capacitor (C_o) = 2200 uF

5 Control of the PFC Cuk Converter-fed BLDC Motor Drive

Two different control schemes of the PFC Cuk converter are the current multiplier and the voltage follower approach for its operation in CCM and DCM, respectively. Here we are using the current multiplier approach for CCM operation.

5.1 Current Multiplier Approach for the Cuk Converter Operating in the CCM

An equivalent reference voltage V_{dc}^* corresponding to the particular reference speed N^* is generated by a "Reference Voltage Generator" as the speed of the BLDC motor which is proportional to the dc-link voltage of the VSI. Fig. 3 shows that the Cuk converter feeding BLDC motor drive using a current multiplier approach.

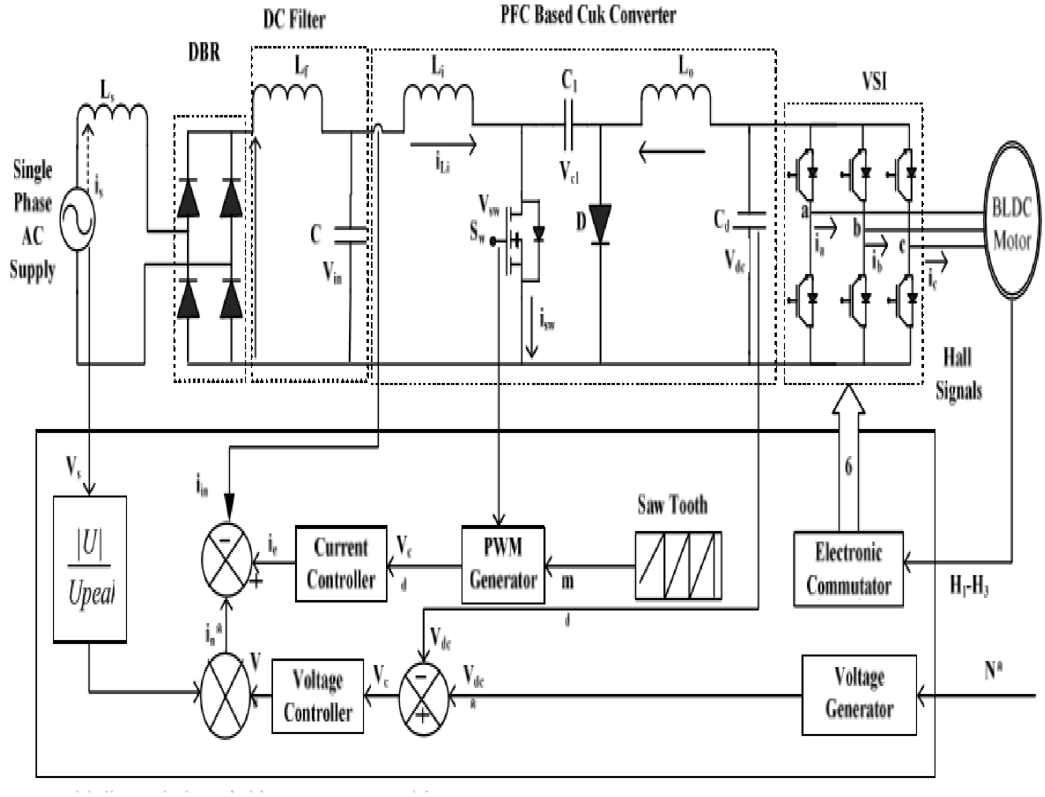

Fig. 2: Flow of current in three windings for 120°commutation

We achieved this control in following steps:

- A reference voltage is generated by the product of speed and the voltage constant K_b of the BLDC motor and is given as:

$$V_{dc}^{*} = K_b N^{*} \tag{3}$$

- This reference voltage is compared with the sensed dc-link voltage (Vdc) to generate a voltage error V_e. This voltage error is given to voltage proportional-integral (PI) controller for generation of a controlled output V_c.
- The reference current I_{in}^{*} is generated by multiplying the controller output with the unit template of supply voltage as:

$$I_{in}^{*} = \frac{|V_s|}{|V_m|} V_c \tag{4}$$

- This reference current is compared with the sensed input current to generate a current error I_e.

Now this current error is given to the current controller to generate a controlled output voltage V_e.

- Finally, the controller output (V_e) is compared with the high frequency sawtooth waveform to generate the PWM signal to be given to the PFC converter switch.

6 Specification of BLDC Motor

Following specificatios are used to simulate the BLDC motor in close-loop control by using current multiplier approach:

Sl. No.	Parameter	Value
1	No. of Pole (P)	4
2	Rated Power (P)	251 W
3	Rated DC-link Voltage (V)	200 V
4	Rated torque	1.2 N-m
5	Rated Speed	4000 rpm
6	Back emf Constant	100 $\frac{V}{krpm}$
7	Phase Resistance	0.36 Ω
8	Phase Inductance	0.4 mH
10	Moment of Inertia	$0.008 kg.m^2$

7 Close-loop simulation

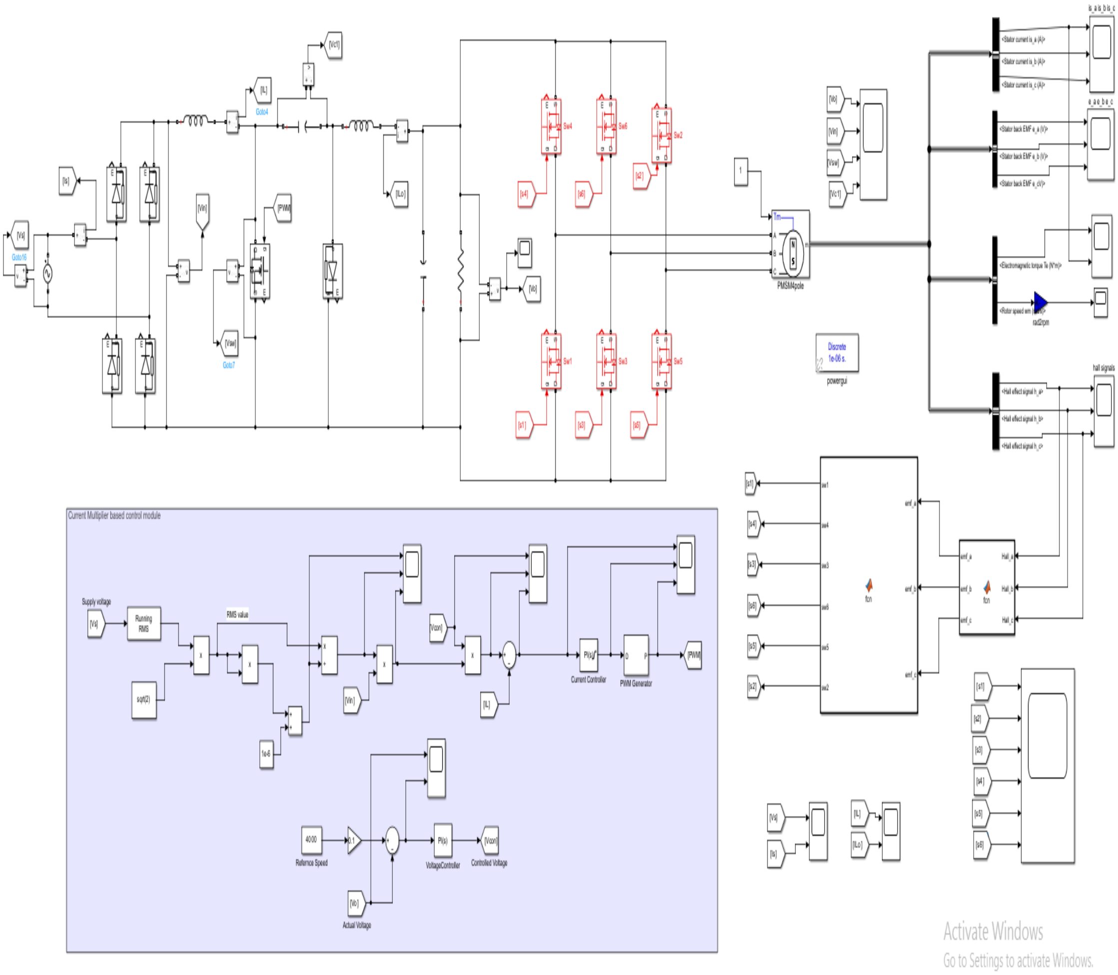

Fig. 3: Close-loop simulation circuit

7.1 Close-loop simulation results

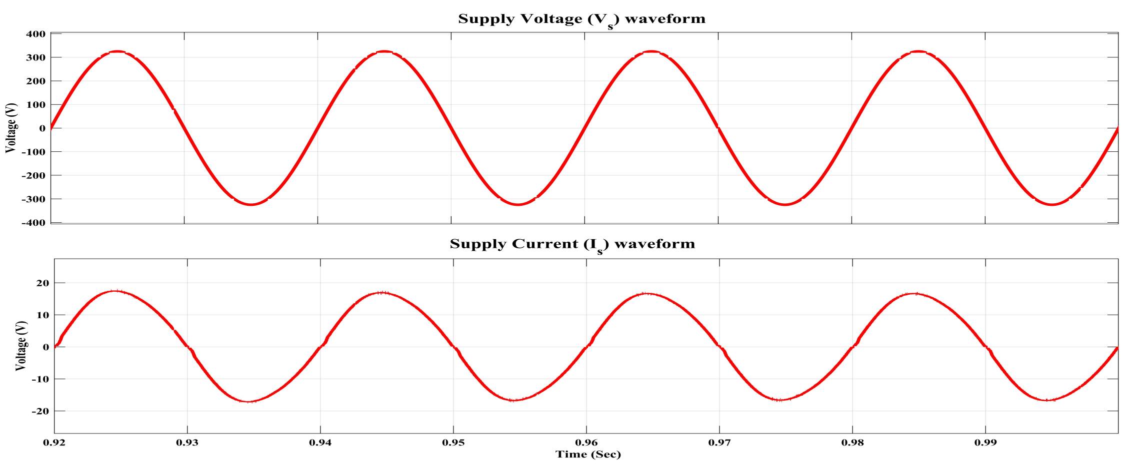

Fig. 4: Supply Voltage and Supply Current waveform

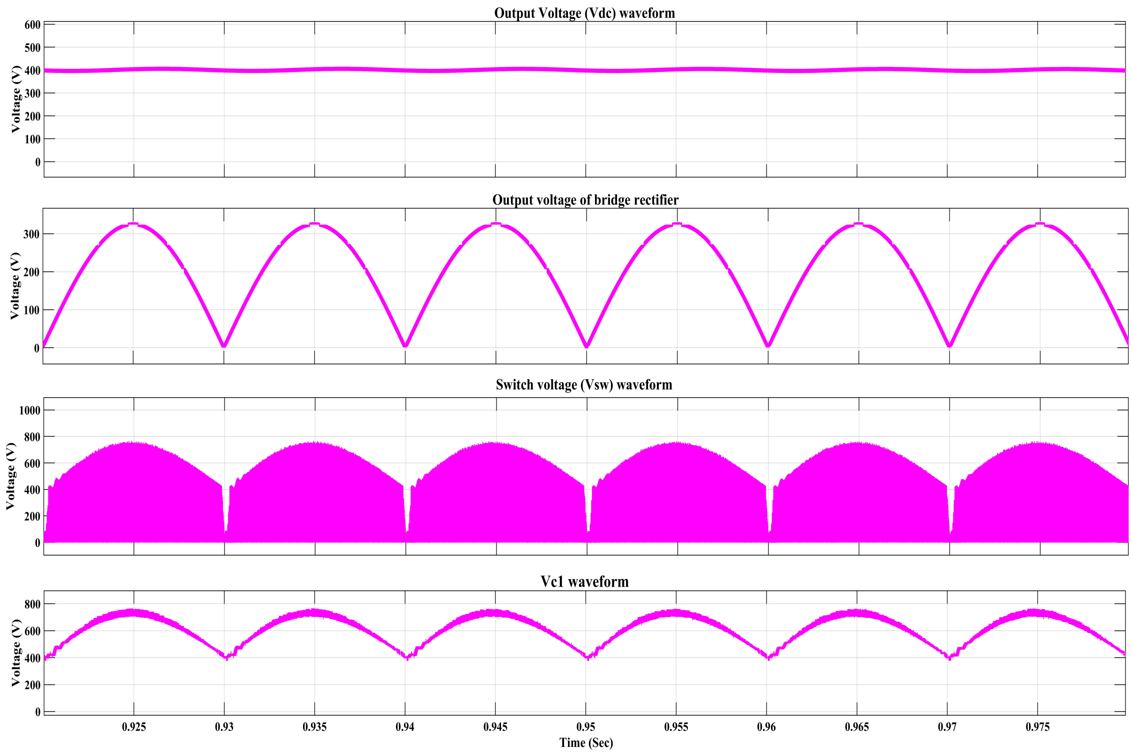

Fig. 5: V_{Dc}, Output voltage of bridge rectifier, Switch voltage and V_{c1} waveform

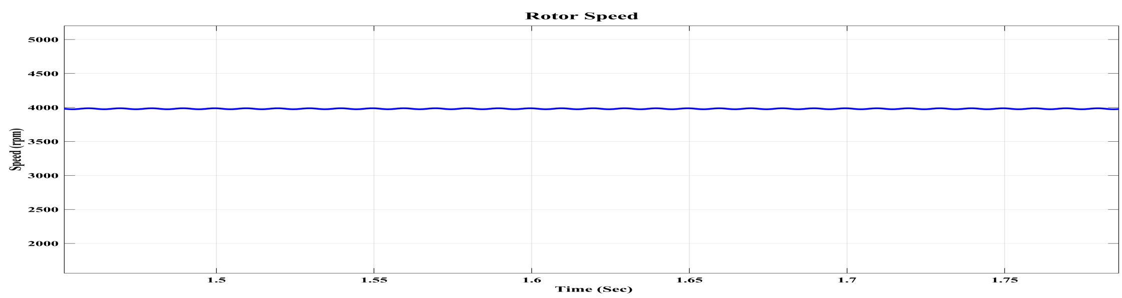

Fig. 6: Rotor Speed waveform

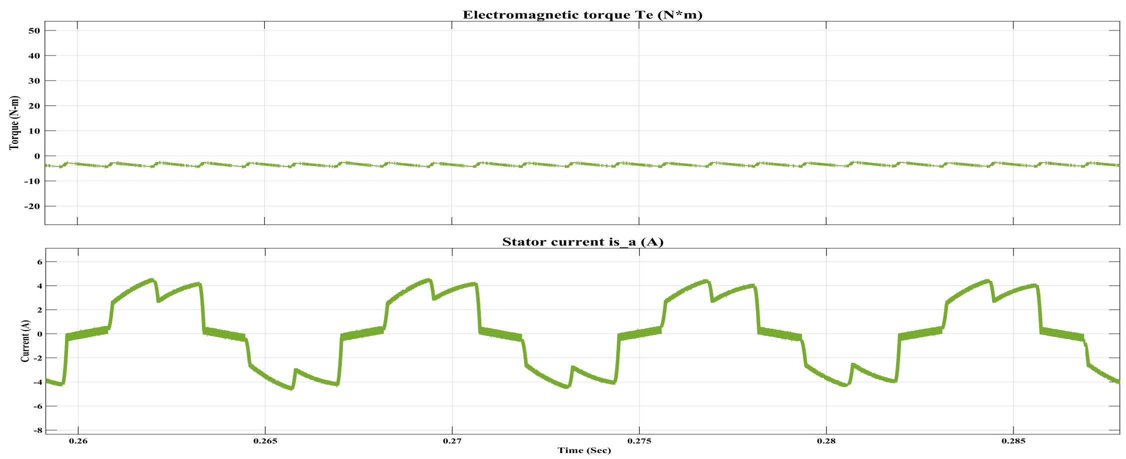

Fig. 7: Torque and Stator Current waveform

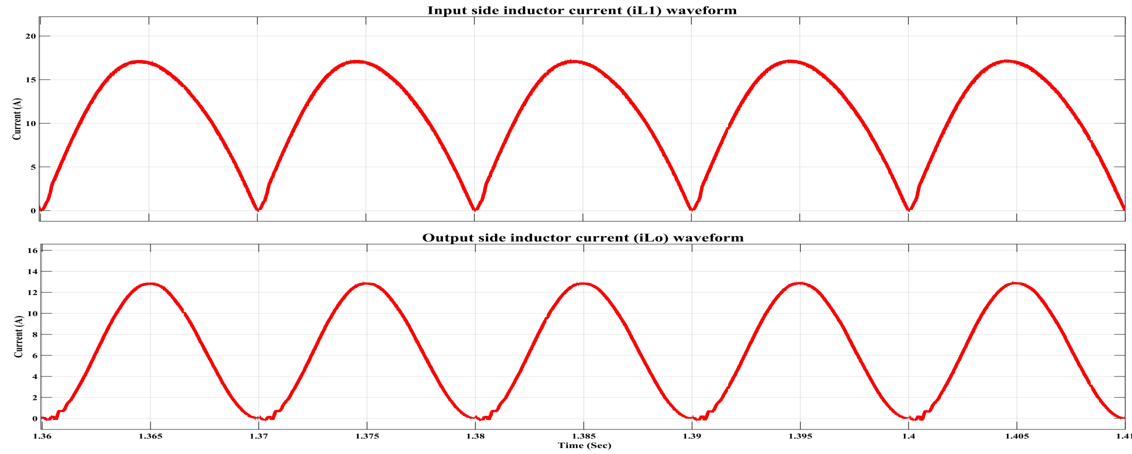

Fig. 8: Input side inductor I_{L1} and Output side inductor I_{Lo} Current waveform

8 Conclusion

A Cuk converter for VSI-fed BLDC 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 equipments such fans, blowers, water pumps, etc. The speed of the BLDC motor drive has been controlled by varying the dc-link voltage of VSI, which allows the VSI to operate in the fundamental frequency switching mode for reduced switching losses.

9 References:

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