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A PFC Cuk Converter for BLDC Motor Drive with One Cycle Control

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Abstract:
In this concept a bridgeless Cuk rectifier is used for Power factor correction (PFC) for a BLDC motor. Bridgeless Cuk converter has only two semiconductor switches in the current flowing path. During each interval of the switching cycle it result in less conduction losses and an improved thermal management compared to the conventional Cuk PFC rectifier. To achieve almost unity power factor and to reduce the input current stress, the topologies are designed to work in discontinuous conduction mode (DCM). The DCM has additional advantage such as zero-current turn-on in the power switches, zero current turn-offs in the output diode. The ac-dc conversion of electric power is usually required for the BLDCM drive; it causes many current harmonics and results in poor power factor at input ac mains. This concept deals with power factor correction of BLDCM with bridgeless Cuk converter. A three phase voltage source inverter is used as an electronic commutator to operate BLDCM.

Keywords: ***Nonlinear Control, OCC (One Cycle Control), Conventional Control, Switch Variable.***

I. INTRODUCTION

Brushless DC (BLDC) motors are preferred as small horsepower control motors due to their high efficiency, silent operation, compact form, reliability, and low maintenance. However, the problems are encountered in these motor for variable speed operation [1-3]. Over last decades continuing technology development in power semiconductors, microprocessors, adjustable speed drivers control schemes and permanent-magnet brushless electric motor production have been combined to enable reliable, cost-effective solution for a broad range of adjustable speed applications. Recent research has indicated that BLDC motor drives could become serious competitors to the induction motor for servo applications [4-6]. BLDC motor is an ideal motor for low-medium power applications because of its high efficiency, high torque to inertia ratio, low maintenance and wide range of speed control. It consists of three phase windings on the stator and permanent magnets on the rotor. Being an electronically commutated motor, the commutation losses in the BLDC motor are negligible BLDC motor when fed by an uncontrolled bridge rectifier with DC link capacitor results in highly distorted supply current which results in low PF (Power Factor) and high THD (Total Harmonic Distortion); hence various improved power quality AC-DC converters are used in these drives [7-8].

Solid-state ac–dc conversion of electric power is widely used in adjustable-speed drives (ASDs), switch-mode power supplies (SMPSs), uninterrupted power supplies (UPSs), and utility interface with nonconventional energy sources such as solar PV, etc., battery energy storage systems (BESSs), in process technology such as electroplating, welding units, etc., battery charging for electric vehicles, and power supplies for telecommunication systems, measurement and test equipment [9-10]. Conventionally, ac–dc converters, which are also called rectifiers, are developed using

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diodes and thyristors to provide controlled and uncontrolled dc power with unidirectional and bidirectional power flow. The proposed scheme for the Sensor less BLDC motor drive fed by a ta based PFC converter operating in DICM mode is shown in Fig. 1. The front end Cuk DC-DC converter maintains the DC link voltage to a set reference value. Switch of the Cuk converter is to be operated at high switching frequency for effective control and small size of components like inductors. A sensor less approach is used to detect the rotor position for electronic commutation A high frequency MOSFET of suitable rating is used in the front end converter for its high frequency operation whereas an IGBT’s (Insulated Gate Bipolar Transistor) are used in the VSI for low frequency operation.

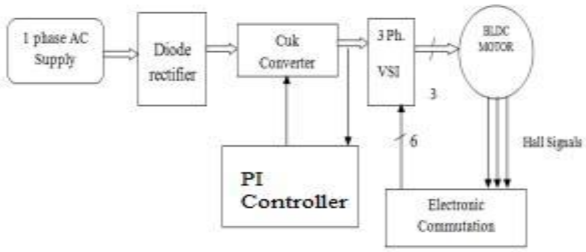

Fig.1.Block diagram for Cuk converter fed BLDC motor Drive.

The proposed scheme maintains high power factor and low THD of the AC source current while controlling rotor speed equal to the set reference speed. A voltage follower approach is used for the control of DC-DC converter operating in DICM. Applications, where over a speed range the load on the motor varies, demand good dynamic responses and a high speed control accuracy. Automotive, electronic steering control, fuel pump control, electric vehicle control and engine control are good examples of these. In aerospace also there are a number of applications. In order to use these motors effectively at their optimal efficiency and in safe operating zone they must be driven at their nominal power requirement. Power electronic converters provide the required solution to meet the demand of the desired regulated electrical power for dynamic and efficient operation of BLDC motor drives. Here, a BLDC motor drive fed by a PFC Cuk converter with One Cycle Control is proposed as in Fig. 2.

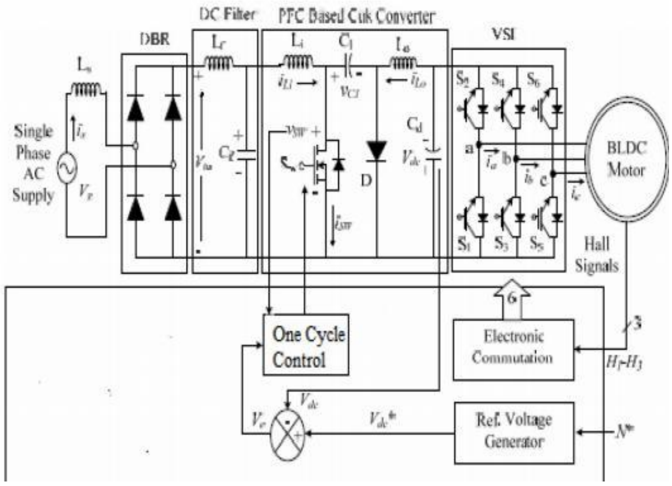

Fig.2. Proposed Cuk PFC with OCC Topology.

II. ONE CYCLE CONTROL

The "One Cycle Control" technique was developed as a general pulse width modulator control method [1- 8]. It is also known as the integration with reset technique where the key element is the resettable integrator. The One Cycle Controller is comprised of an integrator with reset switch, a comparator, a flip-flop and a clock as shown in Fig. 3. The clock triggers the SR flip flop to turn ON the transistor with a switch function K (t) and constant frequency fs given as:

$$K(t)=\begin{cases}1 & 0<t<Ton\\ 0 & Ton<t<Ts\end{cases} \qquad (1)$$

The input signal x(t) is chopped by the converter switch and given to the output node of the switch to form a switched variable yet). The frequency and the pulse width of the switched variable yet) is the same as that of the switch function K(t) , while the envelope of yet) is the same as that of the input signal x(t). The corresponding waveforms are given in Fig. 4. When the switch is turned on by a fixed frequency clock pulse, voltage available across the switch variable is being integrated. The integrator output is compared with the control reference by using a comparator. When the integrated value of the voltage becomes equal to the control reference, the integration is immediately reset to zero to prepare for the next cycle. Since the switched variable always follows the control reference the output voltage is independent of all input voltage variations.

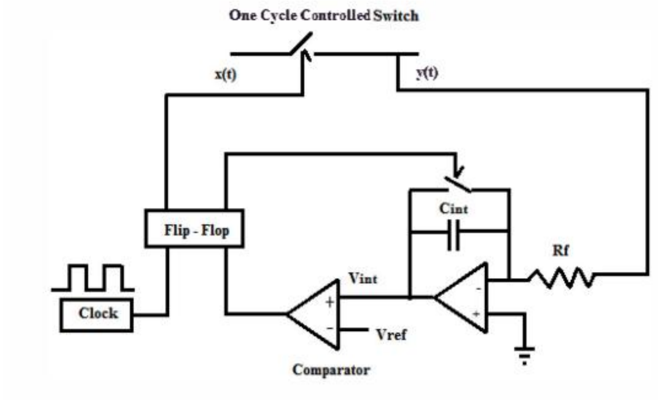

Fig.3. One Cycle Control.

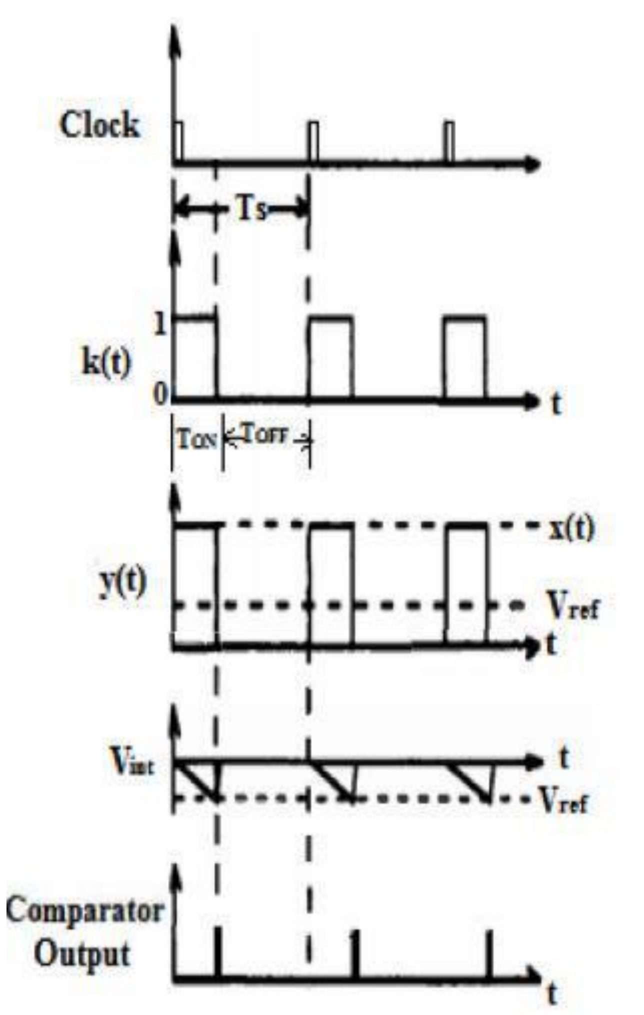

Fig.4. One Cycle Controlled Switch Waveforms.

ONE CYCLE CONTROL OF CUK CONVERTER Flow-Graph which is a nonlinear modelling technique, can be used to study the OCC converters [10]. A switching converter usually contains more than one signal switch in its Flow-Graph. A Cuk converter, contains four signal switches in its switching Flow-Graph, two current switches and two voltage switches, as shown in Fig. 5. Any signal switch can be selected for One Cycle Control, current or voltage depending on the application of the circuit. The One Cycle Control breaks the Cuk converter into two second order systems, input loop and output loop, on which the stability of the One Cycle Controlled system depends. The output loop being a linear system is always stable. The input loop is a second order nonlinear system. The large-signal dynamic analysis concludes that the One Cycle Controlled system is not globally stable, but with proper limitation of the Duty Ratio (below 70%), a global stability can be attained. In the converging region the One Cycle Control achieves zero steady-state error and zero dynamic tracking error between the control reference value and the average value of the switched variable. The transients of the capacitor voltage and the inductor current are not instantaneous. The One Cycle Control takes advantage of the pulsed and nonlinear nature and achieves the instant control over the average value of the switched variable.

Simplified Voltage Control and One Cycle Control of PFC Cuk Converter for BLDC Motor Drive

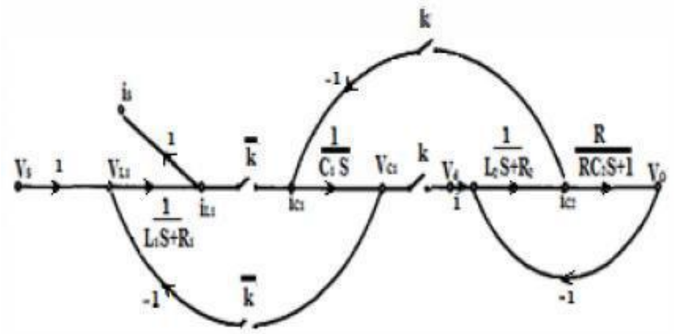

Fig. 5. The Signal Flow Graph of Cuk converter.

IV. OPERATION AND CONTROL OF BLDC MOTOR The Cuk PFC converter topology has a conventional diode bridge rectifier fed from AC mains followed by the One Cycle Controlled Cuk converter, an output voltage ripple filter and a three phase VSI to drive the BLDC motor. The Cuk DC-DC converter gives a controlled DC voltage by suitable conditioning of the

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uncontrolled DC output of DBR and the power factor is controlled through the high frequency switching of the Power Factor Correction switch [9]. The regulated DC output voltage from the Cuk converter is decided by its Duty Ratio (D) which in turn is controlled by the One Cycle control. The switching frequency (fs) of the converter is fixed by the switching device used, power level, operating voltage and switching losses of the device. The control technique requires a voltage sensor for controlling the DC link voltage with a unity power factor. For the control, the DC link voltage (i.e. the converter output voltage) is sensed and compared with the set reference DC link capacitor voltage or Hall effect sensors are used to sense the rotor position of BLDCM and converted to speed signal, this motor speed is compared with a reference speed. This error in speed is compared with the converter output voltage and given to the integrator. The input current reference is compared with speed error controller output. The integrator and the speed error controller output are given as inputs to the comparator followed by a flip flop to produce the gating signals for the switch. The control strategy is represented through a block diagram in Fig. 6.

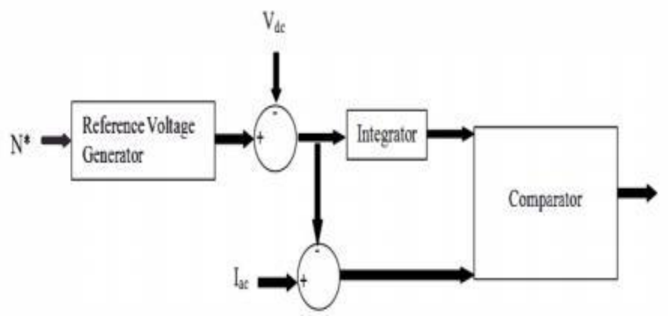

Fig.6. Controller Block Diagram.

V. DESIGN OF A PFC CUK CONVERTER

The Cuk converter is designed for DCM operation. In DCM, any one of the energy storing elements Li, Lo or CI are allowed to operate in discontinuous mode. Here, Lie is operated in DCM. The output voltage, V_{de} of Cuk converter is given as:

$$V_{dc} = \frac{D}{1-D} V_{in}(t) \quad \textbf{(2)}$$

Where D represents the duty ratio.

The instantaneous value of duty ratio, D(t) depends on the input voltage appearing after DBR Vinet) and the required DC link voltage, V_{de}.

The critical value of input inductor Lie is expressed as:

$$L_{ic} = \frac{1}{2f_s}\left(\frac{V_s^2}{P_i}\right)\left(\frac{V_{dc}}{V_{in}(t)+V_{dc}}\right) \quad \textbf{(3)}$$

The value of input inductor has to be selected lower than the value obtained for V_{de} max to work in discontinuous
conduction mode.

The critical output side inductor is designed as:

$$L_{OC} = \left(\frac{V_s^2}{P_i}\right)\frac{V_{dc}}{0.25V_{in}(t)f_s}\left(\frac{V_{dc}}{V_{in}(t)+V_{dc}}\right) \quad \textbf{(4)}$$

The critical value of intermediate capacitance Cle is as:

$$C_{ic} = \frac{V_{dc}D(t)}{2V_{c1}(t)f_s R_L} \quad \textbf{(5)}$$

The value of DC link capacitor is calculated by:

$$C_d = \frac{I_{dc}}{2\omega\delta V_{dc}} = \frac{\left(P_i/V_{dc}\right)}{2\omega\delta V_{dc}} = \frac{P_i}{2\omega\delta V_{dc}^2} \quad \textbf{(6)}$$

Where represents the permitted ripple in DC link voltage which is taken as 4% Of V_{dc}.

VI. MATLAB/SIMULATION RESULTS

Matlab/Simulation model of with fixed speed as shown in Fig.7.

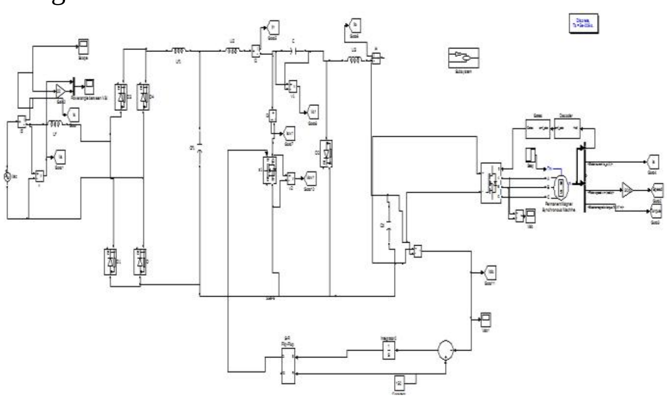

Fig.7.Matlab/Simulation model of with fixed speed.

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A. PFC at Input Mains

The current and voltage waveforms at AC input mains (Fig.8) for input of 130 V and its harmonic spectra during steady state at 1000 rpm are shown. It is observed that the current THD at AC mains remains less than 3% (Fig.9).

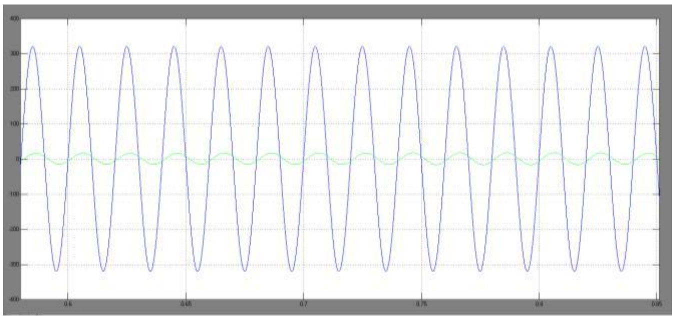

Fig. 8. Power Factor at AC mains.

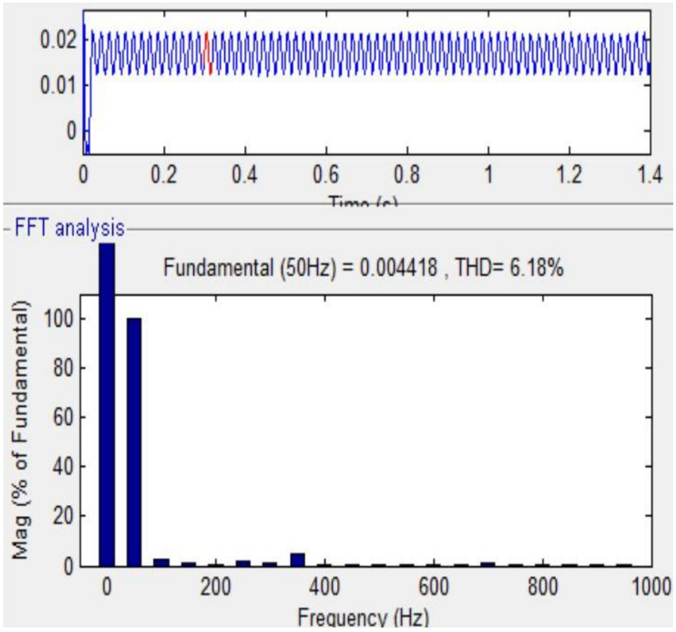

Fig.9. Input Current THD.

B. Following the Reference Speed

It is observed that the starting of the drive is smooth. The motor is started from 220 Vrms AC input with a reference speed of 1000 rpm. The motor speed reaches the reference speed within 0.05 s as given in Fig.10. The reference speed is varied for detailed evaluation of the drive as shown in Figs.10 to 13. The motor attains the reference speed within couple of cycles of AC mains frequency.

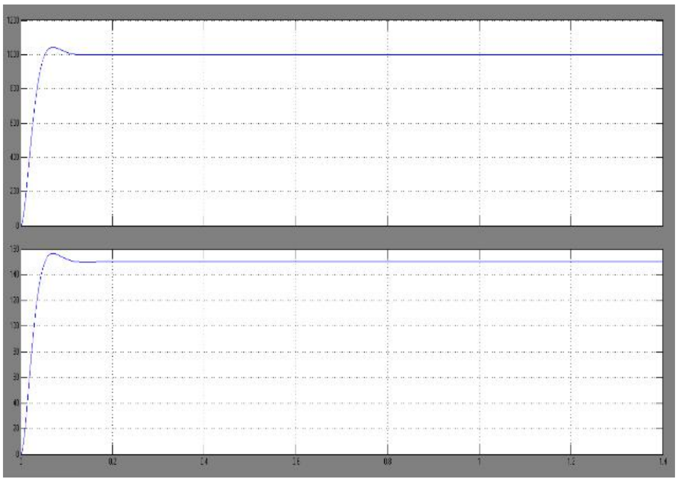

Fig.10.actual speed and converter output voltage.

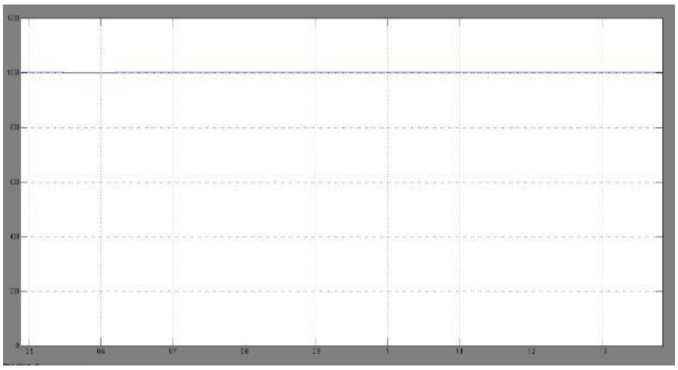

Fig. 11. Steady State Output at Reference Speed of 1000 rpm.

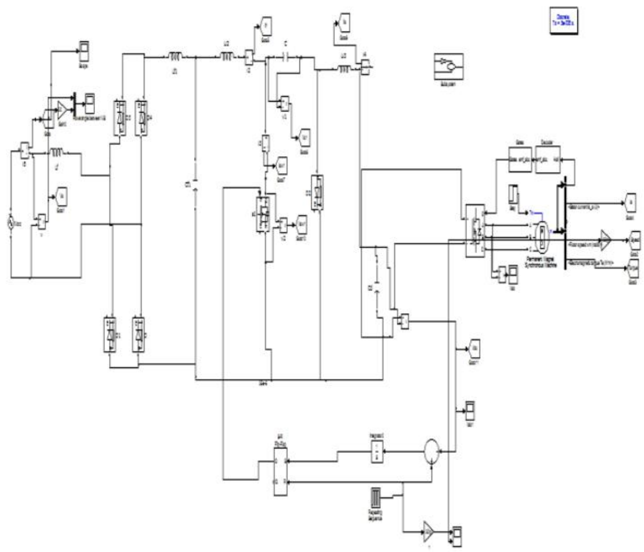

Fig.12.Matlab/Simulation model of with variable speed.

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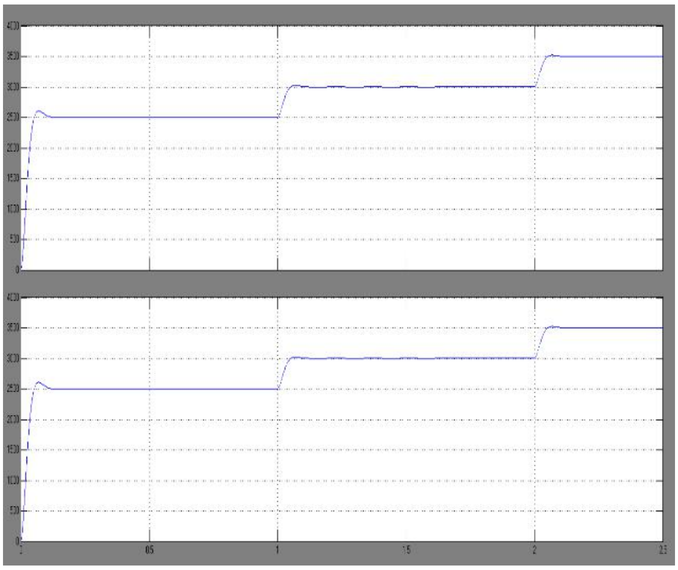

Fig. 13. BLDC Motor output at Varying Reference Speed.

C. Performance During Varying Load

As the load increases more current is drawn by the motor. In such conditions the control should be able to maintain the motor speed at the desired reference speed.

A torque input of 2Nm is given to the motor with desired speed of 2000 rpm at Is (Fig. 14). It is observed that the rotor speed attains the reference speed by proper control after a load variation is applied. The BLDC Motor stator current and back EMF during loading is observed to be as given in Figs. 14 to 17.

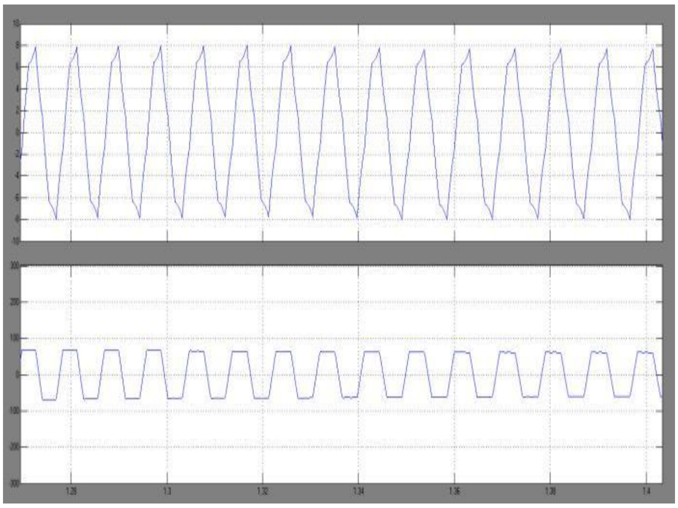

Fig.14. BLDC Motor Stator Current and Back EMF during Loading.

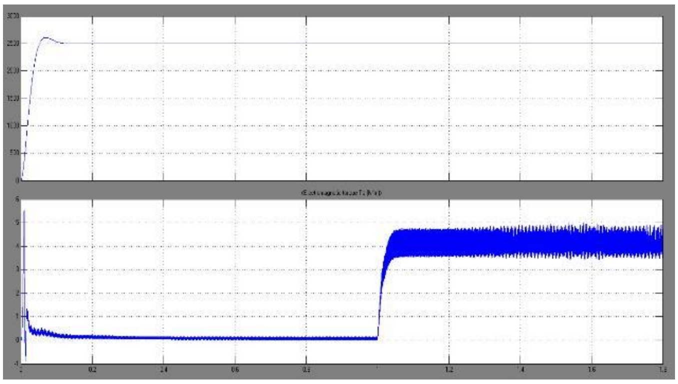

Fig. 15. Performance Evaluation during Loading (2 Nm at 1sec.)

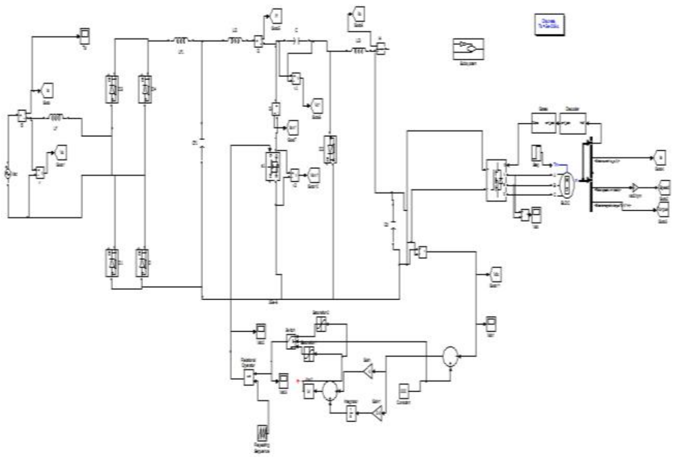

Fig.16.Matlab/Simulation model of with fixed speed and PI Controller.

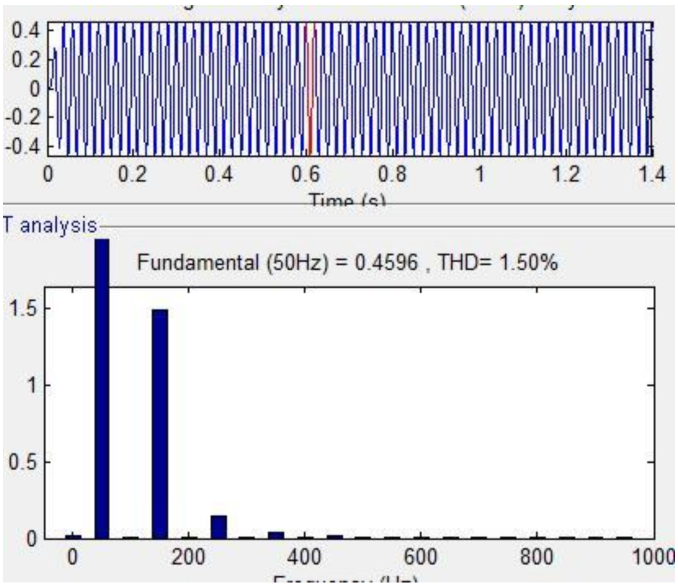

Fig.17. Input Current THD with PI Controller.

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VII. CONCLUSION

A OCC Cuk converter based PFC topology for a PMBLDCM drive has been proposed and validated, The performance of the drive has been found very well in the wide range of input AC voltage, The simulation results attained under various operating conditions illustrate that the One Cycle Control gives robust performance and faster dynamic response. Moreover, no PI tuning is required. The One Cycle Controlled PFC Cuk converter is observed to give the desired performance, i.e., fast response and near unity power factor at AC mains.This topology has been found suitable for the applications involving speed control at constant torque load due to its fast dynamic response. The concept of One Cycle Control is straightforward and its implementation circuits are general and simple, yet it provides excellent control.

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