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Control of Brushless DC Motor Drive with BL Luo Converter using Sliding Mode Control

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This paper proposes a Sliding Mode Control (SMC) for Luo Converter operated in Discontinuous Conduction Mode. Due to the time varying and switching nature of Luo converter, its dynamic behaviour becomes highly non-linear. In order to improve dynamic performances of Luo converter for both static and dynamic specifications, SMC is proposed. The SMC is designed by using state-space average modelling of Luo converter. The Luo converter is developed as a power factor correction (PFC) converter with DC link voltage control for speed control of a permanent magnet brushless DC motor (PMBLDCM). The voltage source inverter (VSI) is used as an electronic commutator of PMBLDCM. The proposed converter performs the PFC action and DC link voltage control in single stage using only one controller. A rate limiter in the reference DC link voltage is designed for the control of current and torque in PMBLDCM. The designed PFC converter results in an improved power quality at AC mains in a wide range of speed control and input AC voltage.
Keywords— Sliding Mode Control (SMC), Luo converter, Power Factor Correction, Speed Control, Voltage Source Inverter(VSI), DC link voltage, Power Quality;

I. INTRODUCTION

International concern of power quality (PQ) problems has prompted the use of power factor correction converters with a brushless DC motors (BLDCM) for numerous low power applications. Brushless dc (BLDC) motors are becoming popular due to their advantages of high efficiency, high energy density, high torque/inertia ratio, variable speed operation, and low electromagnetic interference (EMI). They find applications in household appliances, medical equipments, robotics and automation, transportation, and industrial tools. The BLDC motor is a three-phase synchronous motor with three-phase concentrated windings on the stator and permanent magnets on the rotor. It needs a three-phase voltage source inverter (VSI) for achieving an electronic commutation of BLDC motor based on the rotor position as sensed by Hall Effect position sensors. Power factor correction (PFC) converters are widely used for improving the power quality at ac mains. In this project, the SMC based bridgeless luo converter designed for power factor correction converter. Sliding Mode Control (SMC), which is derived from variable structure system theory, extends the properties of hysteresis control to multivariable environments, resulting in stability even for large supply and load variations, good dynamic response, and simple implementation over the conventional controller. A permanent magnet brushless dc motor is fed through a voltage source inverter, which is used to drive a BLDC motor, and it is variable speed operation under rated torque. The power quality issues because of uncontrolled charging the dc connect capacitor in the PMBLDCM drive is diminished to a more noteworthy degree utilizing PFC converter. The proposed topology is simulated by MATLAB / Simulink software to validate the accuracy of the theoretical analysis. Finally, a prototype of the proposed system has been built and tested.

II. EXISTING SYSTEMS

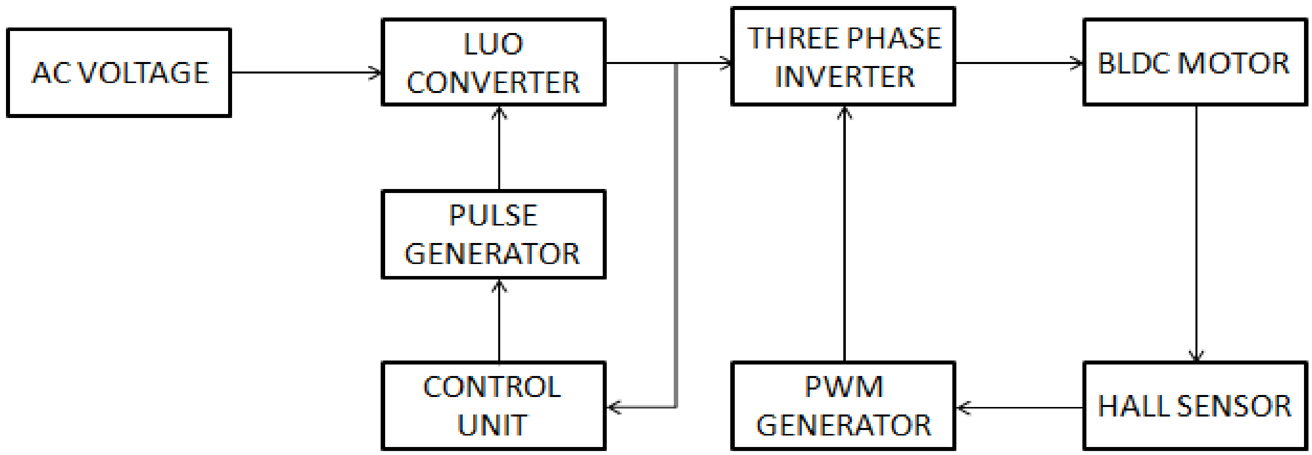
In existing system converter is used widely for feeding BLDC motor for improving power factor correction technique. PWM is used for giving the pulse to the switches. DC link voltage is varied in the VSI side. Cost of the system also high for using large number of sensors. CCM mode of PFC cuk converter is used, which requires 3 sensors for monitoring the 3-phase ac supply. This suited for only high power applications.

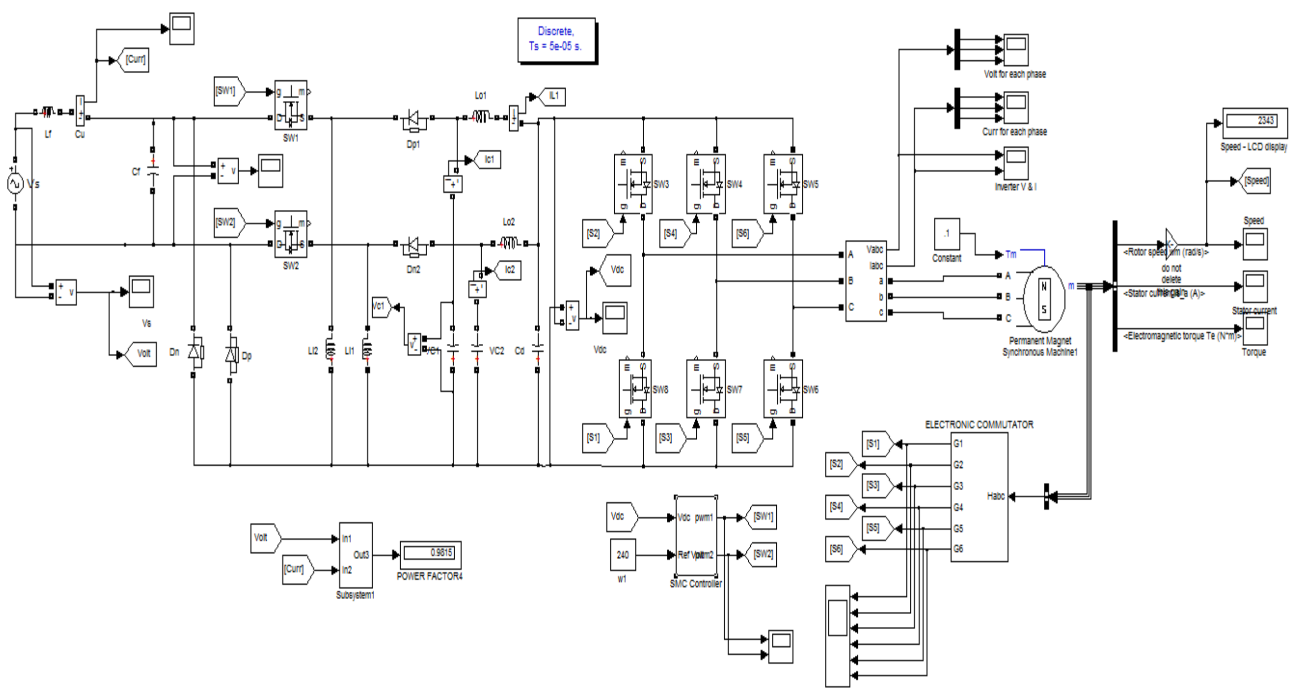
A. Drawbacks of Existing System

1) PI control could be used only for steady state and time response.
2) Integral action leads to oscillation.
3) PI controller has greatest overshoot and high settling time.

III. PROPOSED SYSTEM

This project proposes the analysis and control of BLDC Motor with the output Luo converter by using sliding mode control. The performance of the Sliding Mode Controller in terms of robustness and dynamic response will be improved by proper selection of the controller gains. A voltage sensor is utilized for the speed control of BLDC engine and Power Factor Correction at ac mains. The voltage devotee control is utilized for the BL-luo converter in Discontinuous Inductor Current Mode(DICM). The speed of the BLDC engine is controlled by an approach of variable dc link voltage which permits a low frequency switching of VSI for electronic commutation of BLDC engine. The proposed BLDC engine is intended to work over an extensive variety of speed control with an enhanced power quality at AC mains. The simulation of proposed Luo converter fed BLDC with its control model is implemented in MatLab/Simulink.





A. Advantages of Proposed system

1) It operates in a low frequency switching for reduced switching losses.
2) The proposed drive is actualized to accomplish a unity power factor at ac mains for an extensive variety of speed control and supply voltage fluctuations.

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IV. HARDWARE ARCHITECTURE

A. BLDC Motor

DC motors are available in many different power ratings from very small motors as used in hard drives to large motors used in electric vehicles however main drawback of the dc motor is need of periodic maintenance. BLDC motor is an AC synchronous motor when operated under rated conditions, the life expectancy is over 10,000 hours. This BLDC motor is powered by DC electrical source via voltage source inverter which produces AC signal to drive the motor. BLDC motors gained importance in last decade due to power quality improvement and resulted in exceptional performance compared with other devices. These motors have permanent magnet on the rotor and three phase winding on the stator. Electronic commutation is based on the rotor position sensed by hall effect sensor. The rotor position feedback from the hall effect sensor helps to determine when to switch the armature current.

B. Advantages of BLDC motor

1) High efficiency
2) Better speed vs torque characteristics
3) Noiseless operation
4) Higher speed range

C. Commutator

An electronic commutation of BLDC motor includes proper switching of VSI in such a way that a symmetrical dc current is drawn from the dc link for 120◦ and placed symmetrically at the centre of back-EMF of each phase. A Hall effect position sensor is used to sense the rotor position on a span of 60◦; which is required for the electronic commutation of BLDC motor. When two switches of VSI, are in conduction states, a line current is drawn from the dc link capacitor whose magnitude depends on applied dc link voltage, back EMF's, resistances, and self and mutual inductance of stator windings. This current produces the electromagnetic torque which in turn increases the speed of the BLDC motor.

D. AC Power Supply

An AC power supply typically takes the voltage from a wall outlet (mains supply) and lowers it to the desired voltage.

E. Rectifier

It is often used for serving as component of DC power supply to convert AC to DC.

F. Converter

In electronics engineering, a DC to DC converter is a circuit which converts a source of direct current from one voltage to another. Here, DC to DC conversion is done by using Luo converter. It uses voltage lift technique in which output is increased stage by stage.

G. Three Phase Voltage Source Inverter

Single-phase VSIs cover low-range power applications and three-phase VSIs cover the medium- to high-power applications. The principle of motivation of this topology is to give three phase voltage source where amplitude, phase and frequency of the voltage should be controllable.

H. DsPIC30F2010 Microcontroller

We are using dsPIC30f2010 for producing switching pulses to multilevel inverter so as to use those vectors which do not generate any common mode voltage at the inverter poles. This eliminates common mode voltage. The microcontroller are driven via the driver circuit so as to boost the voltage triggering signal to 9V.To avoid any damage to micro controller due to direct passing of 230V supply to it we provide an isolator in the form of optocoupler in the same driver circuit. The dsPIC30FXXXX series has more advanced and developed features when compared to its previous series.

V. OPERATION OF LUO CONVERTER

The operation of Luo Converter has two modes named as Mode I and Mode II which has been explained below.

A. Mode I

When the switch is ON, the inductor L1 is charged by the supply voltage E. At the same time, the inductor L2 absorbs the energy from source and the capacitor C1.

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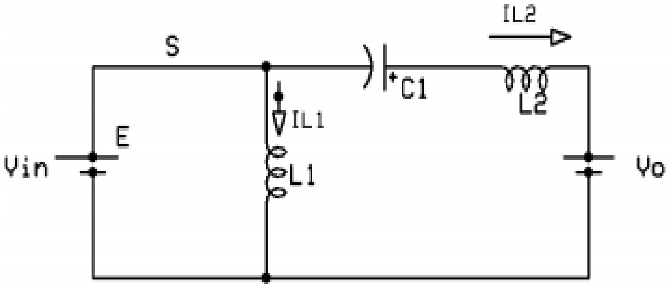
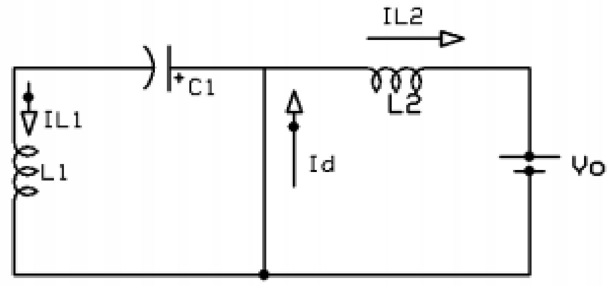
B. Mode II

During switch is in OFF state, and hence, the current is drawn from the source becomes zero. Current IL1 flows through the freewheeling diode to charge the capacitor C1. Current IL2 flows through C2 and the freewheeling diode D to keep itself continuous. If adding additional filter components like inductor and capacitor to reduce the harmonic levels of the output voltage.





VI. DESIGN OF BRIDGELESS LUO CONVERTER

The Luo converter is the next stage to the bridgeless concept. The PFC BL-Luo converter is designed for its operation in DICM to act as a power factor pre-regulator. The currents in the input inductors becomes discontinuous in a switching period, whereas the output inductor currents (ILo1 and ILo2) and intermediate capacitor's voltages (VC1 and VC2) remain continuous. A Pmax PFC converter is designed to control the DC link voltage from Vdcmin to Vdcmax. Since the speed is directly proportional to DC link voltage, hence output power is taken as linear function of the DC link voltage. Therefore, the output power corresponding to minimum DC link voltage is taken as Pmin.

The average voltage (Vin) appearing at the input of filter is given as,

$$V_{in}=\frac{2\sqrt{2}V_s}{\pi}$$

Vin - average voltage

VS – source voltage

The relation between the input and output voltages for a BL-Luo converter is given as,

$$d=\frac{V_{dc}}{V_{in}+V_{dc}}$$

Vdc – DC link voltage

The critical value of input inductor operating in DICM for a worst duty ratio of dmin is given as,

$$L_{ic}=\frac{d_{min}(1-d_{min})V_{in}}{2I_0 f_s}$$

where fs is the switching frequency and Io is the load current. Now, the value of input inductor's is to be selected much less than this critical value to achieve a deep discontinuous conduction over a wide range.

The value of intermediate capacitors (C1 and C2) is calculated for worst duty ratio (dmax) and is given as,

$$C_{1,2}=\frac{d_{max}V_C}{2f_s R_L\left(\frac{\Delta V_C}{2}\right)}$$

f s - switching frequency

where RL is the emulated load resistance i.e. Vdc 2/Pmax, VC is the voltage appearing across C1 or C2; (i.e. Vin+Vdc) and ΔVC is the permitted voltage ripple which is taken as 60% of VC. The value of output inductor's (Lo1 and Lo2) for the permitted ripple current in output inductors (which is taken as 10% of Io) is calculated as,

$$L_{01,2}=\frac{d_{max}I_0}{16f_s^2 C_{in}\left(\frac{\Delta i_0}{2}\right)}$$

The value of DC link capacitor (Cd) is obtained for worst duty ratio as,

$$C_d=\frac{I_0}{2\omega_L \Delta V_{dcmin}}$$

where ΔVdc is the permitted ripple voltage in DC link capacitor (taken as 3%) and ωL is line frequency in rad/sec.

An input filter (L-C filter) is designed to avoid the reflection of high current ripple in the supply system. The maximum value of filter capacitor (Cmax) is given as,

$$C_{max}=\frac{I_{peak}}{\omega_L V_{peak}}\tan(\theta)$$

Now, the value of filter inductor is designed by considering the source impedance (Ls) of 4-5% of the base impedance. Hence the additional value of inductance required is given as,

$$L_f=L_{req}+L_s \Rightarrow \frac{1}{4\pi^2 f_c^2 C_f}$$

where fc is the cut-off frequency which is selected such that vfL< fc< fS; hence it is taken as fS/10.

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A. Control of BLDC Motor

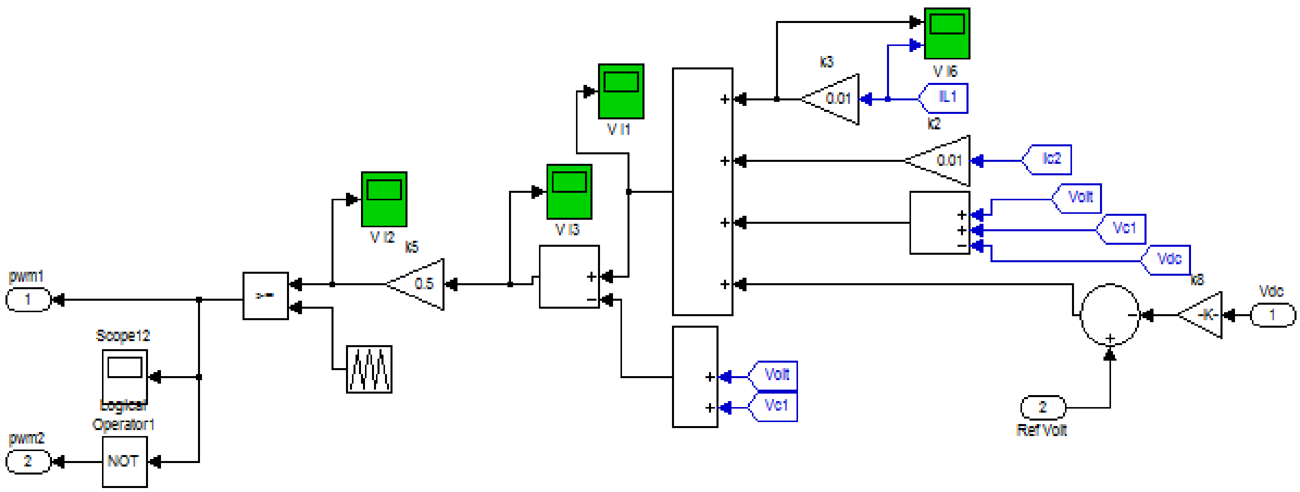
An electronic commutation of BLDC motor includes proper switching of VSI in such a way that a symmetrical dc current is drawn from the dc link for 120◦ and placed symmetrically at the centre of back-EMF of each phase. A Hall effect position sensor is used to sense the rotor position on a span of 60◦; which is required for the electronic commutation of BLDC motor. When two switches of VSI, i.e., S1 and S4 are in conduction states, a line current iab is drawn from the dc link capacitor whose magnitude depends on applied dc link voltage (Vdc), back EMF's (ean and ebn), resistances (Ra and Rb), and self and mutual inductance (La, Lb, and M) of stator windings. This current produces the electromagnetic torque (Te) which in turn increases the speed of the BLDC motor.

B. Pulse Width Modulation

The Sinusoidal Pulse Width Modulation (SPWM) is a well-known wave shaping technique in power electronics for realization, a high frequency triangular carrier signal, V1, is compared with a sinusoidal reference signal, V, of the desired frequency. The crossover points are utilized to find the switching instants. The magnitude ratio of the reference signal to that of triangular signal is known as the modulation index. By varying the modulation index output voltage is controlled.

VII. PROPOSED ALGORITHM (SLIDING MODE CONTROL)

Sliding mode control (SMC) is a nonlinear control method including striking properties of accuracy, robustness, and easy tuning and implementation. This system is designed to drive the system states onto a particular surface in the state space, named sliding surface. Once the sliding surface is reached, sliding mode control keeps the states on the close neighbourhood of the sliding surface. Hence the sliding mode control is a two part controller design. The first part involves the design of a sliding surface so that the sliding motion satisfies design specifications. The second is concerned with the selection of a control law that will make the switching surface attractive to the system state. First is that the dynamic behaviour of the system may be tailored by the particular choice of the sliding function. Secondly, the closed loop response becomes totally insensitive to some particular uncertainties. This principle extends to model parameter uncertainties, disturbance and nonlinearity that are bounded.



A. Sliding Surfaces

It investigates variable structure control (VSC) as a high-speed switched feedback control resulting in sliding mode. For example, the gains in each feedback path switch between two values according to a rule that depends on the value of the state at fig 5. Sliding mode control each instant. The purpose of the switching control law is to drive the nonlinear plant's state trajectory onto a pre-specified (user-chosen) surface in the state space and to maintain the plant's state trajectory on this surface for subsequent time. The surface is called a switching surface. When the plant state trajectory is "above" the surface, a feedback path has one gain and a different gain if the trajectory drops "below" the surface. This surface is known as sliding surface. Ideally, once intercepted, the switched control maintains the plant's state trajectory on the surface for all subsequent time and the plant's state trajectory slides along this surface.

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C. Sliding Mode Observer

Sliding mode control can be used in the design of state observers. These non-linear high-gain observers have the ability to bring coordinates of the estimator error dynamics to zero in finite time. Additionally, switched-mode observers have attractive measurement noise resilience. In this particular example, the estimator error for a single estimated state is brought to zero in finite time and after that time the other estimator errors decay exponentially to zero. A sliding mode observer for non-linear systems can be built that brings the estimation error for all estimated states to zero in a finite (and arbitrarily small) time.

D. Sliding Mode Control Working

The phenomenon "Sliding Mode" may appear in dynamic systems governed by ordinary differential equations with discontinuous state functions in the right-hand sides.

The control input in the second order system, may take only two values, M and M−, and undergoes discontinuities on the straight line s=0 in the state plane The analysis of the state plane that,in the neighborhood segment on the switching line s = 0, the trajectories run in opposite directions, which leads to the appearance of a sliding mode along this line.

$$\dot{x}+cx=0$$

The equation of this line may be interpreted as the sliding mode equation. Note that,

The order of the equation is less than that of the system .

The sliding mode does not depend on the plant dynamics, and is determined by parameter c only.

$$\ddot{x}+a2\dot{x}+a1x=u,$$

$$u=-Msing(s), s=cx+\dot{x}, a1, a2, M, c – const$$

Luo convertor is used for power factor correction and the PWM signal to the Luo convertor is given by using SMC algorithm. Error voltage can be avoided by considering inductor voltage , inductor current, capacitor current, DC link voltage. Thus it reduces oscillations and operates under uncertain conditions. It is one of the main advantage of SMC .

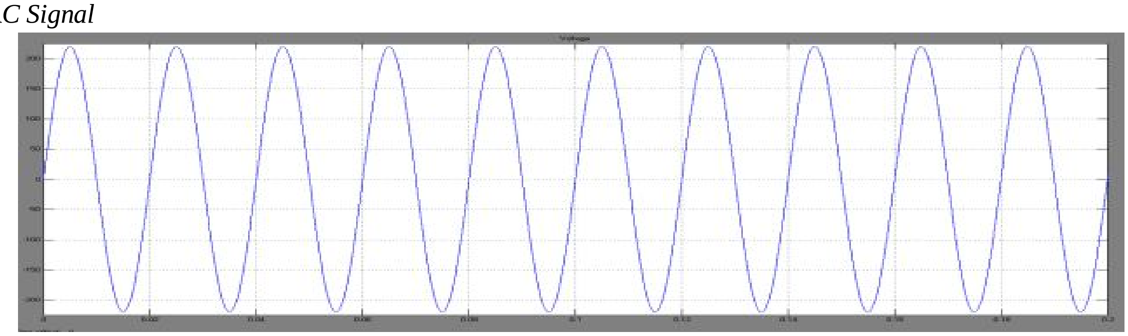
This could be used in several applications such as Overhead crane, Marine vehicles, Electrohydraulic valve actuator, Combined cycle plants.

VIII. SOFTWARE USED

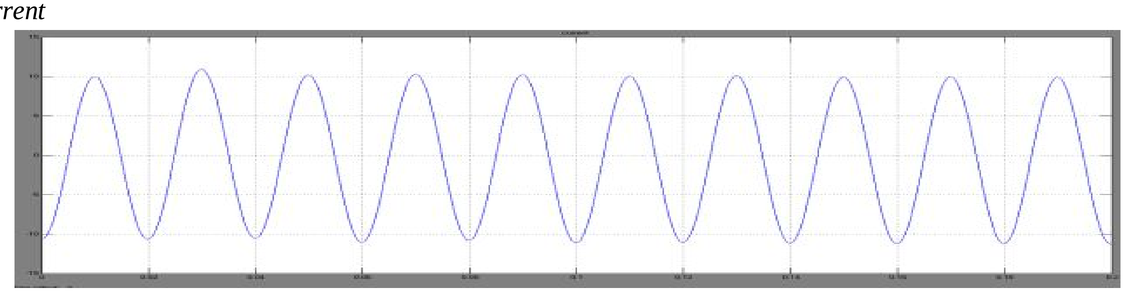
MATLAB is a software package for computation in engineering, science, and applied mathematics. It offers a powerful programming language. OrCAD is an electronic design automation software used to create electronic schematics . Driver circuit is designed by OrCAD. MPLAB is a proprietary freeware embedded application and are developed by microchip technology.

IX. RESULTS

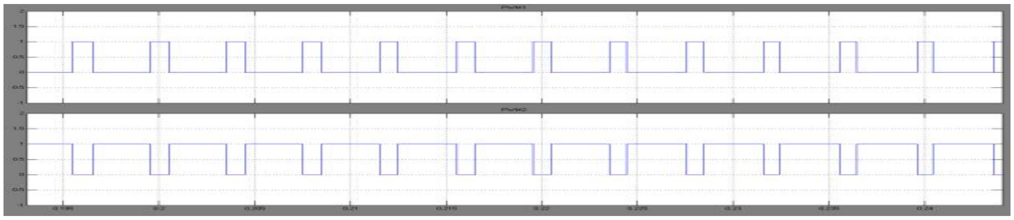
A. T Input AC Signal



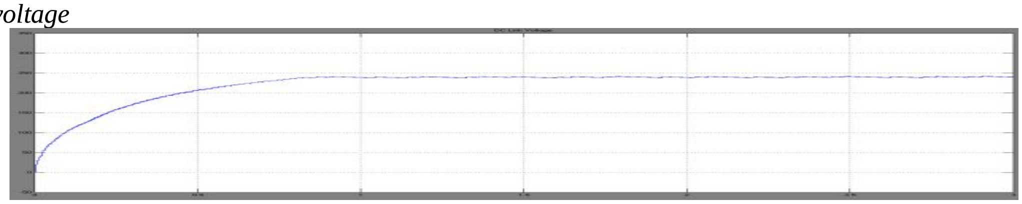
B. Input Current



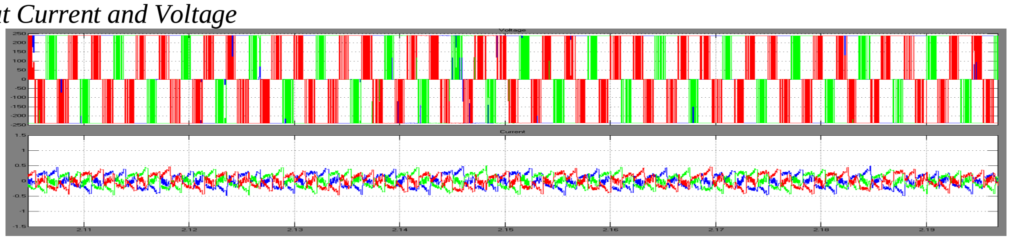
C. PWM Pulses for Luo Converter



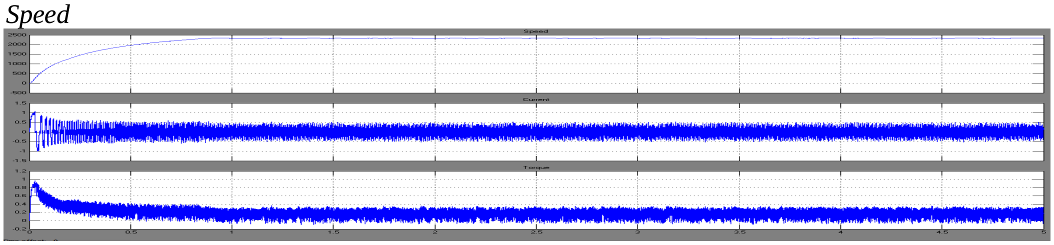
D. Luo conveter voltage



E. Inverter Output Current and Voltage



F. BLDC Motor Speed



X. CONCLUSIONS

The design and output voltage regulation of SMC for Luo converter operated in DICM has been proposed in this project. A SMC over the output capacitor voltage and inductor current has been used for the control. The effect of proper selected controller parameters of sliding mode controlled Luo converter fed BLDC Motor resulted in fast dynamic response and excellent static and transient responses over the conventional controller. A PFC converter system is designed for reducing the system cost and validated for the speed control with improved power quality at the

AC mains for a wide range of speed. The performance of the proposed drive system has also been evaluated for varying the voltages and found satisfactory.

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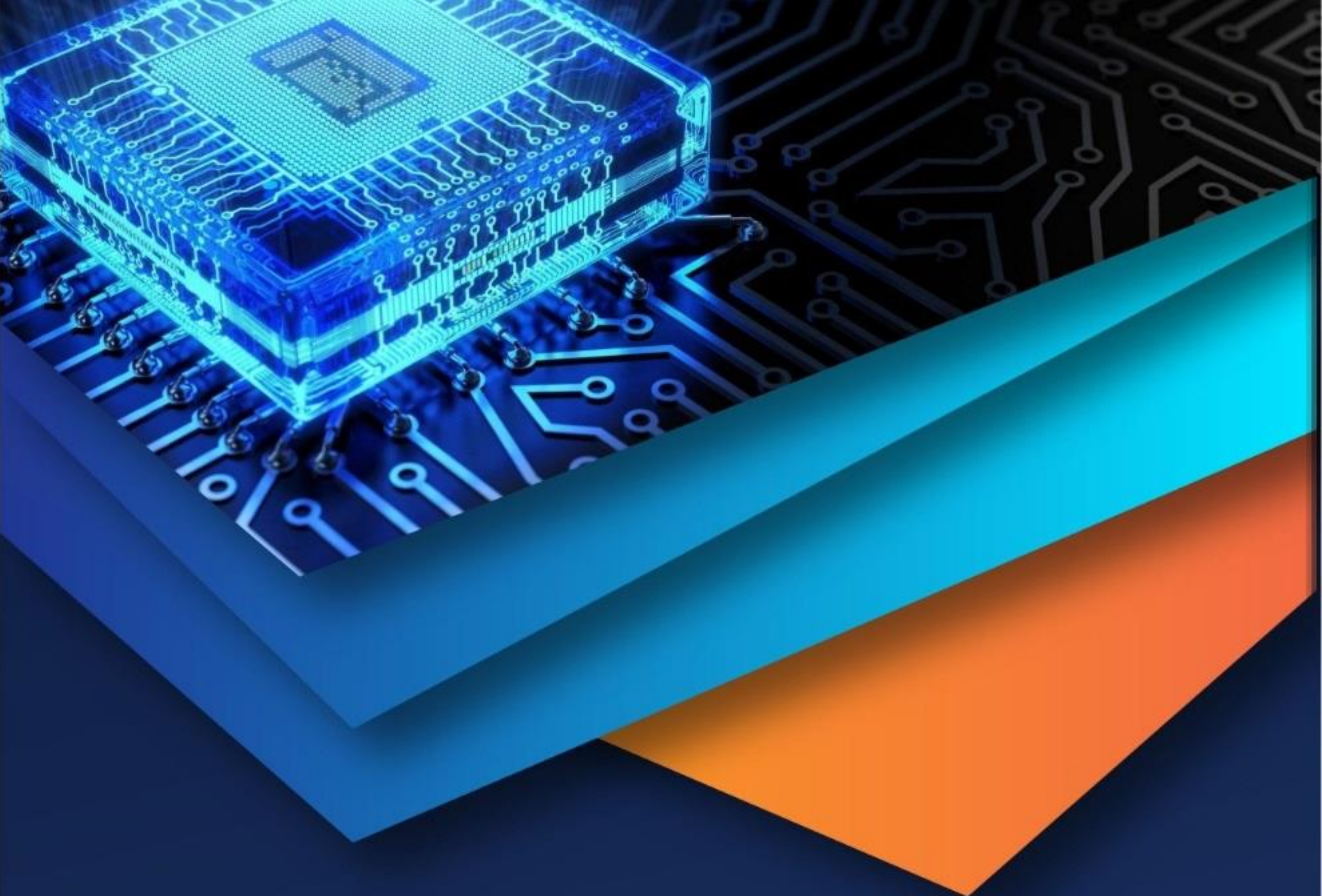

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