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Design and Improvement of BLDC Motor Speed control using Interleaved Boost Converter

P. R. Srinivasan [1] | Dr. J. S. Christy Manoraj[2]

[1]PG Scholar, Department of EEE, Government College of Engineering, Salem, Tamil Nadu, India.
[2]Professor, Department of EEE, Government College of Engineering, Salem, Tamil Nadu, India.

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ABSTRACT

This paper presents the design and improvement of BLDC motor speed control using interleaved boost converter. Solar photovoltaic system commits a fascinating energy resources due to ubiquitous and copiousness of solar energy. In the last decade, the so-called SPV technology is discussed one of the advanced technologies amongst the manifold renewable energy sources. In this proposed work, the idea of PV system, Interleaved Boost Converter (IBC) and Brushless (BLDC) motor is highlighted. For getting better efficiency with diminishing voltage and current ripples IBC are used. IBC predominantly employed for renewable energy origins having an amount of Boost Converter is joined to shunt with phase shift and the same frequency. To accomplish of interleaved converter is to diminish voltage and current ripples, good accomplishment of to power applications and prolongation efficiency. A BLDC motor is deliberated to be eminent performance due to its high reliability, little protection charge and boundless torque (T) and speed (S). To analyze and improve the performance and efficiency in terms of torque and speed using three-stage IBC fed BLDC motor with Fuzzy controller has been proposed. The modeling and MATLAB Simulink outcomes are provided to make out the theoretical exploration of PV panel, IBC and BLDC motor.

KEYWORDS:PI controller, Closed loop interleaved boost converter, Three-phase inverter, Matlab/Simulink

I. Introduction

Brushless DC (BLDC) motors have become increasingly popular 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 [1]-[2]. A BLDC motor is a three-phase synchronous motor having torque-speed characteristics of a DC motor. It has three phase windings on the stator which are excited by a voltage source inverter (VSI) and permanent magnets on the rotor[3]-[4]. It does not require any brushes and commentator assembly; rather an electronic commutation based on the rotor position as sensed by Hall Effect position sensors is used[9]. Hence the problems such as sparking, wear and tear of brushes, EMI and noise interference are eliminated in the BLDC motor.Figure :1 shows, the block diagram of proposed model

Problem statements

ThetrendofusingPM-BLDC motorisobviously growingamongthe domestic and industrial application due to its characteristics. However, the drawback ofhaving nonlinearcharacteristicmakesitdifficulttobecontrolled.Therewere several parameters need to be considered before designing the controller, such as load torque, stator resistance, rotor resistance, and output motor line current. The existence of control strategies such as Field-Oriented Control (FOC) suffers from sensitivity to the motor parameter variations even adaptive schemes tend to be sensitive but poor in the flux, torque, and current estimation specially during low-speed operation. The current was varying during the operation be cause it is depending on the torque and the load. An alternative to overcome this situation was to use the low cost and robust control techniques which take the motor's line current as a feedback to the controller.

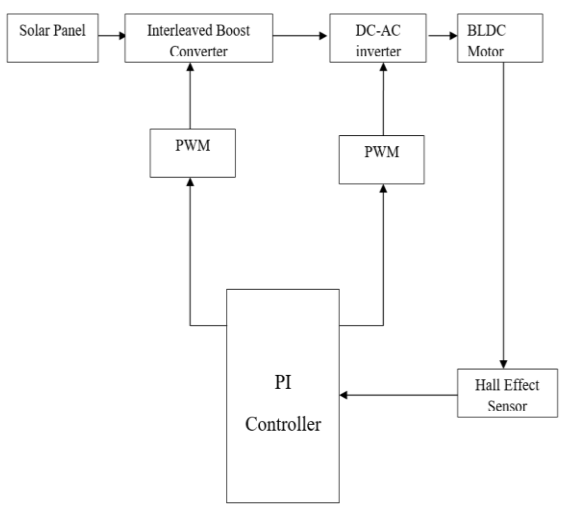

Figure :1 Block diagram of proposed model

II. CONFIGURATION OF PROPOSED MODEL

The Configuration of proposed model consist of solar panel, Interleaved boost converter, Three-phase inverter and BLDC motor, as shown in Figure:2.

A. SOLAR PANEL

Solar panel (**photovoltaic module** or **photovoltaic panel**) is a packaged interconnected assembly of solar cells, also known as photovoltaic cells. The solar panel is used as a component in a larger photovoltaic system to offer electricity for commercial and residential applications. Because a single solar panel can only produce a limited amount of power, many installations contain several panels. This is known as a photovoltaic array. A photovoltaic installation typically includes an array of solar panels, an inverter, batteries and interconnection wiring. Solar panels use light energy (photons) from the sun to generate electricity through the photovoltaic effect. The structural (load carrying) member of a module can either be the top layer (superstrate) or the back layer (substrate). The majority of modules use wafer-based crystalline silicon cells or a thin-film cell based on cadmium telluride or silicon. Crystalline silicon, which is commonly used in the wafer form in photovoltaic (PV) modules, is derived from silicon, a commonly used semi-conductor. In order to use the cells in practical applications, they must be: connected electrically to one another and to the rest of the system protected from mechanical damage during manufacture, transport, installation and use (in particular against hail impact, wind and snow loads). This is especially important for wafer-based silicon cells which are brittle. protected from moisture, which corrodes metal contacts and interconnects, (and for thin-film cells the transparent conductive oxide layer) thus decreasing performance and lifetime. Most modules are usually rigid, but there are some flexible modules available, based on thin-film cells. Electrical connections are made in series to achieve a desired output voltage and/or in parallel to provide a desired amount of current source capability. Diodes are included to avoid overheating of cells in case of partial shading. Since cell heating reduces the operating efficiency it is desirable to minimize the heating. Very few modules incorporate any design features to decrease temperature, however installers try to provide good ventilation behind the module.New designs of module include concentrator modules in which the light is concentrated by an array of lenses or mirrors onto an array of small cells. This allows the use of cells with a very high-cost per unit area (such as gallium arsenide) in a cost-competitive way. Depending on construction, the photovoltaic can cover a range of frequencies of light and can produce electricity from them, but sometimes cannot cover the entire solar spectrum (specifically, ultraviolet, infrared and low or diffused light). Hence much of incident sunlight energy is wasted when used for solar panels, although they can give far higher efficiencies if illuminated with monochromatic light. Another design concept is to split the light into different wavelength ranges and direct the beams onto different cells tuned to the appropriate wavelength ranges. This is projected to raise efficiency by 50%. Also, the use of infrared photovoltaic cells can increase the efficiencies, producing power at night.

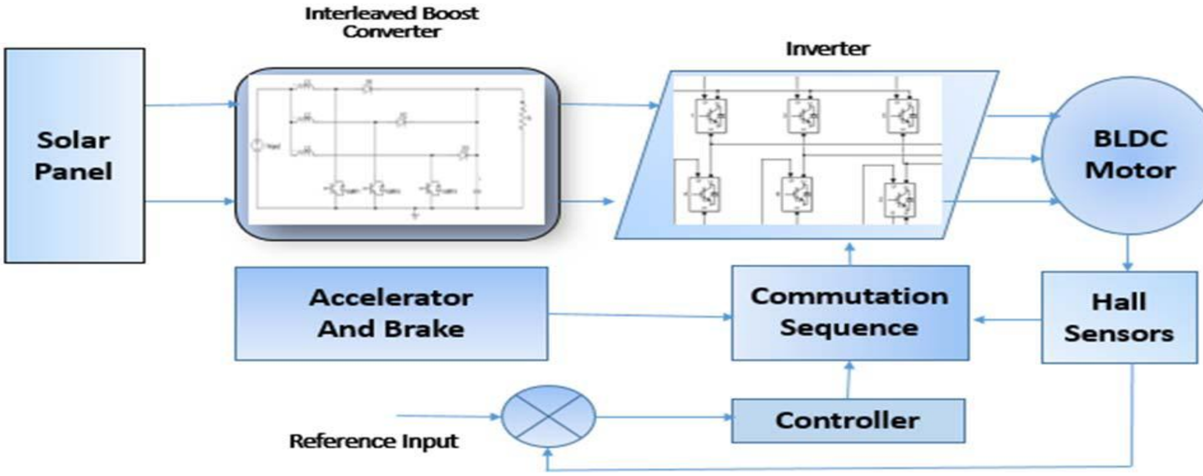

Figure :2 Configuration of proposed BLDC motor speed control using interleaved boost converter

B. INTERLEAVED BOOST CONVERTER

The interleaved boost converter, it operates depending upon the Interleaving property. The circuit contains two boost converters in parallel operating 180° out of phase as shown in Figure:3 Interleaved boost converter. The inductor 's ripple currents are out of phase, so They tend to cancel each other and reduce the input ripple current caused by the boost switching action. The input current is the sum of the two inductor currents ILB1 and ILB2. Moreover, the effective switching frequency is increased by switching 180° out of phase and introduces smaller input current ripples. So, the EMI filters in the input side will be smaller.

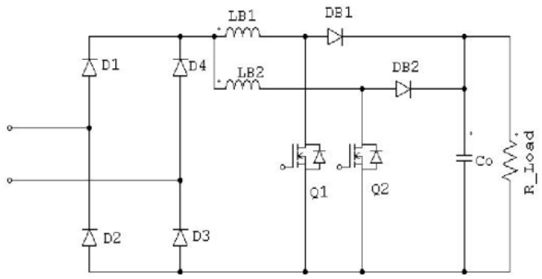

Figure :3 Interleaved boost converter

DC to DC converters is important in portable electronic devices such as cellular phones and laptop computers, which are supplied with power from batteries primarily. Such electronic devices often contain several sub-circuits, each with its own voltage level requirement different from that supplied by the battery or an external supply (sometimes higher or lower than the supply voltage). Additionally, the battery voltage declines as its stored power is drained. Switched DC to DC converters offer a method to increase voltage from a partially lowered battery voltage thereby saving space instead of using multiple batteries to accomplish the same thing.

Most DC to DC converters also regulate the output voltage. Some exceptions include high-efficiency LED power sources, which are a kind of DC to DC converter that regulates the current through the LEDs, and simple charge pumps which double or triple the input voltage.

Linear regulators can only output at lower voltages from the input. They are very inefficient when the voltage drop is large and the current is high as they dissipate heat equal to the product of the output current and the voltage drop; consequently, they are not normally used for large-drop high-current applications.The inefficiency wastes power and requires higher-rated and consequently more expensive and larger components. The heat dissipated by high-power supplies is a problem in itself and it must be removed from the circuitry to prevent unacceptable temperature rises.Linear regulators are practical if the current is low, the power dissipated being small, although it may still be a large fraction of the total power consumed. They are often used as part of a simple regulated power supply for higher currents: a transformer generates a voltage which, when rectified, is a little higher than that needed to bias the linear regulator. The linear regulator drops the excess voltage, reducing hum-generating ripple current and providing a constant output voltage independent of normal fluctuations of the unregulated input voltage from the transformer/bridge rectifier circuit and of the load current.Linear regulators are inexpensive, reliable if good heat sinks are used and much simpler than switching regulators. As part of a power supply, they may require a transformer, which is larger for a given power level than that required by a switch-mode power supply. Linear regulators can provide a very low-noise output voltage, and are very suitable for powering noise-sensitive low-power analog and radio frequency circuits. A popular design approach is to use an LDO, Low Drop-out Regulator, that provides a local "point of load" DC supply to a low power circuit.

Switched-mode conversion

Electronic switch-mode DC to DC converters convert one DC voltage level to another, by storing the input energy temporarily and then releasing that energy to the output at a different voltage. The storage may be in either magnetic field storage components (inductors, transformers) or electric field storage components (capacitors). This conversion method is more power efficient (often 75% to 98%) than linear voltage regulation (which dissipates unwanted power as heat). This efficiency is beneficial to increasing the running time of battery-operated devices. The efficiency has increased since the late 1980s due to the use of power FETs, which are able to switch at high frequency more efficiently than power bipolar transistors, which incur more switching losses and require a more complicated drive circuit. Another important innovation in DC-DC converters is the use of synchronous rectification replacing the flywheel diode with a power FET with low "on resistance", thereby reducing switching losses. Before the wide availability of power semiconductors, low power DC to DC converters of this family consisted of an electro-mechanical vibrator followed by a voltage step-up transformer and a vacuum tube or semiconductor rectifier.

Most DC-to-DC converters are designed to move power in only one direction, from the input to the output. However, all switching regulator topologies can be made bi-directional by replacing all diodes with independently controlled active rectification. A bi-directional converter can move power in either direction, which is useful in applications requiring regenerative braking.

Drawbacks of switching converters include complexity, electronic noise (EMI / RFI) and to some extent cost, although this has come down with advances in chip design.

DC-to-DC converters are now available as integrated circuits needing minimal additional components. They are also available as a complete hybrid circuit component, ready for use within an electronic assembly.

Magnetic

In these DC-to-DC converters, energy is periodically stored into and released from a magnetic field in an inductor or a transformer, typically in the range from 300 kHz to 10 MHz by adjusting the duty cycle of the charging voltage (that is, the ratio of on/off time), the amount of power transferred can be controlled. Usually, this is applied to control the output voltage, though it could be applied to control the input current, the output current, or maintain a constant power. Transformer-based converters may provide isolation between the input and the output. In general, the term "DC-to-DC converter" refers to one of these switching converters. These circuits are the heart of a switched-mode power supply. Many topologies exist. This table shows the most common.

In addition, each topology may be:

- Hard switched - transistors switch quickly while exposed to both full voltage and full current
- Resonant - an LC circuit shapes the voltage across the transistor and current through it so that the transistor switches when either the voltage or the current is zero

Magnetic DC-to-DC converters may be operated in two modes, according to the current in its main magnetic component (inductor or transformer):

- Continuous - the current fluctuates but never goes down to zero
- Discontinuous - the current fluctuates during the cycle, going down to zero at or before the end of each cycle

A converter may be designed to operate in continuous mode at high power, and in discontinuous mode at low power.

The Half bridge and Flyback topologies are similar in that energy stored in the magnetic core needs to be dissipated so that the core does not saturate. Power transmission in a flyback circuit is limited by the amount of energy that can be stored in the core, while forward circuits are usually limited by the I/V characteristics of the switches

C. THREE - PHASE INVERTER

The dc to ac converter commonly known as inverter, depending on the type of the supply source and the related topology of the power circuit. They are classified as voltage source inverters (VSIs) and current source inverters (CSIs). Single-phase VSIs cover low-range power applications and three-phase VSIs cover medium to high power applications.
The main purpose of these topologies is to provide a three-phase voltage source, where the amplitude, phase and frequency of the voltages can be controlled. The three-phase dc/ac voltage source inverters are extensively being used in motor drives, active filters and unified power flow controllers in power systems and uninterrupted power supplies. It is to generate controllable frequency and ac voltage magnitudes using various pulse width modulation (PWM) strategies. The standard three-phase inverter shown in Figure 4. It has six switches the switching of which depends on the modulation scheme. The input DC usually obtained from a single- phase or three phase utility power supply through a diode-bridge rectifier and LC or C filter.

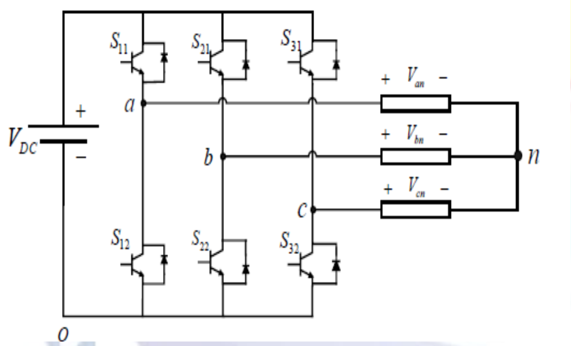

Figure :4 Three-phase inverter

D. BLDC MOTOR

Conventional dc motors are highly efficient and their characteristics make them suitable for use as servomotors. However, their only drawback is that they need a commutator and brushes which are subject to wear and require maintenance. When the functions of commutator and brushes were implemented by solid-state switches, maintenance-free motors were realized. These motors are now known as brushless dc motors.In this chapter, the basic structures, drive circuits, fundamental principles, steady state characteristics, and applications of brushless dc motors will be discussed.This invention relates to a brushless DC motor having a magnet (field flux generating means) and multiphase coils, and more particularly to a brushless DC motor in which a current is distributed from a DC voltage source to said multiphase coils by selectively activating two sets of output transistors, according to the relative position between said magnet and said multiphase coils. In a brushless DC motor having a magnet and multiphase coils, a current is distributed from a DC voltage source to the multiphase coils according to a set of output signals of a position detector for detecting the relative position between the magnet and the multiphase coils. First and second sets of output transistors are used so as to distribute a current to the corresponding multiphase coils. A first distributor selectively activates the first output transistors corresponding to the output signals of the position detector so as to supply the multiphase coils with a current according to a command signal, and a second distributor also selectively activates the second output transistors corresponding to the output signals of the position detector. A second distributor has a voltage drop controller for detecting voltage drops across the first set of output transistors (or the second set of output transistors) in each activated period and for controlling output currents of the second set of output transistors so as to maintain the voltage drops across the first set of output transistors (or the second set of output transistors) in each activated period at a predetermined value regardless of the relative position between themagnet and the multiphase coils.

Structures and Drive Circuit

Basic Structures
The construction of modern brushless motors is very similar to the ac motor, known as the permanent magnet synchronous motor. Figure:5 illustrates the Disassembled view of a brushless dc motor. Figure:6 illustrates the structure of a typical three-phase brushless dc motor. The stator windings are similar to those in a polyphase ac motor, and the rotor is composed of one or more permanent magnets. Brushless dc motors are different from ac synchronous motors in that the former incorporates some means to detect the rotor position (or magnetic poles) to produce signals to control the electronicswitchesasshowninFigure:6.Themostco mmonposition/polesensoristhe Hall element, but some motors use optical sensors.

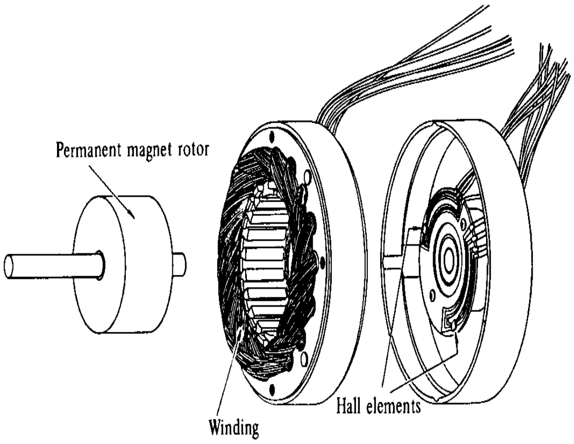

Figure:5 Disassembled view of a brushless dc motor

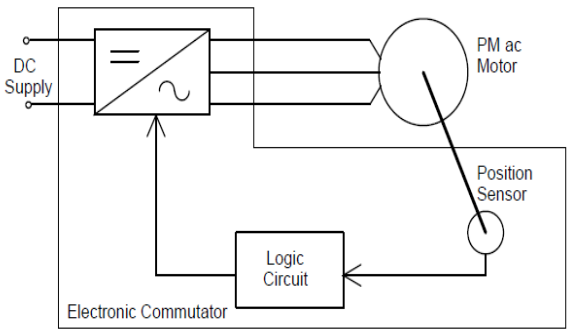

Figure :6 Brush less dc motor = Permanent magnet ac motor + Electronic commutator

III. PI CONTROLLER IMPLEMENTATION

Proportional Integral (PI) controller will eliminate forced oscillations and steady state error resulting in operation of on-off controller and P controller respectively. However, introducing integral mode has a negative effect on speed of the response and overall stability of the system. Thus, PI controller will not increase the speed of response. It can be expected since PI controller does not have means to predict what will happen with the error in near future. This problem can be solved by introducing derivative mode which has ability to predict what will happen with the error in near future and thus to decrease a reaction time of the controller. Figure:7 shows, the block diagram of PI controller. PI controllers are very often used in industry, especially when speed of the response is not an issue. A control without D mode is used when:

a) Fast response of the system is not required
b) Large disturbances and noise are present during operation of the process
c) There is only one energy storage in process (capacitive or inductive)
d) There are large transport delays in the system

Proportional–integral (PI) control combines the advantages of integral control (zero steady-state error) with those of proportional control (increasing the speed of the transient response). As shown in Figure 9.8, the control input is the sum of the proportional and integral terms. For proportional control, the control input is proportional to the control error, and for integral control, the change in control

The control actions of the proportional or integral controllers are based on the current error or past errors. In derivative control the controller output is proportional to the *rate of change* of the error. The idea behind derivative control is that the controller should react immediately to a large change in the control error; in essence, predicting that the error will continue to increase (or decrease) and act accordingly. Although this quick reaction can result in fast response times, it can also result in undesirable overreaction, especially if the system output has significant stochastics.
where the derivative control gain K_D defines the ratio of the input magnitude to the change in the error (Figure 9.18). Since the derivative controller adjusts the control input according to the speed of error variation, it is able to make an adjustment prior to the appearance of even larger errors. Practically, the derivative controller is never used by itself since if the error remains constant, the output of the derivative controller would be zero.

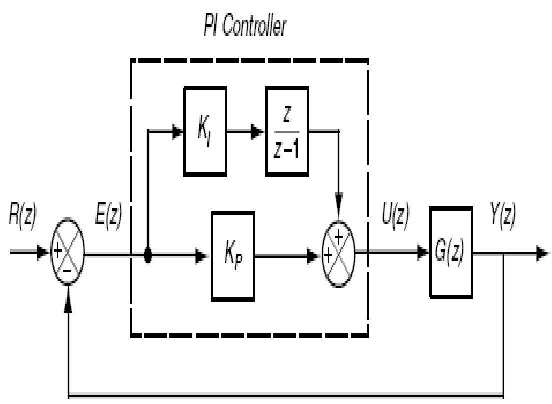

Figure :7 Block diagram of PI controller

PI CONTROL ALGORITHM:

A proportional-Integral (PI) controller is a generic control loop feedback mechanism (controller) widely used in industrial control systems. Figure :8 shows, the block diagram of system with PI controller. A PI is the most commonly used controller and it calculates an "error" value as the difference between a measured process variable and a desired set point. The controller attempts to minimize the error by adjusting the process control inputs. The Proportional and Integral values are denoted as P and I. Heuristically, these values can be interpreted in terms of time such as P depends on the present error and I depend on the accumulation of past errors. The weighted sum of these two actions is used to adjust the process via a control element such as the position of a control valve, or the power supplied to a heating element. By tuning the two parameters in the PI controller algorithm, the controller can provide control action designed for specific process requirements. The response of the controller can be described in terms of the responsiveness of the controller to an error, the degree to which the controller overshoots the set point and the degree of system oscillation. Some applications may require using only one or two actions to provide the appropriate system control. This is achieved by setting the other parameters to zero. A PI controller will be called a P or I controller in the absence of the other parameter. According to the system requirements, the PI controller is designed. PI controller consists of two types of controls namely Proportional and Integral control.

The transfer function of the PI controller for continuous system is defined as follows.

$$G_e(S) = K_p + \frac{K_i}{S} \quad (1)$$

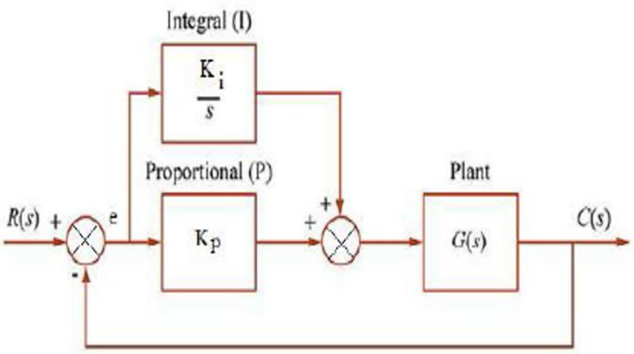

Figure:8 Block diagram of system with PI controller

First, let's take a look at the effect of a PI controller on the closed loop system using the schematic above. To begin with, variable 'e' is the tracking error or the difference between the desired reference value and the actual output. The controller takes this error signal and computes both its proportional and its integral values. The signal which is sent to the actuator is now equal to the proportional gain (Kp) times the magnitude of the error plus the integral gain (Ki) times the integral of the error. As the name suggests, the PI algorithm consists of two basic modes namely the Proportional mode and the Integral mode. When utilizing this algorithm, it is necessary to decide the modes that are to be used and then specify the parameters for each mode 44 used. Two basic algorithms used are P or PI. Tuning a system means adjusting two parameters Kp and Ki adding various amounts of these parameters to get the system to behave in the desired manner. Although it is found many methods and theories on tuning a PI, there is a straight forward approach to get you up and solving quickly.

ALGORITHM FOR THE DESIGN OF PI CONTROLLER:

The following steps are considered for the design of PI controller.

1. Read the open loop transfer function of the given higher order
system.
2. Form the closed loop transfer function.
3. Obtain the step response of closed loop system.
4. Check the response for the required specifications.
5. If the specifications are not met, get a reduced order model and design a controller for the reduced order model.
6. Obtain the initial values of the parameter Kp and Ki by pole zero Cancellation method.
7. Cascade the controller with reduced order model and get the closed loop response with the initial values of the controller parameters.
8. Find the optimum values for the controller parameters which satisfy the required specifications.
9. By applying the optimum values, cascade this controller with the original system.
10. Obtain the closed loop step response of the system with the controller.
11. If the specifications are met give exit command else tune the parameters of the controller till, they meet the required specifications.

For designing the PI controller, the values of controller parameters Kp and Ki are obtained through existing tuning method. The GA is employed to obtain the optimized values of Kp and Ki to meet out the design's specifications.

IV. SIMULATION RESULTS AND ANALYSIS

The proposed model has been developed and simulated in Matlab/Simulink Platform. The Simulation diagram of proposed BLDC Motor Speed Control Using Interleaved Boost Converter is shown in Figure:9. The circuit components are obtained from Sim Power System library. A PI controller is developed by Matlab/Simulink Platform refer section 3 for PI controller implementation. Scope is used for viewing the simulation results. The proposed boost converter is simulated at a switching frequency of 25kHz. The values of circuit components for the simulation are selected based on the design considerations. The discrete state variable model of sampling time $T_{S=}$ $1e^{-005}$ sec is used for simulation. The various waveforms for the proposed converter and inverter are shown in Figure:10.

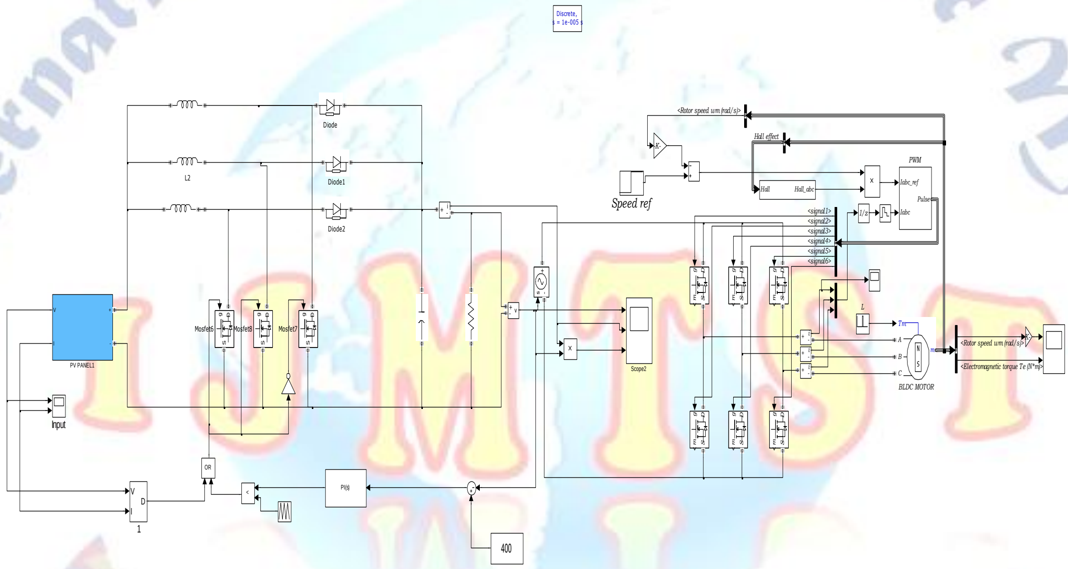

Figure :9 Simulation diagram of proposed BLDC Motor Speed Control Using Interleaved Boost Converter

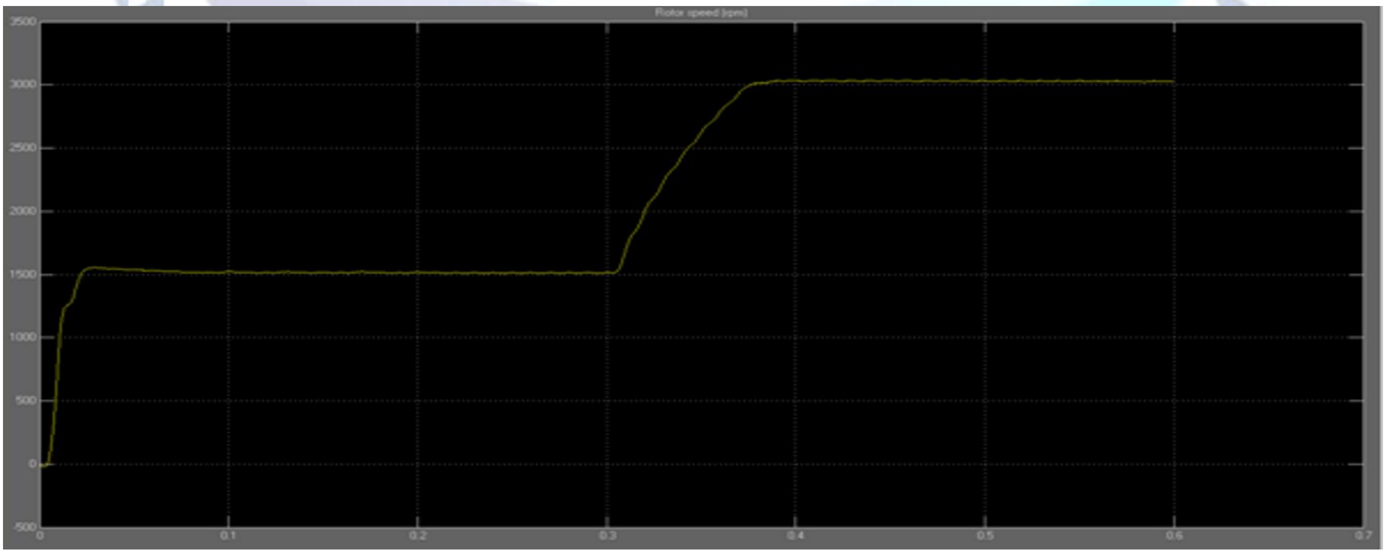

Figure :10 BLDC Motor speed waveform of proposed model

V. CONCLUSION

Amid multitudinous obtainable renewable energy origins due to non-appearance of changeable parts photovoltaic system is prolongation free, facile placing, availability, low cost and extremely reliable sources of variant energy. To commit any renewable energy system proficient, it is obligatory to have the compatible converter topology like boost converter. The IBC is one of the popular and efficient forms for the operation of BLDC motor. This interleaving process can diminish harmonic contents, assuage currents and voltage ripples, augmentation of efficiency and eminent power density. The proposed Fuzzy controller-based BLDC motor design is presented with control system characteristic parameters like (Tr), (Ts), and (Mp). So, considering the other parameters and due to the faster response Fuzzy controller is proposed

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