# Photovoltaic Based Brushless DC Motor Closed Loop Drive for Electric Vehicle

*G.Paranjothi and R.Manikandan*

**Abstract- This paper proposes the development of BLDC motor using photovoltaic array to run the electrical vehicle. The development of advanced magnetic materials, power electronics and digital control systems make the Permanent Magnet BLDC motors an effective solution for wide range of inverter fed variable speed drives. The obtained power from the photovoltaic array can be fed to the BLDC motor through buck-boost converter. The Hall Effect sensor mounted on the motor shaft provides a position feedback to the driver circuitry of the inverter circuit, which allows the flow of current to stator phase windings in a controlled sequence to produce the desired torque and speed. In electric vehicle the BLDC motor drive is made by the power electronics devices and integrated circuits, its function is to receive the electric bike motor's start, stop and brake so that control the hub motor to start, stop and brake. The speed feedback signal is used to control and adjust the speed and also provide protection and display. Using MATLAB the driver circuit was simulated and plotted.**

*Keywords:* **PV, Buck-Boost Converter, Brushless DC motor, MATLAB.**

## I. INTRODUCTION

BLDC motors, also called Permanent Magnet Synchronous motors, are one of the motor types that have more rapidly gained popularity, mainly because of their better characteristics and performance [1]. These motors are used in a great amount of industrial sectors because their architecture is suitable for any safety critical applications. The brushless DC motor is a synchronous electric motor that, from a modeling perspective, looks exactly like a DC motor, having a linear relationship between current and torque, voltage and rpm. It is an electronically controlled commutation system, instead of having a mechanical commutation, which is typical of brushed motors. Additionally, the electromagnets do not move, the permanent magnets rotate and the armature remains static. This gets around the problem of how to transfer current to a moving armature. In order to do this, the brush-system / commutator assembly is replaced by an intelligent electronic controller, which performs the same power distribution as a brushed DC motor [2].

BLDC motors have many advantages over brushed DC motors and induction motors, such as a better speed versus torque characteristics, high dynamic response, high efficiency and reliability, long operating life, noiseless operation, higher speed ranges, and reduction of electromagnetic interference (EMI).

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In addition, the ratio of delivered torque to the size of the motor is higher, making it useful in applications where space and weight are critical factors, especially in aerospace applications. All of the electrical motors that do not require an electrical connection between stationary and rotating parts can be considered as brushless permanent magnet (PM) machines [3], which can be categorized based on the PMs mounting and the back-EMF shape. The PMs can be surface mounted on the rotor (SMPM) or installed inside of the rotor (IPM) [4], and the back-EMF shape can either be sinusoidal or trapezoidal. According to the back-EMF shape, PMAC synchronous motors (PMAC or PMSM) have sinusoidal back-EMF and Brushless DC motors(BLDC or CLM) have trapezoidal back-EMF. A PMAC motor is typically excited by a three-phase sinusoidal current, and a BLDC motor is usually powered by a set of currents having a quasi-square waveform [5,6]. Because of their high power density, reliability, efficiency, maintenance free nature and silent operation, permanent magnet (PM) motors have been widely used in a variety of applications in industrial automation [7] and household products.

The first section gives the introduction about the paper. The second section of the paper discuss about the photovoltaic panel. BLDC motor drive is discussed in the third section. The fourth section deal with the simulation work carried through MATLAB environment. The fifth section is about the results and discussions. The final section presents the conclusion.

## II. PHOTOVOLTAIC ARRAY

Solar electric systems convert sunlight to "DC" or direct current electricity the same type of electricity that is produced by every-day batteries where electrons flow in one direction. Solar cells, generally consisting of 2 layers of silicon (semi-conductor material) and a separation layer, are wired together and assembled into panels or modules. When the cells are exposed to sunlight, photons from the sun interact with electrons in the upper silicon layer, basically knocking them loose from their associated atoms. The loose electrons are attracted to atoms in the lower layer of silicon and travel through the wire to get there. This movement of electrons from one side of the cell to the other through the wire is electrical current.

When a solar panel is manufactured, the PV cells are wired together in "series". The output voltage of the panel depends on the number of cells in the series. Common nominal output voltages are 12, 18, and 24 volts DC. The output wattage is dependent on the efficiency of the cells and the size or area of each cell in the panel. The larger and more efficient the cells, the greater the wattage will be per square foot. Panels made using more efficient cells tend to be more expensive.

When the installer assembles a PV system, an exact number of panels are wired in series strings to achieve the target voltage required by the inverter or other load. Then groups of panel strings are often wired together in "parallel" in order to increase the wattage of the system. Once all these components are in place, the sun provides the energy.

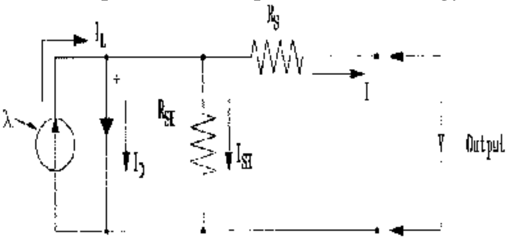


Fig.1. Equivalent Circuit of PV Array

In fig 1.the PV module consists of voltage-controlled current source connected in parallel with a diode [8]. The output current depends on the available sunlight and the temperature of the module. The unit used to measure the available power which can be drawn from the sun is called irradiance and expressed in W/m$^2$.

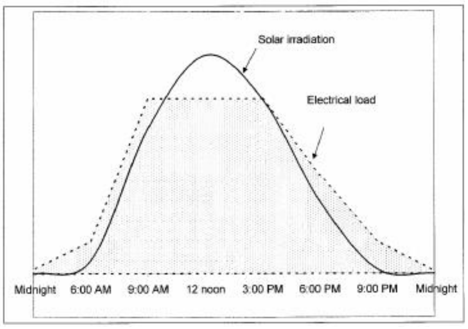


Fig.2.Solar Irradiance per Day

### III. BLDC MOTOR DRIVE

A Brushless DC motor has a permanent magnet rotor and a wound stator. The windings are connected to an inverter. The inverter energizes the windings in a pattern which rotates the magnetic field around the stator. The energized stator winding causes the PM rotor to rotate in a synchronous fashion around the stator. So it is important to know the perfect sequence to energize the stator windings. In BLDC motor the armature does not rotate, instead the PMs rotate. In brushed DC motor, windings are in the rotor. So it becomes difficult to transfer the current to the moving rotor. In a three phase BLDC six step commutations is the simplest method to drive the motor. One set of sequence represents a full electrical rotation. Number of electrical cycle is equal to the number of pole pairs. Increase in pole pairs may decrease the torque ripple.

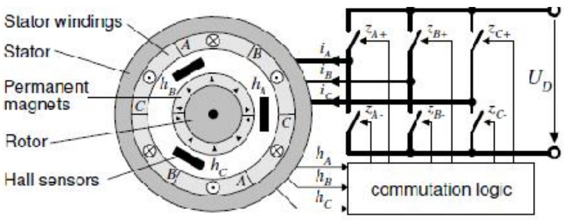


Fig.3 BLDC Motor with Inverter Circuit

The speed and torque of the motor depend on the strength of PMs and in certain instances the magnetic field generated by energized winding. The two main objectives are to control the speed and torque of the BLDC motor as shown in figure 3.The phase A terminal voltage with respect to the star point of the stator Van is given in as

$$V_a = R_a i_a + L\ \frac{di_a}{dt} + e_a \quad (1)$$

Where, Ra is the stator resistance of the 'A' phase, La the phase inductance, $e_a$ the back-EMF and $I_a$ the phase current. Similar equations can be written for the other two phases.

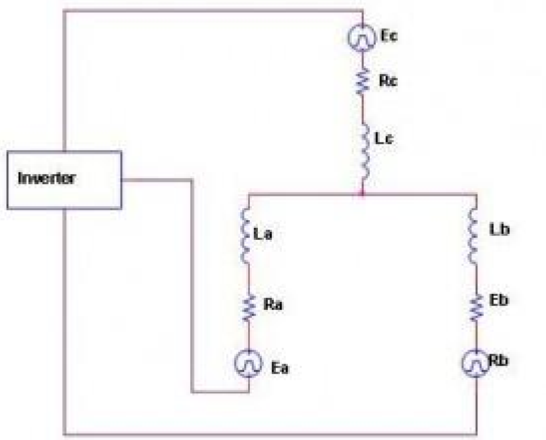


Fig.4.Equivalent circuit of the BLDC motor

$$V_b = R_b i_b + L\ \frac{di_b}{dt} + e_b$$

(2)

$$V_c = R_c i_c + L\ \frac{di_c}{dt} + e_c c$$

(3)

The torque may be determined as,

$$T_e = K_f \omega_m + j\ \frac{d\omega_m}{dt} + T_L$$

(4)

Where

e- back-emfs
Kf-fiction constant
J-rotor inertia
Te-electric torque
$T_L$-load torque
$\omega_m$- rotor speed

Three hall sensors read the rotor position every 60 electrical degrees of rotation. So in one complete electrical rotation hall sensors provide six unique position values. Table 1 shows hall sensor table for a three-phase BLDC motor with six unique values along with active phase voltages and switches.

TABLE I- HALL SENSOR SIGNALS FOR BLDC MOTOR

| Hall Sensor Values | Phases | Switches |
|---|---|---|

| | | |
|---|---|---|
| (H3,H2,H1) | | |
| 100 | $V_a$-$V_b$ | $Z_A^+$- $Z_B^-$ |
| 101 | $V_a$-$V_c$ | $Z_A^+$- $Z_C^-$ |
| 001 | $V_b$-$V_c$ | $Z_B^+$- $Z_C^-$ |
| 011 | $V_b$-$V_a$ | $Z_B^+$- $Z_A^-$ |
| 010 | $V_c$-$V_a$ | $Z_C^+$- $Z_A^-$ |
| 110 | $V_c$-$V_b$ | $Z_C^+$- $Z_B^-$ |

Generally the hall table is provided by the motor manufacturer. Depending on the current hall value, firing signal is given to the corresponding switches of the inverter as per Table 1.

Speed of a BLDC motor is proportional to the applied voltage across its windings. A precise speed can be controlled using a conventional PI controller. A well designed PI controller generates a duty cycle command based on the difference between the actual and commanded speed. Depending on the duty cycle command, PWM pulses are generated that vary the gate drive of the inverter switches to get the required speed.

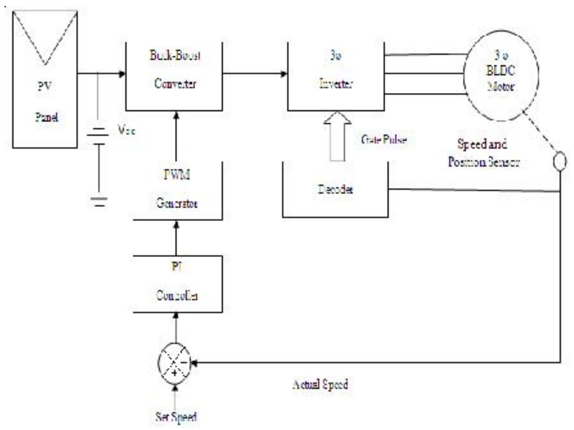


Fig 5.Block Diagram of PV Based BLDC Motor

The block diagram in fig 5 represents the speed control of BLDC motor, which consists of PV panel, buck-boost converter, inverter, decoder, PWM generator and PI controller.

The inverter along with the position sensor is functionally analogous to the commutator of a conventional DC motor.

A brushless dc motor has a permanent magnet rotor and wound stator .the windings are connected to an inverter. The inverter energizes the windings which rotate the magnetic field around the rotor. The speed of a BLDC is proportional to the applied voltage across its windings precise speed can be controlled using a conventional PI controller. A well designed PI generates a duty cycle command based on the difference between the actual and commanded speed. Depending on the duty cycle command the PWMpulses are generated that vary the gate drive of the inverter switches to get the required speed.

By simply varying the voltage across the motor, one can control the speed of the motor. When using PWM outputs to control the six switches of the three phase bridge, variation of the motor voltage can be achieved easily by changing the duty cycle.

## IV. Simulation Of Proposed Scheme

The closed loop controller for a three phase BLDC motor is modeled using MATLAB/SIMULINK environment

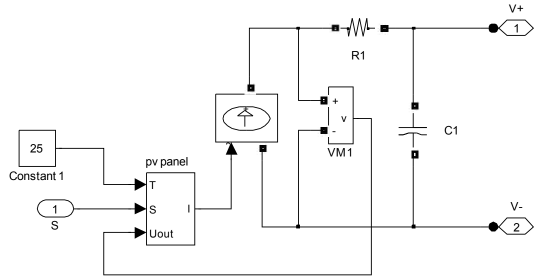


Fig.6 Simulation Model of PV Panel

Figure 6. Shows the sub system block of simulation model of PV panel from which a constant and variable voltage were obtained, usually the output voltage is between (18-24) V

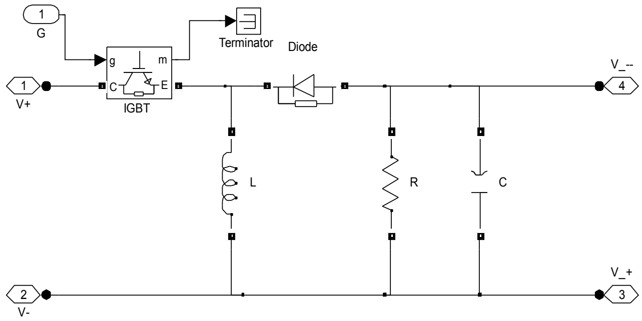


Fig.7 Simulation Model of buck-boost converter

Figure 7 shows the simulation model of buck-boost converter, the voltage obtained from the PV panel is given to the buck-boost converter by which the rated voltage is obtained.

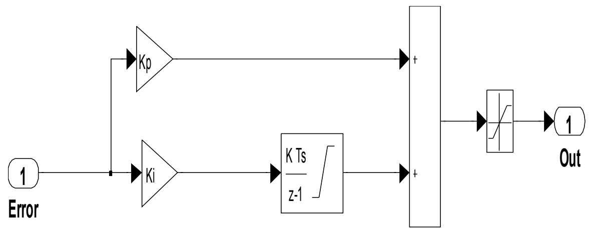


Fig.8 Simulation Model of PI controller

The conventional PI controller is one of the most common approaches for speed control in industrial electrical drives. In industrial process PI controller attempts to that error between a tracked variable and reference set point and then the output is corrected which can adjust the process accordingly. The calculation involves two separate modes namely proportional mode, integral mode. The proportional mode determines to the current error and the integral mode determines the reaction based recent error. As shown in fig 8.the error signal is given to the proportional and integral controller. The set values used for Kp, Ki are 0.000585 and 0.05 respectively.

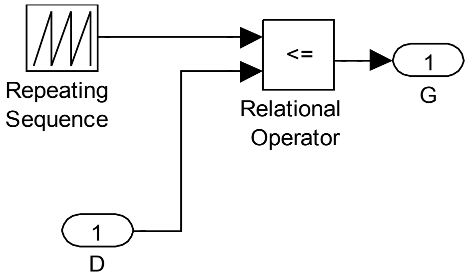


Fig.9 Simulation Model of PWM generator

Proper control of PWM ensure efficiency and accuracy in applications such as brushless motor control the pulses are generated by comparing a triangular carrier waveform to reference modulating signal as shown in fig 9. The relational operator logically compares the output from PI controller with repeating sequence and generates PWM signals required for triggering the converters. Fig 10 shows the complete view of proposed simulink model.

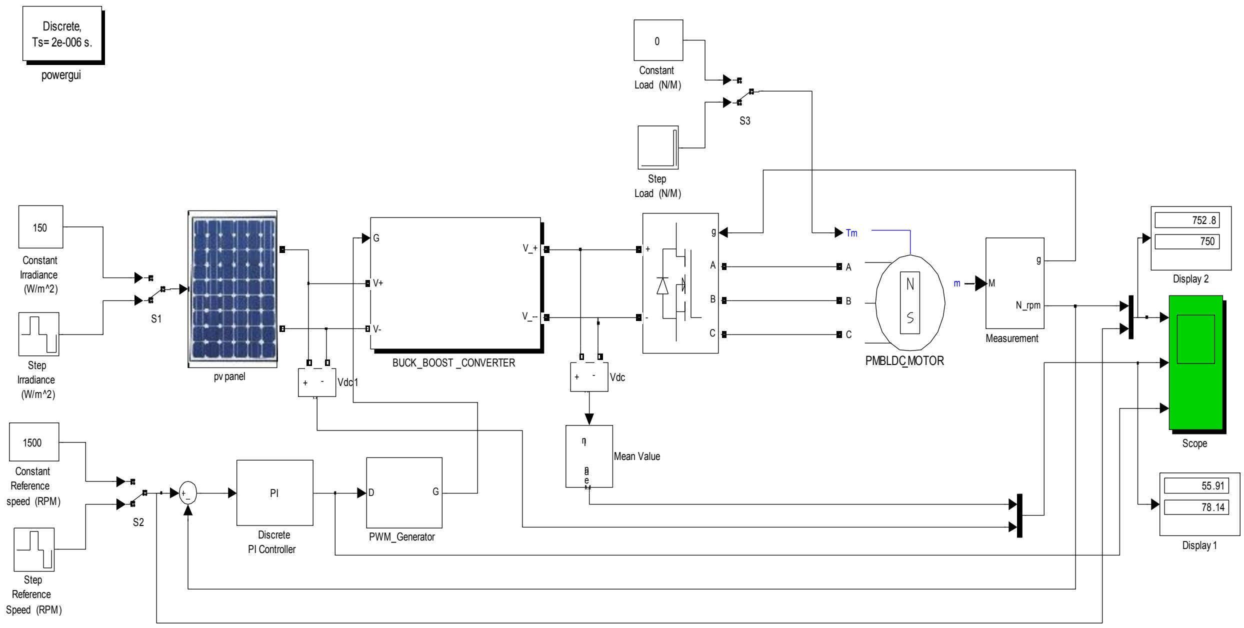


Fig.10.Simulink model of PV Based BLDC motor drive

### V. Results And Discussion

Several results were performed to evaluate the performance of the proposed PV based closed loop control of PMBLDC motor drive system which is simulated in MATLAB/SIMULINK environment. To evaluate the performance of the system, series of measurements have been accomplished. The results can be divided into four groups such as constant output set speed up/down, voltage up/down, load impact response.

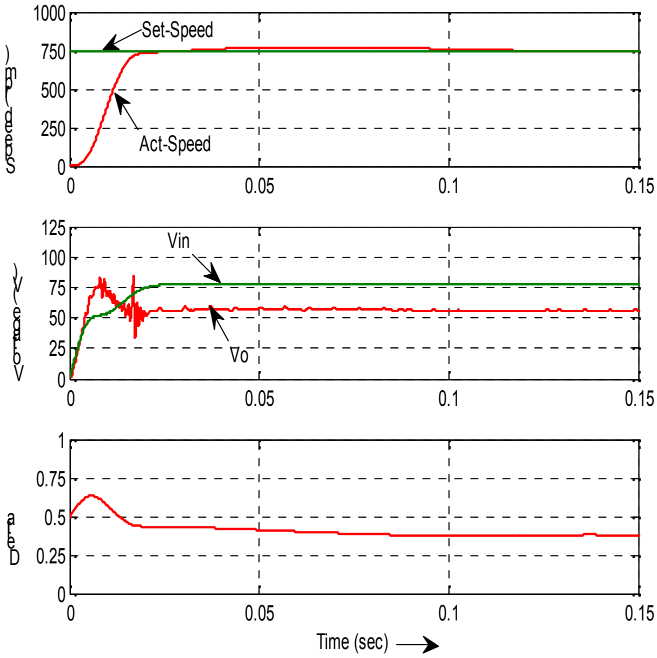


Fig.11.Starting Response with Steady State

The starting response shows the relationship between speed, voltage and duty cycle fig 11. At initial condition the actual speed is lesser than the set speed up to 0.05sec and after that the response represents a steady state condition in which all the response is to their rated values by reducing duty cycle from 0.6 percent to 0.4 percent.

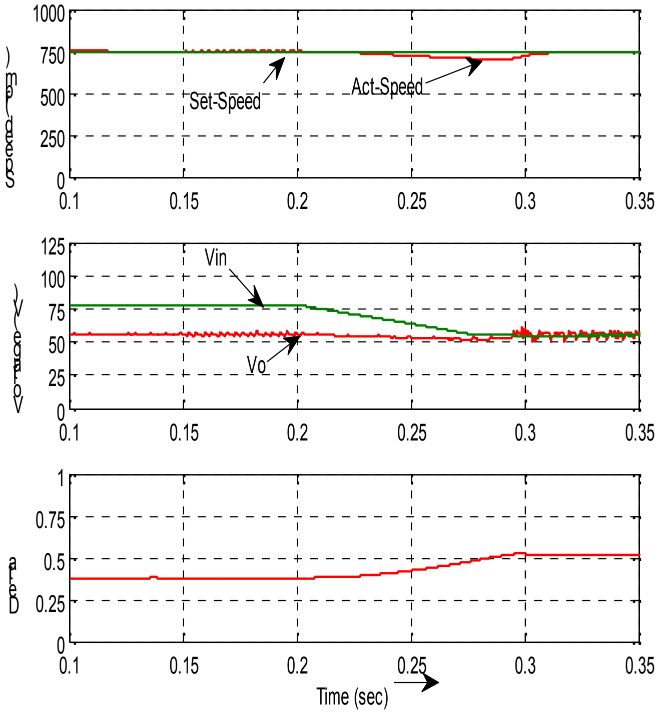


Fig.12.Step-down Voltage Response

The stepdown voltage response shown in fig 12.represents the change in voltage at 0.2sec from 75v to 55v. then the output voltage of the photovalatic array gets decreases upto 0.255 which makes speed gets decreases from 0.25 to 0.3 at the same time the dutyn cycle of buck-boost converter gets increases from 0.25 to 0.3 to improves the output voltage $V_o$, so as to maintain the rated speed as constant at 750 rpm.

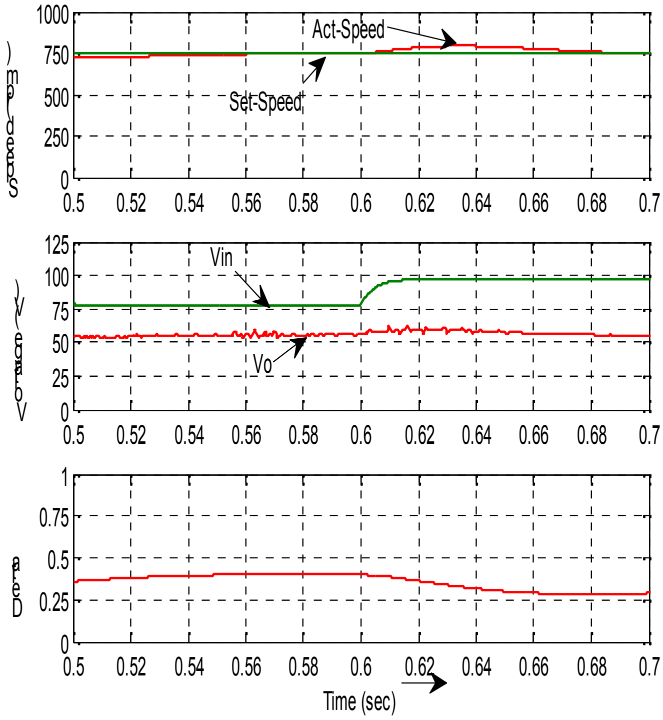


Fig.13.Step-up Voltage Response

The step up voltage response in fig 13 shows that upto 0.6sec the output voltage and speed are in rated values, if the solar irradiation is very high, then the output voltage of the photovoltaic array gets increases from 75v to 95v. so the motor speed will get increasest thus increses the negative error. Since the PI controller get reduce the duty cucle fron 0.4 to 0.3 the output voltage of buck boost converter get reducess so as to maintain the rated speed as constant at 750 rpm.

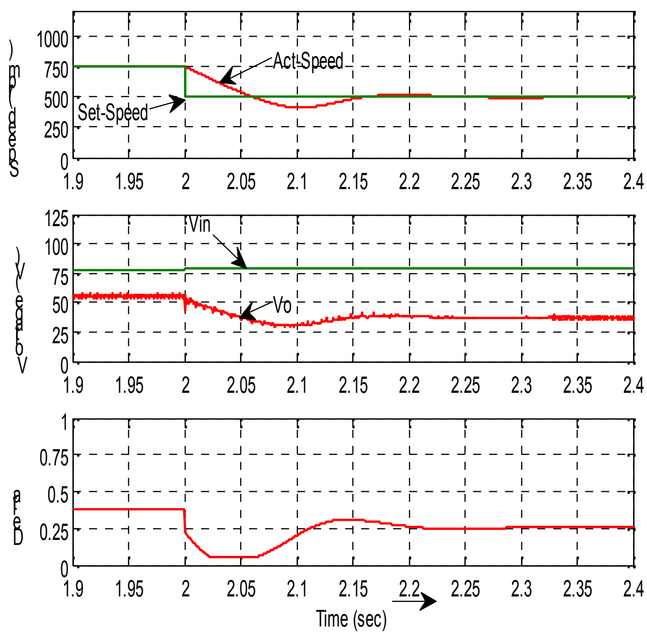


Fig.14.Response of Speed Step-down

When the set speed is decreasing from 750 rpm to 500 rpm at 2 sec correspondingly the duty cycle decreases from

0.4 to 0.25 upto 2.2 sec. So the output voltage decreases from 55v to 45v,and hence the speed gets decreases from 750rpm to 500 rpm and settles at 2.2 sec.

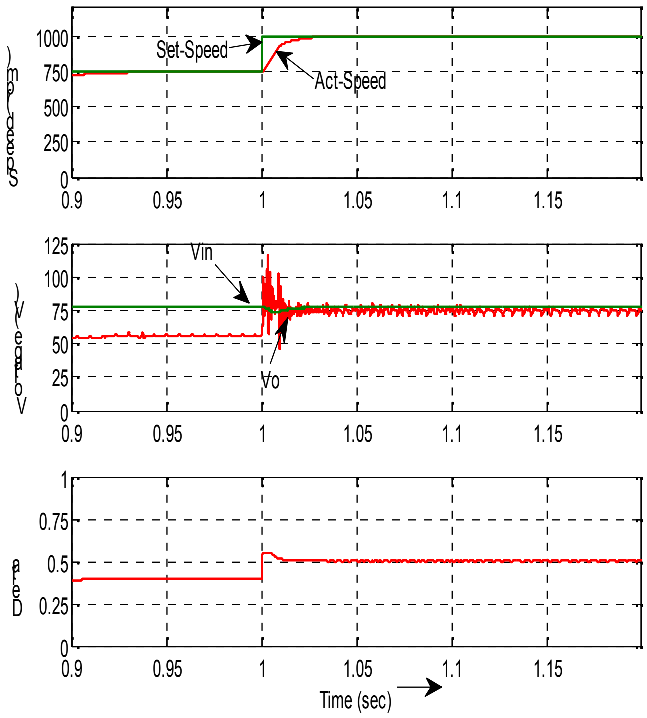


Fig.15. Response of Speed Step-up

As shown in fig 15 the set speed gets increases from 750 rpm to 1000 rpm at 1 sec a sudden voltage transient may occur, to achieve the rated speed the duty cycle of the buck-boost converter increases from 0.4 to 0.5 by using PI controller. So the output voltage of converter increases from 55v to 75v to reach the decided speed of 1000rpm at 1.05 sec.

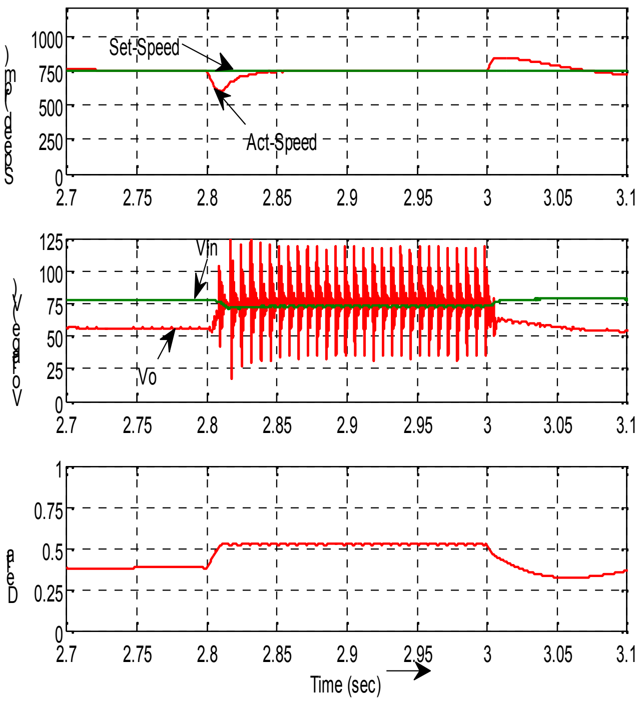


Fig.16 Load Impact Response

Fig 16 shows the response of load impact, increase or decrease in load causes a corresponding change in speed, in order to maintain the set speed the duty cycle of the converter gets varied and regulates the output voltage of buck-boost converter accordingly.

## VI. CONCLUSION

This paper discuss about the closed loop speed control of BLDC motor in accordance with the change in load condition of an electric vehicle. The BLDC motor is a correct choice for various applications due to higher efficiency, higher power density and higher speed ranges compare to other motor drives.The simulation result shows that for various voltage level of PV array the set speed gets maintained by controlling the duty cycle of the buck-boost converter. The output characteristics and simplicity of model make it effectively useful in design of BLDC motor drives in various fields .From this proposed technique ensures the reliability of BLDC motor through renewable source by eliminating the fossil fuels and also environmental friendly for end of life vehicle.

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