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SPEED CONTROL OF PV FED BLDC MOTOR THROUGH SEPIC CONVERTER FOR WATER PUMPING APPLICATION

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ABSTRACT

This paper presents a solar powered based single ended primary inductance converter (SEPIC) fed brushless dc (BLDC) motor drive for low power household applications. The speed of the BLDC motor is controlled by adjusting the dc link voltage of the VSI feeding a BLDC motor. The VSI feeding BLDC motor is used for achieving an electronic commutation of the BLDC motor operates in a low frequency switching for reduced switching losses it. The SEPIC is proposed which offer lower conduction losses due to SEPIC converter at the front end. The solar powered based SEPIC converter operates in a continuous current mode (CCM) for achieving a constant DC voltage at the end of the SEPIC converter. The performance of the proposed drive is simulated by using MATLAB Simulink software.

Keywords: CCM, MATLAB, BLDC Motor.

1. INTRODUCTION

Renewable energy sources are given utmost importance in the present environmental scenario because of the hazardous effect of the conventional energy sources such as pollution which is a potent threat for mankind and all living beings. Solar energy system or the pv system provides clean energy and it is the widely used renewable source of energy. Brushless dc motors are widely popular nowadays because of the advantages it has over conventional dc motors. The range of applications is in plenty for bldc motors.

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.

Due to its output gain flexibility, single ended primary inductor converter (SEPIC) acts as a buck boost DC-DC converter providing non-inverting polarity output voltage where it changes its output voltage according to its duty cycle. The SEPIC has the desirable feature of the switch control terminal being connected to ground; this simplifies the gate-drive circuitry. Because of its non-inverting polarity output voltage, unlike the buck-boost and a Cuk DC-D converter, the use of either splitting power supply or optocouple or associated circuit for negative voltage feedback sensing, which added complexity and slowed down the response of the system.

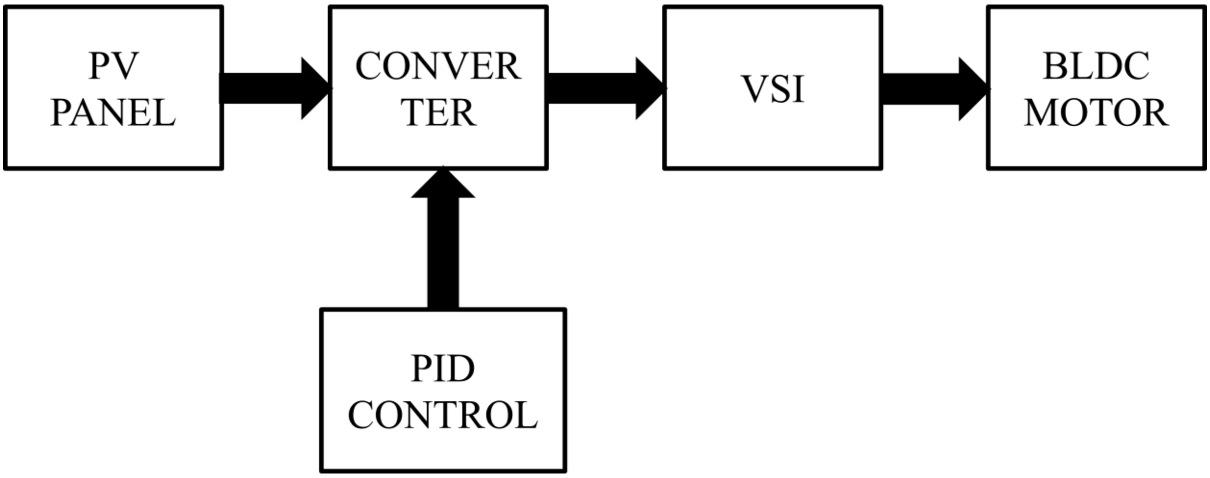
The existing technique is an arrangement of MPPT configuration that provides the same polarity of output for either polarity of input. The MPPT gives the duty cycle based on the reference value of voltage and current from the solar panel. Based on the duty cycle the pules is generated by using the saw tooth generater, based on the the pulses the SEPIC converter produces the output, it may be boost or buck.

This project emphasises on water pumping application using bldc motor which is fed with power from sepic converter and its speed control, with solar energy as source. BLDC motors when compared with DC motors have many advantages, electronic commutation being one of the major advantages. Other advantages include, greater efficiency, better speed-torque characteristics, wide speed ranges, less EMI issues. The bldc motors can be driven with various techniques or topologies. Intermediate stage between solar panel and vsi fed bldc motor is converter. The converter topology which is used is sepic converter. The sepic converter poses many advantages over other converters like non inverting polarity, reduced ripple due to input inductor etc.

The control of converter pulses can be done using mppt techniques when solar energy is used as source. But the mppt can regulate only the pv voltage and current to produce maximum pv power. The speed control of bldc motor can then be done only on inverter side by controlling pulses of switches. The speed control of the motor is much easier when the control is on the converter side. Thus for the water pumping application of bldc motor,the speed control is carried out by the closed loop of converter giving switching pulses to converter switches thereby driving the motor with desired speed.

2. PROPOSED SYSTEM

This project deals with a solar powered based SEPIC converter-fed brushless dc motor (BLDC) driveas a cost-effective solution for low-power applications. The speedof the BLDC motor is controlled by varying the dc-bus voltage of avoltage source inverter (VSI) which uses a low frequency switchingof VSI (electronic commutation of theBLDCmotor) for lowswitchinglosses. A solar panel followed by a SEPIC converterworking in a continuous conduction mode (CCM) is used forcontrol of dc-link voltage. Performanceof the SEPIC converter is evaluated under four differentoperating conditions of continuous conductionmodes (CCM).



The pv panel convert the input solar energy to the electrical energy. The pv energy can't be directly fed to the the bldc motor as the efficiency will be less. So sepic converter is used in the intermediate stage so as to provide with the required voltage for driving the bldc motor. The output of the sepic converter is fed to 3 phase voltage source inverter. The sinusoidal current produced by the inverter energizes the corresponding stator windings. The bldc motor has basically a synchronism action where the stator and the rotor magnetic field have to rotate in the same frequency. Stator windings have to be energized in a sequence so that torque production is maximum for the rotor. For energising stator windings in a sequence, rotor positions have to be found. Rotor position is found using hall effect sensors. Hall effect sensors produce the signals and is given to a controller which produces pulses for the switches of voltage source inverter. As the insolataion changes, pv input changes. Accordingly the output of the converter changes. Thus the speed of the motor gets varied. Speed control of the motor is achieved by controlling the duty cycle of the switch of sepic converter using pid control, so that output voltage of the converter is maintained in the desired value to get the required speed.

3. MODULES NAME

- SOLAR PANEL
- BRUSHLEESS DC MOTOR
- SEPIC INVERTER
- PI CONTROLLER

MODULE DESCRIPTION

SOLAR PANEL

Photovoltaic (PV) array which is composed of modules is considered as the fundamental power conversion unit of a PV generator system. The PV array has nonlinear characteristics and it is quite expensive and takes much time to get the operating curves of PV array under varying operating conditions. In order to overcome these obstacles, common and simple models of solar panel have been developed and integrated to many engineering software including Matlab/Simulink. However, these models are not adequate for application involving hybrid energy system since they need a flexible tuning of some parameters in the system and not easily understandable for readers to use by themselves. Therefore, this paper presents a step-by-step procedure for the simulation of PV cells/modules/arrays with Tag tools in Matlab/Simulink. A DS-100M solar panel is used as reference model. The operation characteristics of PV array are also investigated at a wide range of operating conditions and physical parameters.

MATHEMATICAL EQUIVALENT CIRCUIT FOR PHOTOVOLTAIC ARRAY

The equivalent circuit of a PV cell is shown in Fig. 1. The current source I_{ph} represents the cell photocurrent. $R_{sh}$and R_s are the intrinsic shunt and series resistances of the cell, respectively. Usually the value of R_{sh} is very large and that of R_s is very small, hence they may be neglected to simplify the analysis. Practically, PV cells are grouped in larger units called PV modules and these modules are connected in series or parallel to create PV arrays which are used to generate electricity in PV generation systems. The equivalent circuit for PV array is shown in Fig. 2.

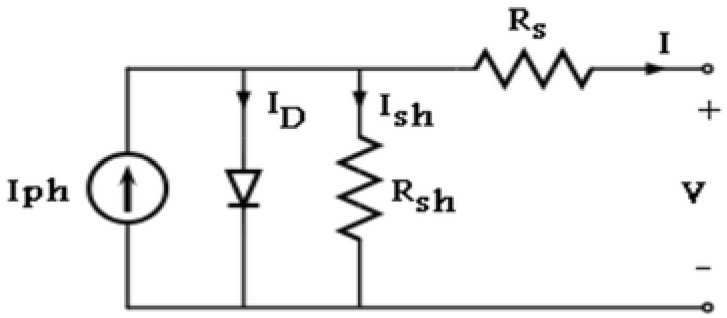


Fig1. PV cell

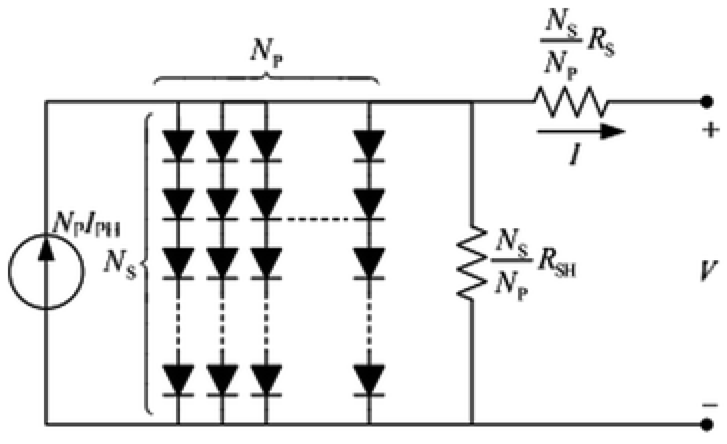


Fig.2. PV array

The voltage–current characteristic equation of a solar cell is provided as Module photo-current I_{ph}:

Iph= [Isc+Ki (T−298)] ×Ir/1000Iph……………………..(1)

Here, I_{ph}: photo-current (A); I_{sc}: short circuit current (A); K_i: short-circuit current of cell at 25 °C and 1000 W/m^2; T: operating temperature (K); Ir: solar irradiation (W/m^2).

Module reverse saturation current I_{RS}:

IRS=Isc/ [exp (qVOC/NSknT) −1] Ir………………….. (2)

Here, q: electron charge, = 1.6 × 10^{-19}C; V_{oc}: open circuit voltage (V); N_s: number of cells connected in series; n: the ideality factor of the diode; k: Boltzmann's constant, = 1.3805 × 10^{-23} J/K.

The module saturation current I_0 varies with the cell temperature, which is given by:

I_o=IRS [TTr] 3exp [q×Eg0nk (1T−1Tr)]…………………… (3)

Here, T_r: nominal temperature = 298.15 K; E_{g0}: band gap energy of the semiconductor, = 1.1 eV; The current output of PV module is:

I=NP×Iph−NP×I0× [exp (V/NS+I×Rs/NPn×Vt) −1] −Ish………. (4)

With

Vt=k×TqVt=k×Tq………………… (5)

And

Ish=V×NP/NS+I×RSRshIsh=V×NP/NS+I×RSRsh …………… (6)

Here: N_s: number of PV modules connected in series; R_s: series resistance (Ω); R_{sh}: shunt resistance (Ω); V_t: diode thermal voltage (V).

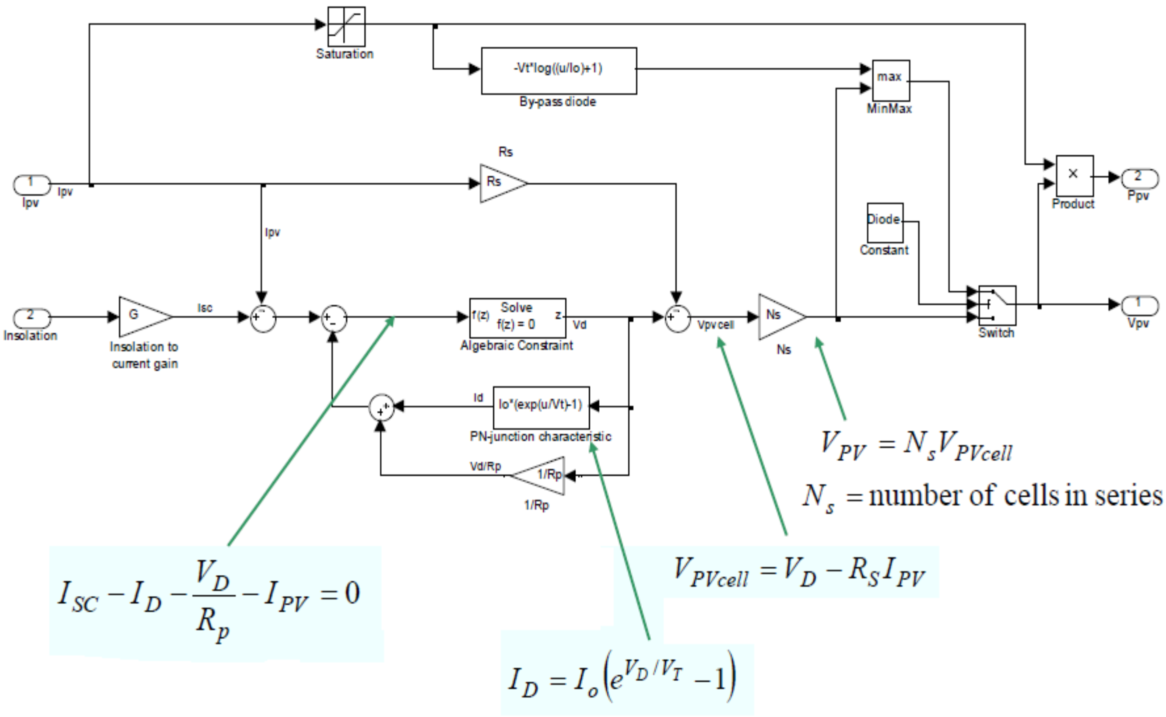


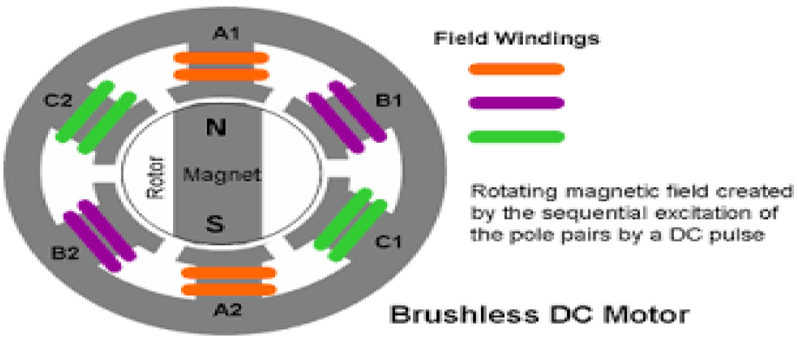
Fig.3. Matlab Implementation

4. BRUSHLEESS DC MOTOR

Brushless DC electric motor (**BLDC motors**, **BL motors**) also known as **electronically commutated motors** (ECMs, EC motors) are synchronous motors that are powered by a DC electric source via an integrated inverter/switching power supply, which produces an AC electric signal to drive the motor. In this context, AC, alternating current, does not imply a sinusoidal waveform, but rather a bi-directional current with no restriction on waveform. Additional sensors and electronics control the inverter output amplitude and waveform (and therefore percent of DC bus usage/efficiency) and frequency (i.e. rotor speed).

The rotor part of a brushless motor is often a permanent magnet synchronous motor, but can also be a switched reluctance motor, or induction motor[citation needed].

Brushless motors may be described as stepper motors; however, the term stepper motor tends to be used for motors that are designed specifically to be operated in a mode where they are frequently stopped with the rotor in a defined angular position. This page describes more general brushless motor principles, though there is overlap.



VSI FED BLDC MOTOR

The bldc motor has basically a synchronism action where the stator and the rotor magnetic field have to rotate in the same frequency. Stator windings have to be energized in a sequence so that torque production is maximum for the rotor. The stator winding get the energy from sepic converter output. The switches of vsi inverter should be controlled by the pulses from the controller circuit which gets the hall effect signals as input. For energising stator windings in a sequence, rotor positions have to be found. Rotor position is found using hall effect sensors. There will be 3 hall effect sensors which are displaced by 120 degree at the non-rotating end of motor. Whenever the rotor poles pass near the hall effect sensors, it will producea high or low signals

The hall effect signals will be sent to controller circuit. The controller circuit involves decoder logic for converting the hall effect signals into corresponding equivalent stator emf signals. The signals will be converted to the pulses for the inverter in the controller. The controller block diagram is shown in fig.4

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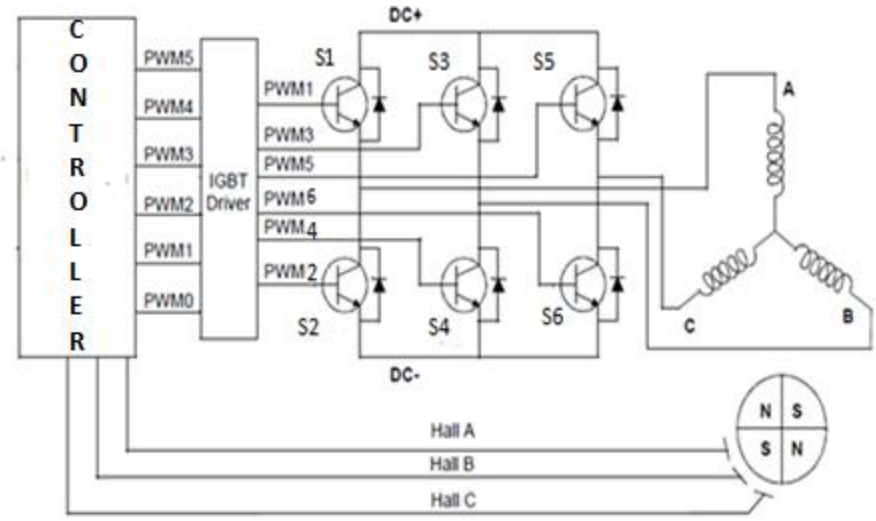

Fig.4 Controller Block Diagram

The switching sequence of the inverter is shown in fig.5. There will be 6 combinaation of 3 hall effect signals which are given as input to the controller. For each set of the signals, one pair of switches of the inverter has to be switched on. When each of these pair of switches are turned on,one stator winding of bldc motor will be energised, one winding will be denergized, one winding will neither be energised nor be denergised. The winding energising sequence is shown in fig.6 with corresponding pair of inverter that has to be turned on as well as hall effect input signals.

HALL SENSOR INPUT			ACTIVE SWITCHES		PHASE CURRENT		
A	B	C			A	B	C
0	0	1	S4	S5	OFF	-	+
0	1	0	S2	S3	-	+	OFF
0	1	1	S2	S5	-	OFF	+
1	0	0	S1	S6	+	OFF	-
1	0	1	S1	S4	+	-	OFF
1	1	0	S3	S6	OFF	+	-

Fig 5. Switching Sequence

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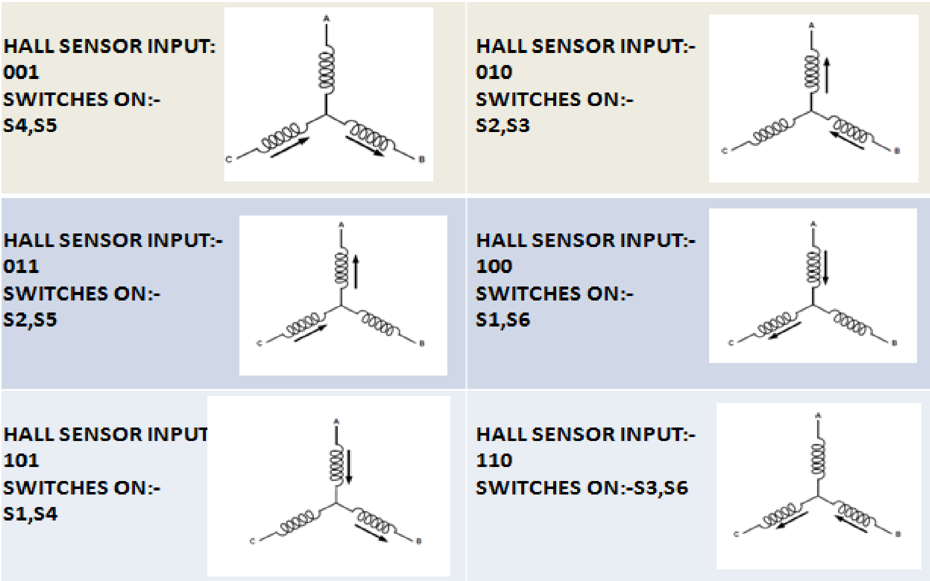

Fig.6 Winding Energising Sequence

5. SEPIC CONVERTER

The **SEPIC** converter is a type of DC/DC converter that has an output voltage magnitude that is either greater than or lesser than the input voltage magnitude. It is essentially a boost converter followed by a buck converter with a capacitor to couple the energy. A non-isolated SEPIC converter comprises two inductors, two capacitors, a switch (usually a transistor), and a diode. Its schematic is shown in figure.

The capacitor C is used to transfer energy and is connected alternately to the input and to the output of the converter via the commutation of the transistor and the diode.

The two inductors L_1 and L_2 are used to convert respectively the input voltage source (V_i) and the output voltage source (C_o) into current sources. At a short time scale an inductor can be considered as a current source as it maintains a constant current. This conversion is necessary because if the capacitor were connected directly to the voltage source, the current would be limited only by the parasitic resistance, resulting in high energy loss. Charging a capacitor with a current source (the inductor) prevents resistive current limiting and its associated energy loss.

As with other converters (buck converter, boost converter, buck-boost converter) the SEPIC converter can either operate in continuous or discontinuous current mode. However, unlike these converters, it can also operate in continuous voltage mode (the voltage across the capacitor drops not to zero during the commutation cycle).

The voltage ratio of a SEPIC converter is the same as that of a buck-boost converter, but its main advantage over other converters is that the input and output inductors result in a filtered current on both sides of the converter, while buck, boost, and buck-boost converters have a pulsating current that occurs on at least one side of the circuit i.e. either on input side or output side.
This pulsation will increase the ripple in the circuit and due to this ripple, the efficiency of battery gets lowered. To ensure good efficiency ripple should be reduced.
By controlling the duty cycle of the switch, the output voltage Vo can be controlled and can be higher or lower than the input voltage vg. By using a controller to vary the duty cycle during operation, the circuit can also be made to reject disturbances ,as second part of circuit consists of parallel resonance circuit and it work as a tank circuit for specific frequency (resonant frequency) , and during resonance current will not be allowed to enter in the circuit.

6. CIRCUIT EXPLANATION

The circuit block diagram of the system is shown in Fig.7

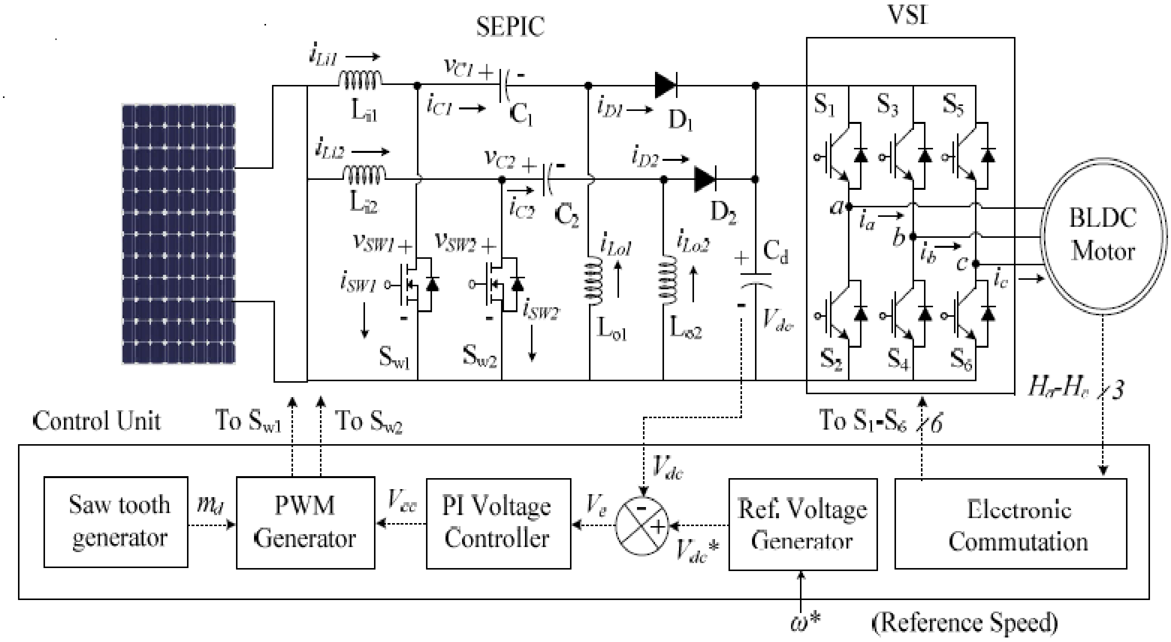

Fig.7 circuit block diagram

OPERATION MODES

Three modes of operation in a complete switching cycle are given as follows.

MODE -I:

In this mode, when switch (*Sw1*) is turned-on, the input inductor (*Li1*) and output inductor (*Lo1*) start charging as shown in Fig.7.1 (a). The intermediate capacitor (*C1*) discharge via output side inductor (*Lo1*) and the voltage across it decreases). The diode (*D1*) remains in non-conducting state and the DC link capacitor (*Cd*) supplies the required energy to the VSI fed BLDC motor.

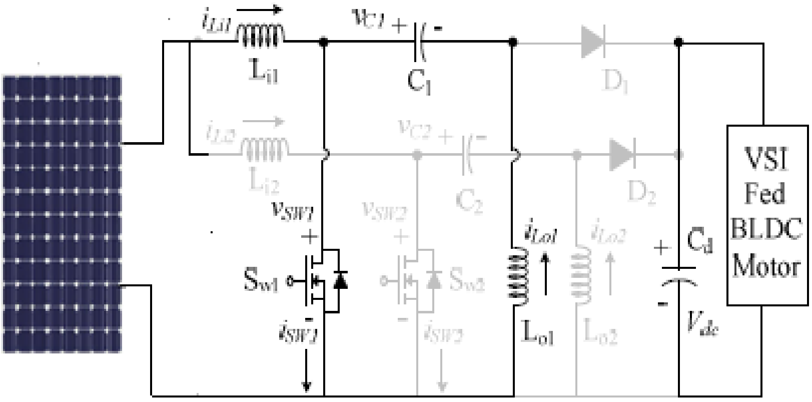

Fig.7.1 Mode-1 (a)

When switch (*Sw1*) is turned-off, the input inductor (*Li1*) and output inductor (*Lo1*) start discharging via diode (*D1*) as shown in Fig. 7.2(b). Moreover, the intermediate capacitor (*C1*) charges in this mode of operation.The DC link capacitor (*Cd*) charges in this interval and the DC link voltage (*Vdc*) increases in this mode

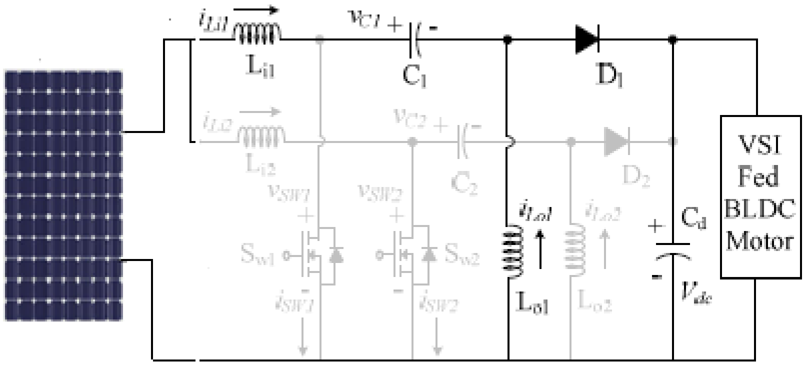

Fig.7.2 Mode-1 (b)

Mode-II:

During this interval, the output side inductor (*Lo1*) is completely discharged and the input inductor (*Li1*) continues to discharge as shown in Fig. 7.3 (a). The intermediate capacitor (*C1*) continues to charge via input inductor (*Li1*) and the DC link capacitor (*Cd*) supplies the required energy to the VSI fed BLDC motor drive.

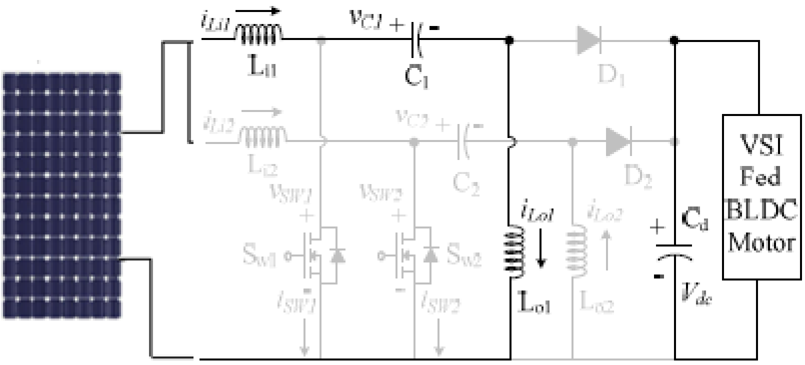

Fig.7.3 Mode-II (a)

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After completely discharging the Cd the Sw2 is turn on, when switch (*Sw2*) is turned-on, the input inductor (*Li2*) and output inductor (*Lo2*) start charging as shown in Fig. 7.4 (b). The intermediate capacitor (*C2*) discharge via output side inductor (*Lo2*) and the voltage across it decreases. The diode (*D2*) remains in non-conducting state and the DC link capacitor (*Cd*) supplies the required energy to the VSI fed BLDC motor.

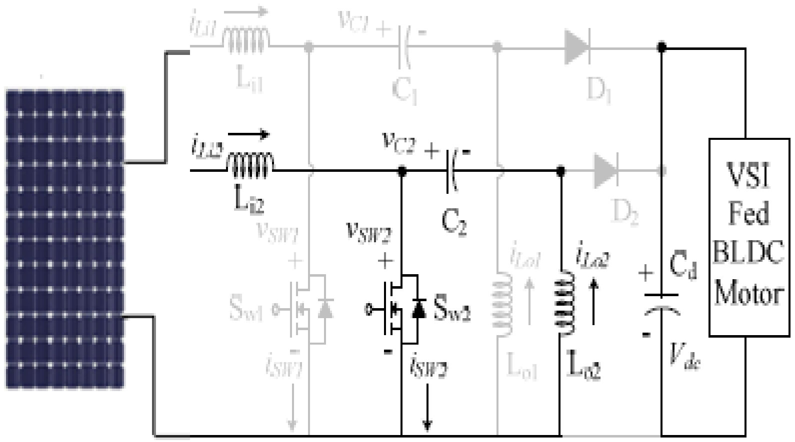

Fig.7.4 Mode-II (b)

MODE-III

When switch (*Sw2*) is turned-off, the input inductor (*Li2*) and output inductor (*Lo2*) start discharging via diode (*D2*) as shown in Fig. 7.5 (a). Moreover, the intermediate capacitor (*C2*) charges in this mode of operation. The DC link capacitor (*Cd*) charges in this interval and the DC link voltage (*Vdc*) increases in this mode.

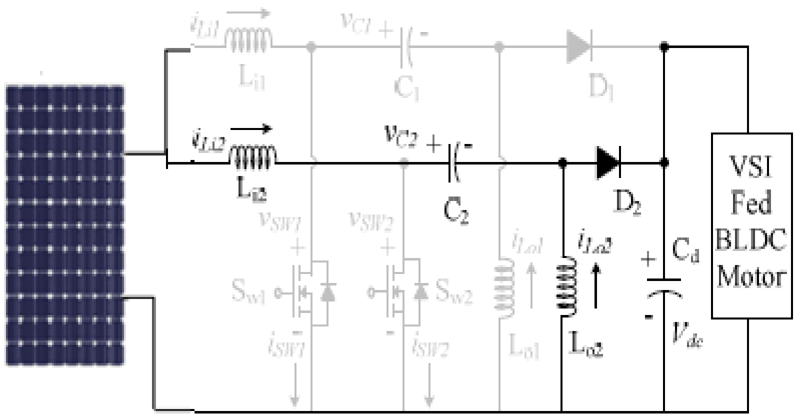

Fig.7.5 Mode-III (a)

During this interval, the output side inductor (*Lo2*) is completely discharged and the input inductor (*Li2*) continues to discharge as shown in Fig. 2.5(b). The intermediate capacitor (*C2*) continues to charge via input inductor (*Li2*) and the DC link capacitor (*Cd*) supplies the required energy to the VSI fed BLDC motor drive.

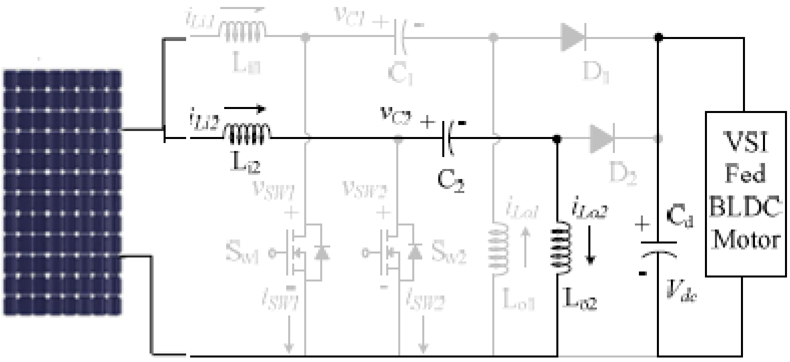

Fig.2.6 Mode-III (b)

SPEED CONTROL

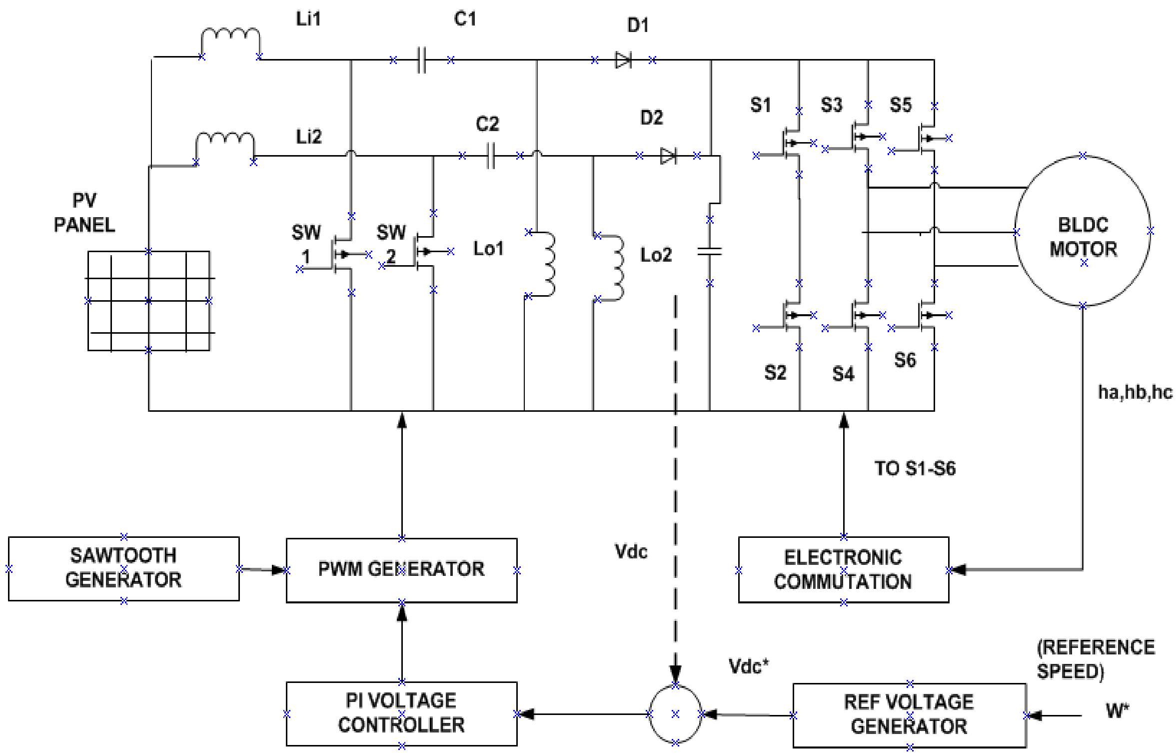

Fig.8 Speed control block diagram

Solar panel acts as the source and it converts the solar energy to electrical energy. This voltage cant drive motor and so this voltage is stepped up using sepic converter. The sepic converter provides energy to 3 phase voltage source inverter which is operated in 120 degree conduction mode of operation. The stator windings will be energised by electronic commutation of inverter switches thus driving the bldc motor. Hall effect sensors produce signals based on rotor position and produce hall effect signals. The 6 combination of 3 hall effect signals is given as input to the microcontroller which has logic for converting the hall effect signals to pulses for inverter switches.

The speed control is carried out by the pid control. As the irradiance of sun vary over a day, the output pv voltage changes. Accordingly the input of sepic and its output changes. This voltage when given to inverter changes the speed of bldc motor, because speed of the motor is proportional to applied voltage. So the voltage has to be maintained contstant to obtain constant speed. This is where the control of converter comes into picture. If we maintain the output voltage of the converter to be constant evenif the irradiance changes, the speed can be maintained constant.

The reference speed of the motor is converted into reference voltage using gain constant. This reference voltage is compared with output voltage of the converter. An error signal will be generated. This error is passed through pid controller. The controller computes both the derivative and the integral of this error signal. The control signal (u) to the plant is equal to the proportional gain (K_p) times the magnitude of the error plus the integral gain (K_i) times the integral of the error plus the derivative gain (K_d) times the derivative of the error. The output of the pid controller which is the control voltage is compared with sawtooth wave to generate pulse for the converter switch. So each time, when the pv output changes due to variations in irradiance, the converter output is compared with reference voltage (equivalent of reference speed), and the output/dclink voltage is maintained constant. Thus speed control is obtained.

7. SIMULATION RESULTS

A simulation design system is implemented in MATLAB SIMULINK

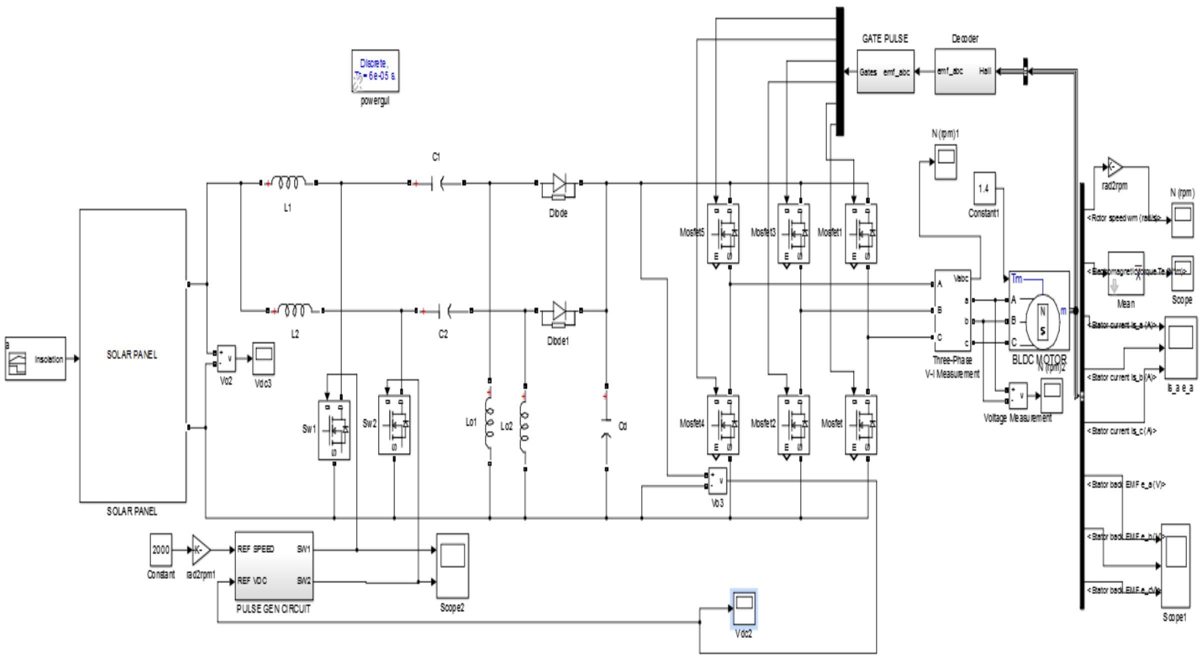

Fig.9 Matlab Simulation file

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SOLAR MODULE SPECIFICATIONS:

Short circuit current=5.45 A, Open circuit voltage=30V,Current at P_{max} =4.95 A, Voltage at P_{max}=24 V ,Maximum Power=118.8W. Total 5 modules are connected in series as source. Net maximum power=594W

BLDC MOTOR PARAMETERS:

No of poles=4, power rating=360W, voltage rating=180V, resistance of stator phase=0.8Ω, inductance of stator phase=2.7Mh, Voltage constant=88 $\mathrm{V_{peak}L_L/krpm}$, Torque constant=0.84Nm/ $\mathrm{A_{peak}}$, Rated torque=0.84Nm, inertia=0.8kg.m^2, Rated speed=2000rpm@180V DC.

SEPIC CONVERTER PARAMETERS:

Input inductors, $L_{i1,} = L_{i2} = 3.8mH$, Input capacitors,$C_{in1} = C_{in2} = 50\mu f$,Output inductors,$L_{o1}, L_{o2} = 6.8mH$, Output capacitor $C_{o1} = 100\mu f,\ C_{o2} = 1155\mu f$

Solar irradiation is varied in two steps 1100w/m^2till 2.5sec and 1200w/m^2 after 2.5sec.Output voltage of the pv changes from 109V to 136V after 2.5sec as shown in the figure10.

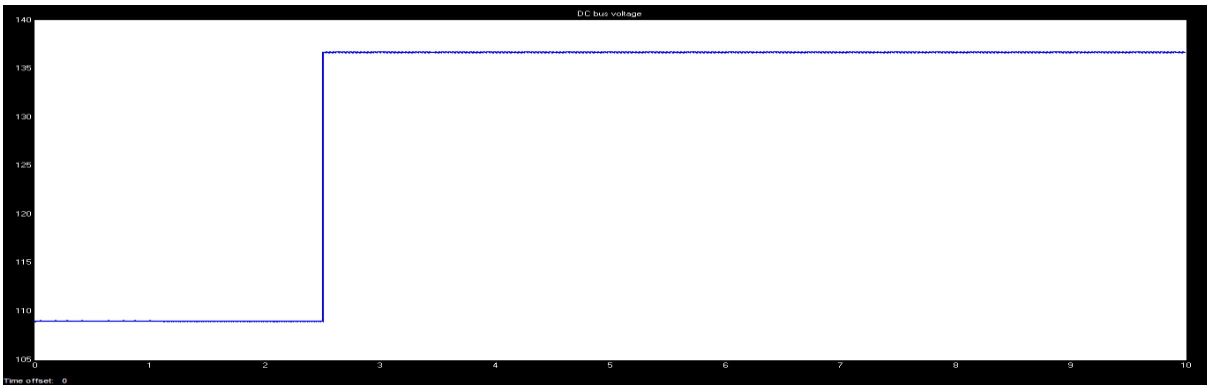

Fig.10 PV Output Voltage

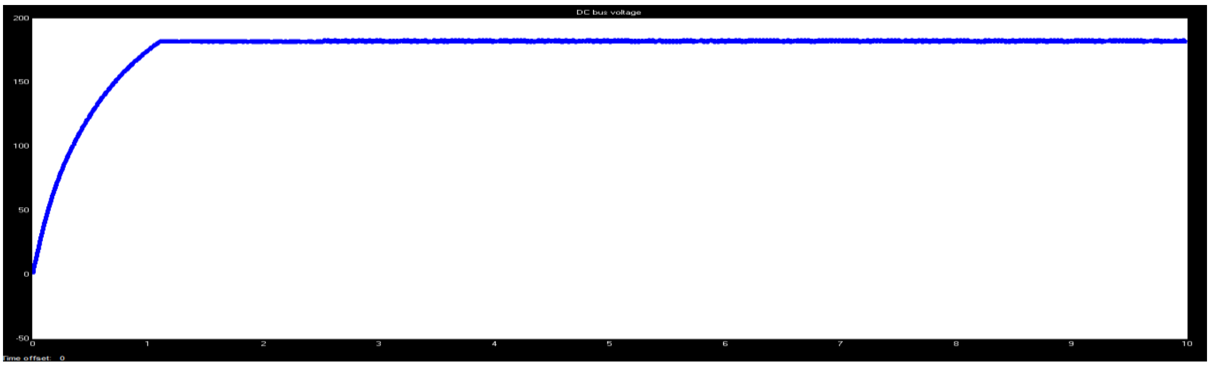

Fig.11 Converter output voltage

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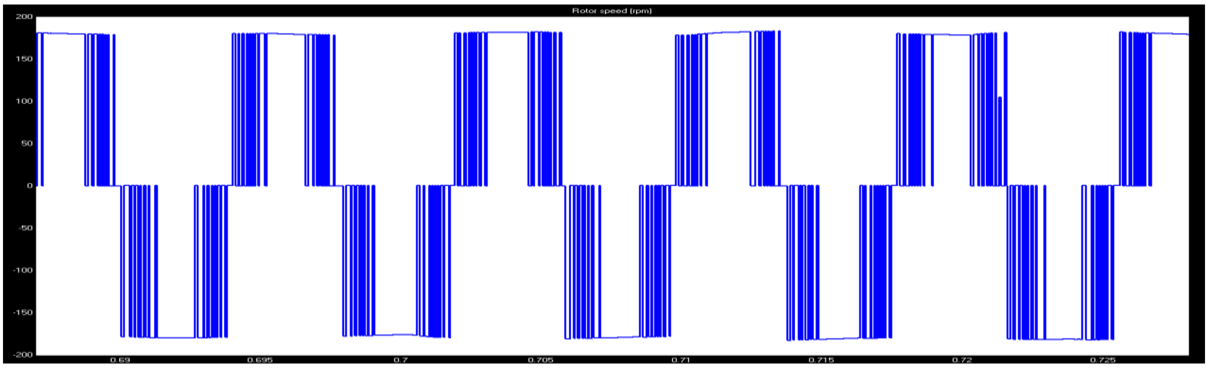

Fig.12 Phase to phase voltage of 3-ph vsi

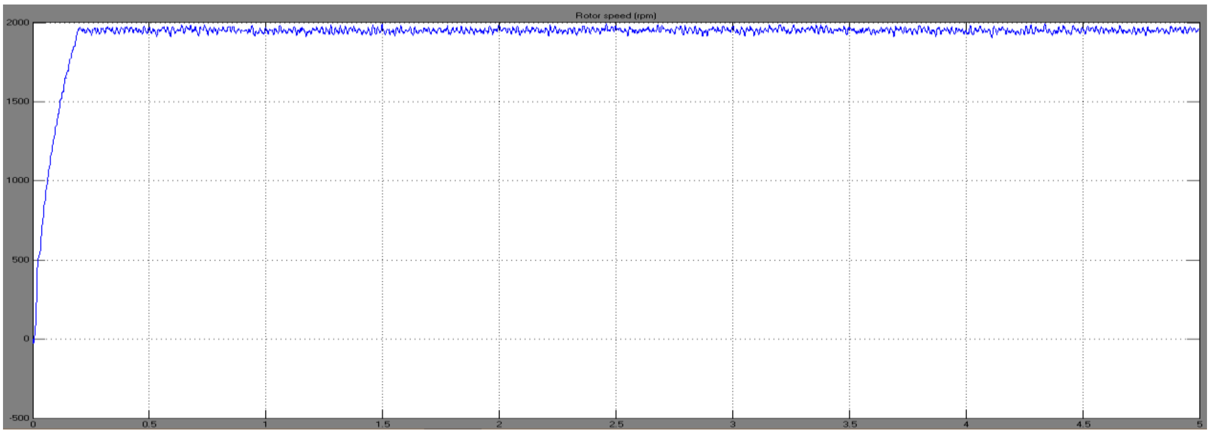

Fig.13 Speed of BLDC Motor

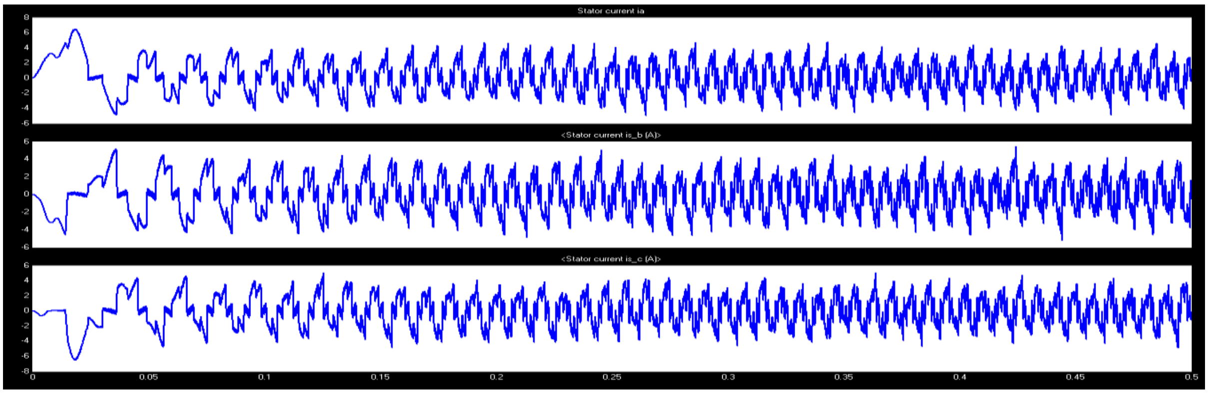

Fig.14 Stator rms current

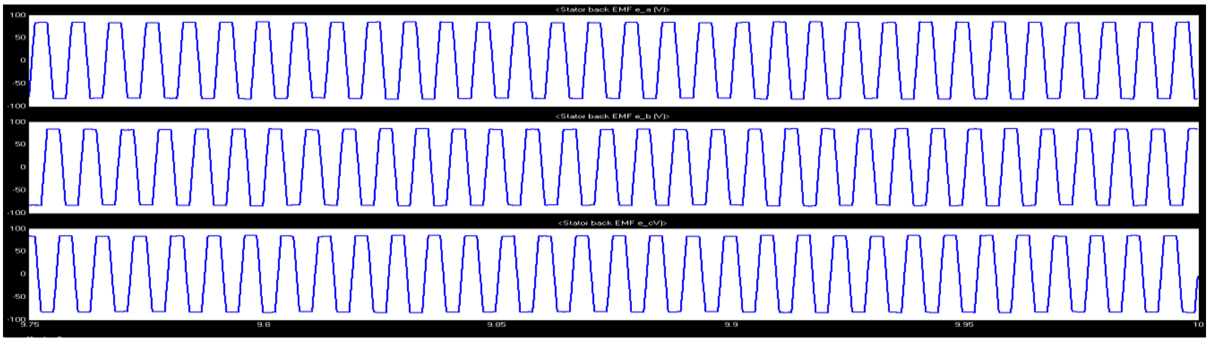

Fig.15 Stator back emf

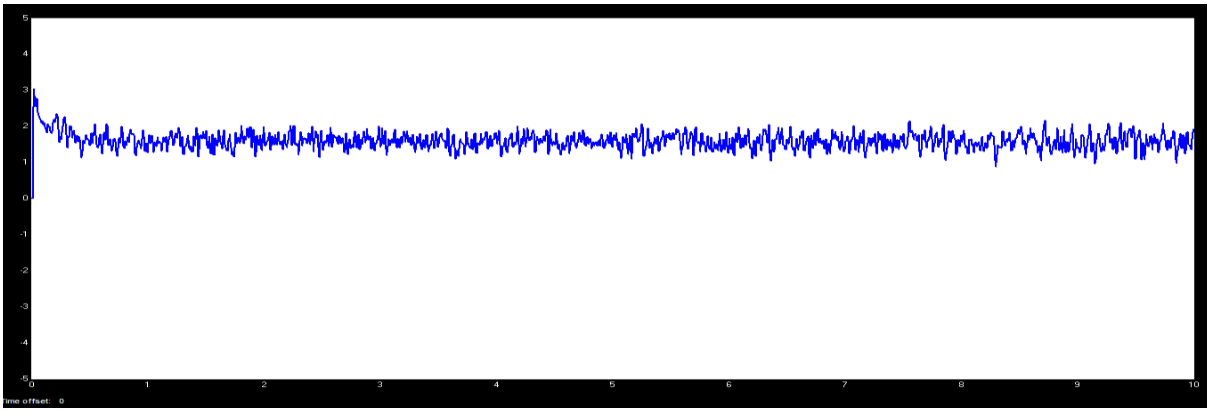

Fig.16 Torque of BLDC Motor

The converter voltage(Fig.11) is constant due to pid control action even if the pv voltage changes. The voltage is around 180V. This voltage is given to vsi which produces ac voltage with phase to phase peak voltage of 180V as in Fig.12. This is fed to bldc motor. The speed of bldc motor (Fig.13) is proportional to dc link voltage which is maintained constant. Stator rms current is quasi-sinusoidal in shape and is displaced by 120 degree in each phase as shown in Fig.14. Back-emf is trapezoidal in shape and is displaced by 120 degree in each phase(Fig.15). Torque (Fig.16) is proportional to stator current and the oscillations in the torque waveform is due to electronic commutation.

CONCLUSION

The performance of the system is verified using matlab simulation. The system is best suited for water pumping application as the speed of the bldc motor is maintained at desired value even though the solar irradiation varies over time. The advantages of sepic converter over other converters like less ripple and non-inverting polarity are affirmative or positive features for the design of this system. Pid control is used for the speed control of bldc motor which thereby controls the dc link voltage or in other means the output of the converter. Bldc motor is the most effiecient and suitable drive for solar powered water pumping system.

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