SPEED CONTROL OF BLDC MOTOR USING PV AND SEPIC CONVERTER

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ABSTRACT
This paper is based on Speed control of BLDC motor using PV and SEPIC converter. Nowadays BLDC motor drive is more used as it has many advantages like high power density, high efficiency etc. Solar Panels have become an increasingly popular form of renewable energy. Photovoltaics (PVs) is the input source to SEPIC converter. SEPIC converter have high voltage ratings which can operate in step up and step down mode. For commutation by electronic switches three phase voltage source inverter is used. BLDC motor winding of stator is connected to Electronic commutator. A closed loop operation of BLDC motor to attain speed control is used by PI controller. The components are simulated in MATLAB 2019b software. And the simulation results are presented.

Keywords: SEPIC, PV, BLDC Motor, Hall sensors, PI controller.

INTRODUCTION
BLDC (BRUSHLESS DC) Motor is used in many low and medium power applications like electric vehicles, household appliances, aerospace, industrial tools, robotics and automation for their efficient operation [1][2]. It converts electrical energy into mechanical energy. BLDC drive input is Voltage source inverter powered by uncontrolled rectifier coming from one phase AC mains then a DC link capacitor. Power quality disturbances arises as DC link capacitor have uncontrolled charging leads current waveform as pulsed, at AC mains the fundamental input current its amplitude is lower than peak current waveform .so to overcome this a SEPIC converter is used [3]. SEPIC has got voltage ratings higher [4][5], in which it is formed when a Capacitor and Inductor is connected in between Boost converter [6]. BLDC motor is done with electronic commutator. BLDC motor stator is connected with Inverter. Inverter has got top and bottom switches which can conducts will positive and negative pulse which can run the motor [7][8]. Electronic controller is controlled with help of VSI. BLDC motor have Hall sensors which are placed on stator which will sense position of rotor generate signals given to feedback controller [9], output PWM signals are given to Inverter switches to run the BLDC motor [10][11].

System Description
PV (photovoltaic) modules with help of light energy getting from Sun is used to generate electricity through photovoltaic effect. It is used as source input to SEPIC converter. PV is connected to SEPIC converter which will produce DC output. SEPIC output is connected to VSI.VSI converts DC to AC output is connected to BLDC motor. All-Effect sensor senses rotor position and produce Hall effect signals which is sent to controller circuit to generate gate signals for Inverter switches.

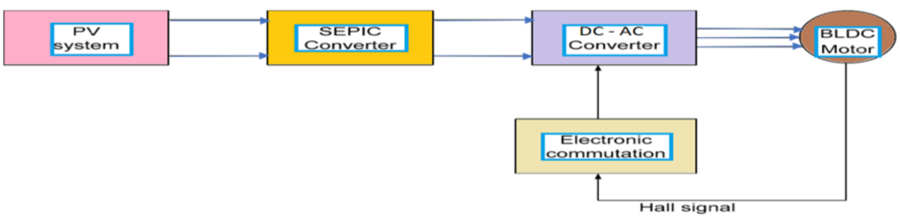


Fig. 1. Block diagram of BLDC Motor using PV and SEPIC converter.

1.1 Photovoltaic Cell

Photovoltaic (PV) system is a semiconductor device with photovoltaic effect can convert light energy into electrical energy. The converted energy of photovoltaic module depends on solar radiation, temperature, and voltage. A voltage of 0.5 to 0.8 volts a PV cell can generate, to get more amounts of voltage and current a numbers of PV cells are connected in series and parallel to form PV module. Equivalent circuit of solar cell consist of current source, resistance in parallel and series, a diode as shown in Fig 2.

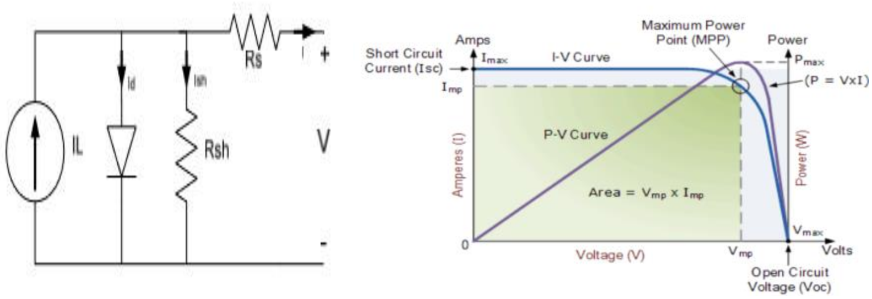


Fig. 2. Equivalent circuit of Solar cell and V-I and P-V characteristic curves of Solar panel under an irradiation and temperature of output current and voltage graphs.

1.2 SEPIC Converter

Single ended primary inductor converter is called as SEPIC converter. It's used for low power (MOSFET) and high power (IGBT) applications. It acts as buck and boost converter It can increase input voltage (Boost) or decrease (Buck). The SEPIC output is connected to BLDC motor drive via VSI. The advantages of SEPIC converter over other converters like less ripple and non-inverting polarity, higher efficiency.

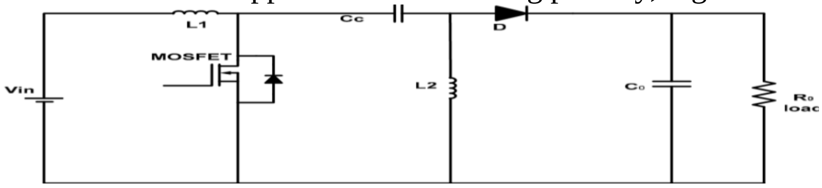


Fig. 3. Circuit of SEPIC converter.

1.3 BLDC Motor

Brushless DC (BLDC) motor is used in this Project as speed control of wide range is possible. BLDC motor consist of stator with 3 phase concentrated windings and rotor with permanent magnets There is no mechanical commentator and brushes. It is electrically commutated by power switches which is commutated every sequentially 60 degrees rotation of rotor. Electronic commutation is achieved by using a three-phase voltage source inverter .VSI converts DC to AC. To get rotor position hall sensors are placed on stator of BLDC motor. Hall signals given to Electronic controller which converts to back emf signal and with proper switching sequence will generate PWM gate signals to control Inverter switches. BLDCM has back-Emf as Trapezoidal waveform and stator current have rectangular waveform. Electronic commutation avoids sparking and wearing out of the commutator brush.

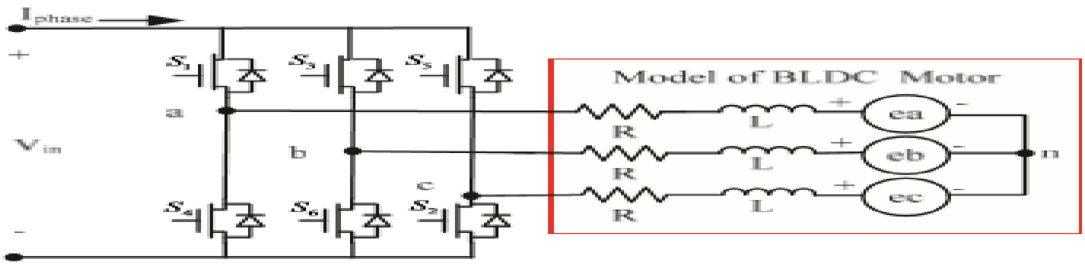


Fig. 4. Circuit diagram of BLDC Motor.

Voltage Equation

$Va = Ia. Rs + L\ d\ Ia/dt + Ea$

$Vb = Ib. Rs + L\ d\ Ib/dt + Eb$

Vc = Ic. Rs + L d Ic/dt + Ec (1)

where Va, Vb, Vc are phase voltages , Ia, Ib, Ic are phase current , Ea, Eb, Ec are Back emf of a, b, c phases Rs, phase resistance , Ls self inductance.

Back Emf Equation

Ea= Ke.f(θ).wm

Eb= Ke.f(θ- 2.pi/3).wm

Ec= Ke.f(θ + 2.pi/3).wm (2)

where ea, eb,ec back emf of phase a, b,c , wm rotor mechanical speed ,ke back emf constant and f(θ) is trapezoidal function.

Torque Equation

Te = (Ea. Ia + Eb. Ib + Ec. Ic)/ wm (3)

Te = TL + B. wm + J. d wm/dt (4)

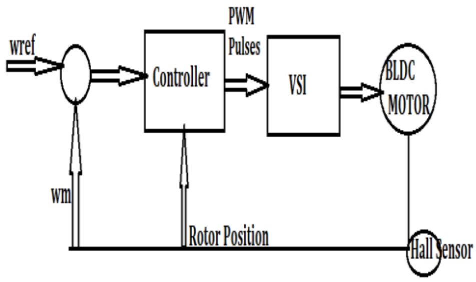
Te is electromagnetic torque ,TL load torque , J inertia, B friction factor

Hall Signals			Back Emf			Commutation Signals (pulses)					
H_a	H_b	H_c	E_a	E_b	E_c	Q1	Q2	Q3	Q4	Q5	Q6
1	0	1	+1	-1	0	1	0	0	1	0	0
1	0	0	+1	0	-1	1	0	0	0	0	1
1	1	0	0	+1	-1	0	0	1	0	0	1
0	1	0	-1	+1	0	0	1	1	0	0	0
0	1	1	-1	0	+1	0	1	0	0	1	0
0	0	1	0	-1	+1	0	0	0	1	1	0

Fig. 5. Inverter switching pattern depends on Hall signal and Back Emf.

Hall sensor is used to determine the position during commutation. BLDC motor get position feedback from rotor via encoder or optical devices etc, Rotor position depends on the accurate position with stator. Hall sensors which are displaced by 120 degree get position of Rotor generate signals given to controller logic. The controller has decoder logic to convert hall signals into emf signals which in turn converted to PWM pulses for the inverter switches.

Simulation and Results



Parameters	Values
Voltage	320V
No. of Poles	4
Resistance	0.2 Ohm
Inductance	0.0085mH
Flux Linkage	0.175
Inertia	0.089kgm2
Friction factor	0.005Nms

Fig. 6. Proposed system and BLDC motor parameter.

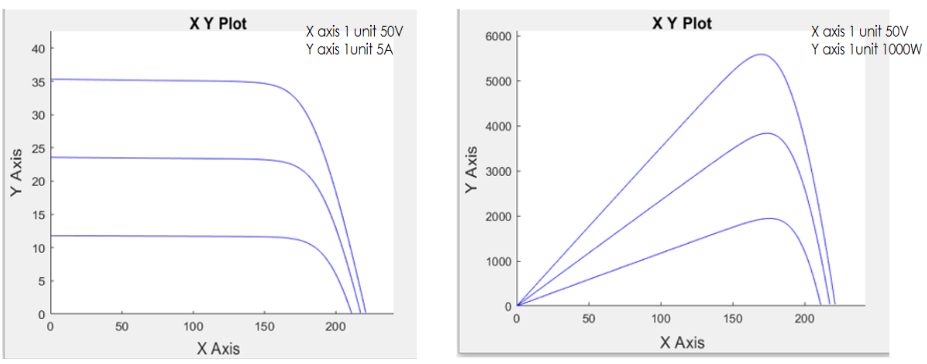


Fig. 7. VI and PV characteristics of PV analyzed for various condition to operate in different irradiations 500w/m2, 1000w/m2 , 1500w/m2 and temperature of 25 degrees of PV-SEPIC system.

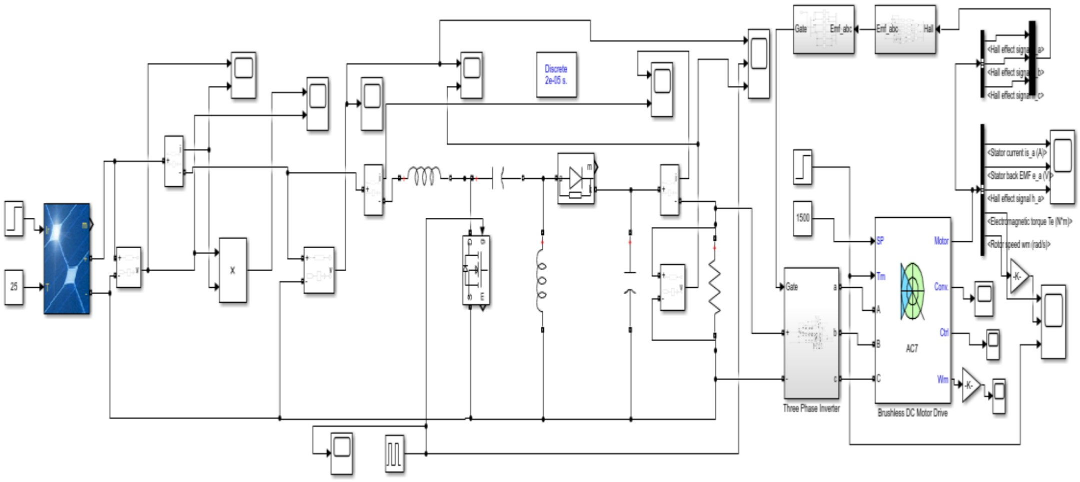


Fig. 8. Simulation of PV-SEPIC-VSI-BLDC motor whole system in Open Loop

Here PV Irradiation 500w/m2 till 1.5second after that 1000w/m2,duty cycle 0.6, Load Torque 0NM is given to PV-SEPIC-VSI-BLDC Motor whole system and corresponding waveforms are obtained below.

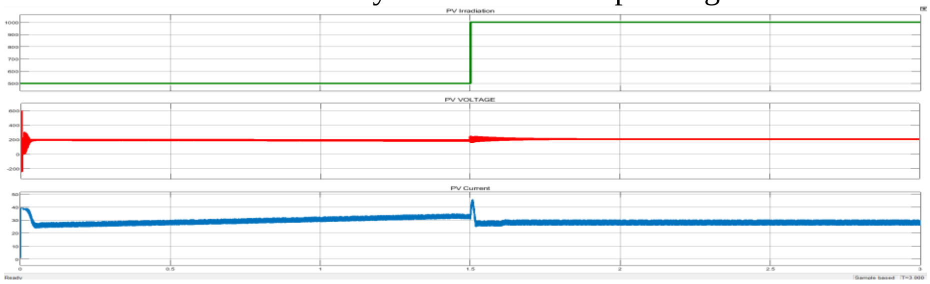


Fig. 9. PV Irradiation ,PV Voltage and PV Current waveform

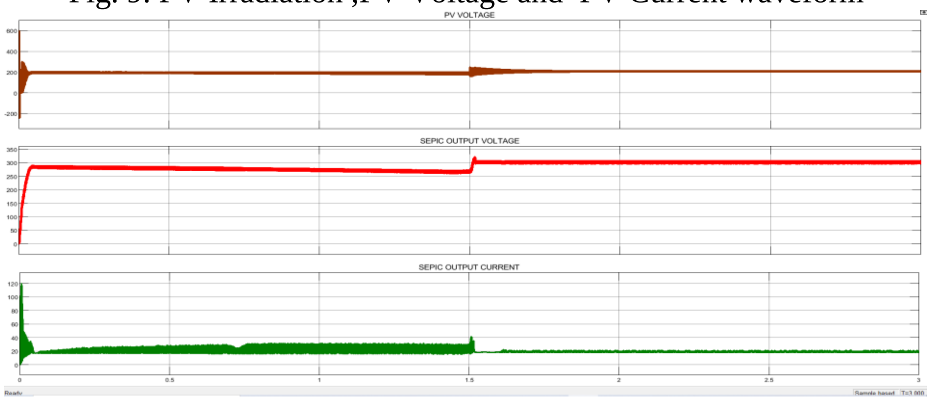


Fig. 10. PV Voltage,SEPIC Output Voltage , SEPIC Output current waveform

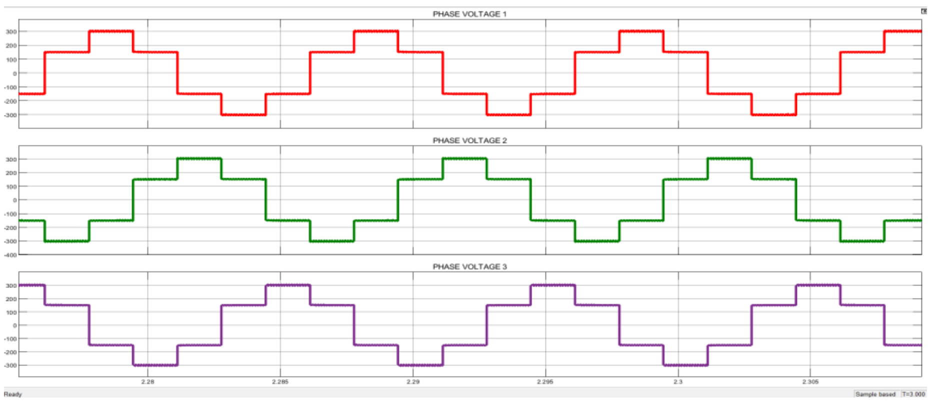


Fig. 11. Inverter Phase voltage waveform

When irradiation increases from 500w/m2 to 1000 w/m2 SEPIC voltage,Inverter voltage also increases and when duty cycle is 0.6 SEPIC output voltage is boosted from 208V to 304V.Voltage source inverter phase voltage is having six step wave form.

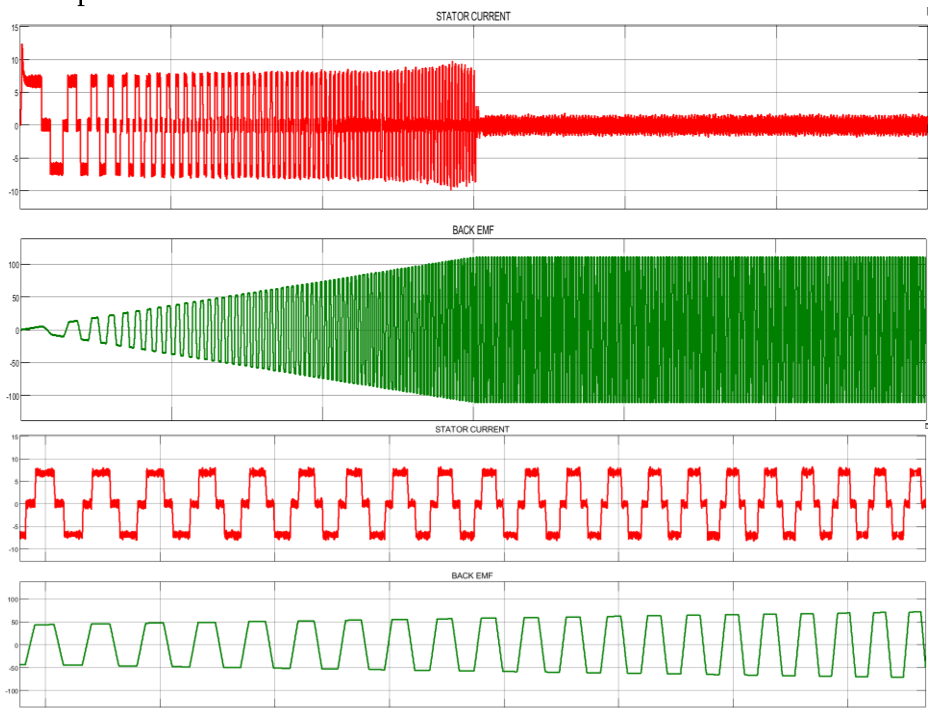
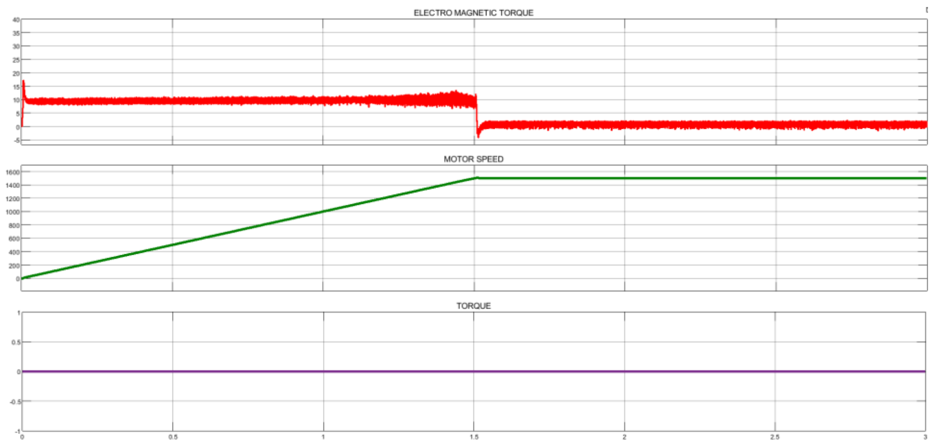


Fig. 12. BLDC Motor Stator current, Back Emf waveform with PV Irradiation of 1000w/m2, Dutycycle



0.6,LoadTorque0Nm Fig. 13. BLDC Motor Electromagnetic Torque, Motor Speed, Load Torque wave form with PV Irradiation of 1000w/m2 ,Duty cycle 0.6, Load Torque 0 Nm

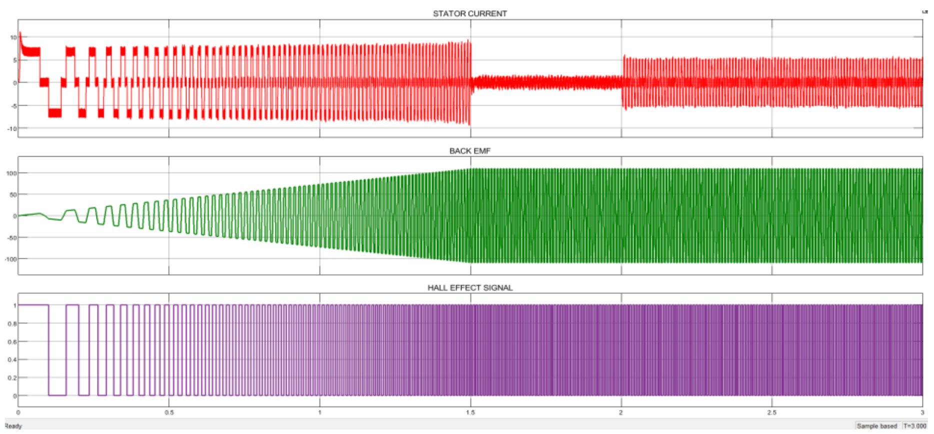


Fig. 14 BLDC Motor Stator current, Back Emf waveform with PV Irradiation of 1000w/m2,Dutycycle 0.6, Load Torque 0 Nm till 2sec after that 5 Nm

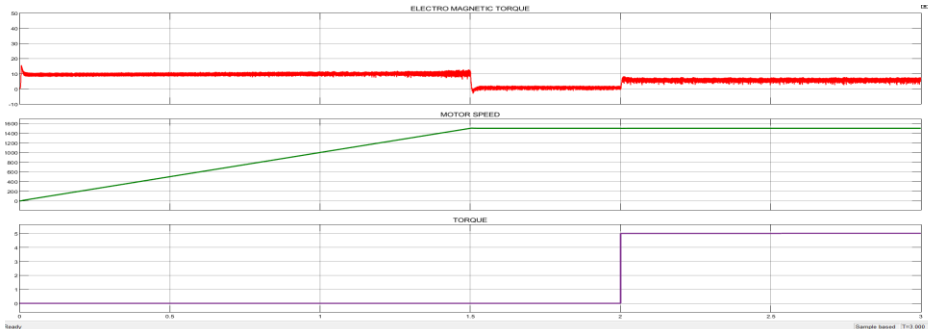


Fig. 15. BLDC Motor Electromagnetic Torque, Motor Speed, Load Torque wave form with PV Irradiation of 1000w/m2 ,Duty cycle 0.6, Load Torque 0 Nm till 2sec after that 5 Nm

Table 1. Table of Result

PV Irradiance(w/m2)	PV Voltage(V)	PV Current(A)	PV Power(W)	Duty Cycle	SEPIC Boost Voltage(V)	SEPIC Boost Current(A	Motor Speed(rpm)	Torque (Nm)
1000	208.5	27.57	5747	0.6	304.3	18.27	1500	0
1000	207	31.26	6471	0.6	301	32.98	1500	5

By varying the duty cycle SEPIC converter can operate as Buck and Boost converter. SEPIC as Boost converter with duty cycle 0.6 output voltage is increased and output current reduced. The stator current of BLDC motor depends on Torque and Back emf depends on Speed. They both are proportional. Stator current is 120 degree displayed having quasi square and back emf is 120 degree displayed having trapezoidal waveform. Speed is increasing and attaining steady state so initially there is some torque. Under steady state electromagnetic torque of BLDC motor will be equal to load torque.

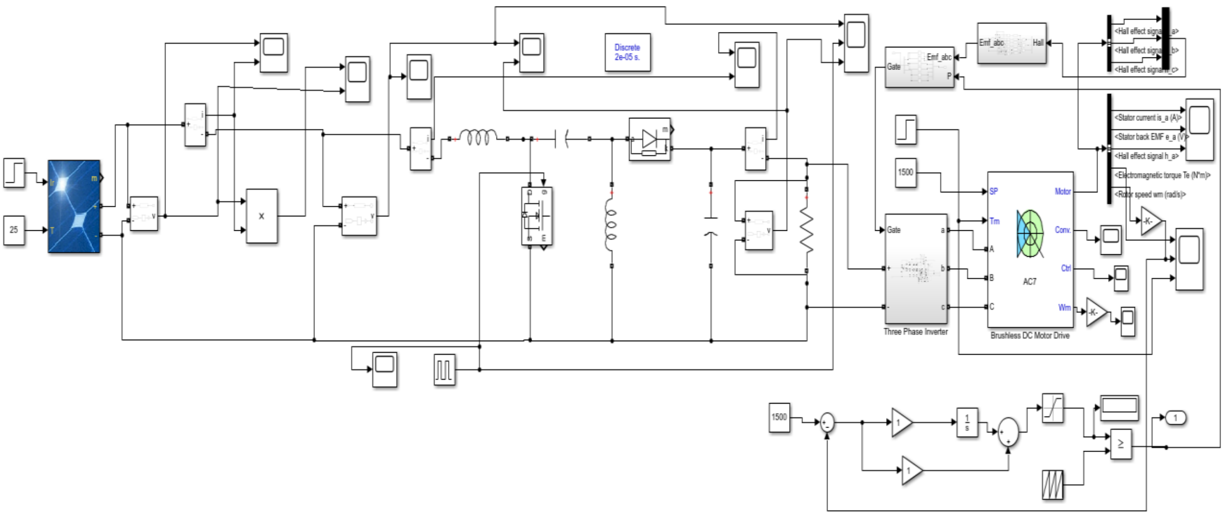


Fig. 16. Simulation of PV-SEPIC-VSI-BLDC motor whole system in Closed Loop

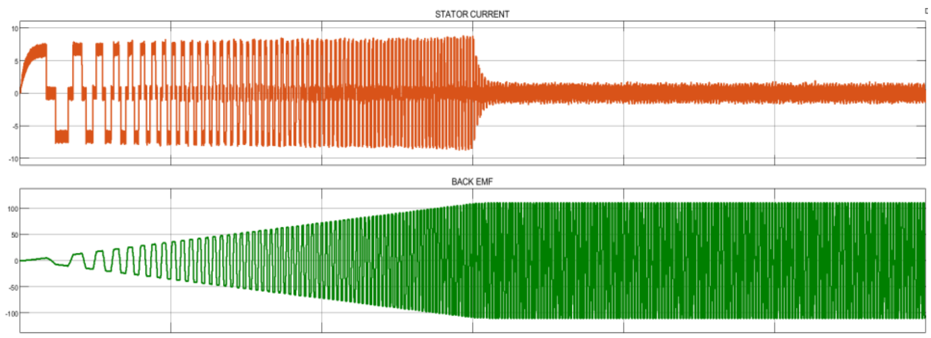


Fig. 17 BLDC Motor Stator current, Back Emf waveform with PV Irradiation of 1000w/m2,Dutycycle 0.6, Load Torque 0 Nm

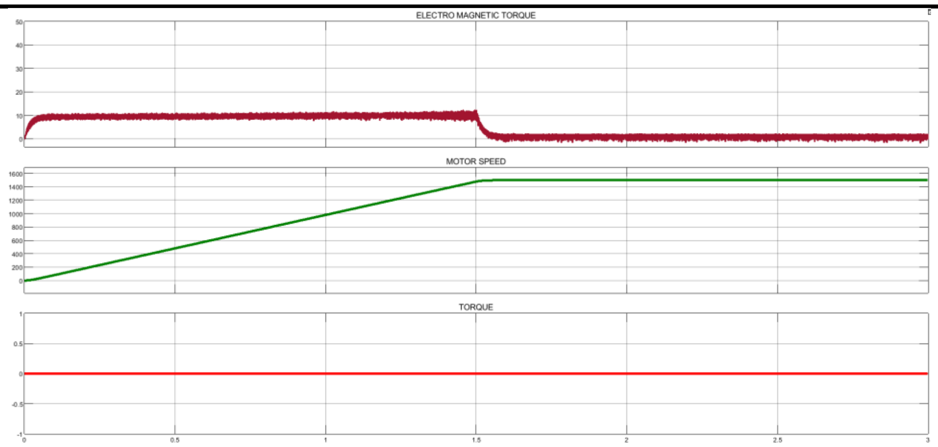


Fig. 18 BLDC Motor Electromagnetic Torque, Motor Speed, Load Torque wave form with PV Irradiation of 1000w/m2 ,Duty cycle 0.6, Load Torque 0 Nm

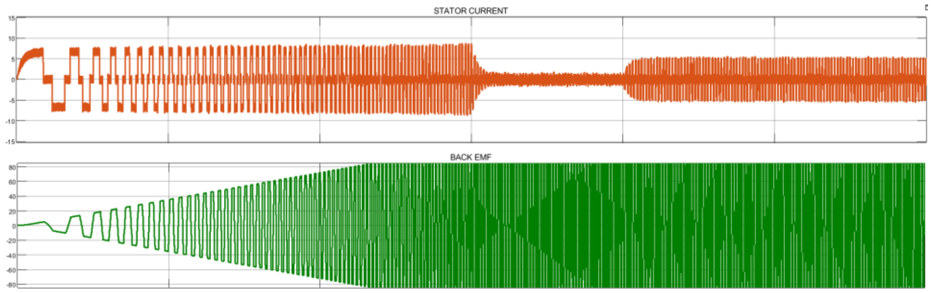


Fig. 19. BLDC Motor output waveform with PV Irradiation of 1000w/m2, Duty cycle 0.6, Load Torque 0 Nm

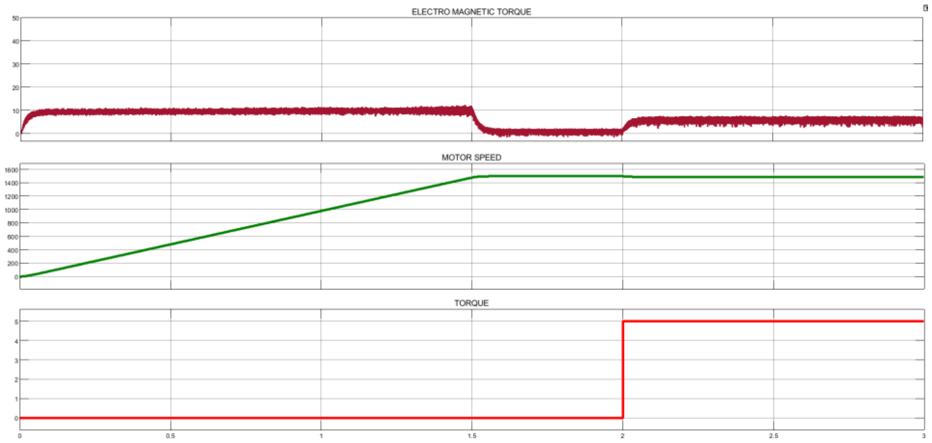


Fig. 20. BLDC Motor output waveform with PV Irradiation of 1000w/m2 ,Duty cycle 0.6, Load Torque 0 Nm till 2sec after that 5 Nm

In closed loop operation speed is controlled at 1500 rpm when reference speed and actual speed of BLDC motor is compared and that error is given to Speed PI controller with values Kp (0.4921) and Ki (0.001) which will amplify the speed error and that feedback is given to gate signal which control the switches of inverter.

CONCLUSION

Solar energy is used in many applications. This Project is based on Speed control of BLDC Motor using PV and SEPIC Converter. This can be used in low power application. Normally conventional BLDC motor do not have speed and current controls. Here uses simplified speed control for BLDC motor. Electronic commutation of the BLDC motor is done with help of Inverter. The SEPIC converter is a DC to DC converter placed at the input of Inverter. SEPIC converter operates as Buck and Boost converter. BLDC Motor using

PV and SEPIC Converter for open loop and closed loop is presented. A closed loop operation of BLDC motor to attain speed control is used by Speed PI controller. Speed is smooth and regulated in closed loop operation.

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