Volume 9, Issue 3
June 2020

ITEE Journal
Information Technology & Electrical Engineering

ISSN: - 2306-708X

Coupled Inductor SEPIC Converter fed BLDC Motor in Electric Vehicle

[1]Sabna Abbas, [2]Princy Philip
[1]Department of Electrical and Electronics Engineering, Govt. Engineering College Idukki, Kerala, India
[2]Department of Electrical and Electronics Engineering, Govt. Engineering College Idukki, Kerala, India
E-mail: [1]sabnaabbas@gmail.com, [2]princyphilip@gecidukki.ac.in

ABSTRACT

This paper discusses the design and matlab simulation of solar powered Coupled Inductor SEPIC converter fed BLDC motor. The system under consideration includes a Solar panel, MPPT (Maximum Power Point Tracking) controller, a dc-dc converter, a 3 phase VSI (Voltage Source Inverter) and a BLDC Motor. Coupled Inductor SEPIC Converter is used as the dc-dc Converter, which employs MPPT technique to control its duty cycle. Perturb and Observe algorithm is used for controlling the converter switch. By this method, the converter output is maintained at the desired level even during varying irradiance. BLDC motors are found to be the most efficient and suitable drives for solar powered electric vehicles. Coupled Inductor SEPIC Converter along with BLDC Motor is designed and simulated using MATLAB software.

Keywords: *Coupled Inductor SEPIC Converter, Electric Vehicle, BLDC Motor, PV Panel, P and O algorithm.*

1. INTRODUCTION

Renewable energy is becoming an emerging trend as it is environment friendly, needs less maintenance and has reduced installation effort. Electric vehicles, being more environment friendly, are fast replacing the conventional internal combustion engine vehicles. In this paper, Coupled Inductor SEPIC Converter design and implementation is discussed. Based on the irradiance available solar cells provide dc output voltage. Nominal voltage and current conditions will not be available from the PV array at all times due to frequent changes in solar irradiance and climatic conditions. To attain maximum power, MPPT technique is employed. Here Perturb and Observe algorithm is used by which PV output voltage is changed in small steps and the power output is monitored until maximum power point is reached.

To obtain desired level of DC voltage from the solar panel, dc-dc converters are used. Conventionally Boost Converters or Buck-Boost converters are used for this purpose. As the names suggest, boost converter converts dc voltage to a higher value than the value obtained from the solar panel and Buck-Boost converter maintains the dc voltage from the panel at a constant value even during varying input conditions. In this work a Coupled Inductor SEPIC Converter is used. SEPIC Converter can be used to maintain the output voltage at constant value even if the input voltage is varying. Advantages of SEPIC Converter over Buck-Boost Converter are minimal number of active components, simplicity in design and low noise operation. The SEPIC Converter has two separate magnetic windings. These two windings can be wound on a common core to form coupled inductor. Thus, Coupled Inductor is used because, it has less number of components and lower inductor requirements as compared to two separate inductors.

Obtained dc output is used to drive a BLDC Motor, which is in turn considered as one of the efficient drives for solar powered electric vehicles, through an inverter. Inverter produces an AC signal to drive the BLDC Motor. The Inverter switches are controlled using the controller circuit, to which hall effect signals as given as input. Rotor position can be found out using these hall effect sensors. The 3 hall effect sensors, displaced by 120 degree, send hall effect signals to the controller circuit. The controller circuit includes decoder for hall effect signals for converting them into corresponding equivalent stator emf signals. These signals are converted to the pulses for the inverter switches.

The input current ripple of the above converter, lower than that of uncoupled inductor, is minimised by using coupled inductor[1]. By employing MPPT technique in the converter, the PV system performance under varying weather conditions can be increased[2]. Also coupled inductor SEPIC converter has advantages like increased output power and low switching losses[3].

2. BLOCK DIAGRAM

The block diagram of the Solar powered Coupled Inductor SEPIC Converter fed BLDC Motor is as shown in figure 1. A Coupled Inductor SEPIC Converter along with a Solar panel is used to control the dc voltage. The converter switch is controlled by MPPT technique.

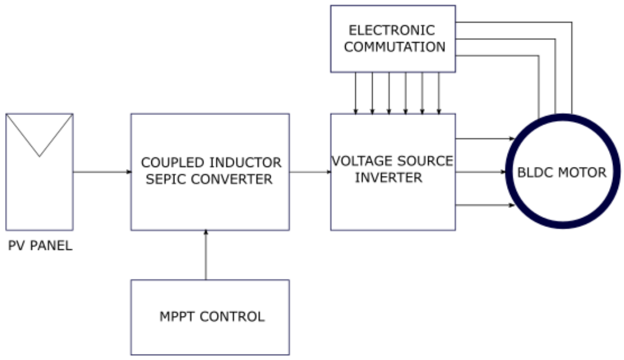

Fig.1. Block Diagram.

Panel converts the solar energy into electrical energy. This electrical energy is fed to the converters to obtain a constant output dc voltage. The dc output, so obtained, is fed to a 3 phase voltage source inverter. The sinusoidal current produced by the inverter energizes the corresponding stator windings of the BLDC motor. Rotor positions have to be found for energizing stator windings in a sequence[5].

3. MODULE DESCRIPTION

The proposed system includes a PV Panel, Converter, Voltage Source Inverter and BLDC Motor.

A. PV Panel

PV Panel is used to convert solar energy to electrical energy. Solar PV modules are obtained by the interconnection of smaller solar cells. By connecting low power solar cells in series - parallel combination higher power can be extracted. Series connection increases the output voltage. To increase the output current level, parallel connection is used. The power output of solar PV module depends on its solar irradiation. The power output of the module decreases linearly with the decrease in the intensity of solar radiation. Solar irradiation available throughout the day is not constant. In a cloudless day, it increases from morning to noon and decreases from noon till sunset. Due to this variation in the irradiation, the power output of a module also changes throughout the day. The current produced by the PV module is a linear function of the radiation intensity. But the voltage of a module is a logarithmetic function of the radiation intensity[3].

The equivalent circuit of a PV cell is shown in figure 2. The cell photocurrent is represented using current source Iph. Rs and Rsh are the series and shunt resistances of the cell. The value of Rs is very small and that of Rsh is very large, so they can be neglected to simplify the analysis. Usually, PV cells are grouped together and are called PV modules. These modules are connected in series or parallel to create PV arrays and these arrays are used to generate electricity from solar energy[1].

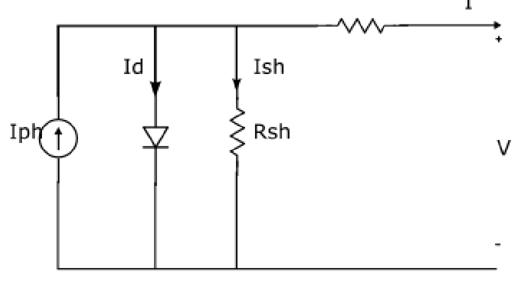

Fig. 2. PV Cell.

B. Coupled Inductor SEPIC Converter

A Coupled Inductor SEPIC Converter is used here to obtain the desired DC voltage level. By using this converter, the output voltage is regulated at a constant value even with varying input conditions. Also this converter has advantages over buck boost converter such as minimum number of components, clamped switching waveforms and simple control approach[4]. Normal SEPIC converter has two individual inductors whereas coupled inductor SEPIC converter is realised using two windings wound on a single core. The circuit operation is similar to that of replacing two uncoupled inductors with a coupled inductor.

For proper circuit operation volt-microsecond balance must be maintained across each magnetic core. That is, the product of voltage and time of each inductor must have equal magnitude and opposite polarity during ON and OFF condition of converter switch. The secondary winding of coupled inductor is clamped to the output voltage during turn off time of switch. A voltage equal to the input voltage and having opposite polarity across the inductor is imposed on the AC capacitor during turn on time of the converter switch. When the switch is turned on, the voltage across the primary inductor becomes equal to the input voltage. When the switch is turned off, the volt-microsecond balance is maintained by clamping output voltage across it. The input voltage is imposed on both primary and secondary windings during the turn on of switch and output voltage will be imposed on both primary and secondary windings during turn off of the converter switch.

The coupled inductor SEPIC converter is often selected than the SEPIC converter with two uncoupled inductors due to less component count, reduced inductance requirement and better integration. Coupled inductors have a turns ratio of 1:1 for volt-microsecond balance[4].

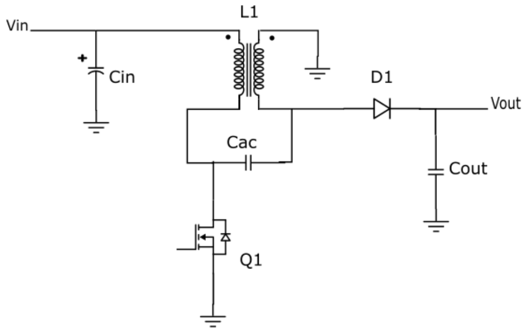

Fig.3. Coupled Inductor SEPIC Converter.

When the switch (Q1) turns on, the input voltage is applied across the primary winding. The winding ratio is 1:1, so the secondary winding is also imposed with a same voltage as in primary winding. Due to the polarity of the windings, the anode of the diode(D1) become negative and reverse-biased. Thus the AC capacitor (Cac) will charged to the input voltage. While Q1 is on, current flow in both windings is through Q1 to ground, and the secondary current flows through the AC capacitor. The total FET current during the ON time is the sum of the input current and the output secondary current.

When the switch is turned off, the voltage on the windings reverses polarity to maintain current flow. The secondary winding voltage will get clamped to the output voltage when the diode conducts, to supply current to the output. Transformer action clamps the output voltage across the primary winding. The voltage on the drain of the switch is clamped to the input voltage plus the output voltage. Current flow during the FET OFF time for both windings is through D1 to the output, with the primary current flowing through the AC capacitor[4].

C. Brushless DC Motor

ITEE Journal
Information Technology & Electrical Engineering
ISSN: - 2306-708X

Brushless DC electric motors are basically synchronous motors. These motors are powered using a DC electric source by an inverter. Inverter produces an AC electric signal to drive the motor. In this, alternating current does not have a sinusoidal waveform. For this additional sensors are used[5].

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 are energized in a sequence so that torque production is maximum for the rotor. 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. 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[5]. The controller block diagram is shown in figure 4.

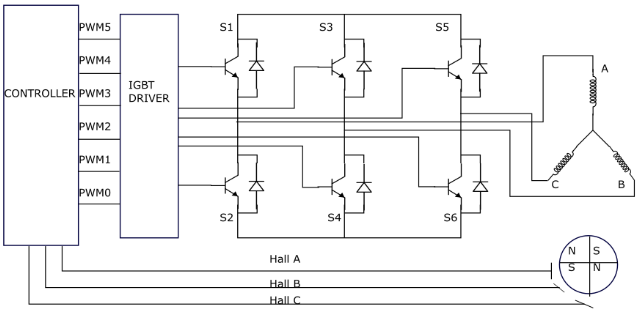

Fig. 4. Controller Block Diagram.

4. CIRCUIT DIAGRAM EXPLANATION

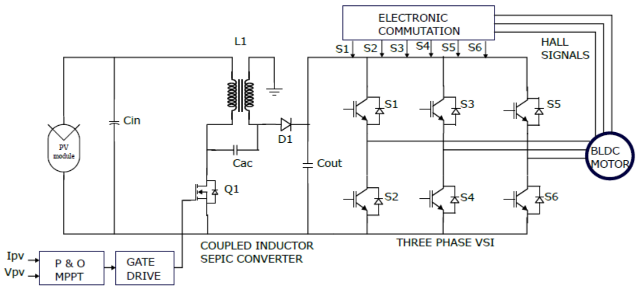

Fig. 5. Circuit Diagram.

Converter used here is the Coupled Inductor SEPIC Converter. It consists of two inductors which is wound on a single core. The winding ratio is 1:1, therefore the voltage across secondary winding will be same as that of primary winding.

When switch Q1 is turned on, input voltage is applied to the primary winding and secondary winding is also imposed with the same voltage as in primary winding. Due to the polarity of the windings, the anode of the diode(D1) will become negative and reverse biased. Thus AC capacitor will charged to the input voltage. Then current flow in both winding is through Q1 to ground and secondary current will flows through AC capacitor.

When Q1 is turned off, winding voltage reverses polarity. Secondary winding voltage is clamped to output voltage and diode conducts to supply current to output. Primary current will flows through AC capacitor[4].

The output obtained from the converter is fed to the inverter to convert the dc input to ac signal and to drive BLDC motor. The inverter switches are controlled by using the control circuit, that is hall effect sensors by measuring the position of rotor.

5. MAXIMUM POWER POINT TRACKING SCHEME

Solar panel is used for converting solar energy to electrical energy. Solar energy is varying largely in a day. Therefore, the solar energy available for the panel and thereby the converted electrical energy, that is the output of the solar panel are also varying. It will be higher in noon times and very little in morning and evening. Also, there may be problems with partial shading too. In order to obtain maximum power for higher efficiency, maximum power point tracking technology is implemented. By using this technology, we can obtain maximum power at output[2].

The most commonly used algorithms are the Perturbation and Observation method and Incremental Conductance method. Here, Perturbation and Observation method is implemented. In this method the array terminal voltage is periodically perturbed and the PV output power is compared with that of the previous perturbing cycle. If the perturbation results in an increase of array power, the following perturbation is made in the same direction. And if the perturbation results in a decrease in array power, the next perturbation is made in opposite direction. Thus the maximum power tracker continuously achieves the maximum power condition[3].

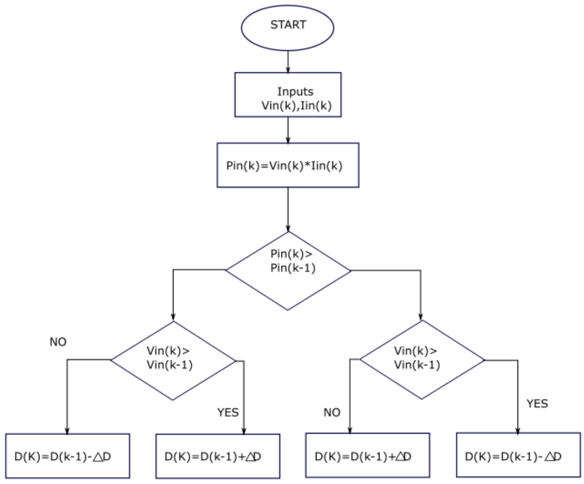

Fig. 6. P and O Algorithm.

Parameter	Value

ITEE Journal
Information Technology & Electrical Engineering
ISSN: - 2306-708X

Vin_dc	8V-32V
Vout_dc	24V
Fs	32kHz
C_coupling	42F
C_out	3.9F
L1=L2	39H

TABLE I
DESIGN VALUES

6. SIMULATION RESULTS

Coupled Inductor SEPIC Converter is designed and the whole system including the converter, inverter and BLDC motor is simulated using MATLAB software. Output voltage of Coupled Inductor SEPIC Converter maintains the desired value even with changing input voltages. Figure 8 shows the output voltage of converter when the input voltage is 8V and figure 9 shows the waveform of output voltage of the converter when the input voltage is 32V.
PV Panel specifications are,
_ Maximum Power- 124.95W
_ Open Circuit Voltage-22V
_ Voltage at Maximum Power Point-17V
_ Short Circuit Current-7.84A
_ Current at Maximum Power Point-7.35A

The values of converter parameters are obtained by using the basic design steps of SEPIC converter. The designed values are shown in TABLE 1. Simulation is done in MATLAB software and the simulated circuit is shown in figure 7.
Design steps are,

$V_{out}/V_{in}=D/(1-D)$

$L= (Vi_{min}*D_{max})/(\delta I*f_s)$

$C_{coupling}=(I_{out}*D_{max})/(\delta V*f_{sw})$

$Cout=(I_{out}*D_{max})/(V_{ripple}*0.5*f_{sw})$

BLDC Motor parameters are,
_ Power Rating- 250W
_ Voltage Rating -24V
_ Torque -7.25Nm
_ Rated Speed -300rpm

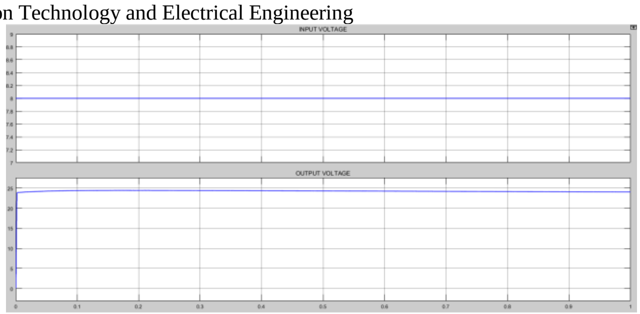

Fig. 8. Converter Output Voltage when Input Voltage is 8V.

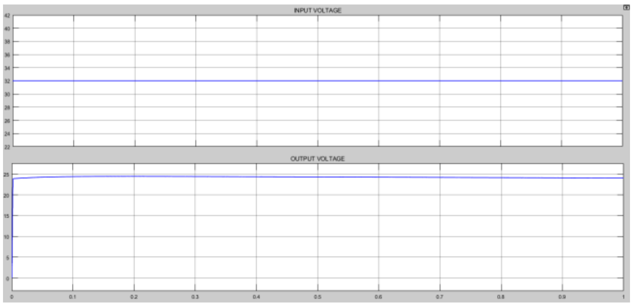

Fig. 9. Converter Output Voltage when Input Voltage is 32V.

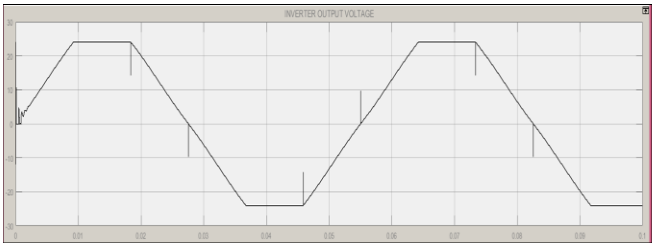

Fig.10. Inverter Output Voltage.

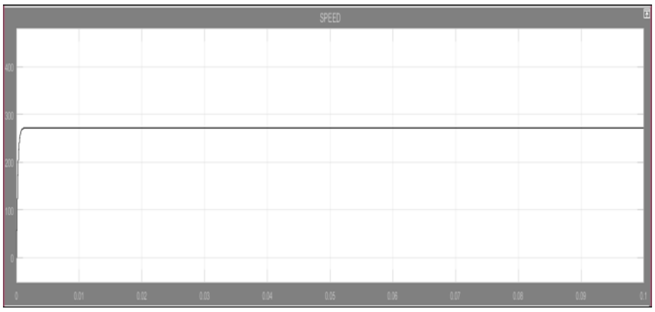

Fig. 11. Speed of BLDC Motor.

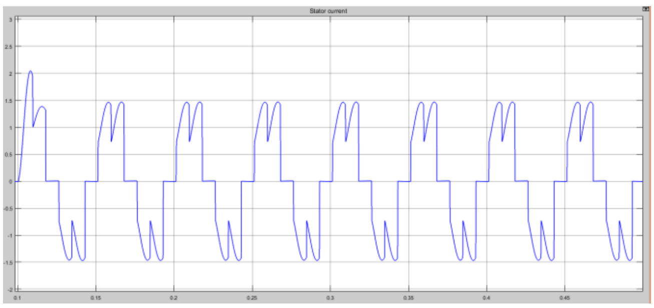

Fig. 12. Stator Current of BLDC Motor.

The converter voltage remains constant even if the PV voltage is varying time to time due the combination of the Coupled Inductor SEPIC Converter and MPPT. The voltage is around 24V, and this is fed to voltage source

Volume 9, Issue 3
June 2020

ITEE Journal
Information Technology & Electrical Engineering

ISSN: - 2306-708X

inverter to convert it into ac voltage. Then the obtained ac output is given to drive BLDC motor, which is considered as the most efficient drive for solar powered electric vehicles.

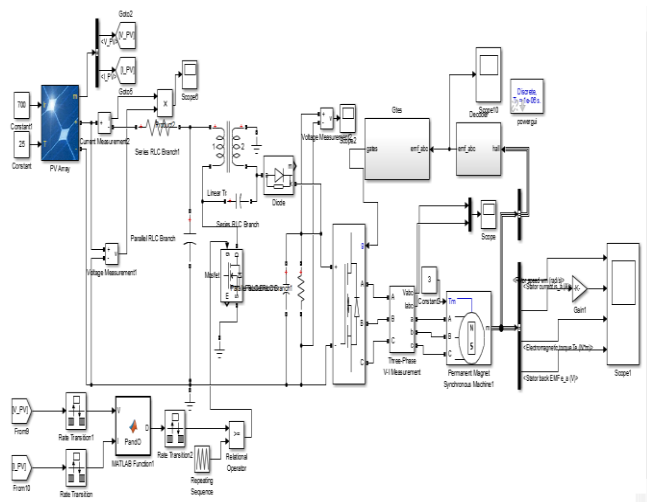

Fig. 7. Matlab Simulation Circuit.

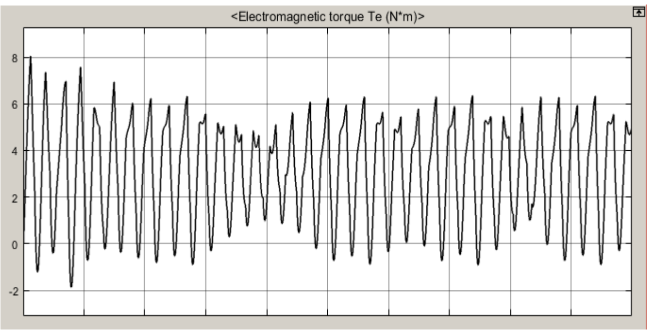

Fig. 13. Electromagnetic Torque of BLDC Motor.

7. CONCLUSION

The performance of coupled inductor SEPIC converter is verified using matlab simulation. The electric energy from solar panel is fed to the converter and used to drive the BLDC motor through an inverter. Maximum power is attained using P and O algorithm. By the coordination of both MPPT and converter the overall performance of the PV system under various weather conditions is improved. The advantages of coupled inductor SEPIC converter over other converters like less input current ripple and non-inverting polarity are the highlighting features of the designed system. MPPT is used to control the switching of the converter.Use of coupled inductor SEPIC converters in electric vehicle applications is also studied. Bldc motors are found to be the most effiecient and suitable drives for solar powered electric vehicles.

REFERENCES

[1] Neha Adhikari, "Performance Evaluation of a Low Power Solar-PV Energy System with SEPIC Converter",IEEE PEDS 2011, Singapore, 5 -8 December 2011.

[2] Mr. R. B. Darla,"Development of Maximum Power Point Tracker for PV Panels Using SEPIC Converter",Proceedings of the IEEE,2007.

[3] Dr.S.Venkatanarayanan ,"MPPT for PV Using Coupled Inductor SEPIC Converter for Standalone Power System",Associate Professor, Department of Electrical and Electronics Engineering, K.L.N. College of Engineering, Madurai, Tamil Nadu, India.

[4] John Betten,"Benefits of a coupled-inductor SEPIC converter",Texas Instruments Incorporated.

[5] Ganesha Udupa,Josh Freeman,Vikas Nimbewal,Rajesh Kumar Choudhary "Design and Manufacture of Amrita Surya Vahini A Solar Auto Rickshaw" 2016 International Conference on Robotics and Automation for Humanitarian Applications (RAHA).

AUTHOR PROFILES

1. Sabna Abbas received UG degree in Electrical and Electronics Engineering from Mahatma Gandhi University in 2018 and is currently pursuing PG degree in the stream of Power Electronics and Control from Kerala Technological University.

2. Princy Philip received the UG degree in Electrical and Electronics Engineering from Mahatma Gandhi University and PG degree in the stream of Instrumentation and Control System from NIT Calicut in 2011 and 2015 respectively. **.** Her area of interest is Control System Engineering. Currently, she is an Assistant Professor at Government Engineering College Idukki, Kerala.