Solar Powered Hybrid Electric Vehicle System using a Bidirectional DC-DC Converter

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Abstract-In this paper, a solar-based hybrid electric vehicle is designed on MATLAB Simulink. In this, the main energy source which is solar and an auxillary energy source which is the battery is used to build a newly designed two- phased interleaved bidirectional DC-DC converter.The newly designed converter operates in two source powering mode. In General idea, an electric vehicle utilizes a battery that is charged from an outer power supply, however, solar PV modules are utilized to charge a battery by methods for engrossing radiation from the sun and changing over it into electrical power (Photovoltaic Effect) by the proposed technique. The electrical power to batteries got from solar PV modules which may be related either in an arrangement or equal and charge controllers. To cross a definitive power point in the solar board, also the Maximum Power Point Tracker (MPPT) controller is utilized. Fuzzy logic MPPT Technique is used for Solar PV array. In the control system for a bidirectional DC-DC converter, an ANFIS system is used to reduce the errors and provide a DC output to the DC machine which represents the Electric Vehicle. The benefit of the ANFIS and Fuzzy combined system provides the best accuracies and efficiency in the system as compared with traditional PI-based which is a more calculative control system. The output voltage of the bidirectional DC-DC converter is about 430V to drive the electric vehicle. The benefit of this design is low calculation complexity by using ANFIS and Fuzzy -based MPPT algorithm for the Photovoltaic module.

Keywords-Solar Electric Vehicle, Bidirectional DC-DC Converter, Fuzzy Logic MPPT, ANFIS

INTRODUCTION

At present, the utilization and extraction of non-renewable energy sources like fossil fuels are very high. This increased usage of fossil fuels has lead to environmental pollution and global warming. With the increasing civilization and mechanization, a huge amount of fossil fuels are used that has lead to drastic problems. These fossil fuels used in Internal combustion vehicle releases gases like CO_2, CO, etc which leads to global warming and can even cause serious diseases in humans. So this emerging problem on the climate leads to the use of an alternative source of energy which gives the concept of the electric vehicle. Different renewable sources of energy can be used for powering the electric vehicle. Among them, solar energy is widely used as it is green and readily available.

Different power converter topology, energy management, power management and other characteristics are reviewed in the literature. In the past, Ching-Ming *et al.* designed a recently structured bidirectional dc/dc converter that interfaces a principle energy storage, a helper energy storage and a dc bus of various voltage levels for application in hybrid electric vehicle framework[1].Ravi *et al*. studied different topologies of bidirectional converters. The Bidirectional converter is the chief device that alliances energy storage devices between source and load. This paper also discussed the Isolated Bidirectional DC-DC Converter that uses galvanic isolation provided by a high-frequency transformer and Non –Isolated DC-DC converters and their types.It was found that Isolated BDC is very expensive so Non-Isolated BDC was a better option for electric vehicles [2].Lai et al. executed a bidirectional dc-dc converter which has well-defined voltage ratio, less current ripple and improved duty ratio for DC micro-grids and electric vehicle [3] Subudhi *et al*. reviewed different MPPT techniques and its classification based on various characteristics such as control systems, type of variables, etc. Hybrid MPPT techniques are also explained which is useful to use in various Photovoltaic Systems [4].Schultz *et al.* presented the architecture, power management system of Fuel Cell Hybrid Electric Vehicle System and analysis design of energy storage device i.e., the battery and ultracapacitor of FCHEV. It proposed double energy management strategies of the storage device.It was found that the overrating of either of the storage device i.e battery or ultracapacitor affect various parameters of the system which include the volume of the system, battery lifetime, the mass of the system. It was concluded that not only the power and energy management should be taken into account but it is also necessary to consider the lifetime of battery [5]. Onar et.al proposed an energy storage system comprised of battery and supercapacitors with the help of an integrated magnetic bidirectional dc-dc converter. With the help of supercapacitors, the stress on battery is significantly reduced which increases the lifetime of battery [6]. Shukla et.al designed a solar electric-powered vehicle. It was found that the battery can run the solar-powered electric vehicle for about 12 km and its speed was found to be 20km/hr [7].Solar-powered Electric vehicle was constructed using various components like PV array, charge controller, battery, motor controller, motor. Calculations were made for all the components and its hardware implementation was carried out and various results obtained were studied [8, 9, 10,11]. Noman et.al designed a DC-DC bidirectional converter with the Maximum power point tracker based on fuzzy logic and compared the Fuzzy Logic MPPT technique with the traditional perturb and observation technique. It was found that the Fuzzy logic MPPT technique is highly efficient than the Perturb and Observe Technique [12].Xia designed a hybrid energy storage system build on the drawbacks of the Lithium-ion battery which has many advantages like the reduction of output current ripple and an increase in battery lifetime [13].

Gite *et.al* proposed the ANFIS controller for a particular application like temperature control of a water bath system. This type of controller combines the concept of fuzzy logic and artificial neural network and is greatly efficient because of its advantage of dealing with non-linear problems [14].Jang *et.al* designed a novel interleaved boost converter that has voltage doubler characteristics which makes it suitable for power factor correction applications [15].

Mouli et. al System plan for a solar-powered electric vehicle charging station for work environments. This paper explores the chance of charging battery electric vehicles at the work environment in the Netherlands utilizing solar energy. The regular and diurnal variety in solar insolation is investigated to decide the energy accessibility for EV charging and the need for framework association[16]. C. Chellaswamy et.al explains the solar and wind energy based charging system (SWCM) to produce the power for charging the battery packs of electric vehicles (EVs). The inexhaustible charging station comprises of both the solar photovoltaic (PV) modules and a breeze generator. The SWCM tremendously lessens the prerequisite of petroleum products to create electricity which brings about extraordinarily diminished CO_2 and CO related outflows. [17].Nirmala et.al explains the solar PV powered Electric Vehicle and it also explains the key drawback of fuel and contamination. This paper discusses electric vehicle that utilizes a battery that is charged from an outside power supply, yet solar PV modules are utilized to charge a battery by methods for retaining radiation from the sun and changing over it into electrical power (Photovoltaic Effect) [18]. Elavogain et.al proposed a propelled DC-DC converter by name Super-Lift Converter (SLC) based Electric Vehicle (EV). Not at all like the customary DC-DC converter, the displayed SLC delivers geometrically advanced DC connect voltage with the swell substance under 1%.

This study proposed a solar-powered hybrid electric vehicle system that comprises the Solar-PV array, battery, a two-phase interleaved Bidirectional dc-dc converter and a DC Motor. The bidirectional dc/dc converter can work in acceleration mode, regenerative braking mode and buck/boost mode .But in our study, our main focus is on the acceleration mode. Also, the BDC converter used has advantages like power can flow between the solar-PV array and battery independently. This study presents the simulation in MATLAB also.

The remainder of the paper is structured as follows. Section II presents the modeling and description of the components used in our work. Section III gives the scheme of converter control. Section IV presents the Simulation and results of this proposed work. Finally, Section V gives the conclusion.

II.MODELING AND DESCRIPTION

A simplified block diagram of the proposed system is given in Fig.1

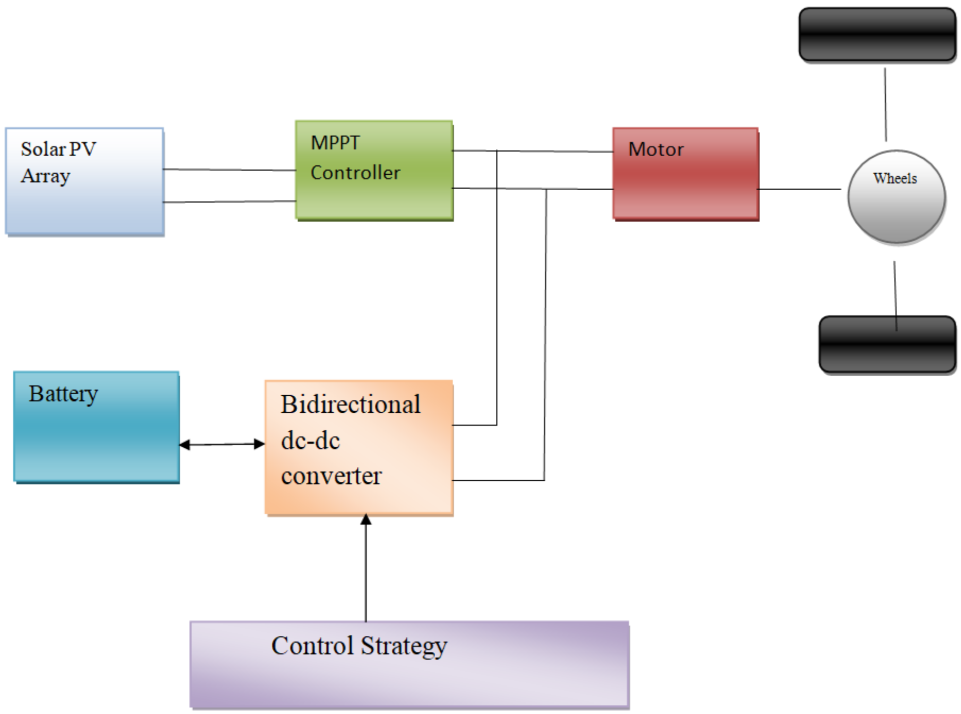

Fig.1 Block diagram of Proposed System

A.Solar PV Array

The Solar PV array is one of the primary components used in Solar-powered Electric Vehicle and it is based on the photoelectric effect. The equivalent diagram of a solar cell is shown in figure 1 which has a current source, a diode, a series resistance and a shunt resistance.

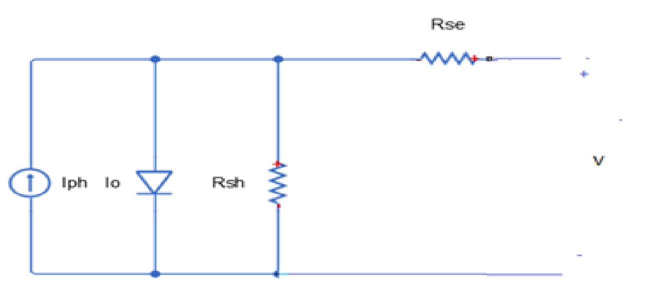

Fig.2. Equivalent diagram of Solar PV cell.

The output current is given by the following equation

$$I = Iph - Io\left[e^{\frac{q(V+IRs)}{KT}} - 1\right] - \frac{(V+IRs)}{Rsh} \qquad (1)$$

Where, I is the solar cell current

Iph is the photo-current

Io is the diode saturation current

q is the charge of an electron

V is the output voltage

T is the temperature of solar cell

Rse is the series resistance

Rsh is the shunt resistance

Photovoltaic cells are connected either in series or parallels. If it is connected in series, the voltage will increase but current will remain the same and if it is connected in parallel, the current will increase but the voltage will remain the same. For extracting maximum power from solar PV array under varying solar irradiance and temperature, various MPPT techniques are used. In this paper Fuzzy logic based MPPT technique is used.

Electrical Characteristics	Values
Open-circuit voltage (Voc)	36 V
Short-circuit current(Isc)	7.84A
Optimum operating voltage(Vmpp)	29 V
Optimum operating current (Impp)	7.35 A
Maximum Power at STC(Pmax)	214 W
Current temperature coefficient of Isc	-0.36099
Voltage temperature coefficient of Voc	0.102

Table 1.Electrical Characteristic data of PV Module

B.Fuzzy logic Controller

Fuzzy logic Controllers are extensively used in renewable energy technology because of its various prons like it can handle non-linearity, do not require a arithmetical model and can deal with indefinite inputs. It mainly comprises of three parts- fuzzification, inference engine, and defuzzification,

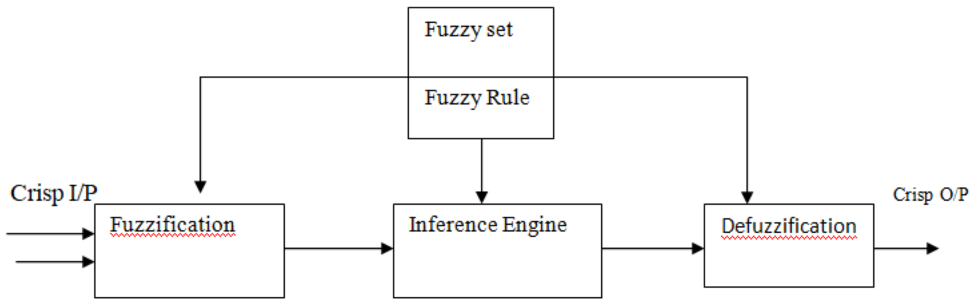

Fig.3 Block Diagram of Fuzzy Logic-based MPPT Technique

- Fuzzification: The crisp values are converted into fuzzy values. Initially, voltage and current are measured from the PV array and power is calculated. The control has to satisfy two chief criteria that are related to error and change in error given by the following equations:

$$e(k)=\frac{P(k)-P(k-1)}{I(k)-I(k-1)} \quad (2)$$

$$ce(k)=e(k)-e(k-1) \quad (3)$$

The error represents the slope of P-I curve and it describes where the MPP is located. The change in error defines the motion of operating point i.e,.the operating point is in the path of maximum power point or not. Based on the Membership Function, the error and change in error is converted into linguistic variables like Positive Tall(PT), Positive Short (PS), Zero (Z), Negative Tall (NT), Negative Short(NS).

- **Inference Engine**: Rules are applied to the fuzzy inputs to have fuzzy output. It stimulates the human decision- making process to infer the fuzzy control action from the knowledge of control rules.25 sets of rules are applied. The main idea of the rules is to bring the operating point to the maximum power point by increasing or decreasing the duty ratio. Trial and hit method is generally used to adjust the membership functions and the rules associated with it.

- **Defuzzification**: It generates an output which is usually the duty ratio that is fed to the converter. It mainly uses two methods: Centre of Gravity and Max Criterion Method. The most commonly used method is the center of gravity.

C.Battery

Batteries are the principal source of power to run the motor. In the charging mode of battery, electric energy is transformed into chemical energy but in the case of discharging of the battery, chemical energy is transformed into electrical energy. Batteries are of different types like lead-acid, lithium-ion, nickel- cadmium, nickel- metal hydride, etc. In this paper, 48 Volts lithium-ion battery is selected because of its various advantages like it has less weight, requires less maintenance, high energy density ratio and most importantly, it takes a long time to discharge it.

D.Motor:

The motor is the most important component of an electric vehicle because it is running the vehicle. The motor transforms electrical energy into mechanical energy to bring the wheels of the vehicle in motion. Many parameters must be considered in order to select the motor like speed, cost, starting torque, weight, characteristics. Various types of dc motors are used like brushless dc motor, permanent magnet dc motor, induction motors. In our work, we are using the Permanent Magnet DC motor.

III.TWO- PHASE INTERLEABED BIDIRECTIONAL DC-DC CONVERTER

In the renewable energy systems, bidirectional dc-dc converter interfaces the energy storage devices like the battery, supercapacitors, etc between the input side and the output side so that power flow is smooth and continuous. BDCs are classified into Isolated Bidirectional DC-DC Converter and Non-Isolated Bidirectional DC-DC converter. In our paper, we have used Two-Phase Interleaved Non –Isolated Bidirectional DC-DC converter. This converter has two power modules that are connected in parallel, which is 180 degrees out of phase. With the interleaving method in DC-DC Converters, the ripple of input current and the output voltage decreases without increasing the switching losses which leads to high system efficiency.

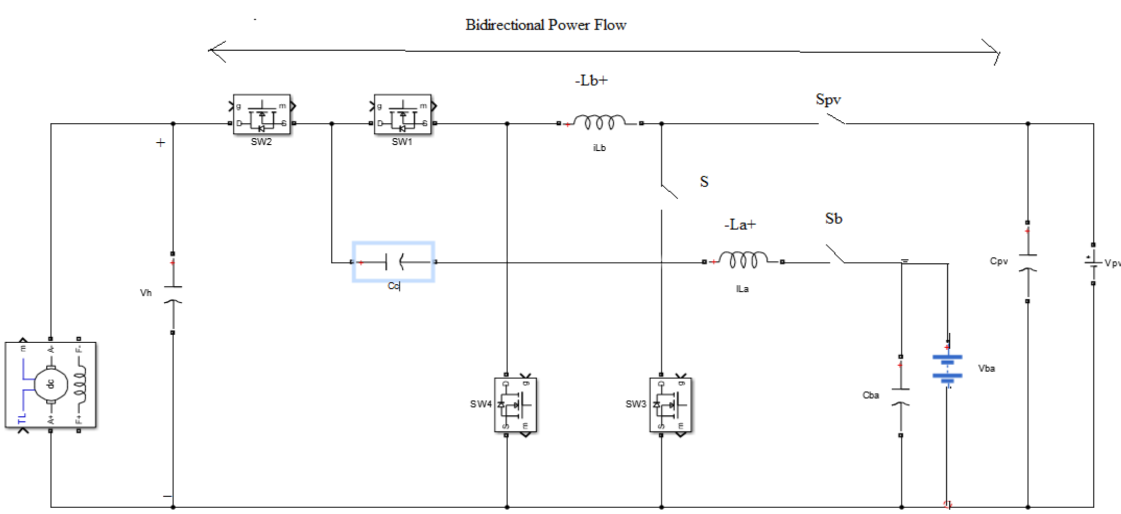

Fig.4 Two- phase interleaved Bidirectional Converter

A.Circuit Configuration and Working:

The converter shown in the figure has two switches represented by Spv, Sb and can switch on and off the current loops of solar array and the battery. The converter has a Charge pump capacitor, Cc which is unified with four switches Sw1,Sw2,Sw3,Sw4 and two inductors La, Lb which ameliorate the stable voltage gain. Moreover, the charge pump capacitor reduces the voltage stress and improves the duty ratio. Although the converter operates in acceleration mode, regenerative mode, buck/boost mode but the main focus of our study is on the acceleration mode.

1.**Acceleration Mode:**

It is a discharging mode. In this mode, switch Sw3,Sw4 are the active switches and have a phase shift of 180 degrees and Sw1,Sw2 are passive switch and act as a synchronous rectifier. When the duty ratio is more than 0.5, the following circuit conditions are possible:

i.Condition 1[t:t_0-t_1]- In this,Sw_1,Sw_3 are turned ON and Sw_2,Sw_4 are turned OFF. The voltage across inductor La is the difference of the solar PV voltage and the charge pump voltage so i_{La} will decrease linearly in this mode. The battery voltage will charge the second inductor, Lb and the current in the inductor L_b will increase linearly. The voltage across inductors L_a and L_b is given by using KVL.

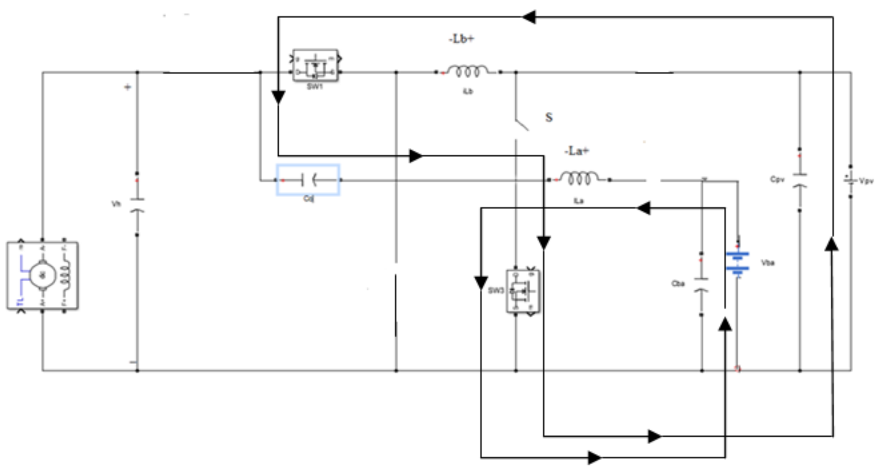

Fig.5 Circuit state in Condition 1

The voltage across inductor L_a,

$V_{La}+V_{Cc}+V_{pv}=0$

$V_{La}=V_{pv}-V_{cc}$

$$La\frac{diLa}{dt}=V_{pv}-V_{cc} \quad (4)$$

The voltage across inductor L_b

$$L_b\frac{diLb}{dt}=V_b \quad (5)$$

ii. **Condition 2**[t:t_1-t_2]-In this state, switches Sw_3,Sw_4 are turned ON and Sw_1,Sw_2 are turned OFF. The solar PV array voltage and battery voltage will charge the inductor and the current in the inductor ,L_a and L_b increases linearly. Using KVL, we get,

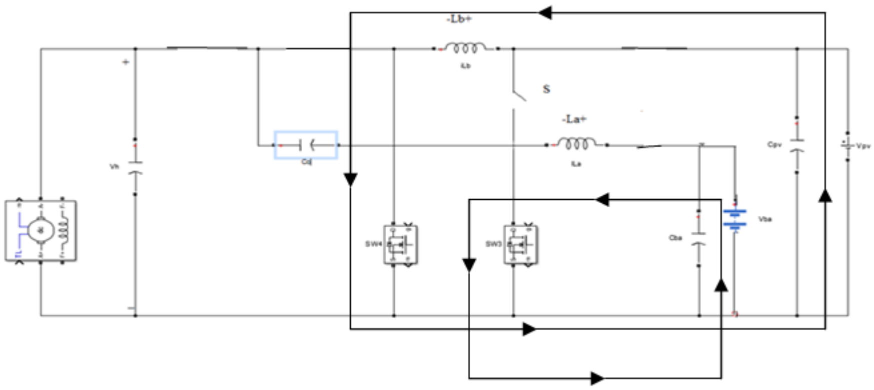

Fig.6 .Circuit State in Condition 2

The voltage across inductor L_a,

$$L_a=\frac{diLa}{dt}V_{pv} \tag{6}$$

The voltage across inductor L_b,

$$L_b\frac{diLb}{dt}=V_b \tag{7}$$

iii. Condition 3[t:t_2-t_3]: In this state,Sw_1,Sw_3 are turned ON and Sw_2,Sw_4 are turned OFF.

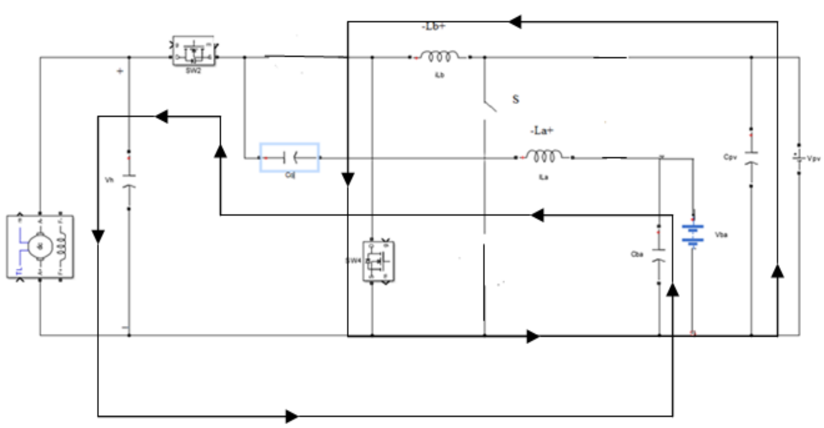

Fig.7. Circuit state in Condition 3

The voltage across inductor L_a,

$$L_a\frac{diLa}{dt}=V_{pv} \tag{8}$$

The voltage across inductor L_b,

$$L_b\frac{diLb}{dt}=V_{cc}+V_b-V_H \quad (9)$$

iv. Condition 4[t:t3-t4]:In this mode, switches Sw_3,Sw_4 are turned ON and Sw1,Sw2 are turned OFF. This mode is similar to condition 2.

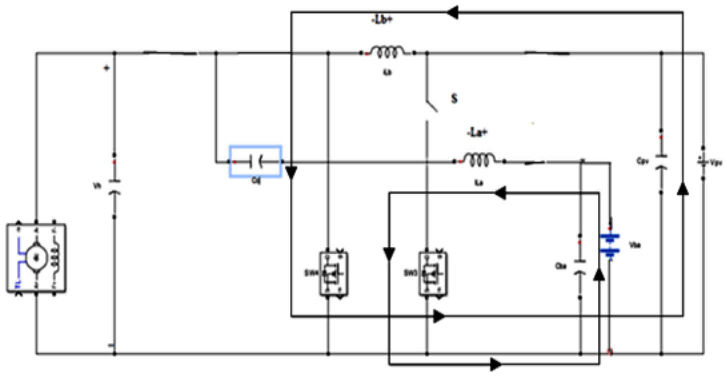

Fig.8.Circuit state in Condition 4

The voltage across inductor, La

$$La\frac{diLa}{dt}=V_{pv} \quad (10)$$

The voltage across inductor Lb,

$$Lb\frac{diLb}{dt}=V_b \quad (11)$$

B. Control for Bidirectional Controller

For the control part, rather controlling the output voltage, the inductor current is used to control power flow. The inductor currents are first identified and then compared with the reference value. A switch is used which selects the BDC mode as per the conditions of the vehicle like the demand of power in the acceleration state and the voltages of solar PV array and battery. Finally the pulse width modulation converts the duty ratio into signals that drive the power switches.Fig.10 gives the block diagram of the closed loop control scheme of the bidirectional dc-dc converter.

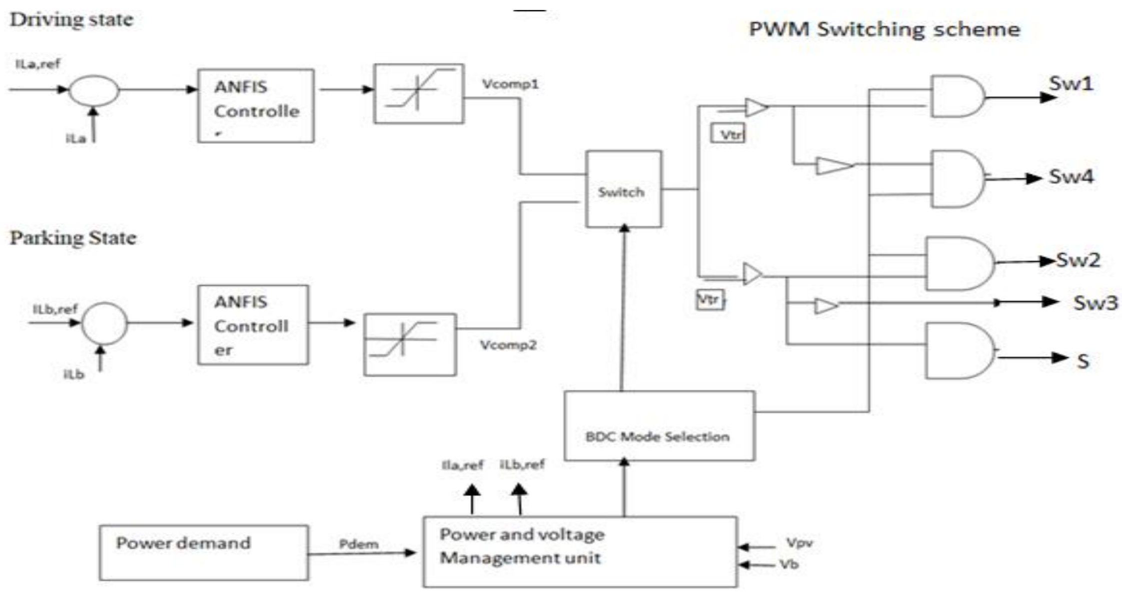

Fig.9. Block diagram of the bidirectional dc-dc controller scheme

Mode	X1	X2	Arithmetic relation
Accelerating mode	1	1	$Pd>0, IL_{a,ref}>0$
Regenerative mode	1	1	$Pd>0, IL_{b,ref}<0$
Buck/Boost mode	0	0	For boost-Vpv>71 V,$iL_{b,ref}>0$ For buck- Vpv<48 V,$iL_{b,ref}<0$

Table 2.Operating Modes of Bidirectional DC-DC Converter

The current reference $iL_{a,ref}$ controls the bidirectional power flow between solar PV array voltage, battery voltage and the high voltage side and the current reference, $iL_{b,ref}$ controls the power flow between the solar PV array and the battery. The mode for the BDC switch is given in table 2.When the vehicle is in the driving state, iLa is the control loop of the controller, it will depict whether the vehicle is in the acceleration state or it is in the regenerative braking state. When the vehicle is in a parking state, iLb is the control loop of the controller.It will depict whether the vehicle is in boost mode or buck mode. All this operation is given in the flowchart as depicted in figure 10.

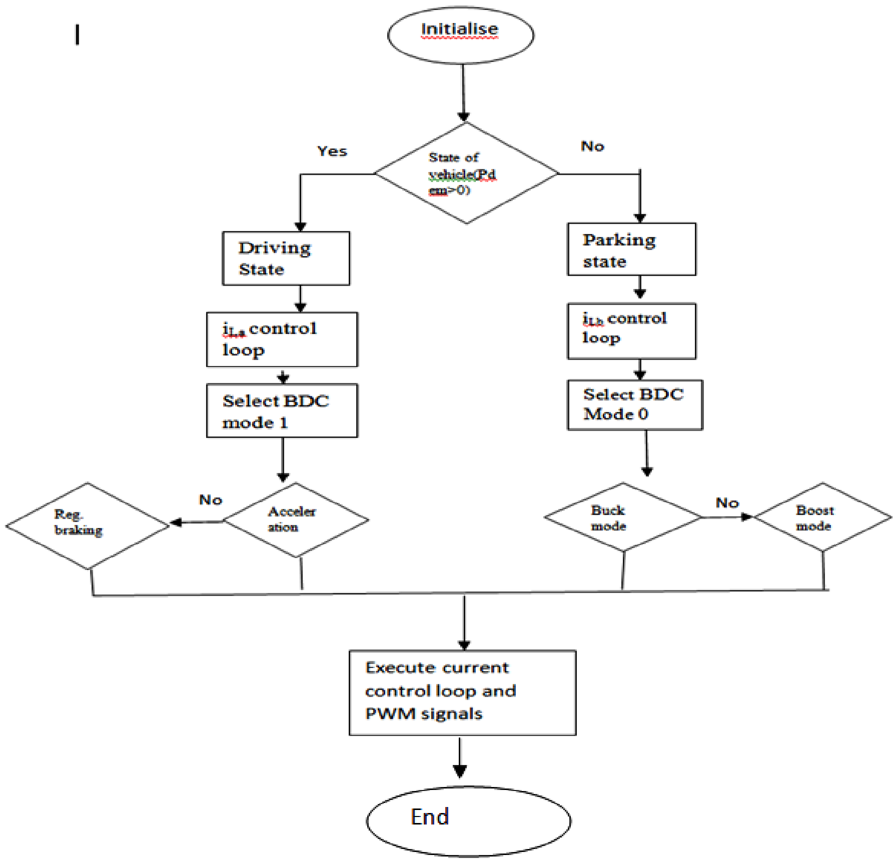

Fig.10. Flowchart of modes of Bidirectional DC-DC Converter

Many researchers have used conventional proportional- integral controllers. But these controllers are not efficient as these controllers cannot deal with variations and they require a linear mathematical model. So in our paper,we have used a highly intelligent hybrid controller i.e the Adaptive Neuro-Fuzzy Inference System (ANFIS) controller. ANFIS performs function by imposing a neural network learning method to enhance the specifications of the fuzzy inference system.

IV.SIMULATION AND RESULTS

The simulation model of our proposed work is shown in the figure. The model is built on MATLAB/Simulink which gives the performance of the system. The Specifications and parameters of the simulation system are given in the table.

Voltage of PV array, Vpv	71 V
Voltage of battery, Vb	48V
Inductor ,La	220µH
Inductor, Lb	220 µH
Capacitor, Cpv	380µF
Capacitor, Cb	380µF
Switching frequency	40 kHz
Charge pump Capacitor	15µF

Table.III Specifications of the system

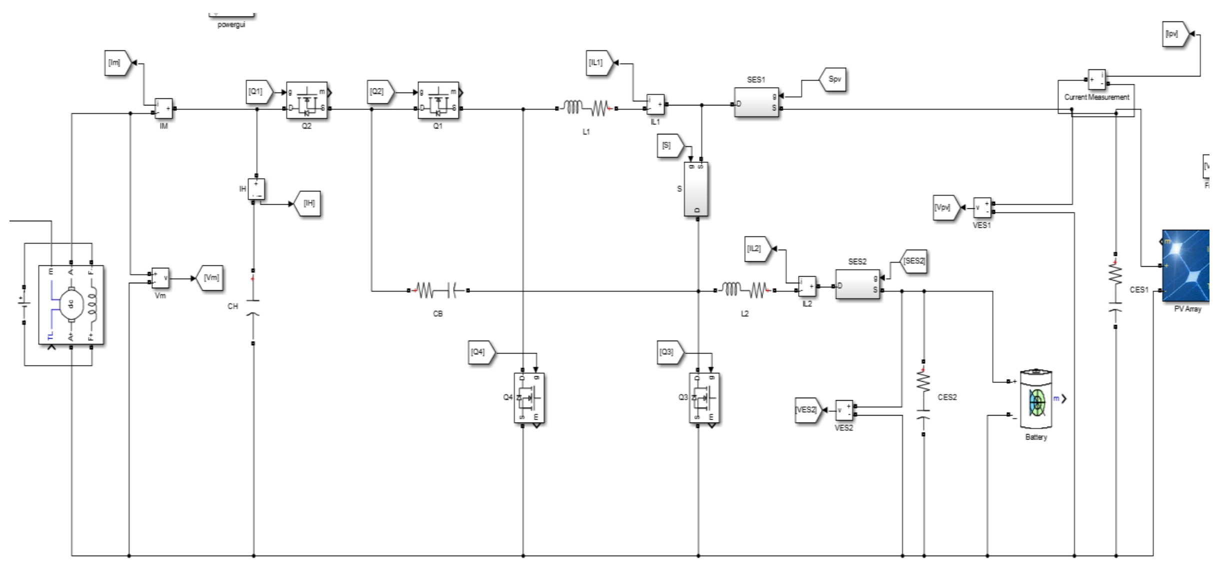

Fig 11.Simulation Model of the system

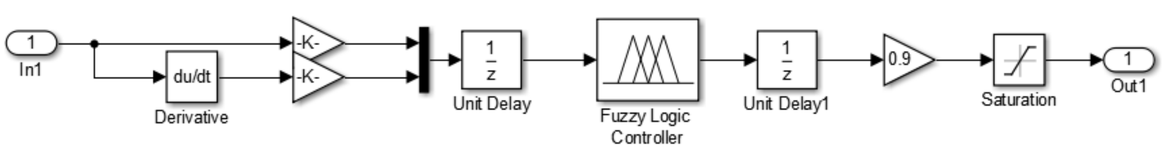

Fig12. Fuzzy logic model

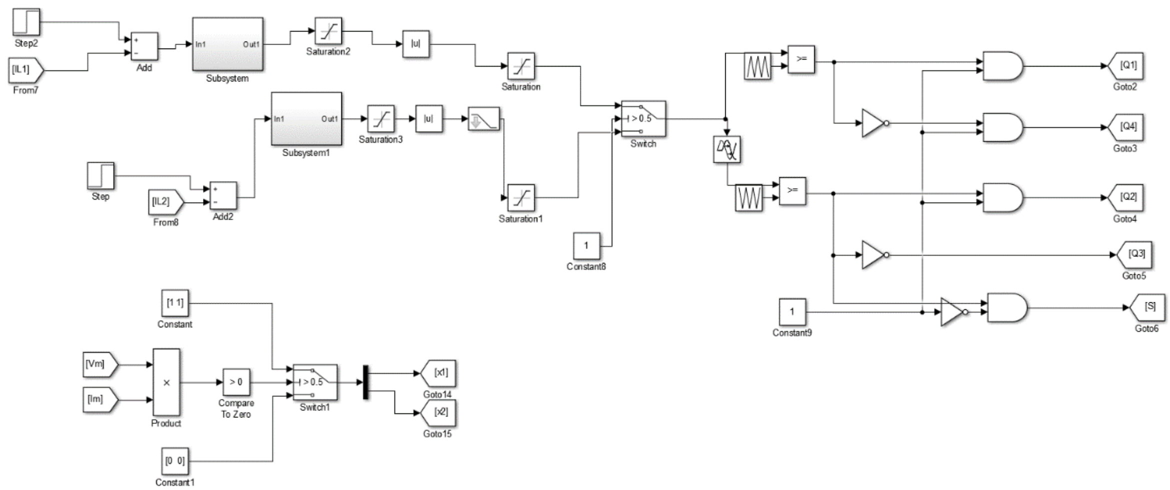

Fig.13. ANFIS Controller Scheme

To obtain maximum power from PV array, the fuzzy logic MPPT technique is used in our work. The conventional MPPT techniques like perturbation and observation technique suffered from a few drawbacks like steady-state oscillation that arise around maximum power point which reduces the efficiency of the system. Fuzzy logic MPPT techniques is a highly efficient technique under varying solar irradiance and temperature and can easily handle non –linear functions. Also the traditional controllers like PI, PIDs are not widely used but they have also some drawbacks like in the PID controller, the gain is fixed which is insufficient for plant variations and these controllers require a linear mathematical model which is somehow difficult to obtain. So, we have used a highly intelligent hybrid controller which is the ANFIS controller. The ANN part in ANFIS reduces the error thus optimizing the parameters and the FI part deals with uncertainty effectively.

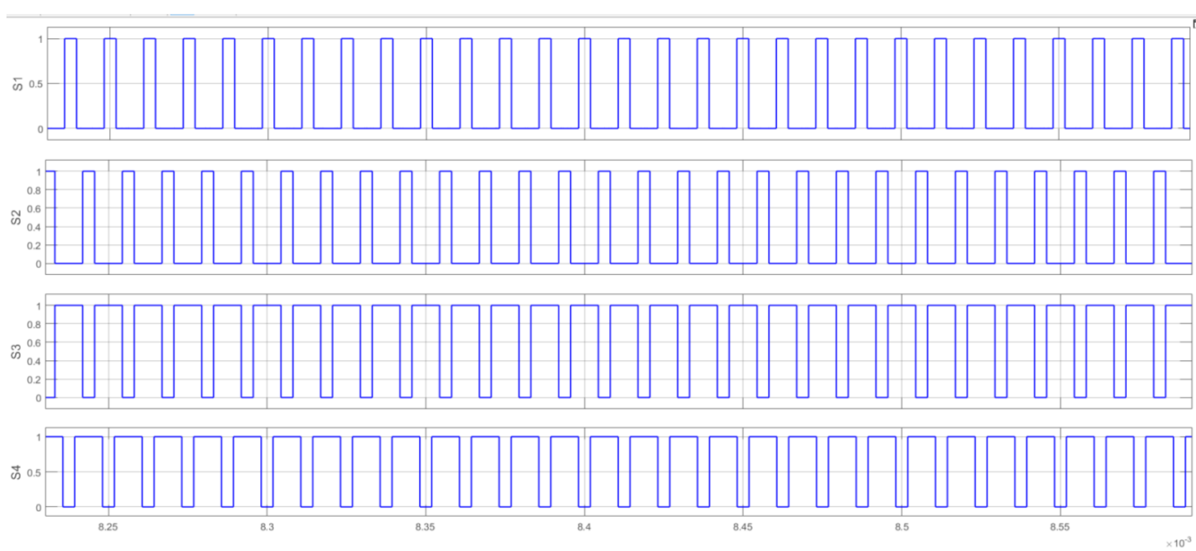

Fig.14 Duty cycle of switches

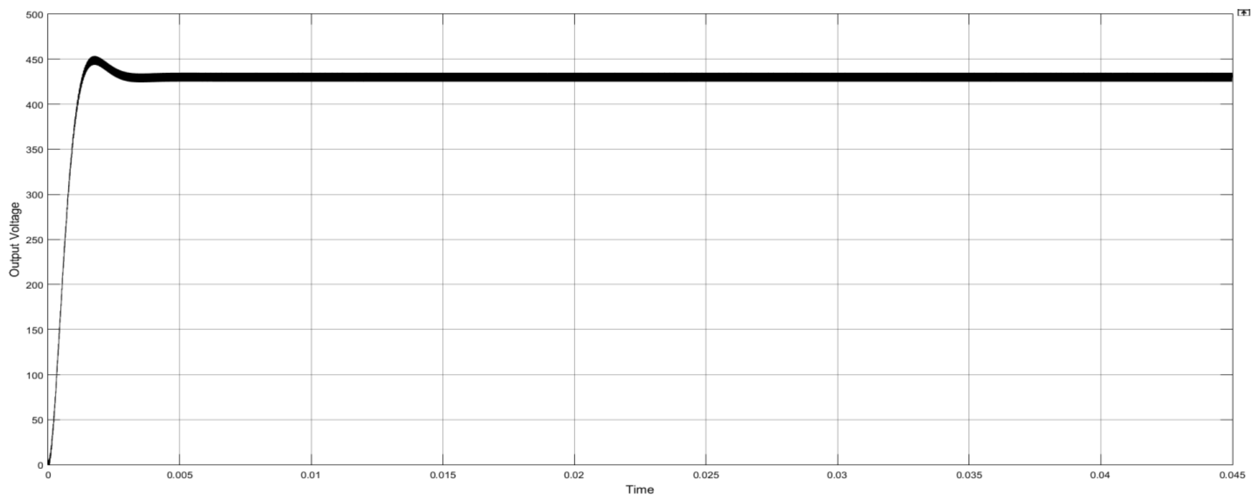

Fig.15 Output Voltage

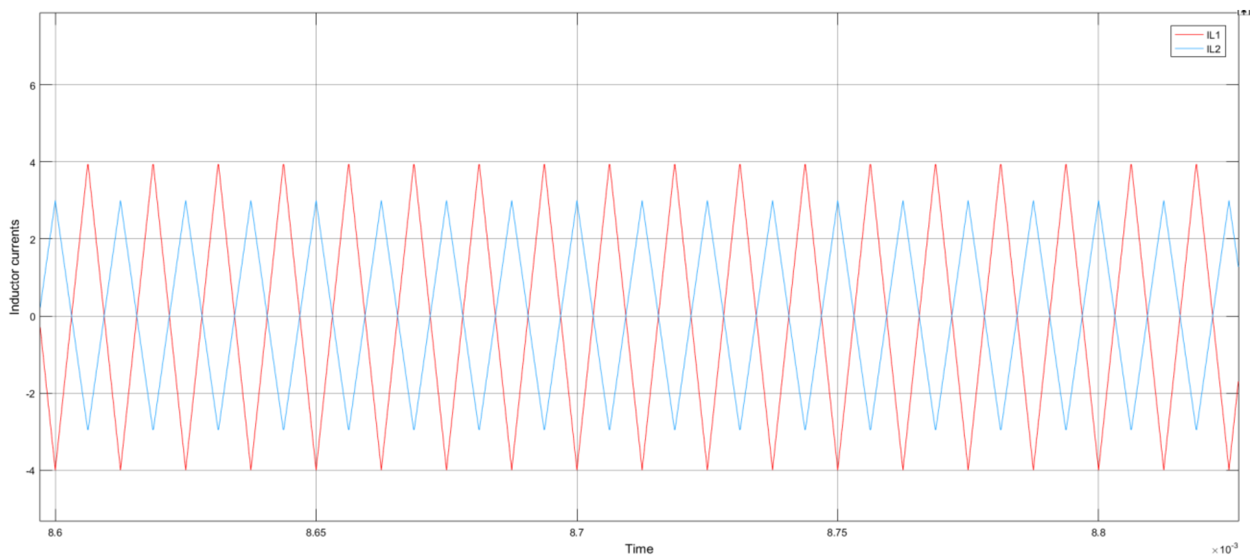

Fig.16 Inductor Currents

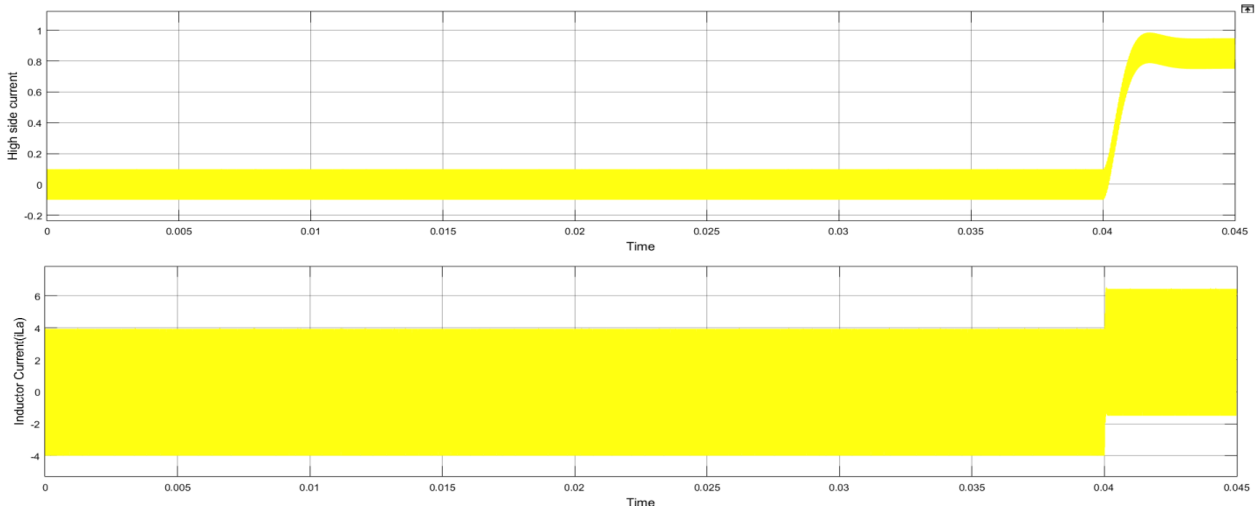

Fig.17 Waveform of controlled current step change in acceleration mode

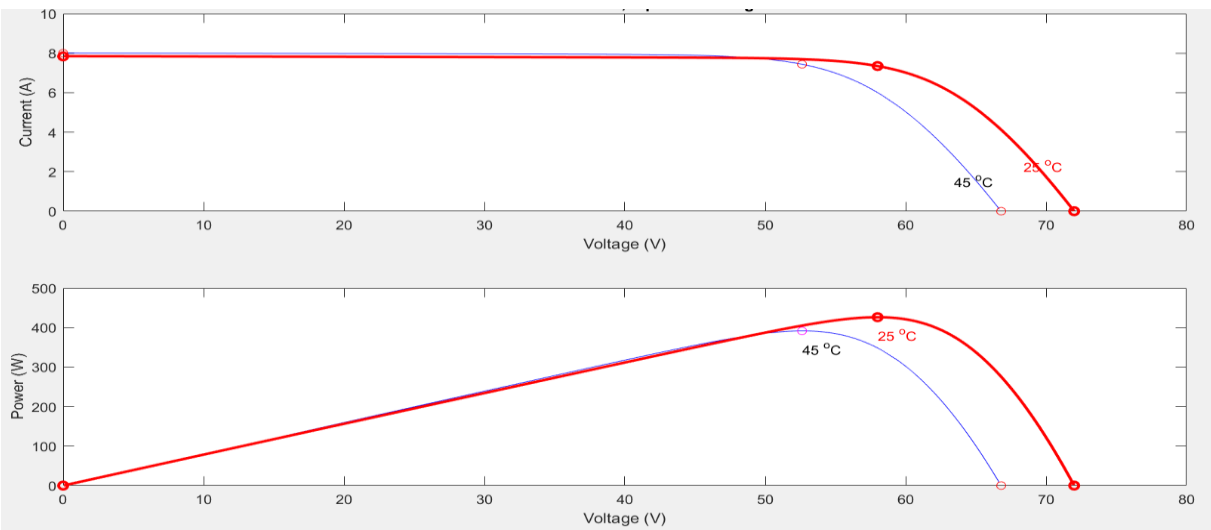

Fig.18 MPPT output

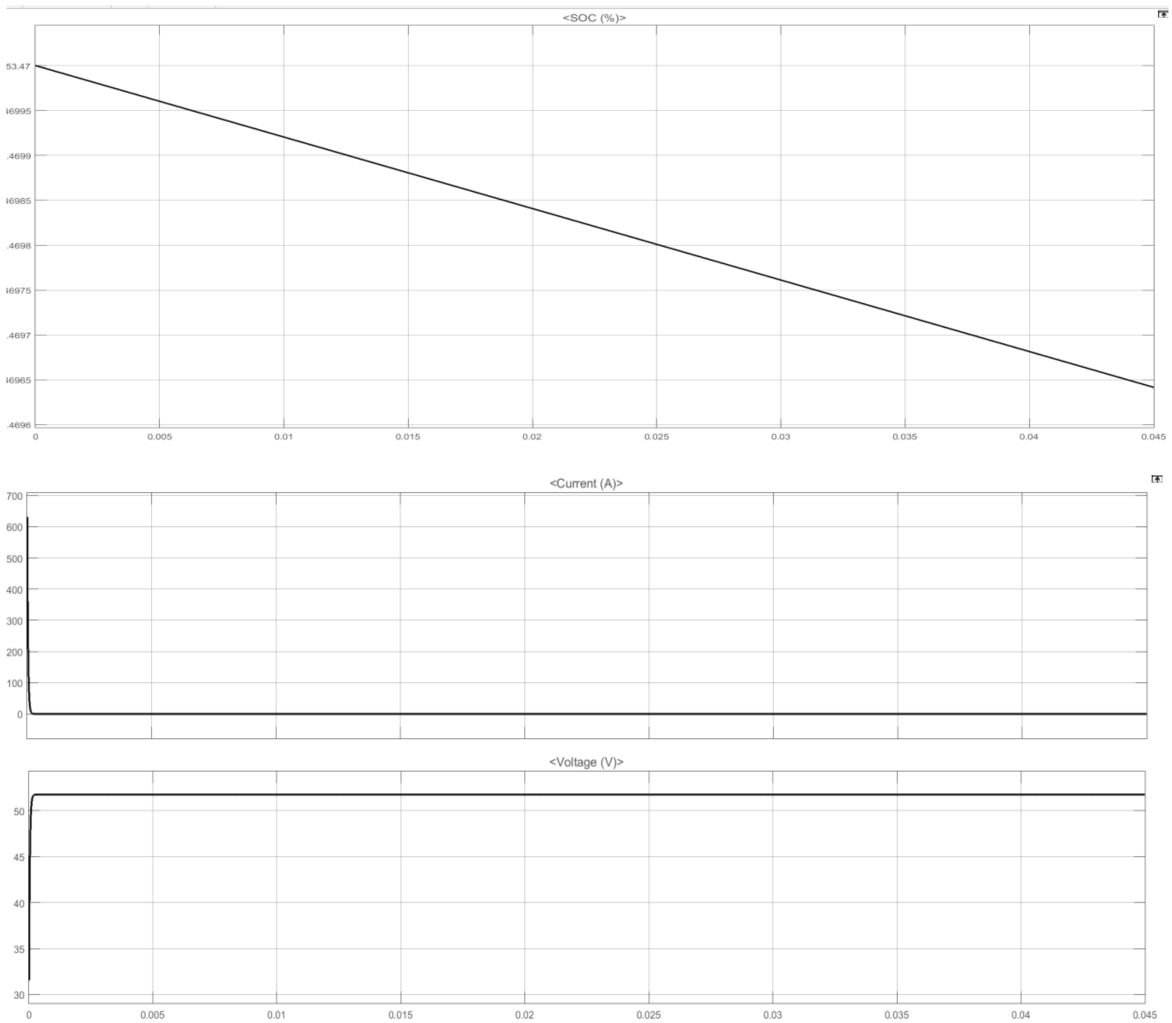

Fig.19 SOC,I,V of battery

Figure 14 shows the duty cycle for the switches Sw1 to Sw4 is shown according to the control system generated. Figure 15 shows the output voltage of Solar-powered electric vehicle which is 430 volts.Figure 16 shows the waveforms of the inductor currents.. Figure 17 shows controlled current step change in the acceleration mode. It shows the waveform of high side current which is changed from 0-0.8A and the inductor current from 0-2.5A in case of accelerating mode. Figure 18 gives the MPPT output for Solar PV module. Figure 19 shows the battery characteristics like the state of charge, current and voltage in the acceleration mode.

In our work, MOSFET semiconductor switches were used because of its various advantages like it has fast turn off characteristics, it has very low ON-state resistance, it doesn't need a special driver circuitry just voltage pulse at the gate is sufficient, etc.PWM signals switch the MOSFETs. In future studies, these MOSFETs can be removed and they can be replaced by breakers. Also the output voltage and input current ripples can be analyzed and it could be found the converter used in the system has few ripples which increase the efficiency of the whole system.

V.CONCLUSION

The proposed solar-powered electric vehicle has a few merits, for example, fuel proficient, decrease in the contamination and gives quiet activity. The paper ponders about the activity of the DC Machine in shut circle control as per the change in solar irradiance condition. The benefits of DC Machine are a higher estimation of productivity, power thickness and speed ranges, which chooses this engine, for different applications. The reproduction result represents that, for the different voltage levels of the PV cluster, controlling of obligation pattern of the DC-DC converter, at that point the set speed gets kept up. The attributes of proposed solar PV based DC Machine driven electric vehicle and effectiveness make it productively helpful in the technique of DC Machine drives in various fields. The proposed system affirms the consistency of DC Machine through non-regular sources by evacuating petroleum products and further natural responsiveness for the life of the vehicle. The proposed system gives the performance of the solar- powered electric vehicle in acceleration mode. The two-phase interleaved converter used in the simulation can be used for any type of electric vehicle to produce highly efficient architecture.The use of ANFIS and Fuzzy based control logic enhances the output and efficiency of the solar-based hybrid electric vehicle system with a bidirectional DC-DC converter as shown in the simulation result section. The output of the converter used in our work is 430V which drives the dc motor representing the electric vehicle.

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