Electric Vehicle Battery Charger using PV Array with FOPID Controller

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Abstract

Electric vehicles (EVs) are emerging as a viable option to gasoline-powered automobiles. The functioning of these vehicles necessitates the "recharging" of their batteries. Although EV charging has usually been done via the grid, solar-powered chargers have emerged as a promising alternative. In addition to this, the biggest concern for experts was to charge EV when solar irradiance is decreased to zero. For this the proposed model used a battery bank as an alternative source of energy and is responsible for providing enough power to EV battery in absence of sunlight. This is done efficiently by using the solar PV panels, sepic dc-dc boost converter, MPPT charging controller, alternate battery bank.This paper proposes an electric vehicle battery charger using PV array with FOPID (fractional order PID) controller. The proposed model works in three modes, firstly when EV battery and battery bank is getting charged by the PV panels, secondly when EV battery is getting charged by the battery bank and third, when battery bank supply is cut off and EV battery is getting charged by solar panel only. Experiments were conducted on MATLAB platform and the simulated outcomes proved that the proposed model is effective in charging the batteries of EVs. A comparative performance analysis of the battery bank SOC and that of EV battery reflects that the proposed FOPID controlleris definitely more efficient and effective for charging the EV.

Keywords

EV battery, battery charger, FOPID controller

1. Introduction

Over the last few years, the use of renewable power generation techniques has expanded drastically, thus it is critical to develop a mechanism in order to ease the implementation of Renewable Energy Resources (RER) so that the overall efficiency, safety and dependability of the grid is enhanced. As there is a drastic increase in electricity demand all over the world which makes it crucial to use new sources of power generation which include solar, wind fuel cells etc. [1]. These RERs have been found very effective in order to meet the rising demand of energy while also addressing some major environmental issues. Out of the all the Renewable power generation sources, Solar PV is the most common and effective one because it is cost effective, highly efficient with low maintenance charges [2].

In a typical solar power generation system, solar PV panels are installed serially or parallelly to maximize power generation. The power generated by the solar panel directly depends on the intensity of sunlight which means if intensity of sunlight is more, more power is generated and vice versa [3]. Solar panels generate DC electrical power. To make this solar energy usable, it must first be converted

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fromDirect Current to Alternating Current with the help of an inverter. The AC electrical energy thus generated can be used to operate local electronics or sent to the electrical grid to be used elsewhere. The major drawback of using solar power generation systems is its dependency of atmospheric factors such as solar irradiance and temperature. This leads to inefficiency as the solar panels are unable to extract maximum power [4]. Owing to their dynamic design, solar power faces difficulties in interacting with automotive systems too. As a result, it is important to have a battery in EVs in order to address the issue.Different MPPT (Maximum Power Point Tracking) techniques are used, toimprove system efficiency and to obtain maximum power from the panels, Some commonly used techniques are: Fuzzy logic, Perturb and Observe (hill climbing method), Neural Network, Fractional open circuit voltage, Incremental Conductance method, Fractional short circuit current.To extract maximum power from the solar PV panels, many techniques have been proposed by several researchers in this field [5-12].

This paper proposes an electric vehicle battery charger using PV array with FOPID(fractional order PID)controller.Experiments were performed in MATLAB platform and a comparative performance analysis with the results obtained by using PI and PID controller is done to illustrate the effectiveness of the proposed method. It uses controller having two stages using a FOPID witha MPPT algorithm to extract maximum power from the PV system. The FOPID controller is used to vary the duty cycle of boost converter.

2. FOPID controller

Fractional-order calculus is amathematical tool fordealing with derivatives and integrals from non-integer orders. In recent times lots of research have been done both by the academicians andindustrialists dealing with Fractional-order proportional-integral-derivative (FOPID) controllers. Fractional system provides a better understanding of system characteristic like system response, rejection of disturbance , better and improved capability of handling model uncertainties in nonlinear as well as real time applications.

The ‘s’ domain representation of PID controller is:

$$C(s)= (K_p +sK_d + (K_i/s))\, E(s) \qquad (1)$$

Where ‘C(s)’ represents the output of the system, ‘E(s)’is error and K_p,$K_d$and $K_i$represent theproportional, derivate and integral parameters of the control system.

And the ‘s’ domain representation of FOPID controller is:

$$C(s)= (K_p +s^{\mu}K_d + (K_i/s^{\lambda}))\, E(s) \qquad (2)$$

Thus, in case of FOPID the power of ‘s’ is fraction compared to PID controller where it is integer. The aim thus is to optimize the value of the two additional parameters ‘μ’ and ‘λ’ in addition to the three K_p ,$K_d$and K_i parameters. Thus, they have additional flexibility in the controller design, compared to the standard PID controller, because they have five degrees-of-freedom (DOF), compared to three DOFs of its integer-order counterpart. Higher DOF provides better time and frequency responses of the control system.

3. The proposed system with FOPID controller

The proposed model consists of solar PV panels, sepic dc-dc boost converter, MPPT charging with FOPID controller, alternate battery bank. The proposed model works in following three modes, Thesepic converter is used to regulate the voltage and current supply. The MPPT technique is thus used to obtain maximum power from solar panels by usingthe FOPID controller.

Mode 1: When the sunlight is at peak, the sunlight falls on the solar panel which converts it into the electrical energy that is capable of charging the battery bank as well as the battery of electric vehicle.

Mode 2: In the next mode, when the input irradiance of sun is very low in such case, the supply of solar panel is cut off and the battery bank is used as a charging source for EV. The battery bank starts getting discharged slowly.
Mode 3: In the 3rd mode of operation, the irradiance is increased so that EV is charged by the solar panel but the battery bank is not charged in this case.

3.1 Design of Converters

(i) Sepicconverter,

Figure1. shows the block diagram of the SEPIC dc-dc boost converter. The main job of FOPID controller is to pass duty ratio cycle(D1) to the sepic converter in order to pass a consistent output voltage to the EV regardless of the input PV voltage.

Another major advantage of using the Sepic converter is that it can operate in boost and buck modes depending on the duty ratio cycle.

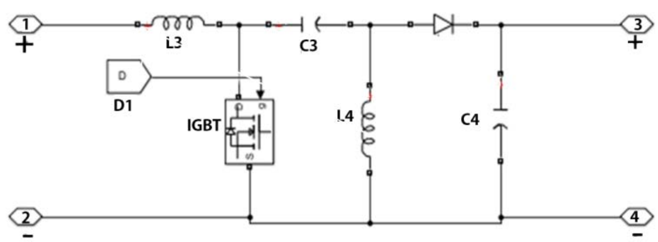


Figure 1:SEPIC dc-dc boost converter

The output voltage produced by the sepic dc-dc boost converter[13]can be calculated by the equation 3.

$$\frac{V_{dc}}{V_{PV}} = \frac{D}{1-D} \quad (3)$$

Where V_{dc} represent dc link voltage, V_{pv} represent the voltage produced by the solar PV array and D is the duty cycle ratio to the sepic converter. The value of capacitors and inductors that are present in the sepic converter can be calculated by equation 4,5 and 6.

$$L_a = L_b = \frac{V_{PV_{min}} D_{max}}{2\Delta i_{PV} f_{SW}} \quad (4)$$

$$C_1 = \frac{I_{dc} D_{max}}{\Delta V_{c1} f_{SW}} \quad (5)$$

$$C_2 = \frac{I_{dc} D_{max}}{\Delta V_{dc} f_{SW}} \quad (6)$$

Where $V_{PV_{min}}$ represents the minimum voltage generated by PV panels, Δi_{PV}represents the input current ripple, f_{SW}represent the switching frequency, I_{dc}represents the dc link current, ΔV_{C1}represents the voltage ripple of capacitor $C1$, ΔV_{dc} represents the output voltage ripple, and D_{max} represents the maximum duty ratio which can be calculated by the equation 7.

$$D_{max} = \frac{V_{dc} + V_D}{V_{PV_{min}} + V_{dc} + V_D} \quad (7)$$

where V_D represents the voltage drop in diode.

(ii) Bidirectional dc-dc converter

Figure 2. below presents the circuit for bidirectional charging circuit.
The diagram of the proposed model is shown in Figure 3, along with its basic components which include PV panel, battery bank, EV battery, switches, MPPT algorithm etc.When the rays of sunlight fall on the solar PV panels, these are converted into the electrical energy in order to provide sufficient amount of voltage and current for charging the EV and battery bank.

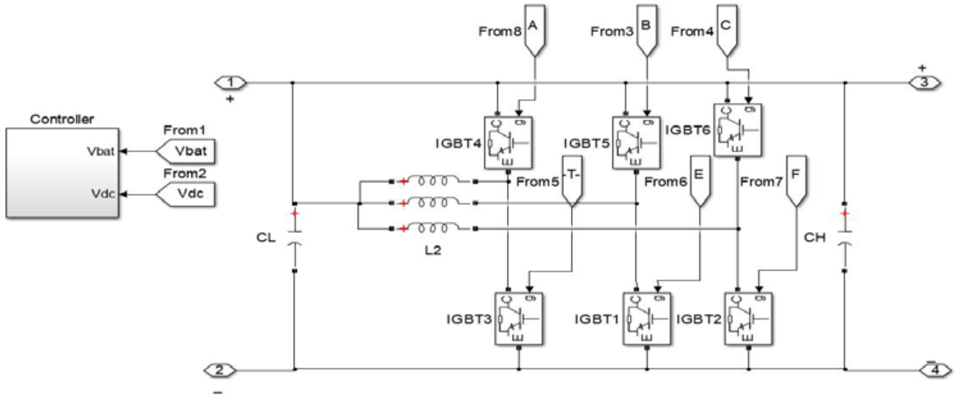


Figure 2: Bidirectionalcharging circuit

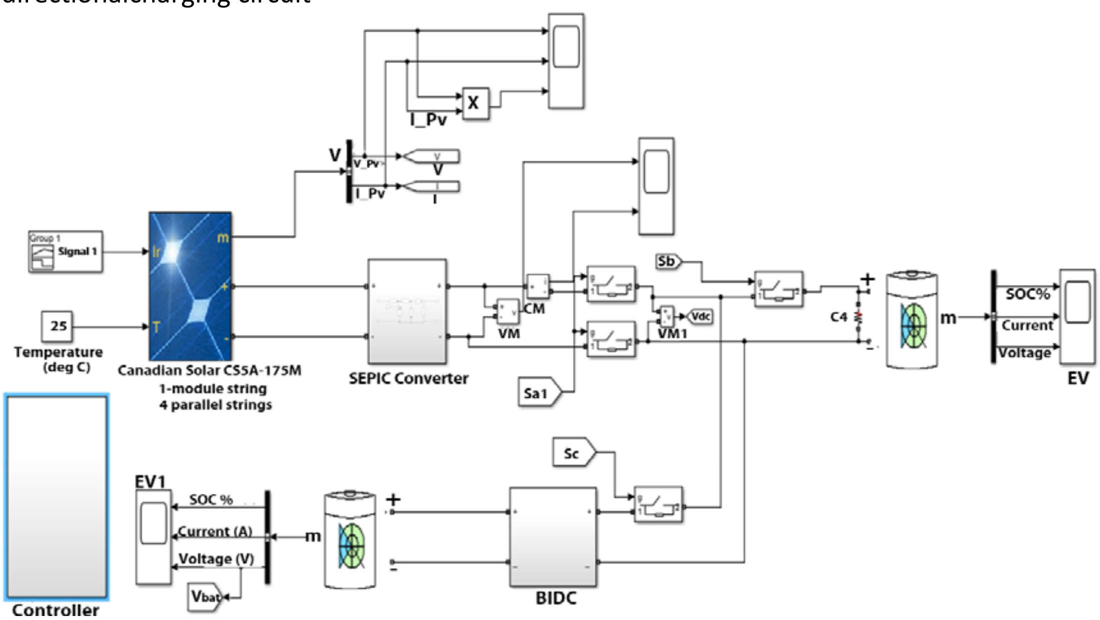


Figure 3: The Proposed Model

To maximize the poweroutput from the solar PV panels, the proposed model utilized the FOPID MPPT controller.

The FOPID controller block diagram is as shown in figure 4.

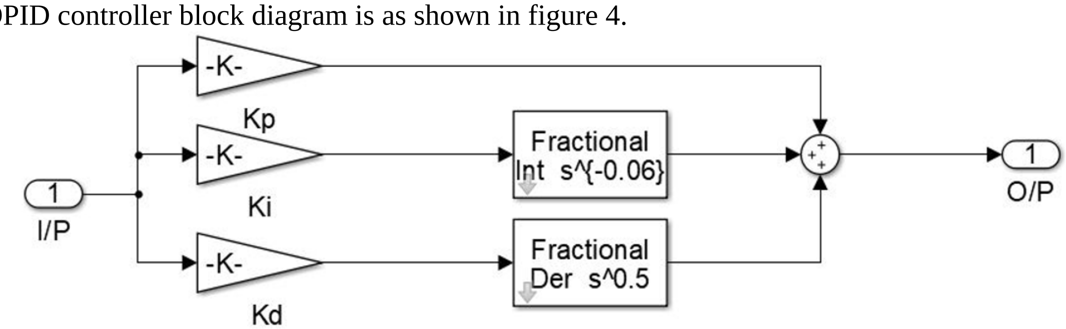


Figure 4: Block Diagram of FOPID Controller

4. Methodology and Results

The process opted by the proposed FOPID system to charge electric vehicles by using solar PV panels are explained briefly here;

1. Initially, when the sunlight falls on the PV panels that are converted to the electrical energy in order to charge the batteries of EVs. As the proposed model is working in three modes, the first mode is when battery bank and EV battery are getting charged by the solar PV panel. A number of parameters are defined such as input solar irradiance, temperature, open circuit voltage etc. Other than this there are some other important parameters which are given in table1.
2. Once the voltage is generated, DC-DC converter requires a duty cycle to perform effective operations. For this a MPPT technique is designed which would assist the converter to produce duty cycle, whichin this case is generated using the FOPID converter (taking λ= 0.0675 and μ= 0.5).

Table 1.

Solar PV panel parameters

Solar Panel Parameter	Value
Input Irridaince (w/m2)	[850,500,100]
Input Tempearture(deg.C)	25
Parallel strings	4
Series-connected modules per string	1
Maximum Power (W)	175.062
Open circuit voltage Voc (V)	44.3
Cells per module (Ncell)	72
Short-circuit current Isc (A)	5.29
Current at maximum power point Imp (A)	4.89
Voltage at maximum power point Vmp (V)	35.8
Temperature coefficient of Voc (%/deg.C)	-0.374
Temperature coefficient of Isc (%/deg.C)	0.088998

3. In the second mode, the battery of EV is getting charged by the battery bank and solar PV supply is switched off. The different parameters of the battery bank are defined which are shown in table 2 along with their values[8].

Table2.Table 3.

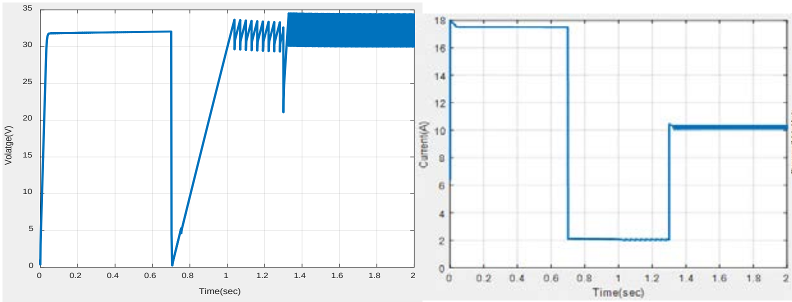
Battery bank parameters EV battery parameters

Battery Bank Parameter	Value
Nominal voltage (V)	25
Rated capacity (Ah)	16
Initial state-of-charge (%)	70
Battery response time (s)	0.001

EV Battery Parameter	Value
Nominal voltage (V)	24
Rated capacity (Ah)	16
Initial state-of-charge (%)	50
Battery response time (s)	0.1

The third mode of the proposed system is when alternate charging source i.e., battery bank is turned off and battery of EV is getting charged by the solar PV panels. Table 3. below represents the different EV parameters along with their configurational values.

4. The waveforms of the energy produced by the solar PV panels for voltage, current and total power in three modes of operation are evaluated and are shown in figure5 (a) and (b)and Fig. 6respectively.



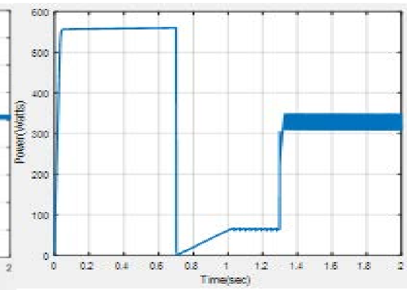


Figure 5:(a) Voltage ofSolar PV panels**(b)**Currentof Solar PV panels**Figure 6**:total power generated

Furthermore, in order to track the MPPT in the system duty ratio is passed to the sepic dc-dc boost converter by the FOPID controller. The regulated voltage and current generated by the sepic dc-dc boost converter is as shown in figure 7.

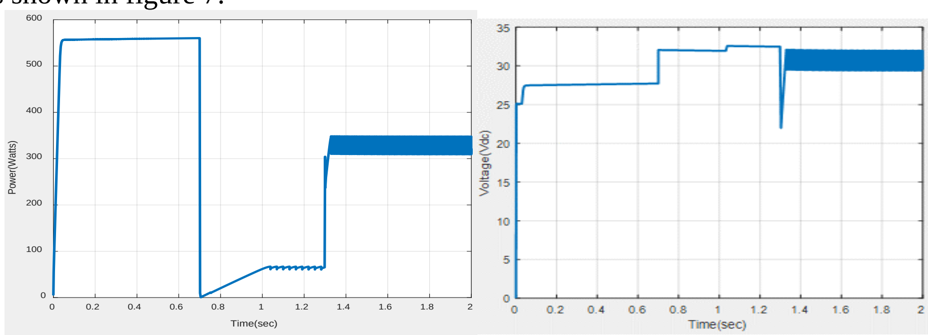


Figure 7: (a) Powerby Sepic converter**(b)**Current waveform by Sepic converter

5. Moreover, the charging and discharging waveform forthe three operating modesfor battery bank is obtained along with its voltage and current waveforms and are shown in figure below.

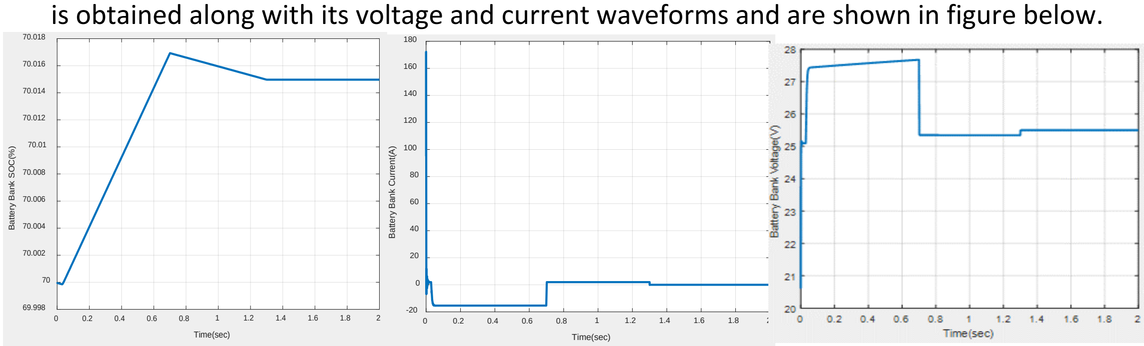


Figure 8: (a)SOC**(b)** current and **(c)**voltage waveforms by battery bank

Figure 8(a) shows the battery bank SOC diagram.From the graph, it is observed that initially the battery is getting charged by the solar PV panel in mode 1. But as soon as the next mode starts the battery starts to discharge slowly up to 1.3 sec. After 1.3 sec, the third mode starts in which the battery is neither getting charged nor discharged i.e., it remains constant.

6. Likewise, the SOC of EVs battery is obtained along with its current and voltage waveform which are shown in figure 9 below.

Figure represents the state of charge of the EV batteries. From the graph, it is analyzed that the EV is getting charged in all the three modes. In the first mode, EV battery is getting charged by the Solar PV panel and battery bank, in the second mode, it’s getting charged by the battery bank and in the third mode, the battery of EV is getting charged by the PV panel.

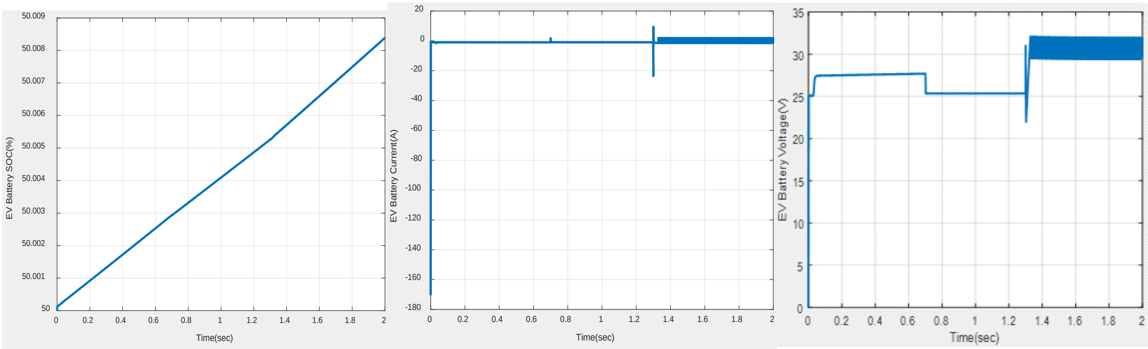
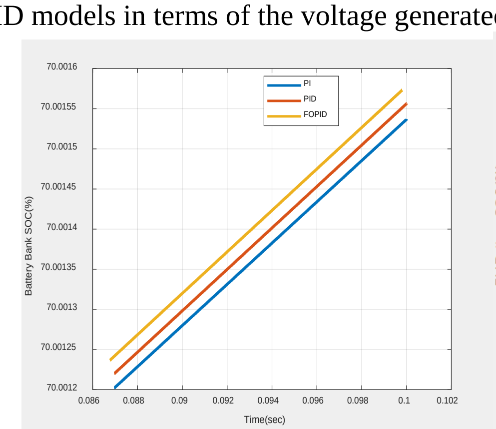


Figure 9: (a) SOCfor EV battery**(b)** currentfor EV battery**(c)** voltage graph for EV battery

The performance of the proposed FOPID model is tested and compared with the PI and PID controller models in the MATLAB simulation software in terms of their voltage and current readings. The simulation outcomes obtained are described in detail in this section.

5. Comparison with PIand PID models

The performance of the proposed FOPID model is analyzed and compared with the conventional PI and PID models in terms of the voltage generated by solar PV panels.



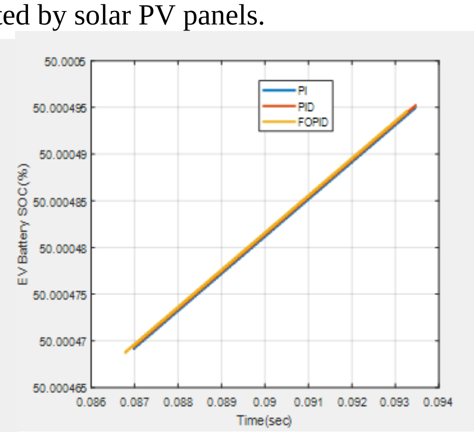


Figure10.SOC of Battery bank**Figure 11.** SOC of EV battery

Figure 10. depicts the comparison graph of the proposed FOPID model and traditional PI and PID models in terms of the battery bank SOC.The performance of the conventional PI and PID model is represented by the blue- and orange-colored lines. On the other hand, the performance of the proposed FOPID model is represented by the yellow-colored line.

From the graph, it is observed that the battery bank SOC in the proposed model is higher than the traditional two approaches which lasts more than 70.00155%, thus making it long lasting and efficient .

Lastly, the performance of the proposed model is also determined in terms of the state of charge of EV battery. Figure 11. demonstrates the comparison graph of the proposed FOPID model and traditional PI and PID models in terms of the EV battery SOC. The performance of the traditional PI and PID model is represented by the blue- and orange-colored lines and the performance of the proposed FOPID model is represented by the yellow-colored line. From the graph, it is observed that in all the three modes of operation the EV is getting charged constantly. However, after analyzing the graph closely it is observed that the EV battery of the proposed FOPID model lasts longer than the conventional two approaches.

From the graphs, it is observed that the proposed FOPID model outperforms the classical PI and PID model in all the factors and is more effective and efficient in charging EV through solar panels.

6. Conclusion

The simulation outcomes are obtained in terms of the voltage and current generated. In case of the proposed FOPID model, the voltage and current doesn't fluctuate much and can effectively charge EVs and battery bank of EVs. Similarly, the performance of the proposed FOPID model is compared with the conventional PI and PID models in terms of the voltage and current generated by the sepic dc-dc converter. The voltage generated by the sepic dc-dc converter remains constant in all three operating modes which ultimately provides sufficient amount of current to the EV for charging. Lastly, the charging state of the battery bank and EV battery is determined in which the proposed model outperforms the classical PI and PID models. All these factors, make the proposed FOPID model more efficient and effective for charging the EV.

7. Future research scope

FOPID has more number of parameters to be tuned, thus providing better and finer tuning than PID

controllers to meet the system target. In spite of the technical advantages offered by FOPID over its integer-order counterparts the adoption of the fractional order controller in the industry is slow. The cost of producing such controllers, the cost-benefit to the end user and the complexity of implementation of FOPID controllers with respect to its extra tuning flexibility verses the extent of performance improvement are certain factors which needs to be investigated to make it readily acceptable to the industry.

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