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CUK converter based Off-board electric vehicle battery charger using PV array

[1]K. Saujanya(M.Tech) , [2]Sammangi . Ramyaka (Assistant Professor ,M.Tech)
[1,2]NRI INSTITUTE OF ENGINEERING AND TECHNOLOGY ,AGIRIPALLI,VIJAYAWADA,ANDHRAPRADESH, INDIA .

Abstract: *During the recent decade, the automobile industry is booming with the evolution of electric vehicle (EV). Battery charging system plays a major role in the development of EVs. Charging of EV battery from the grid increases its load demand. This leads to propose a photovoltaic (PV) array-based off-board EV battery charging system in this study. Irrespective of solar irradiations, the EV battery is to be charged constantly which is achieved by employing a backup battery bank in addition to the PV array. Using the cuk converter and three-phase bidirectional DC–DC converter, the proposed system is capable of charging the EV battery during both sunshine hours and non-sunshine hours. During peak sunshine hours, the backup battery gets charged along with the EV battery and during non-sunshine hours, the backup battery supports the charging of EV battery. CUK Converter has great similarity with Buck- Boost converter. Based on the HEV application purpose this converter will either increase or decrease the output voltage. The advantages of the CUK converter are output having fewer ripples. The size of the capacitor is somewhat more.*

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I. Introduction

Ever increasing effects of green house gases from the conventional IC engines lead to environmental concerns. This paved to the booming of pollution free electric vehicles (EVs) in the automobile industry [1–3]. However, EV battery charging from the utility grid increases the load demand on the grid and eventually increases the electricity bills to the EV owners which necessitate the use of alternate energy sources [4, 5]. Due to inexhaustible and pollution free nature of renewable energy sources (RESs), it can be used to charge the EV battery. Thus, RES driven EV can be termed as 'green transportation' [6]. Solar is one of the promising RESs which can be easily tapped to utilise its energy to charge EV battery [7, 8]. Hence, PV array power is used to charge the EV battery in the proposed system with the help of power converter topologies. Lithium ion batteries are widely used in the EV due to its high power density, high efficiency, light weight and compact size [9, 10]. Also, these batteries have the capacity of fast charging and long lifecycle with low self-discharge rate. They also have low risk of explosion if it is over charged or short circuited. During charging, these batteries require precise voltage control. Hence, various power electronic converterswith voltage controller are used for charging EV battery.

Due to the intermittent nature of the PV array, there is a need for power converters to charge the EV battery. Among different converters, multiport converters (MPCs) are preferred in the onboard chargers of hybrid EVs due to its capability of interfacing power sources and energy storage elements like PV array, ultracapacitors, super capacitors, fuel cells and batteries with the loads in EV like motor, lights, power windows and doors, radios, amplifiers and mobile phone charger. The MPCs have the drawback of increase in weight, cost and maintenance of the EV as all the sources are placed in the EV itself. Also, the complexity of controller implementation increases in these converter-based EV battery charging system [11–13]. Hence, an off-board charger is proposed in this paper in which the EV battery is located inside the vehicle unit and PV array and backup battery bank are located in the charging station or parking station. Various converter topologies for off-board charging system are presented in the literature [14–16]. However, during low solar irradiation and non-sunshine hours, there is a need for an additional storage battery bank to charge the EV battery. This backup battery bank has to be charged in the forward direction and discharged in a reverse direction depending on the solar irradiation. Hence, a bidirectional converter with power flow in either direction is required [19]. The bidirectional converters are classified into non-isolated and isolated converters. Transformer in the isolated converters provides isolation which increases the price, weight and size of the converter. The main concerns of EV are weight and size and hence, non-isolated bidirectional converters are best suited for this application [20–22]. Among various non-isolated bidirectional converter topologies, bidirectional interleaved DC–DC converter (BIDC) is preferred due to its advantages like improved efficiency in discontinuous conduction mode and minimal inductance value, reduced ripple current due to multiphase interleaving technique. Snubber capacitor across the switches reduces the turnoff losses and the inductor current parasitic ringing effect is also reduced by employing zero voltage resonant soft switching technique. These are the added advantages of this bidirectional converter [23–25]. The system in [25] is an off-board EV battery charging system which charges the EV battery from PV array power through bidirectional DC–DC converter in stand-still condition and EV battery gets discharged to drive the dc load in the EV during the running condition. It has the drawback of charging EV battery only during sunshine hours. To overcome this disadvantage and to charge the EV battery without any interruption, the proposed charger is developed using PV array integrated with cuk converter, and backup battery bank for charging the battery of an EV.

Thus the conventional system uses a bi-directional DC-DC converter along with a boost converter but this paper imparts into a new idea of using cuk converter. This paper also gives an idea of using cuk converter without a bi-directional converter to enhance the performance of two wheeled electric vehicles.

II. Operation of the proposed system

The proposed PV-EV battery charger consists of a PV array, cuk converter, a half-bridge BIDC, an EV battery, a backup battery bank and a controller as shown in Fig. 1. The controller is used to generate the gate pulses to the cuk converter for obtaining the constant output voltage at the dc link. The gate pulses to the switches of BIDC are also generated to operate BIDC in boost mode to charge the backup battery from PV array and in buck mode to charge EV battery from the backup battery. Also, the PID controller generates the gate pulses to the auxiliary switches Sa , Sb and Sc . During high solar irradiation, all the auxiliary switches are ON to interface dc link with PV array through the cuk converter, dc link with the backup battery through BIDC and dc link with EV battery. When solar irradiation is low, switch Sa is turned OFF isolating the PV array and cuk converter from the dc link. Whereas the switch Sc is turned OFF to disconnect BIDC and backup battery from the dc link, when the solar power is insufficient to charge backup battery. The proposed system operates in three modes viz., mode 1, mode 2 and mode 3 as explained in this section.

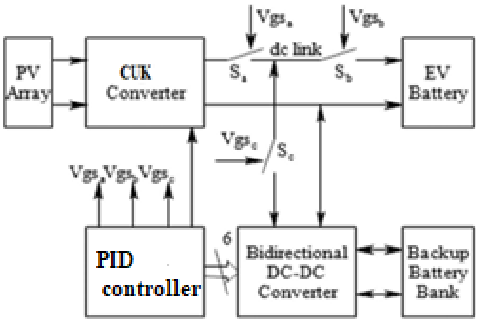


FIG1: block diagram of proposed system

2.1 Pv array

Sun based cells are intended to change over (something like a part of) accessible light into electrical energy, as their name recommends. They achieve this without depending on synthetic cycles or moving parts.

1.CHARACTERISTICS OF SOLAR CELLS

The sun-based cell, which is for the most part made of PV wafers, changes over the light energy from the sun straightforwardly into voltage and stream for load, and sends power without the need of an electrolytic effect. The electric energy is straightforwardly acquired from the PN interface of the semiconductor; thus, the sun-based cell is otherwise called a PV cell. A similar sun based cell circuit as seen in Figure2.

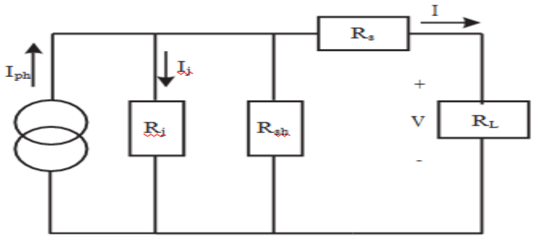


Fig2: equivalent circuit of pv array

The latest data Iph is answerable for the cell photovoltaic current, Rj is liable for the nonlinear check of the p-n crossing point, and Rsh and Rs are liable for the customary shunt and series protections, separately. Commonly, the worth of Rsh is very high, while the worth of Rs is to some degree unobtrusive. Accordingly, the two of them might be eliminated to upgrade the assessment. PV modules are encased PV cells that are gathered in bigger gatherings. They are additionally connected in a series-comparable blend to shape PV bundles. The condition watches out for the numerical model used to work on the PV show

$$I = n_p I_{ph} - n_p I_{rs}\left[e^{\left(\frac{q}{kTA}*\frac{V}{n_s}\right)} - 1\right]$$

.

Where I is the PV bunch yield current, V is the PV show yield voltage, ns is the quantity of series cells, np is the quantity of comparable cells, q is the charge of an electron, k is the Boltzman steady, An is the p-n assembly ideality factor, T is the cell temperature, and Irs is the cell revise dousing current. Factor A picks the deviation of the sun coordinated cell from the best p-n assembly credits to coordinate the peculiarity of the sun controlled cell from the best p-n crossing point character. It has a worth going from one to five. The photograph current Iph is influenced by daylight based irradiance and cell temperature, as displayed beneath.

$$I_{ph} = [I_{scr} + K_i(T - T_r)]\frac{S}{100}$$

Where Iscr is the cell hamper and radiation at reference te... t current temperature coefficient, and S is the sun irradiance in mW/cm2. Figure 4 portrays the Simulink model of a PV cluster. The model is partitioned into three subsystems. One subsystem to recreate a PV module and two extra subsystems to mimic Iph and Irs.

2.2 Design of the converters used in the proposed charger

Cuk converter:

The Cuk converter is a type of DC/DC converter that has an output voltage magnitude that is either greater than or less than the input voltage magnitude. It is essentially a boost converter followed by a buck converter with a capacitor to couple the energy. Similar to the buck–boost converter with inverting topology, the output voltage of non-isolated cuk is typically also inverting, and can be lower or higher than the input. It uses a capacitor as its main energy-storage component, unlike most other types of converters which use an inductor. It is named after Slobodan cuk of the California Institute of Technology, who first presented the design. There are variations on the basic cuk converter. For example, the coils may share single magnetic core, which drops the output ripple, and adds efficiency. Because the power transfer flows continuously via the capacitor, this type of switcher has minimized EMI radiation. The cuk converter allows energy to flow bi-directionally by using a diode and a switch. Figure 3 shows the basic structure of cuk converter.

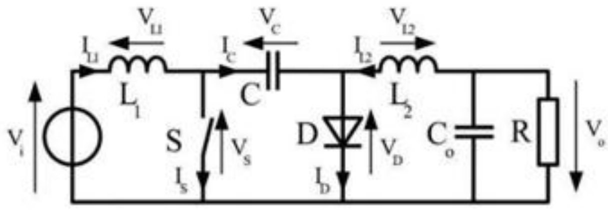


Fig3: block diagram cuk converter

2.3 Bidirectional interleaved DC–DC converter

Fig. 3 shows the schematic diagram of the BIDC employed in the proposed charging system. Backup battery bank is located on the high voltage side while the dc link is on the low voltage side of the converter. This converter operates in boost mode in forward direction and in buck mode in reverse direction. In boost mode, switches SL1 , SL2 and SL3 are the active switches whereas, in buck mode, the active switches are SU1 , SU2 and SU3 . There is an antiparallel diode and parallel snubber capacitor to all the switches employed in this converter. In boost mode, the inductors L1 , L2 and L3 act as boost inductors whereas they act as a low-pass filter in buck mode. The capacitors, CL and CH are the smoothing energy buffer elements of this converter. Interleaved inductor currents minimise the ripples in the current. The modes of operation of the converter are analysed by considering the operation of a single leg converter in [20]. The voltage conversion ratio of BIDC in boost and buck modes are given by (6) and (7), respectively

$$\frac{V_{\text{BackupBatt}}}{V_{\text{dc}}} = \frac{1}{1 - D_{\text{Boost}}}$$

$$\frac{V_{\text{dc}}}{V_{\text{BackupBatt}}} = D_{\text{Buck}}$$

where VBackup Batt is the backup battery voltage and D Boost is the duty ratio of BIDC in boost mode and D Buck is the buck mode duty ratio. The values of inductors are considered less than the critical inductance values in both boost and buck modes to operate the converter in discontinuous conduction mode to improve efficiency.

$$L_{\text{cric}} = \frac{3V_{\text{BackupBatt}}^2 D_{\text{Boost}}(1 - D_{\text{Boost}})^2}{2Pf_s}$$

$$L_{\text{cric}} = \frac{3V_{\text{dc}}^2(1 - D_{\text{Buck}})}{2Pf_s}$$

$$C_H = \frac{D_{\text{Boost}}P}{2f_s V_{\text{BackupBatt}}^2}$$

$$C_L = \frac{V_{\text{BackupBatt}} D_{\text{Buck}}(1 - D_{\text{Buck}})}{8f_s^2 L\Delta V_{\text{dc}}}$$

III. Design of PID controllers

PID Controller of the proposed charger generates gate pulses to the switches present in the cuk converter, BIDC and also to the three auxiliary switches. The algorithm to turn ON and turn OFF the auxiliary switches Controller senses the PV array voltage and current, and computes the PV array power. If the PV array power is greater than EV battery rated power, PR, then the controller generates the gate pulses to turn ON all the auxiliary switches to charge both EV battery and backup battery bank simultaneously from the PV array. If the PV array power is lesser than EV battery rated power but higher than the minimum required power, PM, the switch, Sc is turned OFF disconnecting the backup battery from the charging system and switches, Sa and Sb are turned ON to charge the EV battery alone from the PV array. If the PV array power is lesser than the minimum required power, PM, then the switch, Sa is turned OFF to isolate the PV array and cuk converter from the charging system. The switches, Sb and Sc are turned ON enabling the backup battery to charge EV battery.

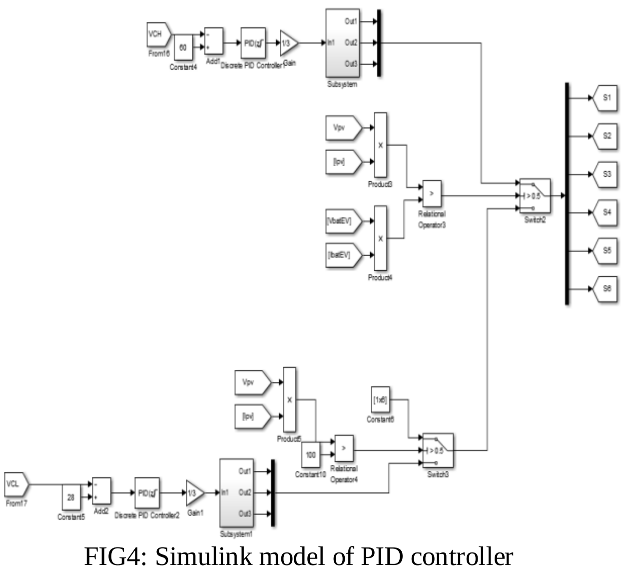
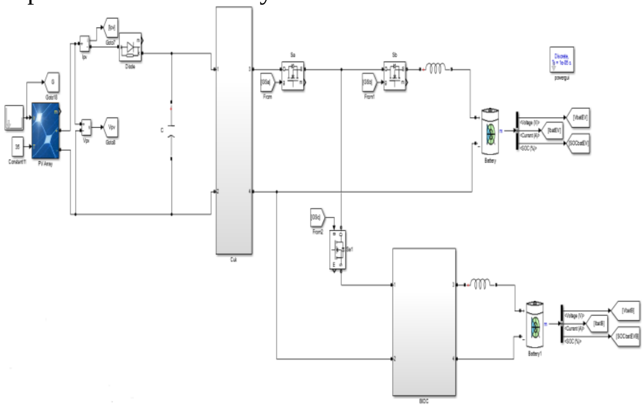


FIG4: Simulink model of PID controller

The PID voltage controller is used in the proposed charging system to generate gate pulses to the MOSFET in the cuk converter to maintain a constant voltage at the dc link irrespective of variations in thePV array voltage. BIDC comprises of three legs with two switches in each leg. Gate pulses have to be provided to the two switches in the same leg with the phase shift of 180° from each other. The PID controller in the proposed system generates six gate pulses to the BIDC depending on the PV array power. If PV array power exceeds PR, gate pulses are generated to the switches of BIDC to operate it in boost mode, stepping up the dc link voltage to charge the backup battery bank.

IV. Simulation results

Fig5: Simulink model of proposed cuk converter system:



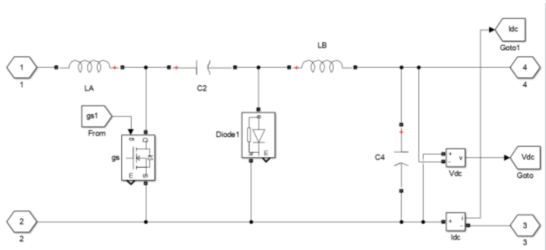
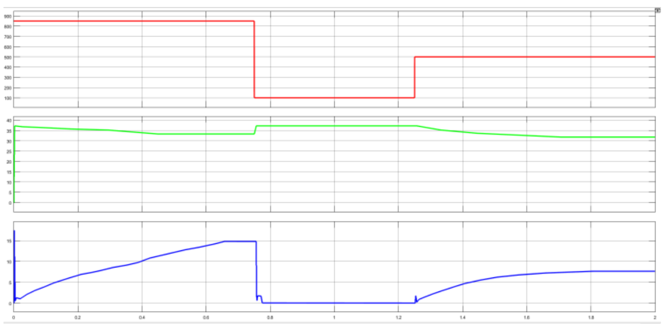
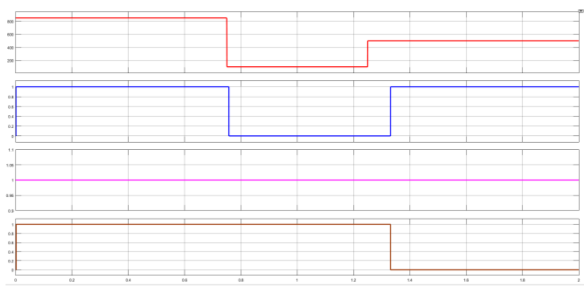
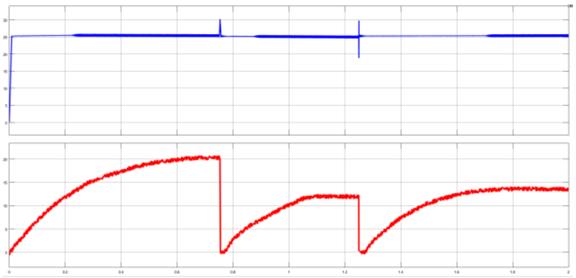


Fig6: Simulink model of cuk converter

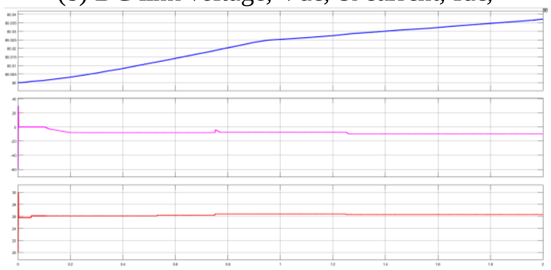




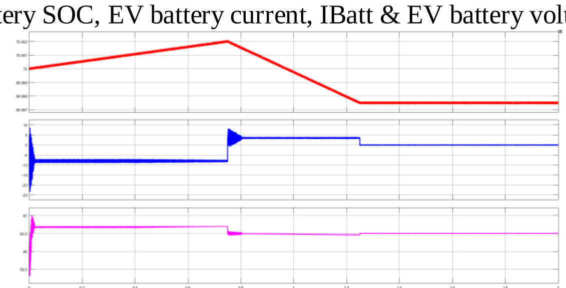
(a) PV array voltage, VPV & PV array current, IPV,



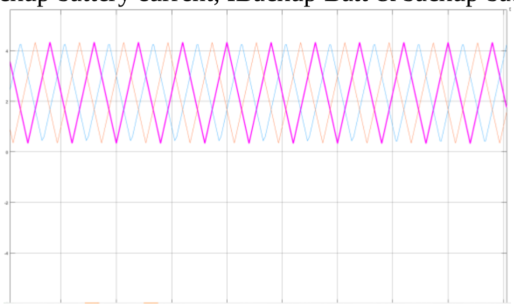
(b) DC link voltage, Vdc, & current, Idc,



(c) EV battery SOC, EV battery current, IBatt & EV battery voltage, VBatt,



(d) Backup battery SOC, backup battery current, IBackup Batt & backup battery voltage, VBackup Batt



Il1,il2,il3 response

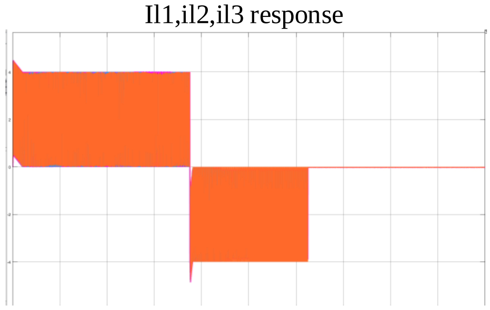


Fig. 7 Inductor current waveforms of BIDC

V. Conclusion

In this paper, an off-board EV battery charging system fed from PV array is proposed. This paper discusses the flexibility of the system to charge the EV battery constantly irrespective of the irradiation conditions. a cuk converter and a PI controlled bi-directional DC-DC converter offers a ripple free and stable output at both acceleration and regenerative mode as compared to the parallel switch based boost converter technique .But as the circuit become more and more complex we have formulated a new idea of using a cuk converter without a bidirectional converter and it showed a better result.Proposed model (CUK with PID) had successfully simulated and obtained more output compared with existing model of sepic with pi controller . The better result obtained for proposed model by using same parameter which used by existing model

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