SOLAR ELECTRIC VEHICLE BATTERY CHARGING WITH HIGH GAIN CONVERTER

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***Abstract:** The solar electric vehicle solves many problems related to the environment and is the best pollution free method. We need to make use of them so that we can reduce our dependence on fossil fuels. Electric vehicle batteries are quite different from those used in consumer electronic devices such as laptops and cell phones. They are required to handle high power and high energy capacity within a limited space and weight and at an affordable price. Solar electric vehicles are full electric vehicles, only using electricity and no petrol or diesel for energy. As such, they produce zero direct carbon emissions. The solar energy may be varying time to time so MPPT algorithms are necessary because PV arrays have a nonlinear voltage-current characteristic with a unique point where the power produced is maximum. This point depends on the temperature of the panels and on the irradiance conditions. Both conditions change during the day and are also different depending on the season of the year. The irradiation can change rapidly due to changing atmospheric conditions such as clouds. The negative output buck-boost converter provides inverse output voltage. The converter has wide conversion ratio with no current spike in output. As compare to other negative output converter the gain of new negative output buck-boost converter is high. All the simulation works are done in MATLAB/SIMULINK software. TMS320 is used for generating control pulses for the switches. The prototype of proposed system is setup and verified its performance.*

***IndexTerms** - DC-DC power converter, Negative output, Wide conversion ratio, PV array, Lead acid battery.*

I. INTRODUCTION

The renewable energy is vital for today world as in near future the non-renewable sources that we are using are going to get exhausted. The solar electric vehicle is a step in saving these non-renewable sources of energy. The basic principle of solar vehicle is to use energy that is stored in a battery during and after charging it from a solar panel. The charged batteries are used to drive the motor which serves here as an engine and moves the vehicle in reverse or forward direction. The solar vehicle solves many problems related to the environment and is the best pollution free method. Solar Electric Vehicles are typically powered by a PV array consisting of multiple strings of series connected PV cells. Electric vehicle batteries are quite different from those used in consumer electronic devices such as laptops and cell phones. They are required to handle high power and high energy capacity within a limited space and weight and at an affordable price [2], [3].

The power train in a full EV is composed of an electric motor, a battery, and a converter to control the power flow between motor and battery. This same converter is also applied to charge the battery. The vehicle battery (VB) can be fast or slow charged. If the battery is slow charged, the converter to manage the power flow is located inside the vehicle, and it is usually called an EV on-board charger. In this way, it will take between 6 and 8 h to charge the battery directly from the utility grid. On the other hand, a fast charger can charge a VB in only 20 min. This is called an EV off-board charger because the charger converter is outside of the vehicle. In this case, the VB is charged using direct voltage [4].

For wider conversion ratio, the voltage lift technique is applied to buck-boost or Cuk converter, such as the N/O self-lift Luo converter [5], the enhanced N/O self-lift Cuk converter [6], the N/O super-lift converter [7] and the voltage-lift-type Cuk converters. However, all the above N/O converters have an unreasonable defect, that is there is abruptly changing on the voltage across the energy-transferring capacitor which results in a very high current spike flowing through it [8].

The N/O quadratic converter with the voltage conversion ratio $D^2/(1-D)$ [9]. The N/O KY buck-boost converter with the voltage conversion ratio $-2D$ who possessed no bilinear characteristics was proposed in [10]. The N/O KY boost converter which was constructed by integrating a positive to negative path to boost converter with the voltage conversion ratio $-1/(1-D)$ was proposed in [11]. In [12] and [13] a switched networks are inserted in the Cuk converter to construct the N/O hybrid Cuk converters. In [14], switched networks are inserted in the buck-boost converter to get hybrid buck-boost converters. One N/O hybrid buck-boost converter with voltage conversion ratio being $-D/((1-D)(2-D))$ uses a switched-capacitor (SC) structure while another N/O hybrid buck-boost converter whose voltage conversion ratio is $-2D/(1-D)$ uses a switched-inductor structure. The added switched networks lead to more diodes, capacitors or inductors to achieve wider conversion ratio, and it results in complex circuit, heavy volume and more power losses. In [15], a single-stage switched-capacitor-inductor N/O boost converter with the voltage conversion ratio $-1/(1-D)$ was proposed.

II. SOLAR ELECTRIC VEHICLE BATTERY CHARGING WITH GAIN CONVERTER

The solar electric vehicle solves many problems related to the environment and is the best pollution free method. We need to make use of them so that we can reduce our dependence on fossil fuels. The block diagram of solar electric vehicle battery charging is shown in Fig. 1.

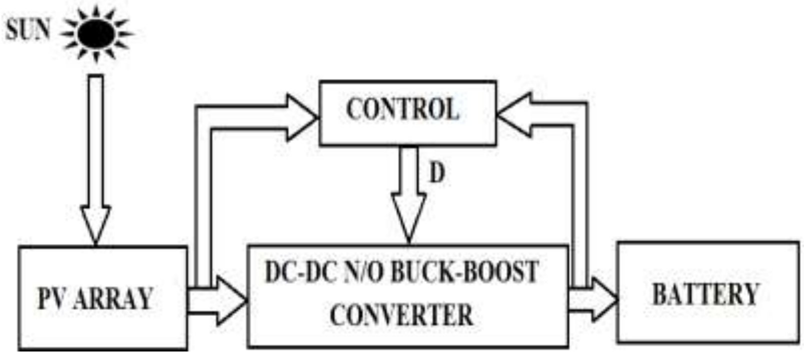

Fig. 1. Block diagram of Electric Vehicle Battery Charging
Fig. 2.

The sunlight is incident on the PV panel which convert solar energy into electrical energy. The output voltage of PV are used for the input of the converter. The converter which buck or boost the voltage for the requirement, is due to the different voltage level of battery charging is possible. The online and offline charging of battery is possible. The solar energy may be varying time to time so MPPT algorithms are necessary because PV arrays have a nonlinear voltage-current characteristic with a unique point where the power produced is maximum. This point depends on the temperature of the panels and on the irradiance conditions. Both conditions change during the day and are also different depending on the season of the year. So closed loop control is used for the proper charging of the battery.

2.1 **Negative Output Buck-Boost Converter**

The negative output converter consists of an input voltage V_{in} two power switches S_1 and S_2 two diodes D_1 and D_2 two inductors L_1 and L_2 two capacitors C and C_0 and one resistive load R. For steady-state theoretical analysis, it is assumed that all components are ideal and the proposed converter operates in CCM.

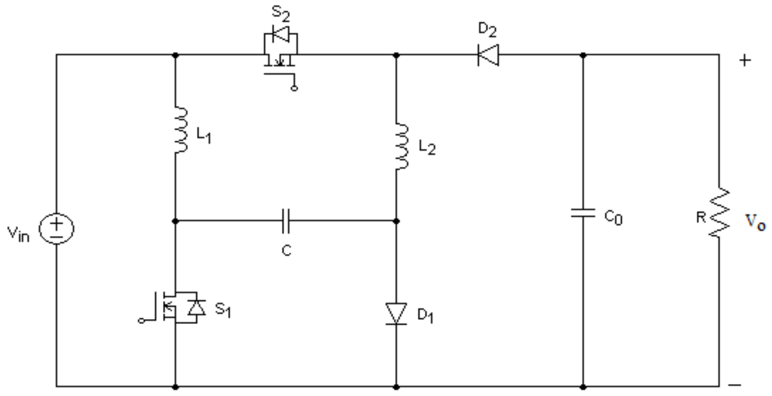

Fig. 3. Negative Output Buck-Boost Converter

2.1.1 Operating Principle

Power switches are turned on and off simultaneously, so there are two operation stages that are shown in Fig. 4 and Fig.5. The first stage when the power switches are turned on and the second stage when the power switches are turned off. Currents through L_1 and L_2 are denoted by i_{L1} and i_{L2} respectively. The voltage across the capacitor C is defined as v_c and the voltage across the output capacitor C_0 is defined as v_0. Some typical time-domain waveforms are shown in Fig. 3, where N is the nature number.

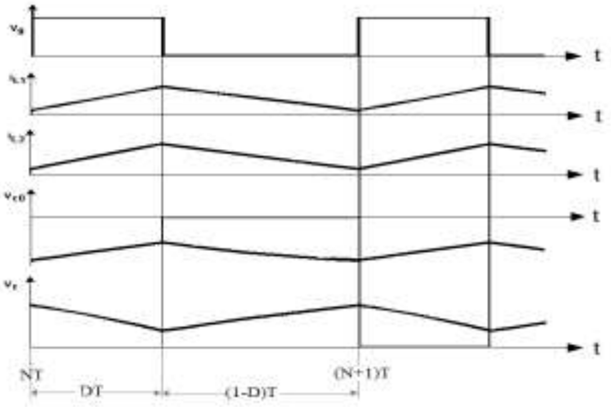

Fig. 4. Time Domain Waveform

2.1.2 First Stage

Power switches S_1 and S_2 are turned on during the subinterval (NT, NT+DT) in switching period as shown in Fig. 4, and diodes D_1 and D_2 are blocked via the reversal voltage. In this stage, the input voltage V_{in} supplies the energy to the inductor L_1, and the capacitor C together with the input voltage V_{in} delivers the energy to the inductor L_2. The voltage across the capacitor C is equal to the voltage stress on the diode D_1. The difference value of the input voltage V_{in} and the output voltageV_0 equals the voltage stress on the diode D_2.

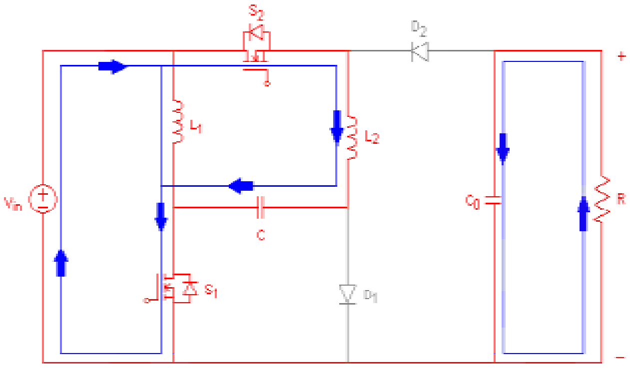

Fig. 5. First Stage

2.1.3 Second Stage

Power switches S_1 and S_2 are turned off during the subinterval (NT+DT, NT+T) in any switching period as shown in Fig. 5, and diodes D_1 and D_2 conduct during this interval. Combining with the input voltage V_{in} the inductor L_1 supplies energy to the capacitor C through the diode D_1. Meanwhile, the inductor L_2 transfers energy to the output capacitor C_0 through the diodes D_1 and D_2. The voltage stress on the power switch S_1 is equal to the voltage across the capacitor C, and the voltage stress on the power switch equals $V_{in}–V_0$.

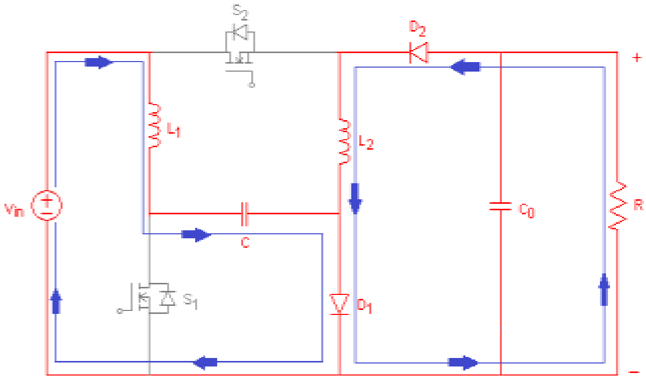

Fig. 6. Second Stage

2.2 Voltage Conversion Ratio

It is assumed that V_{in}, V_C, I_{L1}, I_{L2}, I_0 and V_0 are corresponding DC values of v_{in}, v_C, i_{L1}, i_{L2}, i_0 and v_0. When the proposed converter is in steady state, inductors L_1 and L_2 satisfy the volt-second balance, that is, the net volt-seconds in one period is equal to zero. Thus,

$$DV_{in}+(1-D)(V_{in}-V_c) = 0 \quad (1)$$

$$D(V_{in}+V_c)+(1-D)V_0 = 0 \quad (2)$$

V_0 and V_c can be derived from (1) and (2)

$$V_c = V_{in}/(1-D) \quad (3)$$

$$V_0 = -D(2-D)V_{in}/(1-D)^2 \quad (4)$$

The voltage conversion ratio of the converter can be derived from (4) and its expression is

$$M = V_0/V_{in} = -D(2-D)/(1-D)^2 \quad (5)$$

If the duty cycle D is smaller than 0.29 and the voltage conversion ratio M is less than 1, the converter works in step-down mode otherwise voltage conversion ratio M is greater than 1, the converter works in step-up mode.

2.3 Design of Negative Output Buck-Boost Converter

The typical time-domain waveforms are shown in Fig. 3, one can see that the inductor current i_{L1} and i_{L2} increases during the first subinterval and then decreases during the second subinterval. Also the capacitor C and C_0 charges and discharges, the peak-peak voltage ripple v_c and v_{c0} respectively.

$$L_1 = V_{in}DT/\Delta i_{L1} \quad (6)$$

$$L_2 = D(2-D)V_{in}T/(1-D)\Delta i_{L2} \quad (7)$$

$$C = D^2(2-D)V_{in}T/(1-D)^3R\Delta vc \quad (8)$$

$$C_0 = D^2(2-D)V_{in}T/(1-D)^2R\Delta vc0 \quad (9)$$

III. SIMULATION STUDIES

3.1 Simulation Parameters

A 50W prototype of solar electric vehicle battery charging with high gain converter system has been designed and verify. The proposed system was simulated in MATLAB R2017a. The converter has wide conversion ratio so different level of battery charging is possible.

TABLE I. COMPONENTS VALUE

Parameter	Values
Input voltage	17V
Output voltage	12V, 24V

Parameter	Values
Switching frequency	40KHz
Inductor L_1	0.5mH
Inductor L_2	0.8mH
Capacitor C	50μF
Capacitor C_0	47μF
PV Panel	17V, 50W

3.2 Simulation Model and Simulation Results

The detailed MATLAB/Simulink model of solar electric vehicle battery charging with high gain converter is shown in Fig. 6. There are two MOSFET switches S_1 and S_2 are worked on switching frequency is 40KHz.

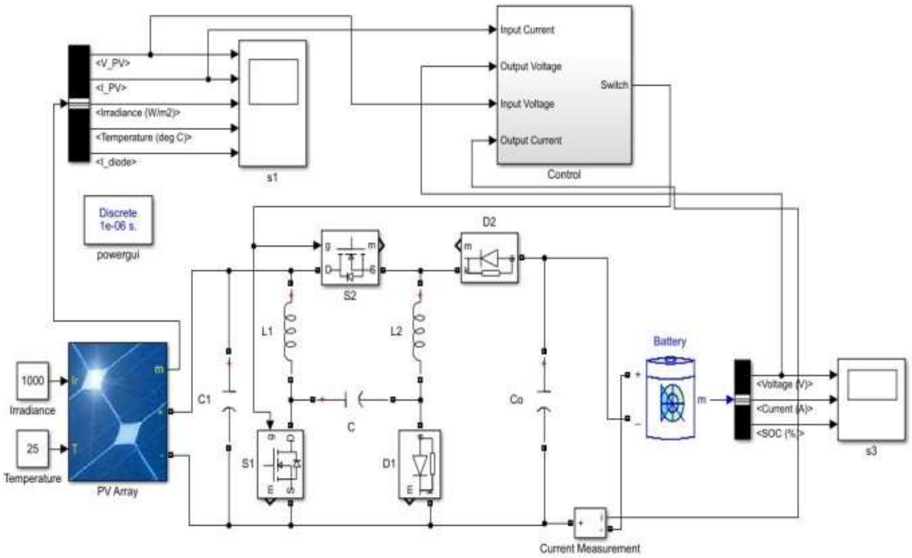

Fig. 7. Matlab Model of Solar Elecrtic Vehicle Battery Charging With High Gain Converter

Fig. 8.

Simulation of solar electric vehicle battery charging with high gain converter is simulated in MATLAB R2017a. The different level of battery charging are possible. The buck-boost converter has used to charging the 12V and 24V battery.

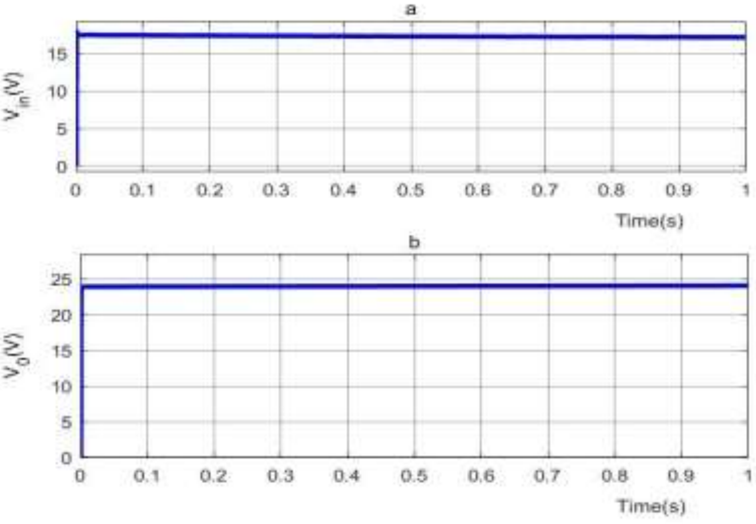

Fig. 9. (a) Input voltage V_{in} (b) Output voltage V_0

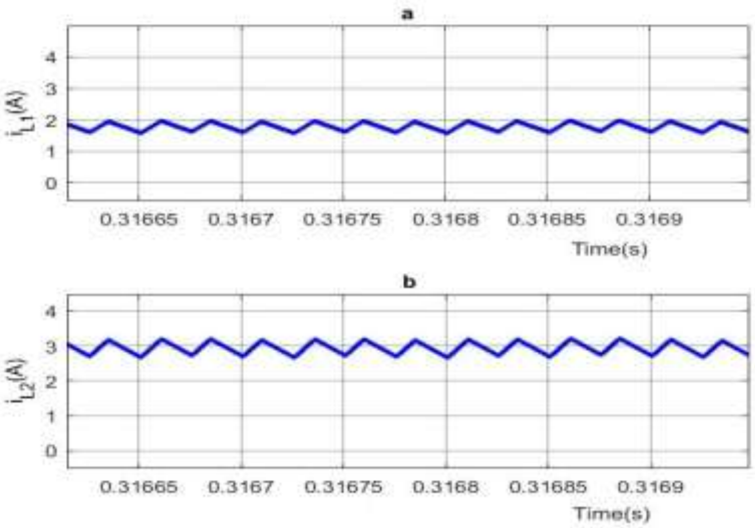

Fig. 10. (a) Inductor current i_{L1} (b) Inductor current i_{L2}

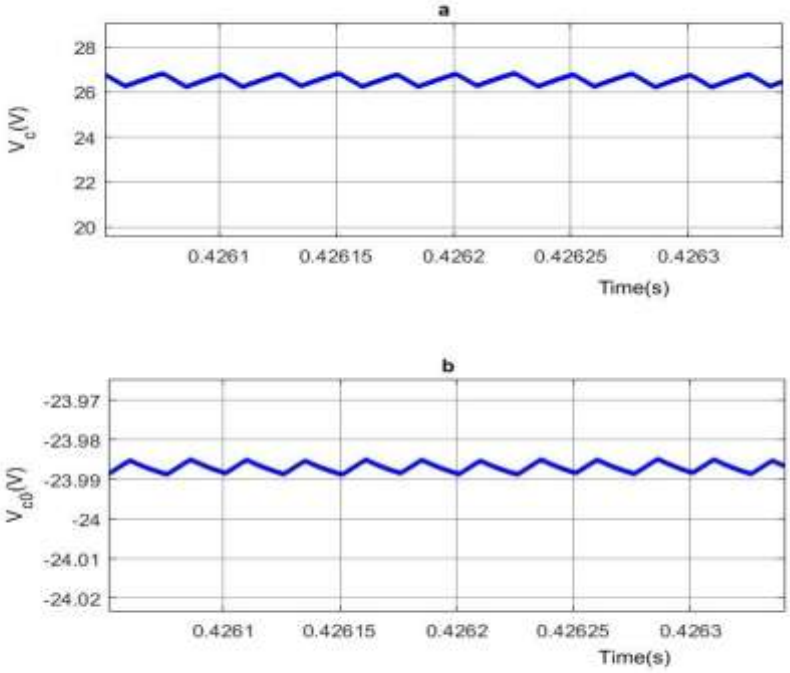

Fig. 11. (a) Capacitor voltage V_c (b) Capacitor voltage V_{c0}

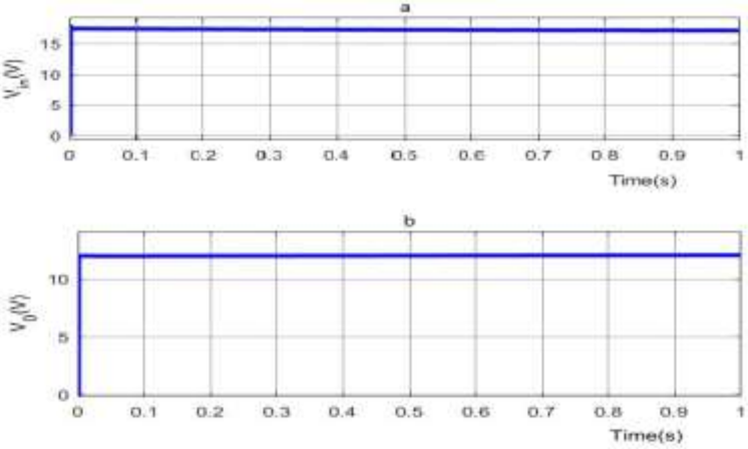

Fig. 12. (a) Input voltage V_{in} (b) Output voltage V_0

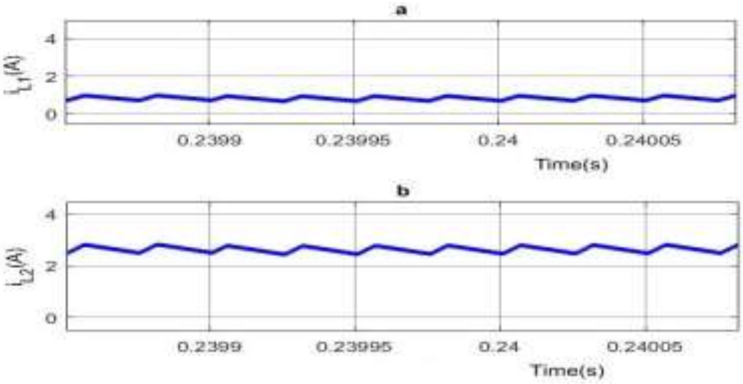

Fig. 13. (a) Inductor current i_{L1} (b) Inductor current i_{L2}

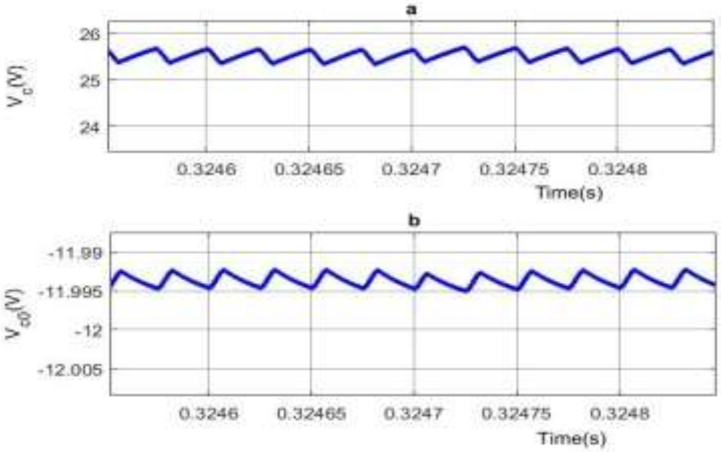

Fig. 14. (a) Capacitor voltage V_c (b) Capacitor voltage V_{c0}

3.3 Simulation Analysis

The negative output buck-boost converter has been simulated. If the dutyratio of the converter has change to operted in buck and boost mode. All the analysis are done by varying the duty ratio.

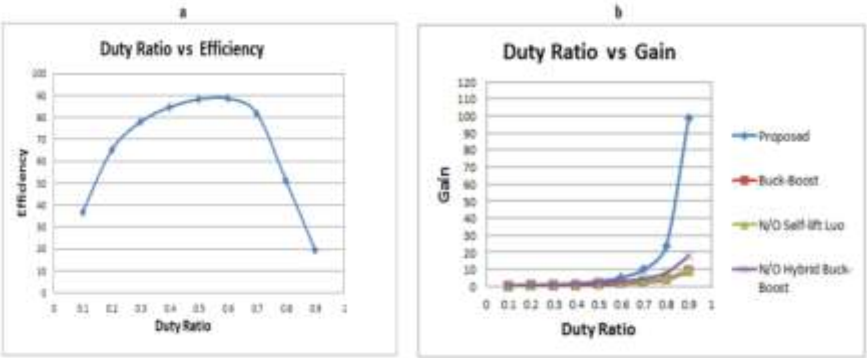

Fig. 15. (a) Efficiency versus duty ratio (b) Gain versus duty ratio

Efficiency curve of negative output buck-boost converter is shown in Fig. 13(a). By varying the duty ratio the efficiency of the converter has been changed. The maximum efficiency is obtained at D=0.6. The graph is plot duty ratio verses gain of different negative output converters is shown in Fig. 13(b). As compare to other negative output converter the gain of new negative output buck-boost is high.

IV. HARDWARE IMPLEMENTATION

The simulation results are verified experimentally by implementing the hardware, due to the lack of PV power supply and other availability of devices, the hardware is done by reducing the parameters of prototype to 17V as the input and for 50W power. The Fig. 14 shows the hardware setup of the solar electric vehicle battery charging with high gain converter. Switching pulses obtained from TMS320 micro controller is given to the driver circuit. Opto-coupler TLP250 provides the isolation between the driver and power circuits. IRF540 is chosen as the power switch. The battery is the load of the converter. The different level of battery is connected as load and charging the battery. The proposed system is used to charging the 12V and 24V battery, due to the buck and boost operation of converter with wide conversion ratio.

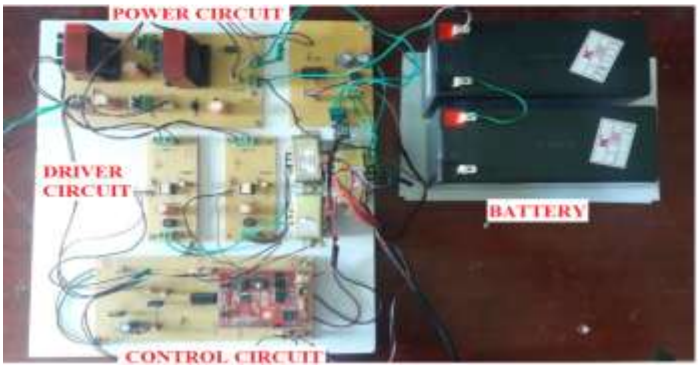

Fig. 16. Experimental Setup

Fig. 17.

From the experimental setup we can assure that the hardware setup is working and produces the desired output. The 12V and 24V battery charging, output waveforms are shown in Fig. 15 and Fig. 16.

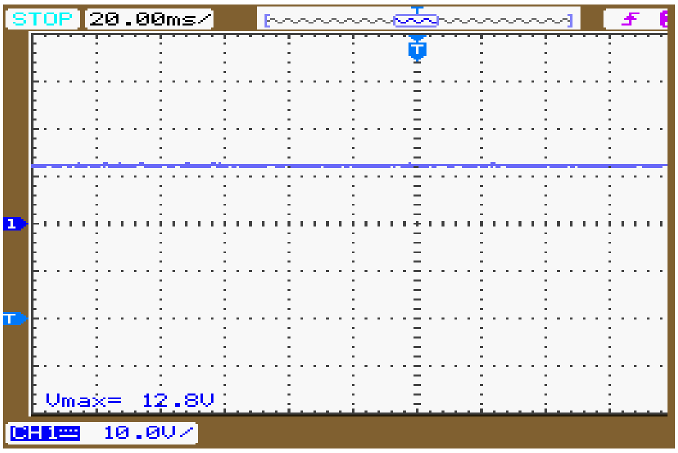

Fig. 18. Experimental Buck Output V_0 (Charging 12V Battery)

Fig. 19.

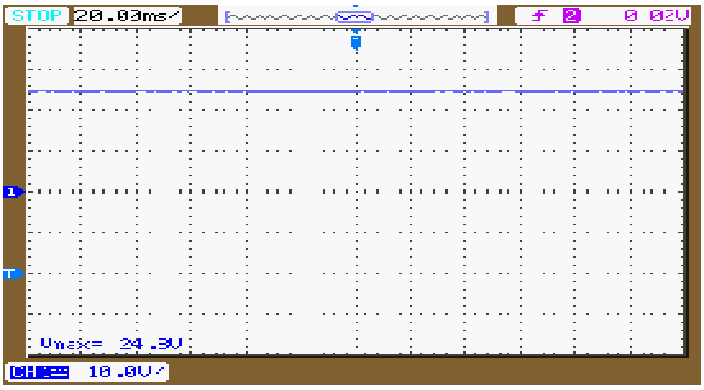

Fig. 20. Experimental Boost Output V_0 (Charging 24V Battery)

V. CONCLUSION

The solar electric vehicle battery charging with high gain converter system has simulated, the simulation results are close agreement with experimental result of the prototype. The N/O buck-boost converter has compared with other N/O converter and the gain of converter is high. The N/O buck-boost converter has wide conversion ratio and no current spikes in output. So the above advantages are used to different levels of battery charging are possible. The maximum efficiency is obtained as 88.89% at input voltage is 17V and 50W load. The closed loop is applied to the input and output side of the converter. The output of the converter is negative so that common ground problem for feedback, to avoid op-amp circuit (TL084) is used to invert the output voltage and feedback to the controller.

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