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Design and Analysis of PV Based Cascaded Buck-Boost Converter for Battery Charging

Dr.M.Ganesh Kumari[1], E.Karthika[2], B.Sathiya Bharathi[3], V.Swetha[4]
[1]Assistant Professor, Department of EEE, K.L.N. College of Engineering, Sivagangai(T.N),India.
[2,3,4]UG Scholar, Department of EEE, K.L.N. College of Engineering, Sivagangai(T.N), India.
Emailid: mganeshkumari2020@gmail.com[1], karthi03latha@gmail.com[2], sathiyabalaji3012@gmail.com[3], swethasenthamil@gmail.com[4]

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Abstract

The main objective of this design is to satisfy the varied battery conditions similar to 4V/ 8V/ 12V/ 16V/ 20V/ 24V by enforcing the automatic buck and boost operation by seeing the input PV source. The new approach has proven delicacy, robustness, and effectiveness of effective energy application for standalone PV systems by knowing the varied data & topologies about transformers, batteries, etc., and PV panel is used as a source and PWM is used to gain maximum power from PV panels by conforming adjusting the duty cycle. This design involves Matlab simulations and experimental demonstrations.

Keywords: Photovoltaic, DC-DC converter, charge controller, MPPT(Maximum Power Point Tracking), Arduino Microcontroller, State of Charge(SOC), Pulse width modulation.

I .Introduction

Wind turbines and photovoltaic cells are the two significant power sources among the available renewable power sources.The PV models are getting the great considerations from the past and present decades because of its significant advantages in the global warming perspective. Adding the temperature is dwindling the installation generated by the PV module at MPP. The PV cells operate with maximum output power and track the utmost available output power of the PV array and make the PV system simpler. The MPPT algorithm adopts criteria dv/ dt = 0 at maximum points to prize the utmost power. The P & O system is most employed in MPPT thanks to its simple fashion and it requires only a few of parameters. It perturbs the terminal voltage of the PV array and compares the generated output power of PV with the last cycle of perturbation. P&O algorithm is applied to the MPP shadowing to manage the duty cycle of the converter. The DC-DC converter is that the first stage and it's to manage the variation of the utmost point of the solar cell output. In other words, modulation of the duty rate of the DC-DC converter controls maximum point shadowing (MPPT) to increase the overall effectiveness of the PV power exertion system, The proposed topology helps us to predict the optimum DC – DC converter duty rate predicated on solar irradiation to run the constant load (i.e., Battery). The Cascaded converter will buck & boost the asked voltage depending upon the Load by manual feedback through Arduino sketch. Also, the steady-state voltage ripples at the affair capacitors were reduced. Although Cascaded topology has been deduced from Cuk operation, linked to the classical boost & buck converter it's chosen thanks to the low ripple content within the input and output sides. The proper- cascaded motor for photovoltaic module operation is usually recommended. Switching beats are generated using Arduino Microcontroller.

II. Literature Review

The comparisons of conformist and cascaded converter are shown in Table 1.

The main intention is to gain a high delicacy converter with reduced input current ripple and reduced affair voltage ripple.

Table 1. Comparison of Conformist and Cuk (Cascaded Buck & Boost) converter

Type of Converter	**Efficiency**	**ripple voltage**	**inductor current ripple**	**switching speed**
Conventional Dc-Dc converter	Low	Increased	Increased	Slow
Cuk converter (Cascaded Buck & Boost)	Improved	Reduced	Reduced	Fast

The conventional Dc-Dc converter as shown in Fig. 1 has varied restrictions in its parameters like input current ripple, produce voltage ripple, the gain of the converter, and effectiveness. So as to beat these issues, Cuk (Cascaded Buck & boost) converter is chosen. the most intention is to realize a high gain converter with reduced input current ripple and reduced yield voltage ripple.

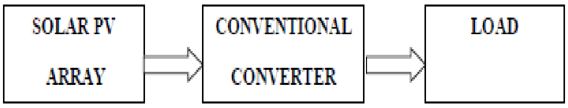


Figure 1. The Existing system operation sequence

The total current is flow through the only switch in order that voltage stress across the switch is accelerated. High input ripple current and produce voltage ripples. High switching losses. Low voltage constancy. Maximum power not attained. Likewise, the hard-switching converters produce other disadvantages nearly as limited frequency, high EMI, high switching losses, big size, heavy weight, and power dissipation in any using condition, which may affect low effectiveness.

Our Proposed system is the Cuk converter delivers flipping output so cascaded buck & boost conception is employed during this work to get-inverting output to run the constant Dc load- battery by the converter through battery charging as shown in Fig. 2. the benefits of the Cuk converter are associated with the traditional Buck & boost converter with certain changes to enhance switching speed, insulation from faults, input current ripple, effectiveness, the planning equations are presented and performance parameters are related using theoretical computations and simulation. The operation principle and steady-state performance are anatomized and ultimately the experimental results are given, also, the derivate of the proposed converter is presented.

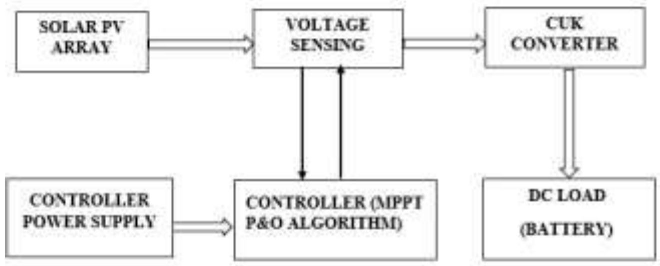


Figure 2. The Proposed system operation sequence

III. Converter Analysis & Design

An introductory boost/ buck converter converts a DC voltage to an advanced/ lower DC voltage. A non- insulated Cuk converter comprises two inductors, two capacitors, a switch (generally a transistor), and a diode. Its schematic are often seen in Figure 3. it's a reversing converter, therefore the output voltage is negative affecting the input voltage. The capacitor C is used to transfer energy and is connected to vary this source because it maintains a unbroken current.

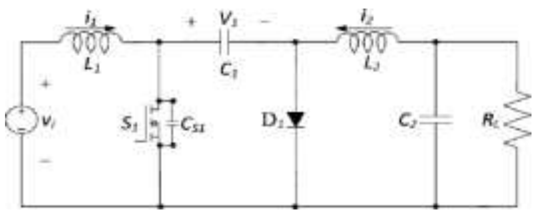


Figure 3. Circuit Diagram

A. Modes of operation

Based on the amount of energy that is delivered to the load during each switching period, the boost & buck converter can be classified into continuous or discontinuous conduction mode as shown in Fig.4.

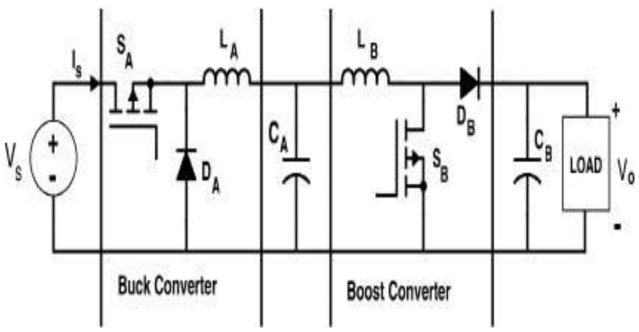


Figure 4. Cascaded Buck Boost converter

A generalized analysis and style of Cascaded buck & boost converters are proposed. The operation of a buck & boost converter along side the consequences of inductor coupling on the key converter performance parameters like inductor ripple current, input ripple current, and minimum load as shown in Table 2

Table 2. Measured values of erformance parameters

Parameters	Theoretical Values
Input voltage $Vin_{(avg)}$	9.5 V
Efficiency of the converter (ŋ)	85%
Buck Inductor (L_1)	0.78 H
Boost_Inductor (L_2)	564 µH
Buck_Capacitor (C_1)	220 µF
Boost_Capacitor (C_2)	22 µF
Switching frequency (F_S)	25 kHz
Buck_Duty cycle (D1)	42.10 %
Boost_Duty cycle (D2)	20.83 %
Load resistance (R_L)	1000 Ώ
Output voltage ripple (ΔV_{out})	1.63 V
Inductor ripple current (ΔI_L)	1.350 A
Output voltage (V_{out})	12 V (Boost)
Output voltage (V_{out})	4 V (Buck)

IV. PWM Signal Generation

PWM signals are used for governing the amplitude of digital signals to control bias and operations taking power or electricity. Due to the high frequency of this mode is smart used for DAC, fading LEDs, rectification, and Power regulation. AVR Counters have different modes of counting. This results in different PWM signals being generated. They're quick PWM and Phase Correct PWM as shown in Fig. 5.

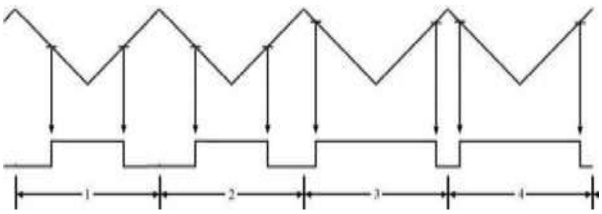


Figure 5. Phase correct PWM

A.Timer/ counter Modules:

Multipurpose tackle inside the AVR that can perform a variety of functions similar as

• Generating PWM signals Freq & Duty – analogWrite ()

• Keeping track of time- detention (), millis ()

Generating interrupts to run a function at a specific time interval

In Arduino UNO, We've used Timer 0 libraries to initiate

timekeeper 1 legs for generating frequency and duty cycle. Arduino has three timekeepers, Timekeeper 0, Timekeeper 1, and Timekeeper 2 which are used to control the PWM legs

• Legs 5 and 6 are controlled by Timekeeper 0.

• Legs 9 and 10 are controlled by Timekeeper 1.

• Legs 3 and 11 are controlled by Timekeeper 2.

Generating frequency and duty cycle in CRO.

It's programmed to induce a constant switching frequency of about 25kHz and a variable duty cycle as shown in Fig.6. &Fig. 7. Leg 9,10 and Leg Gnd are given as input to the MOSFET switch.

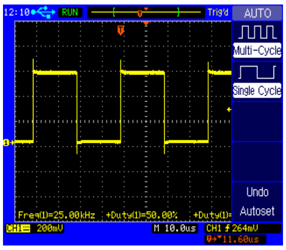


Figure 6. Duty Cycle 50%

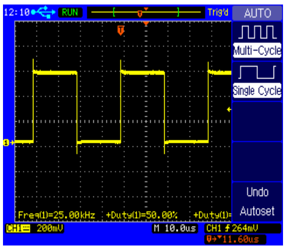


Figure 7. Duty cycle (80%)

V. Component Specifications

The prototype model developed using the hardware materials as shown in Table 1.3. The Arduino microcontroller, which plays a vital role in controlling the cascaded buck & boost converter producing constant switching frequency and variable duty cycle according to the manual feedback entered in arduino coding. The below components specified in Table 3 shows the integrated components and their specified ratings to make the converter topology.

Table 3. Ratings of the Components

Components	Ratings
PV panel	18W; 12V; 1.50A
Potentiometer	1k ohm
Inductor (E-type Bobbin Core)	560 µH/10A
Inductor (Toroidal Core)	0.78H/10A
Mosfet	IRF540/100V;23 A
Capacitor	220 µF/63V
Capacitor	22 µF/63V
Diode (Ultrafast)	UF4007
Load resistor	1000 Ω
Current Limiting resistor	10 kΩ; 10 Ω
Arduino	Arduino UNO
Heat sink with screws	58 °C
Dotted Board	12 x 8; 18 x 10

VI. Software Implementation

The simulation model for cascaded control of DC-DC switching converters is build using MATLAB Simulink.. The DC-DC buck, boost, buck-boost, and Cascaded buck-boost converters was designed, and simulated on digital computer using Matlab package with the parameters given in Inductor current and capacitor voltage for the transient variation of load.

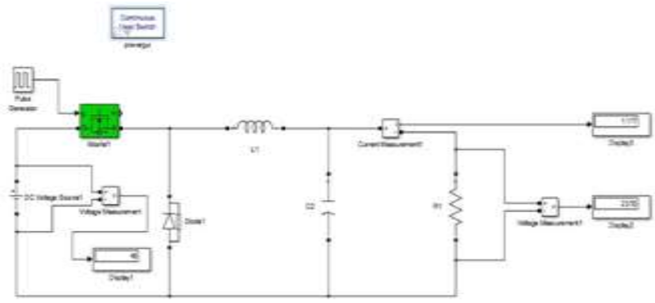


Figure 8. Simulation of buck converter

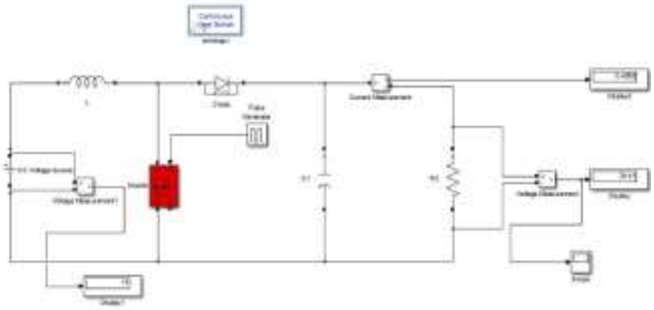


Figure 9. Simulation diagram of boost converter

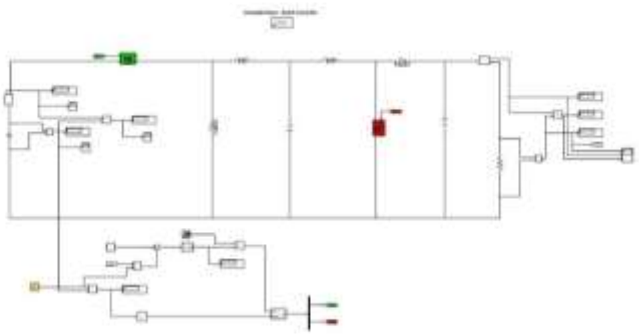


Figure 10. Simulation diagram of cascaded buck-boost converter

A. Results and discussion of Simulation model

When, analyzing the cascaded converter with respect to load with variable voltages, controller in Simulink encouraging results were obtained. When voltage varies with respect to irradiation due to sunlight variable voltage occurs as specified in table 4.Automatic duty cycle changes with respect to increase or decrease in input voltage to maintain the constant desired, specified voltage.

Note:

1. When, varying the input voltage from (6- 12)V the constant output of 4V is given by the converter in order to maintain the constant voltage charging as shown in Table 1.4.
2. In order to satisfy the battery load, we need to maintain the output to 12V condition where there is any changes in input voltage due to solar irradiation.
3. Since we developed the prototype model of Cascaded buck-boost converter with cascaded option we cut off the system under low solar irradiance condition (i.e.)., Less than 8V.
4. Randomly validating the output voltage waveforms is generated with 8V & 11.5V input voltage to maintain constant 12V charging.

5. The output voltage waveform of Cascaded buck-boost converter while boosting the input voltage of 8V to 12V under 1000 Ω load condition.

Table 4. Simulation Results

S.No	Input voltage $V_{in}(avg)$	Output voltage V_{out}	Cascaded operation
	Variable Input	Constant Output	
1.	(6 – 12) V	4.25 V	BUCK MODE
2.	(9 – 12) V	8.40 V	
3.	(8 – 12) V	12.3 V	BOOST MODE
		16.5 V	
		20.4 V	
		24.6 V	
4.	Less than 8 V	CUTTOFF MODE	

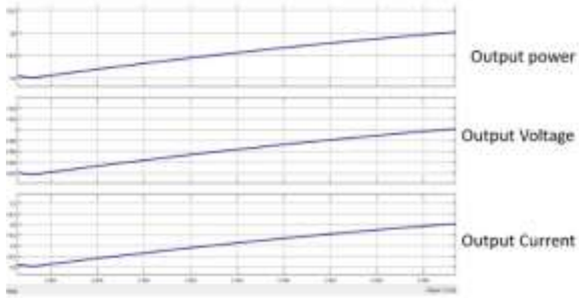


Figure 11. Simulation result of Cascaded buck-boost converter

VII. Hardware Implementation

PV Panel source 18W supplied as a source to the Cascaded buck- boost converter and desired output value declared through arduino coding. Since, battery acts as load as shown in Fig12. The Cuk Converter as shown in Fig.12 contains toroidal core and Bobbin E type core inductor value of 564μH, 0.8H with respective to output capacitor value of 22μF and 220μF and reverse blocking diodes. Mosfet switch IRF540 is chosen for switching circuit and the gate pulses to the switch are given through Arduino microcontroller unit operating at 25 kHz switching frequency through pull up & pull down resistor

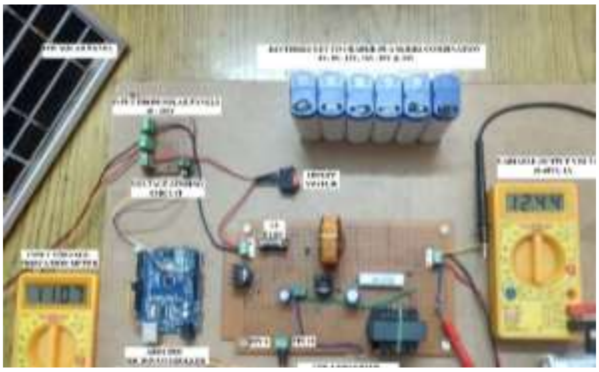


Figure 12. Experimental setup of PV based Cuk converter for battery charging

Note:

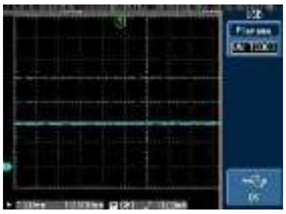
1. When, varying the input voltage of solar panel manually using potentiometer from (8-12)V the constant output of 12V is given by the converter in order to maintain the constant voltage

for the battery load as shown in Table 4.

2. During morning, the solar irradiation will directly satisfy the load batteries.
3. Since we developed the prototype model of Cuk converter with cascaded option, we cutoff the system under low solar irradiance condition (i.e.)., Less than 8V, it cannot able to satisfy the rated current of battery load.

A. CRO Images

Hence, for charging 4V, 8V, 12V, 16V, 20V & 24V battery various CRO Scope results were obtained by analyzing the cascaded converter. Connecting each 4V batteries in series to form the respective battery voltages according to the applications and usage as shown in Fig.13 to Fig



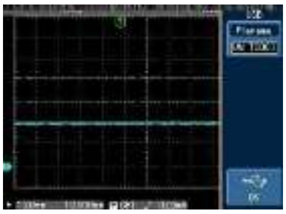


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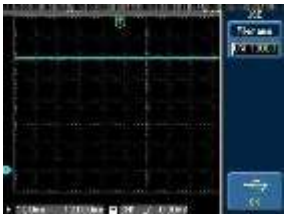
Figure13. Scope 4V Figure 14. Scope 8V Figure 15. Scope 12V

Figure 16. Scope 16V Figure 17. Scope 20V Figure 1. Scope 20V



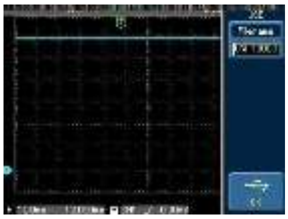


Table 5. Input and output tabulation for various battery system

Input voltage (Vin)	Output voltage (Vout)	Cuk operation (Buck/Boost)
Variable Input	Constant Output	
8.00 V	4.29 V	Buck
8.49 V	4.33 V	
9.08 V	4.30 V	
9.58 V	3.86 V	
10.01 V	4.26 V	
10.41 V	3.87 V	
11.07 V	4.93 V	
11.94 V	4.17 V	
8.00 V	12.14 V	Boost
8.49 V	12.35 V	
9.08 V	12.20 V	
9.58 V	12.45 V	
10.01 V	12.41 V	
10.41 V	12.67 V	
11.07 V	12.44 V	
11.94 V	12.39 V	

VIII. Conclusion

In this work, a Cuk Converter system is designed to tackle the constant voltage and continuous current to the load without any interruption using cascaded buck & boost operation with reference to the input power sensing and manual output load intimating through Arduino coding. The simulation results show that the capability of the converter is improved by reducing the input voltage & current ripple. The converter also capable of buck/boost the average input power to run the variable battery loads such as 4V, 8V, 12V, 16V, 20V & 24V through mosfet switching. In this work cascaded buck-boost converter was designed and the simulation results obtained for the proposed system and the performance of the same will be validated using experimental results. The performance of the converter was analyzed using prototype by both buck & boost operation where rated input voltage of solar panel value from (8-12)V is boosted to 12V, 16V & 24 V then also reduced to 4V & 8 V without any congestion.

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