



HIGH EFFICIENT DC-DC CONVERTER FOR PORTABLE DEVICE

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ABSTRACT

This paper presents a high-efficiency and smooth transition buck-boost converter to extend the battery life of portable devices. The operation time of portable devices decreases significantly with their increasing functions. This problem could be solved by using a non-inverting buck-boost dc-dc converter. Therefore, over a wide input voltage range, the proposed buck-boost converter which has only two switches instead of four power switches is used, to reduce conduction and switching losses. Especially, the proposed buck-boost converter offers good line/load regulation and thus provides a smooth and stable output voltage when the battery voltage decreases. Simulation results show that the output voltage drops is very small during the whole battery life time and the output transition is very smooth during the mode transition by the proposed buck-boost control scheme.

Keywords: buck-boost, efficiency, mode transition.

1. INTRODUCTION

Portable devices have been introduced to the market in the past few decades, these battery-powered devices, such as smart phones and laptops, provide more and more functions, but the battery capacity did not grow as fast as the number of functions provided by these devices. So the operation time of portable devices decreases significantly with their increasing functions. Hence, development of efficient power management system for extending the operation time of portable devices is very important.

For many portable devices Li-ion battery is most popularly used.

The output voltage of a Li-ion battery may gradually decrease with time it could be higher or lower than the required voltage. This problem could be solved by using a non-inverting buck-boost dc-dc converter. However, there are four power switches in a non-inverting buck-boost converter, while there are only two switches in a buck or boost converter. More power switches imply more conduction and switching losses. To reduce the loss of switches, as the positive buck-boost converter operates in wide-range supply voltages, it is necessary to avoid power converters operating in buck-boost mode. Recently in literature, some studies have been developed for controlling of this type of DC-DC converter [9]. Mostly, classic and state feedback control strategies have been designed for non-inverting buck-boost converter. The "min" disadvantage of these control strategies is that they work on fixed operating point. Meanwhile if the input voltage cell of converter or load current change, the designed controller could not operate well. Also, the disadvantages of conventional buck-boost converters are right half (RHP) zeros which restrict the controller response [7].

The positive buck-boost converter can operate in buck mode, Buck-boost mode, and boost mode. But the switching of converters between buck and boost mode is not spontaneous and time taking. Hence, a control strategy should be developed. Feedback controller is used to achieve smooth mode transition in a non-

inverting buck-boost converter. This controller technique has the advantages of more robustness and faster dynamics compared to PI or PID conventional controllers. Based on above justifications, the feasibility of the non-inverting buck-boost converter for battery charging applications is investigated. This paper is organized as follows: In section I, Various non-inverting buck-boost converters are studied, in section II, the preminent converter is proposed and in section III, hybrid fuzzy/ state feedback controller is designed.

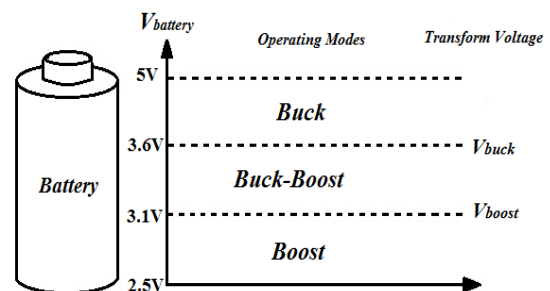


Figure-1. Illustrates the mode of operation of the converter with respect to the voltage level of the battery.

2. PROPOSED METHOD

The converter will operate in different modes: buck, boost, and buck-boost mode according to the relationship between input and output voltage. With the mode select circuit such as buck, boost & buck boost operations can be performed. Four power transistors cause more switching loss and conduction loss in the positive buck boost converter. So it is necessary to avoid power converters to operate in buck-boost mode to reduce the losses to as the positive buck-boost converter operates in wide-range of supply voltages. Therefore, we design a mode-select circuit to detect the output voltage and select the operation mode. It uses only two power transistors when the converter operates in buck mode or boost mode. The conduction loss and switching loss of the



proposed converter can be reduced by using proper control strategy. The proposed converter can operate in wide supply voltage range and extend the battery life.

Firstly, we try various non-inverting buck-boost converters and find the preeminent converter and then we try various control strategies. Initially, a PI controller is used and later fuzzy logic is applied for smooth mode transition of proposed converter.

A. Mode transition issue

Converter cannot decide to work in the buck or boost mode just by comparing the input voltage (V_{IN}) with the output voltage (V_{OUT}) because of the parasitic resistance of the inductor and power transistors. Instead, it should compare ($V_{IN} - V_{PAR}$) with V_{OUT} , where V_{PAR} is the sum of voltage drop across those parasitic resistors. However, it is difficult to know the value of V_{PAR} exactly. Moreover, due to the delay time of the circuits, it is practically difficult to generate a duty ratio around 0-5% or 95-100%. Hence, the discontinuity in the extremely low and high duty-ratio ranges may result in larger output voltage ripples during this transition region (i.e., $V_{IN} \approx V_{OUT}$). In this work, a better control method is proposed.

B. Block diagram and fundamentals of the proposed non-inverting buck-boost converter

Figure-2 shows the block diagram of the proposed method for smooth mode transition of converter, where solar photovoltaic system is used as input and a closed loop control with non-inverting buck-boost converter is implemented. A proportional-integral (PI) compensator is adopted, and it compares the feedback signal V_{FB} with a reference voltage V_{REF} , and sends a control signal VC to the PI controller.

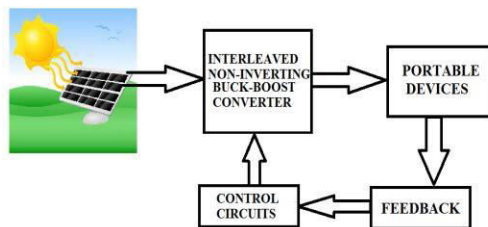


Figure-2. Block diagram of proposed system.

C. Photovoltaic system

With increasing concerns about fossil fuel deficit, sky rocketing oil prices, global warming, and damage to environment and ecosystem, the promising incentives to develop alternative energy resources with high efficiency and low emission are of great importance. Among the renewable energy resources, the energy through the photovoltaic (PV) effect can be considered the most essential and prerequisite sustainable resource because of the abundance, and sustainability of solar radiant energy. Regardless of the intermittency of sunlight, solar energy is widely available and completely free of cost. Solar cell is the basic building block of solar panel. A number of

solar cells are arranged in series and parallel combinations to form a solar PV module. Recently, photovoltaic array system is likely recognized and widely utilized to the forefront in electric power applications.

Being a semiconductor device, the PV system is static, quite, and free of moving parts, and these make it have little operation and maintenance costs. Even though the PV system is posed to its high capital fabrication cost and low conversion efficiency, the skyrocketing oil prices make solar energy naturally viable energy supply with potentially long-term benefits. The output characteristics of PV module depends on the solar insolation, the cell temperature and output voltage of PV module. The mathematical PV models used in computer simulation have been built for over the past four decades. Almost all well-developed PV models describe the output characteristics mainly affected by the solar insolation, cell temperature, and load voltage. However, the equivalent circuit models are implemented on simulation platforms of power electronics. Recently, a number of powerful component-based electronics simulation software Package has become popular in the design and development of power electronics applications. The simplest equivalent circuit of a PV cell is a current in parallel with a diode. The output of the current source is directly proportional to the light falling on the cell. During darkness, the PV cell is not an active works as a diode, i.e., a p-n junction. It produce neither a current nor a voltage. However, if it is connected to an external supply it generates current, called diode current or dark current.

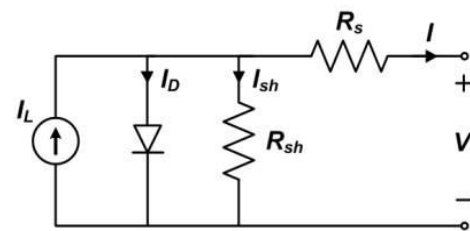


Figure-3. Equivalent circuit of PV cell.

D. Sepic converter

S EPIC (Single ended Primary Inductor Converter): Much attention has been given to the S E P I C topology recently because output voltage may be either higher or lower than input voltage. The output is also not inverted as is the case in a fly back or Cuk topology. Voltage conversion is accomplished with isolation transformer, instead of using inductors to transfer energy. The input and output voltages are DC isolated by a coupling capacitor and the converter works with constant frequency PWM.

A SEPIC is essentially a boost converter followed by a Buck-Boost converter, therefore it is similar to a traditional Buck-Boost converter, but has advantages of having non-inverted output (the output has the same voltage polarity as the input), using a series capacitor to



couple energy from the input to the output (and thus can respond more gracefully to a short-circuit output), and being capable of true shutdown when the switch is turned off, its output drops to 0 V, following a fairly hefty transient dump of charge.

SEPIC principle of operation

As with other switched mode power supplies, SEPIC converter exchanges energy between the capacitor and inductors in order to convert from one voltage to another. The amount of energy exchanged is controlled by switch S1, which is typically a transistor such as a MOSFET. MOSFETs offer much higher input impedance and lower voltage drop than bipolar junction transistors (BJTs), and do not require biasing resistors as MOSFET switching is controlled by differences in voltage rather than a current, as with BJTs.

Design equations

Output voltage is given by: $V_{out} = V_{in} * D / (1-D)$

The calculation of capacitance is given by: $C_p > I_{OUT} \alpha m \text{ in } T / (\gamma V_{INmin})$

The inductance for L1 is given by:

$$L1_{min} = 2 T (1 - \alpha_{max}) V_{INmax} / I_{OUT}$$

The calculation for L2 is similar to that for L1: $L2_{min} = 2 T \alpha_{max} V_{INmax} / I_{OUT}$

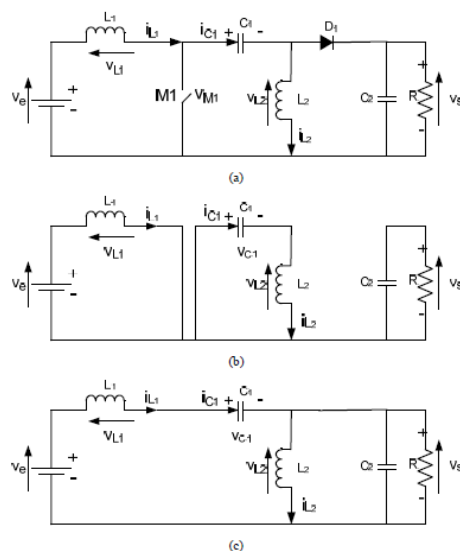


Figure-4. Shows the basic circuit of SEPIC converter and its different modes, (a) SEPIC converter circuit, (b) Equivalent circuit when M1 is ON, (c) Equivalent circuit when M1 is OFF.

E. ZETA converter

Similar to the SEPIC DC-DC converter topology, the ZETA converter topology provides a positive output voltage from an input voltage that varies above and below the output voltage. The ZETA converter also needs two inductors and a series capacitor, sometimes called a flying capacitor. Unlike the SEPIC converter, which is configured with a standard boost converter, the ZETA converter is configured from a buck controller that

drives a high-side PMOS FET. The ZETA converter shown in Figure-5 is another option for regulating an unregulated input-power supply, like a low-cost wall wart.

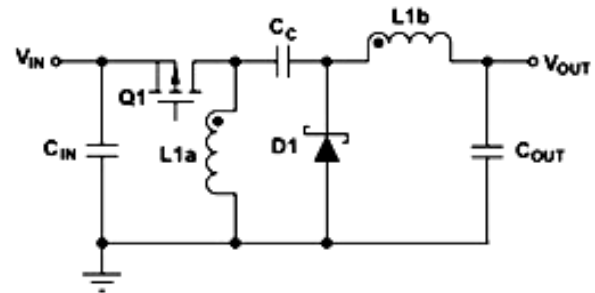


Figure-5. Equivalent circuit of ZETA converter.

Design equations

- Duty cycle, $D = V_{OUT} / (V_{IN} + V_{OUT})$
- The inductance is given by:

$$L \geq [(1-D)RL] / (2F)$$

- The calculation of capacitance is given by:

$$C1 \geq D / [8F(1-D)RL] \quad C2 \geq 1 / (8FRL)$$

F. Solar based interleaved buck-boost converter

A buck (step-down) converter combined with a boost (step-up) converter. The output voltage is typically of the same polarity of the input, and can be lower or higher than the input. Such a non-inverting buck-boost converter may use a single inductor which is used for both the buck inductor mode and the boost inductor mode, using switches instead of diodes. It may use multiple inductors or only a single switch as in the SEPIC and Cuk topologies.

Design calculation for buck-boost converter

Output voltage $V_0 = (D / (1-D)) V_s$, Volts Where,

V_0 = Converter Output Voltage, Volts V_s = Converter input voltage, Volts

D = Duty Cycle (t_{on} / T)

Inductance, $L = (D * V_s) / (f * \Delta I)$

Capacitance, $C = (D * I_{O(AVG)}) / (f * \Delta V)$

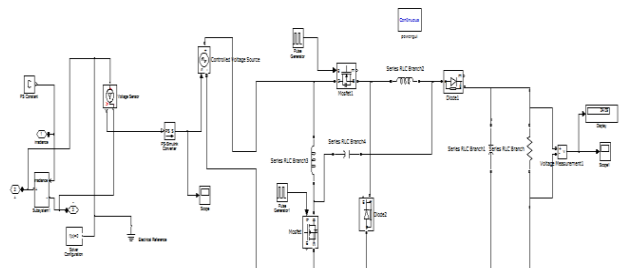


Figure-6. Basic circuit of interleaved buck-boost converter.



3. SIMULATION RESULTS

Simulation results for various non-inverting buck-boost converters are shown below. It is observed that in SEPIC converter the output voltage is 18.59V and the ripple in output voltage is about 3V. Since the SEPIC converter transfers all its energy via the series capacitor, a capacitor with high capacitance and current handling capability is required. Whereas in ZETA converter, the observed output voltage is 16.97V and the ripple in output voltage is about 0.05V. Though output-voltage ripple is less it is difficult to control and the output voltage obtained is very low than required.

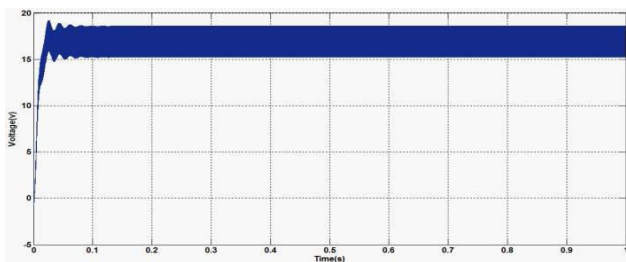


Figure-7. SEPIC converter output waveform.

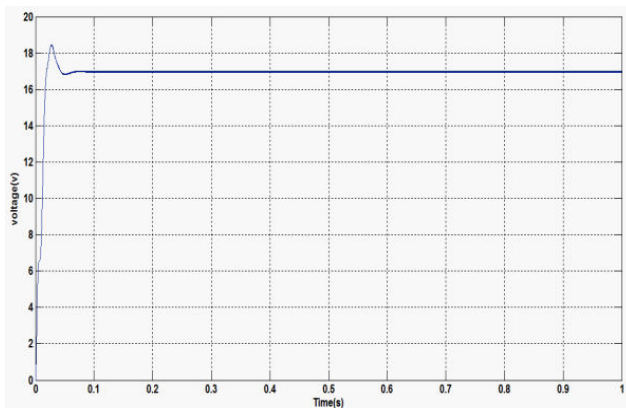


Figure-8. ZETA converter output waveform.

On other hand, it is observed that the ripple in output waveform is comparatively decreased in interleaved buck-boost DC-DC converter. The inductor and switch conduction losses are normalised when compared to the losses in the standard buck-boost converter. It provides fast dynamic response.

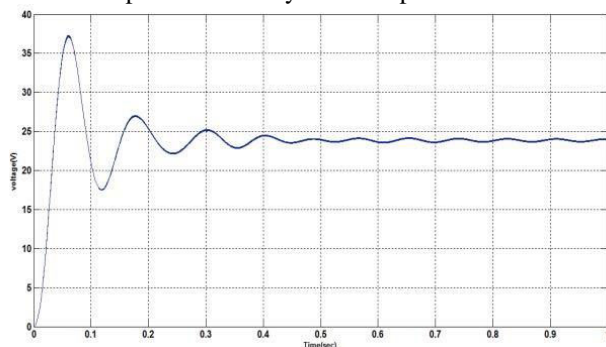


Figure-9. Solar based interleaved buck boost output waveform.

Parameters	SEPIC	ZETA	Interleaved buck-boost
RISE TIME	0.005	0.002	0.05
OUTPUT VOLTAGE	18.59	16.97	23.72
VOLTAGE RIPPLE	3	0.05	1
SETTLING TIME	0.1	0.045	0.35
PEAK TIME	0.025	0.030	0.06

From the above comparison it is observed that interleaved buck-boost converter has less voltage ripple and better output voltage than other standard buck-boost converter. Hence it is the preminent converter.

CONCLUSIONS

The implementation of a positive buck-boost converter with mode-select circuit and with wide range of input voltages is proposed in this paper. By mode-select circuit losses are reduced. Four power transistors produce more conduction losses and switching losses when operated in high frequency by using mode-select circuit we can operate the converter in three different modes as buck, boost and buck-boost mode. To minimize the loss of switches, as the positive buck-boost converter operates in wide range of input voltages, it is necessary to avoid power converters operating in buck-boost mode. Therefore, the mode-select circuit is designed to detect battery energy and select the operating mode. The feed-forward techniques with fuzzy logic controller is used to improve its transient response when the supply voltage changes. It is typically used to compensate the input variations and provide tighter control response of the output voltage. By using the above mentioned techniques, the proposed converter improves power efficiency and extends the battery life.

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