A Charger for Portable Devices

Anjana Sivan and R.S. Sreelekshmi

Abstract**—***Chargers are those devices which require a constant output voltage. For constant output voltage, especially for portable devices , buck-boost converters are usually employed as the charging circuit. Buck-boost converters are dc-dc converters, which is a combination of buck and boost converters. In a conventional non-isolated voltage buck/boosting converter, even though the voltage remains constant, the output current is pulsating. Therefore, the voltage across the output capacitor contains more voltage ripple. Here, a new charging circuit is explained. In the proposed charging circuit, the voltage remains constant with a non-pulsating output current. In this paper, the proposed charging circuit is illustrated in detail and the comparison of conventional buck-boost converter with the proposed converter is also explained.*

Keywords*-Buck-Boost Converter, KY Converter, Non-Pulsating Current, Output Voltage Ripple*

I. INTRODUCTION

POWER electronics is the field of electrical engineering related to the use of semiconductor devices to convert power available from a source to that required by a load. The load may be AC or DC, single-phase or three-phase, and may or may not need isolation from the power source. The power source can be a DC source or an AC source, an electric battery, a solar panel, an electric generator or a commercial power supply. A converter takes the power provided by the source and converts it to the form required by the load. The converter can be an AC-DC converter, a DC-DC converter, a DC-AC inverter or an AC-AC converter depending on the application. Variable output voltage and frequency are transformed to constant values by means of power electronic converters. For many applications, the voltage ripple should be considered. Usually, the chargers for the portable devices employ traditional buck-boost converters as there may be variations in the battery output voltage. Buck-boost converters have a pulsating output current with a constant output voltage. Since, the output current is pulsating, the output voltage ripple tends to be very large [1], [5]. As a result, the system stability and the transient response is very low. To overcome all these problems, a new charging circuit has been presented here. The proposed circuit is a buck-boost converter which is a combination of KY and buck converter. The advantage of this circuit compared to the traditional non-isolated voltage buck/boosting converter is that the output current is non-pulsating. Therefore, the output voltage ripple also gets reduced. The proposed circuit also maintains the voltage constant. Furthermore, the traditional buck-boost converter has a negative output voltage for a positive input voltage and vice-versa. Here the proposed charging circuit, basically a buck-boost converter, produces a positive output voltage for a positive input voltage [2]. Moreover, the circuit presented here consists of minimum number of switches, as the KY converter and the buck converter is combined into a buck-boost converter, both using the same power switches. Due to the decreased number of components in the circuit, the overall system cost as well as the complexity of the circuit is reduced.

The converter proposed here is used to voltage buck/boost only for a narrow range. This converter cannot be used to buck/ boost to very large voltages as the voltage conversion ratio is very low compared to the other traditional buck-boost converters. Therefore, such converters can be used for portable devices compared to the traditional buck- boost converters which can be used for sustainable energy applications as their voltage conversion ratio is high. The proposed converter always has CCM mode of operation. In this paper, the detailed illustration of the converter operation is explained, along with simulation results to verify the performance of the proposed converter topology which can be used as a charging circuit. The paper is divided into five sections. Here, Section II presents the proposed converter topology, section III illustrates the operating principle, section IV explains the control method applied, section V gives the simulink model and the simulation results of the proposed converter, section VI gives the comparison of a conventional buck-boost converter with the proposed converter, and section VII makes some conclusion.

II. PROPOSED CONVERTER TOPOLOGY

Fig.1 shows the proposed buck-boost converter, a combination of two converters which is the KY converter and the buck converter. The proposed circuit consists of minimum number of components as can be seen in the fig.1. The power switches S_1 and S_2 are MOSFETs that are driven by gate pulses generated from the control block. The gate pulses applied to the two switches are complementary to each other. Here the buck converter is built by two power switches S_1 and S_2, an inductor L_1 and a capacitor C_1. The other converter is the KY which also has two switches S_1 and S_2, a power diode D_1, energy transferring capacitor C_2, an inductor L_2 and an output capacitor C_0. The power diode D_1 is connected to the output of the buck converter. The power loss in the circuit is mainly due to the voltage drop across the diode D_1. Here capacitance C_2 is connected in parallel with capacitance C_1.

Since both the KY and Buck converters have individual output inductors, the output currents tends to be pulsating. The

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presence of the two inductors makes the converter to operate in CCM mode. Here the dc input voltage is signified by V_i, the output load is represented by one resistor R_0, and the dc output voltage across R_0 is indicated by V_o. Here the converter has two periods of operation. One is the magnetization period and the other is the demagnetization period. During the magnetization period, the input voltage of the KY converter is from the input voltage source and during the demagnetization period, the input voltage to the KY converter comes from the output voltage of the buck converter.

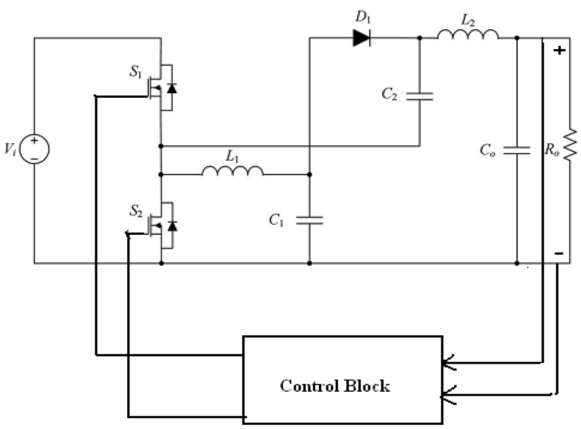

Fig.1. Proposed charging circuit

III. OPERATING PRINCIPLE

The proposed converter is a switching mode dc-dc converter employing pulse width modulation technique. Here the energy is transferred from the voltage source to the load. The circuit operates at a fixed switching frequency. The operation of the proposed converter can be described in magnetization period and demagnetization period. Here the control block generates the PWM pulses required for the complementary working of the switches.

For the convenience of analysis of the proposed converter, some assumptions are given as follows [1] :

1) all the components are ideal;

2) the voltage drops across the switches and diode during the turn-on period are negligible;

3) the dc input voltage is signified by V_i , the dc output voltage is represented by V_0 , the duty ratio is represented as D and the switching time period as T_s , the dc output current is expressed by I_o, the gate driving signals for $S_1$and S_2 are indicated by G_1 and G_2 , and the voltages on S_1 and S_2 are represented V_{S1} and V_{S2} , respectively, the voltages on L_1 and L_2 are denoted by V_{L1} and V_{L2}, the currents in L_1 and L_2 are signified by I_{L1} and I_{L2}, and the input current is expressed by I_i ;

As the input voltage is applied to the proposed converter, the switch S_1 turns ON and the switch S_2 turns OFF. During this mode of operation, the input voltage is supplied to the inductor L_1 and the capacitor C_1.As a result, the inductor gets magnetized and the capacitor C_1 gets charged. Therefore, the voltage across the capacitor C_1 is positive. Hence, the voltage across the inductor is the difference in the input voltage and the voltage across the capacitor. The inductor L_2 also gets magnetized and the energy provided to the inductor L_2 is through the input voltage along with the capacitor C_2. Hence, the capacitor C_2 is reverse charged. Therefore, the voltage across L_2 is the sum of the input voltage and the voltage across the capacitor minus the load voltage. Here the capacitor C_2 gets discharged. Hence, this period of operation is also called as the magnetization period. The corresponding equations are as follows:

$$V_{L1} = V_i - V_{c1} \quad (1)$$

$$V_{L2} = V_i + V_{c2} - V_0 \quad (2)$$

During the second mode of operation, the switch S_1 turns OFF and the switch S_2 turns ON and the input voltage source is isolated from the KY converter. In this mode of operation, the input voltage to the KY converter comes from the output voltage of the buck converter. Here the energy stored in the inductor L_1 and the capacitor C_1 during the first mode of operation is released to C_2 and the output through the inductor L_2. As a result, the inductor L_1 gets demagnetized and the capacitor C_1 gets discharged. Hence, the voltage across the inductor is the negative value of the voltage across the capacitor C_1. The voltage across L_2 is the difference in the voltage across the capacitor C_2 and the output voltage. As a result, the inductor L_2 also gets demagnetized. Here, the capacitor C_2 gets charged. Hence, this mode of operation is also called as the demagnetization period. The corresponding equations are as follows:

$$V_{L1} = -V_{c1} \quad (3)$$

$$V_{L2} = V_{c2} - V_0 \quad (4)$$

$$V_{c2} = V_{c1} \quad (5)$$

The duty ratio of the proposed converter can be found by applying the voltage-balance to (1) and (3) the equation can be obtained as follows [1]:

$$(V_i - V_{c1})DT_s + (-V_{c1}).(1-D)T_s = 0 \quad (6)$$

By simplifying (6) , the equation obtained is

$$V_{c1} = DV_i \quad (7)$$

Similarly by applying voltage balance to (2) and (4), the duty ratio of the proposed converter can be obtained as

$$V_0/Vi = 2D \quad (8)$$

Since the output voltage of the proposed converter is 2D times the input voltage, the proposed converter can work in the buck mode if the duty cycle D is less than 0.5 and in the boost mode if the duty cycle is more than 0.5.

Here the duty cycle varies according to the variation in the input voltage. For an input voltage of 28V the duty cycle will be minimum and duty cycle will be maximum for an input voltage of 20V. The duty ratio can be calculated from (8). The output voltage remains constant for varying input voltage by varying the duty cycle.

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IV. CONTROL METHOD APPLIED

Figure 2 explains the control circuit of the proposed converter. Here the actual voltage thus obtained from the proposed circuit is compared with the reference voltage and the output signal is given to the PI controller as shown in fig.2. The output signal of the PI controller is then compared with a reference signal and the output from the comparator is then given as the gate signals to the two switches. The gate signal applied to switch S_1 is complementary to that applied to switch S_2.

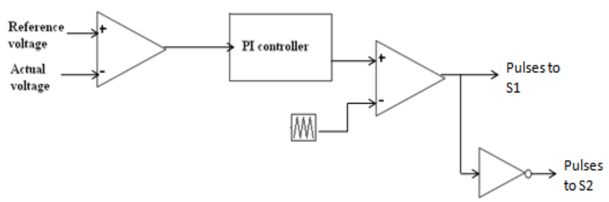


Fig.2.Control circuit of the proposed converter

V. SIMULATION RESULTS AND DISCUSSION

TABLE I PARAMETER SPECIFICATIONS

Parameters	Specifications
Input voltage	20-28V
Inductor L_1	120µH
Inductor L_2	120µH
Capacitor C_1	470µF
Capacitor C_2	100µF
Capacitor C_0	1000µF
Output voltage V_o	25V
Output current I_0	3.9A

The table above gives the values of the parameters used in the simulation. Here the input voltage is varied from 20V to 28V. The output capacitor acts as a filter capacitor and is taken as 1000µF. The output voltage is maintained constant at 25V for the varying input. The output current or the load current is also made constant at 3.9A for rated load condition and the switching frequency is 200kHz. The switching frequency remains constant throughout the simulation. According to the variation in the input voltage only the duty cycle will be varying.

The proposed charging circuit is simulated in MATLAB/SIMULINK and the results are observed. Figure 3 shows the MATLAB/Simulink model of the proposed converter. The circuit is simulated for both the input voltage of 20V and 28V and the results are explained below. The subsystem given in the simulink model in fig.3, is the control block.

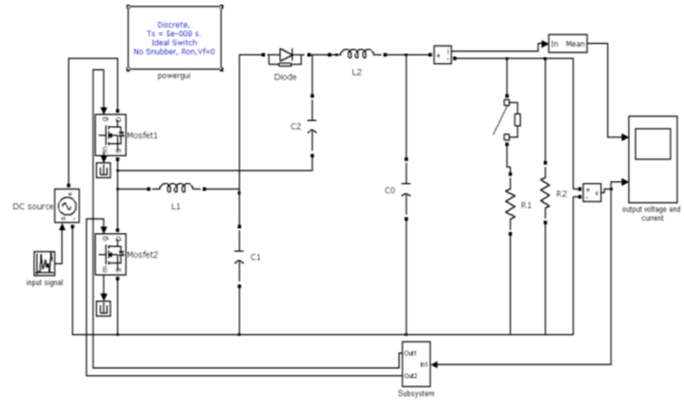
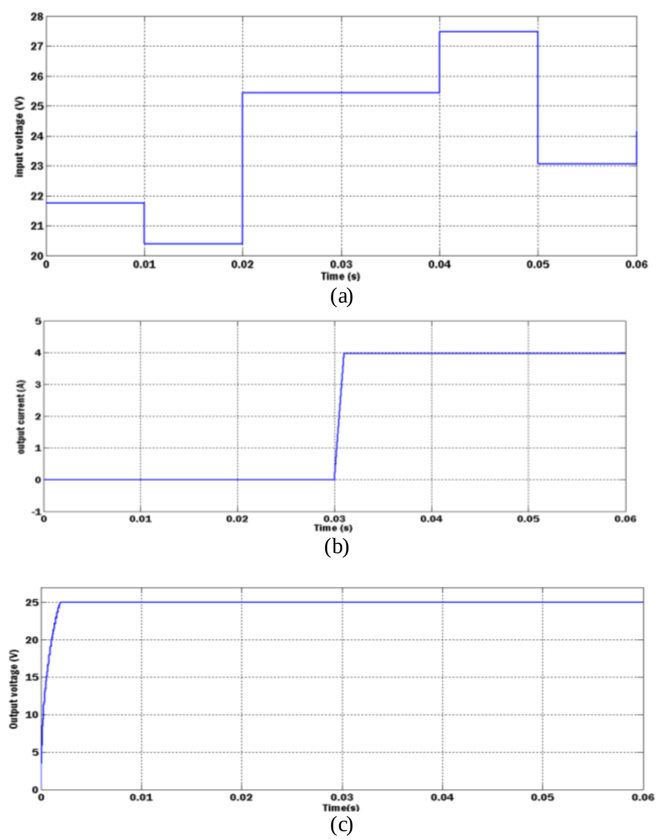
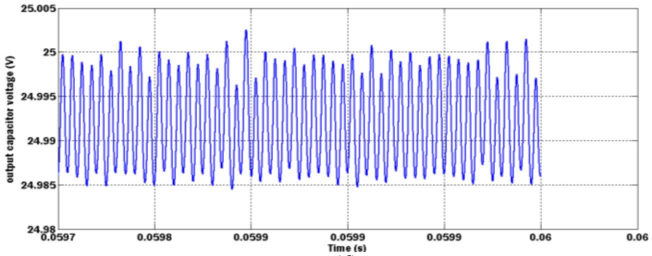


Fig.3. MATLAB / Simulink model of the proposed converter

The simulation waveforms of the proposed circuit is given below. Figure 4 shows the output voltage, the load current and the output voltage for a continuously varying input signal. The minimum value of the step input voltage is set to 20V and the maximum value of the step input voltage is set to 28V. The input signal is shown in fig.4(a). It can be clearly seen that, for any values of input voltage ranging from 20V to 28V, the output voltage is constant and the load current is also non-pulsating even when the load changes from no-load to rated load condition as shown in fig.4(b) and (c). Figure 4(c) gives the output capacitor voltage for the varying input voltage.



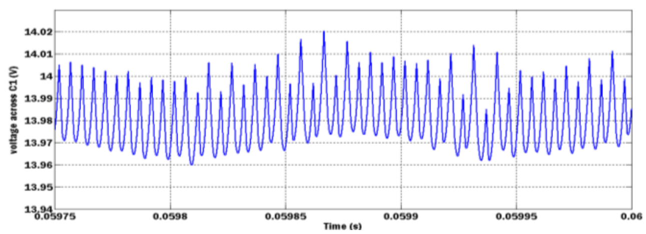
(a) (b) (c)



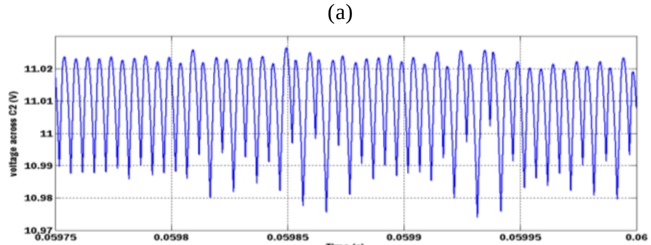
(d)

Fig.4a) varying input voltage b) output current c) output voltage and d) output capacitor voltage due to change of load from no load to rated load

Figure 5 shows the voltages across the capacitors C_1 and C_2. During the magnetization mode, capacitor C_1 charges and capacitor C_2 discharges as given in fig.5 (a) and (b). In the demagnetization mode, capacitor C_2 charges and capacitor C_1 discharges.



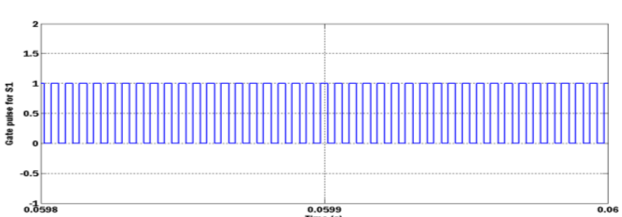
(a)



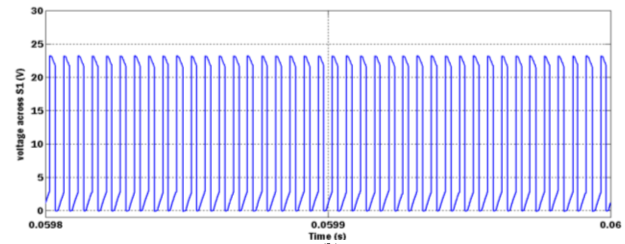
(b)

Fig.5.a) Voltage across capacitor C_1 and b) voltage across C_2 for varying input voltage

Depending upon the switching action, the output voltage remains constant. The switching characteristics of the circuit is shown in fig.6. Here the switching frequency is made constant at 200kHz throughout the operation of the converter. When the pulse is 1, the voltage across the switches have the same amplitude as that of the amplitude of the input voltage applied. The voltage across both the switches are equal in magnitude. Here as seen from the fig.6 (a) and (c), the pulses applied to both the switches are complementary to each other and hence the voltage across the corresponding switches, as shown in fig.6(b) and (d).



(a)



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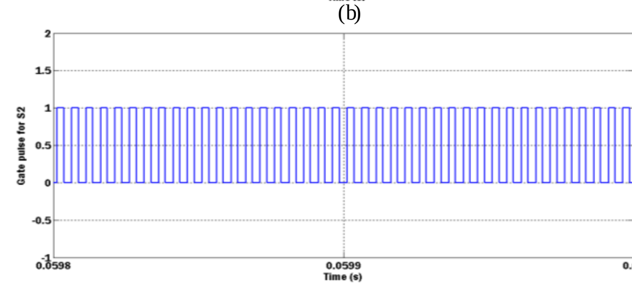
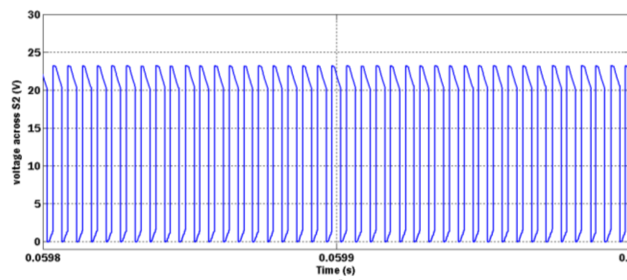


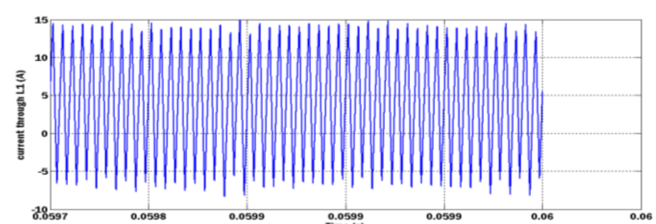
(c)



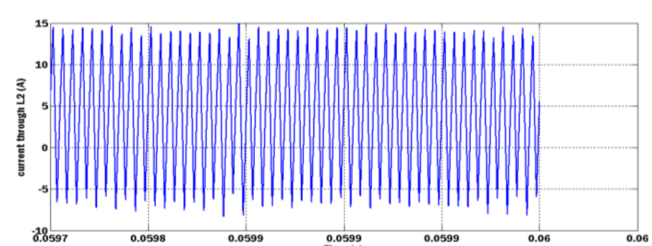
(d)

Fig.6. Switching characteristic a) Gate pulse G_1 for switch S_1 b) voltage across switch S_1 (v_{S1}) c) gate pulse G_2 for switch S_2 and d) voltage across switch S_2 (v_{S2}) for a varying input voltage from 20V to 28V at no load and rated load with respect to time

Figure 7 gives the inductor currents flowing through L_1 and L_2. The inductor current rises to a peak value during the magnetization period and then the current decays during the demagnetization period as shown in fig.7. It can be seen from the fig. below that in both the inductors magnetization and demagnetization takes place at the same duration as explained in the operating modes of the converter.



(a)



(b)

Fig.7. a) Inductor current flowing through L_1 and b) Inductor current flowing through L_2 for varying input voltage

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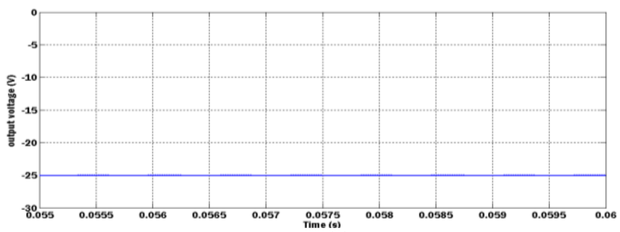
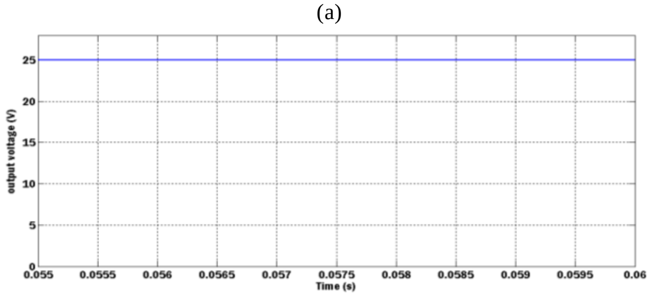
VI. COMPARISON

This section explains the difference between the conventional buck-boost converter and the proposed converter. Here the conventional buck boost converter and the proposed converter is simulated for an output voltage of 25V when the input voltage is 20V. Here a Cuk converter, one among the various conventional non-isolated buck-boost converters, is taken as an example.

As it can be seen from the fig.8(a), the polarity of the output voltage is negative in a conventional Cuk converter whereas in the proposed converter, the output voltage has the same polarity as that of the input voltage as shown in fig.8(b).Therefore, additional components are not required .



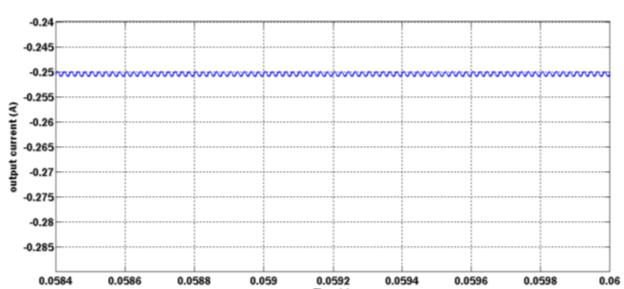
(a)



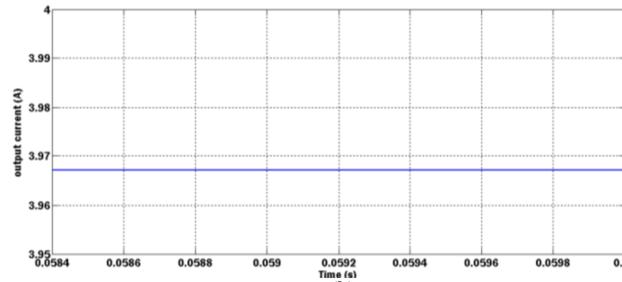
(b)

Fig.8.a) Output voltage for a conventional Cuk converter b) Output voltage of the proposed converter

Figure 9 shows the load current for both the conventional Cuk converter and the proposed converter. As it can be seen from the fig.9(a) that the load current is pulsating which increases the current stress on the output capacitor. In the proposed converter the output current is non-pulsating as shown in fig.9(b).



(a)



(b)

Fig.9.a) Output current for a conventional Cuk converter b) Output current of the proposed converter

VII. CONCLUSION

The proposed charging circuit is discussed. This circuit can be used for portable devices. The advantage of the charging circuit is that due to a non-pulsating output current, the current stress on the output capacitor is less. Unlike the traditional buck-boost converters, the polarity of the output voltage produced is same as the input voltage. Simulation results are also explained. This paper also gives a comparison between the conventional non-isolated buck-boost converter and the proposed converter. The proposed charging circuit explained, is a combination of a KY and buck converter with a closed loop control. Minimum number of components is used in the circuit which reduces the cost and complexity of the circuit. Since only two switches are used in the circuit, the control of the converter also becomes easy. From the simulation results, it can be concluded that, for varying input voltage, the output voltage remains constant and the load current is non-pulsating compared to the conventional non-isolated buck-boost converters as discussed above. The proposed circuit operates stably for a particular range of input voltage. Depending upon the parameters, the circuit operates stably for a range of input voltages which are suitable for portable applications.

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