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PERFORMANCE ANALYSIS OF 2D CONVERTER BY COMBINING SR & KY CONVERTERS

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Abstract-Most mobile equipments use battery as power source. The increasing use of low voltage portable devices and growing requirements of functionalities embedded into such devices. Thus an efficient power management technique is needed for longer battery life for them. Given the highly variable nature of batteries systems often require supply voltages to be both higher and lower than the battery. This is most efficiently generated by a buck-boost switching converter. But here the converter efficiency is decreased since the power loss occurs in the storage devices. Here we analyze and describe step by step, process of designing, feedback control and simulation of a novel voltage-bucking/boosting converter, combining KY and synchronous buck converter for battery power applications. Such a converter operates in continuous conduction mode. Also it possesses the non-pulsating output current, thereby not only decreasing the current stress on the output capacitor but also reducing the output voltage ripple. Both the KY converter and the synchronous buck converter, combined into a positive buck–boost converter, uses the same power switches. Here it makes the circuit to be compact and the corresponding cost to be down.

Index Terms- buck-boost converter, PI control, KY converter, synchronously rectified (SR) buck converter

I. INTRODUCTION

Over the years the portable electronics industry progressed widely. A lot requirement evolved such as increased battery life, small and cheap systems, coloured displays and a demand for increased talk-time in mobile phones. The increasing demand from power systems has placed power consumption at a peak. To keep up with these demands an engineer has worked towards developing efficient conversion techniques and also has resulted in the growth of an interdisciplinary field of Power Electronics. However the introduction of new field has offered challenges owing to the unique combination of three major fields of electrical engineering: electronics, power and control. DC-DC converters are the devices that are used to convert and control the DC electrical power efficiently and effectively from one voltage level to another. The DC-DC converter is a device for converting one DC voltage level to another DC voltage level with a minimal loss of energy. DC conversion technique having a great importance in many applications, mainly from low to high power applications. The circuit mainly consists of at least two semiconductor switches and one energy storage element. The semiconductor switches combines with a diode and a transistor/MOSFET. The Filters made of capacitors. They are normally added to the output of the converter to reduce output voltage ripple. A few applications of DC-DC converters are 5V DC on a personal computer motherboard must be stepped down to 2.5V, 2V or less for one of the latest CPU chips. Where 2V from a single cell must be stepped up to 5V or more, in electronic circuitry operation. Also in LED TV we need 12V output voltage. So we introduce DC-DC converter to step up or step down the voltage to the system. In all of these applications, we want to change the DC energy from one voltage level to another, while wasting of energy as little as possible in the process. In other words, we want to perform the conversion effectively with the highest possible efficiency. DC-DC Converters are in hit list because unlike AC, DC can't simply be stepped up or down using a transformer. DC-DC converter is the DC equivalent of a transformer in many ways. They are essentially just change the input energy into a different level. So whatever the output voltage level, the output power all comes from the input. The fact that some are needful used up by the converter circuitry and components, in doing their work efficiently. A Positive Buck-Boost converter is a DC-DC converter which is controlled to act as Buck or Boost mode with same polarity of the input voltage. This converter has four switching states which include all the switching states of the common DC-DC converters. In addition there is one switching state which provides a degree of freedom for the positive Buck-Boost converter in comparison to the Buck, Boost, and inverting Buck-Boost converters. In other words the Positive Buck-Boost Converter shows a higher level of flexibility, because its inductor current can be controlled compared with the other DC-DC converters. The most common power management problem, especially for battery powered electronics applications, is the need to provide a regulated output voltage from a battery voltage which, when it is charged or discharged. It can be greater than, less than, or equal to the desired output voltage. There are several existing solutions to this problem. But all have significant drawbacks. They are: cascaded buck-boost converter; linear regulator; SEPIC converter; classic 4-switch buck-boost converter; and Cuk-converter. The proposed solution has advantages over all of these converters. Mainly they can improve the efficiency and the simplification of the circuitry needed.

A KY buck–boost converter has been introduced to conquer the mentioned drawbacks of the system. If we introduce a common buck converter with KY boost converter, it has a serious problem in four power switches used. It causes the corresponding cost to be high. Also the switching losses are increased due the increase in number of switching devices. In order to reduce the number of power switches, the KY converter and the SR buck converter, combined into a buck–

boost converter. It also called 2D converter because both use the same number of switching devices. Also the proposed converter has no right half of plane poles due to the input connected to the output during the turn-on period. This converter always operates in continuous current conduction mode due to the positive and negative inductor currents existing at light load. As compared with the other converters, this converter has the non-pulsating output inductor current, thereby causing the current stress on the output capacitor to be decreased. Also the corresponding output voltage ripples to be less. Moreover, this non -inverting converter has the positive output voltage different from the negative output voltage of the traditional buck–boost converter.

In this paper, the detailed study of the operation of this converter, along with some experimental results provided to verify the application wise effectiveness.

II. CIRCUIT CONFIGURATIONS

Normally many applications require voltage-bucking/boosting converters such as LED TV, mobile devices, portable devices, car electronic devices, etc. This is because the battery has quite large variations in output voltage; and hence the additional switching power device is needed for processing the varied input voltage so as to generate the stabilized output voltage. There are several types of non- isolated voltage buck-boosting converter, such as Cuk converter, Zeta converter, inverting buck–boost converter, single-ended primary-inductor converter (SEPIC), Luo converter and its derivatives, etc. However these converters are operating in the continuous conduction mode (CCM). But while taking transfer function we can analyze that they possess left half of the plane poles which are near to imaginary axis, thus causing system stability to be low by root locus. Root locus is a method to establish the stability of a single input, single output system. For the application of the power supply using the low voltage battery, analogue circuits, such as radio frequency amplifier often need high voltage to obtain enough output power and voltage amplitude. This is done by boosting the low voltage to the high voltage required. Therefore, for many of computer, mobile electronic products to be considered, there are some converters needed to supply above or under voltage 1especially for portable communications systems, such as iPods, musical devices, Bluetooth devices, personal digital iPods, etc. For such applications, the output voltage ripple must be taken into account. Regarding the traditional inverting buck–boost converter, their output currents are pulsating, thereby, causing the corresponding output voltage ripples to be large. To overcome these problems, one way is to use the capacitor with large capacitance and low equivalent series resistance (ESR) and another way is to add an LC filter to reduce ripples. Also we can increase the switching frequency to reduce the mentioned drawbacks.

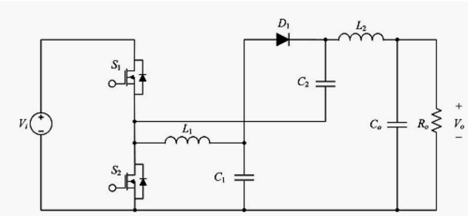

Fig. 1. Proposed buck–boost converter.

Fig. 1. Proposed converter

Figure: 1 shows a novel buck–boost converter, which combines a synchronous buck converter and KY boost converter. The SR buck converter, which consists of two power switches S_1 and S_2, one inductor L_1, one energy -transferring capacitor C_1. The other KY converter is constructed by two power switches S_1 and S_2, one power diode D_1, one energy-transferring capacitor C_2, one output inductor L_2 and one output capacitor Co. The output load is a resistive load and is signified by Ro. During the magnetization period, the input voltage of the KY converter comes from the input voltage source, whereas during the demagnetization period, the input voltage of the KY converter comes from the output voltage of the SR buck converter. In addition, during mode1 operation switches S_1 being ON and S_2 being OFF, L_1 and L_2 are both magnetized. At the same time, C_1 is charged, and hence, the voltage across C_1 is positive, whereas C_2 is reversely charged; and hence, the voltage across C_2 is negative. During the mode2 operation switches S_1 being OFF and S_2 being ON, L_1 and L_2 are both demagnetized. At the same time, C_1 is discharged and C_2 is reverse charged with the voltage across C_2 being from negative to positive. Finally, the voltage across C_2 is the same as the voltage across C_1. Thus the working cycle continues as per sequences.

III. OPERATING PRINCIPLE

The proposed system structure is derived from conventional positive buck boost converter (fig.1) S_1 and S_2 are the main switches. All the components are ideal. The values of C_1 and C_2 are large enough to keep V_{C1} and V_{C2} almost constant. Thus the variations in V_{C1} and V_{C2} are small during the charging and discharging period. The dc input voltage is represented by V_i, the dc output voltage is represented by V_o, and the dc output current is denoted by i_o. The gate driving pulses for S_1 and S_2 are indicated by M_1 and M_2. The voltages on S_1 and S_2 are represented by V_{S1} and V_{S2}. 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}. The currents flowing through $L_1$and L_2 are both positive. Since this converter always operates in CCM, thus the turn-on type is (D, 1−D), where D is the duty cycle.

A.Mode 1:

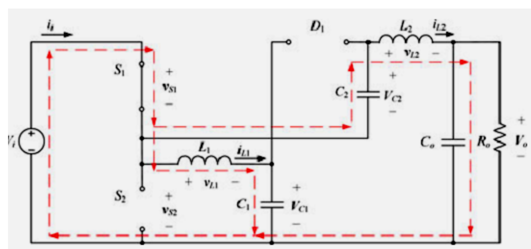

Fig. 2. Current flow mode 1

As shown in figure: 2 S_1 is turned ON but S_2 is turned OFF. During this state, the input voltage provides energy for L_1 and C_1. The voltage across L_1 is V_i minus V_{C1}, thereby causing L_1 to be magnetized and C_1 is charged. At the same time, the input voltage, together with C_2, provides the energy for L_2 and the output. Hence, the voltage across L_2 is V_i plus V_{C2} minus V_o, thereby causing L_2 to be magnetized, and C_2 is discharged. Therefore, the working mode equations are represented as follows

$$V_{L1}=V_i-V_{C1} \qquad \text{--------1}$$

$$V_{L2}=V_i+V_{C2}-V_o \qquad \text{------2}$$

B. Mode 2:

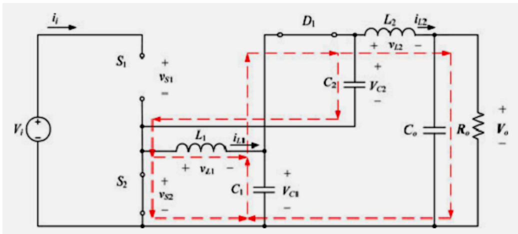

Fig.3. Current flow mode 2

As shown in figure: 3, S_1 is turned OFF but S_2 is turned ON. During this state, the energy stored in L_1 and C_1 is released to C_2 and the output via L_2. The voltage across L_1 is minus V_{C1}; thereby causing L_1 to be demagnetized and C_1 is discharged. At the same time, the voltage across L_2 is V_{C2} minus V_o, thereby causing L_2 to be demagnetized, and C_2 is charged. Therefore, the working mode equations are described as follows:

- $V_{L1} = -V_{C1}$ --------3
- $V_{L2} = V_{C2} - V_o$ --------4
- $V_{C2} = V_{C1}$ ---------5
- By balancing eqn 1 and eqn 3
- $(V_i-V_{C1})DTs+(-V_{C1})(1-D)Ts = 0$ ------6
- $V_iDTs-V_{C1}DTs -V_{C1}Ts+V_{C1}DTs = 0$
- $V_iDTs = V_{C1} Ts$
- $V_{C1}= DV_i$ ----------7
- By balancing eqn 2 and eqn 4
- $(V_i+V_{C2}-V_o)DTs+(V_{C2}-V_o)(1-D)Ts = 0$ ----8
- $V_iDTs+V_{C2}DTs-V_oDTs+V_{C2}Ts-V_{C2}DTs-V_oTs+V_o DTs = 0$
- $V_iDTs+V_{C2}Ts-V_oTs = 0$ ---------9
- Substitute eqn 5 in eqn 9
- $V_iDTs+V_{C1}Ts-V_oTs = 0$ ---------10
- Substitute eqn 7 in eqn 10
- $V_iDTs+V_i DTs-V_oTs = 0$
- $2DV_iTs-V_oTs = 0$
- $2DV_iTs = V_oTs$
- voltage ratio transfer function
- **$Vo/V_i = 2D$**
- Hence $V_{C1}= V_{C2} = 0.5Vo$

IV. APPLICATION IN BATTERY CHARGER

A common power management problem, especially for battery powered electronics applications, is the need to provide a regulated output voltage from a battery voltage which, when charged or discharged. They can be greater than, less than, or equal to the desired output voltage. There are several existing solutions to this problem; But each having significant drawbacks. However, new technologies has developed a solution for a buck-boost converter which maximizes efficiency, minimizes ripple noise on input and output, and minimizes external component requirements and associated cost. We can achieve efficient output voltage effectively. We can use the modified non-inverting buck-boost converter in a combination of different modes as required by the application. The DC-DC converter uses a combination of buck-boost converter and boost converter mode to charge the Li-ion battery as an example. In case of Li-ion, the constant current constant voltage (CCCV) charging is used to charge the battery. Here we have chosen the input voltage just enough to show the functionality of the converter in buck-boost mode.

V. CONTROLLER DESIGN

Based on the research done on the battery power application it is now possible to start developing an efficient control for the plant. As our task is to control the duty cycles of each pair of switches and their phase, so as to ensure the following conditions. Reaching the target steady state should happen in the desired manner, i.e. the controller needs to handle transients properly.

The controller also needs to be able to reject disturbances. First and most important is the reaching of and stabilizing around a given output voltage demand. While doing all this, the controller needs to choose among the infinite possibilities of inputs that would satisfy the above conditions, those that will cause the least losses. To overcome the limitations of the open -loop controller, control theory introduces feedback. A closed-loop controller uses feedback to control outputs of the system. Closed-loop controllers have the following advantages over open -loop controllers: 1)Disturbance rejection. 2) Guaranteed performance even. 3) unstable processes can be stabilized. 4) Reduced sensitivity to parameter variations. 5) Improved reference tracking performance.

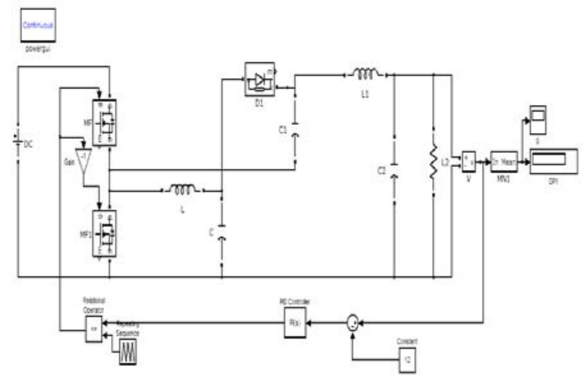

Fig. 4. Simulation block diagram

In this paper we are using PI controller for feedback control. PI controller will eliminate forced oscillations and steady state error resulting in operation of on-off controller and P controller respectively. However, introducing integral mode has a negative effect on speed of the response and overall stability of the system. Thus, PI controller will not increase the speed of response. It can be expected since PI controller does not have means to predict what will happen with the error in near future. This problem can be solved by introducing derivative mode which has ability to predict what will happen with the error in near future and thus to decrease a reaction time of the controller. PI controllers are very often used in industry, especially when speed of the response is not an issue. A control without Dmode is used when; Fast response of the system is not required and large transport delay in the system. Also large disturbances and noise are present during operation of the process.

Since the controller parameter tuning method is widely used in the industry, there are three steps to online tune the parameters of the voltage controller to be described in the following. The proportional gain kp is tuned from zero to the value which makes the output voltage very close to about 80% of the prescribed output voltage. After this, the integral gain k_i is tuned from zero to the value which makes the output voltage very close to the prescribed output voltage but somewhat oscillate. Then, k_i will be reduced to some value without oscillation.

VI. RESULTS AND DISCUSSION

The proposed positive buck-boost converter in figure: 1 was simulated using a matlab simulation program. Figure: 4 shows simulation diagram and waveforms of the converter for the closed loop system with resistive load. The following parameters were adopted in this simulation:

$\Delta i_{L1} = \Delta i_{L2} = 0.5Io{-}rated.$

$L_1 \geq [D_{min} * (V_i - V_{C1})] / [\Delta I_{L1} * f_s]$

$L_2 \geq [D_{min} * (V_i + V_{C2} - V_o)] / [\Delta I_{L2} * f_s]$

$L_1 = L_2 = 14\ \mu H.$

$C_1 \geq [I_o{-}rated * D_{max}] / [\Delta V_{C1} * f_s]$

$C_2 \geq [I_o{-}rated * D_{max}] / [\Delta V_{C1} * f_s]$

$C_1 = C_2 = 470\mu F.$

$V_{in} = 10V$ to $16\ V$

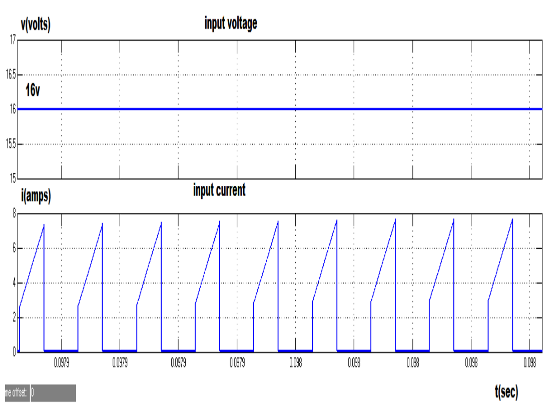

Fig.5. Input voltage & current wave forms

From fig.5. We can observe that the given input voltage is 16v & then we have the output as 12v. Input current contains one spike due to using of inductor. Input current equals 2 times of output current.

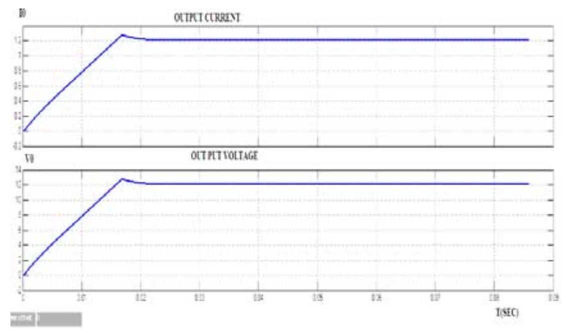

Fig.6. Output current & voltage wave forms

From fig 6. We can observe input voltage is 16v or it may be between 10 to 16 volts by controlled to 12v output. Input current contains one spike due to using of inductor. Input current equals 2 times of output current.

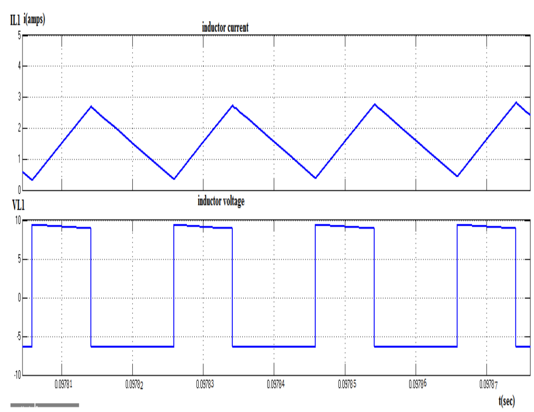

Fig.7. Inductor 1 current & voltage wave forms

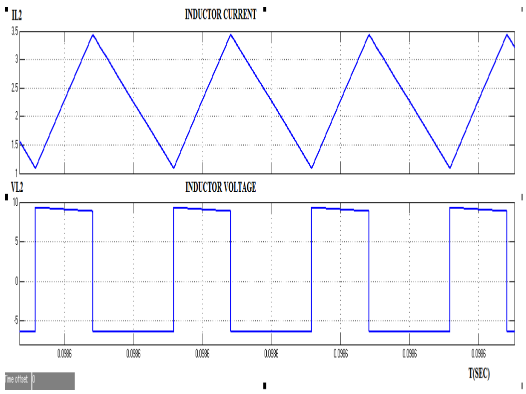

Fig.8. Inductor 2 current & voltage wave forms

From fig 7&8 inductor current is non pulsating type in which current stress on output capacitor, voltage ripple at the output decreases. By current wave form we can observe that converter operate in CCM.

The proposed converter has the voltage conversion ratio of 2D, and hence it possesses voltage bucking with the duty cycle locating between 0 and 0.5 and voltage boosting with the duty cycle locating between 0.5 and 1. By calculation with system working equations we get the proposed converter voltage conversion ratio as 2D.Here an input of 10-16V dc supply is given. The converter works in a linear mode by giving a constant 12V output. Normally many applications working in a voltage range of 12V. Mobile phones and LED TV are working in a voltage range of 12V. Thus we introduce this type of converter. Here if we are giving an input of 10V. We will get a constant output of 12V by the voltage boosting action. If we give an input of 16V we will get an output of constant 12V by voltage bucking action. If we give any voltage in between 10 to 16V, we get a constant voltage of 12V. Here the voltage bucking/boosting action done by the converter with the feedback PI controller. Unlike the traditional buck–boost converter, proposed converter possesses fast transient responses. This converter is very suitable for low-ripple applications. As for the efficiency, this converter has the efficiency of 91% or more above the half load. Indeed, the proposed converter is suitable for the small-power applications because the surge current created by the charge pump is indispensable. But, using the soft switching with surge current suppressed can overcome this problem, and hence, makes this converter likely to be operated in high-power applications. The proposed converter is more efficient and effective than other positive buck-boost converter like Cuk converter, Zeta converter, inverting buck–boost converter, single-ended primary -inductor converter (SEPIC), Luo converter.

VII. CONCLUSION

The proposed buck–boost converter, combining the KY converter and the traditional SR buck by using the same power switches, has a positive output voltage and no right-half plane zero. Furthermore, this converter always operates in CCM inherently, thereby causing variations in duty cycle all over the load range not to be so much, and hence, the control of the converter to be easy. Above all, such a converter possesses the non-pulsating output current, thereby not only decreasing the current stress on the output capacitor but also reducing the output voltage ripple. By means of experimental results, it can be seen that for any input voltage, the proposed converter can stably work for any dc load current;

The Positive Buck Boos Converter Widely Used in many applications such as batter power. We can use the modified non-inverting buck-boost converter in a combination of different modes as required by the application. Thus a Micro system has developed a solution for a buck-boost converter which maximizes efficiency, minimizes ripple noise on input and output, and minimizes external component requirements and associated cost.

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