

Design And Implementation Of Luo Converter For Electric Vehicle Applications

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Abstract— This paper proposes the stable and ripple free output voltage from the design of developed Dc-Dc converter topology. Dc voltage provided by battery contains high voltage ripples and it is not constant enough voltage, thus it is not applicable for most devices like electric-vehicle controller, dc-chargers, etc. Dc-Dc converters are employed to attenuate the ripples regardless of change in the load voltage. In the existing method, the classical buck converter for electric vehicle applications does not meet the load requirement containing more ripples on the output voltage and parasitic effects. To overcome this problem the advanced developed Dc-Dc luo-converter technology was introduced. luo converter is the developed converter derived from the buck-boost converter. In this proposed model the additional filter elements in the luo-converter eliminate the output ripples and effectively enhance the output voltage level. A computer simulation using MATLAB/SIMULINK confirms the predicted results.

Keywords— dc-dc converter, electric vehicle, low pass filter, luo converter

I. INTRODUCTION

The dc-dc conversion technology is a major subject area in the field of power electronics and drives, and has been under development for past six decades. Dc-dc converters are widely used in industrial applications and computer hardware circuits. Dc-dc conversion techniques are developed very quickly. This compares to the ac-dc power supply market, which will have a certain growth of only about 7.5% during the same period. In addition to its higher growth rate, the dc-dc converter market is undergoing evaluate changes as a result of two major trends in the electronics industry like low voltage and high power density. From this investigation it can be seen that the production of dc-dc converters in the world market is much higher than that of ac-dc converters. In 1920s the dc-dc conversion is process is started. A simple voltage conversion, the simplest dc-dc converter is a voltage divider (such as rheostat, potential-meter, and so on) [1], but it only transfers output voltage lower than input voltage with poor efficiency. The multiple-quadrant chopper is the second step in dc-dc conversion more time has been spent for to find equipment to convert the dc energy source of one form voltage to another DC actuator with another voltage form, as does a transformer employed in AC-AC conversion. Some

initial types of DC-DC converters were used in industrial applications before the Second World War. Research of Dc-Dc converter was blocked during the war, but applications of DC-DC converters were recognized. After the war, communication technology developed very quickly and required low voltage DC power supplies for the communication. This resulted in the rapid development of DC-DC conversion techniques. Initial stage prototypes can be derived from choppers. The emerging DC-DC converters can be offered as a method to generate multiple output voltage levels from a single source dc supply voltage to feed the different sub-circuits in the device [2]. This method of generating multiple output voltage levels from a single battery source can reduce the area of the device substantially. On the other hand dc supply voltage provided by battery or rectifier contains high voltage ripples (harmonics) and it is not constant enough, thus it is not applicable for most devices. DC-DC regulators are employed to attenuate the ripples regardless of change in the load current or input voltage [3]. Buck converter is a type of switching-mode power supply which is used for stepping-down dc voltage level. Switch controller circuit and power circuit are two main parts of buck converter circuit.

One of the most critical issues for the environment today is pollution generated by hydro-carbon gases, which is one of the main sources of power for transportation. Hybrid electric vehicles (HEV) and full electric vehicles (EV) are rapidly advancing as alternative power trains for green transportation. The electric vehicle application not only involves the traction parts, but it is also generating the new applications for conversion of electric power from load to source. One of the key blocks inside hybrid electric vehicles is the DC-DC converter for auxiliary power supply of electric loads. This converter has to be possible of handling the electric energy transfer from the 12V DC bus and the high voltage DC bus (used for electric traction applications).The DC-DC converter enables the energy transfer between the high voltage side and low voltage side giving tremendous advantages in terms of low cost, flexible, reliable and efficient, increased due to the possible constraints of easy to make synchronous rectification and implementation. The features include resonant clamping circuit implementation in the boost mode and soft-switching

operation, due to phase shift operation, in the buck mode, without need additional devices, and provide high efficiency and easy to control. Power electronic converters and new semiconductor devices are key components to meet the targets of extended mileage range and reduced pollution. The rapidly efficient DC-DC converters must be used to provide appropriate voltage levels and the power management between different energy level sources and storage elements. The proposed developed DC-DC converter is Luo converter it overcomes the parasitic problems present in the classical dc-dc converter [11]. Fig 1 shows the circuit diagram for developed dc-dc luo converter. The harmonics Levels present in the luo converter less compared to the classical buck converter.

II. CIRCUIT OPERATION OF LUO CONVERTER

The circuit diagram of the Buck - output Luo converter is shown in Fig. 1. In the circuit, S is the power switch and D is the freewheeling diode. The energy storage passive elements are inductors

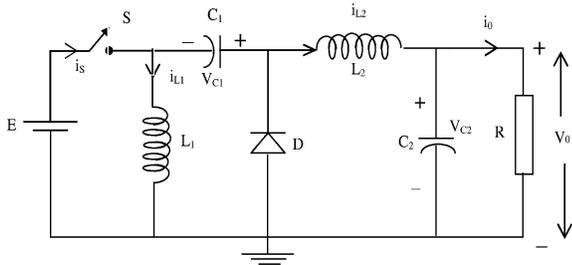
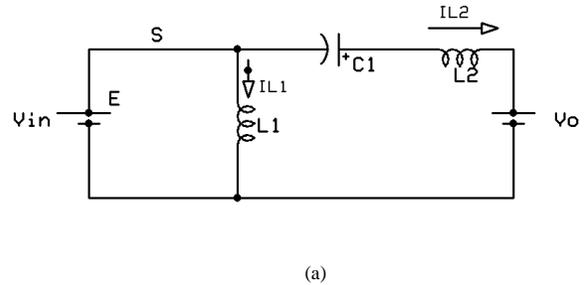


Fig. 1. Circuit diagram of Luo converter.

L_1 , L_2 and capacitors C_1 , C_2 , R is the load resistance. To analyse the operation of the Luo converter, the circuit can be divided into two modes. When the switch is ON, the inductor L_1 is charged by the supply voltage E . At the same time, the inductor L_2 absorbs the energy from source and the capacitor C_1 . The load is supplied by the capacitor C_2 . The equivalent circuit of Luo converter in mode 1 operation is shown in (a). During switch is in OFF state, and hence, the current is drawn from the source becomes zero, as shown in (b). Current i_{L1} flows through the freewheeling diode to charge the capacitor C_1 . Current i_{L2} flows through C_2 - R circuit and the freewheeling diode D to keep itself continuous. If adding additional filter components like inductor and capacitor to reduce the harmonic levels of the output voltage

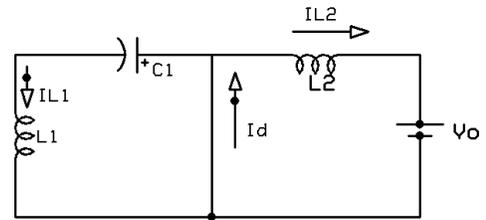


(a)

A. Modes of operation

Mode 1: when the switch is ON, the inductor L_1 is charged by the supply voltage E . At the same time, the inductor L_2 absorbs the energy from source and the capacitor C_1 . The load is supplied by the capacitor C_2 . The equivalent circuit of Luo converter in mode 1 operation is shown in (a).

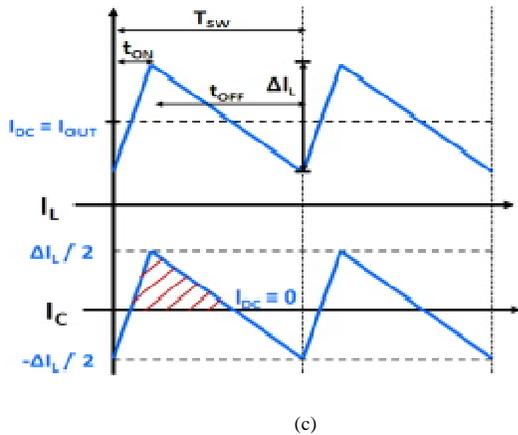
Mode 2: switch is in OFF state, and hence, the current is drawn from the source becomes zero, as shown in (b). Current i_{L1} flows through the freewheeling diode to charge the capacitor C_1 . Current i_{L2} flows through C_2 - R circuit and the freewheeling diode D to keep itself continuous.



(b)

In discontinuous conduction mode, output should be in the form of discontinuous. In this mode diode is not present and inductor discharge through V_0 and L_2 . The output stage of the Luo buck converter is comprised of an inductor and capacitor. The output stages stores and delivers energy to the load, and smooths out the switch node voltage to produce a constant output voltage. Inductor selection directly influences the amount of current ripple seen on the inductor current, as well as the current capability of the buck converter itself. Inductors vary from manufacturer to manufacturer in both material and value, and typically have a tolerance of 20%. Inductors have an inherent DC resistance (known as the DCR) that impacts the performance of the output stage. Minimizing the DCR improves the overall performance of the converter. For that application it requires a high load current, it is recommended to select an inductor with a low DCR. The DCR is smaller for lower inductor values, but there is a trade-off between inductance and ripple current; the lower the inductance, the higher the ripple current through the inductor.

A minimum inductance must be met in order to meet the ripple current requirements of the specific application circuit. The output capacitance directly affects the output voltage of the converter and the response time of the output feedback loop, also the amount of output voltage overshoot that occurs during changes in load current. A ripple voltage exists on the DC output as the current through the inductor and capacitor increases and decreases. Increasing the value of output capacitance value reduces the amount of voltage ripple present in the circuit. However, there is a trade-off between capacitance and the output response. Increasing the capacitance reduces the output voltage ripple and output voltage overshoot, but increases the response time it takes output voltage feedback loop to respond to changes in load. Therefore, a minimum capacitance must be considered, in order to reduce the ripple voltage and voltage overshoot requirements of the converter, while maintaining a feedback loop that can respond quickly enough to load changes. Capacitors also have a parasitic series resistance, known as the equivalent series resistance (ESR). The steady state capacitor value is 0A shown in fig (c).



The ESR impacts the output voltage ripple and the overall efficiency of the converter. Because of this, designers are moving to low ESR designs. Surface mount ceramic capacitors are becoming prevalent in systems that require high performance in a small form factor. The choice of multiple capacitors connected in parallel allows designers to achieve the necessary capacitance for the system while greatly reducing the equivalent ESR.

III. ANALYSIS OF LUO CONVERTER

The inductor current IL2,

$$IL2 = \frac{1-a}{a} I1 \tag{1}$$

Duty cycle,

$$a = \frac{T_{on}}{T}$$

Output voltage equation,

$$Vo = \frac{a}{1-a} Vin \tag{2}$$

Average Voltage across the capacitor C1 is,

$$VC1 = \frac{a}{1-a} Vin \tag{3}$$

Peak to peak inductor current is ,

$$\nabla IL1 = \frac{aTVin}{L1} \tag{4}$$

equation (4) inductor L1 value,

$$L1 = \frac{aTVin}{\nabla IL1} \tag{5}$$

Peak to peak inductor current L2 is,

$$\nabla IL2 = \frac{aTVin}{L2} \tag{6}$$

equation (6) inductor L2 value ,

$$L2 = \frac{aTVin}{\nabla IL2} \tag{7}$$

The charge on series capacitor (C1) increases during off period by IL2 (=Io) and decreases during on period by IL1. The change in charge on C1 must be zero. Peak to peak ripple voltage across the capacitor C1,

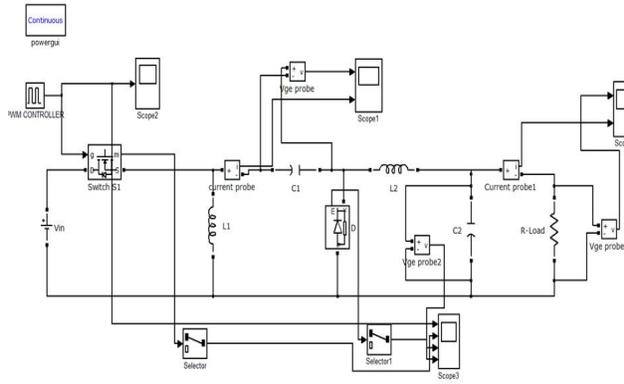
$$\nabla VC1 = \frac{1-a}{C1} T I1 \tag{8}$$

equation (8) C1 value,

$$C1 = \frac{1-a}{\nabla VC1} T I1 \tag{9}$$

IV. SIMULATION RESULTS

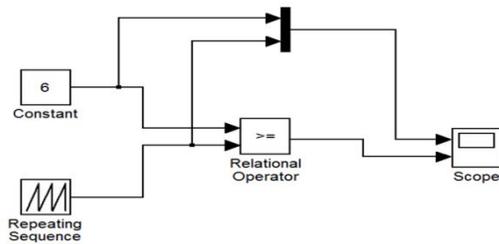
In electric vehicle applications, different kinds of electric loads are used. The applicability of the concept on different electric loads used in electric vehicle applications is tested with simulation models that would provide the most realistic predictions. SIMULINK model for Luo converter is shown in (d).



(d)

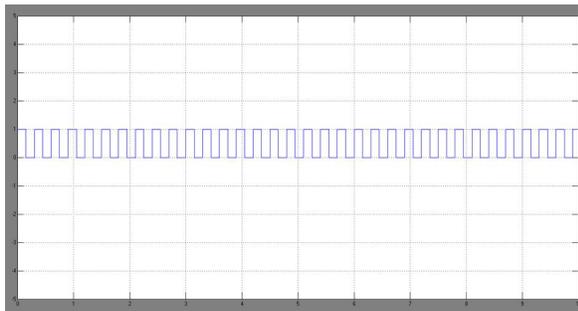
A.Pwm model

The duty cycle 'a' can be generated by comparing the reference dc signal V_r with a sawtooth carrier signal V_c . This is shown in fig(e), Modulation index is the ratio of carrier signal to reference signal the duty cycle a can be varied from 0 to 1. To obtain the square wave pulses compare these signals by a comparator to generate the difference ($V_c - V_r$). Any variation in V_c varies linearly with the duty cycle 'a'.



(e)

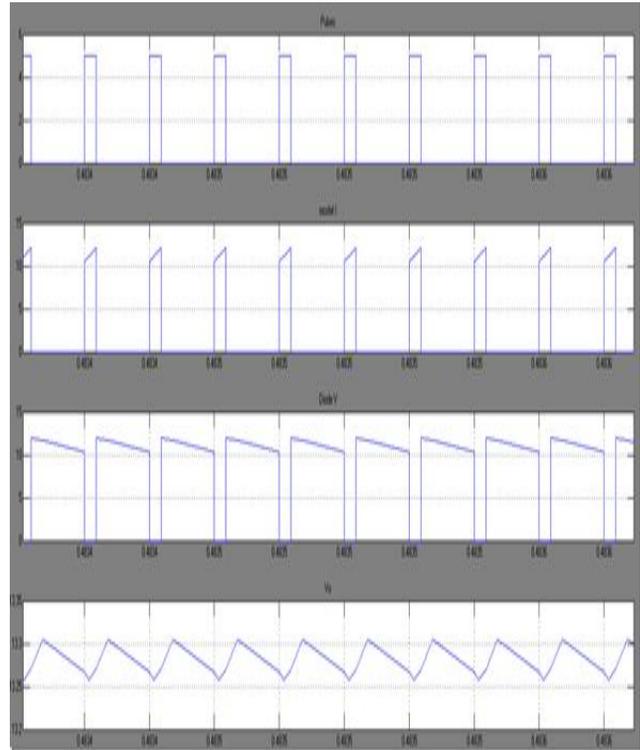
The pulse width modulation output and switching output waveforms of Luo converter is shown in fig (f) and fig(g)



(f)

TABLE I
DESIGN PARAMETERS AND SIMULATION CONDITIONS

Input voltage	60V
Output voltage	12V
Capacitor C1,C2	0.1mF
Inductor L1,L2	0.27mH
Switching frequency	50KHz
Load current	10A



(g)

IV. CONCLUSIONS

In the current study, the proposed developed luo converter has been shown to be capable of providing a topology that reduces the output ripple and parasitic effects. Using this method stable and ripple free output is obtained. Simulation results verified the design and calculations. This developed dc-dc converters are suitable and convenient to be applied into electric vehicle applications with low ripples. The advanced dc-dc converter enhancement technique such as luo converter is used. The main objective is to reach the high efficiency, low THD, high power density and simple structures.

APPENDIX

The Component values are Inductor L1- 0.27mH, L2-0.27mH, Capacitor C1-0.1mF, Capacitor C2-0.1mF, Switching frequency – 50 MHz, Max Load current – 12 A.

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REFERENCES

[1] Marian K. Kazimierczuk, "Pulse-width Modulated DC-DC Power Converters", Edition, Wiley.
[2] Ned Mohan, Tore M. Undeland, William P. Robbins, "Power Electronics: Converters, Applications, and Design", 3rd Edition, Wiley.
[3] Jerrold Foutz, "Switching-Mode Power Supply Design Tutorial Introduction", SMPS Technology, <http://www.smpstech.com/tutorial/t01int.htm>, accessed: Mar 2012.
[4] Abraham I. Pressman, "Switching Power Supply Design", Second Edition, McGraw-Hill, Publication Date: Nov 1997.
[5] Chester Simpson, "Linear and Switching Voltage Regulator Fundamentals", National Semiconductor, <http://www.national.com/assets/en/appnotes/f4.pdf>, accessed: Mar 2012.

[6] Maxim Integrated Products, Inc., "DC-DC Converter Tutorial", Application Note 2031, Nov 29, 2001.
[7] Ray Ridley, "CURRENT MODE or VOLTAGE MODE ?", Switching Power Magazine, Oct2000, <http://encon.fke.utm.my/nikd/latest/OctCurrentMode.pdf> , accessed: Mar 2012.
[8] Madhuravasal Vijayaraghavan G., "Extreme temperature switch mode power supply based on vee-square control using silicon carbide, silicon on sapphire, hybrid technology", Doctoral Thesis, Oklahoma State University, 2009.
[9] L. K. Wong, T. K. Man, "How to best implement a synchronous buck converter", National Semiconductor, Apr 2008, http://www.eetimes.com/design/power-management_design/4012225/Tip-of-the-Week-How-to-best-implement-a-synchronous-buck-converter, accessed: Mar 2012.
[10] Fang Lin and Hong Ye [2004], "Positive Output Multiple-Lift Push-Pull Switched-Capacitor Luo-Converter",
[11] He.Ye and Luo F.L.[2005], "Analysis of Luo converter with Voltage Lift Circuit", IEEE Precedes Electrical on Power Applications, Volume:52, No.5, Page 1239-1252
[12] Luo.F.L and Ye.h [1999], "Positive output cascade Boost converters", IEEE Precedes Electrical on Power Applications, Volume: 151, No.5, Page:590-606.
[13] Fang Lin Luo and Hong ye [2007] , "mathematical modeling for Dc-Dc converter" IEEE transactions on power electronics, vol. 22, no. 1