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Implementation of Ultra-Lift Luo Converter for Electric Vehicle Application

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ABSTRACT: This paper proposes a novel high efficient converter suitable for battery operated electric drive application. The DC output provided by the conventional converter contains high voltage ripples and the voltage is not constant enough. Also in the existing classical buck converter for electric vehicle application does not meet the load requirements and it contain more ripples in the output voltage and parasitic effects. In voltage lift and super lift technique the voltage transfer gain is increased in arithmetic progression and in the super lift technique with four stage series gives the increase in voltage transfer gain in geometrical progression but the proposed novel technique, ultra lift luo converter with single stage gives the increase in voltage transfer gain same as that of the four series super lift technique. The proposed ultra-lift luo converter gives high efficiency, low voltage ripple than super lift technique and voltage lift technique. In this ultra lift luo converter with closed loop control of PI and PWM control capable of providing good static and dynamic performance characteristics to minimize the ripple and from MATLAB/SIMULINK output it is evident that it can be used for electric motor drive.

KEYWORDS: Electric vehicle, low voltage ripple, transfer gain, Ultra-lift luo converter.

I. INTRODUCTION

The higher growth rate in the DC-DC converter market is undergoing dramatic changes as a result of two major trends in the electronic industry. Low voltage and high power density, the production of DC-DC converter in the world market is much higher than that of AC-DC converter. The DC-DC conversion technique was established in 1920's [1]. The DC-DC conversion technique is developed very quickly. To meet the AC-DC power supply market, which will have a certain growth of only about 7.5% during the same period [2]. The voltage lift technique has been widely applied in the electronic circuit design. Using the voltage lift technique to obtain the converter's voltage transfer gain stage by stage in arithmetical series, which is higher than the buck converter, boost converter [3]. The double output from the voltage lifts technique by using transformer less DC-DC converter. The DC-DC converter are widely used in computer hardware and industrial application such as computer periphery power supplies, car auxiliary power supplies, servo motor drives, medical application, cellular phones and laptop[4].The classical topologies, SEPIC and CUK converter have many industrial application like the CUK converter for electric vehicle which is combination of buck and boost converter, on the low voltage side DC supply electric vehicle together with the battery [5] and also the development of luo converter for EV application to reduce the output ripples using additional filter elements with the converter. The voltage lift technique implemented in isolated high step up DC-DC converter to reduce the leakage energy and voltage spike by clamping diodes and capacitors in the primary side of the transformer [6].Although there is some losses in the secondary of the transformer is rectified by using non isolated DC-DC converter, with the voltage multiplier cell, the stress across the semiconductor device is reduced by voltage multiplier cell [7]. The soft commutation of DC-DC converter is achieved by PWM isolated convert with leakage inductance of the transformer and intrinsic capacitor, although it will causes the parasitic effects to the converter and the load [8].

The development of CUK converter gives the self-lift technique to provide a negative to positive voltage conversion with negative DC voltage source [9], but it does not fulfill the variable load requirements due to output voltage ripples and reduce in efficiency. The further development of voltage lift technique in DC-DC converter is super lift technique with PV input or Wind input [10][11], it has the reduced voltage ripples and higher transfer gain in stage by stage process, that is the output voltage transfer gain is increases in geometrical progression[12], in order to solve the this discrepancy in the classical luo converter, another class of proposed converter is ultra-lift Luo converter, this converter gives the reduced voltage ripples, higher efficiency and even higher transfer gain than voltage lift technique and super lift technique. In the single stage ultra lift technique to obtain increased output transfer gain geometrical progression [13]. The bidirectional DC-DC ultra lift luo converter [14] with voltage lift technique to obtain high gain high efficiency, and the stable and ripple free output also obtained by ultra-lift luo converter. 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 EV and full EV is rapidly advancing as alternative power trains for green transportation. The EV application not only involves the traction part, but it is also generating the new application for conversion of electric power from the load to source. One of the key blocks inside the hybrid EV is the DC-DC converter for auxiliary power supply of the electric loads [15].

II. PROPOSED SYSTEM

In this paper, the novel approach of Ultra-lift Luo converter is designed and implemented for electric vehicle application to maintain the stable DC output with reduced ripples. In this proposed system has PI controller and PWM controller to improve the static and dynamic performance of the converter and to get stable DC output. The block diagram of the proposed novel system is shown in Fig. 1.

It consist of Ultra-lift Luo converter, PI controller, PWM controller along with reference voltage input. The voltage is controlled by control logic of PI controller as a closed loop system. The fixed input DC is converted to variable DC output voltage by Ultra-lift Luo converter with high transfer gain.

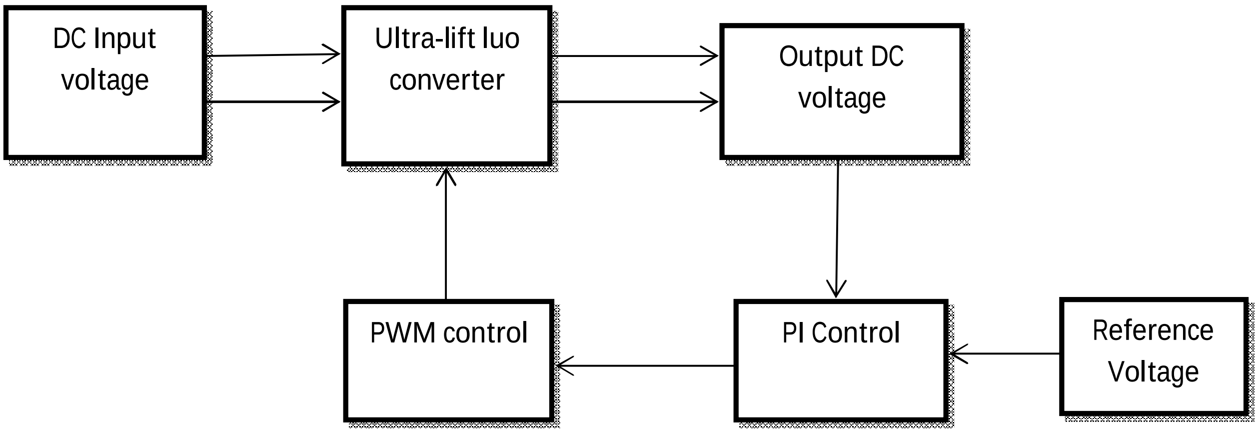

Fig. 1. Block Diagram of Proposed System

III. MODELING OF ULTRA-LIFT LUO CONVERTER

The circuit diagram of proposed system shown in Fig. 2, which consist of one switch, S, and three diodes, two inductors L_1 , L_2, two capacitors C_1, C_2, and the load R. The equivalent circuit of proposed converter when switch ON is shown in Fig. 3,and its switch off equivalent circuit for continuous conduction mode (CCM) is shown in Fig.4, and its switch off equivalent circuit for discontinuous conduction mode (DCM) is shown in Fig.5. It is very simple structure converter compared with other converters. As before, the input voltage and current of the ultra-lift Luo converter are V_1 and I_1,the output voltage and current are V_2 and I_2, the conduction duty cycle is k and the switching frequency is f. consequently, the repeating period T=1/f, switch on period is kT and the switch off period is (1-k)T. to concentrate the load R are ideal ones. Therefore, no power losses are considered during power transformation, i.e. $P_{in}= P_{o.}$

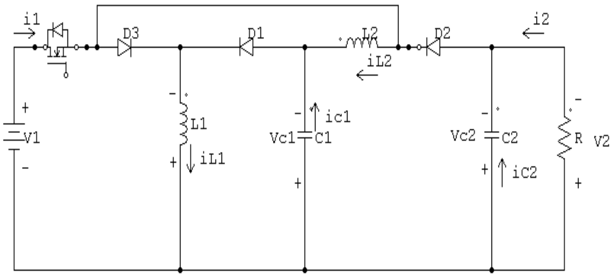

Fig. 2. Circuit Diagram of Proposed System

3.1 MODE 1: The proposed ultra-lift Luo converter during switch on period circuit is shown in Fig.3.This mode of operating condition the diode D_1 and D_2 get reverse biased. The energy stored in inductor and capacitor.

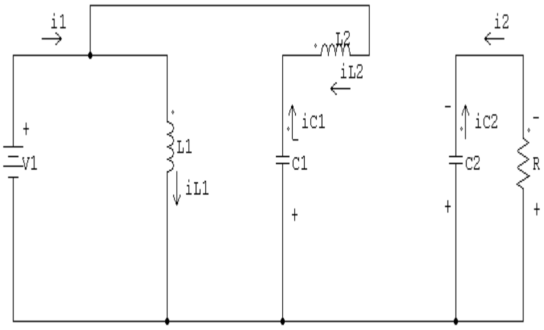

Fig. 3. Equivalent circuit during Switch on period

3.2 MODE 2: In this mode of operation the switch S will be open and the equivalent circuit for the continuous conduction shown in Fig. 4.

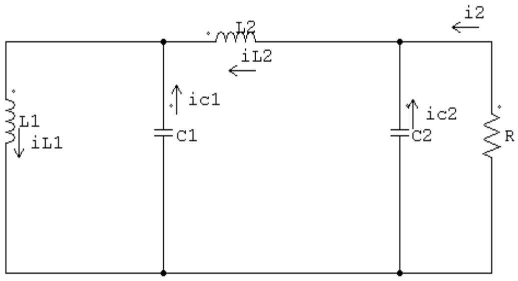

Fig. 4. Equivalent circuit during switch off (CCM)

We note that current i_{L1} increases with the slope $+V_1/L_1$ during switch-on, and decreases with slope $–V_3/L_1$ during switch off. The steady state the current increment is equal to the decrement in a whole period T.

$$kT\left(\frac{V1}{L1}\right) = (1-k)T\left(\frac{V3}{L1}\right) \qquad (1)$$

Thus $V_{c1} = V_3 = \left(\frac{k}{1-k}\right)V1$ (2)

The current i_{L2} increases with slope + $(V_1 - V_3)/L_2$ during switch-on and decreases with slope $-(V_3 - V_2)/L_2$ during switch-off. In the steady state the current increment is equal to the decrement in a whole period T

$$kT\left(\frac{V1+V3}{L2}\right) = (1-k)T\left(\frac{V2-V3}{L2}\right) \quad (3)$$

$$V_2 = V_{c2} = \left(\frac{2-k}{1-k}\right)V3 = \left(\frac{k}{1-k}\right)\left(\frac{2-k}{1-k}\right)V1 = \left(\frac{k(2-k)}{(1-k)^2}\right)V1$$

The voltage transfer gain is:

$$G = \frac{V2}{V1} = \left(\frac{k}{(1-k)}\right)\left(\frac{2-k}{1-k}\right) = \left(\frac{k(2-k)}{(1-k)^2}\right) \quad (4)$$

It is much higher that the voltage transfer gains of the VL Luo converter and the SL Luo converter. The gain of Ultra lift Luo converter is the product of SL and VL gain. Another advantage is the starting output voltage from Zero The relation between input and output average currents is

$$I2 = \frac{(1-k)^2}{k(2-k)}I1 \quad (5)$$

The relation between average currents I_{L2} and I_{L1} is

$I_{L2} = (1-k)\ I_{L1}$ **(6)**

Other relation are:

$$I_{L2} = \left(1 + \left(\frac{k}{1-k}\right)\right)I2 = \left(\frac{1}{1-k}\right)I2 \quad (7)$$

$$I_{L1} = \left(\frac{1}{1-k}\right)IL2 = I2\left(\frac{1}{1-k}\right)^2 \quad (8)$$

The variation of inductor current i_{L1} $is\ \Delta iL1 = kT\left(\frac{V1}{L1}\right)$

And its variation ratio is

$$\zeta 1 = \frac{\frac{\Delta iL1}{2}}{IL1} = ((k(1-k)^2)TV1)/(2L1I2)) = (k(1-k)\hat{}\,2)TR/2L1G$$

$$= \frac{((1-k)^4)TR}{2(2-k)fL1} \quad (9)$$

The diode current i_{D1} is same as the inductor current i_{L1} during the switch off period. For the CCM operation both currents do not descent to Zero. i.e.

$\zeta 1 <= 1$

the variation of inductor current i_{L2} is

$$\Delta i_{L2} = \frac{kTV1}{(1-k)L2} \quad (10)$$

And its variation ratio is

$$\zeta 2 = \frac{\frac{\Delta iL2}{2}}{iL2} = \frac{kTV1}{2L2I2} = \frac{kTR}{2L2G}$$

$$= ((1-k)^2 * TR)/(2(2-k)fL2) \quad (11)$$

The variation of capacitor voltage V_{c1} is

$$\Delta V_{c1}\frac{\Delta Qc1}{C1} = \frac{kTIL2}{C2} = \frac{kTI2}{(1-k)C1} \quad (12)$$

And its variation ratio is

$$\sigma 1 = \frac{\frac{\Delta Vc1}{2}}{Vc1} = kTI2/((2(1-k)V3C1) = \frac{k(2-k)}{(2(1-k)^2)fC1R}$$

The variation of capacitor voltage V_{c2} is

$$\Delta Vc2 = \left(\frac{\Delta Qc2}{C2}\right) = \frac{kTI2}{C2} \quad (13)$$

And its variation ratio is

$$\varepsilon = \sigma 2 = \frac{\frac{\Delta Vc2}{2}}{Vc2} = \frac{kTI2}{2V2C2} = \frac{k}{2fC2R} \qquad (14)$$

From analysis and calculation, we can see that all variations are very small. A design example is that V_1=10 V, L_1=L_2=1mH, C_1=C_2=1μF, R=3000Ω, f=50 kHz and conduction duty cycle k varies from 0.1 to 0.9. We can then calculate that the output voltage variation ratio is less than 0.003. The output voltage is very smooth DC voltage nearly and has no ripple.

3.3 MODE 3: Ultra-lift Luo converter when switch is off with discontinuous conduction mode of operation is shown in Fig 5.

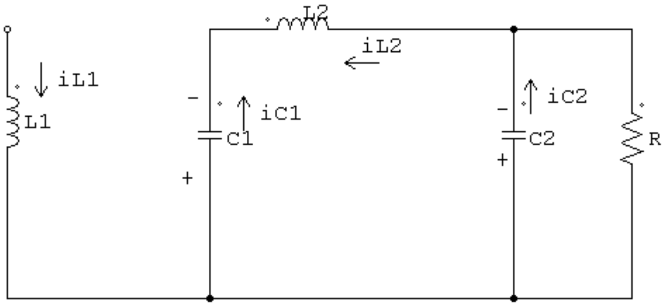

Fig 5. Equivalent circuit during switch off (DCM)

Referring the Fig. 5, we noted that the current iL1 increases with the slope $+V_1/L_1$ during switch-on and decreases with the slope $–V_3/L_1$ during switch-off. The inductor current iL1 decreases to zero before t=T,i.e. the current become zero before the next time that the switch turns on. The DCM operation condition is define as

$$\zeta 1 \geq 1$$

Taking the equal signal, we obtain the boundary between CCM and DCM operation. The normalized impedance Z_n;

$$Zs_n = \frac{R}{fL1} \qquad (15)$$

In the steady state the current increment is equal to the decrement in a whole period T.
It is higher than the voltage transfer gain during CCM operation**.**

$$G_{DCM} = \frac{V2}{V1} = \frac{k(2-k)}{m((1-k)^2)} \qquad (16)$$

IV. PI CONTROL OF ULTRA-LIFT LUO CONVERTER

For the purpose of optimizing the stability of Ultra-lift Luo converter dynamics, while ensuring correct operation in any working condition, a PI control is a feasible approach. The PI control has been presented as a good alternative to the control of switching power converters. The advantage of PI control method is insusceptibility to system parameter variation that leads to invariant dynamics and static response in the ideal case. It ensure the specifying desired nominal operating point for Ultra-lift luo converter, then regulate the converter output, so that it stray very closer to the nominal operating point in the case of sudden disturbance, noise, modeling error and component variation.

The PI regulator is:

$$\frac{U(s)}{E(s)} = Kp + \left(\frac{Ki}{s}\right)$$

V. SIMULATION

Simulation has been performed on the novel approach of Ultra-lift Luo converter with parameter as in the table 2. The static and dynamic performance of PI control for the Ultra-lift Luo converter is evaluated in MATLAB/SIMULINK. The MATLAB/SIMULINK simulation model is depicted in Fig7. It can be seen that error in output voltage of power switch (n-MOSFET) of PI control input is obtained by the difference between feedback output voltage and feedback reference voltage and output voltage of PI control, change in duty cycle of power switch (n-MOSFET). The open loop and closed loop simulation model is depicted in Fig 6 and Fig 7. The output voltage and current waveform is shown in Fig.8. The ripple free output obtained from the proposed converter is shown in Fig. 9.

Table 2. Circuit Parameter

Parameter's Name	**Symbol**	**Value**
Input Voltage	V1	10V
Inductor	L1, L2	1mH
Capacitor	C1, C2	1 µF
Output Voltage	V2	78V
Switching Frequency	Fs	5KHZ
Load Resistance	R	3KΩ
Duty Cycle	D	0.5

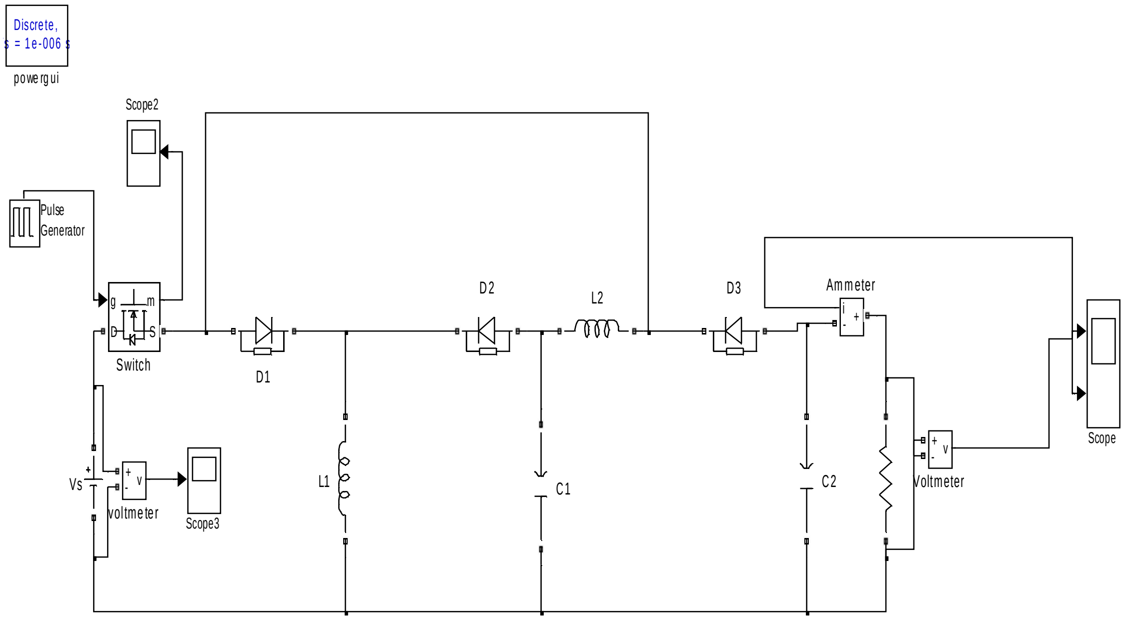

Fig.6 Simulation model of Open loop proposed system

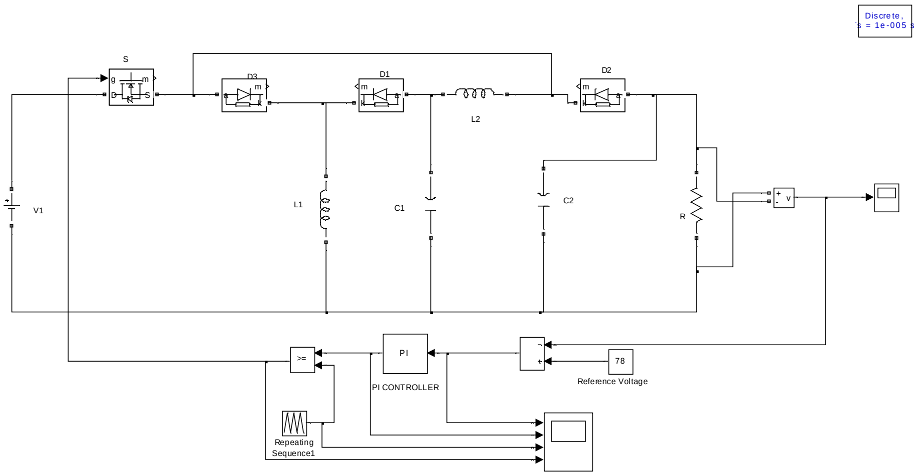

Fig 7. Simulation model of PI control of Ultra-lift Luo converter

VI.SIMULATION RESULTS

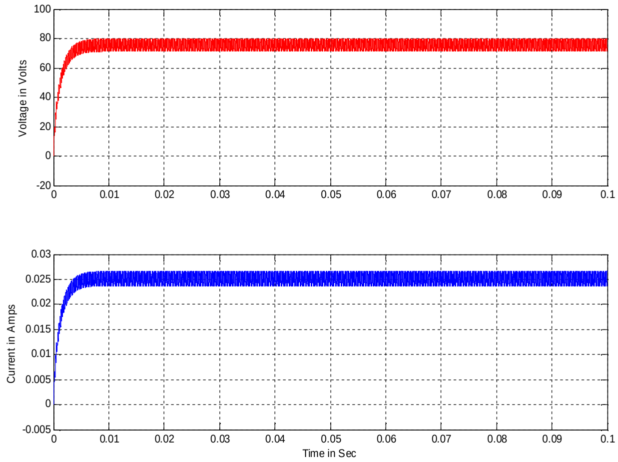

Fig 8. Output voltage of Ultra-lift Luo converter in open loop circuit when input voltage is 10V

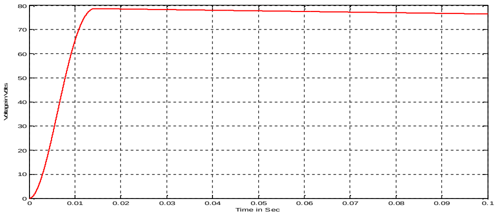

Fig 9. Output Voltage of Closed loop Ultra-lift Luo converter.

VII. HARDWARE IMPLEMENTATION

In this project, the Hardware implementation of ultra-lift Luo converter for electric vehicle application is shown in Fig 10. In this converter single MOSFET switch is used to trigger the converter. The MOSFET switch is controlled by using PIC16F877. The switching pulse was generated by using fast PWM technique , because thus the switching frequency of the circuit is 50KHZ. Thus the hardware results are taken for the input voltage of 12V. The output voltage obtained from the hardware is 44V.

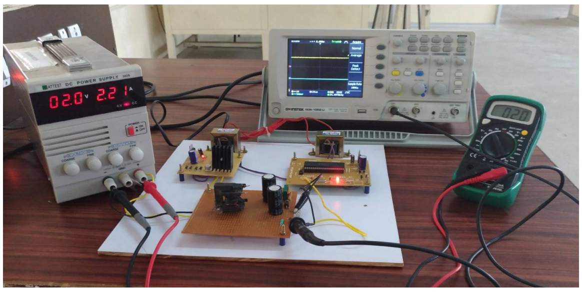

Fig.10 Hardware implementation of Proposed Converter

VIII.CONCLUSION

In this paper, novel approach of Ultra-lift Luo converter has been successfully developed using PI control and PWM control, which produces a high voltage transfer gain, stable and ripple free output. The output DC voltage of the Ultra-lift Luo converter is higher than that of Voltage lift technique and Super lift technique and the voltage transfer gain of Ultra-lift Luo converter is multiplied of super-lift technique and voltage-lift technique. The Ultra-lift Luo converter has a simple construction with a single switch to produce maximum output. The switching loss comparatively lower and thus this type of converter is more suitable for Electric Vehicle and Battery Operated Vehicle. The outputs were verified using MATLAB/SIMULINK and Hardware prototype.

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