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DESIGN AND IMPLEMENTATION OF SWITCHED-CAPACITOR-INDUCTOR PWM CONVERTERS

K. Kaviarasu[1] (Assistant Professor), J. Renciya jaslin[2] (PG Scholar)
[1]Electrical and Electronics Engineering, [2]Power Electronics and Drives
Thangavelu Engineering College, Chennai, India.

Abstract---The design and implementation of switched-capacitor-inductor in a dual step-up converter is presented in this paper. The conventional boost circuit can meet its requirement by cascaded operation and is equal to the product of efficiency of each unit. The proposed converter energy is transferred from the input power sources to the output terminal directly through a two energy components. The proposed converter is simple structure and operates in an single stage, thus this design can meet the high efficiency requirement .The converter has a small resonant inductor to limit the current peak caused by switched capacitor. The advanced performance of the converter is contributed by using the resonant inductor. The analysis of the circuit operation and design procedure is given. The simulation results are also given to verify with the dual step-up converters.

Keywords---RL load, switched-capacitor inductor, DC-DC converter, resonant.

I. INTRODUCTION

The basic buck, boost, buck- boost, cuk, sepic and zeta are used in various electronic applications but it cannot provide a step-up of the line voltage as required by many modern applications. The resonant and quasi resonant converters are very popular in last decade but the control and regulation mechanism of these circuits in their operating frequency is difficult. The switched-capacitor converters have wide applications but their switching current is very high and introduces EMI, because of the absence of inductor which is used to limit the current .These drawbacks are overcome by using switched–capacitor–inductor PWM converters. Thus design can meet the high efficiency requirement with simple structure and good voltage regulation. Many researchers in recent years are trying to take these types of converters in to new combination converters to obtain high step-up. In this paper, a switched-mode converters with different voltage conversion ratios is been proposed. All the members of the family are composed of the same number of electronic components: i.e., two energy transfer components, one SC C_1 and one switched inductor L_1 and a resonant inductor L_r that is used to limit the current peak caused by C_1, three active or passive switches and one output filter capacitor. The important feature of dual step-up converters is that the energy flowing from V_1 and V_2 is directly transferred to the C1 and L_1 and then directly given to the output terminal, i.e., this dual step-up converters are single-stage dc–dc converters rather than like other conventional converters which obtains high voltage gain but by using different cascading methods. When the C1 and L1 are connected in parallel manner the charging process takes place and when connected in series manner discharging process takes place, high output voltage can be obtained and the step-up operation of the converters can therefore be obtained. Thus the step-down operation can be obtained by connecting C_1 and L_1 components in series during the charging and in parallel during the discharging process. This concept is not only used in single-input converters, but can also be used in dual-input dc–dc converters. Thus the dual input step-up dc-dc converters are used in dual level dc distributional system and renewable energy system.

II. DUAL STEP-UP CONVERTER

The energy storage components C_1 and L_1 is connected in parallel to the input sources V_1 and V_2, the switch Q is ON state, and charging process occurs. Then when Q is OFF state discharging process occurs by connecting V_1 and V_2 in series manner to C_1 and L_1. The switching frequency is high when the value of L1 and C1 are large, thus the current flowing through L1 is constant and voltage across capacitor is assumed constant and equal to input voltage. This is based on the volt–second balance across L_1.

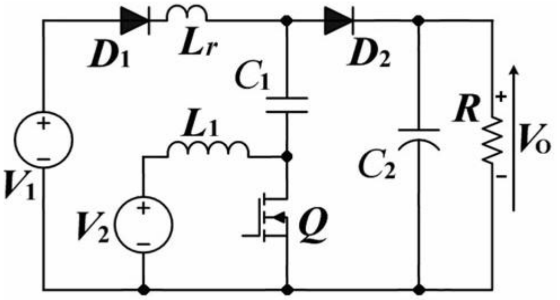


Fig.1 Dual step-up converter.

The output and input voltage relation is expressed as,

$$V_0 = V_1 +(1/(1-d))V_2$$

Each circuit's uses only one switch Q and a small resonant inductor $L_r$which used to limit the current peak caused by capacitor C_1 when Q is in ON state. The energy storage components are connected in series and parallel alternately based on switching states.

A. Analysis and Design

In the dual step-up converters two inductors are been employed, i.e., L_1 and L_r. The main function of L_1 is to transfer the energy; the function of L_r is to limit the peak current caused by C_1 when Q is in ON state. Thus when Q is in on, the C_1 gets charged and discharged. When Q is in OFF state the charging or discharging current will reach very high peak when Q is tuned on if there is no measures to limit it. Thus L_r is connected in series with SC C_1, thus it forms the resonant tank with the resonant frequency $f_O= 1/2\pi\sqrt{(L_r*C_1)}$ during ON time. When an resonant inductor is connected the charging and discharging current will gradually rise from zero when Q is on. Thus to bring the current back to zero before Q is OFF so the switch conduction time is not kept longer than half the period of the resonant frequency i.e.,$dT_S>\pi L_r C_1$

a) State Analysis of Dual Step-up Converter

For dual step-up converters there are three working states in one periodic switching cycle. Thus the analysis is based on assumptions that all component are ideal, and no voltage drop across resistor and L_1 operated in continuous current mode,C_2 value is kept large to ignore the output voltage ripple and seemed as constant voltage source.

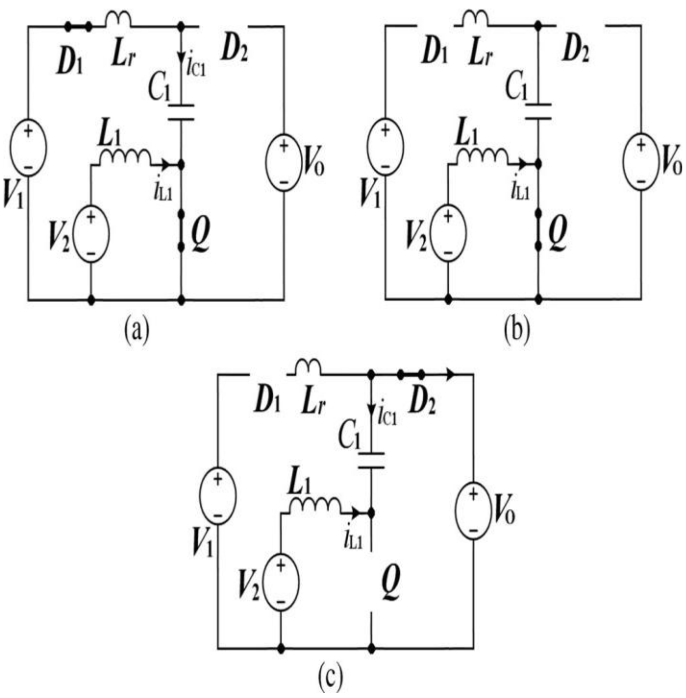


Fig. 2 State circuits for dual step-up converter.

1) State I (t_0-t_1)**:** When Q is in ON state, D_1 is forward biased, D_2 is reversed baised , L_r and C_1 is been connected in series to form resonant tank. Thus when V_1 is developed across C_1 and L_r it causes the resonant current i_{C1} to increases from zero in sinusoidal manner and C_1 is charged and voltage rises from minimum value. Then V_2 is developed across L_1 which causes a linear rise in current i_{L1}. Thus they are mathematically expressed,

$$i_{C1} = I_{C1} \sin \omega (t - t_0)$$
$$V_{C1} = V_1 - \Delta V_{C1}/[2*\text{cost}\ \omega (t - t_0)]$$
$$i_{L1} = I_{L1\_min} + (V_2/L_1)*(t - t_0)$$

where ω is the resonant angular frequency which is equal to $1/\sqrt{(L_r*C_1)}$; I_{C1} and ΔV_{C1} is the oscillation amplitudes of the current and voltage of C_1 , both are related to output current; I_{L1_min} is the minimum value of current flowing through L_1. when $L_r$and C_1 resonate to half a cycle, the resonant current i_{C1} falls back to zero and then D_1 is reversed biased. Thus the resonance stops and capacitor voltage reaches its maximum value at t_1 , i.e.,

$$V_{C1\_max} = V1 + (\Delta V_{C1}/2).$$

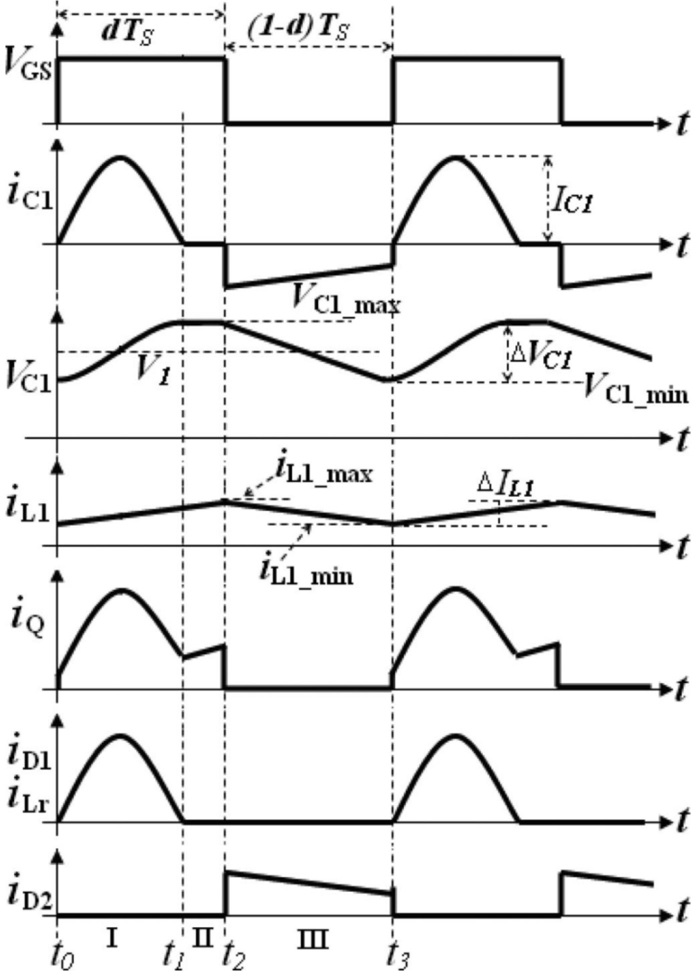


Fig 3. Ideal characteristics of switch during the three states

2) State II (t_1-t_2):when the resonance stops, the switch Q continues to conduct and there is linear rise in inductor current $iL1$. The voltage across C_1 is maintained at maximum value and there is no current flowing through C_1. Until Q is turned OFF from t_1 to t_2 this states continues , and the inductor current i_{L1} rises to maximum value at this state , i.e.,

$$I_{L1\_max} = I_{L1\_m} + (V_2/L_1)* dT_S .$$

3) State III (t_2-t_3):when switch Q is turned OFF, diode D_2 is now forward biased and D_1 is now reversed biased. The input source V_2, the capacitor C_1 and the inductor L_1 are connected in series manner and discharge to V_O occurs. Thus the same

currents flows though C_1 and L_1 and therefore expressed as,

$$i_{L1} = -i_{C1} = I_{L1\_max} - [(V_O - V_2 - V_{C1})/L_1]*(t - t_2).$$

According the assumptions the switching frequency is high enough and it also satisfies the condition of $T_S << 2\pi\sqrt{(L_1*C_1)}$, the change in capacitor voltage V_{C1} and discharging inductor current i_{L1} is been approximated as linear with time, i.e.,

$$i_{L1} = -i_{C1} \approx I_{L\_1max} - [(V_O - V_2 - V_1)/L_1]*(t - t_2)$$
$$V_{C1} \approx V_{C1\_max} - [I_O/(1 - d)C_1]*(t - t_2)$$

where d is the duty ratio, $I_O$is the average output current. At the end of time t_3 ,there is an decrease in the loop current i_{L1} and the capacitor voltage V_{C1} to the minimum values, and expressed as,

$$I_{L1\_min} = I_{L1\_max} - [(V_O - V_2 - V_1)/L_1]*(1 - d)T_S$$
$$V_{C1\_min} = V_{C1\_max} - (I_O/C_1)*T_S.$$

Then again the switch Q is turned ON and the three states is been repeated. During the charging process of the capacitor C_1 for the step-up converter and the discharging process of step-down converter the resonance occurs. The parameters of resonant tank, the output current and the switching cycle period are related to the oscillation amplitudes of capacitor voltage and current. Thus the dual-input step-up converter is taken as an example, when Q is in ON state, the energy flows into capacitor C_1 from input source V_1 which causes a gradual increase in voltage across capacitor VC1. And when , the switch Q is in OFF state and the stored charges in C_1 during the charging process flows out of the capacitor C_1 to the output filter C_2 and then to the load which causes the capacitor voltage V_{C1} to decrease from its maximum to minimum value gradually. During the charging process the amount of charge flowing into C_1 should be equal to the amount of charge flowing out of C_1 during the discharging process, and also should be equal to the amount of charge flowing though the load at one switching cycle, i.e.,

$$(V_{C1\_max} - V_{C1\_min})C_1 = I_O*T_S.$$

There is an change in the charging current i_{C1} in an sinusoidal manner with respect to the resonant frequency $f_O = 1/2\pi\sqrt{(L_r*C_1)}$;thus the amount of charge flowing into C_1 at the charging process is been expressed as,

$$(V_{C1\_max} - V_{C1\_min})C_1 = 2I_{C1}\sqrt{(L_r*C_1)}.$$

The oscillation amplitude of resonant current I_{C1} is been derived as,

$$I_{C1} = (I_O*T_S)/[2\sqrt{(Lr*C_1)}].$$

The oscillation amplitude voltage is been expressed as,

$$\Delta V_{C1} = V_{C1\_max} - V_{C1\_min} = (I_O*T_S)/C1.$$

Thus the inductor L_1 is given as, the amount of charge flowing into it during the discharging process is equal to the amount of charge flowing out the C1. The average current I_{L1} is expressed as,

$$I_{L1} = I_O/(1 - d).$$

The ripple current ΔI_{L1} is been related to input voltage V_2 , the switching cycle T_S, and the duty ratio, i.e.,

$$\Delta I_{L1} = (V_2/L_1)*dT_S.$$

b) Design Procedure

Based on the analysis, the oscillation amplitudes of resonant current and voltage is been calculated by the values of SC C1 and resonant inductor Lr. The values of C1 and Lris determined by the design requirements of the resonant voltage and current. And the value of inductor L1 can be obtained by the design requirements of the ripple current. The design procedure can therefore be divided into the following steps:

1) Determine the minimum and maximum values of the switching frequency and the duty ratio (the switching frequency is usually higher than 50 kHz), and the resonant frequency is calculated according to the condition that, the switch conduction time is longer than half the period of resonant frequency.

2) The capacitor C_1 value can be derived, i.e.,
$C_1 = (I_{Omax}*T_S)/(\Delta V_{C1})$
Where ΔV_{C1} is the voltage oscillation amplitude and I_{Omax} is the maximum output current.

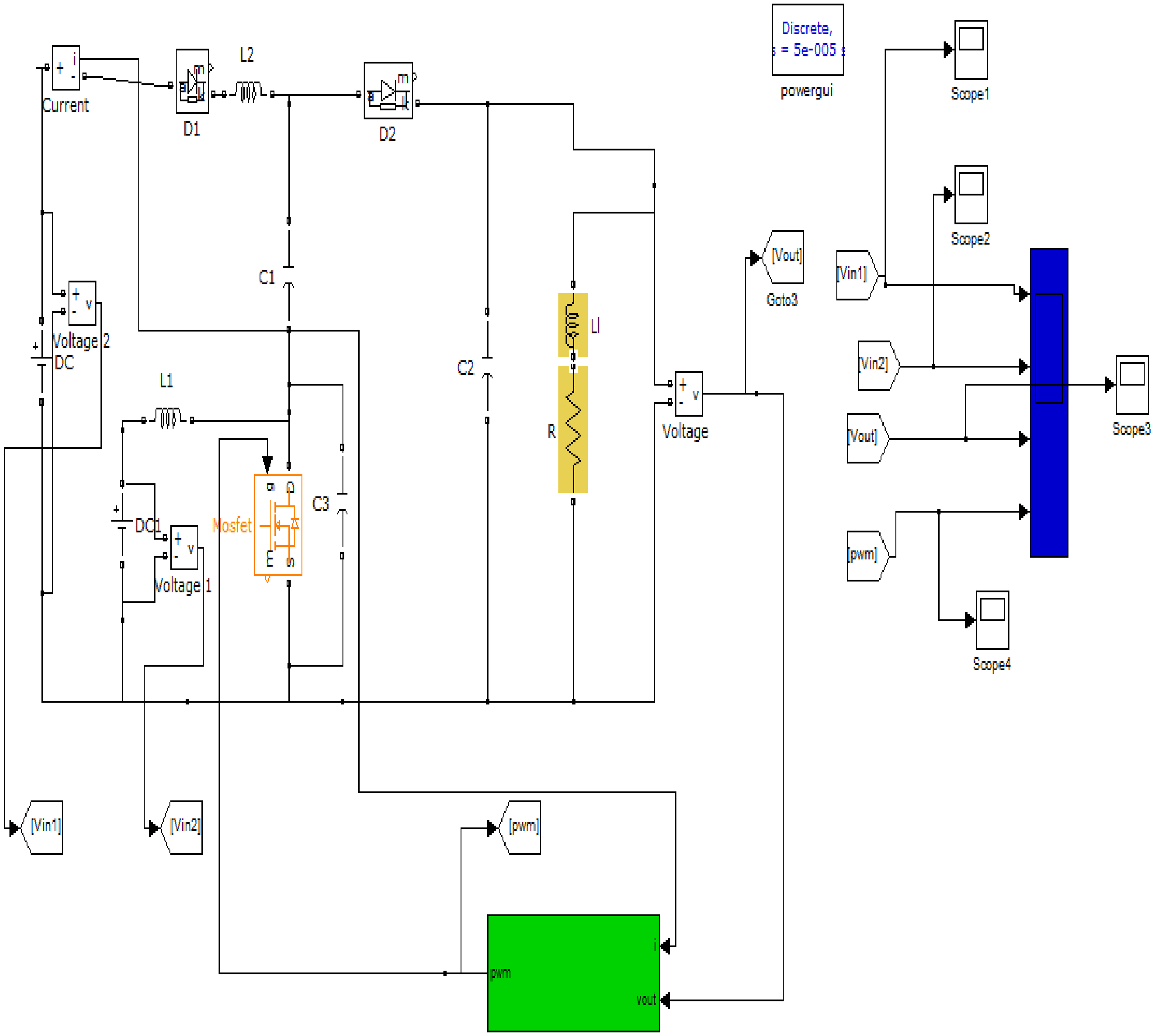
3) From the value of C_1 and the resonant frequency the value of resonant inductor $L_r$hence can be determined.

4) The inductor L_1 value can be determined , i.e.,
$L_1 = (V_2/\Delta I_{L1})*(d\__{max}*T_S)$
Where ΔI_{L1} is the current ripple flowing though L_1 and $d\__{max}$ is the duty ratios maximum value.

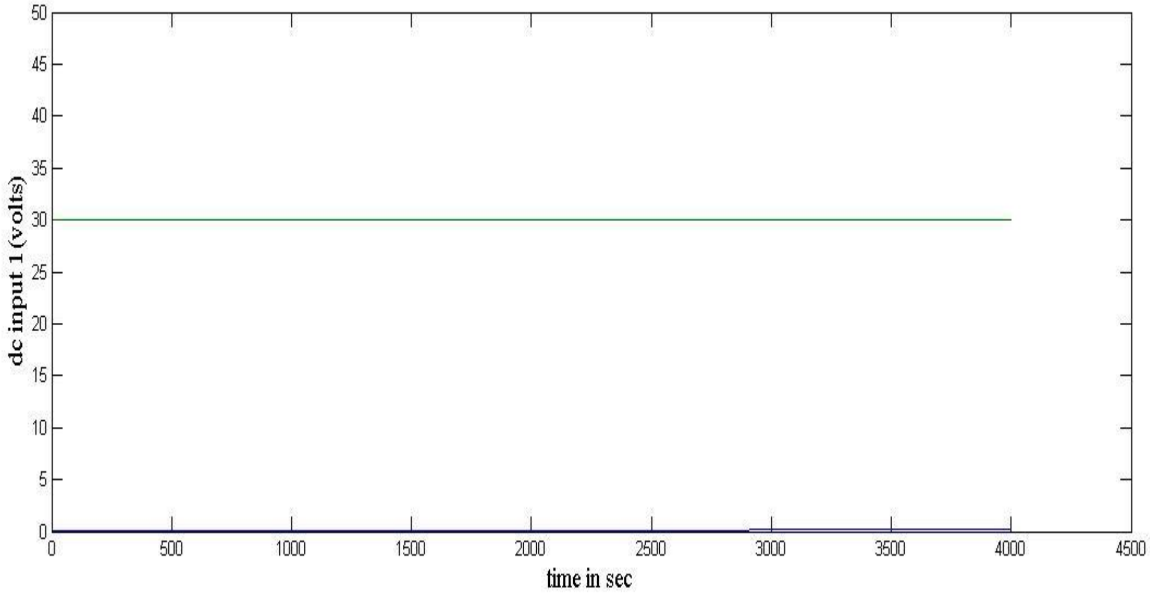
5) According to their switching as given , the average current and maximum transient current the switches are determined.

III. SIMULATION RESULTS

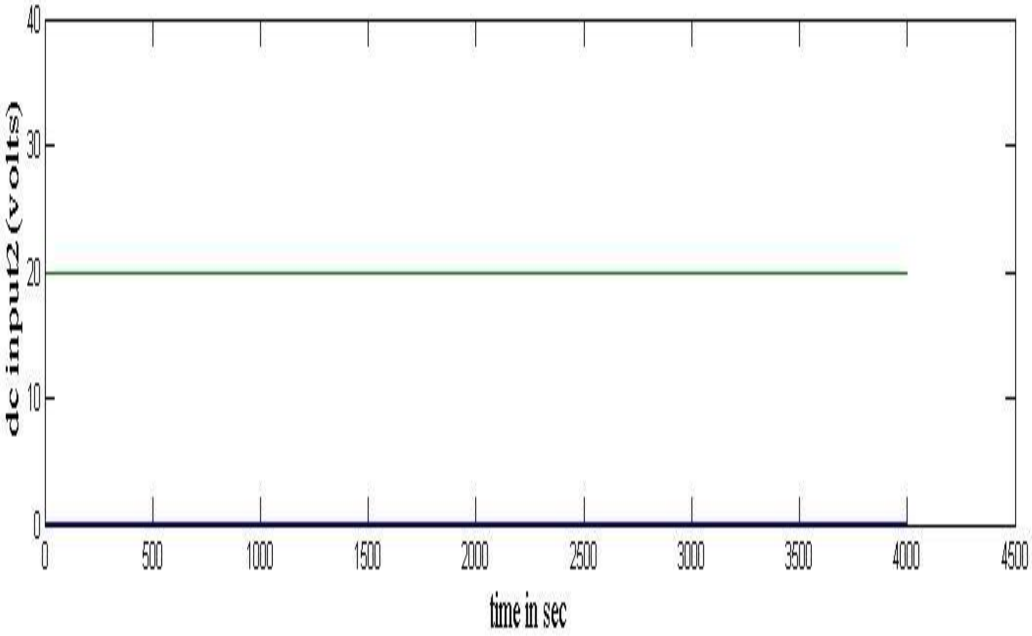
The simulation results are taken for a step-up converter using an RL load and has an dual input V_1 and V_2. The input sources are V_1 and V_2 with 30 and 20 volts. With 102khz of switching frequency and the output voltage obtained is 79.5 volt. The output current is varied from 0.1 to 2.9A when V_1 and V_2 are: 20V and 30V, 30V and 20V, 30V and 30V.



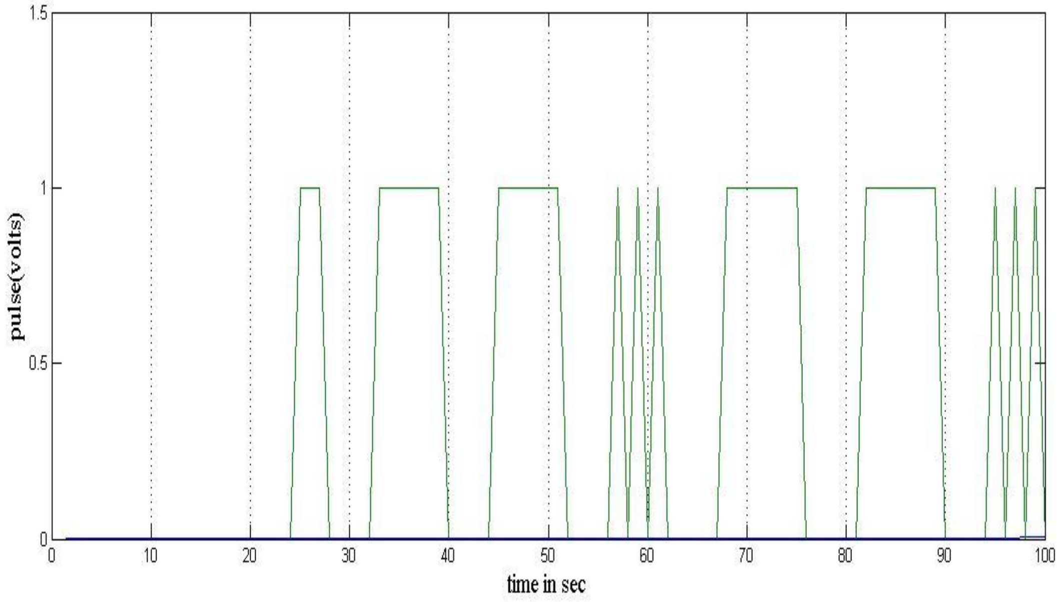
Simulation circuit



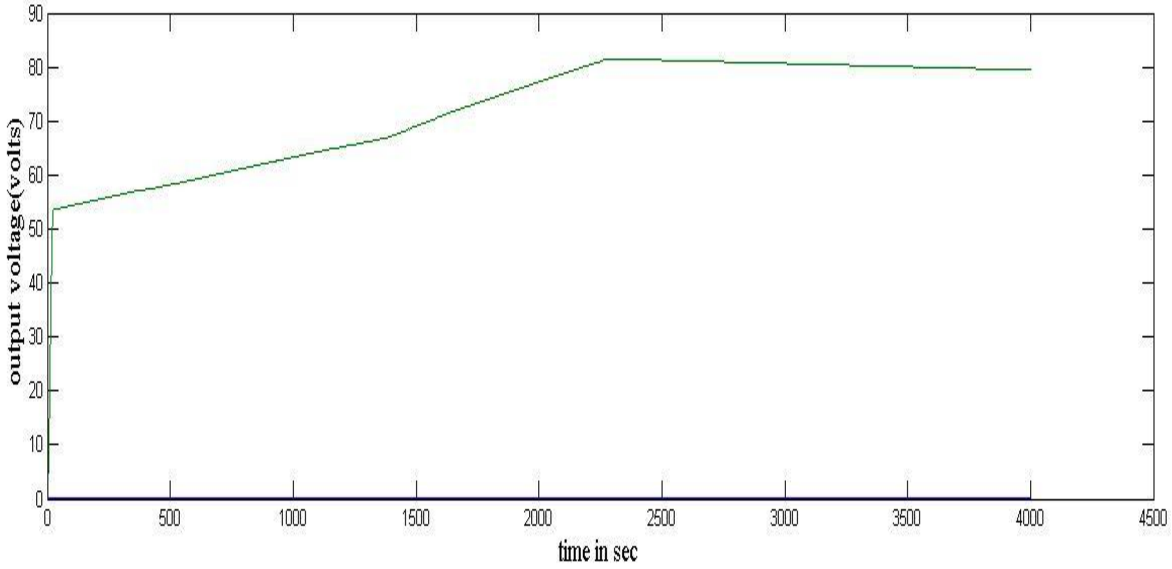
Dc input V_1waveform



Dc input V_2waveform



PWM pulse waveform



Output voltage waveform

IV. CONCLUSION AND FUTURE SCOPE

The design and implementation of switched-capacitor-inductor PWM converter with different voltage ratio has been proposed in this paper. Thus proposed converter is an dual input step-up converter with two energy transfer components and the cascade method is not used to get high output. Thus the energy stored in the energy components got from the dual input sources are directly released to the output terminal. Thus they can meet the high efficiency requirement with a simple structure. Thus to limit the current peak caused by the switched capacitor is been limited by using resonance method. The analysis and design procedure are introduced in this paper. The proposed converter can provide higher voltage gains and the switch stress is low when compared to the conventional switched mode converters. The simulation and experimental results of the dual step-up converter verify confirm their functionality and theoretical analysis. Further the efficiency and voltage under different output power are compared with the conventional converters which indicate that the proposed dual step-up converters can meet good voltage regulation and high efficiency. However, all these can lead to in the direction of further research.

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