ISSN 2229-5518

Implementation of Level shifting Multiple input switched capacitor voltage copier using summation and subtraction circuits

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Abstract— High-efficiency dc–dc converters with high-voltage gain have been researched due to increasing demands. In recent years, multiport (multi-input–multi-output) dc–dc convertors are widely used in photovoltaic systems. The Portable consumer products consists of different sub modules and they require varied voltage or current levels of power supplies. In this paper, a level-shifting voltage-copier circuit is implemented to convert one or two input voltage levels to multiple voltage levels. The voltage copier consists of five kinds of conversion circuits. Each circuit includes only six to seven electronic Components, which can ensure the simplicity and reliability of the voltage copier. A resonant inductor is further added to improve the performance of the circuits implemented. Therefore a high-efficiency resonant voltage copier circuit is introduced. Simulation and experimental results verify the performance of the voltage copier and the design method. The circuit is simulated using MATLAB Simulink. The circuit is implemented using embedded controller. Both Simulation and Hardware results will be verified.

Index Terms— double input, level shifting, power convertor, resonant, switched capacitor, summation, subtraction, voltage copier.

1 INTRODUCTION

TODAY'S power management units of portable products require high power conversion efficiency, fast line or load transient response, and small power module volume. The electronic gadgets like cell phones, digital cameras, MP3 players, PDAs [2], and portable products require varied voltage or current levels of power supplies for delivery to different sub-modules in portable products. In order to combine more than one energy source, such as the solar array, wind turbine, fuel cell, and commercial ac line, to get the regulated output voltage, different circuit topologies of multi-input converters have been proposed in recent years. These MICs are used in the applications of photovoltaic (PV)–wind power system [1], PV–utility system, hybrid vehicle [3], and others. Different PWM converters can be put in series to implement the MIC and the regulated output voltage can be achieved. Such an MIC can continue to operate even if one of the dc sources has failed. Similarly multiple outputs converters are also required in various applications of varied voltage/current levels. Thus a combination of multiple inputs and multiple output converter is obtained. Conventionally, dc-dc converters which employ bulky transformers and inductors are widely employed [4-6]. However, the drawbacks of these types of converters include the high component count, large circuit size, and higher electromagnetic interference (EMI). In this paper, two voltage levels are given as input, and the two voltage levels can be converted to eight voltage levels in order to suit different voltage needs for other electronic appliances. There are circuits in this proposed method to create the summation, subtraction, double, half, and inversion levels from the two voltage levels. Fig. 1 is the diagram of multilevel dc conversion from two voltage levels.

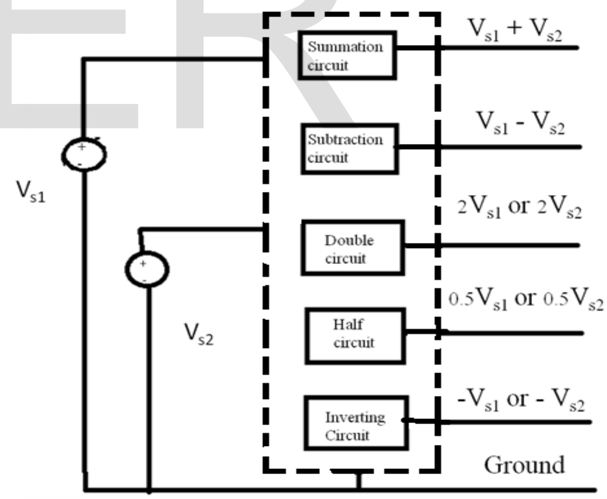

Fig 1.multilevel dc-dc converter

Together with the other three original circuits, the whole family of switched-capacitor convertor can convert two voltage levels to eight voltage levels. Compared with the current mainstream dc power convertors that use inductor or transformer to process energy [8],[9], switched capacitor convertors have no inductive component, small size, and simple structure[10]. The new circuits ensure that the circuit size is small, power loss is very low, and component count is small. This paper describes in detail the summation circuit and subtraction circuit. The switching currents are very high and oscillatory in nature when the voltage is high and the devices are operated at hard switching. It not only induces large

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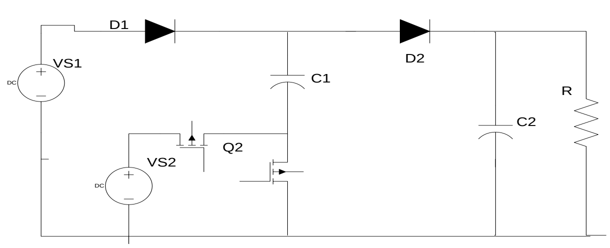
ISSN 2229-5518

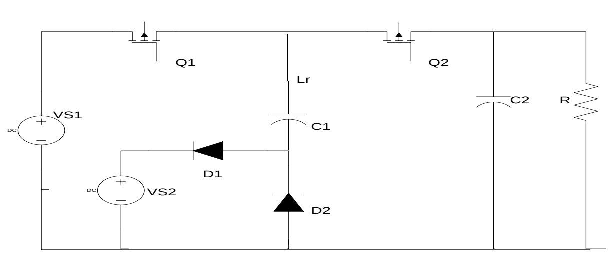
electromagnetic interference, but also shortens the life of a converter and produces more switching loss [11],[12]. Therefore, in this paper, the disadvantage is eliminated. A small resonant inductor is used to limit the current transient, and that the switches are switched ON and OFF under the zero-current condition [13],[14]. The resonant summation circuit is analyzed in detail. The four states of operation of resonant summation circuit and the relationships among the resonant current, voltage, and output current are analyzed below. The designs of the circuits are done on this basis.

2 Multiple Input Multiple Output Converter

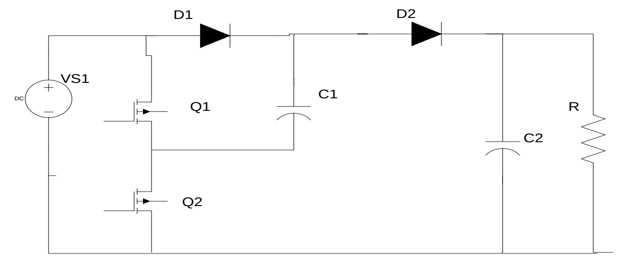
The switched-capacitor dc–dc converter only uses capacitors for energy storage. Its novel feature is that only capacitors switches are required in the power stage. The main advantage of this kind of converter is that no inductive component is required for storing energy, and this feature makes it possible to fabricate a smaller size and light weight converter. The multilevel switched-capacitor converter consists of five kinds of switched-capacitor conversion circuits. It includes summation circuit, subtraction circuit, double circuit, half circuit, and inverting circuit; these circuits are as shown below. The double, half, and inverting circuits are presented in, but the new summation and subtraction circuits are analyzed in detail in this paper. Each of the circuits uses only two switches, two diodes and two capacitors. Therefore, the size of the circuits is very small and simple enough to handle. So, multilevel switched-capacitor converter converts two voltage levels to eight voltage levels. It includes $V_{S1}+V_{S2}$, $V_{S1}-V_{S2}$, $2V_{S1}$, $2V_{S2}$, $0.5V_{S1}$, $0.5V_{S2}$, $-V_{S1}$, $-V_{S2}$ .Five circuits are shown in Fig. 2. Switches *Q*1 and *Q*2 cannot be turned ON at the same time; they can be triggered by a pair of half-bridge pulse signals. Each turn-on time can be half or slightly less than half a period of switching frequency. The five circuits are as shown in the below figures.



a)



b)



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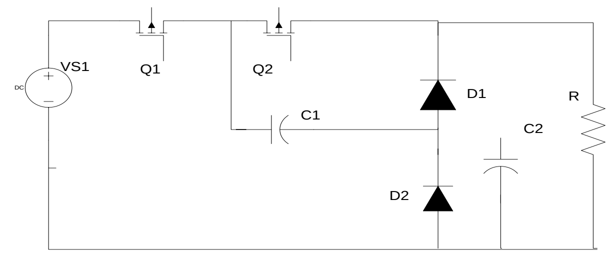
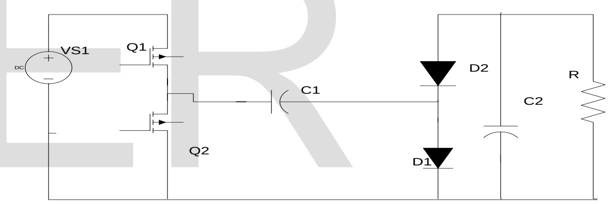


d)



e)

Fig. 2. Composition of the multilevel converter.
(a) Summation circuit. (b) Subtraction circuit. (c) Double circuit. (d) Half circuit. (e) Inverting circuit

3 Resonant Zero Current Switching

A small inductor is introduced and is connected to *C*1 in a series manner; to limit the switching current to a lower value and helps in low-loss energy transfer from the source to the switching capacitor. Fig. 5 is the summation circuit with a small inductor *Lr* . *Lr* and *C*1 form a resonant tank circuit with the resonant frequency $f_O = 1/2\pi\sqrt{L_r C_1}$ .When the switch is turned ON, current gradually increases from zero. If the switching frequency $f_S \le f_O$, the current also becomes zero before the switch is turned OFF. The resonant summation and subtraction circuits are shown as below.

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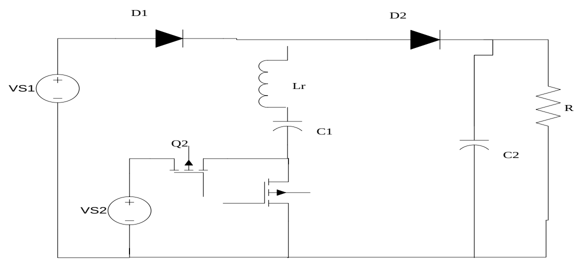
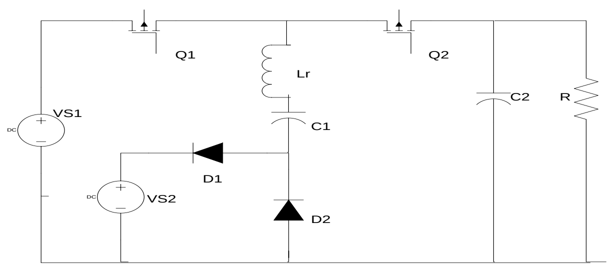


a)

Fig 3a) Resonant summation circuit



b)

Fig 3b) Resonant subtraction circuit

4 Modes Of Operation

The modes of operation of resonant summation and subtraction circuits are as follows.

4.1 Resonant Summation Circuit

4.1.1 Mode 1

When $Q1$ is turned ON , $Q2$ is made OFF and $D2$ is reversely biased. Therefore, $Vs1$, $Q1$, $D1$, Lr , and $C1$ form a resonant loop shown in Fig 4(a). $C1$ begins to charge and the loop current increases from zero.

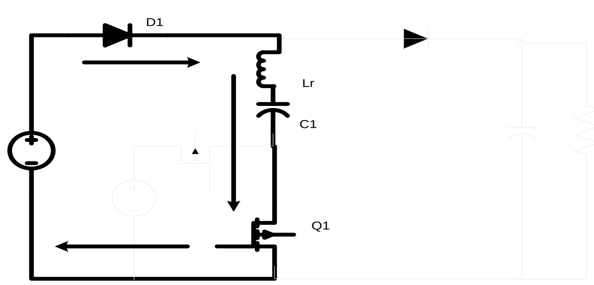


Fig 4a)

$$Lr\frac{diLr}{dt} + Vc = Vs \quad (1)$$

$$iLr = C1\frac{dV_{C1}}{dt} \quad (2)$$

$$VC1 = VS1 - \Delta VC1 \cos \omega o\,(t - to) \quad (3)$$

$$iLr = ILm \sin \omega o\,(t - to) \quad (4)$$

4.1.2 Mode 2

After Lr and $C1$ resonate for half a cycle, the loop current falls to zero, and the resonance stops because $D1$ is reverse biased. At that time, the voltage across $C1$ is maximum and it will remain the same voltage when $Q2$ is turned ON. The state circuit is shown in Fig. 4(b).

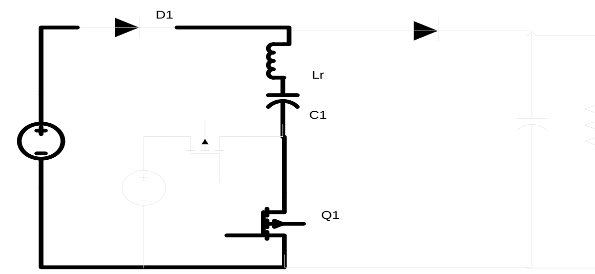


Fig 4b)

$$iLr = 0 \quad (5)$$

$$VC1\ \max = VS1 + \Delta VC1 \quad (6)$$

4.1.3 Mode 3

When $Q2$ is turned ON and $Q1$ is turned OFF, $D1$ is reverse biased. $VS2$, $C1$, Lr, $D2$, $Q2$, and VO , therefore, form a resonant loop. The state circuit is shown in Fig.4(c). The resonant current begins to increase in the opposite direction. $C1$ starts discharging. The state equations are as follows

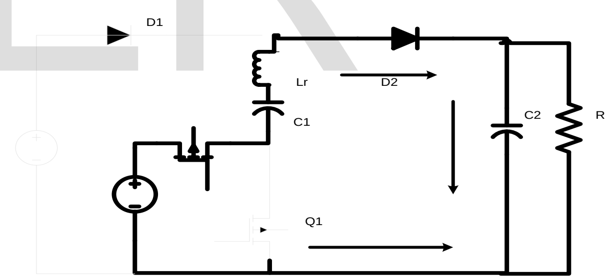


Fig 4b)

$$Lr\frac{diLr}{dt} + V_{C1} + V_{S2} = V_O \quad (7)$$

$$iLr = C1\frac{dV_{C1}}{dt} \quad (8)$$

$$VC1 = VS1 + \Delta VC1 \cos \omega o\,(t - t2) \quad (9)$$

$$iLr = -ILm \sin \omega o\,(t - t2). \quad (10)$$

4.1.4 Mode 4

After resonant current increases, its amplitude traces a sine-wave for half a cycle and it returns to zero again, and the voltage across $C1$ will change .The discharging of $C1$ will, then, stop because $D2$ is reverse biased, and the state circuit is shown in Fig. 4(d).

ISSN 2229-5518

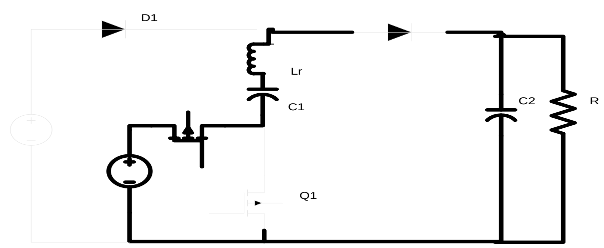


Fig 4d)

$VC\ 1min = VS2 - \Delta VC\ 1$ (11)

4.2 Resonant Subtraction circuit

4.2.1Mode 1

When $Q1$ is turned ON and $Q2$ is OFF, $D2$ is reverse biased. Therefore, $Vs\ 1$, $Q1$, $D1$, Lr , and $C1$ form a resonant loop shown in Fig. 5(a). $C1$ begins to charge, and the loop current increases from zero.

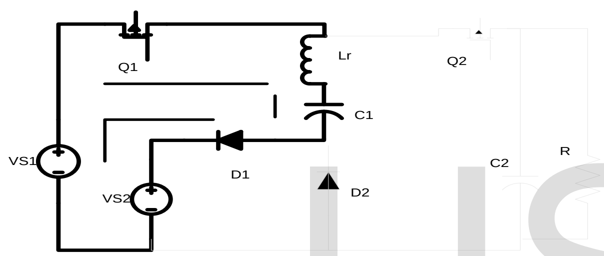


Fig 5a)

$Lr\frac{di_{Lr}}{dt} + V_{C1} = V_{S1} - V_{S2}$ (1)

$i_{Lr} = C1\frac{dV_{C1}}{dt}$ (2)

$VC1 = V_{S1} - V_{S2} - \Delta VC1 \cos \omega o\ (t - to\ )$ (3)

$iLr = ILm \sin \omega o\ (t - to\ )$ (4)

4.2.2 Mode 2

After Lr and $C1$ resonates for half a cycle, the loop current falls to zero, and the resonance stops because $D1$ is reverse biased. At that time, the voltage across $C1$ is maximum $VC1$ max = $VS1 + \Delta VC1$; it will remain the same voltage until $t2$ when $Q2$ is turned ON. The state circuit is shown in Fig. 5(b)

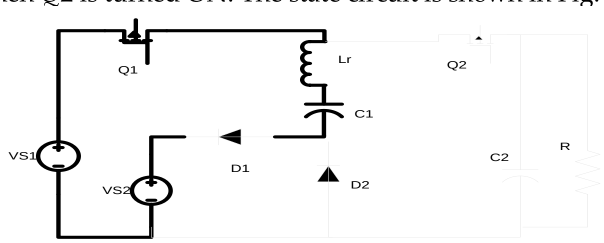


Fig 5b)

$iLr = 0$ (5)

$VC1\ max = V_{S1} - V_{S2} + \Delta VC1$ (6)

4.2.3 Mode 3

After resonant current increases, its amplitude resonates in a sine-wave manner for half a cycle, it will return to zero again, and the voltage across $C1$ will change to $VC\ 1min = \Delta VC\ 1$. The discharging of $C1$ will, then, stop because $D2$ is reverse biased, and the state circuit is shown in Fig. 5(c).

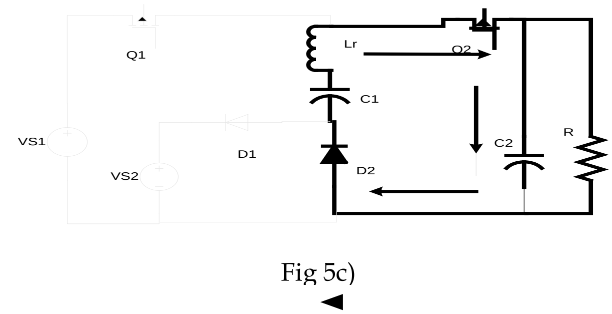


Fig 5c)

$Lr\frac{di_{Lr}}{dt} + V_{C1} = V_O$ (7)

$i_{Lr} = C1\frac{dV_{C1}}{dt}$ (8)

$VC1 = V_{S1} - V_{S2} + \Delta VC1 \cos \omega o\ (t - t2\ )$ (9)

$iLr = -ILm \sin \omega o\ (t - t2\ ).$ (10)

4.2.4 Mode 4

After resonant current increases, its amplitude in a sine-wave manner for half a cycle, it will return to zero again, and the voltage across $C1$ will change to $VC\ 1min = VS\ 1 - \Delta VC\ 1$. The discharging of $C1$ will, then, stop because $D2$ is reverse biased. This state will remain to the next switching cycle shown in Fig. 5(d).

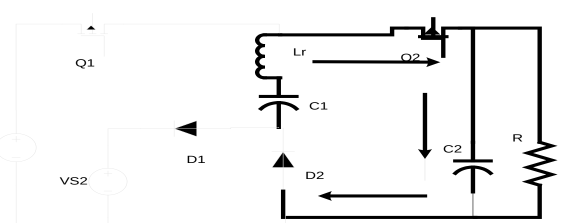


Fig 5d)

$VC\ 1min = \Delta VC\ 1$ (11)

5 Simulation Results

The proposed and the modified circuits are simulated using the MATLAB software and the results can be obtained by graphical waveforms. Two input supply voltages are given and the outputs are obtained. The figure 6 shows the diagram of the resonant summation converter

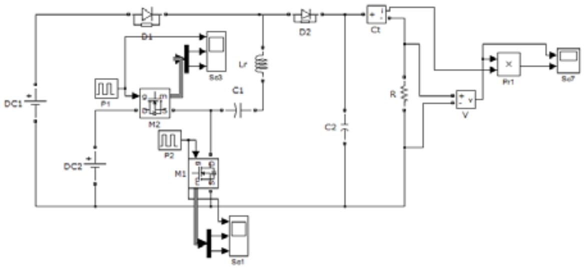


Fig 6) Resonant Summation Circuit

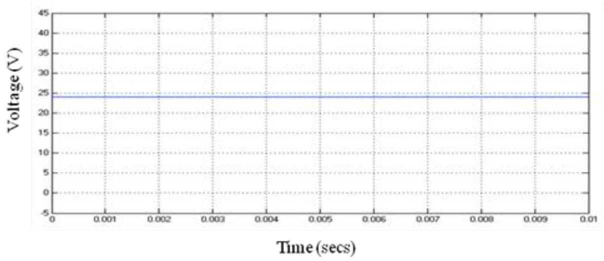


Fig 7)DC Input voltage 1

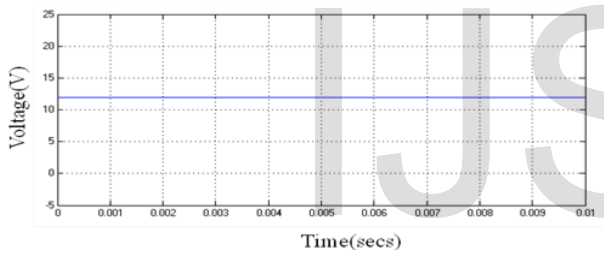


Fig 8) DC Input voltage 2

The figs 7 & 8 show the input voltages of the converter namely 24V and 12V

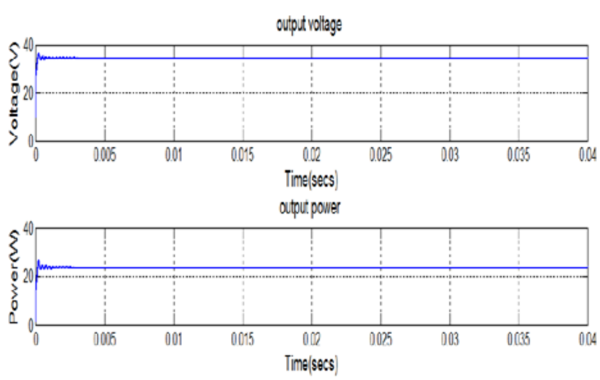


Fig 9) Resonant summation output voltage and output power

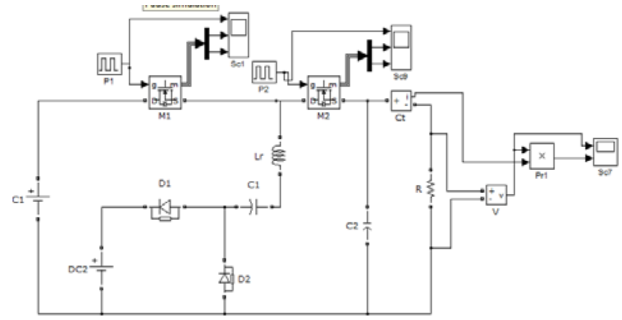


Fig 10) Resonant Subtraction Circuit

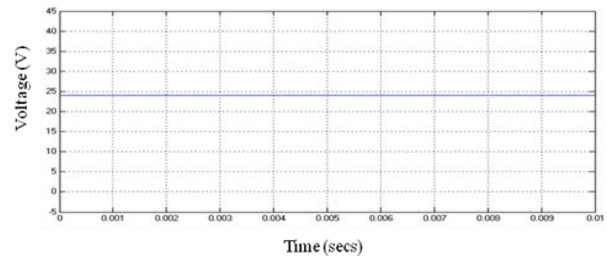


Fig 11) DC Input voltage 1

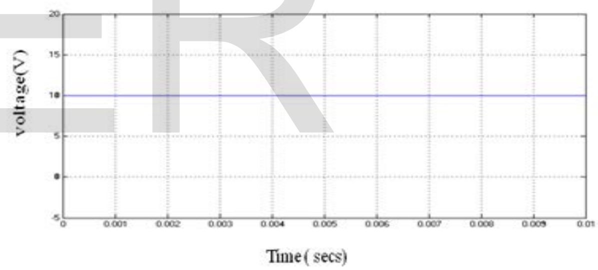


Fig 12) DC Input voltage 2

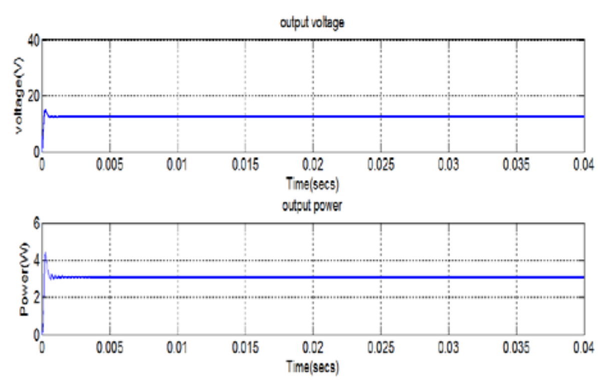


Fig 13) Resonant summation output voltage and output power

The resonant subtraction circuit output voltage (24-10=14V) and power are obtained as above.

6 CONCLUSION

The summation and subtraction circuits are the new topologies proposed and detailed analysis of them are presented in this paper. The summation circuit can give an output of the summation of two input sources. For example, there are two dc generators *VS* 1 and *VS* 2 , and the summation circuit can achieve high-voltage output without direct series connection of the two generators but still maintain the same common neutral. And the subtraction circuit can give an output of the difference voltage of two input sources. In the future work the hardware is to be implemented for resonant summation and resonant subtraction circuits to drive a motor load which can be utilized in renewable energy systems. The LSSVC is efficient in both power and cost. One circuit consists of only seven electronic devices, and the firing pulse circuit used is very simple because the switching frequency can be a constant. So, the design and production cost is very low. And moreover the concept of zero-current switching minimizes the loss and EMI, and the size of the capacitor can be decreased. The simulation is done with a switching frequency of 50 KHz. The resonant or soft switching concept has been implemented which has lead to the reduction of switching losses and the efficiency has been improved. The resonant current is limited and it gives a smooth transient during turn on and turnoff. With sufficient high switching frequency and large-output filter capacitor, the voltage copier can be designed to the power up to 500W and with a stable output voltage. The hardware for the same is to be implemented in the near future.

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