Buck-Boost Resonant DC-DC Converters with AC-link

Mahantesh B H[1] Mahadevi Biradar[2]

M.Tech student[1] *Associate Professor[2]*

[1,2] Electrical and Electronics Engineering Department & Poojya Doddappa Appa college of Engineering Gulbarga, India.

Abstract : This paper explains about high frequency AC-Link dc-dc converter and also presents the simulation and experimental results of the Buck-Boost resonant AC-Link DC-DC converter. simulation is designed in MATLAB/SIMILINK. this dc-dc converter is soft switched converter which consist resonant elements like AC inductor and AC Capacitor as a tank circuit. parallel combination of ac inductor and ac capacitor forms the ac-link., link inductor is the main device for transferring of power from input to output. link capacitor is also main device which create partial resonance with link inductor L to achieve zero voltage turn on and turn off of switches. converter has the capability to operate in buck and boost operation. it also operate in unidirectional and bidirectional operation modes. converter consist Four modes of operation which are explained in detail.

Key words: DC-DC converter , AC- Link, Resonant converters, MATLAB/SIMILINK, Step-up and Step-down operations. soft switching, partial resonance,

1. INTRODUCTION

High frequency operation has numerous advantages such as size and weight of the energy storage elements and transformer decreases in high frequency operation[1]. and also it gives wider control loop bandwidth and good dynamic response. ZVS (Zero Voltage Switching) andZCS(Zero Current Switching) are soft switching topologies. they are widely explained and developed to increase the converter energy efficiency and operating frequency. Voltage and current of the inductor and capacitor varies sinusoidally . turn on and turn off of the semiconductor devices or switches are occurred at zero crossing of the voltage or current of the inductor-capacitor tank circuit as a result the switching losses of the converter is decreases or eliminates and also decreases the converter generated EMI (electromagnetic interference).even though some advantages of soft switching topologies they have some disadvantages[2], while designing of the resonant L-C tank circuit to achieve the high performance at single point of operation it is highly difficult or impossible to adjust the resonant elements to achieve advanced performance over wide range of input voltage variation and load resistance. and also resonant converter suffer from high voltage stress and increases in conduction losses.

there are several DC-DC resonant converter topologies are proposed and developed such as PWM converter resonant based converter[3],[4],[5].. the switching frequency of the soft switching converters with constant frequency have higher components and it requires extra control circuitry. frequency of the converter in resonant topologies varies by changing in the input voltage and load current. they are also not suitable for large range of input voltage. resonant topologies are divided on the basis of the resonant tank circuit structure.

Buck-boost resonant AC-link DC-DC converter is explained in this paper[6]-[8]. the link frequency variation of the converter is less compared to other

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resonant converters. it consists parallel combination of an AC inductor and AC capacitor as AC- link . both inductor and capacitor are small and efficient. inductor charges from the input and discharge to the output, power flow is possible in both forward and reverse directions.

2. PROPOSED CONVERTER

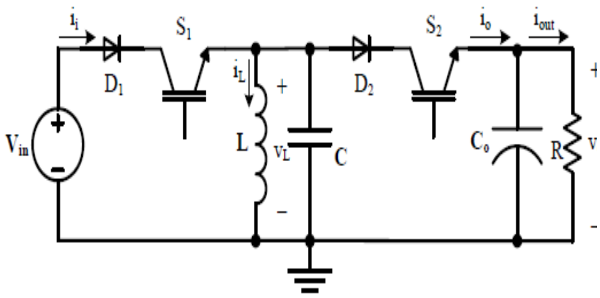

fig.1. Proposed Unidirectional converter

Fig.1.shows that the circuit diagram of buck-boost resonant HFAC- Link converter. it has an inductor and capacitor as tank elements. both are connected in parallel to form an AC-link. an ac inductor L is very small and efficient compared to other DC-inductor and it carries ac current. the link capacitor which has low capacitance value so there is no short bulky life electrolytic capacitors, link capacitor creates partial resonance with link inductor to obtain soft switching of switches of converter. power transfer in both direction is possible by using of two bidirectional switches. fig.2. shows the topology of Bidirectional converter

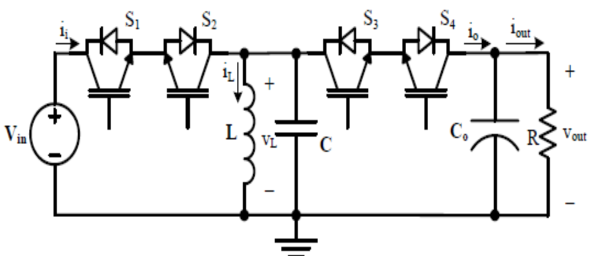

fig.2. Bidirectional topology

2.1. MODES OF OPERATION

The AC-link DC-DC converter consists 4 modes of operation which are explained below.

2.1.1 Mode 1

fig.4 shows the mode 1 operation dark line indicates mode 1 operation. The HFAC-link is connected to the input voltage of the converter, so the link inductor charges in positive direction . this mode runs until when the average of the converter input current meets the input reference current $\mathbf{I_{i,ref}}$ (fig 3) as a result switch S1 turned off.

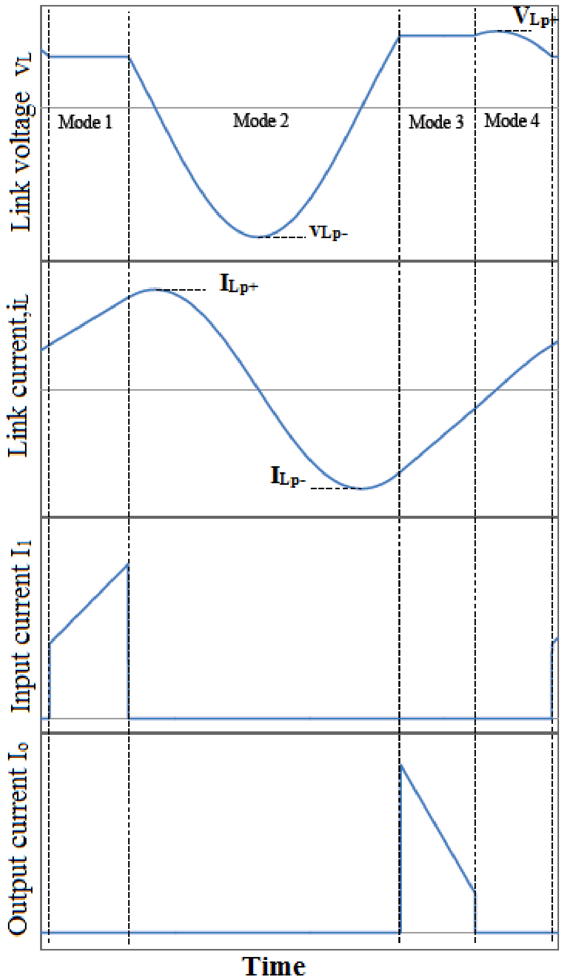

fig.3.Typical waveforms of Converter

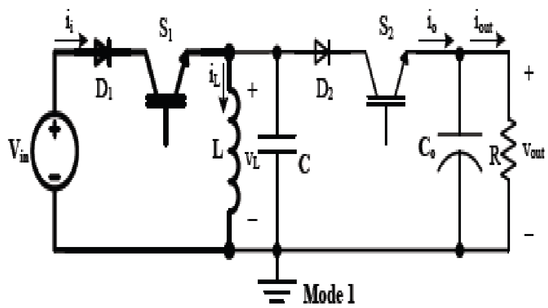

fig.4. Mode 1 operation

2.1.2 Mode 2

Fig 5 shows the circuit diagram of mode 2 operation. after switch S1 turned off in mode 1. the link inductor starts to resonate with link capacitor, it is allowed to run

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until link voltage $v_L(t)$ goes negative and then raises equal to the output voltage in positive direction. link current $i_L(t)$ meet its negative and positive peak values I_{LP+} and I_{LP-}. during this mode 2 (fig.3)operation link current may be expressed as

$$I_{LP+} = -I_{LP-} = \sqrt{{I_1}^2 + \frac{C}{L}{V_{in}}^2} \qquad (1)$$

Where I_1 is the link inductor current at the end of mode 1, V_{in} is dc input voltage of the converter. Link negative peak voltage during mode 2 can be given by

$$V_{LP-} = -\sqrt{{V_{in}}^2 + \frac{L}{C}{I_1}^2} \qquad (2)$$

switch voltage of S1 goes up slowly while switch current reduces quickly in its turn off process this is because of link capacitor C. as a result switch S1 turn off at zero voltage. switch S2 also turns off at zero voltage.

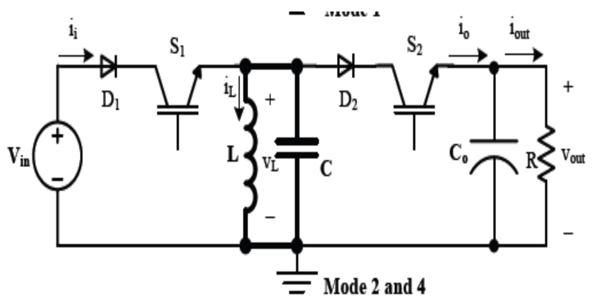

fig.5. Mode 2 and 4 operation

2.1.3 Mode 3

fig 6 shows the mode 3 operation. in this mode switch S_2 is turned on as a result the link inductor starts discharging to the output of the converter. link inductor L discharges until the link inductor current I_L reaches a small value of I_3,(fig 3) after this switch S_2 is turned off.

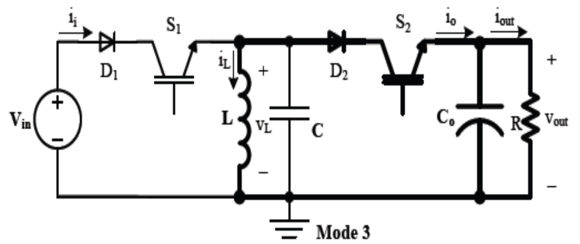

fig .6. Mode 3 operation

When switch S_2 is turned on the link voltage of the converter is equal to the output voltage at the beginning of the mode 3. so the switch S_2 is turned off at zero voltage.

2.1.4 Mode 4

After the completion of mode 3 both link inductor and link capacitor starts to resonate in mode 4 operation shown in fig 5 and the partial resonance is continued until the link voltage becomes equal to input voltage, when link voltage is equal to input voltage then converter goes to mode 1 with zero voltage switching. maintaining of the link voltage equals to input voltage is difficult in mode 4 so to make this process happen properly, the link voltage should rise up to a given amount higher than the input voltage during mode 4 . so some amount of current should be there in the link inductor at the end of mode 3. that current can be calculated as

$$I_3 = -\sqrt{\frac{C}{L}\left({V_{LP+}}^2 - {V_{out}}^2\right)} \qquad (3)$$

Where V_{LP+} is pre-determined peak link voltage of the link in mode 4. V_{LP+} can be 10-15% higher than the input voltage.

In practical digital control execution of the proposed converter , there might be some delay in turning on of the switches at the exact time because of discrete sampling and processing time. to avoid this delay, the converters switches can be turned on before the time while they are negative off- state voltages, as a result they start to conduct when they become forward biased. from fig 3 we can notice that when link voltage reaches its peak value in positive and negative directions, the link current passes through zero in the positive and negative directions. so zero crossing of the link current can be used to understand the link peak voltage .

3. ANALYSIS OF THE CONVERTER

The converter analysis is starts from the specified positive peak voltage of the link. Knowing that the link

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voltage peaks to the value of V_{LP+} in mode 4, the link current at the end of mode 4 can be given by,

$$I_4 = \sqrt{\frac{C}{L}\left({V_{LP+}}^2 - {V_{in}}^2\right)} \quad \textbf{(4)}$$

I_4 is the link current value at the beginning of mode 1. The input reference current is equal to the average link current in mode 1 is given by

$$I_{i,ref} = \frac{(I_4+I_1)T_1}{2T} \quad \textbf{(5)}$$

where I_1 is the link current at the end of mode 1, T_1 is the time length of mode 1 and T is the link period. Applying the inductor principal equation to the link inductor in mode 1 gives,

$$I_1 = \frac{V_{in}T_1 + LI_4}{L} \quad \textbf{(6)}$$

Substituting (6) in (5) and then solving for T_1 gives the time length of mode 1 as follows:

$${T_1}^2 + \frac{2LI_4}{V_{in}}T_1 - \frac{2LTI_{i,ref}}{V_{in}} = 0 \quad \textbf{(7)}$$

A similar analysis provides the time duration of mode 3 as follows:

$${T_3}^2 - \frac{2LI_3}{RI_{out}}T_3 - \frac{2LT}{R} = 0 \quad \textbf{(8)}$$

where I_0 is the converter's output dc current. The output current can be found according to the input-output power balance as follows:

$$I_{out} = \sqrt{\frac{V_{in}I_{i,ref}}{R}} \quad \textbf{(9)}$$

The time lengths of the resonant modes 2 and 4 of the introduced HFAC-link converter can be expressed by,

$$T_2 = \sqrt{LC}\left[\pi + \sin^{-1}\left(\frac{V_{out}}{-V_{LP-}}\right) + \sin^{-1}\left(\frac{V_{in}}{-V_{LP-}}\right)\right] \quad (10)$$

$$T_4 = \sqrt{LC}\left[\pi - \sin^{-1}\left(\frac{V_{out}}{V_{LP+}}\right) - \sin^{-1}\left(\frac{V_{in}}{V_{LP+}}\right)\right] \quad (11)$$

As mentioned earlier, V_{LP+} is a pre-determined value selected higher than the input voltage, and V_{LP-} can be found by replacing (6) in (2). Finally, the sum of the time intervals of all the operating modes of the converter is equal to the link period as follows

$$T_1 + T_2 + T_3 + T_4 = T \quad \textbf{(12)}$$

Substituting (7), (8), (10), and (11) in (12) will result in an implicit equation with the link period T as the unknown term.

4. SIMULATION RESULT

Simulation results for the proposed converter designed for the inputs 150V and 12V and the output voltage is 150V and 24V respectively for boost converter showed in fig 7 , which resulted the output power 750W and 4W for 150 and 24 V inputs respectively with 120Ω resistor. 430µH and 400nF are link inductor and link capacitor values respectively. output capacitor is 1000 µF.

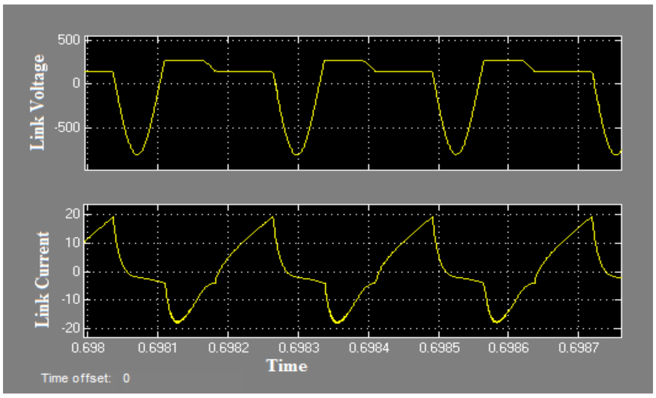

fig.7. shows the simulation waveforms for boost converter for the input 150V.

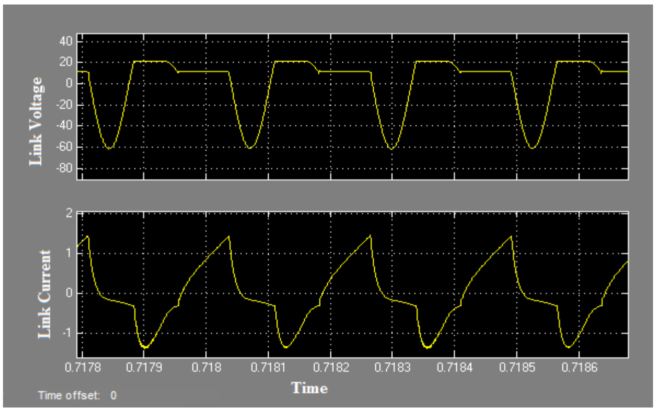

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fig 8 shows the simulation results of link voltage and link current for Boost Converter for the input 12V. Simulation for buck converter is carried out for 150V and 12V inputs and we get 75V and 5V output, respectively with 30 Ω resistor. link voltage and link current waveforms shown in fig (9) and (10) for both 150V and 12V inputs.

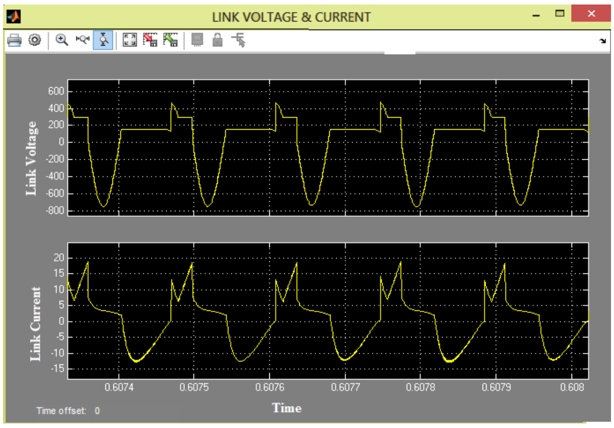

fig. 9 simulation result of link voltage and link current for buck converter for 150V input

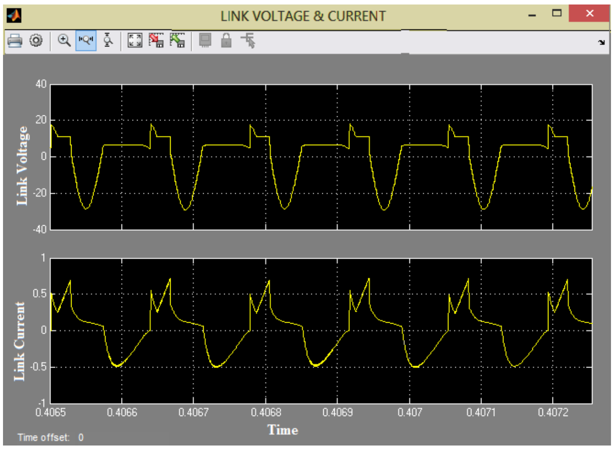

fig 10 simulation result of link voltage and link current for buck converter for 12V input

5. HARDWARE RESULTS:

Prototype of the converter was built to verify its operational principles, advantages, and performances. AT89C51 PIC Microcontroller is used in this prototype. converter link inductor and link capacitor was selected as 6.3mH and 500nF respectively. experimental results are designed for 12V input for boost and buck operations. while output was 24V for boost converter and 5V for buck operation. link frequency was 4.4KHz and 3KHz for boost and buck operations respectively.

fig 11 and fig 12 shows that the experimental link voltage waveforms of boost and buck converter respectively.

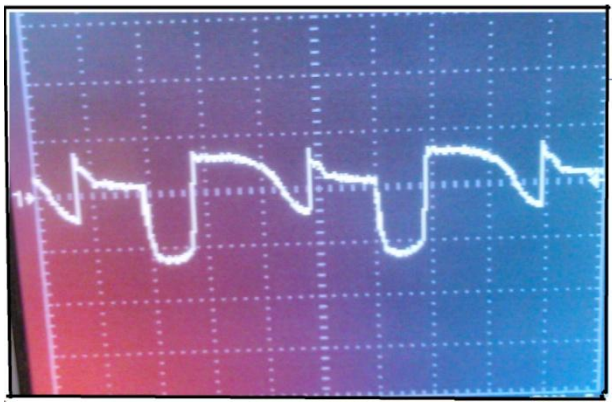

fig 11 experimental link voltage result for V_{in}=12V V_{out} =24V.(link voltage 50V/div, Time 100µs)

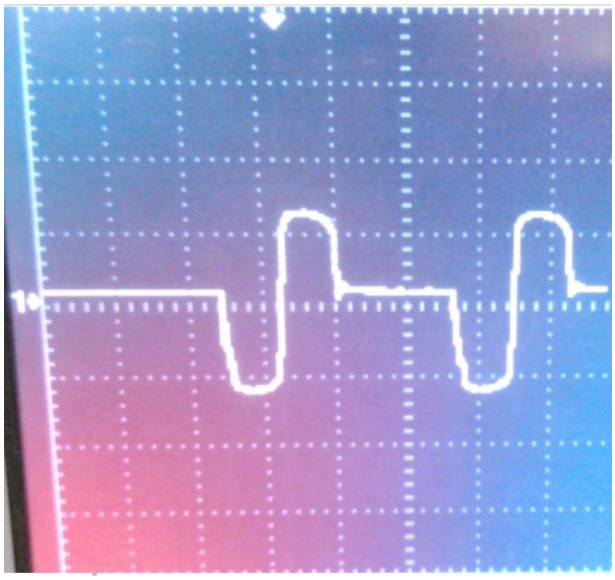

fig 12 experimental link voltage result for V_{in}= 12, V_{out}=5V. link voltage (50V/div), Time (100 µs).

6. CONCLUSION

This paper presents a new concept of DC-DC converter with AC-Link. Inductor and capacitor as a AC-Link. these two are main elements for power transfer. converter performs operation in both step up and step down operations. the variation of the converter's link frequency by altering the input voltage and load current is outstandingly small compared to other resonant topologies. Multiple simulation and experimental results

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were presented in the paper to demonstrate the effectiveness of the proposed power converter.

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