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A Direct Step Down and Step Up AC-AC Converter with Inverting and Non-Inverting Operations

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Abstract: ***In industry, the ac-ac power conversions are performed by using ac thyristor power controllers. But large total harmonic distortion in source current and lower efficiency have limited their use. Here a new single phase ac-ac converter topology is explained which can produce the non inverting step down(buck) ac output, step up(boost) ac output and inverting buck-boost ac output. All the three outputs can be achieved from a single converter using different switching pattern. This converter combines the operation of non-inverting step down(buck) and step up(boost) converters and inverting buck-boost converter in one topology. And a modification is being given so that all these three modes can be incorporated in a single simulink model. The converter has got six diode- switch pairs, one inductor and two capacitors. This converter has no shoot through problem even when all switches are turned on simultaneously. The simulation of the converter is done with MATLAB /SIMULINK software.***

Keywords: AC-AC Converter, Buck-Boost Converter, Inverting Mode, Non inverting Mode, MATLAB/SIMULINK.

1. Introduction

An AC-AC converter converts an AC waveform to another AC waveform. There are two ways of ac-ac conversion,it can be direct ac-ac conversion or indirect ac-ac conversion with dc link and matrix converters. Traditional ac-ac power conversions are performed by using ac thyristor power controllers, which use the phase angle or integral cycle control on input ac voltage, to get the desired output ac voltage .However, the obvious disadvantages of ac thyristor controllers such as low power factor, large total harmonic distortion in source current and lower effciency, have limited their use[7].For applications in which only voltage regulation is needed, the direct PWM ac-ac converters [2-7] are more preferred since they reduce the size and cost of converter. All of the direct PWM ac-ac converters in [10-24] are obtained from their dc-dc counterparts, where all the unidirectional switches are replaced with bidirectional devices[8].However each topology has its own limitations; the buck type ac-ac converter [3] can only step down the input voltage while boosttype [3] can only step up the input voltage. The buck-boost [2,3]topology can both step up and step down the input voltage, however, the phase angle is reversed.

The ac-ac power conversions are usually performed by using ac thyristor power controllers, which use the phase angle or integral cycle control on input ac voltage, to get the desired output ac voltage. However, the disadvantages of ac thyristor controllers are low power factor, large total harmonic distortion in source current and lower efficiency, which have limited their use. For applications in which only voltage regulation is needed, the direct PWM ac-ac converters are more preferred because they can reduce the size and cost of converter. Moreover, these topologies have disadvantage of higher voltage stress across switches, and there are discontinuous input and output currents in case of the buck-boost converter.All of the direct PWM ac-ac converters have a common commutation problem, which occurs because compared to the ideal situation in which the complementary switches do not have any overlap time; however, practically there exists a small overlap time owing to different time delays of gating signals and limited speed of switching devices.

To overcome the aforementioned drawbacks of existing direct PWM ac-ac converters, a direct ac-ac converter is proposed which combines the functionality of non-inverting buck and boost converters, and inverting buck-boost converter, in one topology. This new direct ac-ac converter is immune from shoot-through of voltage source (or capacitors) even when all switches are turned on simultaneously, which enhances its reliability and it does not need PWM overlap time which results in high quality output voltage. Even though it uses six unidirectional current conducting bidirectional voltage blocking switches, only two of them are switched at high frequency in each half-cycle during any operatingmode, resulting in smaller switching losses. In this converter, no current flows through body diodes of switches, and therefore, it can use power MOSFETs along with fast recovery diodes in series, which decreases switching losses and poor reverse recovery problem of MOSFETs body diodes is also avoided. The non-inverting buck and boost modes of this converter are suitable for applications with both step up and step down demand while the inverting buck-boost mode can also be utilized in DVR application to compensate both voltage sags and swells.

2. Step Down and Step UPAC-AC Converter with Inverting and Non Inverting Operations

A new converter in buck-boost configuration is developed to operate in both inverting and non inverting modes. The AC-AC converter consists of six unidirectional current flowing bidirectional voltage blocking switches S_1 to S_6 , six diodes, one inductor L, and filter capacitors C_{in} and C_0. The switches can be realized by series combination of power MOSFETs with external fast recovery diodes. The circuit is as shown in Fig.1.

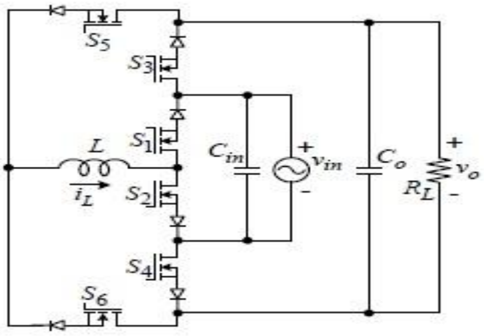


Figure 1: Step down and step up ac-ac converter with inverting and non inverting operations

A. Non-Inverting Step Down (BUCK) Mode Operation

The PWM switching sequence of this converter during non-inverting buck mode operation and key waveforms are shown in Fig 2. For positive half of input ac voltage (v_{in}>0), switches S_1,S_3,S_6 are always turn on and S4, $S_5$are always turn off, while switch S_2 is switched at high frequency.For v_{in}<0, switches S_2,S_4,S_5 are always turn on while switches S_3,$S_6$are always turn off, and S_1 becomes high frequency switch.

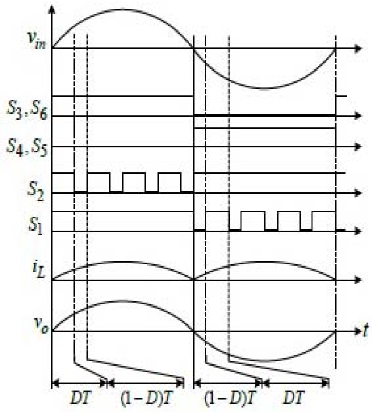
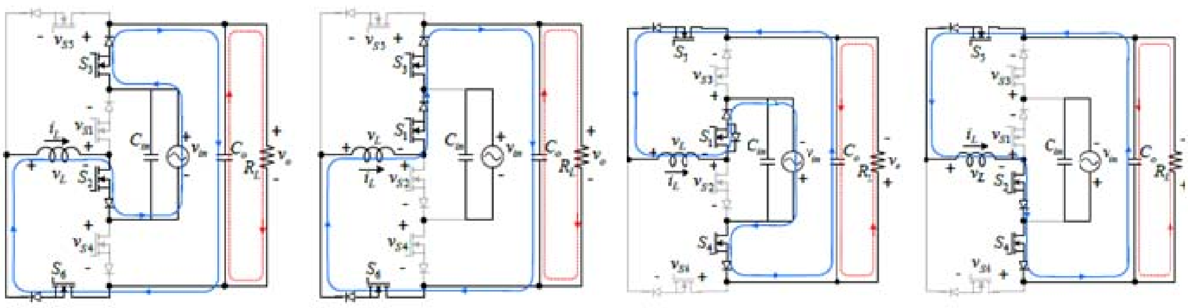


Figure 2: Waveforms during non-inverting buck mode operation.



(a) (b)

Figure 3: (a) Buck operation when V_{in}>0,During *DT* and *(1-D)T* interval (b) Buck operation when V_{in}<0,During *DT* and *(1-D)T* interval

Applying *KVL* and volt-sec balance condition on inductor *L*, gain of buck mode is obtained as $\frac{Vo}{Vin} = D$.

B. Non-Inverting Step Up (Boost) Mode Operation

The switching sequence of this ac-ac converter during non-inverting boost modeoperation and key waveforms are shown in Fig 4.For positive half of input ac voltage (v_{in}>0),switches S_2,S_3,$S_6$are always turn on and S_1, S_4 are always turn off, while switch S_5 is switched at high frequency.For v_{in}<0, switches S_1,S_4,S_5 are always turn on while switches S_2,$S_3$are always turn off, and S_6 becomes high frequency switch.Applying *KVL* and volt-sec balance condition on inductor *L*, gain of boost mode is obtained as $\frac{Vo}{Vin} = \frac{1}{1-D}$.

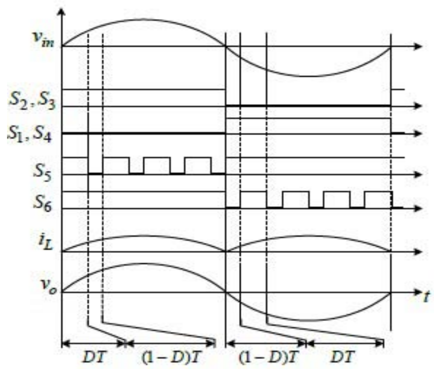
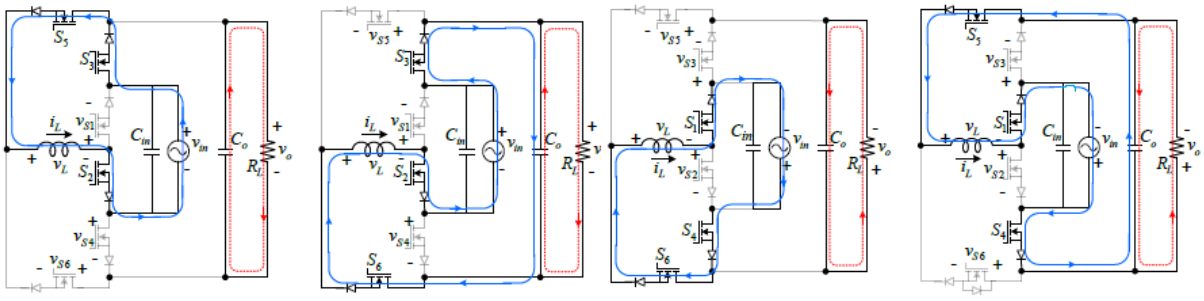


Figure 4: Waveforms during non-inverting boost mode operation



(a) (b)

Figure 5: (a) Boost operation when $V_{in}>0$,During *DT* and *(1-D)T* interval (b) Boost operation when $V_{in}<0$,During *DT* and *(1-D)T* interval

C. Inverting Buck-Boostmode Operation

The switching sequence of this ac-ac converter during inverting buck-boost modeoperation and key waveforms are shown in Fig 6.For positive half of input ac voltage ($v_{in}>0$),switches S_2,S_4,$S_5$are always turn on and S_1, S_6 are always turn off, while switch S_3 is switched at high frequency.For $v_{in}<0$, switches S_1,S_3,$S_6$are always turn on while switches S_2,$S_5$are always turn off, and S_4 becomes high frequency switch.

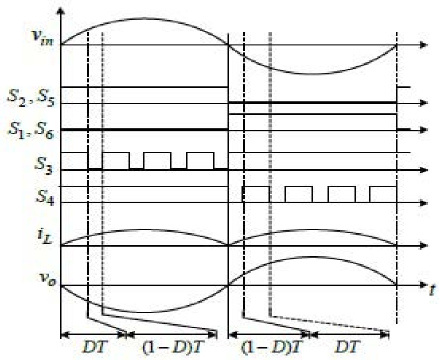
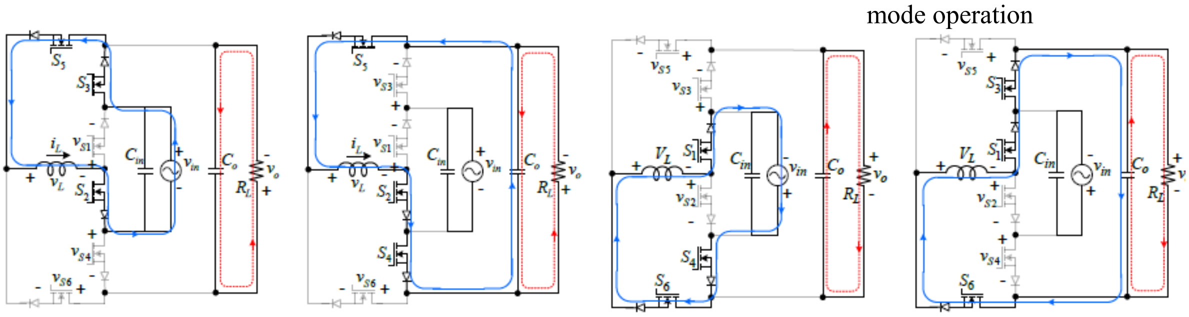


Figure 6: Waveforms during non-inverting buck-boost mode operation



(a) (b)

Figure 7: (a) Buck-Boost operation for$V_{in}>0$,During *DT* and *(1-D)T* interval (b)Buck-Boost operation for $V_{in}<0$,During *DT* and *(1-D)T* interval

Applying *KVL* and volt-sec balance condition on inductor *L*, gain of boost mode is obtained as $\frac{Vo}{Vin} = \frac{D}{1-D}$.

3. Simulation Results

This section presents the simulation studies of buck boost converter with inverting and noninverting modes in MATLAB/SIMULINK environment.Output voltage, Output Current converter in non inverting buck and boost mode is analysed here.

Table 1: Design parameters of the converter

Parameters	Values
Input voltage	70V
Output Frequency	50Hz
Switching frequency	25kHz
L(inductors)	800μH
Input Capacitor	1.5 μF
Output Capacitor	4.5 μF

The Simulink model for non invertingstep down (buck) mode, step up (boost) mode and inverting buck-boost mode are given separately. And a modification is being given so that all these three modes can be incorporated in a single simulink model.

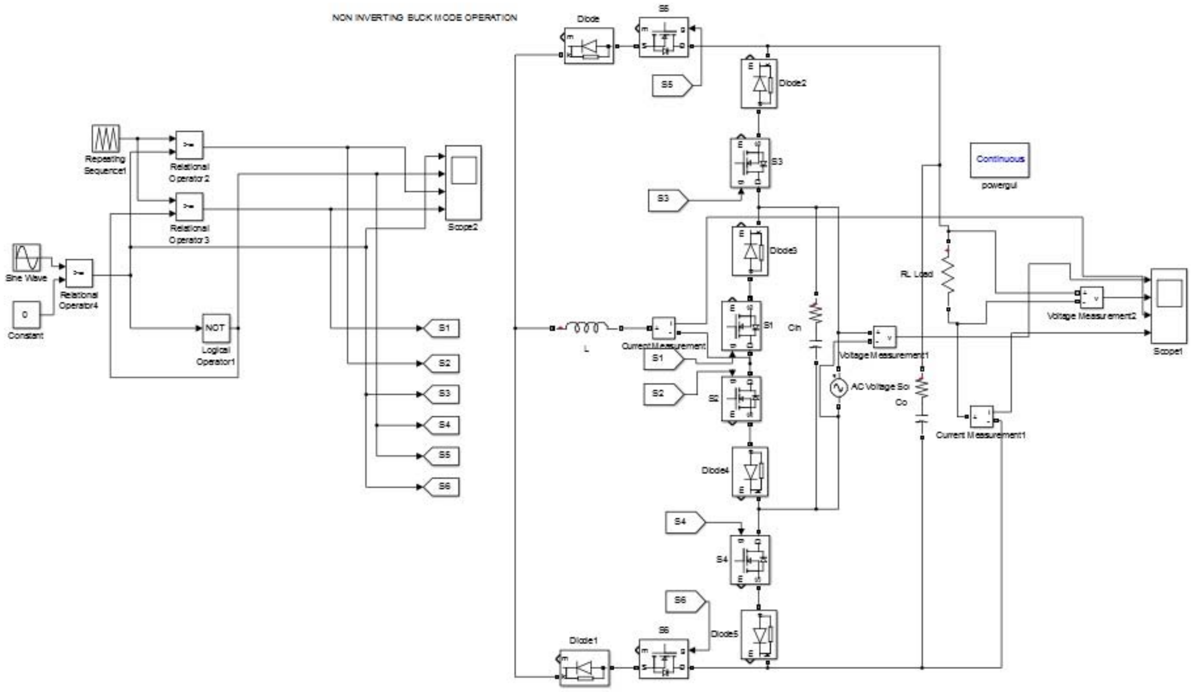


Figure 8: Simulink model of step down (buck) mode

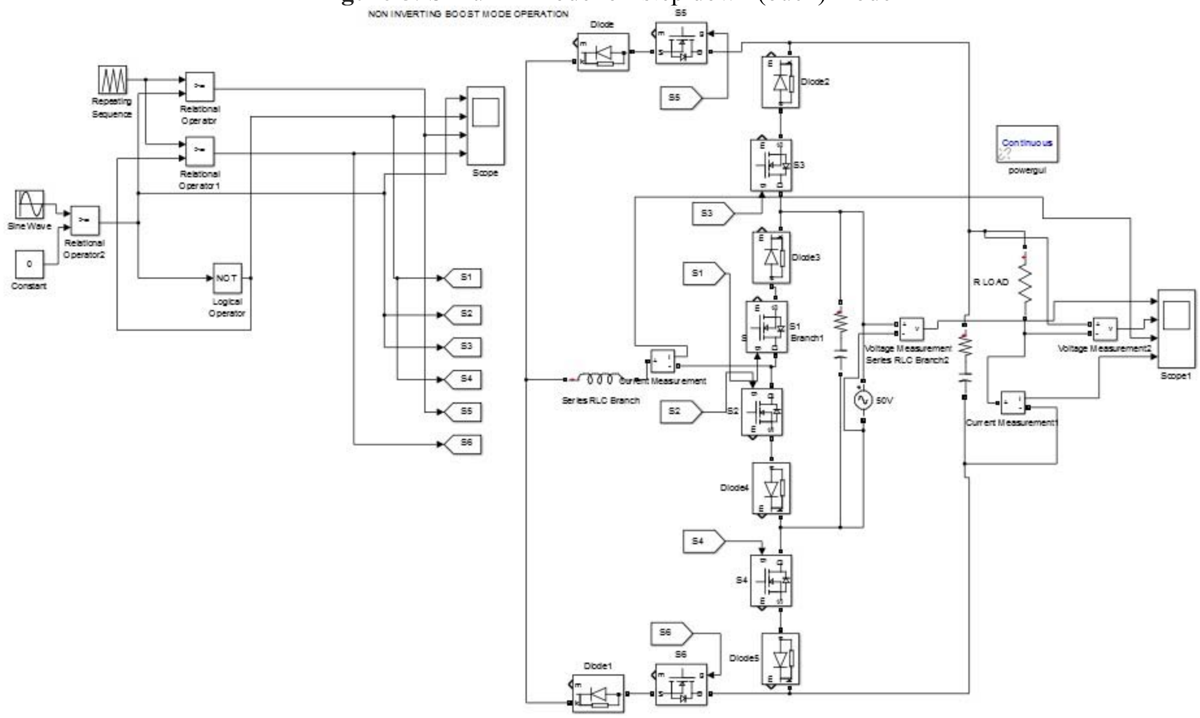


Figure 9: Simulink model of step up (boost) mode

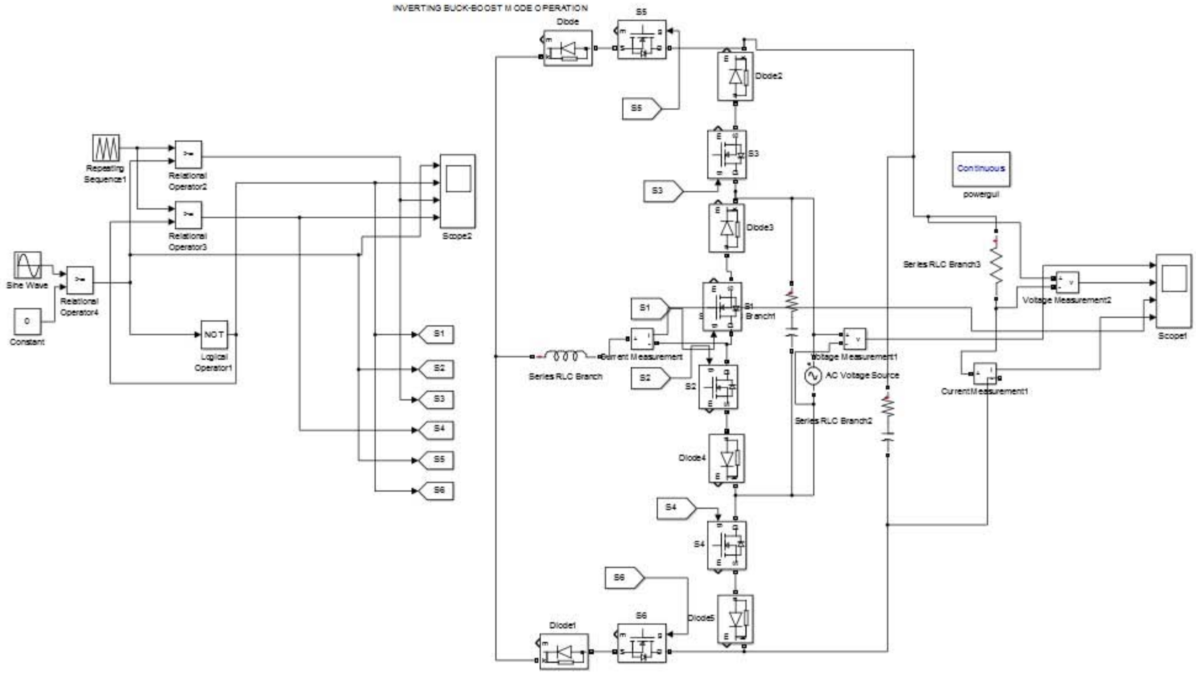


Figure 10: Simulink model of buck-boost mode

4. Mode Selection Control

As a modification a mode selection control scheme is introduced. As a result is being given so that all these three modes (step down mode,step up mode and buck-boost mode)can be incorporated in a single simulinkmode .Now these three modes are combined in a single Simulink model as shown in below. We can select the modes of operation according to our need by using the control given below.Then the pulses are fed to the power semiconductor switches.

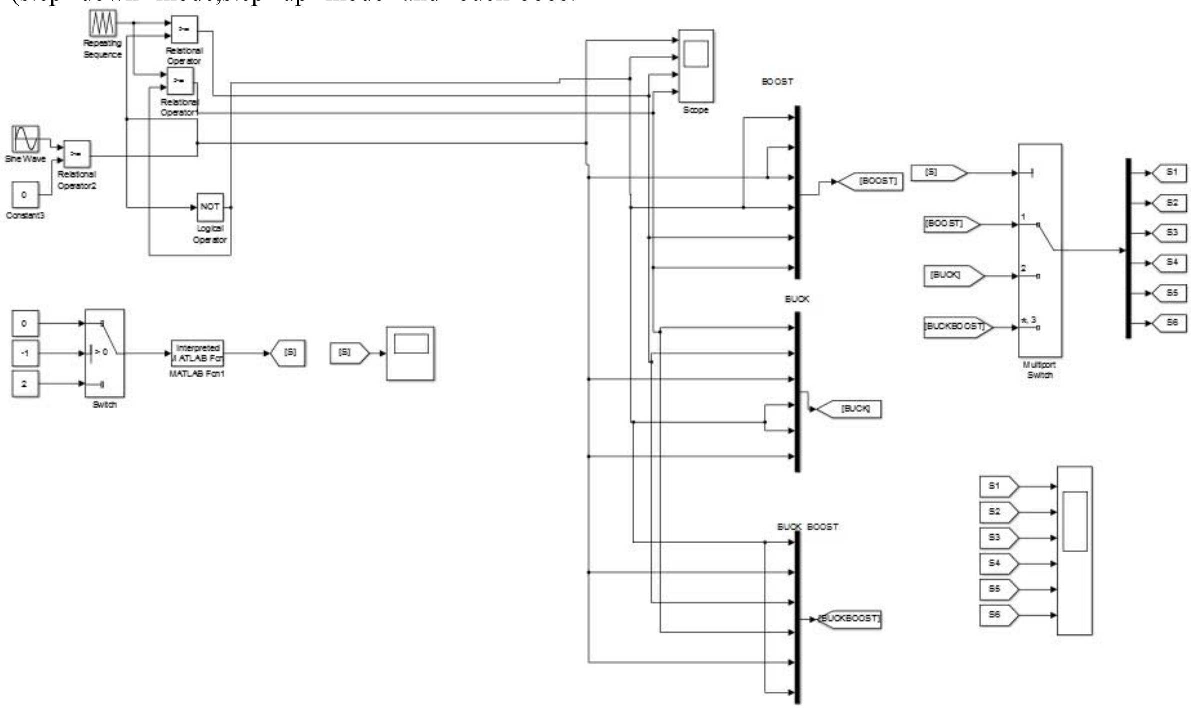


Figure 11: Mode selection control

The output waveforms of each mode is given below for duty ratio,D=0.5.For an input voltage of 70V, the Output voltage, Load current and inductor current waveforms are given.

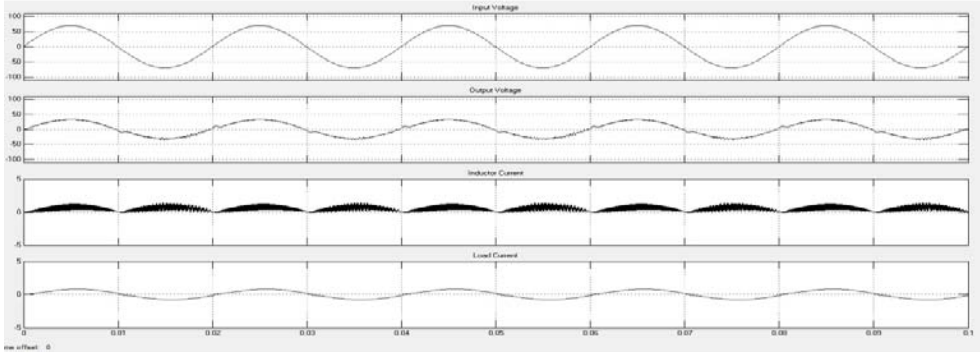


Figure 12: Simulation results of buck mode

From the output voltage waveform itself it can understood the non invertingstep down(buck) mode operation. We obtain a step down output voltage of 35V.

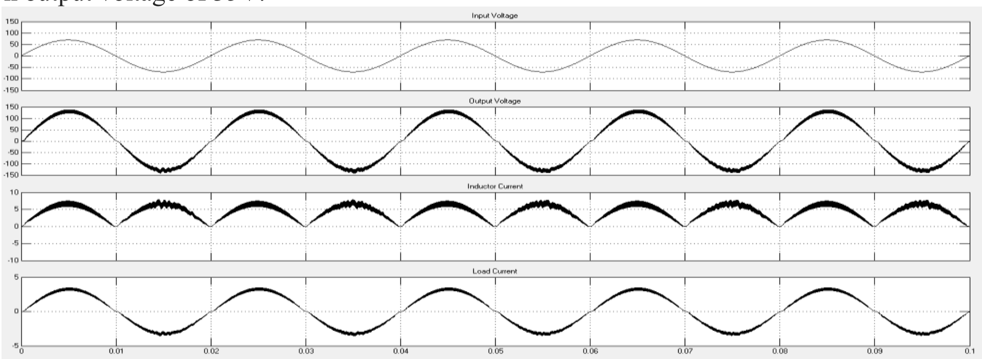


Figure13: Simulation results of boost mode

From the output voltage waveform itself it can understood the non inverting boost mode operation. We obtain a step up output voltage of 140V.

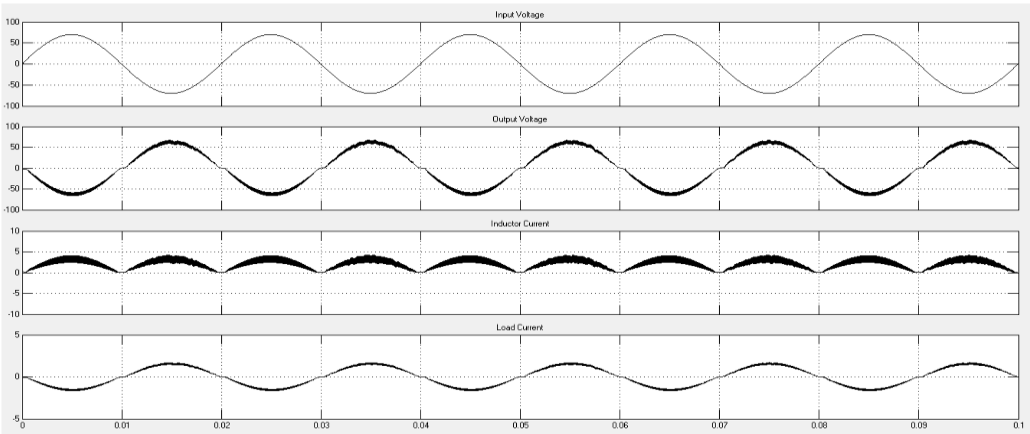


Figure 14: Simulation results of buck-boost mode

From the output voltage waveform itself it can understood the inverting buck-boost mode operation. We obtain an inverting output that is the phase angle is reversed.

5. Conclusion

The simulation has been carried out for the direct step down and step up ac-acconverter with inverting and non inverting operations for R load. The new single phase PWM ac-ac converter has combined the operation of non-inverting buck and boost converters and inverting buck-boost converter in one topology. The simulation results clearly show that this new ac-ac converter can operate in both inverting and non inverting modes. That is,step down ,step up and inverted outputs can be obtained from this single converter topology by adjusting the switching patterns of the switches. And as a modification a mode selection control is introduced here. By using this control we can select the modes of operation, according to our requirements. This converter is immune from shoot-through of voltage source (or capacitors) even when all switches are turned on simultaneously, which enhances its reliability and it does not need overlap time which results in high quality output voltage. Even though it uses six unidirectional current conducting bidirectional voltage blocking switches, only two of them areswitched at high frequency in each half-cycle during any operating mode, resulting in smaller switching losses. The non-inverting buck and boost modes of this converter are suitable for applications with both step up and step down demand while the inverting buck-boost mode can also be utilized in DVR application tocompensate both voltage sags and swells.

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