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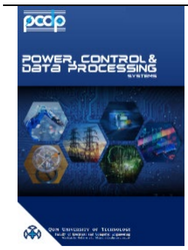

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Design and Simulation of a Buck – Boost PFC Converter with the Approach of Reducing the THD of Input Current

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Authors
A. Puya Behnia

[1] Department of electrical and robotics engineering, Shahrood University of Technology, Shahrood, Iran,
Puyabehnia@gmail.com

**** Correspondence***
Address: Department of electrical and robotics engineering, Shahrood University of Technology, Haftetir Square,
Shahrood, Iran. Postal Code: 3619995161.
Phone: -
Fax: -

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ABSTRACT

In this article it is tried to design a PFC (Power Factor Correction) circuit on the base of Buck – Boost converter in order to increase the power quality transmission of the input voltage source. The first step of this circuit's processing is to rectify the AC input voltage to a DC voltage but due to the use of diodes (in the H – bridge structure; which conduct the current just in a short time of each period the input current's THD (Total harmonic distortion) will increase. The lower THD of input current, the higher input power factor of the PFC converter as a result it is tried to increase the input power factor of the PFC converter. The output of the power factor correction process is a huge DC (Direct current) voltage which is regulated in the range of 400 volts with the help of control circuit. In this article the Boost mode of the Buck – Boost converter is considered.

Keywords: PFC; PF; THD; Buck – Boost converter.

1 Introduction

AC/DC converters (rectifiers) in the CCM mode of the inductor current on the base of PFC circuit are mostly used in the power supplies with medium or high output power. In the single – phase circuits the second – order reactive power in the input side of the circuits causes second – order ripple in the DC – link voltage.[1] A method for optimizing the design of the continuous flexible parameter in the power electronic converters is illustrated in this article.[2] The increasing rate of the requirements of developing the parameters of power quality with reducing the THD of the current and voltage waveforms has been widely studied in many references and papers, therefore it is lead to the proposal of too many high - power factor converters.[3] In MEAs pneumatic systems are being able to be replaced with the electrical systems with the advances in the power electronics.[4] In this article a PFC on the base of Boost circuit with the approach of open – loop interleaving method at the critical conduction mode of the inductor current with the master – slave relationship is illustrated.[5] An active PFC on the base of Boost circuit with the approach of developed soft switched with the usage of a complimentary converter which includes of a switch, one inductor, a capacitor which resonates in the whole of the time and a diode.[6] Power factor is a very important parameter which is the result of dividing the actual power by the apparent power in the three – phase and single – phase circuits.[7] Although the high amount of the THD factor in the power electronic converters is one of the major problems in these systems. Both the high THD and low PF is resulted from two factors: 1- The non – linear performance of the power converters and 2 – The performance of H – bridge structure in the converter.[8] PFC converter is important for the performance of the SRM converters due to the increasing the energy consumption and also decreasing the circuit losses; common PFC methods frequently lean on passive elements or simple active techniques.[9] An application of PFC converter based on the new power stage structure named IDBIC is illustrated in this article.[10] In this article a three – phase PFC converter structures with the alternative sinusoidal input currents and the output voltage which is controlled by the circuit are taken from the single – phase PFC converter's circuit and passive diode converter on the base of three – phase diode converter is shown.[11] In this article a control topology on the base of feedback structure of the considered structure are illustrated and mathematical equations in order to calculate the current's waveform distribution of the semiconductors of power is illustrated.[12] In order to discussing 400 V DC bus voltages a Buck – type converter on the base of PFC circuit is a good choice. An efficiency – optimized, 5 KW and 98.8% efficient PFC converter on the base of Buck circuit is illustrated in this article.[13] The development in structure, control and aspects of design in three – phase PFC methods is illustrated in this article.[14] A common controller of a PFC converter which is constant – frequency for three – phase converters which is connected in parallel structure on the base of dual – Boost structure is illustrated in this article.[15]

2 Power electronic converters

Power electronic converters are electrical power transfers that are divided into four categories:

1- DC to DC power electronic converters (DC Choppers)
2- AC to AC power electronic converters (Cycloconverters and AC voltage controllers)
3- AC to DC power electronic converters (Rectifier)
4- DC to AC power electronic converters (Inverter)

In the first category a DC input voltage will be converted into another DC voltage level. In the second category the AC input voltage will be converted to another AC voltage with another frequency and amplitude. In the third category the input AC voltage will be converted to the DC output voltage; and in the last category the DC input voltage will be converted to the AC output voltage.

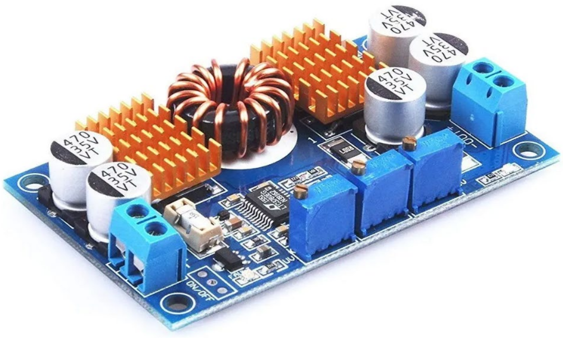

Figure 1: Power electronic converter (https://b.fdrs.ir/49d)

In the all of these four categories it is tried to transfer the electricall power from input side of the converter to the output side of the converter with the least power losses, THD and also the maximum power factor and efficiency.

These four categories of the power electronic converters transfer the electrical power by the usage of a power electronic swith which my be a MOSFET (Metal – Oxid Semiconductor Field Effect Transistor) or an IGBT (Insolated Gate Bipolar Transistor) that they are switched in an specified range of switching frequency.

3 Buck – Boost converter

A Buck – Boost converter is a DC-to-DC converter which can produce a DC output voltage higher than the input DC voltage or vice versa. This is related to the duty cycle of the converter; whenever the duty cycle of the converter is lower than 50% the converter performs like a Buck converter and whenever the duty cycle of the converter is higher than 50% the converter performs like a Boost converter. A high quality and smoother with the least overshoot and higher efficiency is received from the load side of the converter; which is regulated on the DC output voltage amplitude that it is be set up by the control circuit with a specified switching frequency.

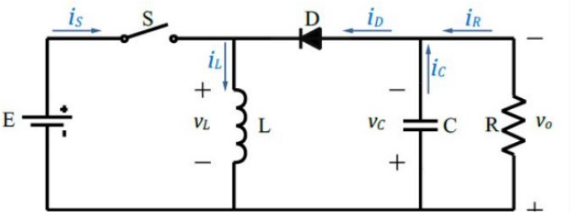

Figure 2: Buck – Boost converter (https://ansyscfd.ir/wp-content/uploads/2021/06/27.jpg)

3.1 Operation modes of the Buck – Boost converter

Buck – Boost converter has two modes of operating:

1 – The switch is connected and the diode is open circuit

2 – The switch is disconnected and the diode is short circuit

In the first case, the switch is connected and current flows from the input voltage source (V_{In}) through the inductor (L) to the ground (GND) and the diode (D) is off in this case; because its anode voltage is less than its cathode voltage (reverse bias). Energy is stored in the inductor in the form of a magnetic field. The inductor current increases linearly. The output capacitor (C_{Out}) in this case feeds the load (Load) and gives the energy stored in it, to the load. Therefore, the output voltage gradually decreases.

In the second state, the MOSFET switch is off and current cannot flow directly from the input voltage source to the ground. Due to the current-conserving property of the inductor, the magnetic field of the inductor begins to collapse and a voltage of reverse polarity is induced across it. This induced voltage turns on the diode (D) (forward bias) and current flows from the inductor, through the diode, to the output capacitor (C_{Out}) and the load (Load). The energy stored in the inductor is transferred to the output capacitor, increasing the output voltage.

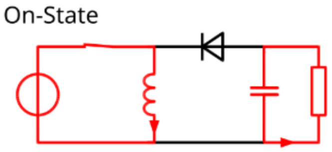

Figure 3: SW: On, D: Off (https://upload.wikimedia.org/wikipedia/commons/8/82/Buckboost_operating.svg)

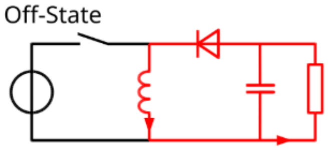

Figure 4: SW: Off, D: On (https://upload.wikimedia.org/wikipedia/commons/8/82/Buckboost_operating.svg)

4 PFC Converter

An AC to DC power supply is made up of several circuits to convert the input AC voltage to DC at the output. One of the main ones is the rectifier section. This circuit is responsible for rectifying the input AC voltage, in other words, rectifying the input alternating voltage. In order for the AC to DC power supply we are using to have proper performance and good safety, it needs to be isolated, have a good power correction factor, and a low voltage ripple level. These things will protect the user, the power distribution network, and the devices connected to the power supply. The first step in the power supply is to rectify the input voltage. Rectification is the process that converts the input alternating voltage to direct voltage (DC) at its output. A full-bridge (full-wave) rectifier consists of 4 diodes, which are also called Graetz (H – bridge) circuits. These diodes will cause the input voltage to be disconnected and connected, and ultimately create a DC voltage at its output similar to the image below. Of course, this voltage is not yet usable and must also pass through a filter to become direct DC.

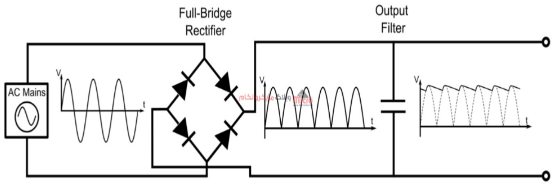

Figure 5: Rectifier circuit (https://blog.microele.com/author/soltanimicroele-com/)

5 Buck – Boost PFC Converter

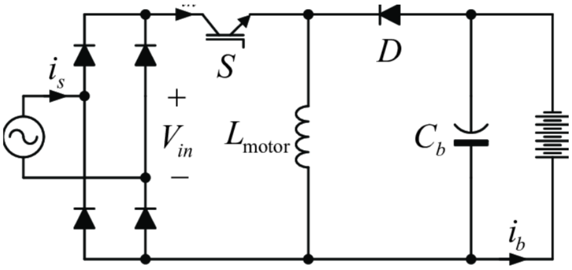

Figure 6: Buck – Boost PFC converter (https://www.researchgate.net/publication/275533959/figure/fig1/AS:671524012978180@1537115209341/The-simplified-equivalent-circuit-of-the-buck-boost-PFC-converter.png)

A Buck – Boost PFC converter is a power factor correction converter on the base of Buck – Boost circuit. It is tried to achieve to the considered output voltage amplitude by the designed control circuit with the approach of reducing the input current's THD in order to increasing the output PF. An AC voltage is used in the input side of the converter as the AC voltage supply; then an H – bridge makes the input voltage of the Buck – Boost circuit by rectifying the AC voltage supply of the input side of the converter then a rectified alternative voltage is produced in the input side of the inductor; according to the inductor's current's waveform the switching method of the power electronic switch is in CCM (Continues Conduction Mode) mode. A sinusoidal voltage will drop across the capacitor as a result the capacitor will be charged until the peak of the input voltage of the capacitor. The capacitor will be discharged on the load of the converter.

6 Discussion

The In this article it is tried to design a Buck-Boost PFC converter in order to achieve high input power factor; this is achieved by decreasing the THD of input current. In the next step it is tried to decrease the overshoot of the output voltage waveform.

The topology of the circuit is as follows:

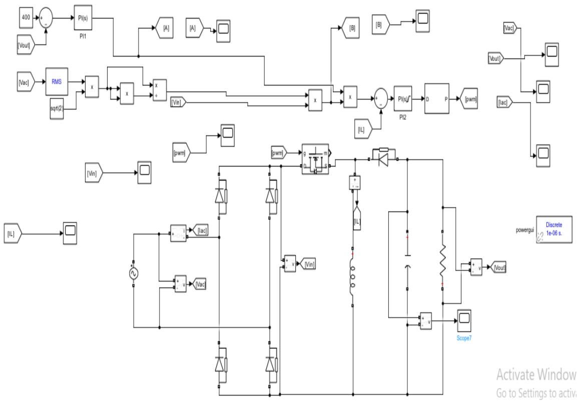

Figure 7: The topology of the proposed circuit

In the above circuit the input voltage source of the circuit is set up on 220 V rms and 50 HZ. The desired output voltage is 400 volts.

6.1 Design of the control circuit

At first the peak value of the voltage source is detected by the block diagram in the next figure:

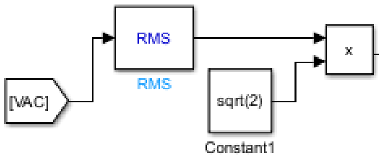

Figure 8: The block diagram of peak of the voltage source detector

In order to generate the sinusoidal reference for the current controller, the big value of the DC input voltage is detected by the block diagram in the next figure:

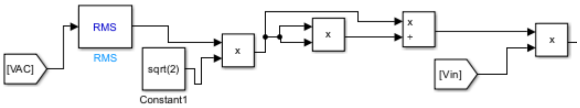

Figure 9: Reference current controller generator

In the figure 10 there is a voltage regulator in order to regulate the output voltage on the desired voltage which in the circuit figure 1 is 400 volts.

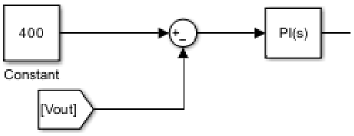

Figure 10: Output voltage regulator

After sinusoidal current reference is generated in the figure 9, it will be compared with the inductor current and then the produced current`s steady state error will be corrected by the PI controller and then with a limiter which is a DC-DC PWM generator the PWM generated signal will be applied to the MOSFET.

7 Math relations

Let the output power be setup on 1 KW. According to the required output voltage which is 400 V the resistant magnitude will be calculated as bellow:

$$R = \frac{V_{orms}^2}{P_O} \qquad (1$$

AS a result, the resistant magnitude will be equal to 160 ohms. The minimum amplitude of inductor that guarantee the inductor works in CCM mode is calculated as bellow:

$$L_{min} = \frac{(1-D)^2 R}{2 f_{sw}} \qquad (2$$

In the formula number 2 the duty cycle of the PFC converter will calculated as bellow:

$$\mathrm{D} = \frac{|V_O|}{V_S - V_O} \qquad (3$$

According to the magnitudes of V_O and V_S the duty cycle of the PFC converter approximately will be equal to 68% as a result the minimum magnitude of the inductor will be approximately equal to 273.06 μH but for guarantee the inductor work in the CCM mode the magnitude of 520 μH will be chosen.

For calculating the capacitors capacitance, the math relation bellow is used:

$$\mathrm{C} = \frac{D}{f_{sw} R \frac{\Delta V_O}{V_O}} \qquad (4$$

Let consider the voltage ripple on 0.01 as a result the capacitor's capacitance will be equal to 1416 μF.

$$\mathrm{DF} = \sqrt{\frac{1}{1 + THD^2}} \qquad (5$$

$$\mathrm{PF} = \mathrm{DF}.\cos(\varphi_V - \varphi_I) \qquad (6$$

8 Simulation Results

In the next figure the reference current's waveform is shown which is produced in order to generate the inductor's current as one of the components between the two components:

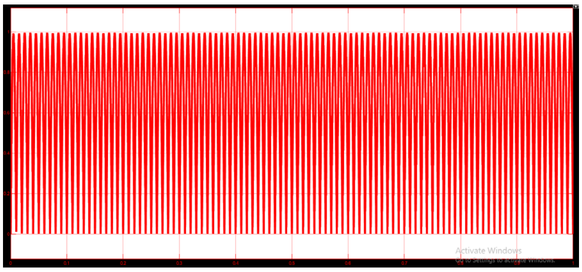

Figure 11: The reference current’s waveform

In the next figure the corrected steady – state error of output voltage’s waveform as the second component between the two components producing the inductor current is shown:

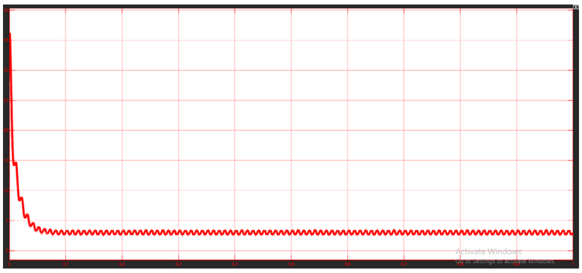

Figure 12: The voltage waveform’s steady – state error correction

In the next figure the input voltage waveform after being rectified by the H – bridge structure is shown:

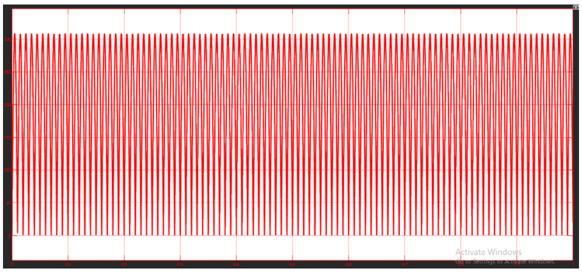

Figure 13: The input voltage’s waveform after the H – bridge structure

In the next figure the PWM (Pulse Width Modulation) waveform is shown which is used in order to switching the power electronic switch in the converter.

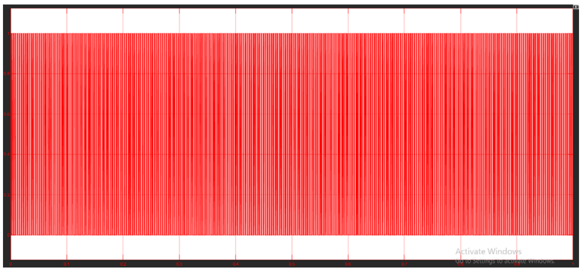

Figure 14: The PWM’s waveform

According to the inductor’s current the CCM (Continuous current mode) method of switching the MOSFET is chosen that is suitable for high output power applications.

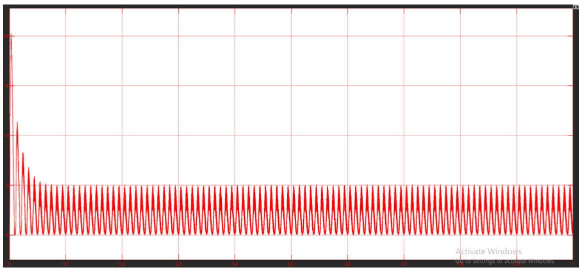

Figure 15: The inductor’s current’s waveform

The output voltage waveform which is regulated completely on 400 volts with a very low overshoot is as follows:

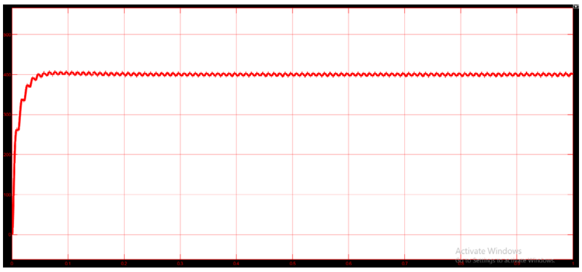

Figure 16: Output voltage waveform

The overshoot percentage of the output voltage in the figure 16 calculated by the MATLAB simulation software in the related scope is equal to 0.962% which is very good.
The voltage source waveform in the next figure is shown:

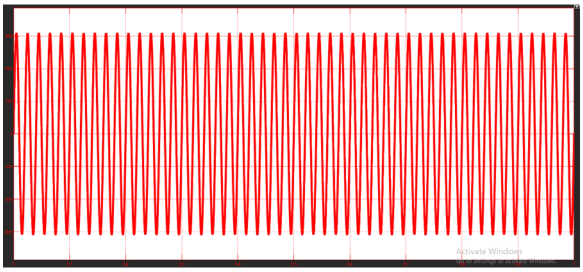

Figure 17: The voltage source’s waveform

The current source waveform in the next figure is shown:

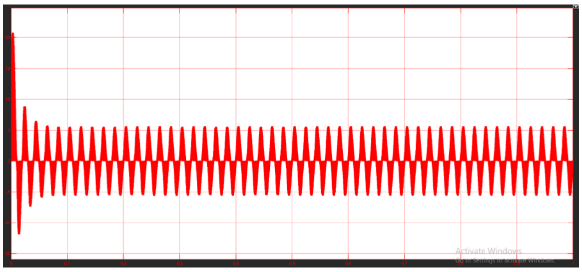

Figure 18: The current source’s waveform

The THD of the current source is calculated which is 6.08% and given in the next figure:
By using MATLAB simulation software, the peak values of both input voltage source and input current source signal calculated by the related scope are in the same times as a result the difference between the input voltage phase and the input current phase equals to zero therefore the power factor of input

voltage source equal to 99.7% according to the THD. As it can be seen in figure 11 the THD of the third harmonic of the input current in the fundamental frequency is 6.08% therefore the input power factor of the Buck – Boost PFC converter according to formula number 5 and 6 is approximately near to 100% and power losses are near to zero joules which is satisfactory.

Parameter	**Value**
Sampling Time	1e-06 sec
Samples per Cycle	20000
DC Component	0.01025
Fundamental	14.15 peak (10.01 rms)
THD	6.08%

Frequency (Hz)	Component	Magnitude (%)	Phase (°)
0	DC	0.07%	90.0°
16.6667	---	0.09%	-63.5°
33.3333	h1	0.09%	119.1°
50	Fnd	100.00%	2.5°
66.6667	---	0.05%	164.1°
83.3333	---	0.04%	20.8°
100	h2	0.05%	81.4°
116.667	---	0.02%	47.6°
133.333	---	0.04%	9.7°
150	h3	5.77%	-55.0°

Figure 19: The THD of current source

9 Conclusion and future works

Power quality is one of the most important aspects of power electronic applications. One of the most practical circuits to improve power quality is PFC circuits. In this article a PFC circuit on the base of Buck-Boost converter is designed. With Buck-Boost PFC circuit the limit usage of Boost PFC or Buck PFC circuits about the output voltage is solved; it means the range of output voltage that can be regulated is wider than Buck or Boost PFC. It is understood that the THD of input current in the Buck-Boost PFC converter which is shown in figure one is reduced to 6.08% due to use of PFC circuit and the input power factor of the circuit is increased to 99.7% due to the THD of input current and the difference between the input voltage phase and input current phase.

Disclosure of Potential Conflicts of Interest

The Authors declare that there is no conflict of interest

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