Modelling and Simulation of Three-Phase Single Switch Active Power Factor Correction Based Quadratic Buck Converter

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Abstract— **In this paper a new three phase single switch active power factor correction (APFC)circuit based on quadratic (square)buck converter is proposed and analysed, through which we get extensive step down ratio and high power factor. This paper proposes a three-phase, single-switch, quadratic step down dc-dc buck converter that can operate with input active power factor correction. Finally, this three-phase single switch quadratic buck APFC circuit was simulated using MATLAB/Simulink software. This result show that the power factor is high to 0.999 and the total harmonic distortion (THD) is low to 3% of the Proposed APFC converter. Simulations and experimental results are given to verify the converter characteristics.**

Index Terms— **Power factor, quadratic buck converter, three-phase APFC circuit, total harmonics distortion (THD).**

1. INTRODUCTION

During the last two decades, a great number of applications for the dc-to-dc converters have been reported. Many applications are found in computers, telecommunications, and aeronautic commercial and industrial applications. The basic topologies buck, boost, and buck-boost, are widely used in the dc-to-dc conversion. Converters, as well as other converters, provide low voltages and currents for loads at a constant switching frequency [7]. In recent years, there has been Need For wider conversion ratios with a corresponding reduction in size and weight. For example, advances in the field of semiconductors have motivated the development of new integrated circuits, which require 3.3 or 1.5 V power supplies.

The automotive industry is moving from 12 V (14 V) to 36 V (42 V), the above is due to the electric-electronic load in automobiles has been Growing rapidly and is starting to exceed the practical Capacity of present-day electrical systems. Today, the average 12V (14V) load is between 750W to 1kW, while the peak load can be 2 kW, depending of the type of car and its accessories. By using the non-controlled rectifier as voltage source of electrical equipment, the input harmonics current of power supply is large and power factor is low. As various electrical equipments increases with time than more the losses in transmission lines increasing. In order to reduce these harmonic pollution due to power supply of AC power grid, dc voltage sources uses power factor correction technology. For the conventional buck DC/DC converter topologies, the voltage conversion ratio is a function of duty ratio D of the buck converter. In recent years, the wider conversion-ratios have required in many industrial applications, therefore, the AC/DC or DC/DC converters must have the ability of operating within wider-conversion ratio that can supply the lower or higher output voltage. For achieve this purpose, the quadratic buck converter is a good choice. The conversion ratio of a quadratic buck converter equals square of the duty cycle, for example, for a 10:1 step down, a quadratic buck converter will operate with the duty cycle of 0.32. This paper introduces a three-phase APFC circuit based on this quadratic buck converter, can not only get high power factor, but also achieve lower output voltage.

A buck converter is a voltage step down and current step up converter. The buck converter with LC input filter operating in discontinuous output inductor current mode has resistive and constant input impedance with a constant duty cycle D and a constant switching cycle Ts. Thus, the average input current of the converter follows the input voltage with a constant duty ratio control. The low-frequency behavior modeling of the Buck converter with LC input filter operating in discontinuous output inductor mode is presented in this paper. Based on the model, the characteristic of the converter and the conditions for power factor correction is studied. The simplest way to reduce the voltage of a DC supply is to use a linear regulator but linear regulators waste energy as they operate by dissipating excess power as heat. Buck converters, on the other hand, can be remarkably efficient (95% or higher for integrated circuits), making them useful for tasks such as converting the main voltage in a computer 12 V in a desktop system, 12-24 V in a laptop down to the 0.8-1.8 volts needed by the processor. The experimental verification is also given. In the three phases APFC circuit based on buck converter needs to make the input filter capacitor works in discontinuous voltage mode (DCVM)[8].so that APFC circuit with resistance load characteristics can achieve high power factor and reduced and low harmonics. For this type of APFC circuit, it can work only in narrow range of voltage to ensure this filter capacitor to work in discontinuous mode.

Need for improvement of Power Factor: Conventional AC rectification is thus a very in-efficient process,gives result in waveform distortion of the current drawn from the mains. That producing a large spectrum of harmonic signals that may interfere with other equipment. At higher power levels (200 to 500 watts and higher) severe interference with other electronic equipment may become apparent due to these harmonics sent into the power utility line. Thus, one Another problem is the power utility line cabling,& the installation process and the distributing transformer, must be designed to withstand the peak current values results in higher electricity costs for any electricity utility company.

In Conventional AC rectification has the following main disadvantages:

- It creates harmonics and electromagnetic interference (EMI).
- It has poor power factor.
- It produces high losses.
- It requires extra dimensioning of parts.
- It reduces maximum power capability from the line.

Active PFC Method:

An active approach is the most effective way to correct power factor of electronic supplies. Here, we place different Active PFC converters between the bridge rectifier and the load. The converter is trying to maintain a constant DC output bus voltage and draws a current that is in phase with and at the same frequency as the line voltage.

Advantages:

• Active wave shape of the input current.
• Filtration of the high frequency switching
• Feedback sensing of the source current for waveform controlling.
• Feedback controlling to regulate output voltage.

2. WORKING PRINCIPLE OF SINGLE SWITCH THE ACTIVE POWER FACTOR CIRCUIT BASED QUADRATIC BUCK CONVERTER*:*

Fig 1 shows the single switch quadratic buck converter where single switch is used for switching between two buck converters .

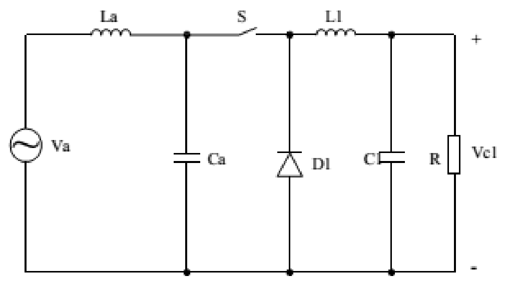


Fig.1 equivalent diagram single switch quadratic buck converter

Fig.1 is a three-phase single switch APFC circuit equivalent diagram based on quadratic buck converter.[3] Va, Vb and Vc are three-phase AC voltages are input filter inductors, Ca, Cb and Cc are input filter capacitors. For getting high power factor and low harmonic rectifier, we have to select large enough input filter inductor La, Lb and Lc to fulfil that the current remains constant in one switching cycle. So that, it must be selected sufficiently small filter capacitor Ca, Cb, and Cc to satisfy the circuit operating at discontinuous voltage mode.

Taking phase 'a' as example, let assume that the switching frequency is larger than the power frequency, the current ia through input filer inductor remain unchanged in one switching cycle. When switch s is off, filter capacitor Ca is in linear charge state by charge current ia. When charging is over peak voltage across filter capacitor is proportional to supply voltage. When switch is on, filter capacitor ca releases electrical energy to load R through inductor L1 &L2 and these two inductors are in energy storage state. When filter capacitor Ca discharged to zero, the energy stored in inductors will continue to transfer the energy in load R. When switch S is 'off', the filter capacitor Ca is in the linear charge state the again by the charge current ia, and the inductor L2 continues to transfer energy to load R through the freewheeling diode D3 until switch S is 'on' again.

While active power factor correction circuit (APFC) is running in steady state, the voltage across filter capacitor Ca is high frequency pulsation and its envelop line is sinusoidal wave. In any half wave cycle the average voltage across Ca is equal to average value of phase voltage and its peak voltage is proportional to current in circuit. When switching frequency is greater than power frequency and three phase voltage is sine wave than input current and voltage is also sine wave. So that high power factor or unity power factor is achieved and THD is also reduced.

The three phase APFC circuit based on quadratic buck converter has following three states:

(1). State 1 ($t_0 < t \leq D_1Ts$)

When switch S is 'on', D2 is the forward conduction, input capacitor is discharged, C1 is also in the discharge state. In this state, the voltage Vc across the capacitor is reduced to 0.

(2). State 2:(D_1 $Ts < t \leq DTs$)

When switch S continues to maintain the 'on' state, the discharge process about the input capacitor is over, there is no current through the input capacitance, C1continues to discharge.

(3). State 3($DTs < t \leq Ts$)

When switch S is turned off, input capacitor begins to charge. At t=DTs, this process is over, and get into the next cycle.

Quadratic buck converter is a cascaded connection by two buck converter which contains two LC filter. In order to analysis and simplify modelling of quadratic buck converter can be referenced [1].

The maximum voltage across the input filter capacitor ca is:

$$Vc = \frac{Ic}{Ca}(1 - D)Ts \quad .... \quad ....(1)$$

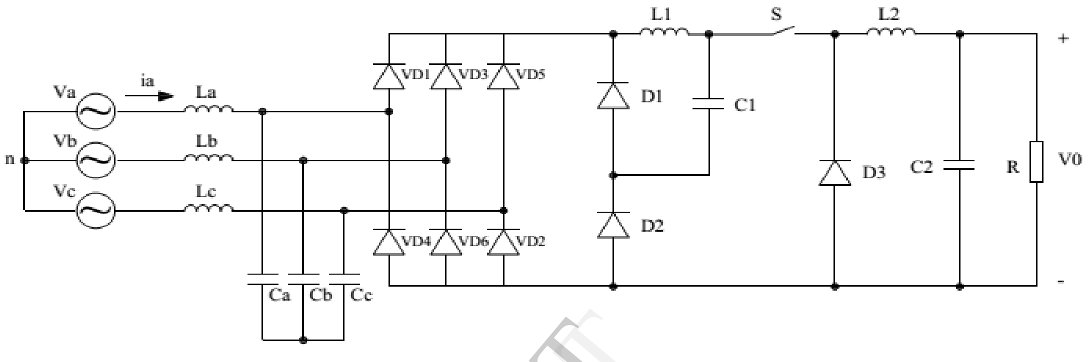
When circuit reaches steady state, the average voltage through the inductor La in one switching cycle is zero and input voltage is written as:

$$Va = \frac{(1-D+D1)(1-D)TsIL}{2\,Ca} \quad .... (2)$$

Similarly average voltage through inductor L2 in one switching cycle is zero and the output voltage can b derived as :

$$Vc1 = \frac{D1(1-D)TsIL}{2Ca} \quad .... (3)$$

From these equations on simplifying, the input current is also sinusoidal; therefore power factor correction is realized.



AC SOURCE	INPUT FILTRS	RECTIFIER	ACTIVE POWER FACTOR CORRECTION	DC FILTER	LOAD

Fig2.Three–phase single switch active power factor circuit (APFC) based on quadratic dc-dc step down Converter

3. THIS SIMULATION AND ANALYSIS OF THREE PHASE SINGLE SWITCH ACTIVE POWER FACTOR CORRECTION BASED QUADRATIC BUCK CONVERTER:

The simulation of three phase model is constructed by MATLAB/simulink 2013a, the closed loop simulation models are shown in fig respectively. Here we are using traditional pid controller method in closed loop system have taken switching frequency in range of 8kHz to 60 kHz. Consider here 50 Hz frequency as base frequency. In simulation, the parameters of quadratic (square) buck converter are assumed below:

L1=5mH,L2=5mH,L3=5mH, C1=C2=C3=0.2μF,L4=0.22mH,L5=20μH, C4=19.3μH, C5=13.4μF, R=1.2Ω

From the simulation result it is showed that the input current & voltage waveform is sinusoidal and input current waveform follows the input voltage waveform, the input current phase is coincident with input voltage phase waveform, and in closed loop circuit input voltage and current are sine waveforms. Hence, this simulation result verify the above analysis and design is correct.

In matlab simulation or in simulink power system graphical user interface (POWERGUI) is used as an integrated environment, and it is compulsory block which is used to convert time in discontinuous mode and it is an effective tool used to analyze power system model.IN POWERGUI, the FFT tool is used to analyze the harmonics order for input current and we can also calculate the THD for input current waveform. The input current harmonic can be shown in fig. 5, 6, respectively.

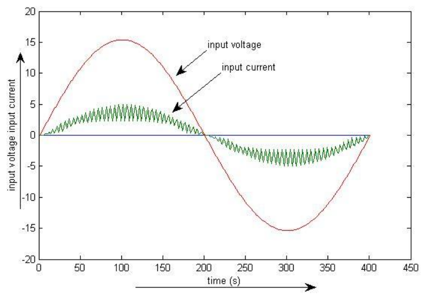


FIG 3.Waveforms Of Closed Loop Input Voltage And Current.

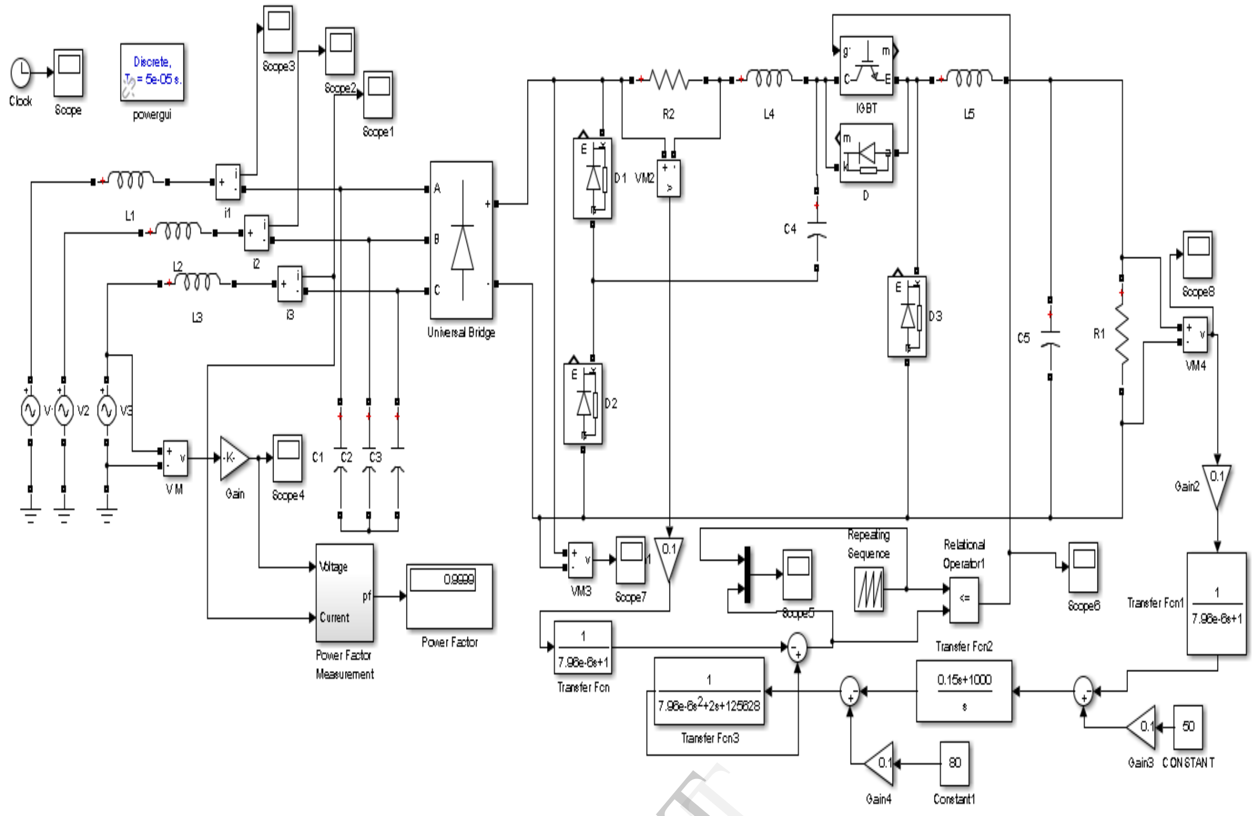


FIG 4 The Closed Loop Simulation Model Of Three Phase Single Switch Active Power Factor Correction Based On Quadratic Buck Converter

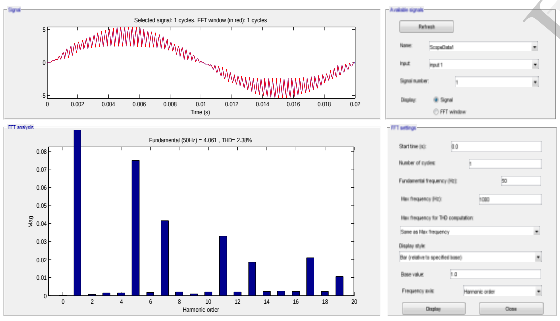


Fig.4 input current amplitude frequency of closed loop system (harmonics and THD)

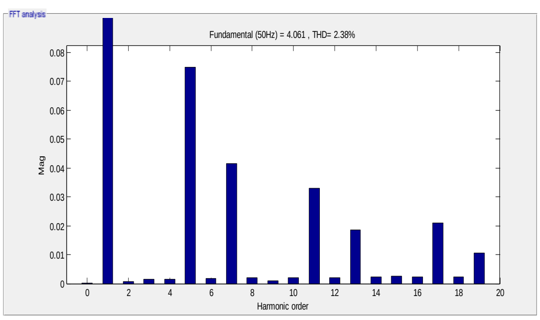


Fig.5 input current amplitude frequency of closed loop system (harmonics and THD)

in case of closed loop system, the Max. Frequency for computation of THD is same as Maximum frequency. The total harmonics distortion is below 3% or 2.38 approx, and power factor is about 0.9995.Therefore, the power factor of tree phase Active Power Factor Correction of single switch quadratic buck converter is close to unity power factor. Waveform of particular input voltage in fig,6 and

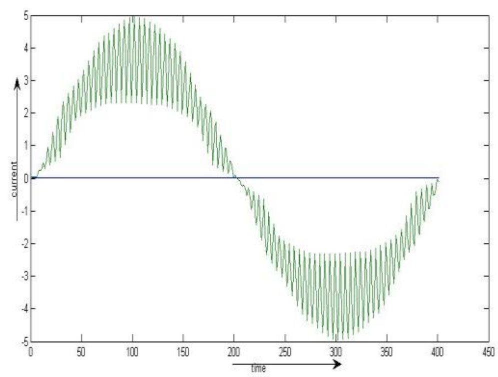


Fig.6 waveform of closed loop input voltage

Input current waveform in fig.6 and also the output voltage in fig .8 is given.

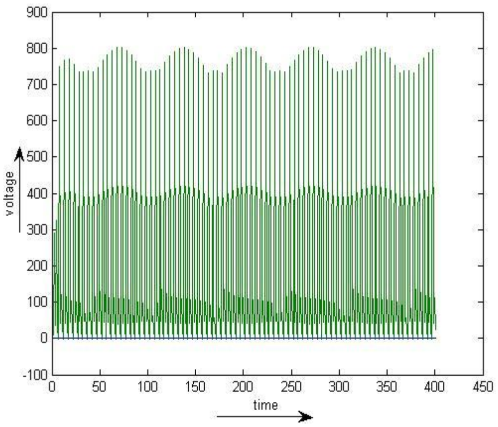


Fig.7 waveform of rectifier voltage

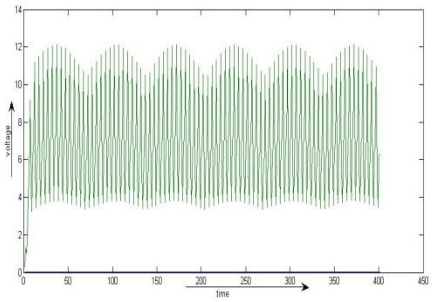


Fig.8 waveform of output voltage

4. CONCLUSION

This paper is analyzed the study of basic principle of a three phase APFC circuit based on step down dc-dc converter and achieve the unity power factor in discontinuous voltage mode. finally, the input voltage and input current waveforms are obtained by using MATLAB/SIMULINK, and input current harmonics and total harmonics distortion can be analyzed through Powergui/FFT toolbox. This result shows that the three phase single switch active power factor correction based on quadratic (square) buck converter can achieve unity power factor and lower THD.

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