IRACST – Engineering Science and Technology: An International Journal (ESTIJ), ISSN: 2250-3498,
Vol.2, No. 3, June 2012

Active Power Factor Correction Using Switching Regulators

Mr. Ghanekar V. D.
Dept. of E&TC Engineering, Sinhgad Academy of Engineering, Kondhwa (Bk), Pune-41104 India

Prof. Molke G. V.
Associate Professor, Dept. of E&TC., Pd. Dr. D. Y. Patil Institute of Engineering and Technology, Pimpri, Pune-411018 India

Prof. Patil M. M.
Assitant Professor, Dept. of E&TC, Sinhgad Academy of Engineering, Kondhwa (Bk), Pune-41104 India

Mr. Travis Helenes A.
Director, Power Integration Pvt. Ltd, Shivne Ind. Estate, Pune India

Abstract - **The most of the equipmentsbeing used in IT industries, commercial and residential applications are internally working on the DC voltage. So either internal to the equipment or externally they need toundergo conversion from AC to DC for their functioning and operation. Depending on the requirement it consists of Single or Three Phase controlled or uncontrolled rectifier. The simple rectification technique leads to degradation in the quality of the current drawn is terms of Harmonics, wave form Distortion, Power Factor (PF) and affect the power distribution system. The increasingdemand of these devices, the line current harmonics and PF pose a major problem by degrading thepower quality of the system thus affecting the performance of the other devices also. Hence there is a needto enhance quality of power drawn by these equipments.**

Thispaper proposesthe front end rectification technique for three phase supply using switching mode active control to enhance these quality factors. The technique is simulated in the MATLAB Simulink environment and results are shown.It also focuses the approach of Pre-regulator integrated circuits towards the power factor correction.

Keywords—**Active Power Factor Correction (APFC),Current Loop, Voltage Loop, Harmonic Current.**

I. INTRODUCTION

The power supplies in most of the equipmentare to convert mains power to the desired level of power that is needed for their proper functioning. This conversion leads to rectification and filtering of input mains power. Then it is scaled down using DC-DC converters as shown in Fig.1.

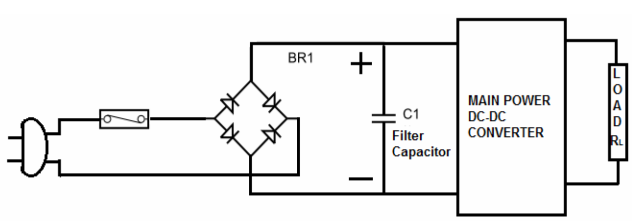

Figure 1*:*Capacitive line filter

The filter used in the supply draws current only when the line voltage exceeds the filter capacitor voltage and the filter capacitor is charged to near the peak level of the input line voltage as shown in figure 2.

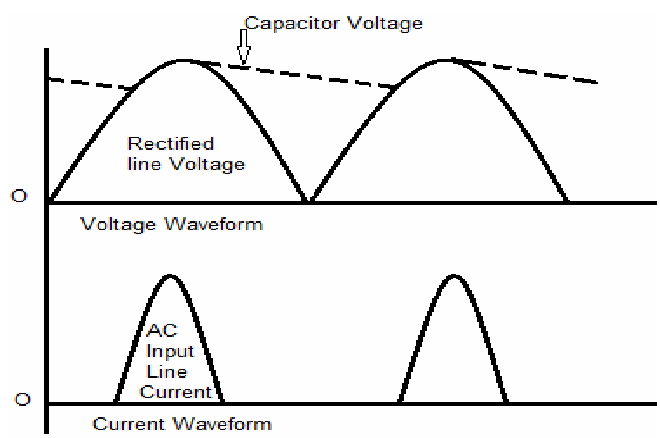

Figure2*:* Input Current with Capacitor Filter

As shown in the Fig.2, the current flows for the short duration where the capacitor voltage reaches to peak of input voltage. Due to this short pulses the RMS value of current increases and average value decreases, which adds line losses and power quality issues in the system.

Power factor correction may lead to have benefits like; reduction in distribution cost, more power can be drawn at the same current rating from the line. Presently it is mandatory requirement in many countries for the equipment to comply the standards led by the government.

II. How Does PFC Works?

The ideal requirement of power factor correction is making nature of input current waveform same as that of the input voltage. Figure 3 shows the line voltage and line current with and without power factor correction. Major two power factor correction techniques are Active PFC and Passive PFC.

A passive PFC uses a filter at the AC input to correct poor power factor. The passive PFC circuitry uses only passive components-an inductor and capacitors. A passive PFC rarely achieves low Total Harmonic Distortion (THD). Also, because the circuit operates at the low line power frequency of 50Hz or 60Hz, the passive elements are normally bulky and heavy [1].

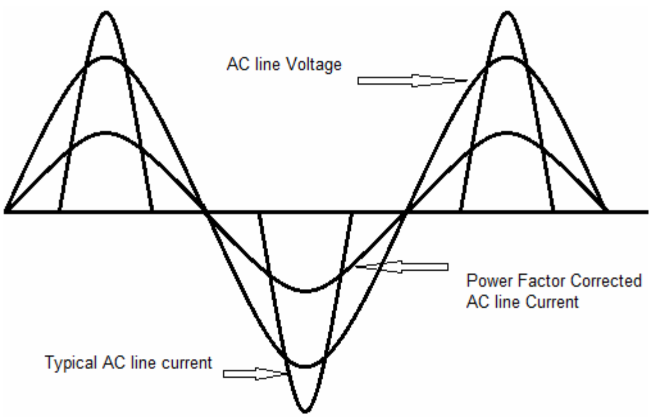

Figure3: Effect of PFC on line current.

Active PFC offers better THD and is significantly smaller and lighterthan a passive PFC circuit. It uses switching regulator technology to draw current from the power line proportional to input voltage [2]. It consists of feedback loops to control input current and to regulate output voltage.

III. Switching Regulator Topologies

Buck, boost, Buck-boost and other converter topologies are used in active PFC circuits.[3], since the only requirement is to close a fast current loop around the input current and make it look like input voltage.

A) Buck Converter:

In this type of topology, the DCoutput voltage which appears across the load is afraction of the input voltageand this fraction turnsout to be equal to the duty cycle. So we can write:

Vout = Vin x D

Where, D is duty cycle

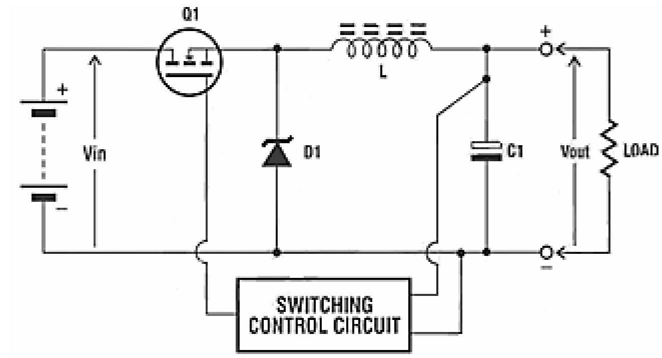

Figure 4: Buck Converter.

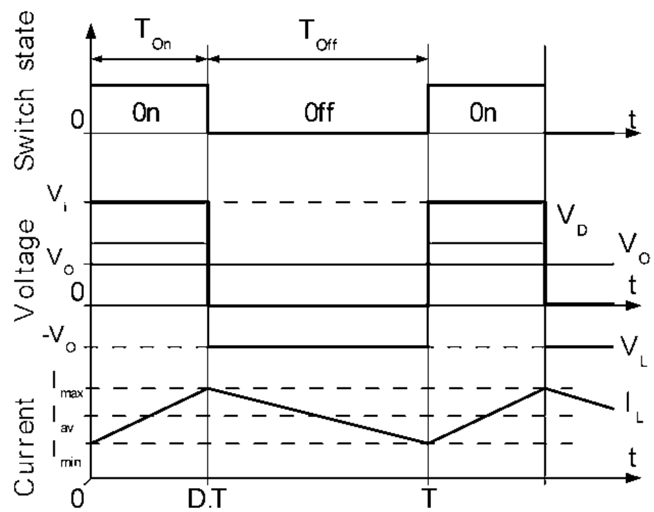

Figure 5: Waveforms of Current and Voltage in Buck Converter operating in continuous conduction mode

So by varying the switching duty cycle, the buckConverter’s output voltage can be varied as afraction of the input voltage.

B) Boost Converter:

The operation of Boost converter [4] consists of using Q1 as high switching speed. When Q1 is switched on, current flows from the inputsource through L and Q1, and energy is stored in theinductor’s magnetic field. There is no current through D1, and the load current is supplied by the charge in C1. Thenwhen Q1 is turned off, L opposes any drop in current by immediately reversing its EMF so that the inductor voltage adds to (i.e. boosts) the source voltage, andcurrent due to this boosted voltage now flows from thesource through L, D1 and the load, recharging C1 as well.

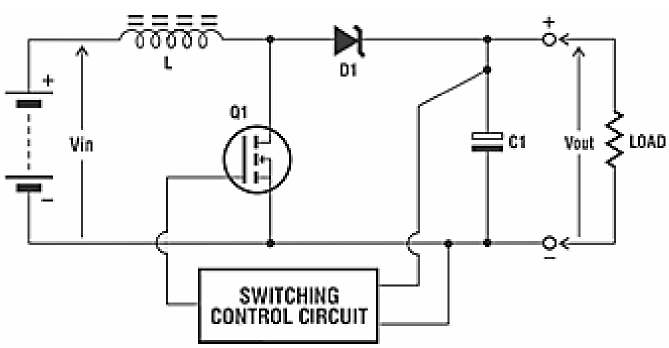

Figure 6*:* Boost Converter

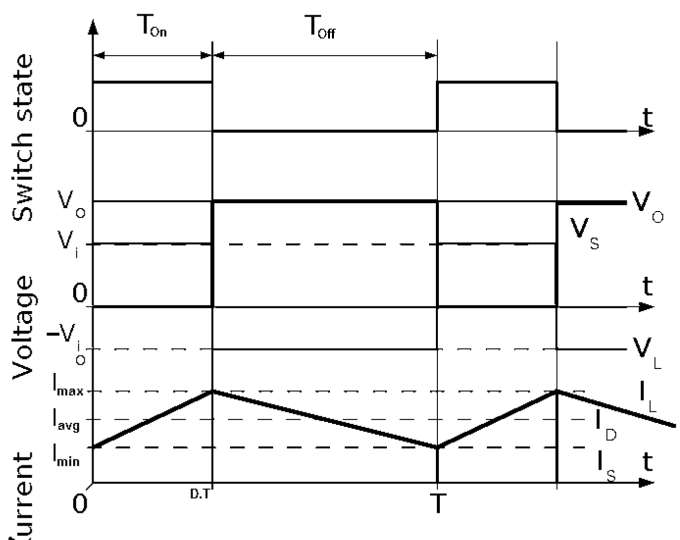

Figure 7*:* Waveforms of Current and Voltage in Boost Converter operating in continuous conduction mode

The output voltage is therefore higher than the input voltage and it turns out that the voltage step up ratio is equal to

Vout/Vin = I/ (I-D) or Vout/Vin = T/Toff

Where, I-D is actually the proportion of switching cycle that Q1 is off, rather than on.

C) Buck-boost Converter

This converter allows the voltage to be stepped either up or down [5], depending on the duty cycle. With this type of configuration the ration between the output and input voltage turns out to be,

Vout/Vin= -D/(1-D) or Vout/Vin= -Ton/Toff

So, the buck-boost converter steps the voltage down when the duty cycle is less than 50%(Ton < Toff) and steps up when duty cycle is more than 50% (Ton > Toff)

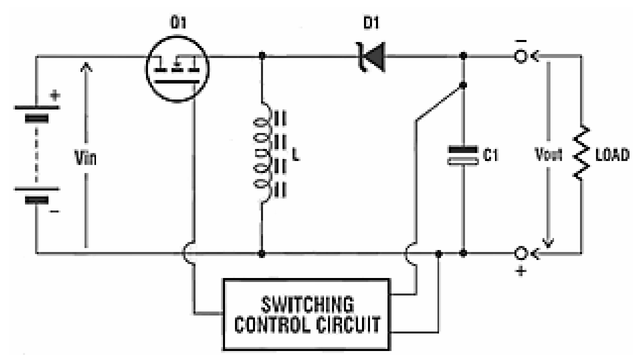

Figure 8*:* Buck-Boost Converter

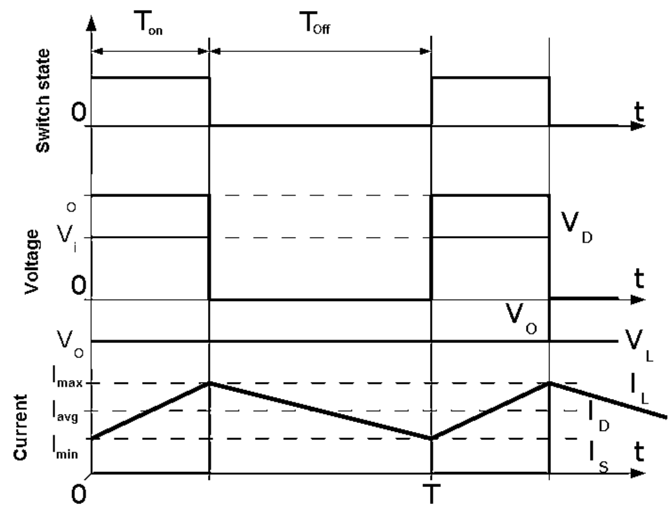

Figure 9*:* Waveforms of Current and Voltage in Buck-Boost Converter operating in continuous conduction mode

The most populartopology seems to be the boost converter [7], since the input current flows through an inductor and is relative smooth and easy to control and also easy to measure with a resistor in the power return.Another popular approach, especially at lower power levels, is the buck-boost converter. Thisapproach allows isolation and output voltage amplitude scaling as part of the power factor correction process.

IV. PREREGULATOR INTEGRATED CIRCUIT

Because of the popularity of power factor correction, a number of companies now manufacturepower factor correction ICs. These include: Cherry Semiconductor Corp., IXYS Corp., Linear Technology Corp., Micro Linear Corp.,Motorola, Inc. (Tempe, AZ),Unitrode Corp., etc.

The Unitrode UC3854 family[6] is typical and is used for the examples in this paper. This IC uses boost topology. Figure 7 is from the Unitrode data sheet and shows the UC3854 connectedin a typical 250-watt power factor corrected pre-regulator.

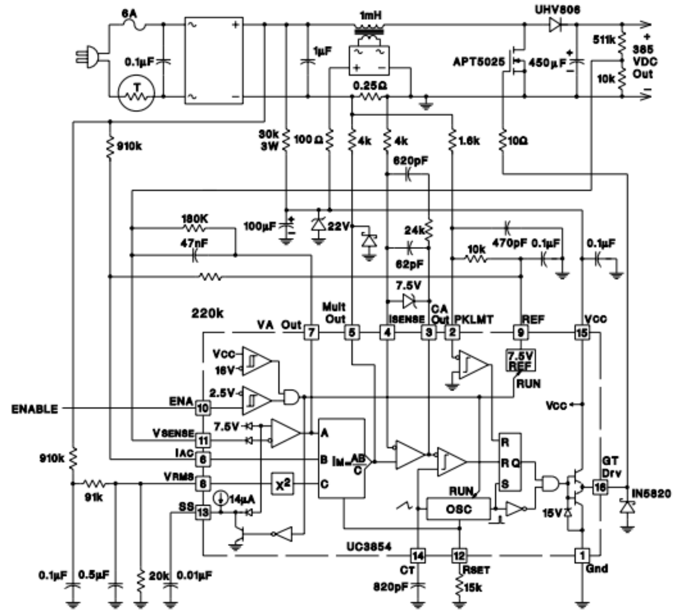

Figure 10*:* Schematic of 250 watt pre-regulator from Unitrode data sheet [6].

A) Current Control Loop

The current control loop contains error amplifier which is used for comparison of sensed current (pin 4) and reference current which comes from the multiplication of output error voltage and absolute value of instantaneous line voltage.The reference takes the form of a current that is injected into the non-inverting input ofthe current error amplifier (pin 5).

PWM pulses are then created by comparing output of error amplifier with fixed amplitude ramp signal (pin 14). These pulses are used to drive the power transistors (pin 16).

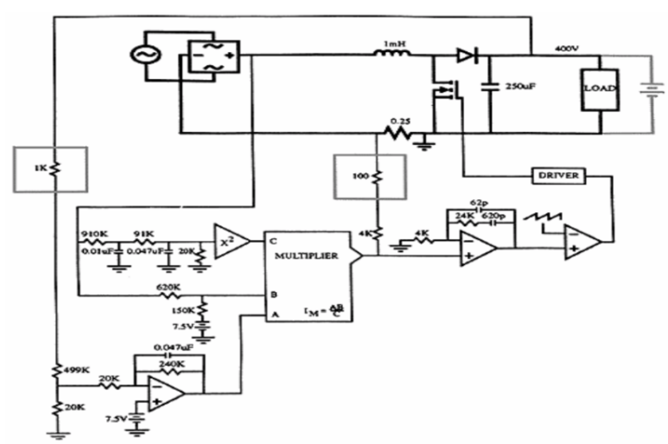

Figure 11*:* Simplified schematic of pre-regulator showing signal paths and loops [6].

B) Voltage Control Loop

The voltage loop is used to compensate changes in line and load voltages. The DC output is sensed (pin 11) and compared with fixed DC voltage in the error amplifier. The output of error amplifier (pin 7) is then converted into current reference waveform by multiplying it with a waveform template (pin 5), which represents the desired current wave shape. This multiplied output drives the current control loop. The DC output of squarer which is proportional to the square of Vm is used to pre-scale the error amplifier output. This makes open loop gain independent of line voltage.

In the Active filter operation,the nonlinear load shown in Fig. 12 is again a three phasefilter[8]. It can be seen that the mains current gets asine waveform, being only slightly distorted in theinstants of the diode switching. This is due to the highdi/dt occurring in these points, which is impossible tocompensate unless with a very high DC voltage or a verylow AC inductance. There should be a compromisebetween the active filter dimensioning and thecharacteristics of the load current to be compensated.

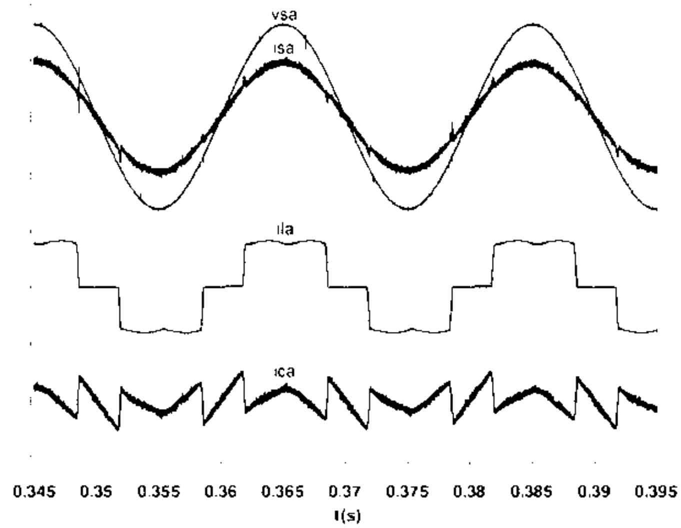

Figure 12*:* Steady-state compensation of a filter. Traces from top to bottom: source voltage, Vsa; source current, Isa; load current, Ila; filter current, Ica[8].

V. SIMULATION MODEL

The APFC control scheme is tested under the MATLAB Simulink environment. The major components of the model are Voltage control loop, Current control loop, PWM generator, steering control [10] as shown in Fig. 13**.**

The model is developed considering the three phase load. It is directly connected to the line without interference to the existing load connection. Three phase IGBT based active rectifier is used as the power topology. The conduction of the IGBT is controlled based on the instantenious correction depending on the current drawn at that instance by the connected load. the topology is tested for the lagging PF load conditions in the preliminary stage.

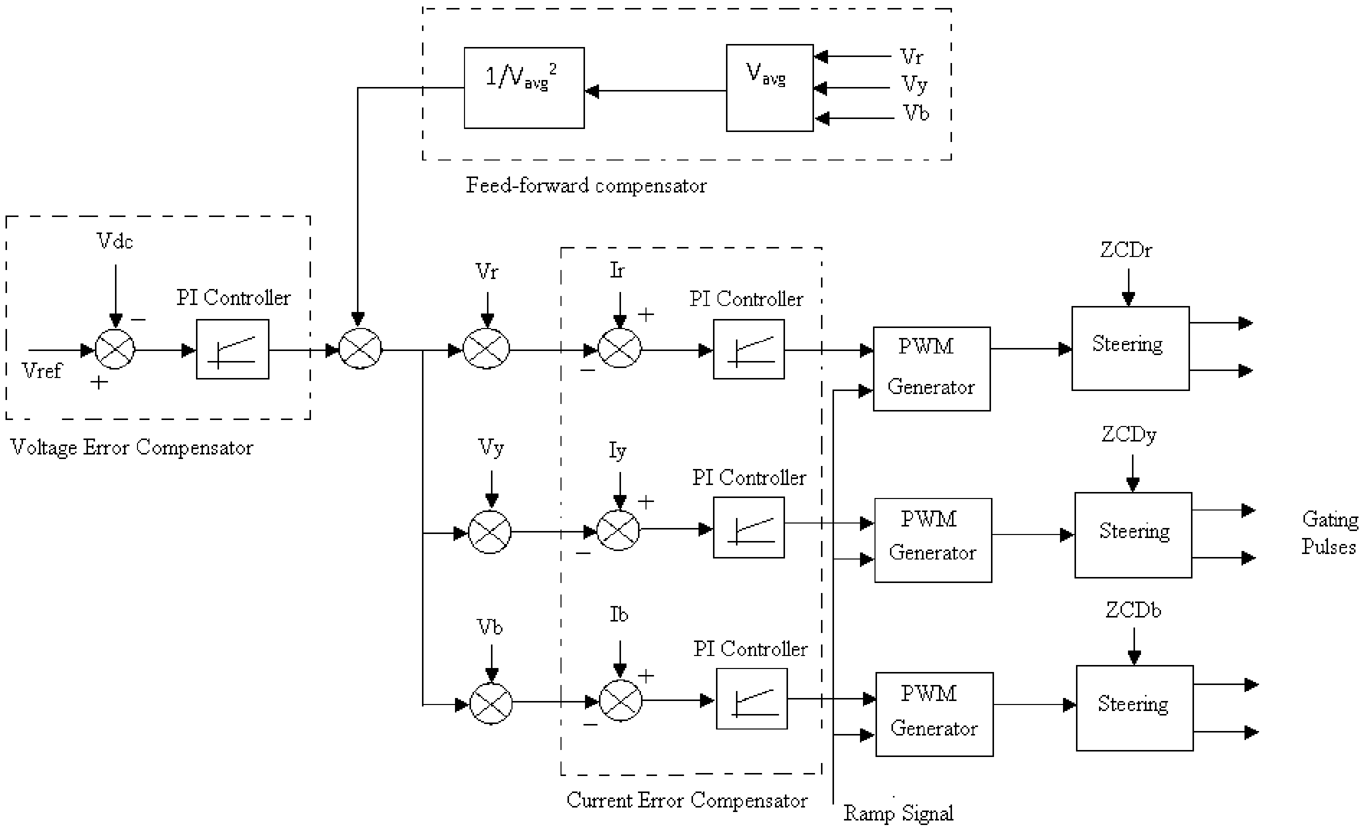

Figure 13: Simplified diagram of Control loops used in Preregulator circuit.

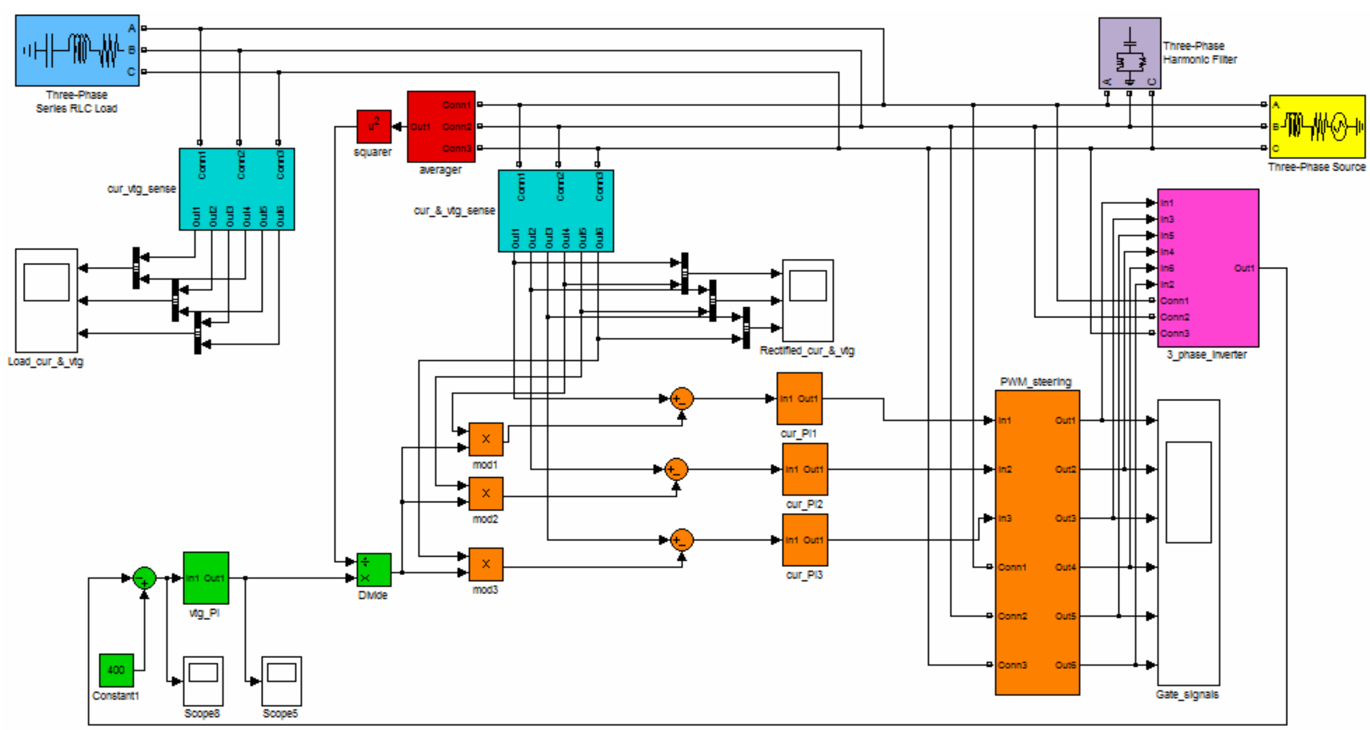

Figure 14: Simulation model of control scheme used for three phase PFC

Outer loop that is voltage control loop generates the reference for the current control loop. According to the error generated in the current error compensator PWM generator generates pulses with reference to ramp signal. The steering control is used along with ZCD circuit to divide the pulses to drive the IGBT switches.

VI. RESULTS

Fig. 15 shows the power quality drawn without APFC. It can be observed that the poor PF, waveform distortions and harmonics are present. .

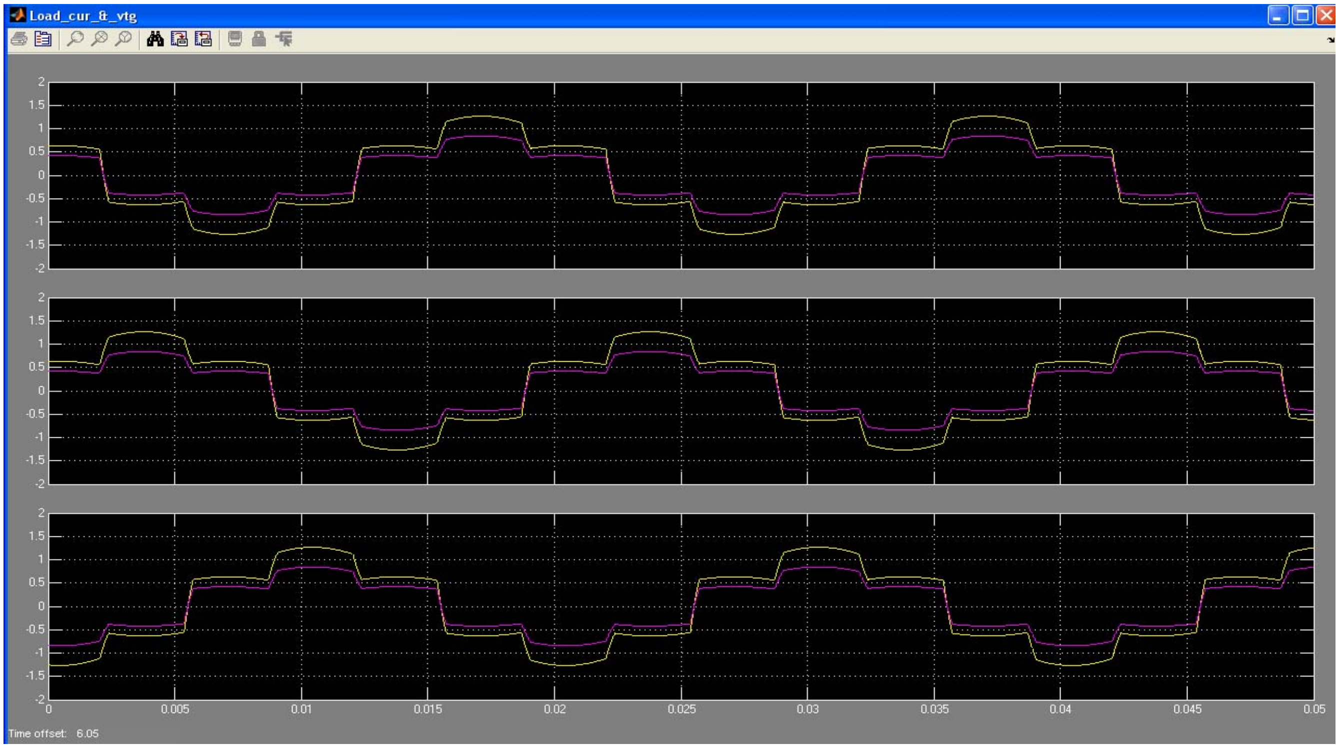

Figure 15: Supply Voltage and Supply Current without Power Factor correction and Harmonic Control

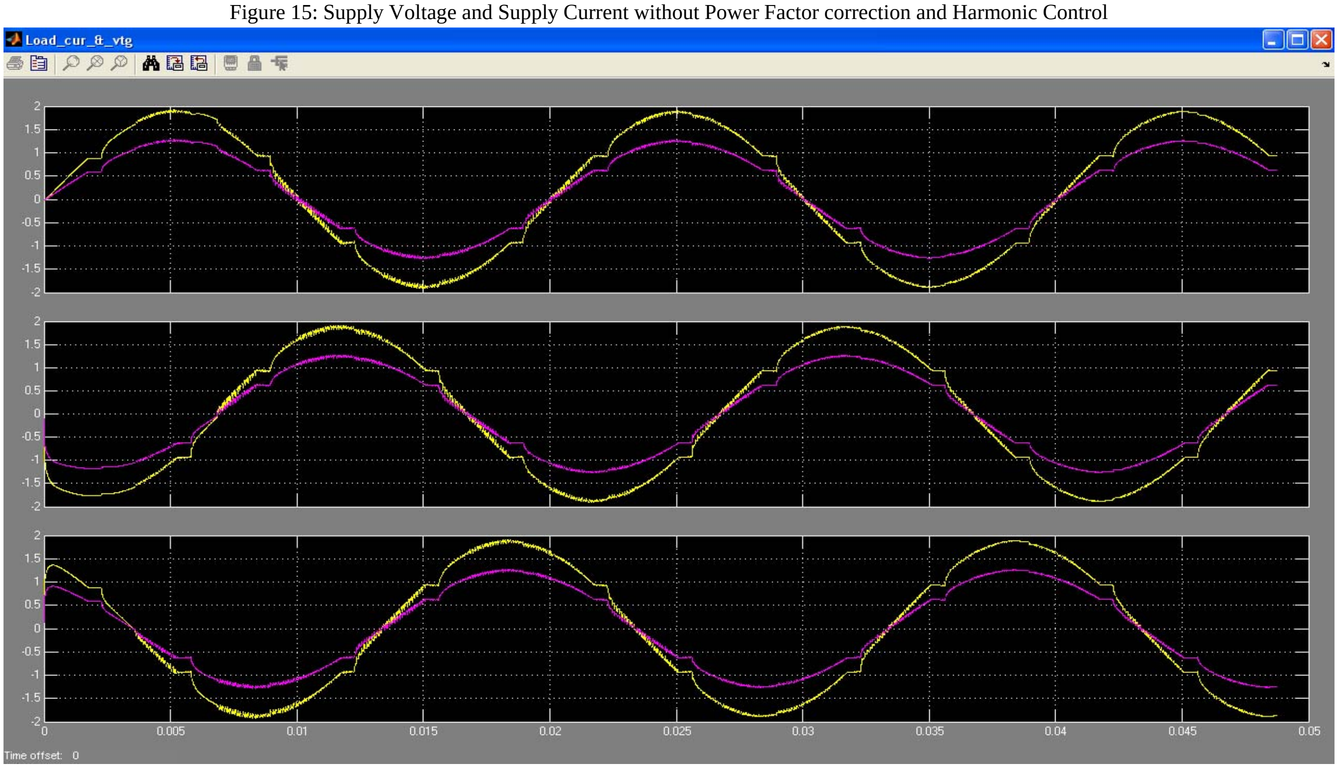

Figure 16: Supply Voltage and Supply Current with Power Factor correction and Harmonic Control

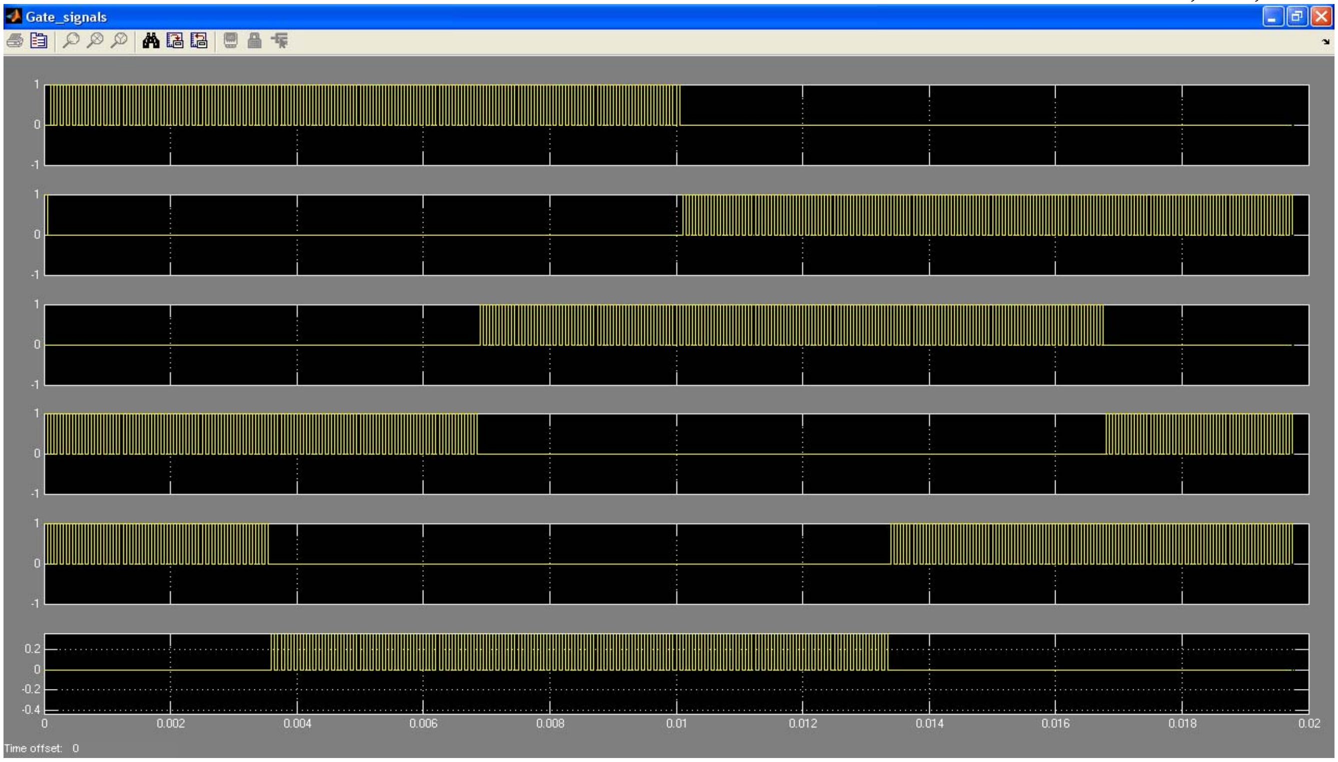

Figure 17: Gate signals for 3 phase inverter or PWM output from control scheme

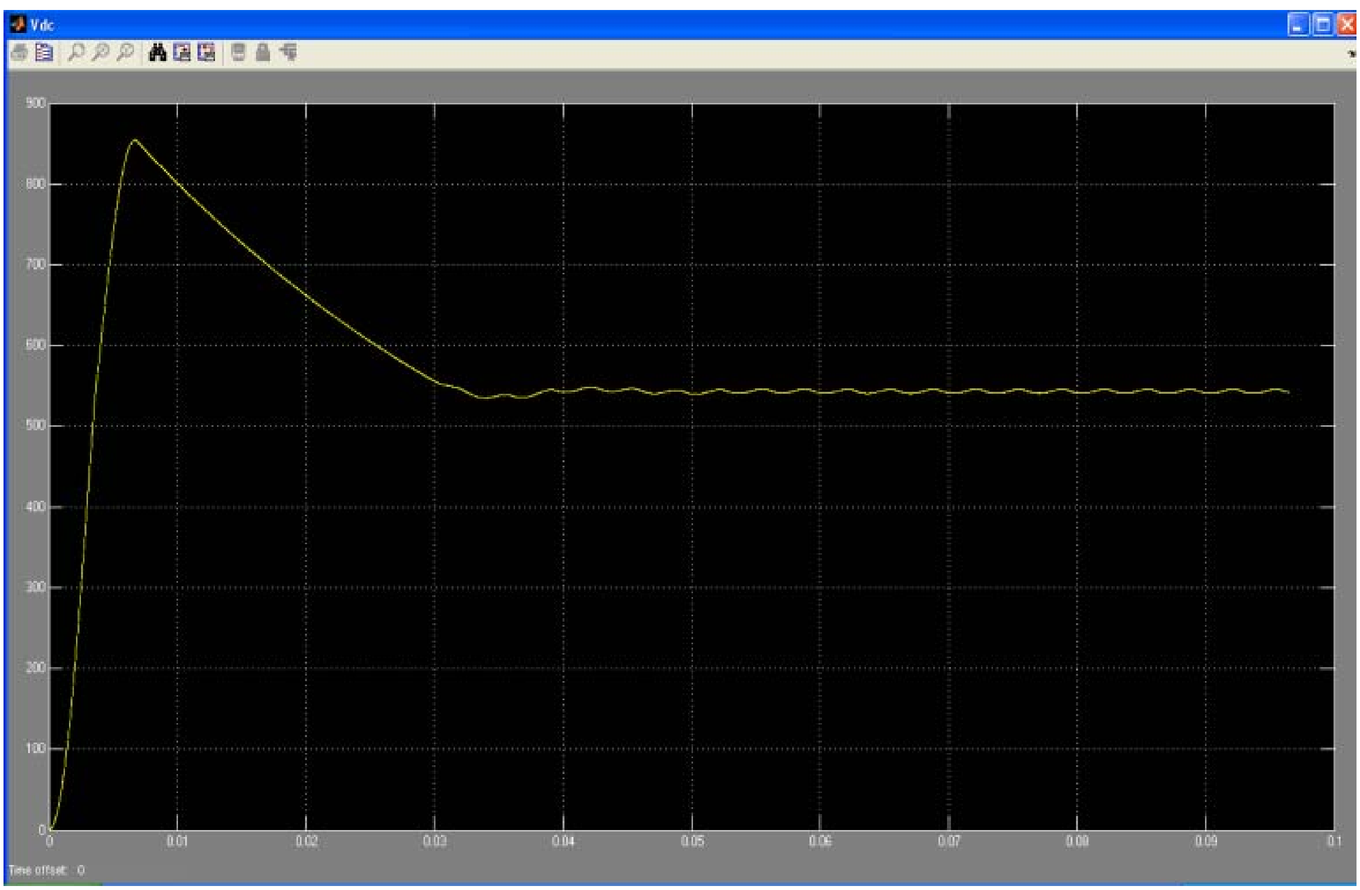

Figure 18: DC Bus Voltage (Capacitor voltage Vdc)

Fig. 16 shows the power quality drawn with APFC. The improvement can be observed in quality of power drawn in terms of PF, waveform distortion and harmonics.Fig. 17 shows the PWM driving signals generated as a result of the current drawn by the load connected.

The resulting power factor of 0.999and Total Harmonic Distortion (THD) of 3.81%, can be achieved to the 50th line frequency harmonic atnominal line and full load [9].

VII. Conclusions

Above result analysis shows that the active power filter using switching regulator is a high performance power electronics converter and can operate indifferent modes: harmonics elimination, power factor correction, voltage regulation andload unbalance compensation.It improves the simplicity and accuracy ofcontrol for the active power filter. Different application may lead to use of different switching regulator topology where they add some advantages.

VIII. References

[1] H.Z.Azazi, E. E. EL-Kholy, S.A.Mahmoud and S.S.Shokralla, "Review of Passive and Active Circuits for Power Factor Correction in Single Phase, Low Power AC-DC Converters", International Middle East Power Systems Conference (MEPCON'10), Cairo University, Egypt, December 19-21, 2010.

[2] António P. Martins, "The Use of an Active Power Filter for Harmonic Elimination and Power QualityImprovement in a Nonlinear Loaded Electrical Installation",Institute of Systems and Robotics - Porto

[3] N. Viuquezl J. Almazin, J. Alvarez, C. Aguilat, J. Arau, "AnalysisandExperimentalStudyof the Buck, Boost and Buck-Boost Inverters", Power Electronics Specialists Conference, 1999. PESC 99. 30th Annual IEEE.

[4] Nikolay I. Borodin, Evgenie A. Makarova, Denis V. Makarov, "Boost Converter Analysis on the Basis of RealParameters", Xi International Conference And Seminar Edm'201o, Section Vi, June 30 - July 4, Erlagol.

[5] Dr.John C. Salmon, Stuart Olsen, Dr. Edwin Nowicki, "A 3-phase buck-boost converter for lowering the input current distortionof a voltage source inverter drive", Industry Applications Conference, 1995. Thirtieth IAS Annual Meeting, IAS '95., Conference Record of the 1995 IEEE.

[6] "Unitrode UC3854 Data Sheet, "Unitrode Integrated Circuits, Merrimack, NH.

[7] Sanjay L. Kurkute, Pradeep M. Patil, Vinod H. Patil, "A Comparative Study and Analysis of Power Factor Control Techniques", International Journal of Computer Science & Emerging Technologies (E-ISSN: 2044-6004) Volume 1, Issue 4, December 2010

[8] António Martins1, José Ferreira2 and Helder Azevedo3, "Active Power Filters for Harmonic Eliminationband Power Quality Improvement".University of Porto, Portugal.

[9] Bill Andreycak, "Optimizing Performance In Uc3854 Power Factor Correction Applications", Unitrode design note.

[10] Lloyd Dixon' "The high power factor switching Preregulator design", Unitrode corporation application note.