Single Stage Power Regulator With High Power Factor using Active Current Wave Shaping Techniques

Lijin K L
M.Tech Research Scholar
Electrical and Electronics Engineering
Govt. Engineering College, Idukki
Idukki, India

Mr. Sunil Kumar P R
Asst. Professor
Electrical and Electronics Engineering
Govt. Engineering College, Idukki
Idukki, India

Abstract**—For low harmonic distortion and high input power factor leads to active current wave shaping techniques. Such circuits consists of input boost converter operated in discontinuous current conduction mode and output dc-dc converter such that flyback converter derived from buck-boost converter such class of power supplies known as single stage single switch power factor correction regulator. Here expression for boost inductance, critical inductance of flyback converter, energy storage capacitance, output capacitance derived .based on that a 50W, 230V, 50 Hz AC/50V DC single stage single switch power factor correction regulator was designed and simulated using orcad 16.5 software package in open loop control and closed loop control, the problem of dc voltage dependency was found eliminated almost.**

I.INTRODUCTION

An AC to DC Converter is an integral part of any power supply unit used in all electronic equipments. Usually Power converters use a diode rectifier followed by a bulk capacitor to convert AC voltage to DC voltage. Since these power converters draw pulsed current from the utility line the power factor becomes poor due to high harmonic distortion of the current waveform. Therefore, a power factor correction stage has to be inserted to the existing equipment to achieve a good power factor. Several standard and review articles in the literature have addressed power quality related issues in AC to DC converters. New configurations of power factor corrections are being developed to mitigate the harmonic effects on the input line current and improve the power factor The input power factor correction stage and the output DC to DC converter stage. Continuous efforts to further make these power converters compact and cost effective to learn to the development of new class of power supplies known as Single Stage Single Switch power factor correction regulator, which is the integration of PFC stage and the DC to DC converter stage. It uses only one switch and controller to shape the input current and regulate the output voltage. The energy storage device in between is necessary to absorb and supply the difference between the pulsating instantaneous input power and constant output power A major problem associated with Single Stage Single Switch power factor correction regulator is strong dependency of DC BUS voltage stress across the capacitor with the output load Power unbalance between PFC stage and DC-DC stage is the inherent reason for causing high DC bus voltage stress. Frequency control is other solution proposed to overcome high DC voltage stress But this call for complex control circuit. The concept of series charging, parallel discharging capacitor scheme is another solution. But this call for more component count in the power circuit In this paper a design solution is proposed to avoid the problem of energy unbalance between energy stored during ON period of switch and energy dissipated in the load by optimally sizing the boost inductor. Maximum energy stored in the inductor shall be limited to such a value that this energy matches with maximum output power required. The instant at which maximum power delivered shall be matched with the instant when the input ac voltage is at the peak. Also consider the fact that maximum power is delivered at a duty ratio which is slightly less than the limiting duty ratio (0.5) for DCM operation[1]. Equal Area Criterion is applied between theoretically calculated fundamental component of input ac current and the peak inductor current when T_{ON} is maximum. Using this approach the design was carried out, and simulated testing as well as experimental observation showed only a very small rise in DC bus voltage at light load condition, even under open loop [2]. After introducing closed loop control with output voltage as controlled variable and duty ratio as manipulated variable the DC bus voltage dependency was found almost insignificant.

Classical line commutated rectifiers suffer from the following disadvantages:

- They produce a lagging displacement factor w.r.t the voltage of the utility.
- They generate a considerable amount of input current harmonics. These aspects negatively influence both power factor and power quality. The massive use of single-phase power converters has increased the problems of power quality in electrical systems.

Power factor is the relationship between working (active) power and total power consumed (apparent power). Essentially, power factor is a measurement of how effectively electrical power is being used.[3] The higher the power factor, the more effectively electrical power is being used and vice versa. A distribution system's operating power is composed of two parts: 1) Active (working) power and 2) Reactive (non-working) magnetising power. The ACTIVE power performs the useful work. The REACTIVE power does not as its only function is to develop magnetic fields required by inductive devices. Generally, power factor decreases (Ø increases) with increased motor loads.[4] Therefore, when more inductive reactive power is needed, more apparent power is also needed. An active approach is the most effective way to correct power factor of electronic supplies. Here, we place a boost converter between the bridge rectifier and the main input capacitors. The converter tries 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 [5].

The paper is organized in the following way. Section II provides Open loop control of S_4 PFC regulator. Section III presents closed loop control of S_4 PFC regulator. Section IV represents design of S_4 PFC regulator and Section V gives Design of a 50W, 230V, 50 Hz, 50 VDC S_4 PFC regulators. Simulations are shown in Section VI.

II.OPEN LOOP CONTROL OF S_4 PFC REGULATOR

Basic configuration of single stage single switch power factor correction regulator with input boost converter and output fly-back converter as shown in the fig .1. When switch s is 'ON' current in inductor Li increases linearly depends on input line voltage, when switch s is 'OFF' the stored energy in inductor to bulk capacitor and to the load. If there is any change in the load will leads to the unbalanced power between input and output,due to this unbalanced power increases output voltage,this can be avoided by closed loop control in which on period of switch is reduces automatically when output voltage increases[6]

III. CLOSED LOOP CONTROL OF S_4 PFC REGULATOR

Closed loop control configuration of single stage single switch power factor correction regulator with input boost converter and output flyback converter as shown in the fig .2 To explain the working of circuit,the operation is divided into three modes.

Mode I

In this mode of operation, switch s is 'ON' so current in boost converter inductor increases linearly, which is depends proportionally to the instantaneous values of input voltage

$$V_m \sin \omega t = L_1 \frac{di}{dt} \qquad (1)$$

$$i = \int \frac{V_m}{L_1} \sin \omega t dt \qquad (2)$$

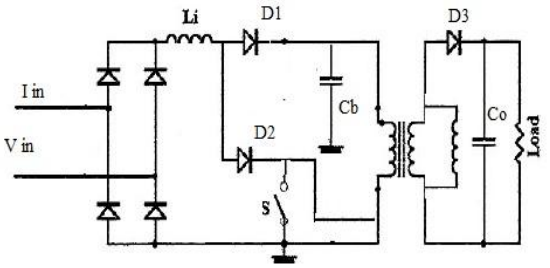

Fig .1: open loop control of S_4 PFC regulator

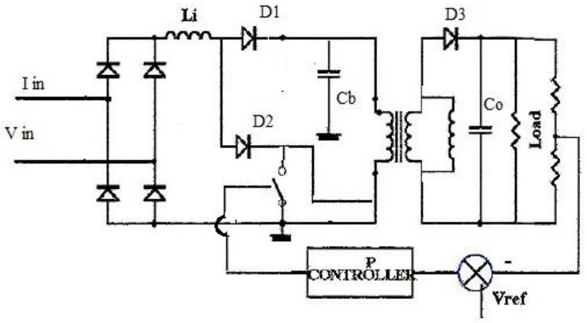

Fig .2:closed loop control of S_4 PFC regulator

Mode II

In this mode, when switch s is turned 'OFF' so current in boost inductor decreases linearly with proportional to the voltage difference between input instantaneous voltage and sum of capacitor voltage and output voltage in transformer primary

$$L_1 \frac{di}{dt} = V_m \sin \omega t - \left[V_{dc} + nV_2\right] \qquad (3)$$

$$i = \int \frac{V_m}{L_1} \sin \omega t dt - \frac{\left[V_{dc} + nV_2\right]}{L_1} dt \qquad (4)$$

Mode III

When current in boost inductor reaches zero mode III starts and the Diode D3 conducts, which leads to the transfer the energy from inductor to the output capacitor and then to the load

IV. DESIGN OF S_4 PFC REGULATOR

For design purpose consider a reference current $I_m \sin \omega t$ and magnitude of this current is chosen such a way that

$$P_{out} = V_{rms} \times I_{rms} \qquad (5)$$

A. Design of boost inductor

From the circuit diagram current in boost inductor during 'ON' time is

$$i_r = I_1 + \frac{V_m}{\omega L_1}\left[\cos \alpha - \cos(\alpha + \omega t)\right]$$

$$\text{Where } \alpha < \omega t < \omega t_{on} \qquad (6)$$

Current in boost inductor during ‘OFF’ time is

$$i_r = I_2 + \frac{V_m}{\omega L_1}\left(\cos\alpha + \omega t_{on}\right) - \left(\cos\alpha + \omega t_{on} + \omega t\right) - \frac{\left(V_{dc} + nV_2\right)}{\omega L_1}\omega t \tag{7}$$

Considering that I_1 =0 and maximum current occurs when $\alpha = 90^0$

Substituting this in equation (1) we get boost inductance as

$$L_1 = \frac{V_m}{I_{2peak}} DT \tag{8}$$

B. Design of fly back converter

For Volt Second transformer Balance

$$\left(V_1 - V_{sat}\right)D = n\left(V_2 + V_f\right)\left(1-D\right) \tag{9}$$

and

$$i_{2(avg)} = \frac{nI_p\left(1-D\right)}{2} = \frac{V_2}{R} \tag{10}$$

From above equation we obtain the equation of critical inductance of flyback converter as

$$L_c = \frac{\left(V_2 + V_f\right)R\left(1-D\right)^2 n^2}{2V_2 f_s} \tag{11}$$

V. DESIGN OF A 50W, 230V,50 HZ,50 VDC S_4 PFC REGULATOR

A. Calculation of boost inductor

Switching instant is considered as $\alpha = 90^0$ for maximum rising and falling

Switching frequency ,f_s = 20 KHz

Duty ratio D = 0.3(for DCM mode operation D should be less than 0.5)

$$P_{out} = V_{rms} \times I_{rms}$$

$$\therefore I_{rms} = \frac{50}{230} = 0.2174A$$

$$I_m = 0.3074A$$

I_{peak} for a duty cycle for duty cycle is obtained as

I_{peak} = 1.36 A

$$\therefore L_1 = \frac{DTE_m}{I_{peak}} = \frac{.3\times 50\times 10^{-6}\times 230\sqrt{2}}{1.36}$$

$$= 3.58mH$$

B. Calculation of critical inductance of flyback converter

For D =.3

Secondary voltage $V_2 = \frac{V_m}{(1-D)^2} \times \frac{D}{n}$ (12)

Substituting the values in above equation we get

V_2= 66.37 V

Value for the 500 W is obtained as

R= $\frac{V^2}{P}$ = 88.09 Ω= 90 Ω and

L_c = 1.2 mH

C. Calculation of energy storage capacitor

$$I_{peak} = \frac{DTE_m}{L_1} \tag{13}$$

$$= \frac{.45\times 50\times 10^{-6}\times 230\times\sqrt{2}}{1.57\times 10^{-3}} = 4.66Amp$$

Energy stored in the boost inductor is transferred to the energy storage capacitor during second mode of operation

$$\therefore\ C_1V^2 = L_1I^2 \tag{14}$$

We get C_1 =22.6μf

D. Design of output filter

V_{base} = 230V = 1 pu

P_{base} = 50W = 1 pu

Assuming zero switching losses $P_{in} = P_{out}$ = 1 pu

This yields

$$I_{base} = \frac{P_{base}}{V_{base}} = \frac{50}{230} = 0.2174A$$

$$Z_{base} = \frac{V_{base}}{I_{base}} = \frac{230}{0.2174} = 1058$$

$$V_{out}pu = \frac{50}{230} = .2174$$

Bulk output capacitor may be determined by settling the output ripple constraint by allowing a 5% output ripple and considering the ripple frequency to be twice the line frequency ,we get

$$V_{ripple} = .05\times V_{out}pu = .05\times 0.2174 = 0.0108$$

$$V_{ripple} = 0.01087\times 230 = 2.5V$$

$$C = \frac{I_2}{n\omega\Delta V} \tag{14}$$

I_2 is twice the line frequency current equating instantaneous input power to out put dc power

$$I_2 = \frac{230\times 0.2174}{50} = .999A$$

$$\therefore C = \frac{0.999}{2\times 2\Pi\times 50\times 2.5} = 6.36\times 10^{-4}$$

=636 μf

E. Design of magnetic components

Maximum energy stored in boost inductor

$= \frac{1}{2}LI^2 = 0.5\times 3.58\times 10^{-3}\times 1.36^2$

$= 3.36\times 10^{-3}$ Joules

$K_wA_w \geq a$

$K_wA_w \geq NI/J$

$K_c = I_m/I_{rms} = \sqrt{2}$

Let $B_{max} = 0.2$, $A_c = 0.4$, $J = 3\times 10^6$ A/m^2

$$A_w A_c = \frac{2E}{K_w K_c J B_{max}} \qquad (15)$$

Area product(A_p) = $K_w A_w$

From equation (15) we get $A_p = 1.98 \times 10^4$ mm^4

So core E 42/21/9 is a proper choice

Then

$$A_w = 2.56 \times 100 \text{ mm}^2$$
$$A_c = 1.07 \times 100 \text{ mm}^2$$

So Number of turns, $N = LI_m / A_c B_m$

$$= \frac{3.58 \times 10^{-3} \times 1.36}{107 \times 10^{-6} \times 0.2}$$

$$= 228 \text{ turns}$$

F. Design of transformer for the flyback converter

The transformer used in flyback converter also acts as inductors so it is different from other transformer configurations

B swing $\Delta B_n = 0.5$ and $\alpha = 0.84$

$\Delta I_n = 0.75$ and $n = N_2/N_1 = 1/3 = 0.333$

$$V_0 = nV_1(D/1-D) \qquad (16)$$

When $D = 0.3, V_0 = 66.7V$

$D_{max} = 0.37$ for 100V

$D_{min} = D_{max}/(D_{max} + (1 - D_{max})) \times (V_{cc\,max}/V_{cc\,min})$

$= 0.328$

$I_1^-/I_1^+ = 1 - \Delta I_n = 1 - 0.75 = 0.25$

$I_1^+ + I_{1\Delta}^- = 2I_{1\,av}/D_{min} = 2nI_{2\,av}/D_{min}$

$I_1^+ = (2nI_0/D_{min})/1.25$

$= 3.24$ A

$\Delta I_1 = 2.43$ A

$\Delta I_2 = I_1/n = 7.31$ A

$\Delta B_m = \Delta B/B_m, B_m = 0.2$

So $\Delta B = 0.1$ T

Now power in obtained by

$Po_2 = (V_0 + V_D)I_0((1 - D_{min})/D_{min})$

$= 102.5$ watts

Now area product ,

$$(A_p) = \frac{Po_2\left(\frac{1}{n}\sqrt{\frac{4D\alpha}{3}} + \sqrt{\frac{4(1-D)\alpha}{3}}\right)}{K_w J \Delta B f_s} \qquad (17)$$

Substituting values in equation (17),we get

$$A_p = 11.4 \times 10^4 \text{ mm}^4$$

Choose a suitable area which has an Ap greater than calculated value E 65/32/13 is a proper choice

The equation for calculating number of turns in primary is

$$N_1 = \frac{V_{cc\,max}\, D_{min}}{\Delta B A_c f_s} \qquad (18)$$

We get $N_1 = 297$ turns and $N_2 = 99$ turns

VI. SIMULATION RESULTS

Simulation of S_4 PFC regulator with circuit parameter having designed values was done in ORCAD software package. Simulation results were satisfies the design intends

A. open loop control

when duty ratio is varied output voltage is varied linearly with change in duty ratio and input voltage is sinusoidal which achieve high input power factor fig. 3 shows the sinusoidal input current in open loop control. But any change in the output voltage will leads to the variation in output voltage as shown in the fig. 4, but there is no change in the input current

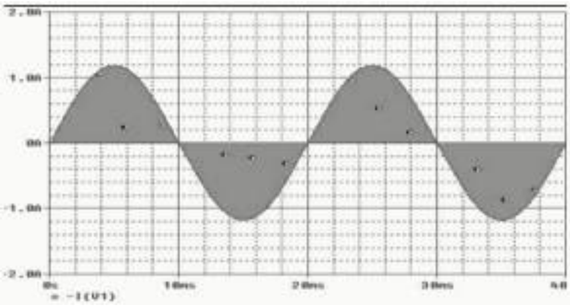

Fig 3: input current waveforms

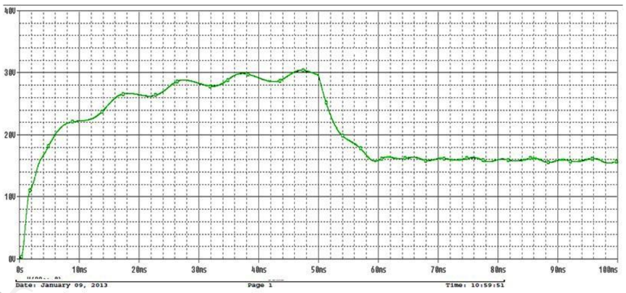

Fig 4: variation in output voltage with load

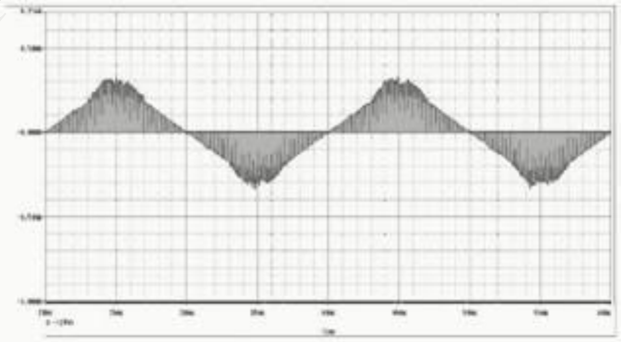

Fig 5: input current waveform

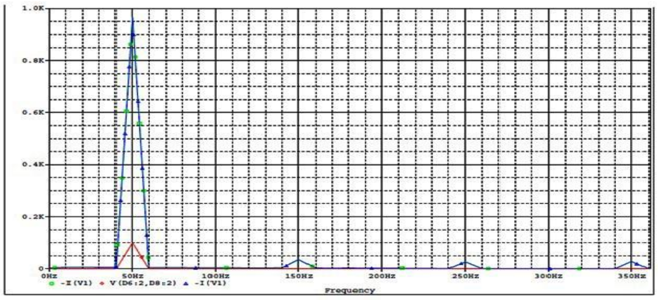

Fig .6 harmonics spectrum of input current,

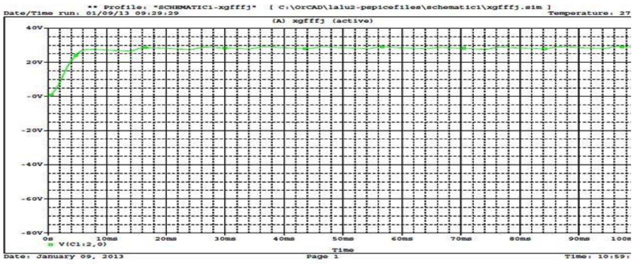

Fig 7. Output voltage

From Fig.4, it is cleared that during light load output voltage will increases. From Fig. 6 the fundamental frequency is dominant and other higher frequencies can be neglected. Fig 7 shows that, the output voltage which is a constant value so it gets the name regulator.

B. Closed loop control

Closed loop simulation is done by varying the reference voltage, output vary linearly with the reference voltage and input current is almost sinusoidal and in phase with the input voltage which leads to high power factor. Fig 5 shows the input current which is almost sinusoidal

VII. EXPERIMENTAL RESULTS

50W, 230V, 50 Hz AC/50V DC single stage single switch power factor correction regulator is built and using IRFPF 50 as switch by taking following circuit parameters

Parameter	values
L1	3.58 mH
C1	22.6uF
n	0.333
L2	636 uF
Fs	20 KHz
D	0.3
Load	90 Ω

D1N 1190 is used in rectifier section, TL 082 opamp is used in control section as differential amplifier and comparator and ICL 8038 as triangular wave generator

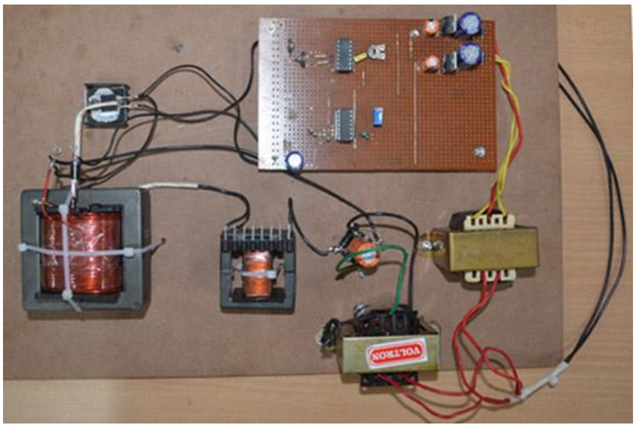

Fig .8 hardware configuration of S4 PFC regulator

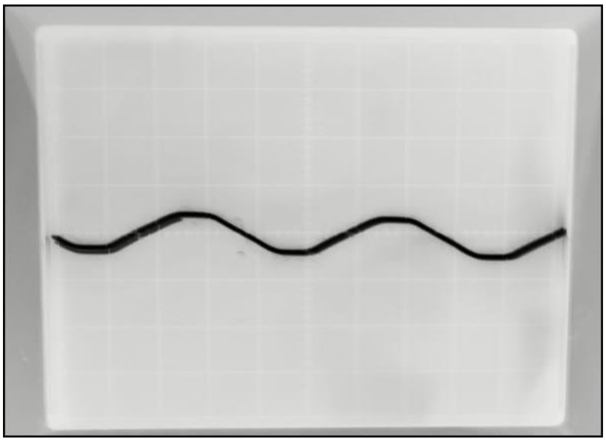

Fig .9 Input current waveform

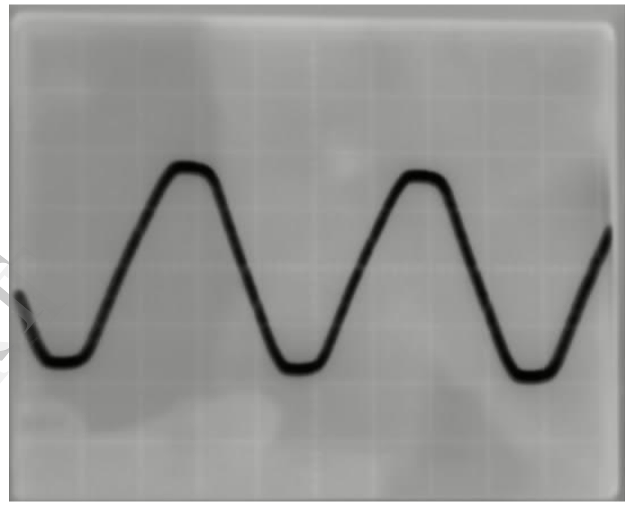

Fig .10 input voltage waveform

From figure 9 and 10 input current and voltage is sinusoidal and are in phase so it achieve high power factor and is satisfy all the conditions

VII. CONCLUSION

S4PFC Regulator design by applying EAC to determine value of boost inductance and by using closed loop control is presented. The dc bus voltage stress at light load is found completely eliminated under closed loop operations. Output voltage regulation using duty ratio variations and fixed switching period is the most simple method of control. For normal performance of the converter the duty ratio needs to be limited up to 0.5. Experimental results demonstrate that it is possible for the proposed converter to have fast response and low line current harmonic content.

A DCM boost converter is chosen here which draws energy at line frequency. It has inherently low line current harmonics. A fly back converter is used to eliminate the disadvantages of boost rectifier. Thus the voltage stress in the capacitor is reduced and the output voltage is tightly regulated. EAC is used for design of boost inductance. Output voltage regulation using duty ratio variations and fixed switching period is the simplest method of control.

Simulation results demonstrate that it is possible for the proposed converter to have fast response and low line current harmonic content. The proposed converter is expected to maintain a good source power factor and tight output voltage regulation without compromising with high DC bus voltage. Moreover, the efficiency of overall power conversion is expected to be high.

REFERENCES

1) Bindu prakash and S Prakash, “Design of single stage single switch switch mode rectifier based on equal area criterion” in 3rd IEEE Conference on Industrial Electronics and Applications, 2008. ICIEA 2008. p.p 2068 – 2073
2) M. Madigan, R. Erickson and E. Ismail, "Integrated High Quality Rectifier Regulators" i*n IEEE power ELECTRONICS SPECIALIST CONF*...... 1992. p.p. 1043 - 1051.
3) Jinrong Qian, Fred C. Lee, "Single - Stage Single - Switch p -f-c Ac/Dc converters with DC - Bus voltage feedback for universal line applications"*in IEEE transactions on P.E. vol: 13*, No-6 Nov 1998 p.p. 1079 – 1088
4) Esam Hamid Ismail, Robert Erickson"Single Switch 3 phase PWM low Harmonic Rectifiers" i*n IEEE Transactions on P.E.* vol: 11, No-2, march 1996 p.p. 338 – 345
5) Manjusha S. Dawande, Gopal K. Dubey, Programmable Input PFC method for SMR" i*n IEEE Transactions on P.E. vol: 11*, No-4 July 1996 p.p. 585 – 591
6) A.R. Prasad, P.D. Ziogas. Stefanos Manias, "An active PFC Technique for 3 phase diode rectifiers" *IEEE Transaction on P.E. vol: 6,* No-1, January1991 p.p. 83 – 91