Soft switching power factor correction of Single Phase and Three Phases boost converter

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ABSTRACT: *This paper presents Soft switching power factor correction(PFC) of single phase and three phases boost converter circuit with a new active snubber circuit and the main switch is turned on and off with zero voltage transition and zero current transition respectively without any additional stresses of voltage and current on the main switch. Auxiliary switch is turned ON and OFF with zero-current switching (ZCS) without additional voltage stress. By connecting the coupling inductance in the output side of the rectifier and it decreases the current stresses on the auxiliary switch because of some current is bypassed through this inductor. The proposed converter has controlled the values of output quantities of this converter with different load ranges. It is a very easy of controlled, cost is low and easy to design. In this project, a completed steady-state analysis of the proposed converter is presented. A three-phase single switch boost rectifier is implemented with same analysis and it is a harmonic injection method, it injected a specific voltage to vary the duty cycle and to meet the reduce harmonic content and also improves the power factor for the boost rectifier.*

Keywords: *Soft switching (SS), power factor correction (PFC), Zero- current switching (ZCS), Zero- voltage switching (ZVS), boost converter.*

I.INTRODUCTION

The power electronic devices are AC-DC converters are having the poor power quality this should maintain the low power factor, voltage distortion and it reduce the efficiency. The AC-DC converters are operated with high switching frequency it consists of high switching losses and low power factor. The major objective of this scheme is to improve the power factor, reducing the current harmonics, voltage stress and current stress and also increasing the efficiency. In case of A-D converters are operating at the high switching frequency, low power factor ,cost will be high and it consists of low efficiency and current harmonics are developed ,this should be not applicable to practical situations so that we preferred low switching frequency ,high power factor converters. This should be possible only these converters having soft switching with PWM techniques only.

The switching converters are mainly operating in the four modes of operation, those are zip voltage switch (ZVS), zip current switch (ZCS), zero voltage transition (ZVT) and zero current transition (ZCT) with PWM method. Here the combination of the zip voltage switch and zip current switch are called as the soft switching (SS).with these soft switching techniques and PWM method, it can be improve the power factor, switching losses will be reduced, voltage and current stresses will be reduced completely. Compare the ZVS and ZCS are the techniques to improve the efficiency and reduce the current harmonics with addition of zero power conversion(ZVT) and zero current conversion(ZCT) it is the main and advanced converters having the four methods those are soft switching ,ZCT and ZVT with PWM technique. The AC-DC converters are operated with high switching frequency it consists of high switching losses and low power factor. These drawbacks can be overcome by these converters with soft switching techniques for improving the power quality, power factor and also the efficiency and reliability with SS technique and PWM.

II. SOFT SWITCHING TECHNIQUES

The soft-switching converter is that combining usual Pulse Width Modulation power converters and resonant converters. The switching conditions are not similar to that of pulse width modulation converter and remaining wave forms are same. The resonant converters are operated in usual manner but in case of conventional pulse width modulation converters in Zero Voltage Switching and Zero Current Switching manner. The integrated circuits are playing important role in soft switching converters. With these modifications turn and turn off losses can be reduced and these converters used for high frequencies. These converters can also EMI is very less and used to power converters(like as controlled rectifiers, choppers and inverters).Here the fundamental analysis of soft switching and resonant converters with Zero Voltage Switching, Zero Current Switching, zero voltage and current transition methods are elaborated. The presences of LC resonant converters are having the zero voltage and current switching. The resonant circuit consists a switch S , L_r and C_r are the resonant inductance and capacitances respectively. The S switch is designed by a single direction or two directional switch and these states that resonant switch operation. There are zero current and zero voltage switching and addition of zero-current (ZC) resonant switch and zero-voltage (ZV) resonant switches.

2.1 ZC resonant switch

By achieving the zero current switching the circuit consists of switch S and resonant inductance .These resonant inductance is connected in series with the switch S. The switch can operated in positive cycle only because of switch is in unidirectional type are considered. By the connecting of diode in parallel with the switch then the switch can be in bidirectional and it says that the switch in full wave mode that is during positive half and negative half cycle. The switch is in on position and current will rise from zero value. This will happen only due to presence of resonant inductance and capacitance and whenever the current will becomes zero then the switch automatically is in off state. This process is known as the zero current switching and this circuit is shown fig2.1.

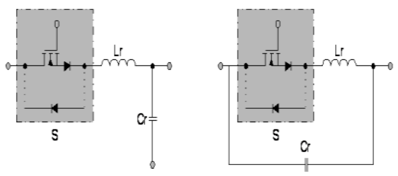


Fig 2.1: Zero-current (ZC) resonant switch.

2.2 ZV resonant switch

The resonant capacitor is connected across to the switch is says that to achieve zero voltage switching. Here the switch can be operated as a unidirectional mode then the voltage across the resonant capacitance becomes oscillated in both during positive and negative half cycles. The diode can be connected across to that of switch and is in bidirectional then diode is disconnected the switch can be in unidirectional. The Switch voltage is zero during resonant turn on condition; this is known as zero voltage switching and this circuit is shown fig2.2.

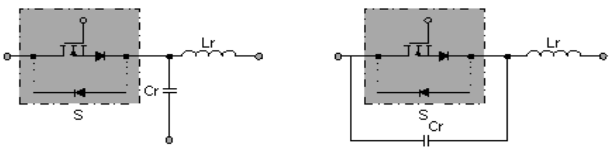


Fig 2.2: Zero-voltage (ZV) resonant switch.

The switching losses during the turn on and off conditions can be reduced to zero in zero current switching. During resonance condition a large value of capacitance is connected across the device then the converter becomes not sensitive to the junction capacitance. The disadvantage of the zero current switching is during turn on process switching losses are increases and this switching frequency is proportional to the switching losses. The switching losses and noise can be increase why because during in on position the dv/dt can be added with the capacitance. The disadvantages of this current stress and conduction losses will increased. So that the zero current switching will be reduced switching losses and high amount of current tail will be obtained with ZCS.

III. POWER FACTOR CORRECTION

The power factor is a measure of the degree to which a given load matches that a pure resistance. The total or apparent power is the sum of active and reactive power. The system consists of energy storage elements that are stored some energy, it is called reactive power and it is waste power and it is called as the useless power. Which is the power is usage that power is called as the real power. Suppose the circuit consisting only the resistive load it supplies the real power only why because, the resistive load are not the energy storage element that's why it doesn't stores energy in the form of electric field and magnetic field. The **rms** values of output voltage and current is equal to the the amount of power delivered to the load then the power factor is unity. Suppose the circuit consisting the inductor and capacitance these has energy storage elements, it stores energy in the form of electric field and magnetic field then the power factor are getting less than unity.

The main focus on power factor, nonlinear loads is actually related to the decrease of the harmonic substance of the line current. There are more than a few methods to obtained PFC depending on whether active switches are used. PFC methods can be classified as "**Passive**" or "**Active**" power factor correction. In case of passive power factor correction methods they are using the passive elements those are resistance, inductance and capacitance with the diode rectifiers. It may improve the input current waveform. This may are not the controllable devices. In case of active power factor correction methods they are using the active elements those are active switches. This may increase the waveform of current and it is controllable of the output voltage. Depends upon the active power factor methods are again classified into two categories. Those are low frequency and high frequency active power factor correction. The switching frequency is lower than the line frequency is called as the low frequency power facto correction and the switching frequency is higher than the line frequency is called as the high frequency power factor correction.

IV. SOFT SWITCHING PF CORRECTION CONVERTER

The single phase diode bridge rectifier with power factor converter circuit is shown in Fig 4.1 Here, dc input voltage V_i, dc output voltage, L_F is main inductance, C_o is output capacitance, D_F is the main diode, R_L is output load resistance, S_2 is the auxiliary switch and S1 is the main switch. It consists of body diode D_{S1}. C_S is the sum of the parasitic capacitors of the main switch and the main diode. Here the C_R is snubber capacitor, and auxiliary diodes are D_1, D_2, D_3, and D_4 and L_{R1} and L_{R2} are upper and lower snubber inductances, L_m, the transformer leakage inductances of input and output are L_{IL} and L_{OL} are respectively. The values of air gap and leakage inductance ratings are considered the large values. In this operation some assumptions are considered ,those are the reverse recovery time for all diodes are taken as zero value, input current I_i and output voltage V_o are constant for one cycle and remaining circuit components are considered the ideal.

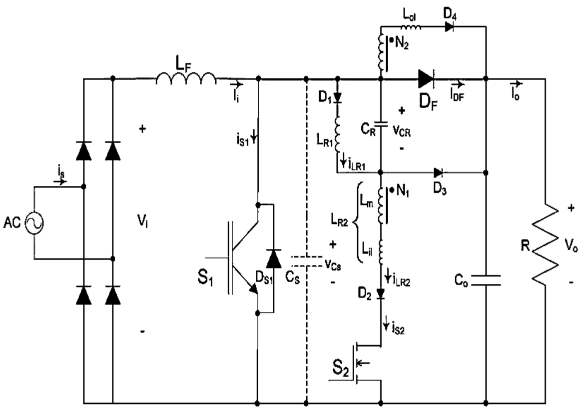


Fig 4.1 Circuit scheme of the proposed new PFC converter

Here the operation of this converter has the one switching cycle consists of twelve stages. The equivalent circuit schemes of the operation stages of this converter are given in Fig 4.2, respectively.

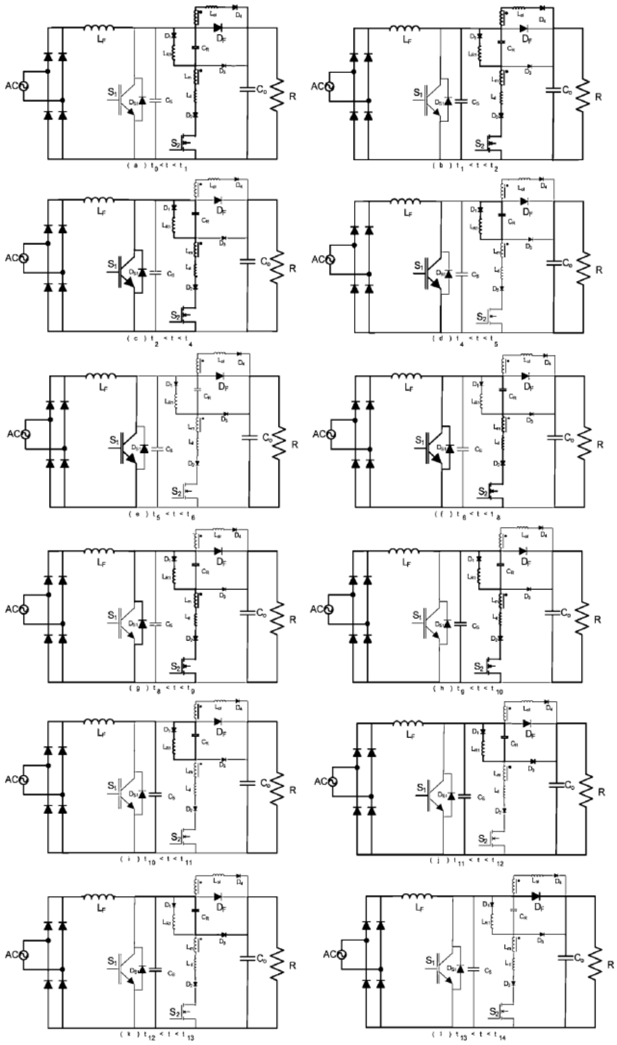


Fig 4.2 Equivalent circuit schemes of the operation mode

1) Stage 1 [$t_0 < t < t_1$]: Assume the S_1 and S_2 switches are in OFF. The input current I_i passes through the main diode D_F at this mode. When control signal is applied to the S_2, the switch S_2 is on. It builds up current through the L_{R1},L_{R2} output side. The resonance circuit is present in between the elements those are starts between L_{R1} , L_{R2} , and C_R and S_2 current rises, meanwhile main diode current D is reduced. Snubber inductance L_{R2} provides turn ON switching with Zero Current Switching of S_2 , D_1 , and D_2 . For this interval

At $t = t_0$ $i_{s1} = 0A$, $i_{s2} = 0A$, $i_{DF} = I_{iA}$, $i_{LR1} = 0A$, $i_{LR2} = 0A$, and $V_{CR} = 0V$

$$i_{LR1} = i_{D1} = (Vo/L_s)(t - t0) - (Vo/\omega_e L_s)\sin(\omega_e (t - t_0)) \quad (4.1)$$

$$i_{LR2} = i_{s2} = Vo/L_s(t - t_0) + (Vo/\omega_e L_s L_{R2})\sin(\omega_e (t - t_0)) \quad (4.2)$$

$$V_{CR} = (Vo\, L_{R1}/L_s)(1 - \cos(\omega_e (t - t_0))) \quad (4.3)$$

$$i_{Lol} = i_{D4} = i_{LR2}\ aL_m/(L_m + a^2L_{ol}) \quad (4.4)$$

$$L_{R2} = L_{il} + L_m a^2 L_o/(L_m + a^2L_{ol}) \quad (4.5)$$

$$L_s = L_{R1} + L_{R2} \quad (4.6)$$

$$L_e = L_{R1}L_{R2}/(L_{R1} + L_{R2}) \quad (4.7)$$

$$\omega_e = (1/L_eC_R)^{1/2} \quad (4.8)$$

2) Stage 2 [$t_1 < t < t_2$]: During the sate S_1 and D_F are in OFF mode and S_2 is in ON mode. $t \le t_1$, i_{s1} = 0, $i_{s2} = I_i$, i_{DF} = 0, $i_{LR1} = I_{LR11}$, $i_{LR2} = I_i - I_{Lol}$, V_{CR} is equal to the V_{CR1} , and V_{CS} is equal to the V_o. The time t = t_1 , a resonance starts between C_S -L_{R1} -L_{R2} -C_R. For this stage,

$$L_{R1}\, di_{LR1}/dt= V_{CR} \quad (4.9)$$

$$L_{R2}\, di_{LR2}/dt= V_{CS}- V_{CR} \quad (4.10)$$

$$C_R\, dv_{CR}/dt= i_{LR2}- i_{LR1} \quad (4.11)$$

$$C_s\, dv_{CS}/dt= I_i - i_{LR2} - i_{Lol}$$

$$=I_i - i_{LR2}(1+ aLm/(Lm +a^2L_{ol})) \quad (4.12)$$

The S_1 consists internal parasitic capacitance C_S discharged, at this time, the L_{R2} is stored energy and it is transfer to the L_o. The time t = t_2, VCS =0and D_{S1}=ON with zero voltage switching, meanwhile D_4 = OFF.

3) Stage 3 [$t_2 < t < t_4$]: At t=t_2 is D_{S1} = ON state ,the beginning of this mode i_{s1} = 0, $i_{s2} = I_{LR2}$, i_{DF} = 0, $i_{LR1} = I_{LR12}$, $i_{LR2} = I_{LR22}$, $V_{CR} = V_{CR2}$, and V_{CS} = 0. The resonant circuit is presented in between L_{R1} -L_{R2} -C_R will be continued. After this stage, $L_{R2} = L_{il} + L_m$. During this interval

$$i_{LR1} =(L_e/ L_{R1})\, I_{LR22}\, (1 - \cos(\omega_e (t - t_2)))+(L_e/L_{R2})\, I_{LR12}\, (1 - \cos(\omega_e (t - t_2)))+ I_{LR12} \cos(\omega_e (t-t_2))- (V_{CR2} /\omega_e L_{R1}) \sin(\omega_e (t-t_2)) \quad (4.13)$$

$$i_{LR2} =(L_e/L_{R1})\, I_{LR22}\, (1 - \cos(\omega_e(t-t_2)))+ (L_e/L_{R2})I_{LR12}(1 - \cos(\omega_e (t - t_2))) + I_{LR22} \cos(\omega_e (t-t_2)) - (V_{CR2} /\omega_e L_{R2})\sin(\omega_e (t-t_2)) \quad (4.14)$$

$$V_{CR} = V_{CR2} \cos(\omega_e (t - t_2))+ Z_e (I_{LR22}- I_{LR12}) \sin(\omega_e (t - t_2))) \quad (4.15)$$

$$Z_e = (L_e/C_R)^{1/2} \quad (4.16)$$

$$\omega_e = (1/L_eC_R)^{1/2} \quad (4.17)$$

Here, Z_e is the equivalent impedance of the resonant circuit.

4) Stage 4 [$t_4 < t < t_5$]: At time t = t_4 the switch S_2 = OFF. For this interval, $i_{s1} = I_i$, i_{s2} = 0, i_{DF} = 0, $i_{LR1} = I_{LR14}$, i_{LR2} = 0, $V_{CR} = V_{CR4}$, and V_{CS} = 0. In this operation the resonant circuit will be formed with elements are L_{R1} -C_R-D_1 . then

$$i_{LR1} = I_{LR14} \cos(\omega_1 (t - t_4)) + V_{CR4} /Z_1 \sin(\omega_1 (t - t_4)) \quad (4.18)$$

$$V_{CR} = V_{CR4} \cos(\omega_1 (t-t_4)) - Z_1 I_{LR14} \sin(\omega_1 (t-t_4)) \quad (4.19)$$

$$Z_1 = (L_{R1}/C_R)^{1/2} \quad (4.20)$$

$$\omega_1 = (1/L_{R1}C_R)^{1/2} \quad (4.21)$$

Here, Z_1 is the equivalent impedance of the resonant circuit. At end of stage t = t_5 , the L_{R1} current is reduced to zero and voltage across C_R is maximum.

$$V_{CRmax} = (V_{2CR4} + (Z_1 I_{LR14})^2)^{1/2} \quad (4.22)$$

5) Stage 5 [$t_5 < t < t_6$]: At t=t_5, the main switch S_1 is turned ON , it increases the I_i and without considering the snubber circuit. In this interval PWM metod is applied and it provides the power factor correction for this converter in this mode with time interval is large.

$$i_{S1} = I_i . \quad (4.23)$$

6) Stage 6 [$t_6 < t < t_8$]: At $t \le t_6$, $i_{s1} = I_i$, i_{s2} = 0, i_{DF} = 0, i_{LR1} = 0, i_{LR2} = 0, $V_{CR} = V_{CR6} = V_{CRmax}$, and V_{CS} = 0. At t = t_6 , whenever the gate signal is applied to the auxiliary switch S_2 and it creates the resonant circuit if formed by the elements are C_R-L_{R2} -S_2 -S_1 .

$$i_{LR2} = i_{S2} = V_{CRmax}/Z_2 \ \sin(\omega_2 (t - t_6)) \quad (4.24)$$

$$V_{CR} = V_{CRmax} \cos(\omega_2 (t - t_6)) \quad (4.25)$$

$$Z_2 = (L_{R2}/C_R)^{1/2} \quad (4.26)$$

$$\omega_2 = (1/(L_{R2}C_R))^{1/2} \quad (4.27)$$

Z_2 is the equivalent impedance of the resonant circuit. The control signal is applied to the S_1 with Zero Current Transition and also the resonant provided with the elements are C_R-L_{R2} -S_2 -D_{S1}.The time t = t_8 , at end of this interval the voltage drop across C_R falls to zero and i_{LR2} reaches its maximum levels and this interval ends.

$$I_{LR2\,max} = V_{CR\,max}/Z_2 \quad (4.28)$$

7) Stage 7 [$t_8 < t < t_9$]: In this mode, i_{s1} = 0, $i_{s2} = I_{LR2\,max}$, i_{DF} = 0, i_{LR1} = 0, $i_{LR2} = I_{LR2\,max}$, V_{CR} = 0 and V_{CS} = 0 are valid. At t = t_8 , V_{CR} is positive voltage will be developed, diode D_1 is in ON position. During this state the elements of L_{R2} , L_{R1} , and C_R is created a resonance circuit.

$$i_{LR1} =(L_e /L_{R1})\, I_{LR2\,max}\, (1 - \cos(\omega_e (t - t_8))) \quad (4.29)$$

$$i_{LR2} = (L_e/ L_{R1})\, I_{LR2\,max}\, (1 - \cos(\omega_e (t - t_8))) + I_{LR2\,max}\, (1 - \cos(\omega_e (t - t_8))) \quad (4.30)$$

$$V_{CR} = I_{LR\,2max} /\omega_e C_R \sin(\omega e (t - t_8))) \quad (4.31)$$

$$L_S = L_{R1} + L_{il} + L_m \quad (4.32)$$

$$Le = L_{R1} (L_{il} + L_m)/(L_{R1} + L_{il} + L_m) \quad (4.33)$$

$$\omega_e = (1/L_eC_R)^{1/2} \quad (4.34)$$

8) Stage 8 [$t_9 < t < t_{10}$]: The beginning of this mode, i_{s1} = 0, $i_{s2} = I_i$, i_{DF} = 0, $i_{LR1} = I_{LR19}$, $i_{LR2} = I_i$, $V_{CR} = V_{CR9}$, and V_{CS} = 0 are valid. At t = t_9 , because of i_{LR2} current reduces to input current.

$$L_{R1}\, di_{LR1}/ dt = V_{CR} \quad (4.35)$$

$$L_{R2}\, di_{LR2}/ dt = V_{CS} - V_{CR} \quad (4.36)$$

$$C_R\, dV_{CR}/ dt = i_{LR2} - i_{LR1} \quad (4.37)$$

$$C_S\, dV_{CS}/ dt = Ii - i_{LR2} \quad (4.38)$$

i_{LR2} is reduce, and the duration time t = t_{10}, the i_{LR2} =0, the auxiliary switch is in off mode. Then the completely switch S_2 is in blocking mode with the presence of zero current switch.

9) Stage 9 [$t_{10} < t < t_{11}$]: Mode $t = t_{10}$, $i_{s1} = 0$, $i_{s2} = 0$, $i_{DF} = 0$, i_{LR1} is equal to the I_{LR110}, $i_{LR2} = 0$, $V_{CR} = V_{CR10}$, and $V_{CS} = V_{CS10}$ are valid. In this interval two stopped circuit are considered. For the first stopped circuit, snubber capacitor is fully charged with respect to I_i by linearly and for the second stopped circuit is created a closed circuit that is L_{R1} -C_R-D_1 is formed a resonance. For this mode

$$i_{LR1} = I_{LR110} \cos(\omega_1 (t - t_{10})) + (V_{CR10} / Z_1) \sin(\omega_1 (t - t_{10})) \quad (4.39)$$

$$V_{CR} = V_{CR110} \cos(\omega_1 (t - t_{10})) - Z_1 I_{LR110} \sin(\omega_1 (t - t_{10})) \quad (4.40)$$

$$V_{CS} = (I_i / C_s)(t - t_{10}) \quad (4.41)$$

can be written. At $t = t_{11}$, $V_o = V_{CS} + V_{CR}$, then the D_3 diode can be turned ON.

10) Stage 10 [$t_{11} < t < t_{12}$]: Mode $t = t_{10}$, $i_{s1} = 0$, $i_{s2} = 0$, $i_{DF} = 0$, $i_{LR1} = I_{LR111}$, $i_{LR2} = 0$, $V_{CR} = V_{CR11}$, and $V_{CS} = V_o - V_{CR11}$ are valid. The input current is flows through the elements of L_{R1}, C_S, and C_R that is a resonance circuit. At $t = t_{12}$, i_{LR1}

$$i_{LR1} = (I_{LR111} - I_i) \cos(\omega_3 (t - t_{11})) + (V_{CR11} / Z_3) \sin(\omega_3 (t - t_{11})) + I_i \quad (4.42)$$

$$V_{CR} = V_o - V_{CS} = V_{CR11} \cos(\omega_3 (t - t_{11})) - Z_3 (I_{LR11} - I_i) \sin(\omega_3 (t - t_{11})) \quad (4.43)$$

$$C_3 = C_S + C_R \quad (4.44)$$

$$\omega_3 = 1/ \sqrt{(L_{R1} C_3)} \quad (4.45)$$

$$Z_3 = \sqrt{(L_{R1}/C_3)} \quad (4.46)$$

11) Stage 11 [$t_{12} < t < t_{13}$]: At $t = t_{12}$, $i_{s1} = 0$, $i_{s2} = 0$, $i_{DF} = 0$, $i_{LR1} = 0$, i_{LR2} is equal to zero value, voltage across snubber capacitance is equal to the VCR12 , and $V_{CS} = V_0 - V_{CR12}$ are valid.

$$V_{CR} = V_{CR12} - I_i/C_3 (t - t_{12}) \quad (4.47)$$

12) Stage 12 [$t_{13} < t < t_{14}$]: At $t = t_{13}$, here snubber circuit is doesn't in switching mode and $D_{F=}$ON and I_i input current will be developed. For this stage

$$i_{DF} = I_i \quad (4.48)$$

Finally, at $t = t_{14} = t_0$,this is the twelve stages of one switching period or it is also one cycle completed and then next cycle will be repeated in the same manner.

V.SIMULATION RESULTS

The evaluation of control strategy can be carried out by simulating the single phase and three phase bridge rectifier with power factor converters with R,RL and RLE loads The power electronic devices are AC-DC converters are having the poor power quality this should maintain the low power factor, voltage distortion and it reduce the efficiency. The AC-DC converters are operated with high switching frequency it consists of high switching losses and low power factor. This drawback can be overcome by these converters with soft switching techniques for improving the power quality, power factor and also the efficiency and reliability with and PWM.

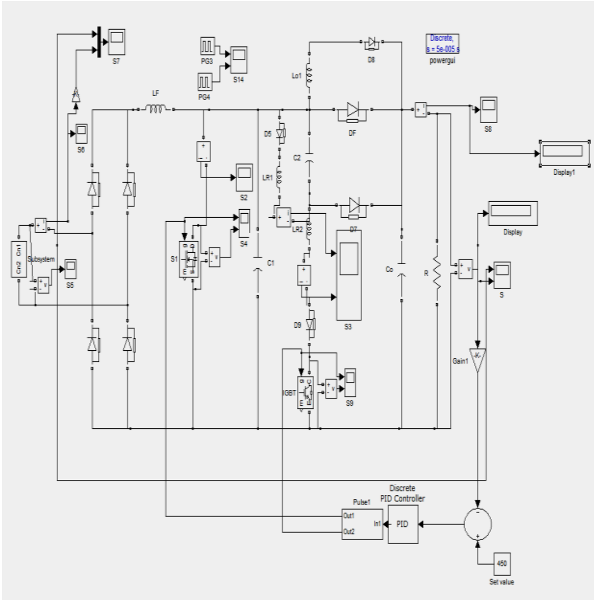


Fig 5.1 Circuit diagram with Closed Loop

The evaluation of control scheme can be carried out in MATLAB plat form by simulating the single phase soft switching power factor correction for boost converter simulink diagram and the results are as follows. Fig 5.2 shows input voltage and current.

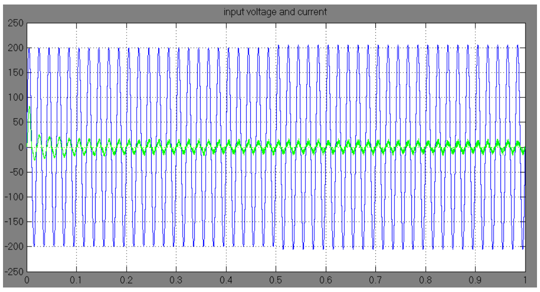


Fig 5.2 Input voltages and current with feedback

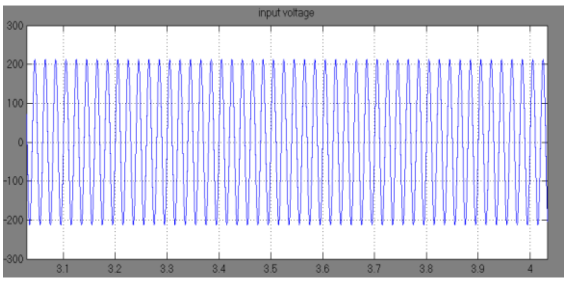


Fig 5.3: input voltage wave form of with feedback

The input, output voltage and output current waveforms of the single phase soft switching power factor correction for boost converter are shown in fig 5.3, fig 5.4, and fig 5.5 respectively.

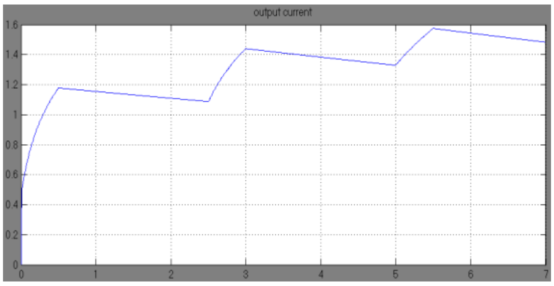


Fig 5.4: Output voltage wave form with feedback

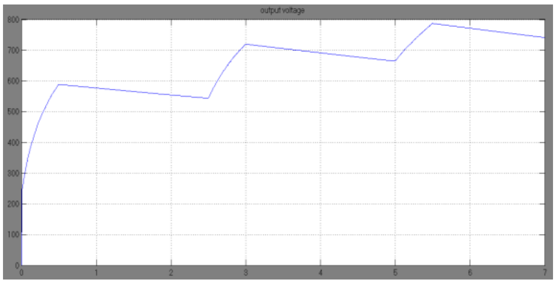
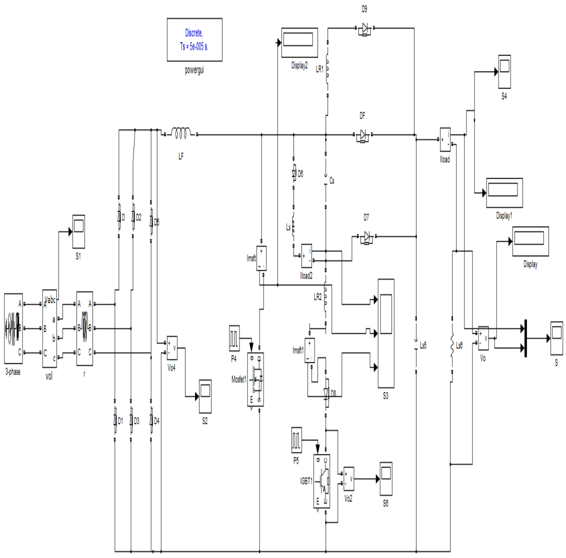


Fig 5.5: output current wave form with feedback

5.1 Simulation Results for 3- Phase bridge rectifier:

Fig 5.6 Circuit diagram of 3-phase bridge rectifier



The above diagram shows that three phase bridge rectifier with active snubber cell. This snubber cell consists of inductance and capacitance and those components can be reducing the voltage and current stress on the main and auxiliary switches during switching periods.

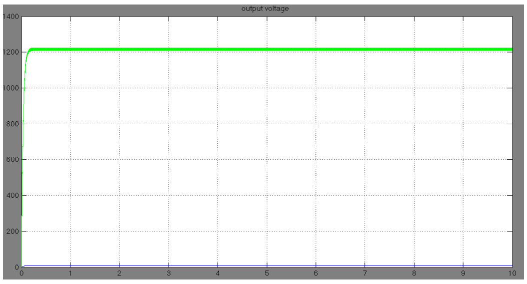


Fig5.7 Input voltage versus time

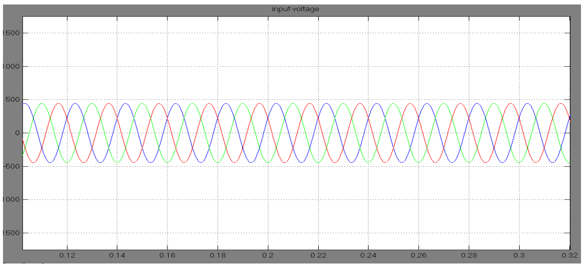


Fig 5.8 Output voltage versus time

The above fig 5.7 and 5.8 shows that three phase input voltage waveform and output voltage values of the boost converter respectively. It says that the input voltage 440V is given to the converter circuit and it will produce the output voltage value is 1270v was obtained and also the power factor is completely improved by the presence of snubber cell.

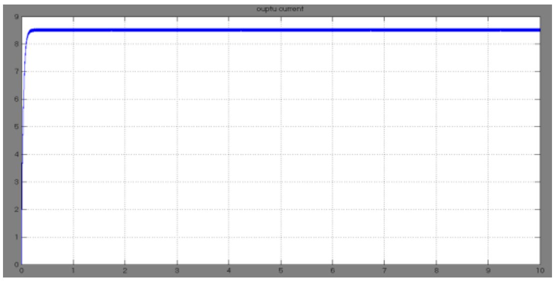


Fig 5.9 Output current versus time

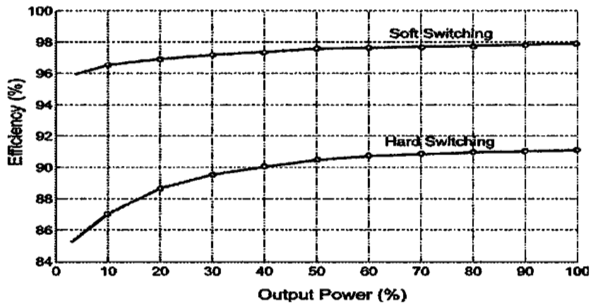


Fig 5.10: Overall efficiency curves

VI. CONCLUSIONS & FUTURE SCOPE

In this project single phase and three phase soft switching power factor correction circuit developed with active snubber cell. This active snubber cell provides ZVT turn ON and ZVS turn OFF for the main switch. ZCS turn ON and turn OFF together are provided for the auxiliary switch. In this project a new single phase/ three phase soft switching power factor correction converter, current stresses, voltage stresses and total harmonic distortion are reduced. By comparing the both single phase and three phase converters the output voltage is 617V and 1257V respectively increased in case of three phase converters with the use of coupling inductor in both converters. In this project new single phase/three phase soft switching power factor correction converter has been proved and verified by the simulation results.

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