A NEW SOFT SWITCHING SCHEME FOR POWER FACTOR CORRECTION IN UPS BASED APPLICATION

I.Mahendravarman[1], A. Ragavendiran[2], M.Arunprakash[3] and S. Preethi[4]

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING
A.V.C COLLEGE OF ENGINEERING, MAYILADUTHURAI.

Abstract— A boost Power Factor Correction (PFC) front end converter followed by a full bridge transformer-isolated dc/dc converter is popular in offline dc power supply. In this configuration switching losses are high and overall efficiency is reduced. For solving this problem individual soft-switching techniques are required for both the converters. A dc power supply system that uses a new Zero-Voltage Switching (ZVS) strategy to get ZVS function is proposed here. A soft-switching dc power supply system with high input power factor and stable dc output voltage is presented with simple and compact configuration. The proposed circuit is not only operated at constant frequency, but all semiconductor devices are operated at soft switching without additional voltage stress. A significant reduction in the conduction losses is achieved, since the circulating current for the soft switching flows only through the auxiliary circuit and a minimum number of switching devices are involved in the circulating current path, and the rectifier in the proposed converter uses a single converter instead of the conventional configuration composed of a four-diode front-end rectifier followed by a boost converter. An average-current-mode control is employed in proposed dc power supply system to synthesize a suitable low-harmonics sinusoidal waveform for the input current.

Keywords— Power Factor Correction, Zero Voltage Switching, Average-current-mode control, Harmonics.

I. INTRODUCTION

In recent years, dc power supplies have been widely used in industrial equipments, such as dc uninterruptible power supply and telecommunications power supply, and high power factor and low input-current harmonics are mandatory performances of the dc power supplies for satisfied agency standards such as EN61000–3-2.

Thus, the PFC must be included in dc power supply. Although the traditional passive diode rectifier/LC filter can be used to correct the power factor and these standards are also possibly satisfied[1], the size of low-frequency inductors and capacitors will result in the dc power supplies, which are very bulky and heavy[2]-[4]. The passive filter approach to PFC is limited to applications where the size and weight of the converter are not major concerns. For overcoming this problem, a boost PFC front-end converter followed by a transformer-isolated dc–dc converter is the most extensively employed in offline power supplies[5], and full-bridge transformer-isolated dc/dc converter is the most extensively applied in medium-to-high power dc/dc power conversion[3].

Thus, a boost PFC front-end converter followed by a full-bridge transformer-isolated dc/dc converter is the most popularly used in offline dc power supplies. A high input power factor soft-switching single-stage dc power supply system using a ZVS-pulse width modulation strategy is proposed here.

II. POWER FACTOR CORRECTION TECHNIQUES

As power electronics equipments are increasingly being used in power conversion, they inject low order harmonics into the utility. Due to the presence of these harmonics, the total harmonic distortion is high and the input power factor is poor. Due to problems associated with low power factor and harmonics, utilities will enforce harmonic standards and guidelines which will limit the amount of current distortion allowed into the utility and thus the simple diode rectifiers may not in use. So, there is a need to achieve rectification at close to unity power factor and low input current distortion.

A. *Passive power factor correction technique*

In passive power factor correction techniques, an LC filter is inserted between the AC mains line and the input port of the diode rectifier of AC/DC converter.

B. *Active power factor correction techniques*

In active power factor correction techniques approach, Switched Mode Power Supply (SMPS) technique is used to shape the input current in phase with the input voltage. Thus, the power factor can reach up to unity The Active PFC techniques can be classified as follows

1) *PWM power factor correction:* In PWM power factor correction approach, the power switching device operates at pulse-width modulation mode. Basically in this technique switching frequency of active power switch is constant, but turn-on and turnoff mode is variable.

2) *Resonant power factor correction:* In the resonant converter, the voltage across a switch or the current through a switch is shaped by the resonance of inductor and capacitor to become zero at the time of turned on or off

3) *Soft Switching Power Factor Correction:* The soft-switching PFC technique combines the advantages of PWM mode and resonant mode techniques with an additional resonant network consisting of a resonant inductor, a resonant capacitor and an auxiliary switch. The PFC circuit works at constant switching frequency and the power switch turns on and off at zero current or zero voltage conditions. Thus efficiency and power factor both improved by this technique.

III. TOPOLOGY FOR POWER FACTOR IMPROVEMENT

A high-input power factor soft-switching single-stage dc power supply system using a ZVS – PWM strategy is proposed here. In the proposed system, the components of boost rectifier in the circuit is rearranged to provide the soft switching on all semiconductors in the full bridge transformer-isolated dc/dc converter, and a ZVS–PWM commutation cell is used to provide the ZVS on all semiconductors in the boost rectifier. Thus, the proposed main circuit can be simplified, and all semiconductor devices in the proposed converter can be operated at ZVS. An average current- mode control is employed in the proposed converter synthesize a suitable low-harmonics sinusoidal waveform for the input current. In this topology the input inductor current wave must follow the line input voltage. In this topology angle between voltage and current becomes near to zero, so the power factor is unity.

A. Circuit diagram

Thus circuit can be divided into three sections. The first one is the input rectifier (boost power factor pre-regulator) that is designed to operate at PWM continuous conduction mode (CCM) and is composed of L_{in}, S_1, S_2, D_1, D_2, and C_1, the switches S_1, S2 operating at soft switching strategy.

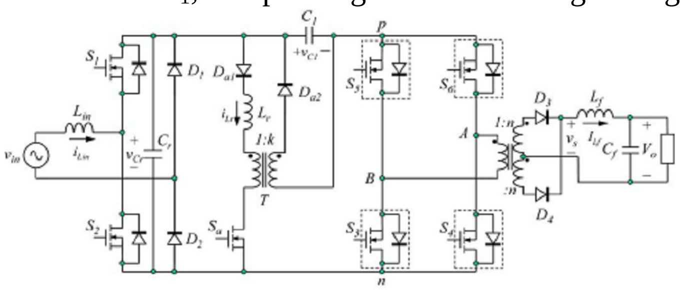

Fig. 1 Proposed high power factor dc power supply system

In this section can perform the functions of PFC and boost ac/dc conversion. The switches S_1 and S_2 are synchronously turned on and turned off. The operation of input rectifier is the same as the conventional boost power factor pre-regulator. It operates at fixed frequency and variable duty ratio dependent on the amplitude of line input voltage, and this duty ratio is a sinusoidal function. The duty ratio is lower when the rectifier operates at higher amplitude of line input voltage, and it is higher when the rectifier operates at lower amplitude of line input voltage. In this method the current of input inductor can control to follow in the line input voltage and reduce its total harmonic distortion to get high power factor.

The second one is a ZVS–PWM commutation cell to provide the soft switching on S_1, $S_2$and other switches in the circuit. This section composed of the auxiliary diodes Da_1 and Da_2, the resonant inductor L_r, the resonant capacitor C_r, the transformer T, and auxiliary switch S_a. The third one is the full-bridge transformer-isolated dc/dc converter and is composed of the switches S_3, S_4, S_5, S_6, D_3, and D_4, and the isolated transformer and output filter L_f and C_f, respectively. This section performs the function of conventional PWM full-bridge transformer-isolated dc/dc conversion.

B. Assumptions in circuit operation

The following assumptions are made during one switching cycle.

1) The power factor pre-regulator inductor L_{in} is large enough to assume that the input current I_{Lin} k is constant and it is much greater than resonant inductor L_r.
2) The output filter inductor L_f is large enough to assume that the output current I_{Lf} is constant and is much greater than the resonant inductor Lr.
3) The capacitorC_1 is large enough to assume that the voltage V_{C1} is constant and ripple free.
4) The resonant voltage v_{Cr} (t) is equal to V_{C1} and the resonant current i_{Lr} (t) is equal to zero. Based on this assumption, circuit operation for single cycle divided in to 24 stages. The power stage diagram and the ideal relevant wave forms during one switching period are shown in Fig. 2 and 3.

C. Modes of operation

1) Mode 1[Fig. 2(a):t_0-t_1]: Before t = t_0, the switches S_3, S_4, S_5, and S_6 maintain turn-ON state, and the switches S_1 and S_2 maintain turn-OFF state. The energy stored in inductor L_{in} is delivered to the capacitor C_1 while the output loop of the dc/dc converter is in a freewheeling state. This stage begins when S_a turns on with zero-current switching (ZCS) at t = t_0. The resonant inductor L_r is charged linearly from voltage $(1 - 1/k)V_{C1}$, where k is the turn ratio of the transformer T. i_{Lr} (t) increases linearly and the stage ends when it reaches I_{Lin} k + I_{Lf} .

*2) Mode 2[Fig. 2(b):t_1-t_2]:*During this stage, the switches S_4 and S_5 are turned off at ZVS when the body diodes of switches S_3, S_4, S_5, and S_6 turn off with ZCS at t = t_1. The capacitor C_r and inductor L_r have started resonant operation. v_{Cr} (t) decreases and i_{Lr} (t) increases. The energy stored in capacitor C_1 is gradually provided to the dc/dc converter. The stage ends when v_{Cr} (t) drops to null.

3) Mode 3[Fig. 2(c):t_2-t_3]: In this stage, the diodes D_1, D_2, and the body diodes of switches S_1 and S_2 are turned on at ZVS. Because the voltage across switches S_1 and S_2 is zero, this is the best time to turn on the switches S_1 and S_2 with ZVS.

In this stage, the freewheeling loop is also formed by D_{a1}, L_r, S_a, the body diodes of S_1 and S_2, and the diodes D_1 and D_2. Thus, the energy stored in resonant inductor L_r is delivered to the capacitor C_1 via transformer T. i_{Lr} (*t*) decreases linearly. In this time, the energy stored in capacitor C_1 is continuously provided to the dc/dc converter and v_{in} (t) charges the input inductor L_{in}.

4) Mode 4[Fig. 2(d):t_3-t_4]: At t = t_4, i_{Lr} (t) is equal to zero. The body diodes of the switches S_1 and S_2, and the diodes D_1 and D_{a1} are naturally turned off at ZCS and this stage begins. In this stage, v_{in} (t) charges continuously the input inductor L_{in} and the energy stored in capacitor C_1 is continuously provided to the dc/dc converter.

The boost power factor pre-regulator has another mission, which provides the ZVS on all semiconductors in the dc/dc converter. Although the duty interval $D_{PFC*}k_{Ts}$ is not complete, the switches S_1 and S_2 must be turned off at t = t_4 for providing soft commutation in dc/dc converter circuit. Therefore, the switches S_1 and S_2 must be turned off at t = t_4.

5) Mode 5[Fig. 2(e):t_4-t_5]: In this stage, the energy stored in input inductor L_{in}charges the resonant capacitor c_r. Thus, v_{Cr} (t) increases linearly and v_{pn} (t) decreases linearly. This stage is finished when v_{Cr} (t) reaches v_{C1} and v_{pn} (t) drops to zero.

6) Mode 6[Fig. 2(f):t_5-t_6]: In this stage, because the voltage v_{pn} (t) drops to zero, the body diodes of the switches S_3, S_4, S_5, and S_6 switch S_4 can be turned on with ZVS. The switch S_6 can be turned off with ZVS. The freewheeling loop is formed in dc/dc converter circuit.

The energy stored in input inductor L_{in} is delivered to the capacitor C_1.

7) Mode 7[Fig. 2(g):t_6-t_7]: Although this mission providing soft commutation on the switches S_3 and S_4 has been complete in stage 6, the switches S_1 and S_2 must perform continuously the turn-ON operation of the boost power factor pre-regulator. Therefore, the switch S_a is turned on with ZCS at t = t_6 again for providing soft commutation on them, and this stage begins. The resonant inductor L_r charges linearly from voltage $(1 - 1/k)*V_{C1}$ again. i_{Lr} (t) increases linearly and the stage ends when it reaches I_{Lin} k + I_{Lf} .

8) Mode 8[Fig. 2(h):t_7-t_8]: During this stage, the body diodes of switches S_5 and S_6 are turned off with ZCS and the dc/dc converter circuit performs continuously the freewheeling state. The resonance of Cr and Lr is started again. v_{Cr} (t) decreases and i_{Lr} (t) increases. The stage ends when v_{Cr} (t) drops to null.

9) Mode 9[Fig. 2(i):t_8-t_9]: In this stage, the diodes D_1 and D_2, and the body diodes of switches S_1 and S_2 are turned on at ZVS. Because the voltage across switches S_1 and S_2 is zero, the switches S_1 and S_2 can be turned on with ZVS again. In this stage, the freewheeling loop is also formed by D_{a1}, L_r, and S_a, the body diodes of S_1 and S_2, and the diodes D_1 and D_2.

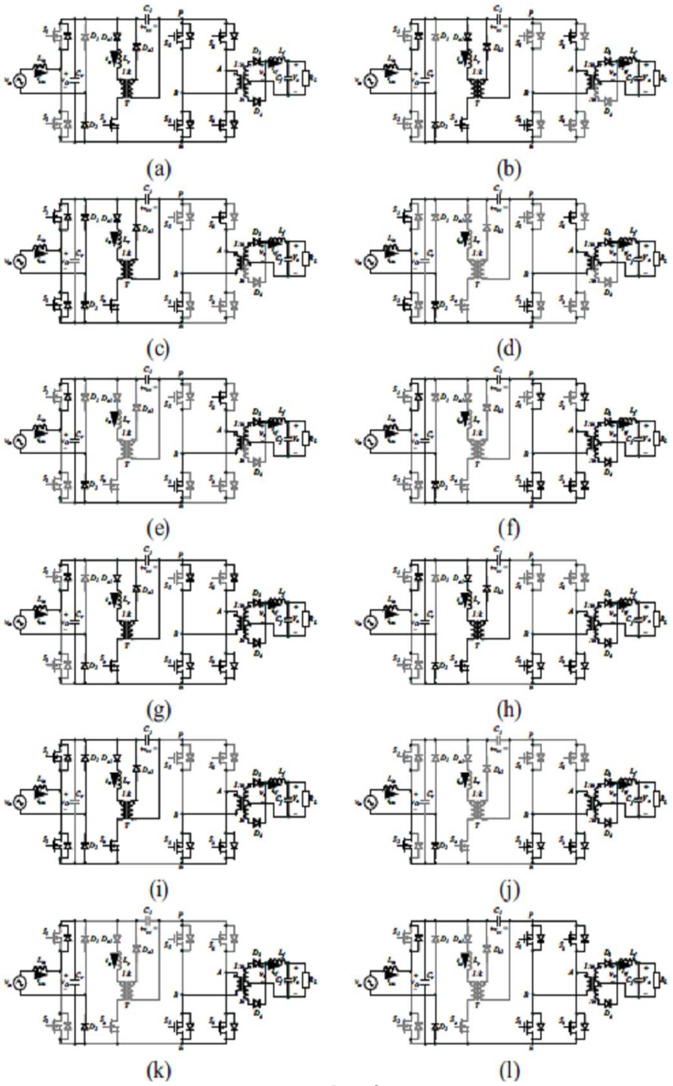

Fig. 2 Modes of operation

10) Mode 10[Fig. 2(j):t_9-t_{10}]: At $t = t_9$, the body diodes of the switches S_1 and S_2, and the diodes D_1 and D_{a1} are turned off at ZCS and this stage begins. In this stage, the input voltage v_{in} (t) charges continuously the input inductor *L*in. This stage ends when the duty interval D_{PFC}kTs is completed and the switches S_1 and S_2 are turned off at $t = t_{10}$.

11) Mode 11[Fig. 2(k):t_{10}-t_{11}]: In this stage, the energy stored in input inductor *L*in charges the resonant capacitor C_r. Thus, v_{Cr} (t) increases linearly and v_{pn} (t) decreases linearly. This stage is finished when v_{Cr} (t) reaches V_{C1} and v_{pn} (t) drops to zero.

*12) Mode 12[Fig. 2(l):t_{11}-t_{12}]:*In this stage, because v_{pn} (t) drops to zero, the body diodes of the switches S_1, S_2, S_3, and S_4, and the switches S_5 and S_6 can be turned on with ZVS. The dc/dc converter circuit performs continuously the freewheeling state. The energy stored in input inductor L_{in} is delivered to the capacitor C_1.

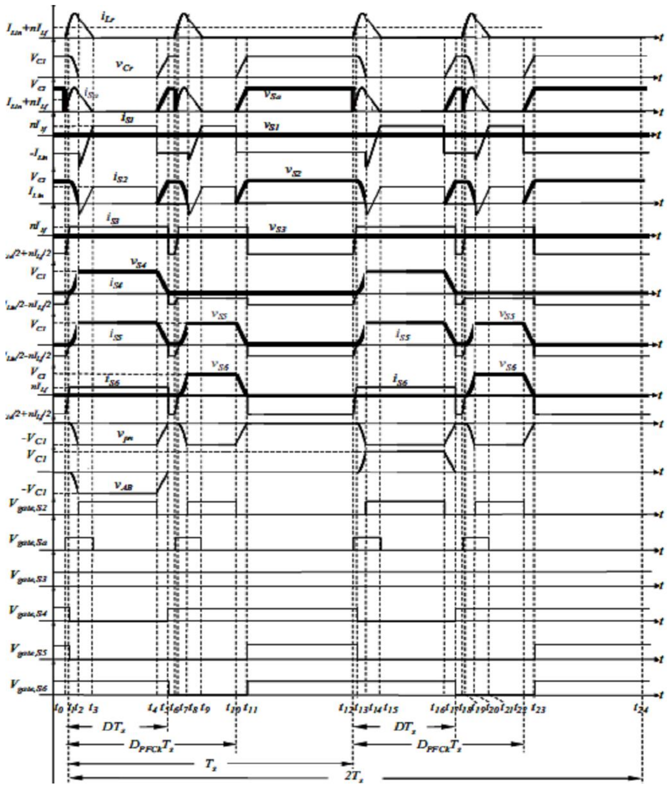

Fig. 3 ideal relevant wave form

The operation principles of stages 13–24 are the same as stages 1–12 except that the play role of the switches S_3, S_4, S_5, and S_6 in circuit operation is changed. After stage 24, the circuit operation is returned to the first stage.

III. PERFORMANCE INVESTIGATION BY MATLAB SIMULATION

The performance of dc power supply system is investigated by means of detailed MATLAB simulation.

A) *Simulation model of open loop system*

Simulation model of open loop system is shown in Fig. 3

In this circuit, the input voltage is 110Vrms and input current is 11A. We get output voltage of 48V and current 21A. The power factor gets improved to 0.99

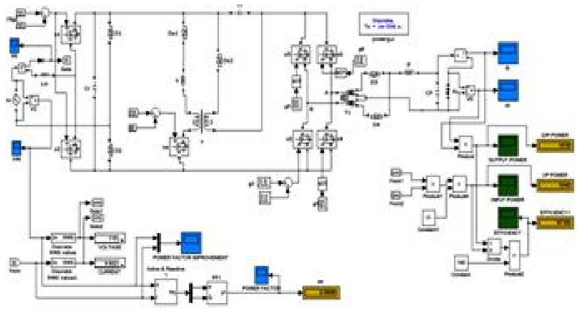

Fig. 4 Open loop simulation model

B) *Simulation model for closed loop system*

Simulation model of closed loop system is shown in Fig. 4 In this circuit, the input voltage is 110Vrms and input current is 11A.

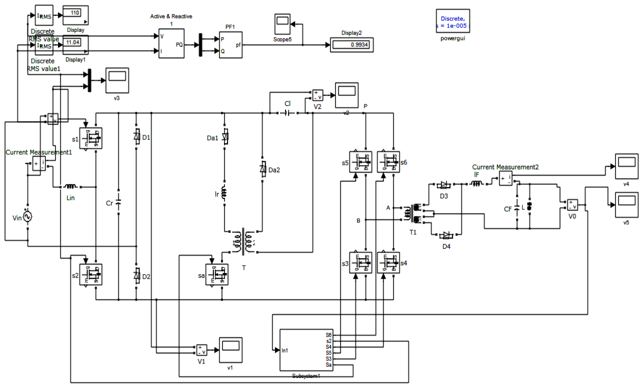

Fig. 5 Simulation model for closed loop system

We get output voltage of 47.35V and current 25A. The power factor is improved to 0.99. Average current control method is used to control the closed loop system.

C) Simulation results for open and closed loop system

1) Voltage, current and power: Input and output voltage, current and power wave forms are carried out by MATLAB simulation for both open loop and closed loop systems. Corresponding wave forms are shown in following figures.

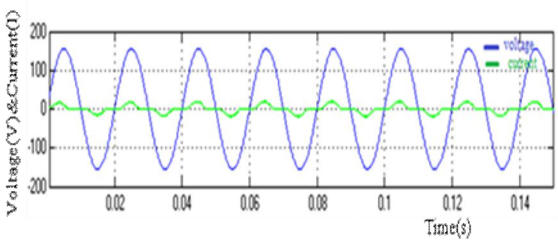

Fig. 6 Input voltage and current(open&closed loop)

Fig. 6 shows the input voltage and current waveforms of both open loop and closed loop system. In these waveforms the current is in phase with voltage, the angle between the voltage and current becomes nearly zero. So the power factor value is almost unity.

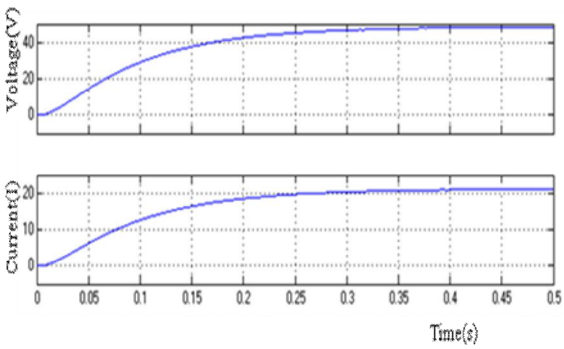

Fig. 7(a) Output voltage and current(open loop)

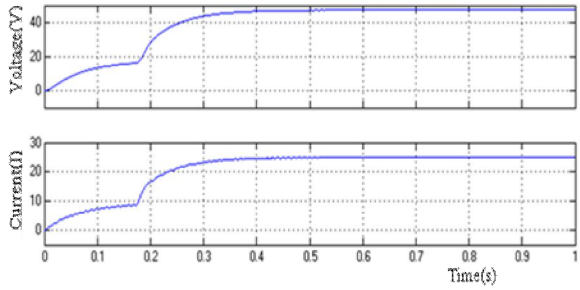

Fig. 7(b) Output voltage and current(closed loop)

Fig. 7(a) & (b) shows the output voltage and current for open loop and closed loop system. From this we observed that voltage and current value are of 48V and 21.5A for open loop system and, 48V and 24A for closed loop system.

Fig. 8(a) & (b) shows input/output power for open loop system. From this we observed that input/output power values are 1040W and 1016W for open loop system

Fig. 9(a) & (b) shows input/output power for closed loop system. From this we observed that input/output power values are 1189W and 1189W for closed loop system.

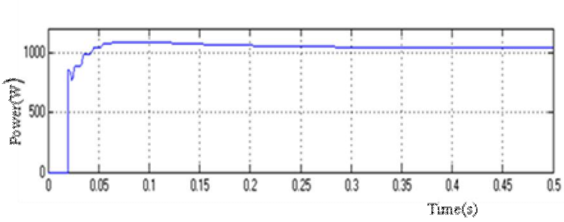

Fig. 8(a) Input power(open loop)

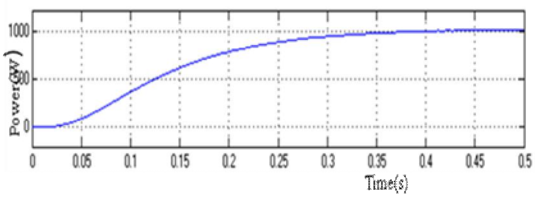

Fig. 8(b) Output power(open loop)

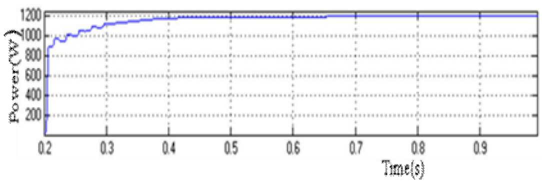

Fig. 9(a) Input power(closed loop)

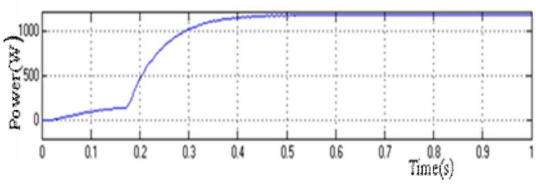

Fig. 9(b) Output power(closed loop)

1) *Power factor and efficiency:* Power factor and efficiency are measured from the open loop and closed simulation models.

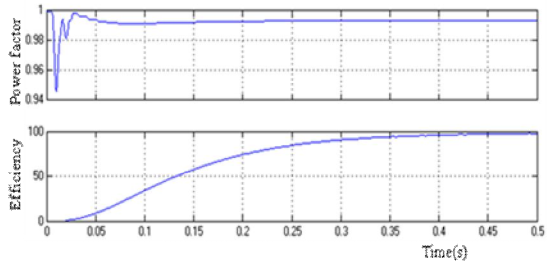

Fig. 10(a) Power factor and efficieny(open loop)

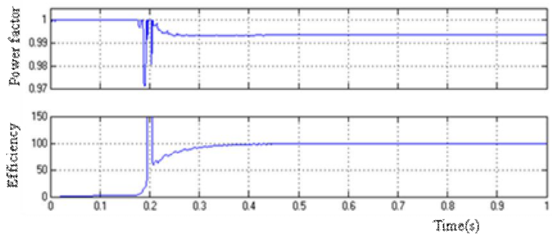

Fig. 10(b). Power factor and efficieny(closed loop)

Fig. 10(a) & (b) shows power factor and efficiency for open loop and closed loop systems. The power factor has been improved to 0.99 in both open loop as well as in closed system, and it is evident from the observations that there is also betterment in efficiency for both open and closed loop configurations.

IV. CONCLUSION

A soft switching single phase dc power supply with high input power factor and stable dc output voltage is designed by using MATLAB simulation software. This dc power supply system is applicable in dc uninterrupted power supply system design. This proposed dc power supply system operating at constant frequency and all semiconductor devices with soft switching strategy. In this proposed system significant reduction in voltage stress and conduction losses are achieved. Power factor and efficiency is improved compared with conventional topology.

REFERENCES

[1] G. Moschopoulos and P. Jain, “Single-stage ZVS PWM full-bridge converter,” *IEEE* Trans. Aerosp. Electron. Syst., vol. 39, no. 4, pp. 1122–1133,Oct. 2003.

[2] S. Luo, W. Qiu, W. Wu, and I. Batarseh, “Flyboost power factor correction cell and a new family of single-stage ac/dc converters,” *IEEE* Trans. Power Electron., vol. 20, no. 1, pp. 25–34, Jan. 2005.

[3] C. M. Wang, “A novel zero-voltage-switching PWM boost rectifier with high power factor and low conduction losses,” *IEEE* Trans. Ind. Electron., vol. 52, no. 2, pp. 427–435, Apr. 2005.

[4] Y. Jang, M. M. Jovanovic, and D. L. Dillman, “Soft-Switched PFC boost rectifier with integrated ZVS two-switch forward converter,” *IEEE* Trans. Power Electron., vol. 21, no. 6, pp. 1600–1606, Nov. 2006.

[5] D. D.-C. Lu, H. H.-C. Iu, and V. Pjevalica, “A single-stage AC/DC converter with high power factor, regulated bus voltage, and output voltage,” *IEEE* Trans. Power Electron., vol. 23, no. 1, pp. 218–228, Jan. 2008.

