AN ELECTRONIC BALLAST WITH U P F

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ABSTRACT

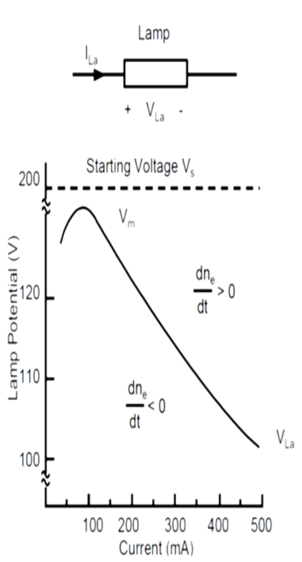
An Electronic Ballast is used for the Compact fluorescent lamp. The present work focus on development of an Electronic Ballast having almost unity power factor (UPF) improved power quality. The electronic ballast consists of a PFC (power factor corrected) Boost converter, which operates in discontinuous conduction mode (DCM), and a high frequency DC-AC inverter. It overcomes the drawback of [1] operating the boost converter in open loop by operating the boost converter in closed loop to provide a constant power to the load within in the specified ratings irrespective of the changes in the load. It uses less number of inductors and capacitors which reduces the cost of the total equipment, especially at high voltage ratings capacitor and inductor cost becomes more and overcomes the drawback of [2] high cost at higher voltage ratings.

In the Series Resonant Parallel Loaded Inverter zero voltage switching is achieved by keeping the switching frequency more than the resonance frequency, which reduces the switching losses and improves the efficiency of the Electronic Ballast. The simulation of Power Factor Correction based electronic ballast is carried out in MATLAB SIMULINK software. The High Frequency Electronic Ballast consists of a Series Resonant Parallel Loaded Inverter (SRPLI) is used to feed constant current to lamp for specified voltage range applications. The power quality indices are calculated such as total harmonic distortion (THDi) of ac mains current, and power factor (PF) for the analysis of the behavior of Unity Power Factor Electronic Ballast.

1. INTRODUCTION

Light is defined as visually evaluated radiant energy, which stimulates man's eyes and enables him to see. Man has always sought to counter the influence of the darkness by creating artificial light. The discovery of electric power and the possibility of transmitting it in a simple manner facilitated the development of modern lamps. Today there are nearly 6,000 different lamps being manufactured, most of which can be placed in the following six categories: incandescent, fluorescent, mercury vapour, metal halide, high-pressure sodium (HPS) and low-pressure sodium (LPS). Except for incandescent lamps, all of these light sources can be termed as gas discharge lamps. Fluorescent and LPS lamps operate on low-pressure gaseous discharge, and the mercury vapour, metal halide and HPS lamps operate on high-pressure gaseous discharge. The mercury vapour, metal halide and HPS types are commonly known as high-intensity discharge (HID) lamps.r

Although gas discharge lamps have tremendous advantages over incandescent lamps, they require an auxiliary apparatus called a ballast to run with them because gas discharge lamps have negative incremental impedance. Figure 1.1(a) shows a typical curve of discharge potential drop versus current when a lamp is operated from a DC power source. The curve can also be regarded as the locus of points (i,v) for which the time rate of change of electron density, dne/dt, is zero. For points above and to the right, dne/dt is greater than zero (production exceeds loss), and electron density would increase with time. For points below and to the left, dne/dt is less than zero, and electron density would decrease with time. Obviously, the slope of the curve, defined as incremental impedance r $\equiv dv/di$, is negative. The negative increase impedance characteristic poses a circuit problem for operating lamps. In general, a starting voltage Vs that is higher than the steady-state operation voltage is needed to establish ionization in the gas. After the discharge begins, the operating point (i, v) of the discharge would lie somewhere on the line of the constant V =Vs, which is in the domain for which the ionization rate exceeds the loss rate, and thus electron density ne increases continuously with time. Consequently, the discharge current increases without any regulation, and eventually causes system failure.



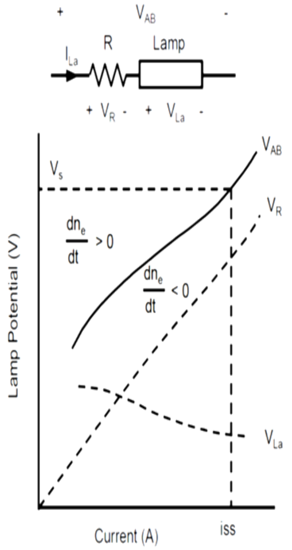


Figure 1.1(a)

Figure 1.1(b)

As a result, gas discharge lamps cannot be directly connected to a voltage source. Certain impedance must be placed between the discharge lamp and the voltage source as a means to limit lamp current. For example, Figure 1.1(b) shows the effect of series resistance in stabilizing lamp current. The dotted lines V_{La} and V_R show the voltage potential across the discharge and resistor, respectively, and the solid line V_{AB} shows the potential across the pair in series. Upon application of a starting voltage to the lamp-resistor system and establishment of ionization, the operating point (*i*,*v*) is in the domain of positive *dne/dt*, increasing the lamp current until it reaches the point (i_{ss}, V_s). A further increase in current would move the operating point into the region of negative *dne/dt*, forcing the current back to i_{ss}. The resistor *R* helps to establish the stable operating point of the discharge lamp and acts as the ballast.

1.1 Magnetic Ballast

Magnetic ballasts are operated in 50/60Hz line frequency. Every half line cycle, they re-ignite the lamp and limit the lamp current. Although magnetic ballasts have the advantages of low cost and high reliability, there exist at least three fundamental performance limitations due to the low-frequency operation. First of all, they are usually large and heavy. Second, the time constant of the discharge lamps is around one millisecond, which is shorter than the half line period (8.3ms for 60Hz line cycle), so the arc extinguishes at line voltage zero crossing, and then is re-ignited. Figure1.2 shows the measured voltage and current waveforms of an F40T12 lamp operating at 60 Hz. After every line zero crossing, the lamp voltage waveform has a re-strike voltage peak; during the rest of the cycle, the voltage does not vary much. This causes two big problems: The lamp electrode wearing is significant, and the lamp's output light is highly susceptible to the line voltage, which results in an annoying visible flickering. Finally, there is no efficient and cost-effective way to regulate the lamp power.

1.2 Electronic Ballast

These drawbacks led to studying the use of high-frequency AC current to drive the discharge lamps. High-frequency operation not only results in significant ballast volume and weight reduction, but also improves the performance of the discharge lamp. Figure 1.3 shows the measured voltage and current waveforms of the lamp operating with the same current level but at high frequency. The voltage and current waveforms are almost proportional with the same *v-i* characteristic of a resistor, although this resistor is not linear and varies as a function of time and lamp current. The re-strike voltage peak no longer exists. The recombination of ions and electrons in the discharge is very low. No re-ignition energy is needed. The lamp electrodes also sustain the electron density during the transition from cathode to anode function, resulting in additional energy savings. Therefore, the gas discharge itself is more efficient in high-frequency operation, contributing to an increased efficacy.

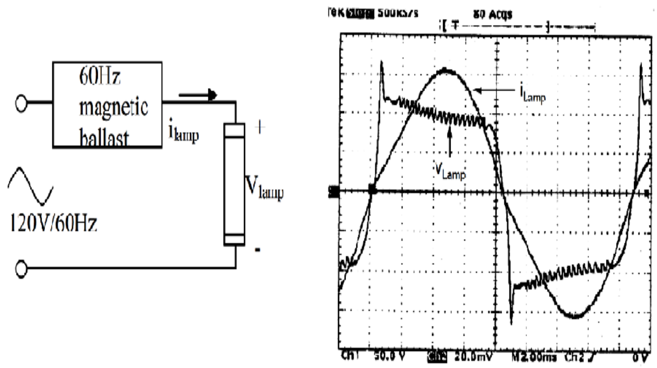


Figure 1.3: Measured lamp voltage and current waveforms at 60Hz

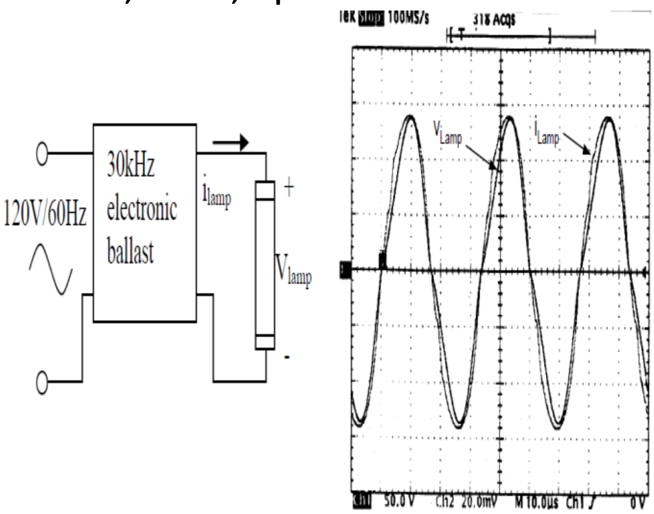


Figure 1.4: Measured Voltage and Current waveforms 30kHz

Figure.1.4 shows the curve of fluorescent lamp efficacy versus lamp operating frequency. It shows that the efficacy increases by about 10% when the operating frequency is above 30 kHz. Other discharge lamps have a similar characteristic. The high-frequency operation also makes the lamp start easily and reliably, and eliminates audible noise and flickering effect. In addition, due to the advances in power electronics, power regulation can be easily incorporated into the ballast, making intelligence and energy management feasible.

2. UNITY POWER FACTOR ELECTRONIC BALLAST

2.1 Diode Bridge Rectifier

It is a Full wave diode bridge rectifier which converts the input ac voltage Vm-110V to dc voltage and it's output is given to the boost converter.

2.2 Boost Converter

A basic boost converter is shown in the figure 2.1 below

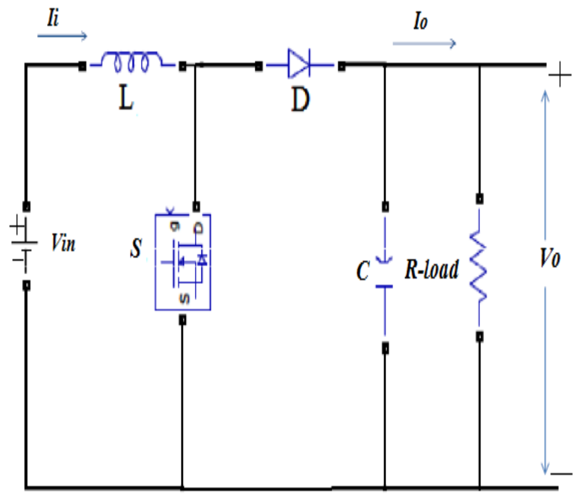


Figure 2.1: Boost converter

In a Boost converter, the output voltage is greater than the input voltage. The operation of a Boost converter consists of using a high speed switch, usually a power MOSFET, with output voltage is controlled by varying the switching duty cycle. The function of the Boost converter is to convert a DC voltage signal to DC signal, at the same time, boosting the voltage. This is accomplished by using an inductor controlling the time it conducts electrical current. Thus, an inductor that is connected and disconnected very quickly will charge and discharge the current very rapidly. The Boost converter acts as a voltage step-up and also current step-down converter. The switching process produces a pulsating current and capacitor will filter and smoothes the pulsating current. Capacitor also provides a dc voltage to the load. The value of capacitor should be sufficient to maintain a minimum ripple output voltage at the load. The load is a resistor in parallel with the capacitor, and resistor has power losses when current flows through it. The circuit operation of a boost converter is divided into two modes of continuous conduction.

Under normal condition, the circuit is in continuous conduction, where the inductor current is not zero. Mode(a), transistor is switched on at t = 0**,** current flows h m the input source through inductor L and transistor. Energy is stored in the inductor's magnetic coil. There is no current flow through the diode, capacitor or load.

Mode(b), then begins when the transistor is switched off at t = tl and the current now flows through L, C, diode and load. The inductor current falls until the switch is turned on again in the next cycle. But it cannot change instantaneously, so it immediately reverses its EMF. Thus the inductor voltage adds to the source voltage. The energy that has been stored in the inductor is transferred to the load. The output voltage is therefore higher than the input voltage, which is shown in fig 2.2

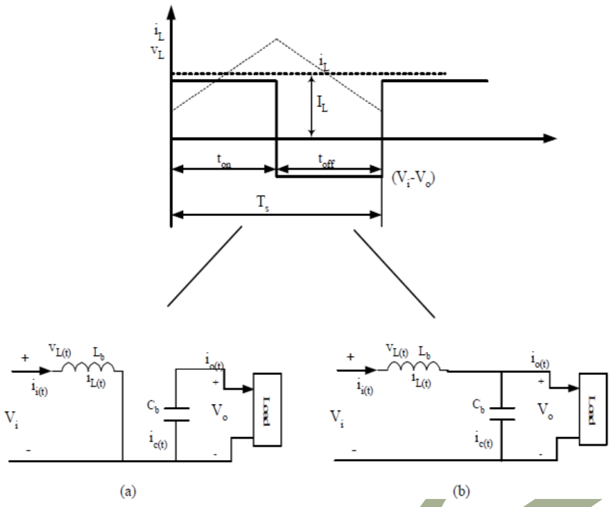


Figure 2.2: Equivalent circuit for Boost converter in CCM

2.2.1 Two Modes of Operation and Design

Boost converter may slip into the discontinuous conduction mode at low load. This situation occurs when the current are near to zero. At that time, the capacitor tries to reverse i_L and "back feed" the inductor, but the diode prevents current reversal.

Thus the diode and switch open, until the switch closes again. All load power is provided by the capacitor. Once discontinuous, the voltage across the inductor is zero, which is shown in fig.2.3.

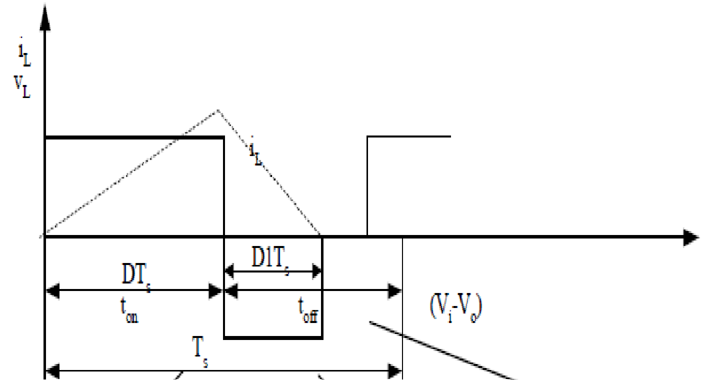


Figure 2.3: Waveforms for discontinuous conduction mode

A basic Boost DC-DC converter is shown in Figure 2.1. If the converter works in CCM, the relationship between the input voltage and the output voltage is given as follows

$$V_i T_{on} + (V_i - V_o) T_{off} = 0 \quad (1)$$

$$V_o = \frac{V_i}{1-D} \quad (2)$$

Where,

$$D = \frac{Ton}{T} \quad - \textit{duty ratio of power switch}$$

Note that D < l, so $V_o > V_s$.

The boundary condition of CCM and DCM is

$$L_c = \frac{R_L d(1-D)^2}{2f} \quad (3)$$

Where L_c is the critical inductance of CCM and DCM, f is the switching frequency, R_L is load resistance. When $L>L_C$, the converter will be in CCM. Otherwise, it is in DCM.

If the Boost converter is in CCM and the inductance is large enough, the output voltage ripple is described by

$$V_{pp} = \frac{dTI_o}{C} = \frac{dV_o}{R_L Cf} = \frac{V_o - V_i}{R_L Cf} \quad (4)$$

From figure 3.1, we can find out that we can't isolate the energy from the input in case of a short-circuit occurring in the output. In another word, even if S is turned off by the protection circuit, much energy will still be transferred from the input power supply to the output. Obviously, the basic converter can't meet the requirement of intrinsic safety. Thus we must improve it.

2.3 Series Resonant Parallel Loaded Inverter

Series Resonant Parallel Loaded Inverter is a Combination of two resonant inverters. They are:

1. Series Loaded Resonant Inverter
2. Parallel Loaded Resonant

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2.3.1 Series Loaded Resonant Inverter

In this Series Loaded Resonant Inverter, the storage elements inductor and capacitor are connected in series with the load as shown below in fig.2.4

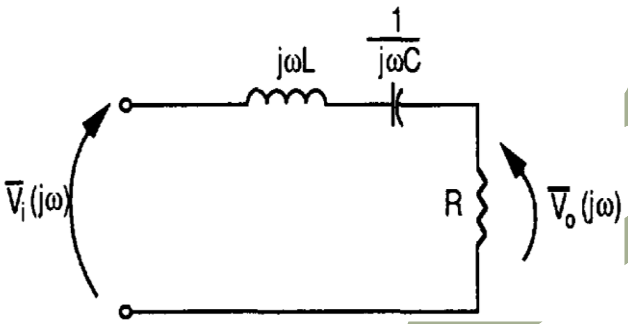

Fig 2.4: Series Loaded Resonant Inverter Topology

The transfer function for this topology in frequency domain is given as

$$\left|\frac{\overline{Vo(j\omega)}}{\overline{Vi(j\omega)}}\right| = \frac{1}{\sqrt{1+Q^2\left(\frac{\omega}{\omega o}-\frac{\omega o}{\omega}\right)^2}} \quad (2.1)$$

Where $\omega_o = 1/\sqrt{LC}$ and $Q = \omega oL/R$ The frequency characteristics for this transfer function are plotted in Figure 2.7 (a). And the ω_o is the resonance frequency and Q is the Quality factor. The next circuit to be studied is the PLR topology where the load is connected in parallel with the capacitor as shown in Figure 2.5

2.3.2 Parallel Loaded Resonant Inverter

In this Parallel Loaded Resonant Inverter the load is connected in parallel with the capacitor as shown below.

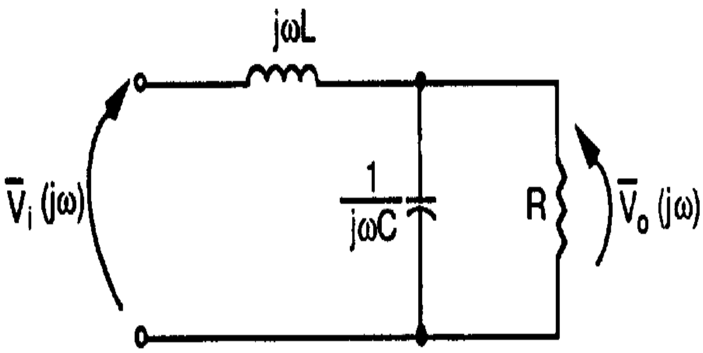

Figure 2.5: Parallel Loaded Inverter Topology

The transfer function is

$$|(\overline{Vo(j\omega)})/(\overline{Vi(j\omega)})| = \frac{1}{\sqrt{(1-(\frac{\omega}{\omega o})^2)^2+(\frac{\omega}{\omega oQ})^2}} \quad (2.2)$$

Where $\omega_o = 1/\sqrt{LC}$ and $Q = R/\omega_o L$. The frequency characteristics for this transfer function are plotted in Figure 2.7 (b). And ω_o is the Resonance Frequency and Q is the Quality Factor. The SPLR topology is a combination of the previous two and is shown in Figure 2.6

2.3.3 Series Resonant Parallel Loaded Resonant Inverter

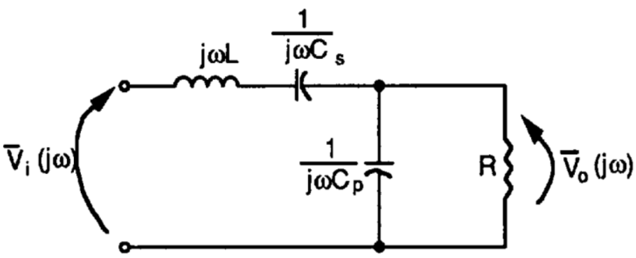

Figure 2.6: Series Resonance Parallel Loaded Resonant Inverter Topology

The transfer function for **Cs=Cp** is

$$\left|\frac{(\overline{Vo}(j\omega)}{(\overline{Vi}(j\omega)}\right| = \frac{1}{\sqrt{(2-(\frac{\omega}{\omega_s}))^2+Q_s^2\left(\frac{\omega}{\omega_s}-\frac{\omega_s}{\omega}\right)^2}} \quad (2.3)$$

Where $\omega_s = \frac{1}{\sqrt{LCs}}$ and $Q_s = \omega sL/R$, the frequency characteristics for this transfer function are plotted in Figure 2.7 (c). Examination of the three transfer functions in Figures 2.7a-c indicates that all of the topologies are frequency selective. Note that the SLR and

SPLR inverters are band-pass filters. If the input voltage in Figures 1 and 3 is a square wave whose frequency falls in the pass band of the filter, the harmonics of the square wave will be greatly attenuated and an approximate analysis can be made using only the fundamental component. In comparison to the SLR and SPLR inverters, the PLR inverter is a low-pass filter. An approximate analysis using the fundamental component only may be performed for this circuit if the frequency of the input square wave is close to ω_o. As a result, these transfer functions may be utilized to determine the steady-state characteristics of each inverter when excited by a square wave whose frequency falls in the range discussed above. *As* stated previously, the HPS lamp will be modelled as an equivalent resistance for high frequency excitation. Each of the transfer functions was derived with a resistive load. Before ionization, a large resistance would be used in each of the circuits in Figures 1-3**.** High lamp voltage is needed to cause ionization. After lamp voltage decreases to a value much lower than the starting voltage. Considering these lamp characteristics, the inverter should be load dependent for a constant operating frequency, providing high output voltage for large resistances and low output voltage for small resistances. The curves plotted in Figures 4a-c. are not valid during lamp starting; however, they may be used to gain insight into the operation of each inverter when driving a load such as a HPS lamp.

As a component in electronic ballast for a HPS lamp, each inverter must be capable of producing a high voltage to ionize the lamp and then a low voltage after the lamp starts. Examination of Figure 2.7 (a) indicates that the gain of the SLR inverter is always less than or equal to one. This inverter could be used with the HPS lamp if its input voltage is greater than the starting voltage of the lamp. Operation from input voltages such as those obtained from 120V AC will require a transformer to produce the necessary voltage for starting.

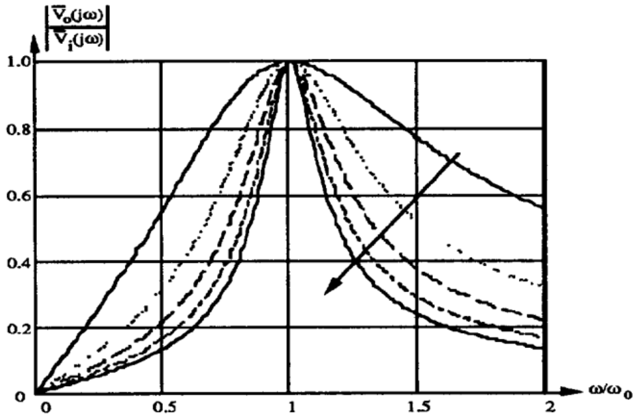

Figure 2.7(a): Frequency characteristics of the SLR inverter topology. Family of Curves for Q = 1-5. Arrow points in the direction of increasing Q.

Figure 2.7(b) shows the transfer function for the PLR inverter. As seen in this figure, both voltage gain and reduction are possible with this circuit. Large voltage gains are possible near ω_o in fact,

$$|Vo/Vi|_{\omega=\omega_o} = Q \qquad (2.4)$$

Since Q is directly proportional to R for this circuit, it offers high output voltages for high resistances and low output voltages for low resistances. The PLR inverter offers the voltage gain necessary when the lamp is starting (large resistance) and a considerably lower Voltage when the lamp is ionized (small resistance). As a result, a transformer is not needed when the PLR inverter is supplied from a relatively low voltage dc source such as that obtained from a rectified 12V AC line. One disadvantage of the PLR inverter compared to the SLR inverter is that its input current is higher than the load current because the capacitor is connected in parallel with the lamp.

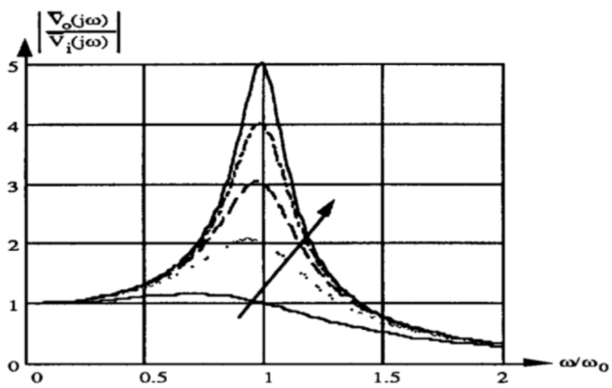

Figure 2.7 (b): Frequency characteristics of the PLR inverter topology. Family of Curves for Q = 1-5. Arrow points in the direction of increasing Q.

The frequency characteristics of the SRPL inverter for Cs = Cp are given in Figure 2.7 (c). Note that this circuit resembles the PLR inverter at light load and the SLR inverter at heavy load. If the ratio Cs/Cp is large, these characteristics will resemble that of the SLR inverter.

The characteristics will shift towards that of the PLR inverter if this ratio is very small. Even though voltage gains greater than one are possible with this inverter, it may not provide enough open circuit voltage for starting the lamp without using a step-up transformer.

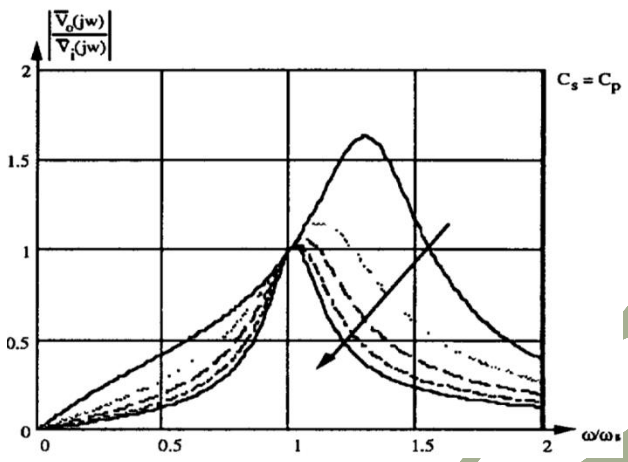

Figure 2.7 (c): Frequency characteristics of the SPLR inverter topology, Family of Curves for Qs = 1-5. Arrow points in the direction of increasing Qs

2.5 Summary

We have seen the detailed explanation of various stages of the Unity Power Factor Electronic Ballast i.e., Diode Bridge Rectifier, Boost Converter and Series Resonant Parallel Loaded Inverter and the design equations of the various parameters of the unity power factor Electronic Ballast were also derived.

3. SIMULATION ANALYSIS

3.1 Designed values of UPF Electronic Ballast

The designed values of Boost converter and Resonant Inverter are given for an input voltage of 110V rms.

Design of Boost Converter Paramaeters : Boost Inductor Lboost -5.676mH

:
Capacitor Filter Cdc1 - 30nF

:
Capacitor Cdc -22microF

Design of Resonant Inverter Parameters : Capacitor Cs -68nF

:
Inductor Lr -2.615mH

: Rlamp -605ohms

:
Capacitor Cp -4.7nanoF

Design of Feedbak Controller : Frequency of the repetitive Sequence 50kH

: Proportional Controller(kp) – 0.0028

: Integral Controller (Ki) – 0.038

3.3 Simulation Results

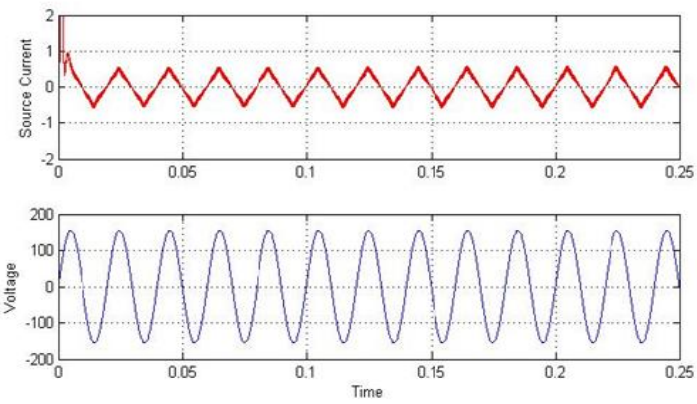

Figure 3.2: Input Current and voltage at Source Voltage 110V

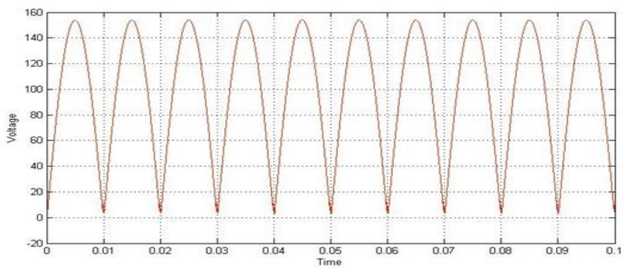

Figure 3.3: DBR Output Voltage at Source Voltage 110V

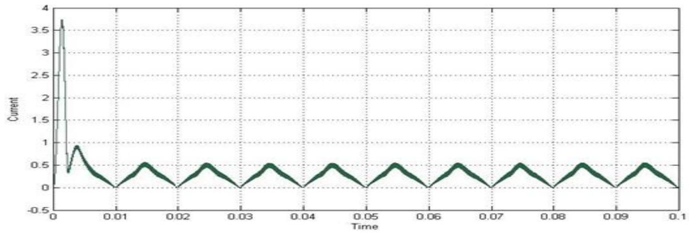

Figure 3.4: Boost Inductor Current Waveform which ensures DCM Operation

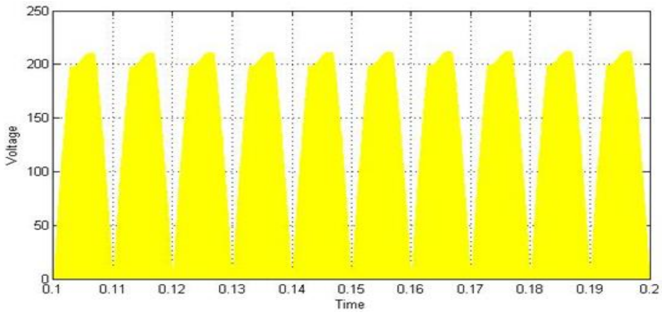

Figure 3.5: Voltage waveform across the switch S1 in the boost converter

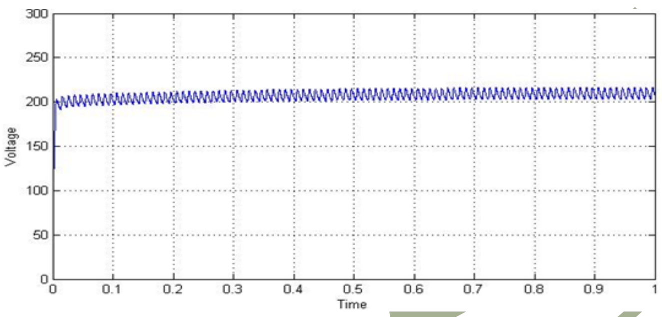

Figure 3.6: Output Voltage waveform of the Boost Converter

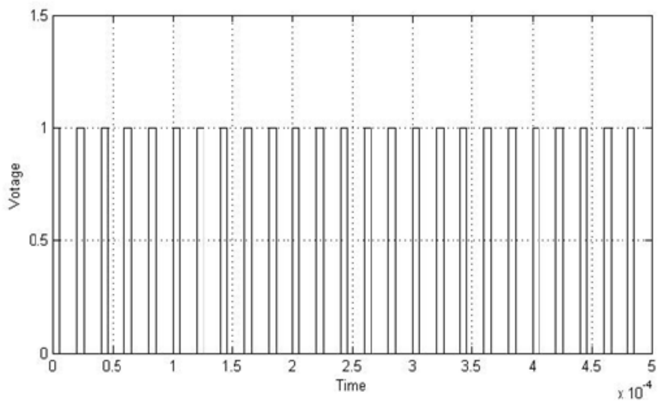

Figure 3.7: Pulses to Switch S1 in the Boost Converter

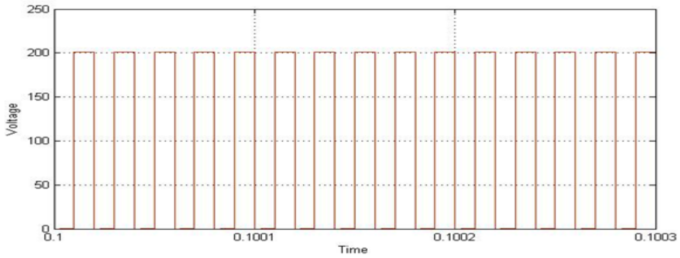

Figure 3.8: Steady state Voltage Across switch M1 in the Inverter

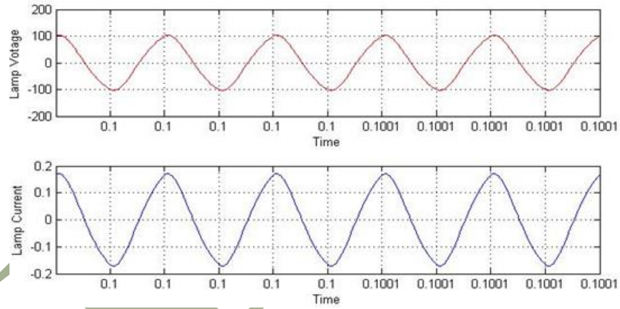

Figure 3.9: High Frequency SRPLI output voltage and Current waveforms.

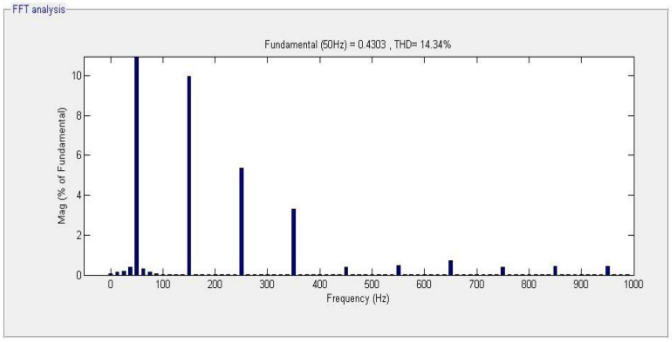

Figure 3.10: Total Harmonic Distortion of Input Current

3.4 Summary

The input AC voltage of 110V is converted into DC by using Diode Bridge Rectifier. The output of the Diode Bridge Rectifier is given to Boost converter, the boosted output is given to the Series Resonance Parallel Loaded Inverter which is in turn connected to load. Thus Unity Power Factor Electronic Ballast is designed successfully with MATLAB Simulink software with input power factor nearly equal to unity which is shown in the input current and voltage waveforms have zero crossings at the same time and Total Harmonic Distortion of input current is 14.34% which are the two indices to study the behaviour of the UPF Electronic Ballast

4. CONCLUSION

A UPF boost converter based HF electronic ballast is developed with improved power quality for ac main voltage. The electronic ballast with PFC boost converter has shown high performance such as nearly Unity Power Factor. The dc link voltage has been maintained constant, which realizes the constant lamp power irrespective of the changes in the load, with an appropriate design of PFC boost converter and resonant inverter parameters, the lamp current has been maintained sinusoidal and close to the rated value. The developed electronic ballast has THD of ac mains current under 14.34%. The zero voltage switching (ZVS) has confirmed because switching frequency has maintained more than the resonance frequency of the resonant inverter, which reduces the switching losses and improves the efficiency of electronic ballast.

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