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# Electronic Ballast Design for Fluorescent Lamps with High Power Factor

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**Abstract**

Fluorescent lamps are used as one of the most important sources of light in residential and commercial applications. A method to increase the power factor in electronic ballasts is proposed in this paper. For the power factor correction circuit, the amplification-based switching method is used, which increases the power factor and provides the DC voltage for starting the half-bridge inverter circuit. Finally, the laboratory sample of the circuit is made at a voltage of 110 V with a power factor of 0.996. This circuit has an efficiency of 94.7% and a total harmonic distortion less than 5%. In addition, the pressure on the lamp at the moment of commissioning is reduced, which increases the life of the lamp.

**Keywords:** Power Factor, Total Harmonic Distortion, Fluorescent Lamp.

## 1. INTRODUCTION

Energy consumption and the growing need for it, has led to the use of different types of energy such as wind, solar, water, nuclear, and so on [1,2]. Therefore, various studies have been conducted in the field of energy consumption and production or protection of energy systems [3,4].

The purpose of energy production is to meet the needs of consumers and industrial centers. One of the needs of homes and factories is lighting.

With the advent of electricity in everyday life, the most important and first application

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for electricity in domestic and industrial applications was the conversion of this energy into light [5,6].

The invention of incandescent lamps has long been able to meet this need. With the increasing use of electricity, the use of incandescent lamps was questioned due to their extremely low efficiency, as these lamps converted most of the received electrical energy into heat and invisible spectra. The efficiency of these lamps improved with the change of filament alloy was still less than ten percent at best, so the use of lamps called gas lamps was on the agenda. There are different types of gas lamps, but what they all have in common is that they cannot be connected directly to the mains due to their negative resistance [7,8].

So far, various studies have been conducted on the application and effect of fluorescent lamps [9,10]. A special type of these lamps called fluorescent lamps, which usually use mercury vapor as a base gas, have been used for many years in domestic and industrial lighting. Initially, the problem of negative resistance was solved by serializing an inductor with a lamp. These modulating circuits are commonly known as ballasts. The inductor called choke, transformer, or ballast is still used in some applications.

To run gas lamps, it is not necessary to ballast because of the negative resistance. Fluorescent mercury vapor lamps, which play an important role in lighting today, were initially driven by a magnetic ballast, but with the advancement of electronic ballast technology, they replaced their magnetic counterpart, which, while increasing the lamp life and efficiency, caused problems such as noise. Reduced audio [11,12]. Nowadays, increasing efficiency, increasing power factor, and decreasing harmonic distortion rate in electronic ballasts is very necessary and important due to their widespread use [13,14].

In ballast circuits, THD decrease and PF increase are the most important parameters for design [15,16]. For ballast to correct the power factor by switching, the best method is to use the boost method [17,18]. Because in addition to increasing the PF, it helps to increase the DC voltage of the circuit, so that there are fewer losses in the inverter and the efficiency of the circuit is increased. One of the disadvantages of a boost circuit is that it is not used at high powers, but in a ballast circuit of about 100 watts, the best way is to use a boost [19,20].

After increasing the output voltage and correcting the power factor, the lamp should be ionized and turned on with the help of a suitable inverter. Among the most used inverters reviewed, the constant power controller of the DC-AC electronic ballast inverter is outstanding [21]. Other commonly used inverters that are considered in ballast circuits are resonant inverters for electronic ballast applications [22]. Resonance structures have also been proposed in this direction, especially structures with the bootstrap technique. In order to have a suitable driver for different ballasts, we often refer to Analysis, selection, and design of resonant inverters for electronic ballasts [23]. In the proper ballast, two important parameters must be covered simultaneously which are having the ability to correct the power factor and increase the efficiency, and feeding the lamp with the least harmful harmonic effects using a suitable inverter.

The purpose of the proposed circuit is to increase the power factor in electronic ballasts. This request has been fulfilled with a half-bridge inverter that is designed to be fully compatible with a particular type of fluorescent lamp, which greatly increases lamp life using the preheating method. Boost-based switching method is used for power factor correction circuit. This method, while increasing the power factor, provides high DC voltage, which is very suitable for starting the half-bridge inverter circuit, and this increase in voltage helps to increase the efficiency.

In this paper, an electronic ballast is proposed. It is clear that in this paper, no programmable element is used. It should be known that the part related to the preheat needs two different working frequencies in each cycle of its operation. In the proposed structure, L6561 [34] and L6569 [35] are used as drive ICs of the proposed structures in the boost section and the inverter section. The way of discussing the preheating of filaments and the technique of creating the appropriate preheating frequency and working frequency which are completely different from the passive elements are specific to this topology.

In this topology, two ICs are used to drive the switches used both in the boost converter section and in the half bridge inverter section. Corrected power factor in circuits with boost topology. L6561 is used to drive the boost converter and control some basic output parameters. The output voltage suitable for powering the lamp is not created by the boost converter. Based on this, an inverter should be used to properly feed the lamp. This inverter will act as an intermediate circuit between the load and the power factor correction section. In this part of the proposed structure, L6569 IC is used to drive and control the inverter.

This topology well fulfills the two main demands of correcting the power factor and suitable voltage to drive the lamp. For this purpose, L6561 [34] is used for power factor correction and L6569 [35] for lamp drive. The PSPICE software was used for simulation. It can provide specialized services such as preheating, lamp detection, and variable frequency generation. Finally, the laboratory sample of the circuit is made. Figures 1 and 2 are used as proposed structures based on the suggested circuits of ICs. This circuit at a voltage of 110 V with a power factor of 0.996, has an efficiency of 94.7% and a total harmonic distortion less than 5%. It also increases the life of the lamp by reducing the pressure on the lamp at the moment of commissioning.

## 2. CORRECTION OF POWER FACTOR IN ELECTRONIC BALLAST OF FLUORESCENT LAMPS

### 2.1. Power Factor Correction Circuit

The circuits that show inductive characteristics, or have an inductive load, consume reactive power due to the phase difference between the voltage and the input current. By consuming reactive power, additional pressure is applied to the network, causing problems such as distortion in the network voltage waveform, increase in harmonic in the network, overheating of transformers, a high ripple in the torque applied to the generator, and creating annoying electromagnetic noise in systems

[24,25]. Telecommunications and processing systems are given. Therefore, passive filters or active filters are used to synchronize the voltage and current consumption of the circuit to correct the power factor [26,27]. Passive power factor correction structures have a simple implementation, but it is still far from the desired optimal performance.

### 2.2. Power Factor Correction in Electronic Ballasts

Fluorescent lamps cannot be connected directly to the power line, because these lamps need a higher voltage than the line voltage to ionize the mercury vapor in their tube [28,29].

An electrical ballast is a device placed in series with a load to limit the amount of current in an electrical circuit [30].

Passive or active methods are used to improve the power factor in ballast. Usually, in active filters, the basis of work is switching. Switches at the input and storage elements such as inductors and capacitors increase the power factor.

Different circuits are used to correct the power factor, such as cascade dc/dc fly-back converter [31], single switch/single stage [32], and boost-type single-stage step-down resonant [33]. In ballasts, correcting the power factor, especially with active techniques, in addition to improving the efficiency, productivity, and lifespan of the circuit helps to reduce harmful harmonics to a great extent. Such methods have significantly increased the life of films and lamp efficiency.

## 3. BOOST CIRCUIT SWITCHING MODEL

In general, the use of a switch at the input after the rectifier leads to a high power factor, but the use of a boost circuit is much more common. There are three methods for the switching model in the boost circuit:

1) PWM constant frequency model for average current control, the implementation of this method is very complicated and requires high calculations to build a sinusoidal model to implement PWM. In this

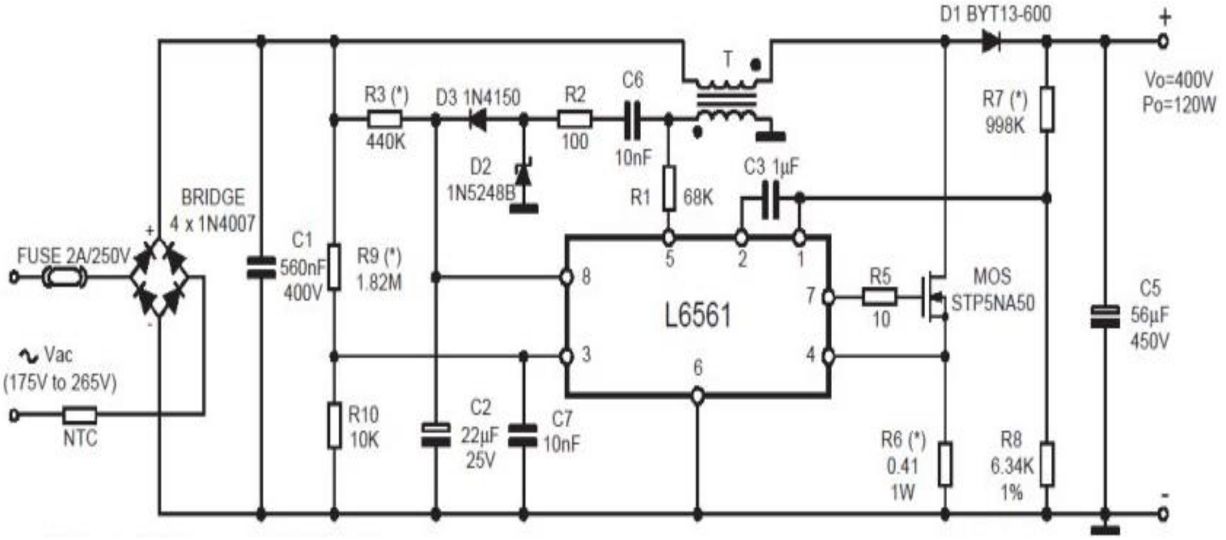

*Fig. 1. Power factor correction proposed circuit [34]*

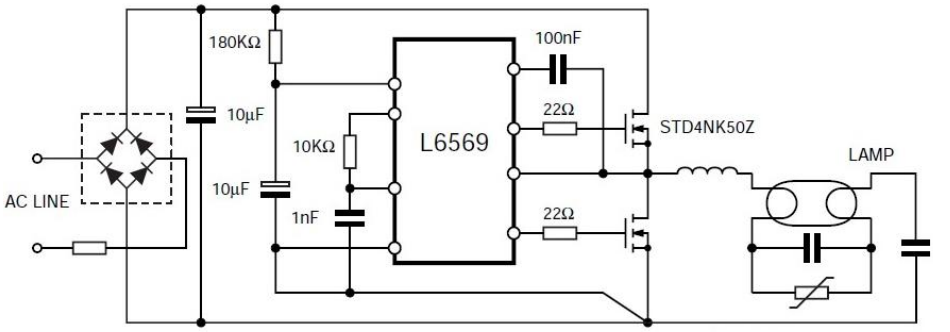

***Fig. 2. Proposed output inverter drive circuit [35].***

model, the period of each constant wave is set by changes in the average current duty ratio anywhere in the voltage cycle.

2) PWM transmission model, including the constant light time, this model is much simpler and its implementation is cheap and requires few accessories.

3) Using the current peak with a fixed shutdown time, this method is also simple to implement and requires an RC timer to provide the shutdown time.

However, whichever of the above methods is used, the result is almost the same. Based on the type of application, one of the above methods should be selected.

Another suitable IC for improving the power factor is L6561. This IC can provide our desired PFC using a boost switching circuit drive. Fig (1) shows the proposed power factor correction topology.

Also, with a suitable bias and a simple design, this IC can easily detect overvoltage in the boost circuit and apply a suitable protection.

The current consumption of this IC is extremely low and it has a voltage reference with an error of 1% for its internal circuits. Other advantages of this IC include the presence of a start timer for stability in the DC line at a clear moment, as well as the presence of a work transfer mode (soft start). The output of the gate driver, the powerful totem bridge of this IC can deliver up to 400 mA output without changing the square wave shape, which makes it suitable for driving power MOSFETs without additional circuitry.

In fluorescent lamps, due to the presence of gas in the lamp tube and the need to ionize this gas to start lighting the lamp, the need for a suitable design is felt. This design should be such that the filaments are heated at the moment of starting so that the highest voltage can be applied for ionization around the lamp with the least pressure on the circuit. The act of heating films before ionization is called preheating. Fig (2) shows the proposed topology of the driver with the bootstrap technique. Preheating the lamp has many advantages, which can be mentioned as follows:

1) increasing the life of the lamp,

2) reducing the possibility of creating dark rings along the tube due to an incomplete ionization process when the lamp is cold,

3) reducing the pressure on the circuit to apply ionization due to reducing the voltage required for ionization;

**Table 1.** ***Design parameters.***

| **Parameters** | **Symbol** |
|---|---|
| Main voltage range | $V_{irms}^{\min} - V_{irms}^{\max}$ |
| Output regulated DC voltage | $V_O$ |
| Output power | $P_O$ |
| Minimum switching frequency | $f_{sw}$ |
| Maximum output voltage ripple | $\Delta V_O$ |
| Maximum conduction time overvoltage | $\Delta V_{OVP}$ |
| Efficiency | η |
| Input power | $P_{in} = \frac{P_O}{\eta}$ |
| Maximum main effective current | $I_{rms} = \frac{P_i}{V_{irms}^{\min}}$ |
| Output current | $I_O = \frac{P_O}{V_O}$ |

It has been investigated so far and the main goal of the proposed topologies is to correct the power factor with a boost converter and then feed the lamp with the help of a half-bridge inverter in which the bootstrap technique is used to drive one of the switches.

## 4. CIRCUIT DESIGN

The design parameters of the circuit are given in table 1. The maximum voltage ripple frequency should be between 1 and 10% of the input voltage. So assuming that 001>r>0.01, we will have:

$$C_{in} = \frac{I_{rms}}{2\pi \times f_{sw} \times r \times V_{irms\,(\min)}} \tag{1}$$

Enlarging this capacitor is to reduce ripple and helps to filter harmonics, but due to the drastic reduction of power factor and input current harmonics, it cannot be considered too large.

The output capacitor ($C_O$) is used on the output DC voltage to provide the output power of the overvoltage part of the guide and reduce the voltage ripple.

The two main frequencies are 100Hz and 120Hz with voltage ripple $\Delta V_o$=12.

$$\Delta V_O = I_O \times \sqrt{\left(\frac{1}{(2\pi \times 2 f_{sw} \times C_O}\right) + (ESR)^2} \tag{2}$$

$$I_O = I_C^{f\ \max} \tag{3}$$

$$C_o \geq \frac{I_o}{4\pi \times F_{sw} \times \Delta V_o} = \frac{P_o}{4\pi \times f_{sw} \times V_o \times \Delta V_o} \tag{4}$$

The acceptable range of $\Delta V_o$ is usually about 5% of the output voltage.

$$I_{crms} = \sqrt{\frac{32\sqrt{2}}{9\pi} \times I_{rms}^2 \times \frac{V_{rims}}{V_o} - I_o^2} \tag{5}$$

$$C_O = \frac{2P_O \times t_{Hold}}{V_{O\min}^2 - V_{OP\min}^2} \tag{6}$$

where $t_{Hold}$ is the desired time. $V_{O\min}$ is the minimum value of the output voltage and $V_{OP\min}$ is the minimum voltage before the PFC detects that the maximum power has been reached and shuts down the circuit.

$$T_{on} = \frac{L \times I_{LPK} \times \sin\theta}{\sqrt{2}V_{irms} \sin\theta} = \frac{L \times I_{LPK}}{\sqrt{2}V_{irms}} \tag{7}$$

$$T_{off} = \frac{L \times I_{LPK} \times \sin\theta}{V_O - \sqrt{2}V_{irms}\sin\theta} = \frac{L \times I_{LPK}}{V_O - \sqrt{2}V_{irms}} \tag{8}$$

$$F_{sw}(\theta) = \frac{1}{T_{ON} + T_{Off}} = \frac{1}{2L \times P} \times \frac{V_{irms}^{2}(V_o - \sqrt{2}V_{irms}\sin\theta)}{V_O} \tag{9}$$

$$L = \frac{V_{irms}^{2}(V_O - \sqrt{2}V_{irms}}{2f_{sw}^{\min} \times P_i \times V_i} \tag{10}$$

Given that the flux density in the core and the air gap are equal, and according to Ampere's law, we will have:

$$\Delta B = \mu_o \Delta H_{gap} \tag{11}$$

$$NI_{LPK} = L_{gap}\Delta H_{gap} \tag{12}$$

According to this relationship and the energy balance relationship [34,35]:

$$L \approx \mu_0 \frac{N^2 \times A_e}{L_{gap}} \approx \sqrt{\frac{L \times L_{gap}}{\mu_0 \times A_e}} \tag{13}$$

$$L = \frac{V_{irms}^{2}(V_O - \sqrt{2}V_{irms}}{2f_{sw}^{\min} \times P_i \times V_i} = \frac{220^2 \times (400 - \sqrt{2} \times 220}{2 \times 35 \times 10^3 \times 80 \times 400} = 1.12\,mH \tag{14}$$

$$C_{in} = \frac{I_{rms}}{2\pi \times f_{sw} \times r \times V_{\min}^{irms}} = \frac{250 \times 10^{-3}}{2\pi \times 35 \times 10^3 \times 0.01 \times 220} = 1\mu F \tag{15}$$

$$PF = \frac{AVG(P_{in})}{V_{rms} \times I_{rms}} = \frac{85.2}{110 \times 0.784} = 0.98 \tag{16}$$

$$PF = \frac{AVG(P_{in})}{V_{rms} \times I_{rms}} = \frac{85.2}{110 \times 0.778} = 0.996 \tag{17}$$

$$THD = \sqrt{\left((\frac{I_{rms}}{I_{1rms}})^2 - 1\right)} \times 100 = \sqrt{\left((\frac{0.778}{0.777})^2 - 1\right)} \times 100 = 5\% \tag{18}$$

$$\eta = \frac{AVG(P_2)}{AVG(P_1)} \times 100 = \frac{80.7}{85.2} \times 100 = 94.7\% \tag{19}$$

It can be seen that efficiency is defined as the ratio of output power to input power. As shown in (19), the efficiency of the proposed topology is 94.7% in the useful power of 80 watts. THD is defined as the ratio of the effective current to the first harmonic. THD, which is a very important parameter in ballasts, is in a suitable range. It is well shown in (18) that the THD is about 5%, which is within the acceptable range according to the relevant standard tables.

## 5. SIMULATION RESULTS

In this section, the laboratory results are presented. The in-phase current and voltage indicate the improvement of the power factor. The results related to the effect of the proposed plan to improve the power factor are shown in graphs (3 and 4). Fig (3) is the simulation results confirming the improvement of the power factor. Fig (4) is the practical results confirming the improvement of the power factor.

Power factor correction can be seen when the circuit voltage and current have the same phase. This results in having the same phase as the voltage, current, and finally the circuit power. Fig. 5 shows the improvement of the power factor along with the waveform of the output power, which is in phase with the

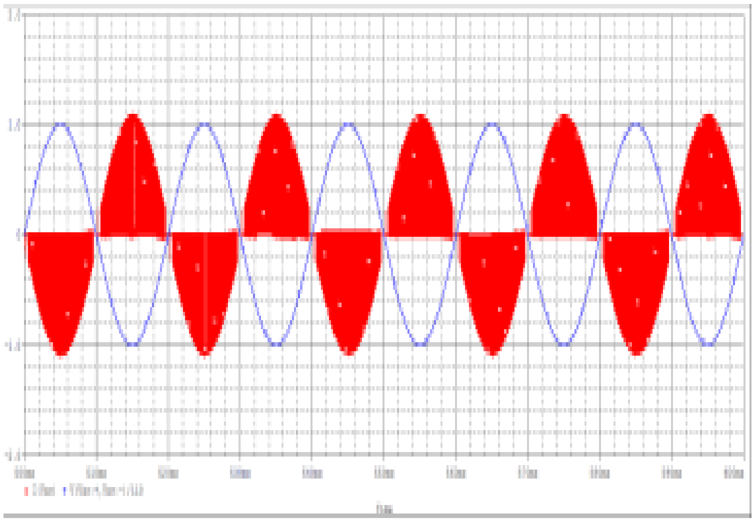

Fig. 3. Voltage-current diagram of the simulation of the proposed circuit.

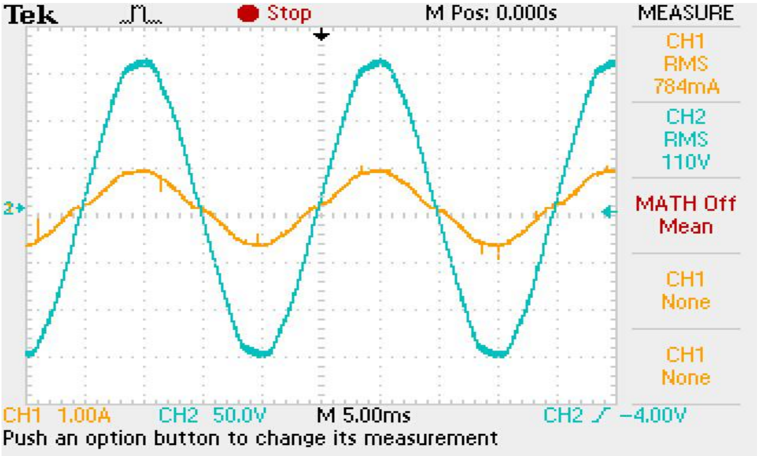

Fig. 4. Laboratory voltage-current diagram of the proposed circuit.

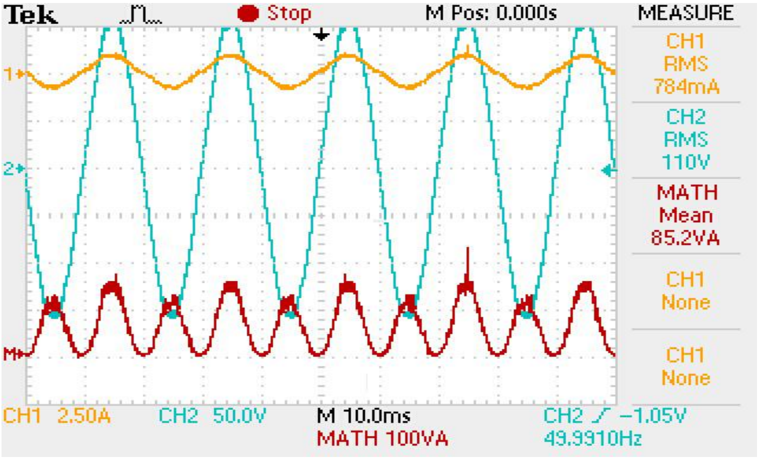

Fig. 5. Laboratory results show power factor correction.

*Fig. 6. Laboratory sample boost circuit.*

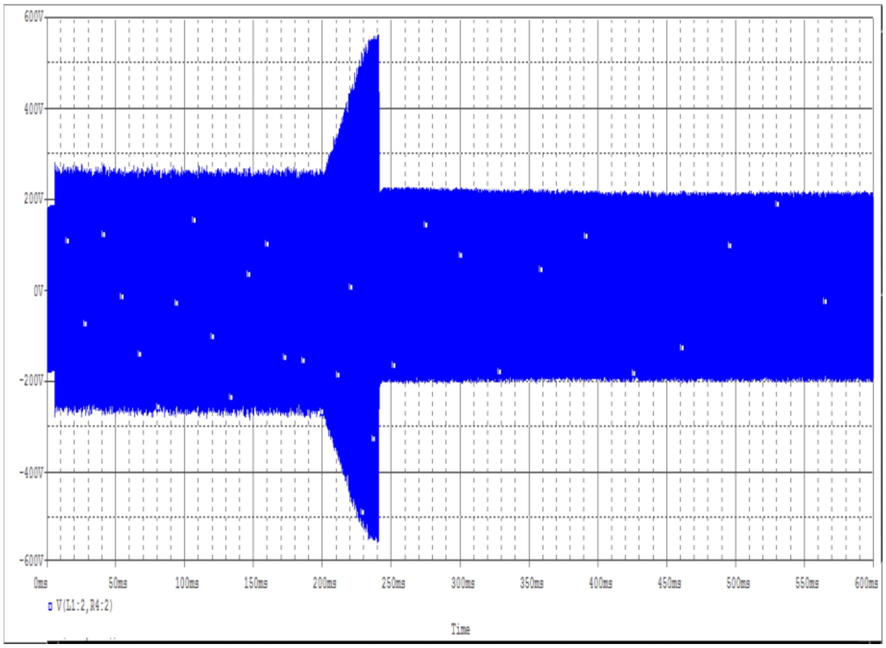

*Fig. 7. Ionization preheating simulation.*

voltage, fully guaranteeing the improvement of the power factor.

Shown in fig. 6 is a built laboratory sample of the power factor correction circuit.

Preheating is one of the most important factors in improving the performance of the lamp.

The frequency preheating proposed in this article greatly reduces the pressure on the main elements of the converter.

On the other hand, it increases the life of the lamp filaments. Preheating is done before the ionization of the lamp gas and reduces the current requirement.

Fig. 7 shows the preheating and ionization in the simulation and well confirmed in the practical results given in Fig. 8.

Fig. 9 shows the inverter with a preheater made in the laboratory.

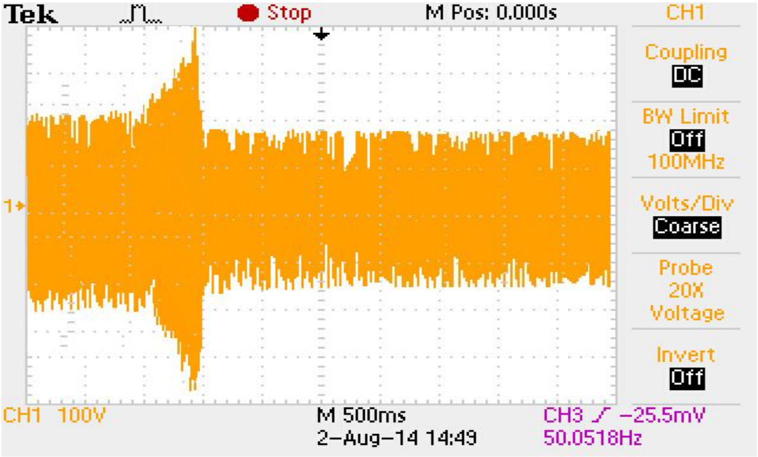

*Fig. 8. Laboratory ionization preheat.*

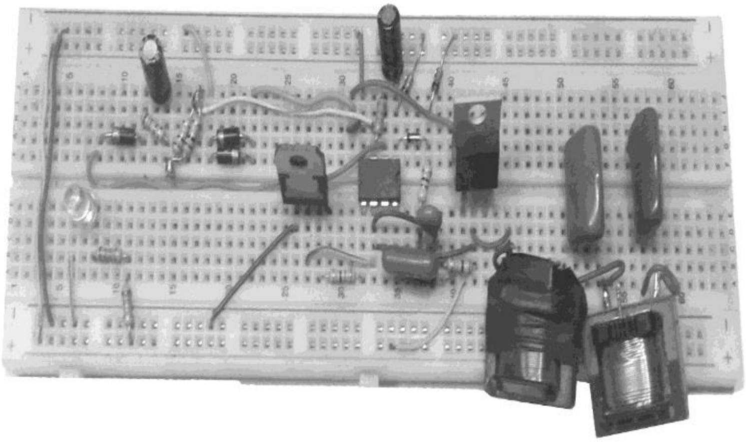

*Fig. 9. Laboratory sample structure of the proposed design.*

## 6. CONCLUTION

The use of a power factor corrector (PFC) in electronic ballasts is necessary to improve the power factor and eliminate harmonic distortion. In this paper, a method for increasing the power factor in electronic ballasts is presented, which is used for power factor correction circuit by amplification-based switching method. The advantages of the designed circuit are: (a) increase of PF by more than 99%, a very desirable limit, (b) increase of efficiency to more than 94% and optimization of the circuit for powers less than 100 watts, (c) reduction of THD to less from 5%, within the existing standards, and (d) cost reduction due to the lack of use of special and expensive elements or programmable devices and ICs.

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