

## A Comparative Study on Design and Operation of Fluorescent Lamps, CFLs and LEDs

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### ABSTRACT

Compact Fluorescent Lights (CFLs) and Light Emitting Diodes (LEDs) have risen to a great popularity in recent years due to outstanding features such as longevity and energy-efficient design. These bright, compact lights are usually designed to reduce the energy consumption without sacrificing light or productivity. In fact, manufacturers are now producing CFLs that are designed to fit into our existing light fixtures which eases the transition from traditional incandescent bulbs to more energy-efficient alternatives. Fluorescent Lamps practically emerged in 1934. During the past 80 years this lamp has undergone numerous changes in materials and design to ensure a leading position as the lamp offering the lowest total cost of ownership while producing a high quality white light.

This paper presents the design, working, operation, advantages and future use of the above technologies. It also compares the LED system with other technologies (CFL and Fluorescent lamps).

**Keywords-**Ballast, CFLs, LEDs, Fluorescent, Lumen

### I. INTRODUCTION

The Household lighting cost typically accounts for 10% of the electric bill. Changing the light bulbs effectively can reduce the long-term energy costs significantly. The popularity of the Fluorescent light can be judged by the fact that it accounts for a greater amount of light produced on our planet than any other light source. It secured this dominating position by the 1970s and today, it approximately accounts for about 80% of the world's artificial light. It is manufactured in almost any shade of white as well as coloured versions. It also has an advantage of a low system cost, its lifetime is very long, it is fully dimmable and is easy to use, and above all it achieves high luminous efficiencies to yield a low cost of operation. In 1980 its position was further strengthened by the introduction of the compact fluorescent lamp. The traditional incandescent bulbs [1] usually convert most of their energy into heat instead of light, leading to wastage of electricity on unnecessary warmth.

Compact fluorescent lights (CFLs) and light emitting diodes (LEDs) on the other hand, convert most of their energy into light [3]. Both CFLs and LEDs are designed to last longer than the average incandescent bulb, reducing both energy and replacement costs and increasing longevity. CFL and LED bulbs consume up to 80 percent less energy than their incandescent counterparts and they can last up to 25 times longer. Compact fluorescent light bulbs (CFLs) use up to 75 percent less energy than traditional incandescent bulbs and can last about six times longer [3]. But, over the years, consumers have started criticizing these energy-saving bulbs for many

reasons – starting from harsh light to humming noises to serious health concerns. But the CFL has been used for a long period since it was first introduced in the market. Keeping the following considerations in mind, a new way is to be developed to shrink those energy bills. [4]

The design and operation process is clearly explained in the next section with detailed information regarding the components which are used, followed by the advantages and applications leading to results and finally ends with conclusion.

### II. FLUORESCENT LAMPS

The fluorescent light bulb was first commercially introduced in 1939, however, it had been on a developed stage for over 80 years, and the idea of using fluorescence as one of the lighting source had existed for even longer. It is easy to understand the charm of fluorescence if taken as a light source. [5]

#### 2.1 LAMP CONSTRUCTION

The fluorescent tube is basically a low pressure mercury discharge lamp. At one end of the tube, there is an electrode coil, popularly known as the cathode, whose serves the purpose to inject a train of electrons right into the discharge space. To compensate its high operating temperature, it is usually made from coiled tungsten wire, and is particularly coated with various refractory oxides which increase its electron-emission efficiency. During its lifetime the electrode disintegrates followed by the end of blackening of the tube. To reduce the severity of blackening it is surrounded by

a metallic shield. This shield purposely serves to minimise the visible 100Hz flicker which appears in the vicinity of the electrodes when operated at ordinary main frequencies. The glass stem assembly is mounted beneath the whole electrode assembly, the rim of which is fused to the end of the discharge tube to produce a sealed vessel. The lamp accompanies a small quantity of mercury which is filled to a low pressure with an inert gas, typically argon or argon mixed with neon, krypton or xenon. The tube length along with diameter and the choice of gas filling plays a major role in determining the lamp's electrical properties. Additionally, a phosphor coating is applied to the internal surface with a metal cap at either end, provides the electrical and mechanical connection with the luminaire. An invisible silicone wax is used for coating the outer surface of the glass which helps in breaking up moisture filmed on lamps when employed in humid environments. This feature, though invisible, is indispensable in ensuring reliable and effective starting.

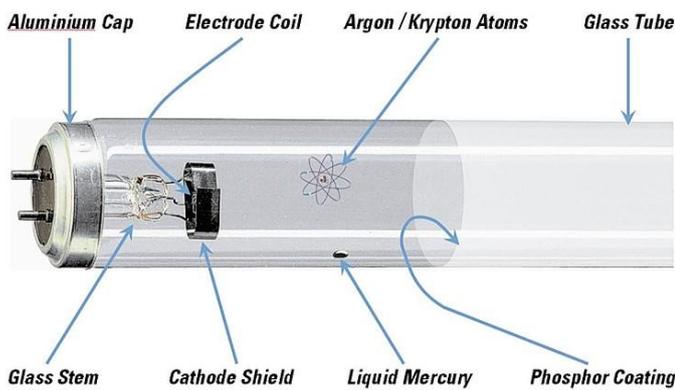


Fig 1 : Construction of a Fluorescent Lamp

## 2.2 OPERATING PRINCIPLE

The operating principle of the Fluorescent lamp has very early origin. In 1676, it was noted that a faint glow emanating from a mercury barometer when the instrument moved back and forth. After 40 years it was examined, that liquid mercury was rubbing against a glass which produces a static charge causing the mercury vapor to glow. This scientific reaction is the basis of the operation of modern fluorescent lighting. A fluorescent lamp does not have any filament running through it. Instead, cathodes at each end throw current through mercury vapors sealed in the tube. Then, the Ultraviolet radiation is produced as electrons from the cathodes and they knock the mercury electrons out of their natural orbit. Some of the displaced electrons settling back into orbit throws off the excess energy absorbed in the collision, resulting in the form of ultraviolet radiation. The principle can be broadly understood with the help of the following circuits;

### 2.2.1 PREHEAT FIXTURES

The original preheater circuit usually have a starter. When the starter switch is turned off, the

current starts running and heats the cathode, resulting in the establishment of arc and the switch gets opened. The most pivotal part of a fluorescent fixture is the ballast. It is the Ballast through which the Electrical current enters the fixture. From here, it flows through wiring to lamp holders, and finally, to cathodes within the tube. The current through the cathodes heat the coated filaments and send the high voltage pulse along the tube through the mercury vapour. Now, the atmosphere inside the tube heats up which increases the electron activity efficiently and the mercury vapor carries the current on its own. The starting circuit is controlled by a starter switch that opens after a short preheat period.

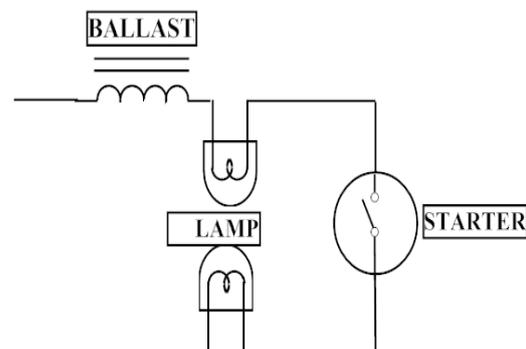


Fig : Preheat Circuit

### 2.2.2 INSTANT START LAMPS

This circuit requires no starter switch. It just uses a special Ballast that supplies enough energy to start and maintain the electric arc through the tube. Both the Instant-Start and the Rapid-Start methods are merely the adjustments to improve reliability and minimise maintenance.

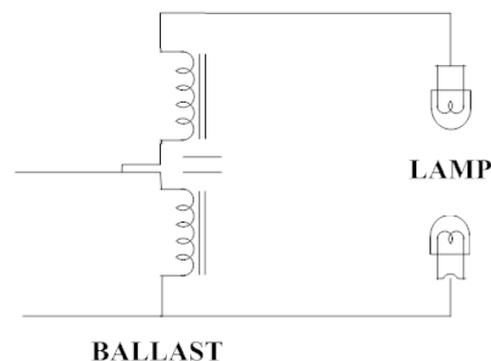


Fig 2 : Instant-Start Circuit

Instant-Start circuits have ballasts with continuous output which is high enough to strike an arc instantly. Since, there is no preheating, Instant-Start tubes requires only one pin at each end. While some Instant-Start tubes do have bi-pin bases but the pins are joined at the base. In this case, they're merely structural and not electrically feasible.

### 2.2.3 RAPID START LAMPS

This type of fixture is similar to a Pre-heater type, but has a smaller starter. Ballast has separate windings which heats the cathodes to start the electric arc. Modern Rapid-Start fixtures are also designed without starters, though they are true bi-pin/preheat fixtures. They contain smaller, more efficient ballasts having built-in heating windings, used to preheat the cathodes for quick starting purposes.

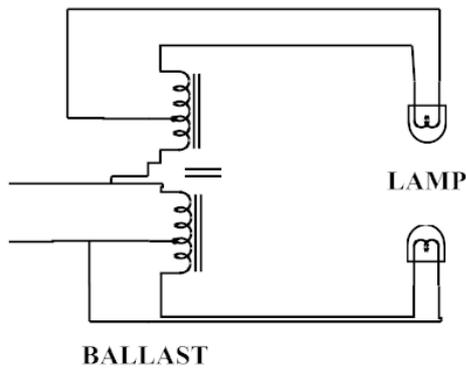


Fig 3 : Rapid-Start Circuit

### 2.3 ADVANTAGES

- It has very high luminous efficiency.
- Colour rendering is excellent.
- Cost is Low and control gear is simple.
- Long lifetime and product durability is high.
- Has even and glare free light distribution.
- Capability of producing any shade of white.
- Its is dimmable with special ballasts.

### 2.4 DISADVANTAGES

- Highly toxic Mercury vapour is of high concern.
- Reduction in light output in cold areas.
- Reduction in light output in hotter luminaries.
- Difficult in handling due to it's length.
- Sensitivity to ambient temperatures.
- Lumen output keeps on decreasing through lifetime.

### 2.5 APPLICATIONS

Fluorescent lamps are eminent for using less electricity and cutting down the mercury that is emitted from power plants. Reducing mercury emissions from power plants is very important. By using and then recycling fluorescent lamps is very pivotal in keeping mercury out of our environment. Due to large physical size, surface luminance is low and it gives rise to glare. It also produces highly uniform and shadow-free illumination. Exterior applications are relatively scarce due to its low luminous flux and due to the fact that its luminous flux decreases sharply at low ambient temperatures.

## III. COMPACT FLUORESCENT LAMP

As a best alternative for light bulb, CFL bulbs are an excellent option. CFLs are a miniature version of the common fluorescent light, glowing phosphor gas by using an electric current. Earlier the CFLs used magnetic ballasts which usually results into delay or flicker when turned on. Whereas, the most new CFLs use electronic ballasts. On comparing with incandescent bulbs, CFLs are approximately four times as efficient i.e. a 25 Watt CFL will have the same light output as a 100 Watt incandescent bulb. They also possess high longevity i.e. 10 times longer, meaning that the life of a standard CFL is comparable to 10 incandescent bulbs. But, a CFL gives off light that looks just like a standard incandescent. [6]



Fig 4 : Compact Fluorescent Lamp

### 3.1 LAMP CONSTRUCTION

Compact fluorescent lights (CFLs) are created by taking a traditional fluorescent tube and bending it into a compact design that fits easily into ordinary incandescent fixtures.

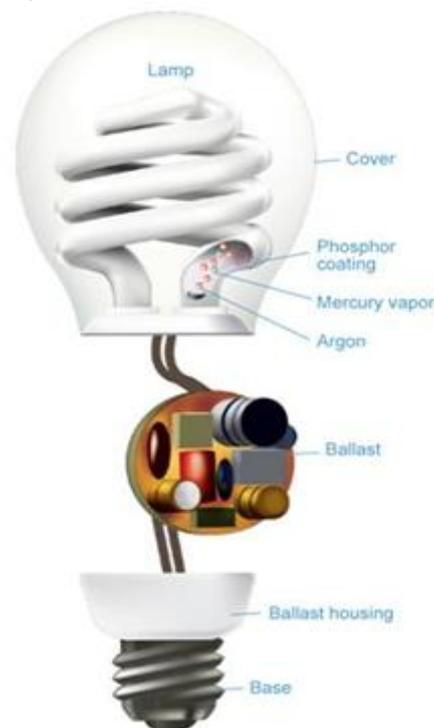


Fig 5 : A CFL Bulb

The most important technical advance has been the introduction of electronic ballasts in place of electromagnetic ballast. This technology has helped in removing most of the flickering and slow starting, considered to be the major flaws among the fluorescent lighting. The compact fluorescent lamp consists of a soda-lime glass tube filled with a few torr of gas basically argon and a drop of mercury. Metal electrodes are sealed at the tube ends and conduct electric current from the external circuit to the gas present internally. There are two main parts in a CFL :

- The gas-filled tube (bulb or burner)
- The electronic ballast

An electrical current from the ballast flows through the mercury vapor, emitting ultraviolet light. This ultraviolet light further excites a phosphor coating present inside the tube. This coating is responsible for emitting visible light. Electronic ballasts usually contain a small circuit board along with rectifiers, a filter capacitor and two switching transistors. These transistors are usually connected as a high-frequency resonant series DC to AC inverter. This high frequency, around 40 kHz is then applied to the lamp tube. There are two types of CFLs ;

1. Integrated CFLs :-

Integrated lamps consist of a tube, electronic ballast and either an Edison screw or bayonet fitted in a single CFL unit. These lamps have allowed consumers to replace incandescent lamps with CFLs. Integrated CFLs work well in many standard incandescent light fixtures, lowering the cost of CFL conversion.

2. Non-Integrated CFLs :-

The ballasts in Non-integrated CFLs are placed in a light fixture that are large and last longer as compared to the integrated ones. Also, they don't need to be replaced when the bulb reaches its end-of-life. Non-integrated CFLs can be both expensive and sophisticated than the integrated ones. There are two types of bulbs namely, bi-pin tubes designed for conventional ballasts and quad-pin tubes designed for electronic ballasts and conventional ballasts accompanying external starter.

**3.2 OPERATING PRINCIPLE**

CFLs operate by producing light while driving electric current through a tube containing argon and a small proportion of mercury vapor. This will generate an invisible ultraviolet light that excites a fluorescent coating i.e. phosphor, on the inner side of the tube, which finally emits visible light. When CFLs are first turned on, they require a bit more energy, but once the movement of electricity starts, they become far more efficient than incandescent bulbs. CFL's ballast helps in starting the bulb and regulates the current once the electricity starts flowing. This process is completed in 30 seconds to three minutes [8]. This is the reason for the

CFLs to take longer time than other lights to become fully lit. The lamp also requires a current to preheat the filaments, a high-voltage for ignition, and finally a high-frequency AC current during running. In order to fulfill these requirements, the electronic ballast circuit first performs an AC-to-DC conversion on low-frequency at the input, followed by DC-to-AC conversion on a high-frequency at the output. On ignition of the lamp, the current through the lamp is controlled such that the lamp runs at the desired power and brightness level.

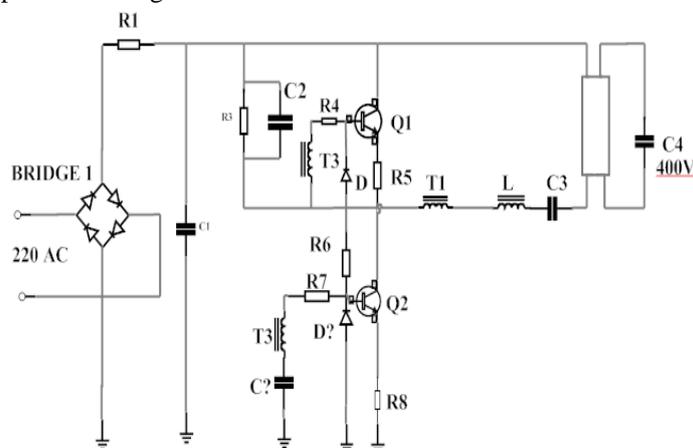


Fig 7 : Electrical circuit of a Compact fluorescent lamp

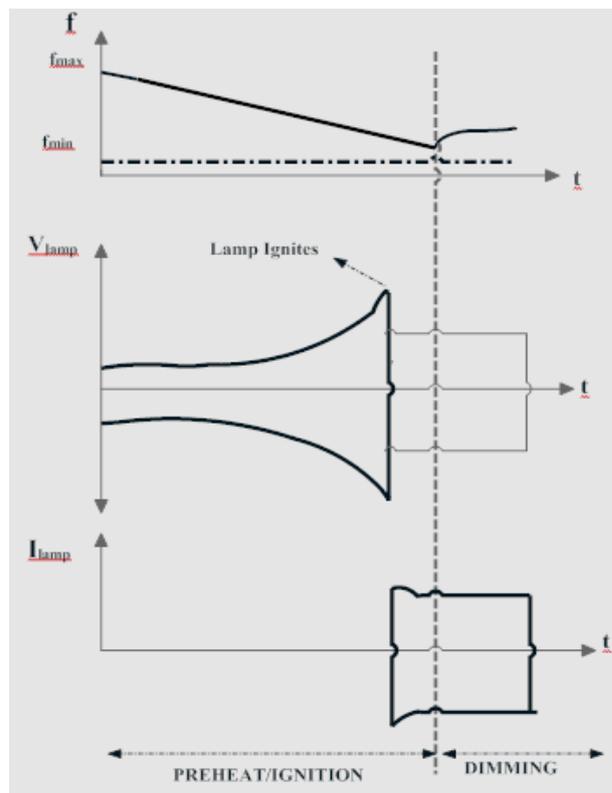


Fig 8 : Timing Diagram Of a CFL Operation

Until the lamp voltage exceeds the lamp ignition voltage threshold, the frequency keeps on decreasing and the lamp ignites. Once the lamp

ignites, the lamp current is controlled such that the lamp runs at the desired power and brightness level.(fig8).

### 3.3 ADVANTAGES

- CFLs are cost efficient.
- CFLs are energy efficient,since it requires less energy to provide same amount of light.
- CFL light bulbs are long lasting and can last upto 10,000 hours.
- CFLs are very versatile and can fit into a standard light socket and do not call for any special lighting fixture.
- Dimmers are also available for some CFLs so as to control their brightness.
- CFLs comes in different colours and various shapes.
- Each CFL over its lifetime saves 450 pounds of carbon from being produced,considered to be a powerful saving.

### 3.4 DISADVANTAGES

- Frequent use of CFLs,also known as flipping can shorten their life span.
- Low temperatures can cause the CFLs to perform with lower light levels, hence reducing their utility.
- CFL contains mercury,a toxic substance. But,it does not pose a health threat unless the bulb is broken.
- Problems with humming noises and flickering light have largely been addressed by improvements in CFL technology(CFLs using magnetic ballasts).

### 3.5 APPLICATIONS

Due to the dramatic energy savings in CFLs,they are a welcome and necessary change from outdated incandescent bulbs.As well as the mercury content is also low and their disposal can be done efficiently.Replacing one regular light bulb with a compact fluorescent light bulb helps in saving consumers \$30 in energy costs over the life of the bulb. Compact fluorescent light bulbs has an upper hand over other bulbs as it also generate 70 percent less heat, so they are much safer to operate and can helps in reducing energy costs that are associated with cooling residences and offices.

## IV. LIGHT EMITTING DIODES (LEDs)

Light-emitting diodes (LEDs) are a relatively old technology dating back to 1970s, has seen an era of advancement from its use in numeric displays and indicator lights to a range of new and potential new applications, including exit signs, accent lights, task lights, traffic lights, signage, cove lighting, wall sconces, outdoor lighting and downlighting.



Fig 9 : A Single LED

LEDs has several advantages such as low heat output,small size, long lamp life, , energy savings and durability.LEDs also occupies extraordinary design flexibility in color changing and dimming.They also possesses property of distribution by combining these small units into desired shapes, colors, sizes and lumen packages.LEDs have been in use for decades in house-hold appliances,computers and clocls.But,it has recently gained popularity as an energy-efficient alternatives to incandescent bulbs.

### 4.1 LED CONSTRUCTION

LEDs are known as tiny lights which are produced by moving electrons in a semi-conductor.Due to the absence of burning gas or filaments,LEDs are considered more durable and produce very little amount of heat.Since,LEDs have an advantage of small size,they are resistant to weather and can also be water-proofed for extreme weather conditions.

LEDs are solid state semiconductor devices.LED units are usually small, typically 5mm (T 1-3/4).

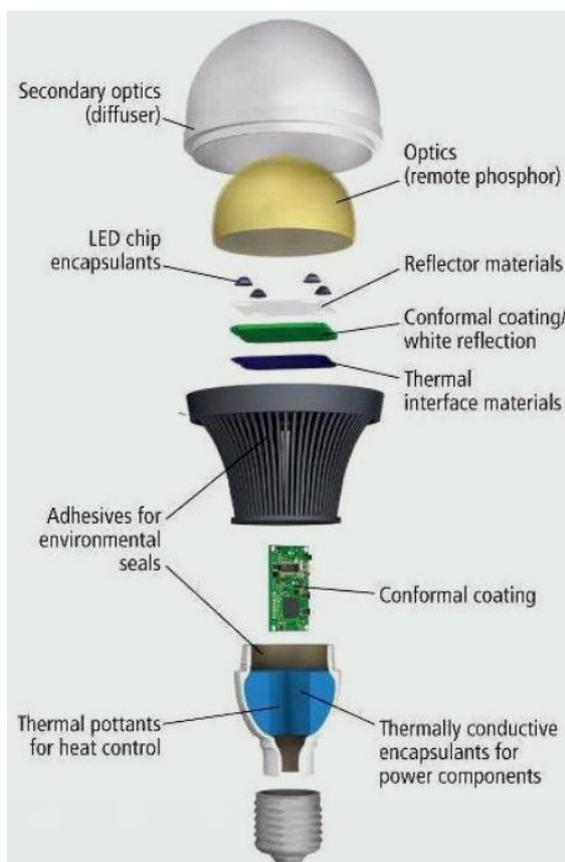


Fig 10 : Construction Of a LED

The construction of a light emitting diode is quite different as compared to a normal signal diode. The PN junction of a LED is surrounded by a transparent, hard plastic epoxy mold which is hemispherical shaped shell and protects the LED from both shock and vibrations. The epoxy resin body is constructed in a manner such that the photons of the light emitted by the junction are reflected away from the surrounding substrate base because the LED junction does not actually emit a good quantity of light. This light is focused upwards through the top of the LED, which itself acts as a lens and concentrates this amount of light. This is the reason for the emitted light to appear brightest at the top of the LED.

However, some of the LEDs are not made with a hemispherical shaped dome for their epoxy shell. Some LEDs have a rectangular or cylindrical shaped construction having a flat surface on top. Also, nearly all LEDs have their cathode (K) terminal identified by either a notch or flat spot on the body, or by one of the leads being shorter than the other, abbreviated as Anode (A).

#### 4.2 LED OPERATION AND BIASING

A light emitting diode (LED) is a semiconductor diode that emits light when a current flows from anode to cathode across the P-N junction of the device. To operate an LED, direct current (DC) is supplied to provide the necessary positive bias (forward voltage) across this junction. When an LED

is activated, a power supply is required to convert AC voltage into sufficient DC voltage, which is then applied across the diode semiconductor crystal. This results in electrons (negative charge carriers) in the diode's electron transport layer and holes (positive charge carriers) in the diode's hole transport layer which later combines at the P-N junction. Hence, it converts this excess energy into light.

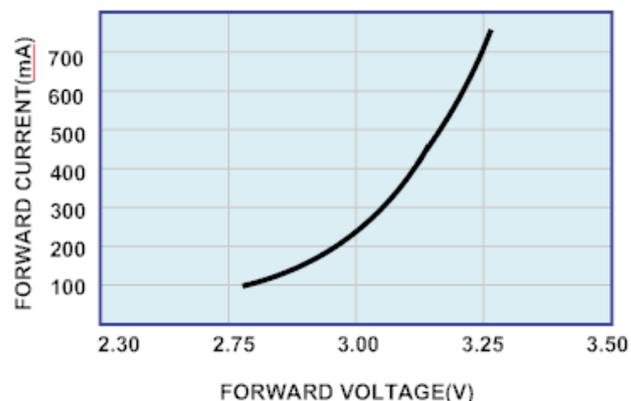


Fig 11 : Current Vs Voltage Characteristics For a typical LED

$$I_F = (V_{DC} - V_F)/R$$

Where,  $I_F$  = forward current

$V_{DC}$  = supply voltage

$V_F$  = forward voltage

$R$  = ballast resistor

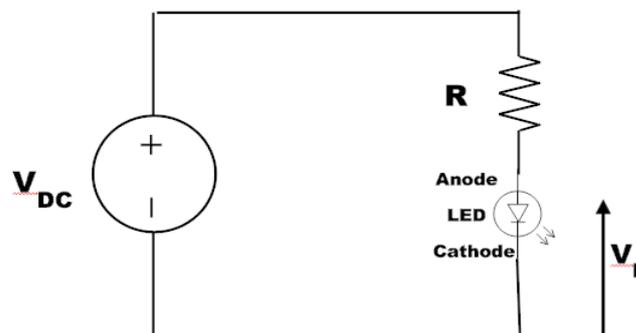


Fig 12 : LED Biasing Circuit

It is feasible to use a rectified and smoothed mains input to power the LED bias circuit (fig. 12), but the resulting supply voltage (V) will be way more higher than the forward voltage ( $V_F$ ) across a single LED. This implies that considerable power would be wasted in the ballast resistor as compared to the power consumed by the LED. To resolve this issue, a number of LEDs can be connected in series which only partially addresses this issue, since the cumulative forward voltage will still be less than the voltage drop across the resistor.

In case of LEDs, the External Current Limiting Resistor,  $R$ , is given by ;

$$R = V_{IN} - yV_F(I_F) - V_D / xI_F$$

$V_{IN}$  = input voltage applied to the circuit

$V_F$  = forward voltage of LED emitter at forward current  $I_F$

$V_D$  = voltage drop across optional reverse transient EMC protection diode

$y$  = number of series connected LED emitters

$x$  = number of paralleled strings

#### 4.3 ADVANTAGES

- LEDs are available in a variety of shades of white light, ranging from warm hues comparable to traditional incandescent bulbs to cool colors that mimic natural daylight.
- A LED style bulb will generally last approximately 100 times as long as an incandescent bulb.
- Most Efficient way of illumination and lighting, with an estimated energy efficiency of 80%-90% as compared to traditional lighting and conventional light bulbs.
- LED lights are free of toxic chemicals. Most conventional fluorescent lighting bulbs contain materials like mercury, that are dangerous for the environment.
- LEDs are highly rugged and can withstand even the roughest conditions.
- Instant Lighting & Frequent Switching-LED lights brighten up immediately and when switched on.

#### 4.4 DISADVANTAGES

- LEDs are currently more expensive, considering price per lumen, on an initial capital cost basis.
- LED performance depends largely on correctly engineering the fixture which is to manage the heat generated by the LED, thus causing deterioration of the LED chip itself.
- LEDs must be supplied with the correct voltage and current at a constant flow. This requires some electronics expertise to design the electronic drivers.
- LEDs can shift color due to age and temperature. Also two different white LEDs will have two different color characteristics, which affect how the light is perceived.
- The retina cells are destroyed by prolonged and continuous exposure to LED rays, they cannot be replaced and will not regrow.

#### V. CONCLUSION

Incandescent bulbs are still popular and make up a majority of the light bulbs in houses today, but as more people are bent towards saving energy and environment, both the CFL and the LED bulbs

are well suited alternatives. If we consider the long term, an LED style bulb will save the most money although the initial cost may be high. But, the good news is that LED bulbs have long life i.e. they last for over 10 years. Considering the CFL bulb, they will save nearly the same amount as an LED.

If we replace just one incandescent light bulb with an ENERGY STAR qualified CFL, in one year it would save enough energy to light more than 3 million homes in America. This will prevent the release of emissions of greenhouse gases which is equal to that of about 800,000 cars. To reduce CO2 emission and nuclear waste, saving electricity is very important.

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