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Reliable Energy Strategy Based on Incandescent Lighting

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Abstract

The artificial lighting used today in home and workplace have confirmed capability to induce skin problems, DNA damage, tumor formation as well as worsening arthritis, migraine and visual fatigue by longer exposure of ultraviolet radiation from discharge lighting sources. In this paper an ignition-angle controller (IAC) is used to demonstrate the reliability of incandescent lamps (ILs) in comparison with discharge lighting feed by switching-mode supplies. Analysis of harmonic of the line-current flow consumed by the ignition-angle controller (IAC) circuit has shown that production of distorted rms currents does not produce hazard, because single harmonic distortion (SHD) values are keeping lower to 50%. As energy policy, the modern artificial lighting must be replaced by economical, stable and nonhazardous incandescent lamps (ILs).

Keywords

Incandescent Lamp, Artificial Lighting, Ignition-Angle Controller, Single Harmonic Content

1. Introduction

Artificial lighting sources are transitioning from incandescent lamp (IL) to compact fluorescent lamp (CFL) and light-emitting diode (LED) bulbs. Both CFL and LED lamps are categorized as hazardous, due to excessive levels of lead (Pb), high content of aluminum, copper, silver, and zinc, while the incandescent lamp (IL) is not hazardous [1]. In most of the literature authors have considered CFL as a replacement of IL for the saving energy. However, people must be well aware about the use of such nonlinear products on the electricity distribution damage in home. Many loads connected to the electricity distribution wires have detrimental effect due to poor power quality on their operation [2].

People are generally not well conscious of the lamp characteristics and lighting design terminologies. They select the lighting system on the basis of power consumption, rather than considering how physiologic mechan-

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ism of human vision has an effect on the quantity of light that enters to the eye through the cornea and pupil aperture which varies by changes in the level of illumination and viewing distance without harmful stress that the eye-brain system is experiencing [3].

It is well known that sensation of vision on the retina is corresponding to the useful wavelength of ultraviolet radiation (UV) from 400 to 700 nm, but UV coming from the sun can induce or exacerbate skin lesions [4]. Nevertheless, little is known about biological effects of longer exposure of artificial lighting sources which could result in an important accumulative damage. People spend much more time exposed to the artificial lighting than they do in direct sunlight.

Doses of UV are greatly interesting in molecular photobiology into the three major groups based on wavelength: UVA (320 - 400 nm), UVB (290 - 320 nm), and UVC (200 - 290 nm). Measurements of UV emission from discharge lighting sources have established that lamps commonly used in the home and workplace, including fluorescent lamps (FLs) and compact fluorescent lamps (CFLs) are emitting appreciable levels of UVA and UVB, and some others emitting UVC. The results indicate that doses of UVA, UVB, and UVC during 8 hours of exposure per day are capable to induce DNA damage, tumor formation as well as worsening arthritis, migraine and visual fatigue [5].

Due to the environmental and health concerns associated to discharge lighting sources, the governments around the world should go for low-cost reliable alternatives to minimize toxic sources. One solution that can be planning is the phasing out of energy inefficient lamps and replacing them with economical and nonhazardous sources as well as must be avoiding relaxed health laws.

This paper presents a brief description of concerns related to artificial lighting. An ignition-angle controller (IAC) used to demonstrate the reliability of incandescent lamps is covered in Section 2. Physical behavior of the 60-W tungsten filament under switching functions is analyzed in Section 3. Experimental results have been conducted by measurement of rms current and FFT spectrum in Section 4.

2. Reliable Energy Strategy

Both FLs and CFLs work under the same principle having negative current-voltage characteristics and driven with electronic ballast to provide the starting voltage and limiting of avalanche current [6]. Traditionally, the electronic ballast operates at switching frequency of 50 kHz, but its electronic circuitry is a major source of harmonic generation and electromagnetic interface into the electricity distribution wires [7]. Electronic ballasts are highly vulnerable to disturbances.

The negative impact of discharge lighting is production of distorted-rms currents with single harmonic distortion (SHD > 80%) leading to excessive energy losses [8]. Also, it is known that CFLs do not operate under humid environments, its efficiency decreases at higher and lower temperatures than that at room temperature. The presence of a low-pressure gas (mercury (Hg) as active gas) into a CFL requires special treatment for their safe disposal [9].

The IL is moderately inefficient for visible light production with their filament temperature of 2700 K particularly rich in red spectral energy, while for visible light emission; the temperature must be about 3000 K [10]. Nevertheless, the IL has the highest color rendering index (CRI) value than those of discharge and monochromatic-LED lamps. The CRI for an IL is around 100% and presents a small fraction of visible emission at wavelength from 390 to 780 nm which is useful UV emission for human vision.

Like the tungsten filament of the IL is a quasi-pure resistive load does not suffer with energy losses issues, therefore an ignition-angle controller (IAC) shown in **Figure 1** is used to demonstrate the reliability of the IL. The operating principle of the IAC is beginning with the conduction of silicon-controlled rectifier (SCR) which depends of both gate-driven pulses train and rectified voltage. Changing the pulse width, the increase or reduction of luminance level of an IL by the impedance change of the SCR is getting. **Figure 2** depicts the waveforms for the IAC.

Due to the bipolar space charge of high concentration of minoritary carriers (electrons and holes) in the middle ***PN*** junction of the SCR is achieving a conduction-regenerative state in the time range of 1.5 to 10 microseconds by recombination processes. In **Figure 2** is exhibited how the on-state of the SCR is holding within of miliseconds after to that gate-driven pulses train had its off-state and concentration of carries is still enough to promote lamp-current flow [11].

The conduction-regenerative state of the SCR provides protection to the IL from disturbs produced in the

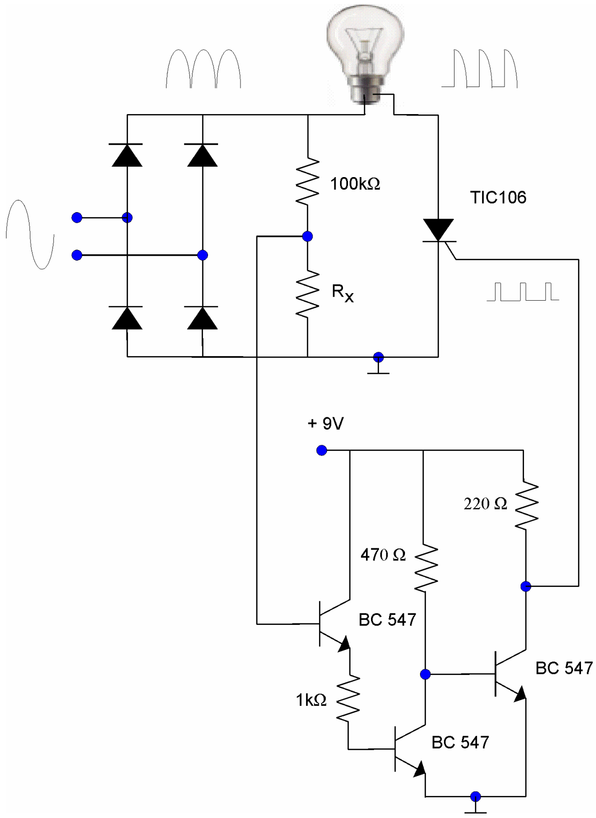

Figure 1. Schematic of the ignition-angle controller (IAC).

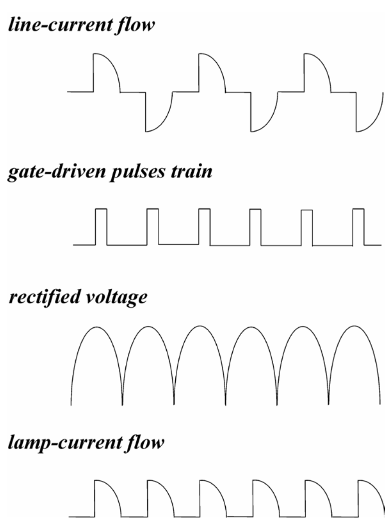

Figure 2. Waveforms from the ignition-angle controller (IAC).

electricity distribution wires. The pulses train injected to the gate of SCR is formed with nonhazardous electronic circuitry to produce conductivity modulation of the ***PN*** junction diode built-in a bipolar junction transistor (BJT). To achieve this feature is used a discrete BJT array connected in Darlington configuration and driven as switches (see **Figure 1**). The width of the gate-driven pulses is dynamically modified by the resistor R_X with range spanning from 0.5 to 5 kΩ to allow changes of the lamp-current flow. The polarization condition of each discrete BJT depends on the gate-driven current [12].

3. Physical Behavior of a Tungsten Filament

To know the behavior of the IL as a function of ignition angle, α it is proposed a mathematical analysis of an tungsten filament modeled by the equivalent circuit of a thermal resistor R_θ (degree Kelvin per watt) in parallel with the thermal capacitor C_θ (Watt per degree Kelvin) [13] with a power dissipation, P_D described by

$$P_D = C_\theta \frac{\mathrm{d}T}{\mathrm{d}t} + \frac{T}{R_\theta}. \tag{1}$$

where P_D is equal to $I_{\text{lamp}}^2 R_f$ with R_f as resistance and T_f temperature of the tungsten filament as a function of time. Both R_f and T_f are minimum if P_D is equal to zero at $t = 0$. The Equation (1) is solved by

$$T(t) = T_m \cdot \mathrm{e}^{-\frac{t}{R_\theta C_\theta}}. \tag{2}$$

where T_m is the maximum temperature without thermal breakdown with value of 2900 K when the initial current flow about 10 times greater than that standard current flow is first turned on at the filament startup with resistance of $0.1R_f$, but leading thermal and mechanical stress [10]. Like the change of the filament temperature from 0 to 2700 K occurs into negligible time ($\mathrm{d}T/\mathrm{d}t$ equal to zero), it is found that $T_m = I_{\text{lamp}}^2 R_f R_\theta$ for the Equation (1).

The lamp-current flow $\left(I_{\text{lamp}}\right)$ can be represented by Fourier's series and switching functions [14]. An IL is supplied by rectified voltage as shown in **Figure 1**, and their operation depends of that switching pattern of the SCR. Consequently, I_{lamp} can be approximately given by

$$I_{\text{lamp}}(\theta,\alpha) = \frac{2I_{rms}}{\pi}\left(\frac{1}{\pi} + \frac{\cos\alpha}{\pi}\right) - \frac{4I_{rms}}{\pi}\sum_{m=1}^{\infty}\frac{\cos 2m\theta}{4m^2-1}\left(\sqrt{1-\frac{\alpha}{\pi}+\frac{\sin 2\alpha}{2\pi}}\right). \tag{3}$$

where I_{rms} is the rms-current flow and θ is the angular frequency. Equation (3) defines two parts; the first corresponds to the average-current flow and the second to the alternating component. The second harmonic 2θ is the more dominant with frequency of 120 Hz at $m = 1$.

4. Experimental Results

A 60-W tungsten filament is assumed to have a thermal time constant $R_\theta C_\theta = 30\ \text{ms}$ with $R_\theta = 48.5\ \text{K/W}$ and R_f equal to $240\ \Omega$ when the IL is used in a 120-V circuit. Substituting Equation (3) into the Equation (2), the T_f as a function of α is solving with MATLAB program in the range from 0 to 90˚. **Figure 3** shows the filament temperature behavior under two conduction conditions.

The behavior of the tungsten filament is stable at $t < 30$ ms when their temperature range is established from 1500 to 2500 K and degradation and premature evaporation of the filament surface must be avoided without

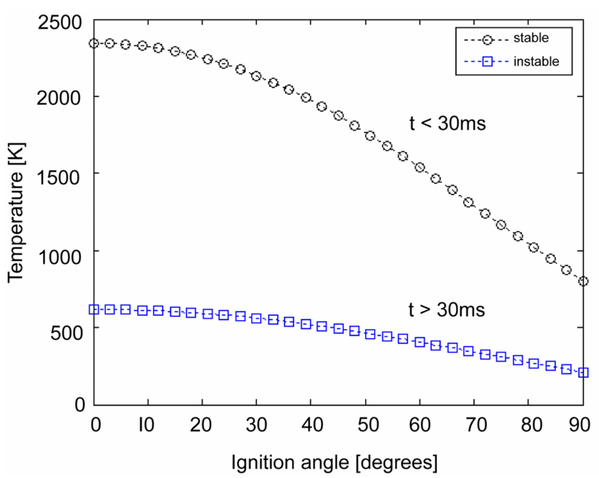

Figure 3. Filament temperature behavior as a function of the ignition angle.

thermal runway cycles. In contrast, a T_f lower to 500 K indicates that thermal breakdown is reached if strong magnetic forces between adjacent coils of the filament take place. This phenomenon as instable condition at $t > 30$ ms is related to surge-current flow in the turn-on state of an IL which is more susceptible to occur.

4.1. Operation of a 60-W Tungsten Filament

After building the circuit of **Figure 1**, the measuring of both line and lamp current flows were done to know the behavior of the 60-W tungsten filament connected to the IAC. In **Table 1** are includes T_f and R_f to correlation these with the measured-current flow. The temperature was obtained from the plot of **Figure 3**, while that the filament resistance by previous studies [10].

From the results of **Table 1** was observed that current level in the lamp is greater than that in the line which is attributed to the presence of two current flows; the average-current flow and the alternating component as defined by Equation (3).

4.2. Reliability of the Controlled Tungsten-Filament

Based on Fast Fourier Transform (FFT) algorithm implemented into a digital storage oscilloscope (Tektronix, TDS1012C), the FFT spectrum of current flow on the electricity distribution wires under different ignition angles, α were registered. The algorithm implemented by Tektronix allows analyzing both odd and even harmonic of any signal.

Figure 4 illustrates the FFT spectrum for different ignition angles. At $\alpha = 0^\circ$, the current flow is quasi-sinusoidal and odd harmonic are lower in accordance with the EN-50160-2-2 standard [see **Figure 4(a)**]. In contrast, for $\alpha = 30^\circ$, $\alpha = 60^\circ$, and $\alpha = 90^\circ$, the current flow is distorted with higher odd harmonic components [see **Figures 4(b)-(d)**].

As comparison, the single harmonic distortion (SHD) values for a switching-mode supply are presented in **Table 2** to demonstrate that the controlled tungsten-filament by the IAC is more reliable. Both third and seventh harmonic are lower for the IAC circuit than those registered by the switching-mode supply [15]. As a result, the overcurrent in the neutral line, resonant over voltages and copper area oversize are reduced even at $\alpha = 90^\circ$, because production of distorted-current with single SHD < 50% do not produce hazard. **Table 2** demonstrate that current flow in the lamp generate even harmonics with the second harmonic higher than those others

Table 1. Behavior of the current flow and temperature in a 60-W tungsten filament.

α	I_{line} (mA)	I_{lamp} (mA)	T_f (K)	R_f (Ω)
0˚	480	495	2700	240
30˚	478	492	2700	240
60˚	465	482	2550	225
90˚	425	445	2450	215

Table 2. Comparison of SHD values for switching-mode supply and ignition-angle controller (IAC).

h	$\alpha = 0^\circ$	$\alpha = 30^\circ$	$\alpha = 60^\circ$	$\alpha = 90^\circ$	Switching-mode supply
2	1.45%	36.10%	52.10%	76.10%	105.50%
3	3.12%	36.10%	43.30%	45.20%	83.30%
4	1.04%	27.80%	30.40%	35.50%	72.20%
5	1.25%	24.20%	17.30%	30.10%	27.80%
6	1.25%	16.40%	13.20%	15.60%	33.30%
7	1.04%	8.10%	8.60%	12.50%	55.50%
8	1.87%	4.25%	4.30%	12.50%	44.40%
9	1.87%	5.50%	0.55%	5.50%	2.70%
10	1.04%	5.50%	2.10%	5.50%	44.40%

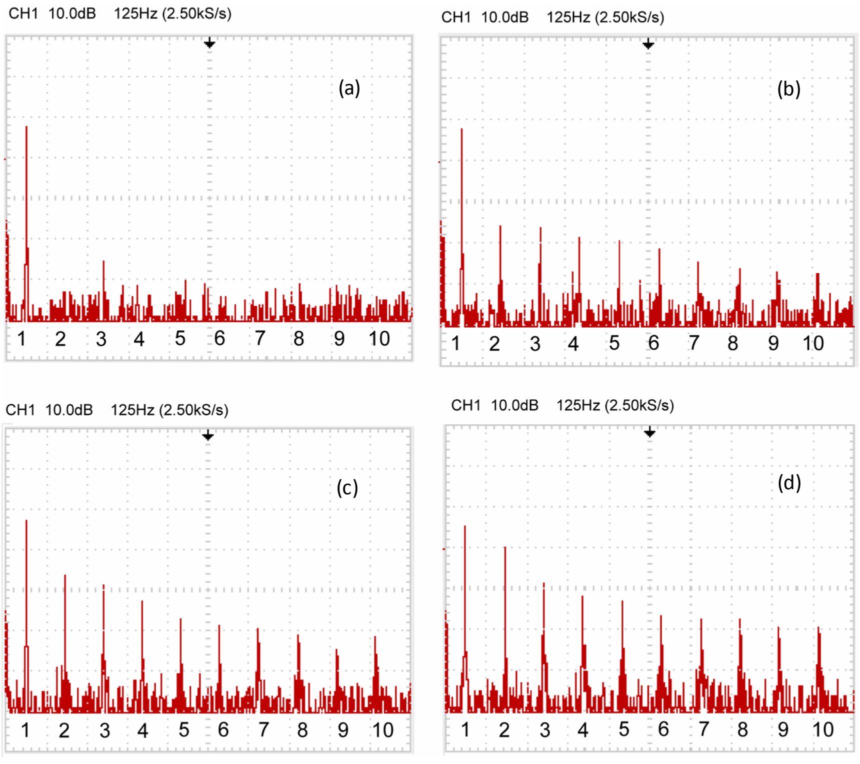

Figure 4. FFT spectrum at different ignition angles: (a) $\alpha = 0^\circ$, (b) $\alpha = 30^\circ$, (c) $\alpha = 60^\circ$, and (d) $\alpha = 90^\circ$.

harmonic components. Therefore, the stable condition for the tungsten filament can be achieved (see Section 3) in comparison with a phase controller done with TRIAC devices [14].

5. Conclusion

The paper has discussed the reliability of the ILs on the environmental and health concerns as well as impact of the power quality in terms of harmonic distortion. After explaining the advantages of the incandescent lamps (ILs), a low-cost reliable strategy has been planned and built based on an ignition-angle controller (IAC). Furthermore, the analysis of operation of a tungsten filament modeled by their physical behavior was conducted. From the experimental results it has been established that an IAC for the ILs is more reliable than that switching-mode supplies for discharge lighting sources and LED lamps. Until that new ecological lighting source is invented, the people should go for reliable energy consumption as the nonhazardous incandescent lamp (IL).

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