IJARSCT

International Journal of Advanced Research in Science, Communication and Technology

International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal

ISSN: 2581-9429

Volume 5, Issue 4, June 2025

Impact Factor: 7.67

Effects of Dimming on Power Consumption in Lighting

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Abstract: *Dimming refers to the control of light intensity, allowing users to create varying lighting conditions and ambiance within a space. A variety of dimming technologies are available, including Phase-Cut, Analog (0-10V), and DALI (Digital Addressable Lighting Interface).*

Lighting plays a significant role in the overall energy usage of residential, commercial, and industrial buildings.As there is an increasing emphasis on energy efficiency and sustainability, dimming technologies are being widely adopted to minimize power use and enhance the comfort of users. Common dimming techniques include 0–10V analog control, phase-cut dimming—both leading-edge and trailing-edge—and the Digital Addressable Lighting Interface (DALI). These methods each offer distinct features in terms of performance and compatibility with different lighting loads such as LEDs, CFLs, and incandescent lamps.

However, there is limited research comparing how these dimming techniques affect power consumption across various dimming levels, particularly at lower light outputs. Understanding the relationship between dimming levels and energy consumption for each dimming protocol is vital for:

- *Choosing the most energy-efficient dimming approach.*
- *Designing optimized lighting control systems.*
- *Supporting the development of energy standards and building regulations..*

Keywords: 0-10V Analog Dimming, Phase-Cut Dimming, DALI Dimming, Dimming Methods, Lighting Energy Efficiency

I. INTRODUCTION

Dimming is the technique used to control and vary the intensity of light emitted by a lighting source.It has become a crucial feature in contemporary lighting systems, providing greater flexibility, energy savings, and the ability to enhance the ambiance of a space. Over time, different dimming technologies have been developed, each offering distinct features and suited for various applications.In the past, incandescent bulbs were the primary lighting option, and dimming was typically achieved through the use of simple rheostats or variable resistors. These early methods worked by dissipating excess energy as heat, which resulted in reduced efficiency and shorter lamp lifespans.

With the rise of solid-state lighting (SSL) and advancements in electronic control, modern dimming methods have become significantly more efficient and adaptable. Today, some of the most widely used dimming technologies include:

I. 0-10V Dimming: This analog technique utilizes a voltage signal to control the brightness of LED drivers or ballasts.

II. Phase-Cut Dimming: Mainly applied to incandescent and halogen lamps, this method adjusts the AC waveform supplied to the lamp, cutting portions of the waveform to control light intensity.

III. DALI (Digital Addressable Lighting Interface) Dimming: This is a digital protocol that facilitates accurate control of individual lights or groups, offering enhanced flexibility, energy efficiency, and customization options.

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DIMMING TECHNOLOGIES

This paper explores how different dimming techniques impact the energy usage and electrical performance of lighting systems. It focuses on key parameters such as voltage behavior, harmonic distortion, power factor, and current consumption. Three common dimming methods are evaluated: Digital Addressable Lighting Interface (DALI), phase-cut dimming, and 0–10V dimming.

Dimming modifies the electrical characteristics of lighting circuits in complex ways, often resulting in waveform distortion and increased harmonics that can negatively affect power quality. Phase-cut dimming, in particular, is known to degrade the power factor due to its abrupt and nonlinear voltage regulation. Meanwhile, DALI and 0–10V systems offer more advanced control, typically yielding better power factor performance and lower harmonic interference. However, their effectiveness can vary depending on how the system is configured and used.

The study also looks at how each dimming method influences current draw, aiming to identify the most efficient approach for reducing energy consumption while maintaining sufficient lighting quality. The results offer practical guidance for selecting the most suitable dimming technology in both residential and commercial lighting applications to improve energy efficiency and electrical performance.

ANALOG (0-10) DIMMING

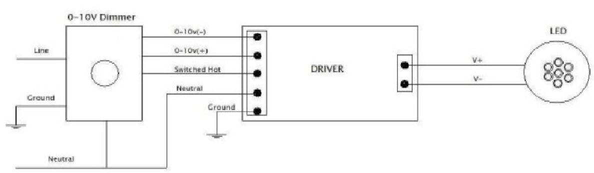

Figure 1Analog (0-10v) Dimming Circuit Diagram

0-10V Dimming is one of the earliest and simplest lighting control systems. It operates through a DC control signal that varies between 0 and 10 volts, with the light output adjusting accordinglyAt a control voltage near 10V, the light operates at full brightness (100%), while a voltage close to 0V results in the lowest light output. The minimum output level can vary depending on the design of the LED driver, typically ranging from 1% to 10%. The 0-10V control specification is outlined in IEC standard 60929 Annex E2.

This dimming method is particularly popular for controlling LED lights, offering a straightforward, reliable, and compatible solution with a wide range of LED drivers and fixtures. The 0–10V dimming method enables users to modify light levels according to their preferences, helping to create diverse lighting moods and ambiances across different settings. Additionally, it contributes to energy savings and extends the lifespan of LED fixtures by reducing both power consumption and heat generation when the lights are dimmed.

II. PHASE CUT DIMMING

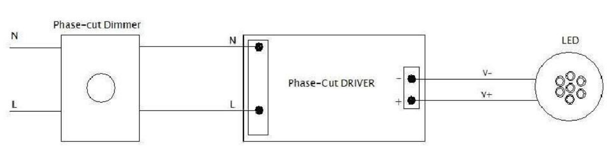

Figure 2 Phase Cut Dimming Circuit Diagram

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Phase-Cut Dimming (also known as trailing edge or leading edge dimming) is one of the most basic dimming methods, originally developed for resistive incandescent loads, where it worked quite effectively. This method is commonly seen in residential wall dimmers, using standard wiring with active, neutral, and earth connections. The dimmer essentially "chops" or "cuts" the 240V AC phase before it reaches the LED driver, adjusting the amount of power supplied to the LEDs.

However, phase-cut dimming can lead to issues with LED lighting, such as flickering, poor dimming performance, or even total failure to dim. Some common problems include LEDs that do not dim properly or fail to reach the desired dimming level, lights flickering or turning off at low levels, and sudden, large jumps in light output as the dimmer is adjusted. In certain areas, such as in New South Wales (NSW), LEDs can even flicker around 10 PM due to external electrical loads, such as water heating systems switching on

There are two types of phase-cut dimmers:

Leading-edge phase-cut dimmers, also known as Triac or rising-edge dimmers, function by interrupting the AC power at the zero-crossing point and reactivating it later within the same cycle.The length of the "off" period determines how much energy reaches the LED. A longer "off" period results in dimmer light output.

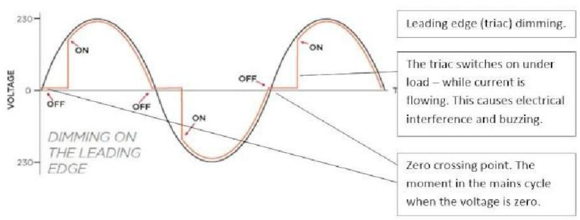

Figure 3 Waveform of Leading - edge

Trailing Edge Phase-Cutting Dimmers operate by turning the current on at the zero-crossing point of the AC waveform and then turning it off later in the cycle. This process is typically controlled by an electronic component known as an Isolated Gate Bipolar Transistor (IGBT). The amount of energy that reaches the LEDs is determined by the length of the "off" period during each AC cycle. The longer the "off" duration, the dimmer the LEDs will appear, as less energy is supplied to the light source.

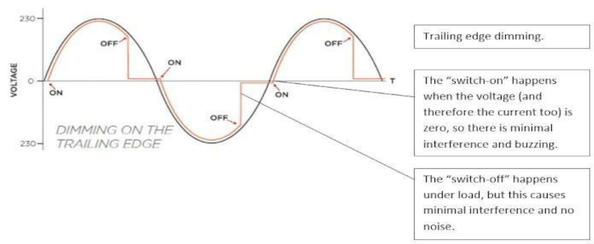

Figure 4 Waveform of Trailing - edge

DALI DIMMING

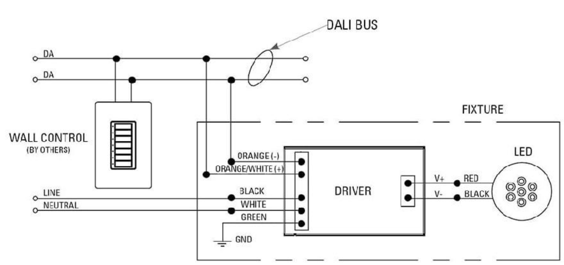

Figure 5 DALI Dimming Circuit Diagram

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DALI (Digital Addressable Lighting Interface) is a two-way communication protocol used to control and manage the components within a lighting system. First introduced in the late 1990s and defined under IEC60929, DALI has undergone significant updates over the years. The current version, DALI-2, which was finalized in IEC62386, enhances the protocol's functionality and interoperability.

Key Features of DALI:

Open Protocol: DALI is an open standard, meaning it can be adopted by any manufacturer, ensuring widespread compatibility.

Interoperability with DALI-2: With the DALI-2 standard, manufacturers must undergo mandatory certification, ensuring that devices from different makers can work seamlessly together.

Flexible Wiring Topology: The system can be set up in various wiring configurations, including star (hub and spoke), tree, or line arrangements, or combinations of these.

Digital Communication: Unlike analog systems, DALI uses digital communication, meaning the same dimming values can be accurately received by multiple devices, ensuring precise and stable performance.

III. IMPLEMENTATION SETUP

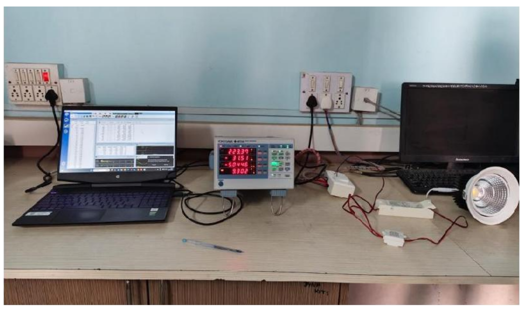

Fig. 3.1 Experimental Setup of Analog (0-10V)

Fig. 3.2 Phase-Cut Experimental Setup

Fig. 3.3 DALI Experimental Setup

Component List

Sr.No.	Components	Specifications	Qty.
1.	Dimmer	10 A, 240 V, 50 Hz	1
2.	Phase-Cut Dimmable Driver	50-1200mA,220-240VAC, 30W, 47-53Hz	1
3.	Casambi Dimmer	220-240VAC,50Hz,0.6A	1
4.	0-10V Dimmable LED Driver	50-1200mA, 230V AC, 30W,47-53Hz	1

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5.	DALI Driver	250mA,220-240VAC,40W,50Hz	1
6.	LED	30 Watt	3
7.	Power Analyzer	YOKOGAWA WT330 20A,600V	1

V. RESULT

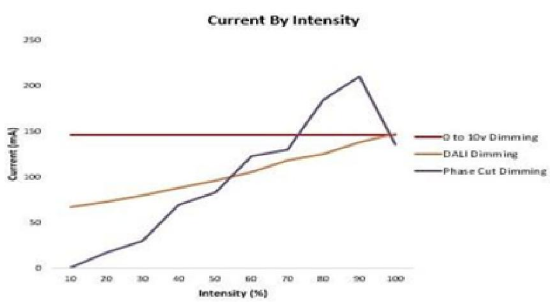

Fig 4.1 Current By Intensity

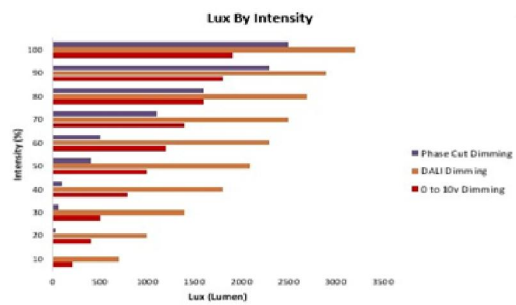

Fig 4.2 Lux By Intensity

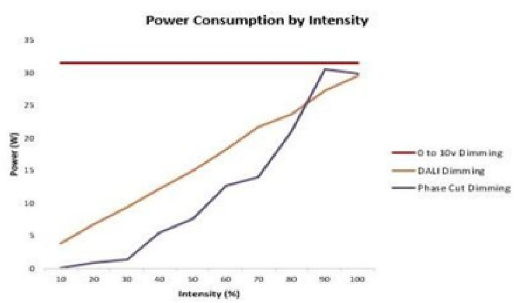

Fig 4.3 Power Consumption By Intensity

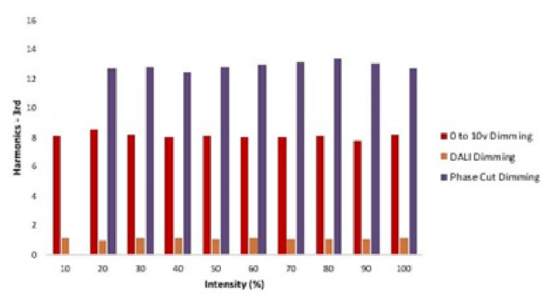

Fig 4.4 Harmonics – 3rd By Intensity

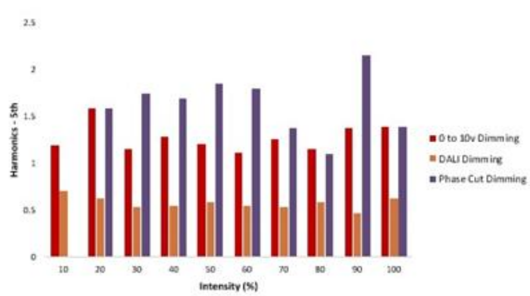

Fig 4.5 Harmonics – 5th By Intensity

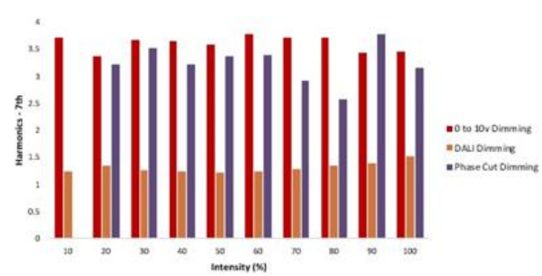

Fig 4.6 Harmonics – 7th By Intensity

VI. CONCLUSION

Different dimming methods draw different amounts of current even at the same intensity level, affecting energy efficiency. Some dimming techniques are more efficient in converting power to light, while others waste energy by producing less brightness at the same intensity. Choosing the right dimming technique can save power, especially at lower intensities. High harmonics can lead to inefficiencies and electrical issues in a lighting system. Lower harmonics mean better power quality and efficiency in the system. Reducing harmonics is essential to prevent electrical issues like overheating and poor efficiency.

Based on all observations, DALI Dimming is the most optimal technique among the three. It offers:

1. Better energy efficiency
2. Higher brightness output
3. Lower current draw
4. Minimal harmonic distortion

While Phase Cut Dimming shows decent brightness, its harmonics and current profile are unstable.0-10V Dimming, though simple, is the least efficient, consuming more power and producing higher harmonics with lower brightness. DALI Dimming is the recommended solution for both residential and commercial lighting where energy savings, power quality, and lighting performance are priorities. In this project the best technology is DALI as it draws balanced current of 66.9mA at 10% intensity and 146.88mA at 100% intensity that shows gradual growth with increase in intensities. It has highest brightness of 3200 Lumens. It is energy efficient and consumes lowest power (29.5W) at high intensity. It has lowest values of harmonics generated i.e. 3rd order harmonics (0.97), 5th order harmonics (0.45), 7th order harmonics (1.23).

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