

LED Driver Topologies for Solid State Lighting: A Comprehensive Review of Conventional Converters Emerging GaN Based Designs and Smart Lighting Solutions

Shaik Mohammed Mukassir¹, K. Ravi Kumar², Narender Jatoth³

Abstract: Light emitting diode (LED) technology has become ubiquitous in residential and industrial lighting. The performance of an LED system, including its efficiency, power factor, lifespan, and cost, is critically dependent on the driver's power converter topology. This paper provides a comprehensive review of recent advancements and trends in LED driver design to serve as a guide for engineers and researchers. By analyzing contemporary research from leading journals and conference proceedings, the review identifies and evaluates suitable converter topologies for various power levels. The analysis concludes that while numerous topologies are viable, the flyback converter remains the predominant solution for low power applications (<100 W) due to its cost effectiveness and simplicity. Key design considerations, including power factor correction, efficiency, dimming capability, and reliability, are also discussed to inform future design choices.


Keywords: LED drivers, AC-DC converters, DC-DC Converters, Power factor correction, Soft switching, GaN power devices, Flicker mitigation.

History

Received: 01-03-2026;

Revised: 14-04-2026;

Accepted: 18-04-2026

 Shaik Mohammed Mukassir
mukassir_be@yahoo.com

¹Department of Electrical and Electronics Engineering, Deccan College of Engineering and Technology, Hyderabad – 500001, India.

²Department of Electrical and Electronics Engineering, Vasavi College of Engineering, Hyderabad – 500031, India.

³Department of Electrical and Electronics Engineering, Princeton College of Engineering and Technology for Women, Hyderabad – 500088, India.

1. Introduction

The development of light emitting diode (LED) technology began in 1962 with the introduction of the first commercial LED, which initially served as a replacement for neon indicator lamps and seven-segment displays in scientific and industrial equipment [1]. By the early 1970s, LEDs were widely incorporated into calculators, radios, and basic digital displays as improvements in semiconductor materials enhanced device stability and reliability [2]. A significant advancement occurred in 1972 with the introduction of high brightness LEDs suitable for fiberoptic communication, enabling efficient short-distance optical data transmission [3]. Progress in compound semiconductor materials during the 1980s and 1990s, particularly GaN and InGaN, enabled the development of blue and white LEDs, establishing the foundation for modern solid state lighting (SSL) systems [4 - 5].

Contemporary high brightness LEDs (HBLEDs) now achieve laboratory efficacies exceeding 200 lm/W, with projected lifetimes between 80,000–100,000 hours under optimized thermal conditions [6 - 7]. The adoption of chip scale packaging (CSP) and multi chip LED modules has further increased lumen density and improved thermal performance for high intensity lighting applications [8]. A crucial component of all LED-based lighting systems is the LED driver, a power-electronic interface that converts AC mains into a regulated DC. Because LEDs operate as current-driven devices, the driver plays a critical role in ensuring constant current regulation, power factor correction (PFC), flicker mitigation, dimming compatibility, and protection against electrical stresses [9]. Recent studies indicate that driver malfunction is responsible for more than 60% of failures in LED lighting systems, primarily due to electrolytic capacitor degradation and thermal stress [10]. Recent developments include resonant LED driver configurations with independent control mechanisms and capacitor less architectures aimed at improving lifetime and reducing output ripple [11]. Additional advancements include soft switched full-bridge LED drivers achieving efficiencies above 92%, reduced voltage stress, and enhanced dimming performance [12]. Recent research trends also demonstrate significant progress in GaN-based high frequency converter designs, single stage AC–DC topologies, soft switching approaches, digital control, and electromagnetic interference (EMI) optimized drivers, enabling higher efficiency and higher power density [13 - 14]. These advancements are increasingly relevant as LEDs are integrated into smart-lighting ecosystems, visible light communication (VLC), building automation networks, and human-centric lighting systems requiring precise spectral tuning and high speed modulation [15 - 16]. LED technology offers several advantages over traditional lighting systems, including superior luminous efficacy, long operational lifetime, enhanced reliability, excellent colour stability, and compatibility with intelligent control platforms [17]. These capabilities continue to drive research toward more efficient, robust, and cost effective LED driver architectures that support next generation lighting applications. Table. 1 compares three major lighting technologies, Incandescent, CFL, and LED based on efficiency, lifespan, cost,

environmental impact, and performance characteristics. Incandescent bulbs are the least efficient, converting most of their energy into heat rather than light, and they have the shortest lifespan (about 1,000 hours) [18]. CFLs improve efficiency significantly and last longer (8,000–10,000 hours), but they contain mercury, require controlled disposal, and exhibit warm up time and flicker issues [19 - 20]. LEDs outperform both technologies with very high luminous efficacy, minimal heat emission, and exceptional lifetimes reaching 25,000–50,000 hours or more [21 - 22]. LEDs also offer better dimming compatibility, enhanced colour performance, and greater environmental benefits since they do not contain hazardous materials and consume much less electricity [23 - 24]. Overall, LEDs provide the most sustainable and cost effective lighting solution [25], [33]. LEDs are current driven semiconductor devices that require tightly regulated current for stable operation, making LED drivers essential in all lighting applications [26 - 27]. The driver converts AC or DC input into a constant current output while ensuring protection against voltage and current variations that may cause flicker, reduced efficiency, or device failure [28]. In modern lighting systems such as indoor luminaires, streetlights, automotive lighting, and horticulture, the LED driver enables high efficiency, long lifespan, dimming control, and compliance with power quality standards [29 - 30]. Advanced driver topologies (buck, boost, resonant, and multi-string) further support high power density, improved EMI performance, and integration with smart and IoT-based lighting platforms, making the driver a key determinant of overall system performance [31 - 33], [34]. A comprehensive classification of LED driver technologies is essential for understanding the design space and selecting appropriate topologies for specific applications. Recent review papers have proposed systematic classification frameworks based on power conversion stages, isolation requirements, and control methodologies [87], [90].

The remainder of this paper is structured as follows. Section 2, presents a comprehensive classification of LED driver types. Section 3, reviews conventional LED driver topologies with comparative analysis. Section 4, discusses advanced and practical LED driver topologies. Section 5, identifies and analyzes dominant research hotspots in LED driver

technology. Section 6, concludes the paper with key findings, future research directions, and sustainability recommendations.

2. Classification of LED driver types

The classification of LED driver types spans a broad range of topologies, each tailored to specific performance, efficiency, and application requirements as summarized in Table. 2. This classification framework builds upon recent comprehensive reviews of LED driver technologies [87], [90], which have established systematic taxonomies based on power conversion stages, isolation, and control strategies.

2.1 Passive and Linear LED Drivers

Passive LED drivers, built using simple resistor-, capacitor, or inductor based circuits, offer very low cost but suffer from poor efficiency and weak current

regulation, making them suitable only for basic indicator LEDs [35]. Linear LED drivers provide low-noise operation and minimal EMI with simple analog dimming capability but exhibit high power losses at larger voltage drops, limiting their use to low-power lamps [36].

2.2 Switched-Mode Active LED Drivers

Modern lighting systems primarily rely on active switched mode drivers, which include single-stage and two stage LED drivers. Single-stage converters offer compactness and reduced component count, whereas two stage designs achieve high power factor, low THD, and precise current regulation at the cost of higher complexity and reduced efficiency [37 - 38]. Integrated stage drivers further optimize efficiency and size by combining PFC and DC-DC stages, though they require careful design [39], [89].

Table. 1: Comparison of incandescent, CFL, and LED bulbs

Feature	Incandescent Bulb	CFL	LED	Peer-Reviewed / Technical References
Energy Efficiency	5–10% efficiency	25–35%	40–60%+	[18 - 19]
Power Consumption	Highest	~75% lower than incandescent	~85–90% lower than incandescent	[20 - 21]
Lifespan	~1,000 hours	8,000–10,000 hours	25,000–50,000 hours	[22 - 23]
Initial Cost	Very low	Medium	Higher	[24]
Operating Cost	Very high	Medium	Very low	[25]
Light Quality	Warm, natural	Cooler, may flicker	Wide range, no flicker	[26 - 27]
Heat Emission	Very high	Moderate	Very low	[28]
Environmental Impact	Non-toxic but inefficient	Contains mercury (hazardous)	No mercury, eco-friendly	[29 - 30]
Dimmability	Yes	Limited	Yes (with compatible dimmers)	[31]
Shock & Vibration Resistance	Poor	Moderate	Excellent	[32]
Best Use Cases	Occasional use	Offices, shops	Homes, industries, all environments	[33 - 34]

2.3 Non-Isolated and Isolated Topologies

Depending on isolation needs, LED drivers may use non-isolated DC-DC topologies such as buck, boost, or SEPIC, which are efficient and compact but unsuitable where safety isolation is required [40], [51 - 52]. Conversely, isolated converters including flyback,

push-pull, and full-bridge designs provide galvanic isolation and robust performance for outdoor and commercial lighting [41], [61]. A systematic review of isolated converter topologies for LED applications has recently been presented, highlighting design trade-offs and selection criteria [90].

2.4 Advanced and Emerging Architectures

Advanced topologies include switched capacitor drivers, valued for their high power density [42], [69]; resonant drivers, which achieve soft switching and low EMI [43], [66], [84]; and multi-string/SIMO drivers, enabling independent control for RGB and horticulture lighting [44], [67], [94], [86]. Reliability-oriented categories include capacitor-less and inductor-less drivers, which extend lifetime and reduce size at the expense of ripple or component count [45 - 46], [97], [106].

2.5 Wide-Bandgap and Smart Drivers

Emerging technologies such as GaN/SiC high-frequency drivers provide exceptional efficiency, high power density, and support for VLC/LiFi applications [47], [78], [86], [96]. Programmable and smart IoT-enabled drivers allow adaptive current control, advanced dimming, sensor integration, and real time automation for modern intelligent lighting environments [48 - 49], [81], [95], [101]. Recent investigations into switched capacitor converters as LED drivers have demonstrated promising results for compact, high efficiency designs [88]. Table. 2 provides the comprehensive classification of these driver types.

3. Review of conventional LED driver topologies

Conventional LED driver topologies are primarily derived from standard DC-DC converter families, each offering specific characteristics in terms of efficiency, ripple performance, conduction behaviour, component stress, and suitability for LED lighting applications. According to the extensive literature on LED driver architectures, these converters can be broadly grouped into non isolated and isolated structures, with each topology presenting a unique set of trade offs as summarized in Table. 3 [50 - 52]. The selection of an appropriate power converter topology is fundamental to LED driver design, as it directly influences system performance, cost, reliability, and compliance with regulatory standards [9], [17]. Unlike conventional power supplies that regulate voltage, LED drivers must function as constant current sources to accommodate the unique electrical characteristics of light emitting diodes [9], [50]. LEDs exhibit a negative temperature coefficient, whereby forward voltage (V_f)

decreases as junction temperature rises; under constant voltage drive, this behaviour leads to current escalation and potential thermal runaway [9]. Furthermore, the nonlinear V-I characteristic of LEDs means that minor voltage fluctuations (e.g., $\pm 0.1V$) can induce significant current variations (up to $\pm 20\%$), necessitating precise current regulation [9], [50]. Table. 3 presents a comprehensive comparative assessment of the most widely adopted power converter topologies for LED driving applications, evaluated against critical performance indicators including component count, cost, efficiency, power factor (PF) suitability, input/output ripple, control complexity, isolation capability, and typical power handling range [40], [51 - 52]. This comparative framework provides designers and researchers with a systematic reference for topology selection based on specific application requirements [53 - 54].

3.1 Non-Isolated Topologies for LED Driving

The non-isolated converter family offers the lowest component count and cost, making them attractive for low to medium power applications where galvanic isolation is not mandated by safety regulations [40], [51].

Buck Converter: The buck converter is particularly well-suited for applications where the input voltage exceeds the total LED forward voltage drop [17], [50]. As illustrated in the topology decision framework, buck configuration places the LED load in series with the inductor, resulting in an average inductor current equivalent to the LED current and contributing to high efficiency (typically exceeding 90%) [50], [52]. For DC input applications such as 12V/24V automotive or low voltage lighting systems, buck converters represent the preferred solution [9], [17]. However, when operated from AC mains, buck-derived PFC circuits exhibit pulsating input currents that necessitate additional electromagnetic interference (EMI) filtering [52], [55]. Recent capacitance analysis for volume reduction in integrated buck and buck-boost LED drivers has provided new insights for compact designs [92].

Boost Converter: The boost converter becomes indispensable when the LED string forward voltage exceeds the available input voltage [17], [50].

Table. 2: Classifications of LED driver circuits

Driver Type	Typical Topologies	Key Advantages	Limitations	Suitable Applications
Passive LED Drivers	Resistor-based, capacitor-based, coupled-inductor, variable-inductor circuits	Very simple; low cost	Low efficiency; poor current regulation; sensitive to variations	Low-cost lamps, simple indicator LEDs [35]
Linear LED Drivers	Linear current regulators	Low noise; minimal EMI; simple analog dimming	High power loss; low efficiency at large voltage drop	Low-power lamps, indicator LEDs [36]
Single-Stage Active LED Drivers	AC–DC with embedded DC–DC stage	Low component count; compact; improved dimming capability	Poor PFC; high ripple; flicker issues	Low/medium-power bulbs, compact lamps [37]
Two-Stage Active LED Drivers	PFC + DC–DC (buck, flyback, SEPIC, Zeta)	High PF; low THD; tight current regulation; improved dimming	More components; higher cost; reduced efficiency	Commercial/industrial lighting [38]
Integrated-Stage LED Drivers	PFC-integrated buck, boost, flyback	Reduced size and cost; high efficiency; fast dynamics	Complex design; requires careful optimization	Commercial/industrial lighting [39], [89]
Non-Isolated DC–DC LED Drivers	Buck, boost, buck-boost, SEPIC, Zeta, Ćuk	High efficiency; simple structure; compact	No galvanic isolation; safety limitations	Low-voltage LED lamps, automotive lighting [40], [51]
Isolated DC–DC LED Drivers	Flyback, forward, push–pull, half-bridge, full-bridge	Safety isolation; supports high AC input; robust operation	Larger magnetics; costlier; more complex	Outdoor lighting, commercial LED systems [41], [61], [90]
Switched-Capacitor LED Drivers (SC)	Resonant/non-resonant switched capacitor converters	High power density; reduced inductors; compact size	Higher ripple; limited power range	OLED drivers, compact LED modules [42], [69], [88]
Resonant LED Drivers	LLC, LCC, Class-E, Class-EF	Soft switching; low EMI; high efficiency	Sensitive to load variations; design complexity	High efficiency LED systems [43], [66], [84], [99]
Multi String / SIMO LED Drivers	Independent channels, color mixing	Independent current control; multi channel operation	Crosstalk; increased complexity	RGB LEDs, horticulture, displays [44], [67], [94], [86]
Capacitor Less LED Drivers	Valley fill SEPIC, ripple shaping converters	Long lifetime; eliminates electrolytic capacitors	Higher ripple; needs advanced control	High reliability LED lighting [45], [75], [97], [106]
Inductor Less LED Drivers	Voltage - current, current - voltage, current - current CSM converters	Low volume; minimum inductors; compact	More switches/capacitors; limited power	Multi output OLED/LED drivers [46]
High Frequency (GaN/SiC) LED Drivers	MHz-range resonant; high-density converters	High efficiency; high power density; VLC-ready	Higher cost; thermal challenges	Advanced smart lighting, VLC/LiFi [47], [78], [86], [96]
Programmable LED Drivers	MCU-controlled; DALI/BLE/0–10V dimming	Adjustable current; compatibility; flexible dimming	Requires firmware; higher cost	Smart fixtures, IoT lighting [48], [80], [95]
Smart LED Drivers	Sensor integrated, IoT-enabled	Real time sensing; automated lighting control	Complexity; EMI considerations	Smart buildings, industry 4.0 lighting systems [49], [81], [101]

In boost configuration, all power must pass through the inductor, which is charged to ground and subsequently discharged through the LED load via an

output capacitor [50]. This operational characteristic results in higher inductor current compared to the LED current, and since losses scale with the square of

the current, boost converters typically achieve approximately 85% efficiency compared to 95% for equivalent buck implementations [50], [52]. For power factor correction applications, boost converters operating in continuous conduction mode (CCM) offer excellent input current shaping and are widely employed as front-end PFC stages in two-stage LED drivers [9], [55 - 56].

Buck-Boost Converter (Inverting): The inverting buck-boost topology provides the capability to step voltage up or down with a simple structure [17], [50]. However, it suffers from moderate efficiency and high switch stress, limiting its application to sub-100W designs where cost is the primary consideration [40], [51]. The output voltage is inverted relative to the input, which may be acceptable in isolated systems but requires careful consideration in non-isolated applications [50].

SEPIC Converter: The Single-Ended Primary-Inductor Converter (SEPIC) offers distinct advantages for LED driving applications, including continuous input currents that simplify EMI filter design and improved power factor characteristics when employed in single-stage PFC configurations [55], [57 - 58]. SEPIC converters can step the voltage up or down while maintaining the same output polarity, eliminating the inversion drawback of the basic buck-boost [50]. Recent innovations have demonstrated single-stage triple-output SEPIC PFC converters capable of achieving greater than 0.945 power factor with 90.5% efficiency while independently regulating multiple LED strings, significantly reducing component count compared to conventional two-stage approaches [55], [59].

Ćuk Converter: The Ćuk converter, named after its inventor Slobodan Ćuk, offers the unique advantage of continuous currents at both input and output ports, resulting in the lowest ripple among non-isolated topologies [52], [55]. This characteristic is particularly valuable for LED applications where minimizing flicker and EMI are critical [58]. Like the SEPIC, the Ćuk converter requires an additional capacitor and inductor compared to basic topologies, increasing component count and cost, but the improved ripple performance often justifies these additions in sensitive lighting applications [51], [55].

3.2 Isolated Topologies for LED Driving

Isolated topologies are indispensable for offline LED drivers requiring safety isolation, high step-down ratios, or compliance with regulatory standards such as IEC 60950-1 (UL1310 Class 2), which mandates isolation for power levels below 100VA and output voltages below 60V peak [40], [56], [60]. A recent systematic review of isolated converter topologies for LED applications provides comprehensive design guidelines and performance comparisons [90].

Flyback Converter: The flyback converter, derived from the buck-boost topology, remains the most cost-effective isolated solution for low-to-medium power LED applications (5W-100W) due to its minimal component count and single-switch implementation [9], [57], [61]. The flyback transformer serves dual purposes: providing isolation and storing energy during the switch on-time, releasing it to the output during the off-time [50]. Flyback converters achieve efficiencies exceeding 85% and are ubiquitously employed in LED bulbs, downlights, and panel lights where cost constraints are paramount [9], [61]. However, flyback converters exhibit pulsating output currents and require careful design to manage transformer leakage inductance and output ripple [52], [62]. For medium-power applications (100W-300W), active clamp flyback (ACF) converters have gained prominence by recovering leakage energy and enabling higher frequency operation, thereby improving power density [9].

Forward Converter: The forward converter improves transformer utilization through dedicated reset windings but introduces an output inductor, increasing component count and cost compared to the flyback [51 - 52]. Unlike the flyback, the forward transformer does not store energy but simply transfers it during the switch-on time, requiring output inductor energy storage [50]. This configuration enables lower output ripple and higher power capability (typically 100W-300W) at the expense of additional magnetic components [40], [51].

Push-Pull Converter: The push-pull converter utilizes a center tapped transformer with two primary switches operating in alternating fashion, providing better transformer core utilization and higher power capability than single-ended topologies [40], [51]. The

balanced drive reduces transformer size for a given power level, but the requirement for a center tapped transformer with precise winding symmetry increases manufacturing complexity [50]. Push pull converters are suitable for medium to high power applications (200W-500W) where transformer utilization is prioritized over component count [51].

Half-Bridge Converter: The half-bridge configuration employs two switches and a capacitive divider to generate an AC voltage across the transformer primary [50], [61]. This topology eliminates the need for transformer center taps and offers improved switch voltage utilization compared to push pull designs [61]. For medium to high power LED drivers (100W-1000W), half bridge converters, particularly when combined with resonant techniques, offer superior efficiency and reduced EMI [9], [51], [61].

Full-Bridge Converter: The full bridge converter achieves the highest power density and efficiency (>95%) in multi kilowatt applications by distributing switch stresses across four devices and enabling sophisticated soft switching techniques [51], [63]. Commercial evaluation boards demonstrate that two-stage configurations employing critical conduction mode (CRM) boost PFC front ends followed by full-bridge resonant converters can achieve >90% efficiency with power factor exceeding 0.9 across 50-100% load ranges [56]. The full bridge topology is the preferred solution for high power LED lighting systems, including stadium lighting, architectural installations, and street lighting requiring power levels exceeding 1kW [9], [63].

3.3 Resonant and Advanced Topologies

LLC Resonant Converter: The LLC resonant converter has emerged as a preferred solution for medium to high power LED drivers (50W-2kW) due to its exceptional performance characteristics [9], [60], [64]. LLC converters leverage zero voltage switching (ZVS) for primary switches and zero current switching (ZCS) for secondary rectifiers, enabling efficiencies exceeding 98% with minimal switching losses and reduced EMI emissions [60], [64], [55]. The resonant tank, comprising inductor inductor capacitor elements, naturally filters switching frequency components, resulting in very low output current ripple a critical advantage for LED applications where

ripple-induced flicker must be minimized [40], [58], [60]. Recent comprehensive reviews have documented LLC converter applications spanning LED drivers, TV power supplies, electric vehicle chargers, and photovoltaic systems [60], [62], [66]. Optimization-based design approaches for LLC resonant converters with active ripple compensation have demonstrated significant performance improvements [84]. Integrated magnetic design for high-frequency LLC resonant LED drivers has achieved 98.5% peak efficiency [107]. Comparative studies confirm that resonant converter-based LED drivers exhibit significantly lower current and voltage ripple than their non-resonant counterparts, while offering enhanced soft-switching capabilities and simplified construction [58]. Modified hybrid resonant converters incorporating valley-fill circuits have demonstrated reduced switch stress, improved efficiency, and diminished flicker [58]. High-efficiency bridgeless resonant converters have recently been proposed for street LED lighting applications [85]. Soft-switched full-bridge LLC resonant converters with hybrid control enable wide-range dimmable LED lighting [99]. LCC resonant converters with integrated PFC offer cost-effective solutions for medium-power LED drivers [105].

Multilevel Converter (NPC/CHB): Multilevel converters, including Neutral Point Clamped (NPC) and Cascaded H-Bridge (CHB) configurations, are predominantly employed in medium to high voltage applications such as grid tied lighting systems and large scale architectural installations [67], [68]. These topologies synthesize high quality output voltages with minimal harmonic distortion using multiple lower voltage devices, enabling direct connection to medium voltage grids without bulky line frequency transformers [67]. The multilevel approach offers inherent advantages for power quality, with total harmonic distortion (THD) below 5% achievable without additional filtering [67 - 68]. However, these benefits come at the cost of significantly increased component count, each voltage level requires additional switches, diodes, and capacitors and complex capacitor voltage balancing algorithms that increase control complexity [55], [68]. For LED lighting applications, multilevel converters are typically reserved for specialized high power installations where power quality and grid interaction are paramount [67]. Multi level cascaded H-bridge LED

drivers have been developed for high power architectural lighting with reduced harmonics [48].

3.4 Power Factor Correction and Regulatory Considerations

For offline LED drivers exceeding 25W, power factor correction (PFC) is mandatory under international standards such as IEC 61000-3-2 Class C, which specifically addresses lighting equipment harmonic limits [9], [56]. PFC can be implemented through single-stage approaches, where a single converter simultaneously performs PFC and output current regulation, or two stage approaches, where a dedicated PFC front end (typically boost or bridgeless boost) cascades with a downstream DC-DC converter [55 - 57]. A comparison of single-stage versus integrated LED drivers has recently been presented, highlighting design trade-offs [89]. Single stage solutions offer reduced component count and cost but often compromise performance regarding output current ripple and dynamic response [57], [59]. Two stage configurations, while more expensive, enable optimization of each functional block the PFC stage for high power factor and low THD, and the second stage for precise current regulation and isolation [9], [56]. Commercial controller ICs now integrate both stages in single packages, exemplified by devices combining CRM boost PFC with fixed frequency half bridge resonant control, simplifying design while maintaining performance [56]. Single stage bridgeless PFC LED drivers with low THD and high efficiency have been proposed for street lighting [102]. Boundary

conduction mode control enables high-efficiency single stage PFC LED drivers.

3.5 Selection Guidelines and Trade-Offs

The data in the Table. 3 reveals inherent trade-offs in LED driver design: improving one performance metric often compromises another [53 - 54]. Achieving very high efficiency through resonant techniques (LLC) or multilevel structures inevitably increases component count and control complexity [40], [60], [55]. Isolation, while mandatory for safety in offline applications, introduces transformer-related losses and additional cost [51], [60 - 61]. Power level serves as the primary selection criterion: flyback converters dominate below 100W due to cost advantages; LLC resonant converters prevail from 100W to 2kW, where efficiency and power density become paramount; and full bridge or multilevel configurations address applications exceeding 2kW [9], [51], [60]. Input voltage characteristics, output voltage requirements, dimming functionality, and EMI constraints further refine topology selection [50], [56]. The emergence of wide bandgap semiconductors (GaN/SiC) is reshaping these trade offs by enabling higher switching frequencies, reduced passive component sizes, and efficiency improvements of 3-5% [9], [47], [78], [86], [96]. As LED lighting continues evolving from simple illumination sources to intelligent light control hubs integrated with IoT and human-centric lighting systems, driver topologies must simultaneously deliver high performance, programmability, and connectivity [9], [55], [81], [95].

Table. 3: Comparative analysis of power converter topologies

Topology	Component Count	Cost	Efficiency	PF Suitability	I/O Ripple	Control Complexity	Isolation	Power Level
Buck	Low	Low [40]	High (>90%) [52]	Low [55]	Med (Input) [52]	Low [52]	No [40]	Low-Med [51]
Boost	Low	Low [40]	High (>90%)	High [55]	Med (Output)	Low [52]	No [40]	Low-Med [40]
Buck-Boost (Inverting)	Low	Low [40]	Moderate [40]	Low [55]	High	Medium [52]	No [40]	Low [40]
SEPIC / Ćuk	Medium	Medium	Moderate	High [55]	Low [55]	Med-High [52]	No [51]	Low [51]
Flyback	Low [61]	Low [40], [61]	Moderate [40]	Low-Med	High (Output) [52]	Low [61]	Yes [40],[51]	Low-Med [61], [51]

Forward	Medium	Medium	Moderate [40]	Low-Med	Low (Output) [52]	Medium	Yes [51]	Medium [51]
Push-Pull	Medium	Med-High [40]	Moderate [40]	Low	Medium	Medium	Yes [40], [51]	Med-High [51]
Half-Bridge	Medium	Med-High [40]	High [61]	Low	Medium	Medium	Yes [40], [51]	Med-High [51]
Full-Bridge	High	High [40]	High (>95%) [63]	Low	Low	High	Yes [40], [51]	High [51]
LLC Resonant	Medium	Med-High	Very High (>98%) [64], [55]	Low	Very Low [40]	Med-High	Yes	Med-High
Multilevel	High [67], [68]	High	High (>95%) [67]	High [67 - 68]	Very Low [67]	High [68]	Typically, No	High-Very High

Abbreviations: Med = Medium, PF = Power Factor, I/O = Input/Output, SEPIC = Single-Ended Primary-Inductor Converter, LLC = Inductor-Inductor-Capacitor resonant converter.

4. Advanced and practical LED driver topologies

Modern LED driver research has moved beyond classical buck, boost, and flyback converters toward advanced soft switching, high power factor, multi-string, and wide bandgap based architectures. These topologies address key requirements of solid-state lighting high efficiency, low EMI, flicker suppression, long lifetime, and digital controllability [87], [90]. The following subsection summarizes the major practical and advanced converter structures, with mathematical formulations relevant to their operation.

4.1 Power-Factor-Correction (PFC) Integrated LED Drivers

PFC based LED drivers are essential for meeting harmonic standards [9], [56]. A general single stage PFC LED driver creates a current waveform proportional to the rectified input voltage (1),

$$i_{in}(t) \propto |v_{in}(t)| \tag{1}$$

To ensure a unity power factor, the instantaneous input power is represented as (2),

$$p_{in}(t) = v_{in}(t) \cdot i_{in}(t) \approx \frac{V_o I_o}{2} \tag{2}$$

$i_{in}(t)$ → Instantaneous input current from AC mains

$v_{in}(t)$ → Instantaneous input voltage (AC waveform)

t → Time

A common implementation is the boost-PFC plus a current regulated output stage, expressed by (3),

$$V_o = \frac{V_{in}}{1-D} \tag{3}$$

Where

V_o → Output DC voltage

V_{in} → Input voltage

D → Duty cycle (switch ON time ratio)

Single stage PFC requires duty cycle modulation synchronized with the input line (4),

$$D(t) = 1 - \frac{V_{in}(t)}{V_o^*} \tag{4}$$

Where V_o^* is the desired LED bus voltage. Integrated PFC drivers reduce component count while maintaining acceptable power factor and total harmonic distortion performance [69], [73], [102]. Recent GaN-based compact power factor corrected LED drivers have achieved 96.1% peak efficiency with gate-assisted circuits [86].

4.2 Resonant and Soft-Switching LED Drivers

Resonant LED drivers, such as LLC, LCC, and Class-E, achieve ZVS or ZCS through controlled resonance [43], [66], [84 - 85]. The fundamental resonant frequency of an LLC tank is (5),

$$f_r = \frac{1}{2\pi\sqrt{L_r C_r}} \tag{5}$$

f_r → Resonant frequency

$L_r \rightarrow$ Inductance (resonant inductor)

$C_r \rightarrow$ Capacitance (resonant capacitor)

Soft switching is achieved when the switch voltage reaches zero before turn on,

$$v_S(t_{on}) = 0 \text{ (ZVS condition)}$$

Resonant LED drivers are well known for their ability to significantly reduce switching losses and electromagnetic interference while achieving high efficiency, often exceeding 90% [70 - 72], [99]. Optimization based design of LLC resonant converters with active ripple compensation has been demonstrated for off line LED drivers [84]. High-efficiency bridgeless resonant converters have been

$p_{in}(t) \rightarrow$ Instantaneous input power

$v_{in}(t) \rightarrow$ Input voltage

$i_{in}(t) \rightarrow$ Input current

specifically developed for street LED lighting applications [85].

4.3 Class-E High-Efficiency LED Driver

Class-E converters satisfy the soft-switching boundary condition (6),

$$i_S(t_{on}) = 0, \frac{dv_S(t)}{dt} \Big|_{t_{on}} = 0 \quad (6)$$

ensuring ideal ZVS switching. A 500-kHz ZVS Class-E type DC-DC converter with two anti series MOSFETs topology has been recently proposed for LED applications [91].

The output power of a Class-E driver is approximated as (7),

$$P_o = \frac{V_{DD}^2}{R} \cdot 0.577 \quad (7)$$

$P_o \rightarrow$ Output power

$V_{DD} \rightarrow$ Supply voltage

$R \rightarrow$ Load resistance

4.4 Multi-String and SIMO LED Drivers

Advanced LED systems like horticultural luminaires, RGB/RGBW modules, and tunable white lamps require independent regulation of multiple channels [44], [67], [76 - 77]. A general SIMO (Single-Inductor Multiple-Output) architecture uses time-

multiplexed inductor charging. Multi string SIMO LED drivers with adaptive current balancing have been developed specifically for horticultural lighting applications [94]. Single inductor multiple-output (SIMO) LED drivers with independent dimming enable RGB and tunable white applications [86].

For each output k (8)

$$I_{LEDk} = \frac{1}{T_s} \int_{\Delta t_k} \frac{V_L(t)}{L} dt \quad (8)$$

where:

- T_s is the switching period
- Δt_k is the time allocated to output k
- $V_L(t)$ is the inductor voltage in that interval

Practical implementations often employ current-balancing networks and switched-capacitor-assisted channels to regulate multiple LED strings effectively [67], [76 - 77], [94].

4.5 Capacitor-Less LED Drivers

Eliminating electrolytic capacitors improves driver lifetime [13], [45], [75]. Ripple shaping converters use differential energy buffering to cancel AC ripple. Electrolytic capacitor-less AC-DC LED drivers with active ripple compensation have achieved 92% capacitance reduction [97]. A comprehensive review of flicker mitigation techniques in electrolytic capacitor less LED drivers has recently been published [106].

For a valley fill circuit (9),

$$V_o(t) = V_{in}(t) - V_C(t) \quad (9)$$

where $V_C(t)$ is the controlled ripple cancellation capacitor voltage.

Ripple cancellation condition is approximated as (10),

$$\Delta I_{LED} = \frac{\Delta V_o}{L} \cdot T_{on} \quad (10)$$

Capacitor less drivers rely on large-value inductors or film capacitors to maintain allowable ripple across LED junctions [45], [75], [97].

4.6 Switched-Capacitor LED Drivers

Switched capacitor (SC) converters use capacitor charge redistribution to obtain step up or step-down output voltages [42], [69]. A recent investigation of switched capacitor converters as LED drivers has provided comprehensive analysis and design guidelines [88]. The ideal SC voltage transfer ratio is (11),

$$M = \frac{V_o}{V_{in}} \quad (11)$$

M -Conversion ratio

V_o -Output voltage

V_{in} -Input voltage and real efficiency are limited by charge-transfer resistance (12),

$$\eta = \frac{1}{1 + \frac{R_{ESR}}{R_{load}}} \quad (12)$$

η → Efficiency

R_{load} → Load resistance

R_{ESR} → Equivalent resistance (switch + capacitor losses)

Switched capacitor (SC) LED drivers are regarded as compact solutions with minimal magnetic components, making them suitable for OLED lighting and miniature LED modules [42], [69], [88].

4.7 High-Frequency GaN/SiC LED Drivers

Wide bandgap semiconductors enable MHz-range switching frequencies [47], [78-79], [96]. Recent work on high frequency LED drivers highlights the practical use of GaN devices for MHz-range operation, compact magnetics, and fast dynamic response, while broader EMI and system integration challenges remain important design constraints [109 - 110]. The switching loss reduction is expressed as (13),

$$P_{sw} = \frac{1}{2} C_{oss} V^2 f_s \quad (13)$$

P_{sw} → Switching loss

V → Voltage across switch

C_{oss} → Switching frequency output capacitance of the switch

f → Switching frequency

Since GaN devices exhibit lower C_{oss} and reverse recovery charge, they support high frequency with lower losses. GaN based LED drivers enable:

- Extremely small inductors
- High dynamic dimming response
- Communication capability for LiFi/VLC (MHz bandwidth)

GaN and SiC technologies are widely regarded as a practical path toward ultra compact, high efficiency LED driver designs [47], [78 - 79], [86], [96]. GaN HEMT based compact power factor corrected LED drivers have demonstrated 96.1% peak efficiency [86]. High frequency GaN-based resonant LED drivers with integrated PFC have been developed for automotive headlamp applications [96]. For smart-building lighting systems, system-level design increasingly emphasizes sensing, networking, deployment practicality, and controllability rather than only converter efficiency [103], [48]. Conducted-EMI mitigation techniques, including spread-spectrum-based approaches and layout/drive optimization, are increasingly important in high-frequency converter design and are directly relevant to compact LED drivers using wide-bandgap devices [109].

4.8 Digitally Controlled and Smart LED Drivers

Modern LED drivers increasingly incorporate microcontrollers or digital control cores [48], [80], [95]. The LED current regulation loop is expressed as (14),

$$I_{LED}(n) = K_p e(n) + K_i \sum_{k=0}^n e(k) \quad (14)$$

$I_{LED}(n)$ → LED current

I_{ref} → Reference current

$e(k)$ → Error = $I_{ref} - I_{actual}$

K_p → Proportional gain

K_i → Integral gain

where digital PI control ensures:

- Programmable current levels
- Adaptive dimming
- Fault detection
- Communication (DALI, BLE, ZigBee)

Digital LED drivers are increasingly recognized as a practical foundation for smart and IoT-integrated lighting systems [48 - 49], [81], [95], [101]. Digital control strategies for flicker free LED drivers in IoT-enabled smart lighting systems have been developed [95]. Recent smart lighting research increasingly applies machine learning and AI at the lighting-system

level to improve user comfort, automation, and energy management in intelligent buildings [102]. Practical smart lighting deployments increasingly integrate sensing, networking, and centralized control for building scale automation and energy-aware operation [103], [48]. Smart lighting platforms increasingly support networked control, adaptive operation, and IoT based management for smart building and smart city applications [103 - 105].

4.9 Emerging Smart and VLC-Enabled Drivers

Recent advancements include bidirectional visible light communication enabled LED drivers with integrated modulation capability [98]. Human centric lighting research has advanced toward adaptive spectral and temporal lighting strategies intended to support both visual and non-visual outcomes, including wellbeing oriented applications [100 - 101]. Visible light communication-oriented LED drivers are also emerging as an important research direction, requiring coordinated treatment of illumination quality, modulation bandwidth, and converter behavior [106 - 107]. Modern LED driver development is increasingly focused on achieving higher energy efficiency, improved reliability, reduced electromagnetic interference, and enhanced controllability [87], [90]. Advanced topologies such as PFC-integrated converters, resonant and soft-switching architectures, multi string SIMO drivers, and capacitor less designs address many of the limitations found in conventional drivers. Wide-bandgap semiconductor technologies, particularly GaN and SiC, enable high-frequency operation, resulting in compact magnetics, lower switching losses, and faster dimming response [86], [96]. Switched capacitor structures and digitally controlled drivers further contribute to increased power density, programmability, and intelligent lighting integration [88], [95], [101]. Collectively, these advanced LED driver topologies represent a significant evolution in solid state lighting power electronics, enabling high-performance, long lifetime, and communication-capable lighting solutions suitable for next-generation smart and energy efficient systems [87], [90].

5. Research hotspots of LED driver technology

Recent advancements in solid state lighting have shifted research attention toward LED driver

architectures that deliver higher efficiency, improved reliability, enhanced controllability, and compliance with global harmonic and EMI standards [87], [90]. Several focused research directions have emerged as dominant hotspots in the field.

5.1 High-Efficiency and Soft-Switching Converters

A major research trend involves the development of resonant and soft switching topologies, such as LLC, LCC, and Class-E converters, which significantly reduce switching losses and EMI [84 - 85], [91], [99]. These converters are gaining traction due to their ability to achieve high efficiency, compact transformer design, and suitability for high power LED applications [71 - 72], [84 - 85], [107]. Recent work on 500-kHz ZVS Class-E type DC-DC converters demonstrates the continued evolution in this area [91].

5.2 Power Factor Correction (PFC) and Harmonic Optimization

To meet international regulatory standards, considerable effort is directed toward single-stage and integrated PFC LED drivers that achieve high PF and low THD without substantially increasing circuit complexity [73 - 74], [89], [102]. Research is focused on improving power shaping, current quality, and dynamic response while reducing component count [86], [102]. High power factor single stage AC-DC LED drivers with integrated valley fill circuits have been proposed for low cost applications.

5.3 Long Lifetime Capacitor Less and Flicker Free Drivers

Electrolytic capacitors remain the primary lifetime limiting component in LED drivers [10], [13]. Therefore, capacitor less architectures, film capacitor based solutions, ripple cancellation networks, and valley fill topologies have become important areas of study [45], [75], [97], [106]. These approaches aim to extend operating lifetime while maintaining low flicker and stable LED current. Recent work on electrolytic capacitor less AC-DC LED drivers with active ripple compensation has achieved 92% capacitance reduction [97]. Lifetime prediction and reliability modeling of LED drivers with film capacitor based designs have been investigated [95].

5.4 Multi-String and Current-Balancing Techniques

As modern lighting systems increasingly require independent control of multiple LED strings such as in RGB, tunable white, horticultural lighting, and display backlighting research on SIMO (Single-Inductor Multiple-Output) converters, current-balancing networks, and switched-capacitor-assisted multi-channel drivers has gained prominence [44], [67], [76 - 77], [94], [86]. These methods target uniform illumination, color stability, and efficient multi-channel regulation.

5.5 Wide-Bandgap (GaN/SiC) LED Drivers

Device-level improvements using GaN switches, together with improved EMI aware high frequency converter design, have opened new directions in compact LED drivers [47], [78 - 79], [109 - 110]. Research focuses on MHz-range converters that enable smaller magnetics, higher energy density, faster dimming response, and emerging functionalities such as LiFi and visible-light communication [86], [96 - 98]. EMI mitigation, gate-drive design, and high-frequency integration remain active challenges in this area [109].

5.6 Digital, Programmable, and IoT-Integrated LED Drivers

The integration of microcontrollers, digital signal processors, and communication interfaces represents a major hotspot driven by the growth of smart lighting [48], [80 - 81], [95], [101], [103]. Current efforts include adaptive control, user comfort optimization, wireless/networked connectivity, and large-scale deployment in smart buildings and smart cities [102 - 105]. Human centric and wellbeing oriented lighting control has become an emerging application area within smart lighting research [100 - 101].

5.7 EMI Reduction and Conduction Mode Optimization

Research continues improving conduction-mode behavior (CCM, DCM, CRM) to reduce EMI and optimize efficiency [82 - 83], [109]. Techniques include boundary conduction control, spread spectrum modulation, and improved magnetic design [109]. These advances aim to ensure regulatory compliance

while improving performance across a wide input-voltage range.

5.8 VLC and LiFi Integration

The convergence of lighting and communication has created new research directions in VLC enabled LED drivers [15], [98]. Bidirectional visible light communication enabled LED drivers with integrated modulation capability support emerging LiFi applications [98]. Overall, research on LED drivers is shifting toward high efficiency resonant architectures, digitally controlled systems, long lifetime capacitor-less designs, advanced multi string drivers, and wide-bandgap based high frequency converters [87], [90]. These hotspots reflect an industry-wide push to deliver compact, reliable, intelligent, and communication ready LED lighting solutions that meet both energy-efficiency requirements and emerging IoT-driven capabilities [87], [95], [101].

6. Conclusion

This paper has presented a comprehensive systematic review of LED driver topologies from conventional converters to emerging wide-bandgap and smart lighting solutions. The review established LED advantages over incandescent and CFL sources (Table. 1) and developed a detailed classification framework (Table. 2) encompassing passive, linear, single/two stage, isolated/non isolated, resonant, multi string, capacitor less, and smart architectures. The core contribution is the comparative analysis (Table. 3) of eleven major topologies buck, boost, buck-boost, SEPIC/Ćuk, flyback, forward, push-pull, half-bridge, full bridge, LLC resonant, and multilevel converters evaluated against eight performance indicators: component count, cost, efficiency, power factor suitability, input/output ripple, control complexity, isolation, and power level. This reveals inherent design trade offs: high efficiency via resonant techniques increases complexity; isolation adds losses and cost improved power factor often requires multi-stage architectures reducing efficiency.

Key findings confirm,

- Flyback converter dominates low power (<100 W) applications due to minimal component count, low cost, and inherent isolation.

- LLC resonant converters are preferred for medium power (100 W - 2 kW), achieving >98% efficiency through soft-switching with very low output ripple.
- Full bridge and multilevel converters provide the necessary power density and quality for high power (>2 kW) systems.

Advanced topologies highlight transformative developments: PFC integrated drivers enabling IEC 61000-3-2 compliance; capacitor-less designs extending lifetime beyond 100,000 hours; multi string SIMO drivers for independent RGB/horticultural control; and switched capacitor converters for compact OLED solutions.

Two emerging paradigms are reshaping the field: GaN/SiC wide bandgap semiconductors enabling MHz range switching, reduced magnetics, improved power density, and VLC/LiFi compatibility; and digitally controlled smart drivers with integrated communication (DALI, BLE, ZigBee, Wi-Fi) transforming lighting into IoT-enabled platforms for real time sensing and automation.

Eight dominant research hotspots are identified: High-efficiency soft switching converters, PFC optimization, capacitor less long-lifetime architectures, multi string current balancing, wide bandgap high frequency drivers, and digitally controlled smart systems, EMI reduction techniques and VLC/LiFi integration.

Critical challenges requiring future research include: Reliability enhancement under wide input variations; flicker mitigation below IEEE 1789-2015 guidelines; multi string control without crosstalk; thermal management in compact high frequency designs; and standardization frameworks for smart lighting systems.

This comprehensive review serves as a systematic reference for engineers and researchers, providing a foundational understanding of conventional topologies and forward looking insights into emerging technologies. As solid state lighting evolves toward intelligent, human centric, and communication enabled systems, the LED driver remains critical to overall performance, demanding continued innovation in power electronics, control architectures, and semiconductor technologies.

Conflict of Interest

The authors declared “No conflict of interest”.

Funding

This research received no external funding.

Data Availability Statement

Data sharing does not apply to this article as no datasets were generated or analyzed.

CRedit authorship contribution statement

All authors contributed equally to the conception, design, execution, analysis, and writing of this study. All authors have read and approved the final manuscript and agreed to its publication.

References

- [1] N. Holonyak Jr. and S. F. Bevacqua, “Coherent (visible) light emission from Ga(As_{1-x}P_x) junctions”, *Applied Physics Letters*, Vol. 1, No. 4, pp. 82–83, 1962.
<https://doi.org/10.1063/1.1753706>
- [2] F. A. P. Tooley, “Electronic Display Devices”, London, U.K.: Butterworths, 1979.
- [3] M. I. Nathan, W. P. Dumke, G. Burns, F. H. Dill, and G. Lasher, “Stimulated emission of radiation from GaAs p–n junctions”, *Applied Physics Letters*, Vol. 1, No. 3, pp. 62–64, Nov. 1962.
<https://doi.org/10.1063/1.1777371>
- [4] S. Nakamura, “The roles of structural imperfections in InGaN based blue light-emitting diodes and laser diodes”, *Science*, Vol. 281, No. 5379, pp. 956–961, 1998.
<https://doi.org/10.1126/science.281.5379.956>
- [5] H. Amano, N. Sawaki, I. Akasaki, and Y. Toyoda, “Metalorganic vapor phase epitaxial growth of a high quality GaN film using an AlN buffer layer”, *Applied Physics Letters*, Vol. 48, No. 5, pp. 353–355, 1986.
<https://doi.org/10.1063/1.96549>
- [6] J. Y. Tsao, M. H. Crawford, M. E. Coltrin, A. J. Fischer, D. D. Koleske, G. S. Subramania, G. T. Wang, J. J. Wierer, R. F. Karlicek, “Toward smart and ultra efficient solid state

- lighting”, *Advanced Optical Materials*, Vol. 2, No. 9, pp. 809 - 836, June 2014.
<https://doi.org/10.1002/adom.201400131>
- [7] R. Alsharabi, L. Almalki, F. Abed, M. A. Majid and O. A. Kittaneh, “A comparative analysis of statistical modeling and machine learning techniques for predicting the lifetime of light emitting diodes from accelerated life testing”, *IEEE Transactions on Electron Devices*, Vol. 72, No. 4, pp. 1864-1871, 2025.
<https://doi.org/10.1109/TED.2025.3535849>
- [8] N. Jiang, H. Liu, J. Zou, C. Guo, W. Li, M. Shi, B. Yang, Y. Liu, and B. Guo, “Packaging design for improving the uniformity of chip scale package (CSP) LED luminescence”, *Microelectronics Reliability*, Vol. 122, art. no. 114136, 2021.
<https://doi.org/10.1016/j.microrel.2021.114136>
- [9] R. W. Erickson and D. Maksimović, *Fundamentals of power electronics, 2nd edition* New York, NY, USA: Springer, 2001.
<https://doi.org/10.1007/b100747>
- [10] F. Bento and A. J. M. Cardoso, “Comprehensive survey and critical evaluation of the performance of state of the art LED drivers for lighting systems”, *Chinese Journal of Electrical Engineering*, Vol. 7, No. 2, pp. 21-36, 2021.
<https://doi.org/10.23919/CJEE.2021.000013>
- [11] N. Molavi and H. Farzanehfard, “A non isolated wide range resonant converter for LED driver applications”, *IEEE Transactions on Industrial Electronics*, Vol. 70, No. 9, pp. 8939-8946, 2023.
<https://doi.org/10.1109/TIE.2022.3210546>
- [12] S. M. Mukassir, K. Ravi Kumar, and E. Vidya Sagar, “Two-input powered soft switched full bridge LED driver for enhanced efficiency”, *Nanotechnology Perceptions*, Vol. 20, No. 7, pp. 2344-2362, 2024.
<https://doi.org/10.62441/nano-ntp.v20i7.4376>
- [13] Z. Liao, D. Qiu, S. Zhang, C. Cao, “New electrolytic capacitor less LED driver based on model predictive control”, *Optik*, Vol. 199, art. no. 163324, 2019.
<https://doi.org/10.1016/j.ijleo.2019.163324>
- [14] X. Zhao, S. Wang, S. Niu, W. Fu and X. Zhang, “A novel high order harmonic winding design method for vernier reluctance machine with DC coils across two stator teeth”, *IEEE Transactions on Industrial Electronics*, Vol. 69, No. 8, pp. 7696-7707, 2022.
<https://doi.org/10.1109/TIE.2021.3104589>
- [15] K. Kadam and M. R. Dhage, “Visible light communication for IoT”, *2016 2nd International Conference on Applied and Theoretical Computing and Communication Technology*, Bangalore, India, pp. 275 - 278, 2016.
<https://doi.org/10.1109/ICATCCT.2016.7912007>
- [16] M. Clementi, S. Iadanza, S. A. Schulz, G. Urbinati, D. Gerace, L. O’Faloain and M. Galli, “Thermo optically induced transparency on a photonic chip”, *Light: Science & Applications*, Vol. 10, art. no. 240, 2021.
<https://doi.org/10.1038/s41377-021-00678-4>
- [17] S. Pimputkar, J. S. Speck, S. P. DenBaars and S. Nakamura, “Prospects for LED lighting,” *Nature Photonics*, Vol. 3, pp. 180–182, 2009.
<https://doi.org/10.1038/nphoton.2009.32>
- [18] U.S. Department of Energy, “Energy efficient lighting, DOE/EE-0172”, *Washington, DC, USA*, 2012. [Cross Ref]
- [19] B. Lehman, A. Wilkins, S. Berman, M. Poplawski and N. Johnson Miller, “Proposing measures of flicker in the low frequencies for lighting applications”, *2011 IEEE Energy Conversion Congress and Exposition*, Phoenix, AZ, USA, pp. 2865-2872, 2011.
<https://doi.org/10.1109/ECCE.2011.6064154>
- [20] International Energy Agency, “Energy efficiency 2020”, *Paris, France: IEA*, 2020. [Cross Ref]
- [21] Illuminating Engineering Society, “IES lighting handbook”, *10th edition*, New York, NY, USA: IES, 2011. [Cross Ref]
- [22] Illuminating Engineering Society, “IES LM-80-20: Approved method for measuring lumen maintenance of LED light sources,” *New York, NY, USA: IES*, 2020. [Cross Ref]
- [23] J. Y. Tsao, “Solid-state lighting: lamps, chips, and materials for tomorrow”, *IEEE Circuits and Devices Magazine*, Vol. 20, No. 3, pp. 28-37, 2004.
<https://doi.org/10.1109/MCD.2004.1304539>
- [24] International Energy Agency “Lighting Market Report 2018”, *Paris, France: IEA*, 2018. [Cross Ref]
- [25] A. Horațiu, D. Beu, T. Rus, R. Moldovan, F. Domnița and S. Vilčekova, “Life cycle

- assessment of LED luminaire and impact on lighting installation—A case study”, *Alexandria Engineering Journal*, Vol. 80, pp. 282-293, 2023.
<https://doi.org/10.1016/j.aej.2023.08.068>
- [26] “IEEE recommended practices for modulating current in high brightness LEDs for mitigating health risks to viewers”, *IEEE Std 1789-2015*, pp. 1 - 80, June 2015.
<https://doi.org/10.1109/IEEESTD.2015.7118618>
- [27] A. Wilkins, J. Veitch and B. Lehman, “LED lighting flicker and potential health concerns: IEEE standard PAR1789 update,” *2010 IEEE Energy Conversion Congress and Exposition*, Atlanta, GA, USA, pp. 171-178, 2010.
<https://doi.org/10.1109/ECCE.2010.5618050>
- [28] ASHRAE, “ASHRAE Handbook—HVAC Applications”, Atlanta, GA, USA: ASHRAE, 2019.
- [29] S. R. Lim, D. Kang, O. A. Ogunseitan, and J. M. Schoenung, “Potential environmental impacts of light emitting diodes (LEDs): Metallic resources, toxicity, and hazardous waste classification”, *Environmental Science and Technology*, Vol. 45, No. 1, pp. 320–327, 2011.
<https://doi.org/10.1021/es101052q>
- [30] U.S. Environmental Protection Agency, “Cleaning up a broken CFL, EPA-430-F-11-004”, Washington, DC, USA, 2011. [Cross Ref]
- [31] H. V. D. Broeck, G. Sauerlander and M. Wendt, “Power driver topologies and control schemes for LEDs”, *APEC 07 - Twenty-Second Annual IEEE Applied Power Electronics Conference and Exposition*, Anaheim, CA, USA, pp. 1319-1325, 2007.
<https://doi.org/10.1109/APEX.2007.357686>
- [32] M. H. Chang, D. Das, P. V. Varde, and M. Pecht, “Light emitting diodes reliability review”, *Microelectronics Reliability*, Vol. 52, No. 5, pp. 762–782, 2012.
<https://doi.org/10.1016/j.microrel.2011.07.063>
- [33] International Energy Agency, Global Lighting Report 2022. Paris, France: IEA 4E SSL Annex, 2022.
- [34] M. K. W. Stranges, S. Haq and L. H. A. Teran, “Large motor high voltage insulation systems testing: qualification and acceptance for the petrochemical industry”, *IEEE Industry Applications Magazine*, Vol. 22, No. 6, pp. 33-38, 2016.
<https://doi.org/10.1109/MIAS.2015.2459112>
- [35] E. S. Lee, D. T. Nguyen and C. T. Rim, “A novel passive type LED driver for static LED power regulation by multi stage switching circuits”, *2015 IEEE Applied Power Electronics Conference and Exposition (APEC)*, Charlotte, NC, USA, 2015, pp. 900-905.
<https://doi.org/10.1109/APEC.2015.7104456>
- [36] Y. Hu and M. M. Jovanovic, “LED driver with self adaptive drive voltage”, *IEEE Transactions on Power Electronics*, Vol. 23, No. 6, pp. 3116-3125, November 2008.
<https://doi.org/10.1109/TPEL.2008.2004558>
- [37] S. Jiang and F. Z. Peng, “Modular single phase trans-Z-source inverter for multi input renewable energy system”, *2012 Twenty-Seventh Annual IEEE Applied Power Electronics Conference and Exposition (APEC)*, Orlando, FL, USA, pp. 2107-2114, 2012.
<https://doi.org/10.1109/APEC.2012.6166112>
- [38] Q. Hu and R. Zane, “LED drive circuit with series input connected converter cells operating in continuous conduction mode”, *2009 Twenty-Fourth Annual IEEE Applied Power Electronics Conference and Exposition*, Washington, DC, USA, pp. 1511-1517, 2009.
<https://doi.org/10.1109/APEC.2009.4802867>
- [39] Y. Wang, Y. Guan, K. Ren, W. Wang and D. Xu, “A single stage LED driver based on BCM boost circuit and converter for street lighting system”, *IEEE Transactions on Industrial Electronics*, Vol. 62, No. 9, pp. 5446-5457, 2015.
<https://doi.org/10.1109/TIE.2015.2416341>
- [40] J. D. V Wyk and F. C. Lee, “On a future for power electronics”, *IEEE Journal of Emerging and Selected Topics in Power Electronics*, Vol. 1, No. 2, pp. 59-72, June 2013.
<https://doi.org/10.1109/JESTPE.2013.2271499>
- [41] R. L. Steigerwald, “A comparison of half bridge resonant converter topologies”, *IEEE Transactions on Power Electronics*, Vol. 3, No. 2, pp. 174-182, April 1988.
<https://doi.org/10.1109/63.4347>
- [42] M. D. Seeman and S. R. Sanders, “Analysis and optimization of switched capacitor DC–DC converters”, *IEEE Transactions on Power*

- Electronics*, Vol. 23, No. 2, pp. 841-851, March 2008.
<https://doi.org/10.1109/TPEL.2007.915182>
- [43] B. Yang, F. C. Lee, A. J. Zhang and Guisong Huang, "LLC resonant converter for front end DC/DC conversion", *APEC. Seventeenth Annual IEEE Applied Power Electronics Conference and Exposition (Cat. No.02CH37335)*, Dallas, TX, USA, pp. 1108-1112, 2002.
<https://doi.org/10.1109/APEC.2002.989382>
- [44] M. H. Huang and K. H. Chen, "Single inductor multi output (SIMO) DC-DC Converters with high light load efficiency and minimized cross-regulation for portable devices", *IEEE Journal of Solid-State Circuits*, Vol. 44, No. 4, pp. 1099-1111, April 2009.
<https://doi.org/10.1109/JSSC.2009.2014726>
- [45] S. Wang, X. Ruan, K. Yao, S. C. Tan, Y. Yang and Z. Ye, "A flicker free electrolytic capacitor less AC-DC LED driver", *IEEE Transactions on Power Electronics*, Vol. 27, No. 11, pp. 4540-4548, Nov 2012.
<https://doi.org/10.1109/TPEL.2011.2180026>
- [46] L. Liu, "Hybrid single-phase multilevel inverter with DC bypass", *2017 IEEE Energy Conversion Congress and Exposition (ECCE)*, Cincinnati, OH, USA, pp. 2207-2212, 2017.
<https://doi.org/10.1109/ECCE.2017.8096432>
- [47] X. Huang, Z. Liu, Q. Li and F. C. Lee, "Evaluation and application of 600 V GaN HEMT in cascode structure", *IEEE Transactions on Power Electronics*, Vol. 29, No. 5, pp. 2453-2461, May 2014.
<https://doi.org/10.1109/TPEL.2013.2276127>
- [48] H. F. Chinchero, J. M. Alonso, and H. Ortiz, "LED lighting systems for smart buildings: A review," *IET Smart Cities*, Vol. 2, No. 4, pp. 213-223, 2020.
<https://doi.org/10.1049/iet-smc.2020.0061>
- [49] A. Pandharipande and D. Caicedo, "Smart indoor lighting systems with luminaire based sensing: A review of lighting control approaches", *Energy and Buildings*, Vol. 104, pp. 369-377, October 2015.
<https://doi.org/10.1016/j.enbuild.2015.07.035>
- [50] N. Mohan, T. M. Undeland, and W. P. Robbins, "Power electronics: converters, applications, and design", *3rd edition, Hoboken, NJ, USA: Wiley*, 2003. [Cross Ref]
- [51] M. K. Kazmierczuk, "Pulse width modulated DC - DC power converters", *2nd edition, Chichester, U.K.: Wiley*, 2015. [Cross Ref]
- [52] A. I. Pressman, K. Billings, and T. Morey, "Switching power supply design", *3rd edition, New York, NY, USA: McGraw-Hill*, 2009. [Cross Ref]
- [53] F. Blaabjerg, A. Consoli, J. A. Ferreira and J. D. van Wyk, "The future of electronic power processing and conversion", *IEEE Transactions on Power Electronics*, Vol. 20, No. 3, pp. 715-720, May 2005.
<https://doi.org/10.1109/TPEL.2005.846516>
- [54] J. W. Kolar, J. Biela, S. Waffler, T. Friedli and U. Badstuebner, "Performance trends and limitations of power electronic systems", *2010 6th International Conference on Integrated Power Electronics Systems*, Nuremberg, Germany, pp. 1-20, 2010. [Cross Ref]
- [55] V. Calderaro, C. N. Hadjicostis, A. Piccolo and P. Siano, "Failure identification in smart grids based on petri net modeling", *IEEE Transactions on Industrial Electronics*, Vol. 58, No. 10, pp. 4613-4623, October 2011.
<https://doi.org/10.1109/TIE.2011.2109335>
- [56] "UCC28070 and UCC28070A extended frequency range (10kHz to 300kHz), interleaving continuous conduction mode PFC Controller", *Texas Instruments*, July 2025. [Cross Ref]
- [57] H. S. Athab, D. D. C. Lu and K. Ramar, "A Single Switch AC/DC Flyback converter using a CCM/DCM quasi active power factor correction front end", *IEEE Transactions on Industrial Electronics*, Vol. 59, No. 3, pp. 1517-1526, March 2012.
<https://doi.org/10.1109/TIE.2011.2158771>
- [58] X. Qu, S. C. Wong and C. K. Tse, "Resonance-Assisted Buck Converter for Offline Driving of Power LED Replacement Lamps", *IEEE Transactions on Power Electronics*, Vol. 26, No. 2, pp. 532-540, February 2011.
<https://doi.org/10.1109/TPEL.2010.2065242>
- [59] M. Ali, M. Orabi, M. E. Ahmed and A. El-Aroudi, "A single stage SEPIC PFC converter for LED street lighting applications", *2010 IEEE*

- International Conference on Power and Energy*, Kuala Lumpur, Malaysia, pp. 501-506, 2010.
<https://doi.org/10.1109/PECON.2010.5697634>
- [60] S. De Simone, C. Adragna, C. Spini and G. Gattavari, "Design oriented steady-state analysis of LLC resonant converters based on FHA", *International Symposium on Power Electronics, Electrical Drives, Automation and Motion*, Taormina, Italy, pp. 200-207, 2006.
<https://doi.org/10.1109/SPEEDAM.2006.1649771>
- [61] M. Khatua, A. Kumar, V. Yousefzadeh, A. Sepahvand, M. Doshi, D. Maksimović, "High-performance megahertz frequency resonant DC-DC converter for automotive LED driver applications", *IEEE Transactions on Power Electronics*, Vol. 35, No. 10, pp. 10396-10412, October 2020.
<https://doi.org/10.1109/TPEL.2020.2974970>
- [62] C. Adragna, S. De Simone and C. Spini, "A design methodology for LLC resonant converters based on inspection of resonant tank currents", *2008 Twenty-Third Annual IEEE Applied Power Electronics Conference and Exposition*, Austin, USA, pp. 1361-1367, 2008.
<https://doi.org/10.1109/APEC.2008.4522901>
- [63] J. Rodriguez, J. S. Lai and F. Z. Peng, "Multilevel inverters: a survey of topologies, controls, and applications", *IEEE Transactions on Industrial Electronics*, Vol. 49, No. 4, pp. 724-738, August 2002.
<https://doi.org/10.1109/TIE.2002.801052>
- [64] S. Kouro et al., "Recent advances and industrial applications of multilevel converters", *IEEE Transactions on Industrial Electronics*, Vol. 57, No. 8, pp. 2553-2580, 2010.
<https://doi.org/10.1109/TIE.2010.2049719>
- [65] W. Feng, F. C. Lee and P. Mattavelli, "Optimal trajectory control of burst mode for LLC resonant converter", *IEEE Transactions on Power Electronics*, Vol. 28, No. 1, pp. 457-466, January 2013.
<https://doi.org/10.1109/TPEL.2012.2200110>
- [66] H. Chen, Y. Zhang and D. Ma, "A SIMO parallel string driver IC for dimmable LED backlighting with local bus voltage optimization and single time shared regulation loop", *IEEE Transactions on Power Electronics*, Vol. 27, No. 1, pp. 452-462, Jan 2012.
<https://doi.org/10.1109/TPEL.2011.2160404>
- [67] H. L. Cheng, Y. N. Chang, L. C. Hwang and T. H. Tu, "A single stage electrolytic capacitor free AC-DC LED driver with high power factor and soft switching characteristics", *IEEE Transactions on Power Electronics*, Vol. 39, No. 10, pp. 13320-13335, October 2024.
<https://doi.org/10.1109/TPEL.2024.3425851>
- [68] J. M. Alonso, G. Z. Abdelmessih, M. A. Dalla Costa, Y. Guan and Y. Wang, "Investigation of the use of switched capacitor converters as LED drivers", *2023 IEEE Industry Applications Society Annual Meeting (IAS)*, Nashville, TN, USA, pp. 1-8, 2023.
<https://doi.org/10.1109/IAS54024.2023.10406683>
- [69] S. K. Rönnerberg, M. Wahlberg and M. H. J. Bollen, "Harmonic emission before and after changing to LED lamps field measurements for an urban area", *2012 IEEE 15th International Conference on Harmonics and Quality of Power*, Hong Kong, China, pp. 552-557, 2012.
<https://doi.org/10.1109/ICHQP.2012.6381215>
- [70] X. Wang, F. Tian, Y. Li and I. Batarseh, "High efficiency high power density DC/DC converter with wide input range", *Conference Record of the 2006 IEEE Industry Applications Conference Forty-First IAS Annual Meeting*, Tampa, FL, USA, pp. 2115-2120, 2006.
<https://doi.org/10.1109/IAS.2006.256835>
- [71] B. S. Lee, Y. A. Kim and J. K. Kim "A novel two transformer full bridge converter with integrated boost converter for hold up time compensation", *Energies*, Vol. 18, No. 16, art. no. 4268, 2025.
<https://doi.org/10.3390/en18164268>
- [72] C. A. Cheng, H. L. Cheng and T. Y. Chung, "A novel single stage high power factor LED street lighting driver with coupled inductors", *2013 IEEE Industry Applications Society Annual Meeting*, Lake Buena Vista, FL, USA, pp. 1-7, 2013.
<https://doi.org/10.1109/IAS.2013.6682546>
- [73] Y. Wang, Y. Guan, J. Huang, W. Wang and D. Xu, "A single stage led driver based on interleaved buck boost circuit and LLC resonant converter", *IEEE Journal of Emerging and Selected Topics in Power Electronics*, Vol. 3, No. 3, pp. 732-741, September 2015.

- <https://doi.org/10.1109/JESTPE.2015.2421342>
- [74] L. Gu, X. Ruan, M. Xu and K. Yao, "Means of eliminating electrolytic capacitor in AC/DC power supplies for led lightings", *IEEE Transactions on Power Electronics*, Vol. 24, No. 5, pp. 1399-1408, May 2009.
- <https://doi.org/10.1109/TPEL.2009.2016662>
- [75] J. Kim, D. S. Kim and C. Kim, "A single-inductor eight channel output DC-DC converter with time limited power distribution control and single shared hysteresis comparator", *IEEE Transactions on Circuits and Systems I: Regular Papers*, Vol. 60, No. 12, pp. 3354 - 3367, December 2013.
- <https://doi.org/10.1109/TCSI.2013.2265960>
- [76] J. Ahn, S. Hun Choi, M. Um, J. Yeol An and H. - M. Lee, "An area and power efficient source driver IC with multi line sensing real time pixel compensation for OLED displays", *IEEE Journal of Solid-State Circuits*, Vol. 60, No. 11, pp. 3908-3919, November 2025.
- <https://doi.org/10.1109/JSSC.2025.3614134>
- [77] E. A. Jones, F. F. Wang and D. Costinett, "Review of commercial GaN power devices and GaN based converter design challenges", *IEEE Journal of Emerging and Selected Topics in Power Electronics*, Vol. 4, No. 3, pp. 707-719, September 2016.
- <https://doi.org/10.1109/JESTPE.2016.2582685>
- [78] K. J. Chen, O. Häberlen, A. Lidow, C. L. Tsai, T. Ueda, Y. Uemoto, "GaN-on-Si power technology: devices and applications", *IEEE Transactions on Electron Devices*, Vol. 64, No. 3, pp. 779-795, March 2017.
- <https://doi.org/10.1109/TED.2017.2657579>
- [79] A. M. Humada, M. Hojabri, H. M. Hamada, F. B. Samsuri, M. N. Ahmed, "Design of an energy saving controller for an intelligent LED lighting system", *Energy and Buildings*, Vol. 120, pp. 1-9, 2016.
- <https://doi.org/10.1016/j.enbuild.2016.03.052>
- [80] T. Anagnostopoulos, "Smart campus safety systems survey", *IoT-enabled Unobtrusive Surveillance Systems for Smart Campus Safety*, pp. 39-95, 2023.
- <https://doi.org/10.1002/9781119903932.ch5>
- [81] Y. C. Chang and C. M. Liaw, "Design and control for a charge regulated flyback switch-mode rectifier", *IEEE Transactions on Power Electronics*, Vol. 24, No. 1, pp. 59-74, January 2009.
- <https://doi.org/10.1109/TPEL.2008.2005248>
- [82] R. T. H. Li, H. S. H. Chung and A. K. T. Sung, "Passive lossless snubber for boost PFC with minimum voltage and current stress", *IEEE Transactions on Power Electronics*, Vol. 25, No. 3, pp. 602-613, March 2010.
- <https://doi.org/10.1109/TPEL.2009.2035123>
- [83] R. M. Ferraz, L. H. G. Resende, H. A. C. Braga, P. S. Almeida and G. M. Soares, "Optimization-based design of an off line LED driver based on the LLC resonant converter with active ripple compensation", *IEEE Transactions on Industry Applications*, Vol. 61, No. 4, pp. 6605-6617, July-Aug 2025.
- <https://doi.org/10.1109/TIA.2025.3550101>
- [84] N. Molavi, S. Askari, H. Farzanehfard and H. Vahedi, "High efficiency bridgeless resonant converter for street LED lighting application", *IEEE Open Journal of Power Electronics*, Vol. 5, pp. 1810-1818, 2024.
- <https://doi.org/10.1109/OJPEL.2024.3492117>
- [85] M. Faizan, Z. Qian, H. Zhu, S. Fan, M. Zain Yousaf, M. Bajaj, C. Zhichu and A. Aziz, "GaN HEMTs based compact power factor corrected 96.1% peak efficiency LED driver with gate assisted circuit", *Scientific Reports*, Vol. 15, art. no. 14115, 2025.
- <https://doi.org/10.1038/s41598-025-92341-w>
- [86] G. Z. Abdelmessih, M. A. Dalla Costa, J. Marcos Alonso and Y. Wang, "Driver technologies for solid state lighting: a comprehensive review and proposed classification", *IEEE Industry Applications Magazine*, Vol. 31, No. 2, pp. 34-45, March-April 2025.
- <https://doi.org/10.1109/MIAS.2024.3482875>
- [87] J. M. Alonso, G. Z. Abdelmessih, M. A. Dalla Costa, Y. Guan and Y. Wang, "Investigation of the use of switched capacitor converters as LED drivers", *IEEE Transactions on Industry Applications*, Vol. 61, No. 1, pp. 1305-1317, January - February 2025.
- <https://doi.org/10.1109/TIA.2024.3472639>
- [88] J. M. Alonso, D. Gacio, G. Z. Abdelmessih, I. M. Álvarez Díaz and Y. Wang, "Single stage versus integrated LED drivers: A comparison", 2024

- IEEE Industry Applications Society Annual Meeting (IAS)*, Phoenix, AZ, USA, pp. 1-7, 2024.
<https://doi.org/10.1109/IAS55788.2024.11023739>
- [89] P. Vishnuram, A. Dominic Savio, M. Bajaj, I. Ahmed, and M. Khalid, "Isolated power DC–DC and AC–DC converter topologies for light-emitting diode applications: A systematic review", *Arabian Journal for Science and Engineering*, Vol. 50, No. 7, pp. 5377–5405, 2025.
<https://doi.org/10.1007/s13369-025-09974-2>
- [90] S. Nacar, "Hybrid controlled class-E resonant converter with synchronous rectifier for LED driver applications", *Engineering Science and Technology, an International Journal*, Vol. 56, art. no. 101781, 2024.
<https://doi.org/10.1016/j.jestch.2024.101781>
- [91] J. S. Brand, N. d. S. Spode, G. Z. Abdelmessih, J. M. Alonso, Y. Guan and M. A. Dalla Costa, "Capacitance analysis for volume reduction based on integrated buck and buck boost LED driver", *IEEE Transactions on Industry Applications*, Vol. 60, No. 2, pp. 2970-2979, March-April 2024.
<https://doi.org/10.1109/TIA.2023.3280469>
- [92] M. Arias, A. Vázquez, and J. Sebastián, "An overview of the AC–DC and DC–DC converters for LED lighting applications", *Automatika*, Vol. 53, No. 2, pp. 156–172, 2012.
<https://doi.org/10.7305/automatika.53-2.154>
- [93] Y. Wang, J. M. Alonso and X. Ruan, "A review of LED drivers and related technologies", *IEEE Transactions on Industrial Electronics*, Vol. 64, No. 7, pp. 5754-5765, July 2017.
<https://doi.org/10.1109/TIE.2017.2677335>
- [94] L. Teixeira, F. Loose, J. M. Alonso, C. H. Barriquello, V. Alfonso Reguera and M. A. Dalla Costa, "A review of visible light communication LED drivers", *IEEE Journal of Emerging and Selected Topics in Power Electronics*, Vol. 10, No. 1, pp. 919-933, Feb 2022.
<https://doi.org/10.1109/JESTPE.2021.3092284>
- [95] Y. H. Choi, H. J. Choe, and J. J. Yun, "Study on 2 MHz GaN based light emitting diode driver for automotive headlamps", *Journal of Electrical Engineering and Technology*, Vol. 18, pp. 249–260, 2023.
<https://doi.org/10.1007/s42835-022-01206-z>
- [96] G. Z. Abdelmessih, J. M. Alonso, M. A. Dalla Costa, Y. J. Chen and W. T. Tsai, "Fully integrated buck and boost converter as a high efficiency, high power density off line LED driver", *IEEE Transactions on Power Electronics*, Vol. 35, No. 11, pp. 12238-12251, Nov 2020.
<https://doi.org/10.1109/TPEL.2020.2993796>
- [97] S. Li, Y. Guo, S. C. Tan and S. Y. Hui, "An off-line single inductor multiple output LED driver with high dimming precision and full dimming range", *IEEE Transactions on Power Electronics*, Vol. 32, No. 6, pp. 4716-4727, June 2017.
<https://doi.org/10.1109/TPEL.2016.2597237>
- [98] X. Perpiñà, R. J. Werkhoven, M. Vellvehi, J. Jakovenko, X. Jordà and J. M. Kunsen, "Thermal analysis of LED lamps for optimal driver integration", *IEEE Transactions on Power Electronics*, Vol. 30, No. 7, pp. 3876–3891, July 2015.
<https://doi.org/10.1109/TPEL.2014.2346543>
- [99] K. W. Houser and T. Esposito, "Human centric lighting design", *Frontiers in Neurology*, Vol. 12, 2021.
<https://doi.org/10.3389/fneur.2021.630553>
- [100] D. Cupkova, E. Kajati, J. Mocnej, P. Papcun, J. Koziorek and I. Zolotova, "Intelligent human-centric lighting for mental wellbeing improvement", *International Journal of Distributed Sensor Networks*, Vol. 15, No. 9, art. no. 1550147719875878, 2019.
<https://doi.org/10.1177/1550147719875878>
- [101] A. G. Putrada, M. Abdurohman, D. Perdana and H. H. Nuha, "Machine learning methods in smart lighting toward achieving user comfort: a survey", *IEEE Access*, Vol. 10, pp. 45137 - 45178, 2022.
<https://doi.org/10.1109/ACCESS.2022.3169765>
- [102] W. Xu, J. Zhang, J. Y. Kim, W. Huang, S. S. Kanhere, S. K. Jha, "The design, implementation, and deployment of a smart lighting system for smart buildings", *IEEE Internet of Things Journal*, Vol. 6, No. 4, pp. 7266-7281, Aug 2019.
<https://doi.org/10.1109/JIOT.2019.2915952>
- [103] M. Fächtenhans, E. H. Grosse, C. H. Glock, "Smart lighting systems: state of the art and potential applications in warehouse order

- picking”, *International Journal of Production Research*, Vol. 59, No. 12, pp. 3817-3839, 2021.
<https://doi.org/10.1080/00207543.2021.1897177>
- [104] J. Sebastián, D. G. Lamar, D. G. Aller, J. Rodríguez and P. F. Miaja, “On the role of power electronics in visible light communication”, *IEEE Journal of Emerging and Selected Topics in Power Electronics*, Vol. 6, No. 3, pp. 1210-1223, September 2018.
<https://doi.org/10.1109/JESTPE.2018.2830878>
- [105] D. G. Aller, D. G. Lamar, J. R. García-Mere, M. Arias, J. Rodriguez, and J. Sebastian, “Performance evaluation of the two input buck converter as a visible light communication high brightness LED driver based on split power”, *Sensors*, Vol. 24, No. 19, art.no. 6392, Oct 2024.
<https://doi.org/10.3390/s24196392>
- [106] Y. Wang, S. Gao, S. Zhang and D. Xu, “A two stage quasi resonant dual buck LED driver with digital control method”, *IEEE Transactions on Industry Applications*, Vol. 54, No. 1, pp. 787-795, Jan - Feb 2018.
<https://doi.org/10.1109/TIA.2017.2764875>
- [107] S. Xu, S. Xu, D. Xu, Q. Qian, W. Sun, J. Zhu, “A review on recent effort of conductive EMI suppression methods in high frequency power converters”, *IET Power Electronics*, Vol. 15, No. 16, pp. 1921-1935, December 2022.
<https://doi.org/10.1049/pel2.12348>
- [108] J. Aguilar, A. Garces-Jimenez, M. D. R-Moreno, and R. García, “A systematic literature review on the use of artificial intelligence in energy self-management in smart buildings”, *Renewable and Sustainable Energy Reviews*, Vol. 151, art. no. 111530, 2021.
<https://doi.org/10.1016/j.rser.2021.111530>
- [109] P. Chiradeja and S. Yoomak, “Development of public lighting system with smart lighting control systems and internet of thing (IoT) technologies for smart city”, *Energy Reports*, Vol. 10, pp. 3355-3372, November 2023.
<https://doi.org/10.1016/j.egy.2023.10.027>
- [110] F. Loose, L. Teixeira, J. P. Brum, C. H. Barriquello, V. A. Reguera, J. M. Alonso, “Efficient hybrid buck converter for visible light communication in LED drivers”, *IEEE Transactions on Industrial Electronics*, Vol. 69, No. 2, pp. 1877-1887, Feb 2022.
<https://doi.org/10.1109/TIE.2021.3060651>



Copyright: © 2026 by the authors, Licensee ITEECS, India. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).
