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Non-Isolated LED Drivers

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Introduction

A non-isolated driver is a power supply that does not include safety isolation between its input and output. This design requires fewer components and simplifies the approach to achieving ultra-high efficiency. High efficiency reduces energy costs over the product's life and limits the driver's generated heat, facilitating reliable size reduction. This size reduction directly translates into lower product costs and costs associated with weight and transportation. As a result, non-isolated drivers enable lighting OEMs to support projects with less upfront investment while improving the ROI through most-optimized energy savings.

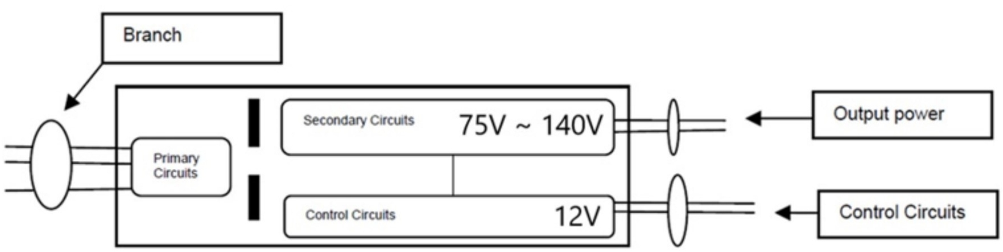
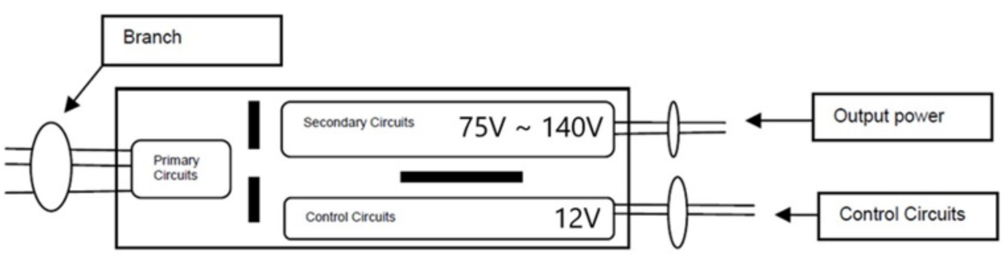
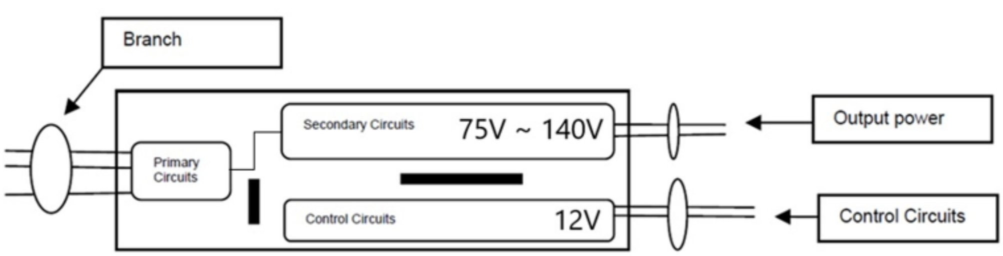
This paper further describes design and performance differences between isolated and non-isolated drivers, followed by considerations for luminaire design and system suitability.

Introduction

What is “Isolation” in LED Drivers?

Product safety standard committees work diligently to protect against electric shock and fire. Design requirements are implemented to prevent users from accidentally touching live electricity and to prevent circuits from shorting or arcing. The barrier between hazardous AC power and people or other circuits is called electrical isolation and is the unique characteristic when discussing “isolated” or “non-isolated” LED drivers. It's worth noting that even a non-isolated driver will provide an electrically isolated barrier to the dimming circuit as per UL 8750 (V2), Supplement SF, and IEC/EN 61347-2-13:2024, clause 12. *Drawings in Table 1 are adapted from UL 8750 Figure SF2.1.*

Table 1: Driver Classification vs Location of Electrical Isolation

Legacy Isolated Driver *The control and output circuit are connected together, but isolated from the input.*	
Today’s Isolated Driver *The control, output, and primary circuits are all isolated from each other.*	
Today’s Non-Isolated Driver *The output and primary circuits are directly connected but isolated from the control circuit.*	

= electrical isolation

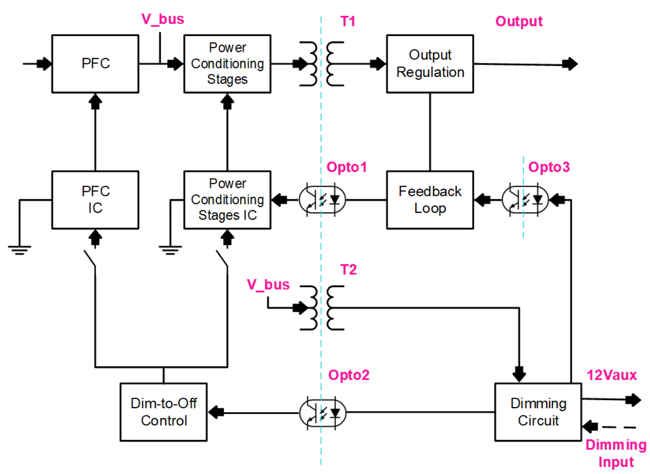
Introduction

Electrical Isolation in Isolated LED Drivers

In LED driver designs, isolation is typically achieved through the use of transformers and optocouplers. A transformer, which consists of at least two inductors and a core, uses inductive (magnetic) coupling to transfer energy from one inductive winding to the other without any direct electrical connection. This is the same way phones charge wirelessly.

The primary circuit is the side of the transformer that is connected to and consumes AC power, whereas the secondary circuit is the side that delivers power to the LEDs. An optocoupler is used to close the feedback loop between the primary and secondary sides of the driver while still maintaining the integrity of isolation provided by the transformer.

Figure 1: Block Diagram of Today's Isolated LED Driver Design



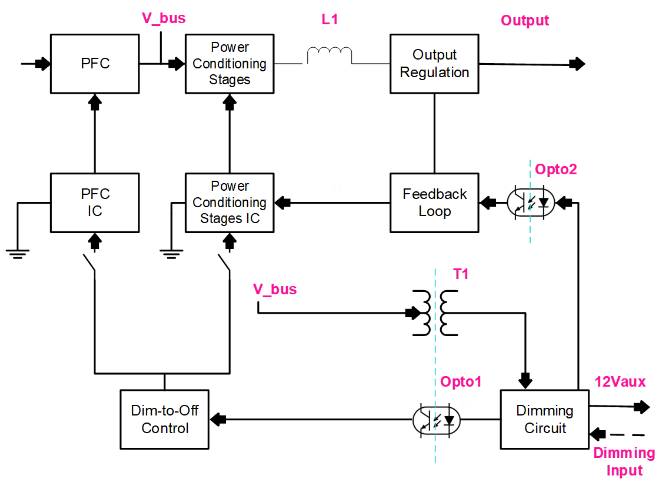
Electrical Isolation in Non-Isolated Drivers

Non-isolated drivers use a single inductor (L1 in Figure 2) to replace the power transformer (T1 in Figure 1). This means that the optocoupler (Opto1 in Figure 1), previously used to maintain isolation between the primary and secondary circuits, is no longer necessary and is therefore removed.

As a result, the circuit that draws AC power is directly connected to the circuit that supplies power to the LEDs. This eliminates the distinction between the primary and secondary sides of the driver and is why it is sometimes called "direct connected" or "direct power".

Treat the outputs of non-isolated LED drivers with the same safety precautions as live AC power lines.

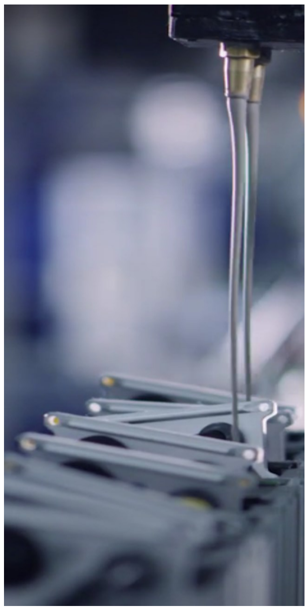
Figure 2: Block Diagram of Today's Non-Isolated LED Driver Design



LED Driver Performance Comparison

Potting

A driver that is fully potted offers greater flexibility during the driver safety evaluation compared to an unpotted design. It decreases the likelihood of electrical shorts or flashovers leading to a fire but does not directly prevent electric shock.



Though related to safety, potting is not synonymous with isolation, and vice versa. A driver can be unpotted or potted and also being isolated or non-isolated.

New Operating Region

Isolated drivers often have several models. Both SELV and Class 2 drivers require isolation and supply limited outputs of 120V DC and 60V DC respectively. Above this, designs under 300V are common to optimize cable costs. However, when isolation is removed from the driver, the system must protect against the highest voltage present. For instance, if the luminaire is rated for 277V AC, the entire system must protect against 277V AC, even if the LEDs are only driven at 54V. With this, there is little advantage to running lower LED voltages with a non-isolated driver. Conversely, running higher voltages with lower current reduces losses throughout the cabling system and generally results in higher driver efficiency. Consequently, non-isolated LED drivers often have one model with high voltage and low current operating regions (compare Table 2 and Table 3).

Table 2: Rated Current/Voltage Operating Region for Isolated LED Driver Models

Full-Power Current Range	Default Output Current	Output Voltage Range	Max. Output Power	Model Number
1.25-1.7A	1.7 A	200~544Vdc	680 W	ESM-680S170Mx
1.8-2.4A	2.1 A	141.5~378Vdc	680 W	ESM-680S240Mx
2.6-3.5A	3.5 A	97.1~262Vdc	680 W	ESM-680S350Mx
4.2-5.6A	5.6 A	60.7~163Vdc	680 W	ESM-680S560Mx
6.3-8.4A	8.4 A	40.4~108Vdc	680 W	ESM-680S840Mx
12.6-15.0A	15.0 A	22.6~54Vdc	680 W	ESM-680S15AMx

Table 3: Rated Current/Voltage Operating Region for Non-Isolated LED Driver Model

Full-Power Current Range	Default Output Current	Output Voltage Range	Max. Output Power	Model Number
1100-2200mA	1650mA	150-550Vdc	600 W	NEL-600S220Mx

LED Driver Performance Comparison

In addition to important safety considerations, non-isolated drivers also pose performance differences that may impact the reliability or behavior of the system.

Let-through Voltage

Electrical disturbances such as surges, sags, swells, and fast transients, commonly called "dirty power," are prevalent in electrical distribution systems. The investment in safeguarding and cleansing power throughout the distribution system is tailored according to the sensitivity and cruciality of the equipment in use.

When a surge protective device (SPD) triggers, some voltage still passes downstream to the circuits or equipment it protects. This voltage is called the "let-through voltage".

Equipment should be appropriately sized or rated to withstand the maximum let-through voltage. This is true for LED boards, drivers, SPDs and continues upstream throughout the distribution and electrical feed.

LED drivers include integrated levels of surge protection to safeguard not only itself but also low voltage controls and the LEDs. The level of surge the driver can withstand is rated and qualified (see Figure 3), but the let-through voltage allowed between the output and metal substrate of the LED PCB is not specified in safety certifications.

LED Printed Circuit Boards (PCBs) are generally designed to withstand at least 2kV. Therefore, the let-through voltage for isolated drivers is usually specified to be around or below this limit (see Figure 4). With conventional design methods, non-isolated drivers tend to pass on significantly higher let-through voltage to the LEDs.

With an isolated design, the transformer attenuates electrical disturbances, which, dampens noise passing through to the LEDs. By removing components in non-isolated drivers, the dampening effect and overall impedance is reduced, which may expose LEDs to higher levels of electrical noise.

Let-through voltage can be quantified given a surge waveform with specified conditions, but exposure to electrical noise in the field is more challenging not only to characterize but also to understand the system-level impact.

Figure 3: 10kV Pulse Waveform Input to LED Driver According to IEC/EN 61000-4-5

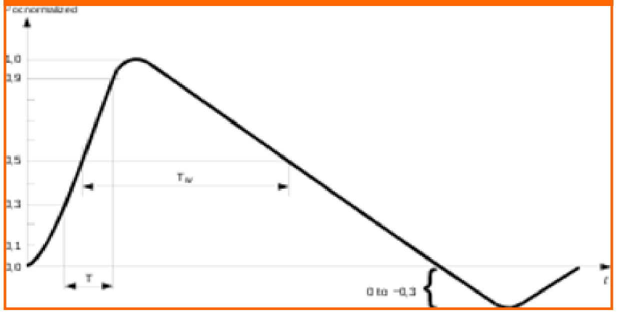
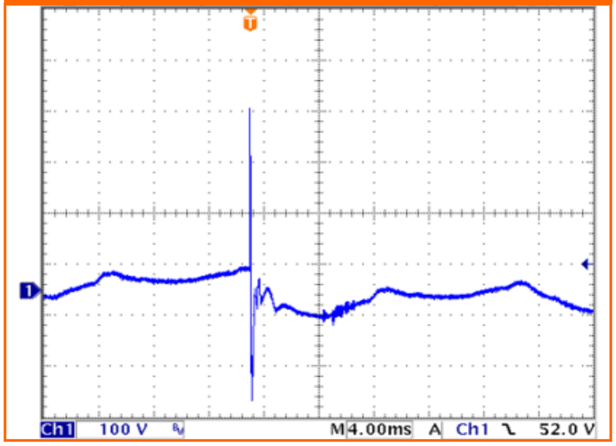


Figure 4: Measured Let-through to LEDs During 10kV Pulse (358V, –216V Peaks)



LED Driver Performance Comparison

Afterglow

Afterglow is a phenomenon in which grounded LEDs unintentionally emit very faint light when the luminaire is considered off. Where there is any physical connection to an AC signal, LED drivers have an AC residual voltage and leakage current. For isolated drivers, this is due to filtering capacitors referencing earth ground and is impacted by the design of the luminaire. For non-isolated drivers, this is due to the LEDs being directly connected to the mains voltage, resulting in much higher residual voltage.

As the driver's residual voltage exceeds the LED threshold (minimum bias) voltage, the leakage current passes through the LEDs, causing afterglow. A relay can be used on the input or output to prevent this phenomenon, but it should be done with caution to avoid unintentionally introducing a wear out mechanism, or failure point.

DC Output Voltage to Ground

In addition to higher residual voltage, the DC voltage between output and ground is also higher for non-isolated designs. The Vout+ conductor has a notably higher potential voltage compared to the Vout- conductor when referencing ground.

Reliability & Lifetime

Theoretically, non-isolated drivers have better reliability and lifetime, but in practice they are likely to be similar.

While a non-isolated driver has fewer components, consequently improving the MTBF calculation, the supplier's design and manufacturing processes are still the same which is not captured in the MTBF calculation. For example, suppose a manufacturer designs critical components with little electrical margin where another has deep derating guidelines. The isolated driver with deep derating guidelines will generally be more reliable even though it has more components.

Likewise, both drivers' lifetimes depend on the electrolytic capacitors' thermal characterization within the design. A non-isolated driver may be more efficient, but if the power density is increased (more power integrated in a smaller package), it may have a similar thermal profile and, therefore, similar lifetime (compare Table 4 and Table 5).

Table 4: MTBF and Lifetime Hours in Isolated LED Driver

Hours	Test Conditions	Power Density	Part Number
MTBF: 200,000	Measured at 480Vac Input, 80% Load and 25°C ambient temperature (MIL-HDBK-217F)	$0.438W/cm^3$	ESM-680SxxxMG
Lifetime: 102,000	Measured at 480Vac input, 80% Load and 70°C case temperature;	($7.13W/in^3$)	

Table 5: MTBF and Lifetime Hours in Non-Isolated LED Driver

Hours	Test Conditions	Power Density	Part Number
MTBF: 270,000	Measured at 400Vac Input, 80% Load and 25°C ambient temperature (MIL-HDBK-217F)	$0.833W/cm^3$	NEL-600SxxxMG
Lifetime: 103,000	Measured at 400Vac input, 80% Load and 70°C case temperature;	($13.63W/in^3$)	

LED Driver Performance Comparison

THD, PF, EMI

The power factor correction (PFC) circuit is responsible for regulating both the total harmonic distortion (THD) and power factor (PF) in the driver. This circuit is located on the primary side and is always connected directly to AC power. Independent of the driver's isolation, using the same PFC circuit design in either an isolated or non-isolated driver will provide similar THD and PF performance.

Likewise, both isolated and non-isolated designs use comparable electromagnetic interference (EMI) filtering techniques. One design has no inherent advantage compared to the other at the driver level. However, systems using non-isolated drivers may be more prone to ground loops which in turn may amplify EMI.

Impact to Luminaire

As with any design, considerations around safety, performance, and the life of the luminaire are critical per the needs of the application and target market.

Electrical Isolation in Luminaires

Like LED drivers, the luminaire design also includes electrical isolation, but the design requirements vary depending on the LED board configuration and the type of LED driver used. If switching to a non-isolated driver, coating thickness may need to be increased, or the LED lens or diffuser may require an upgrade to a 5VA flammability rating. The LED board must be grounded, and creepage and clearance spacings may also need to increase.

However, it's also possible that an existing design may already meet any new requirements. This can be proven through simple specification review, additional testing, or following appropriate exceptions outlined in the safety standard. For example, if increased spacing is required to prevent fire, an additional short circuit test may be considered to demonstrate that the design poses no risk of fire under worst-case conditions.

Preventing Electric Shock

UL requires Class 2 LED drivers to have electrical isolation and to limit the output energy based on the environmental location. The Class 2 luminaire requirements are specified based on the understanding that the driver provides a safe output, so additional leniencies are allowed in the luminaire design and site installation (see System 1 in Table 6).

UL non-Class 2 designs exceed 100W or 8A and are therefore considered dangerous due to the risk of fire. At the same time, if the design's voltage is limited to 60V or below and has isolation, it can still be considered safe from the risk of electric shock in dry and damp locations, allowing for relevant leniencies (see System 3 in Table 6).

If the driver output exceeds 100W and 60V DC, hazardous energy flows through the LED board. In this case, the LED board must provide its own protection against electric shock and risk of fire. With this, the leniencies introduced by the driver's isolation no longer apply, and the driver's isolation becomes redundant (see System 5 in Table 6).

Table 6: UL Classification and Driver Isolation vs System Allowances

Both LED Board and Driver Meet	System	Driver Isolation	LED Board Requirements	LED Board Grounding	Installation Limitations & Inspection Complexity
UL Class 2	1	Yes	Most Lenient	Optional	Low
	2	No	Strict	Required	High
UL non-Class 2 < 60V	3	Yes	Lenient	Optional	Mid
	4	No	Strict	Required	High
UL non-Class 2 >60V	5	Yes	Strict	Required	High
	6	No	Strict	Required	High

Impact to Luminaire

If the target application cannot ensure the integrity of ground bond connections throughout the system or if users may easily contact with the luminaire while it is still connected to AC power, redundant isolation may be valuable in further reducing the risk of electric shock (see Figure 5).

However, if the grounding connections can be ensured and if only trained electrical professionals interface with the luminaire (always disconnecting power before contact), optimizing the design to eliminate this redundancy of isolation is worth consideration (see Figure 6 and Figure 7). This optimization can lead to more cost-effective solutions while supporting sustainability initiatives, including but not limited to the potential boost in efficiency, as well as the reduction in materials, weight, and shipping.

Figure 5: UL non-Class 2 Luminaire with Redundant Isolation in LED Driver and Lens

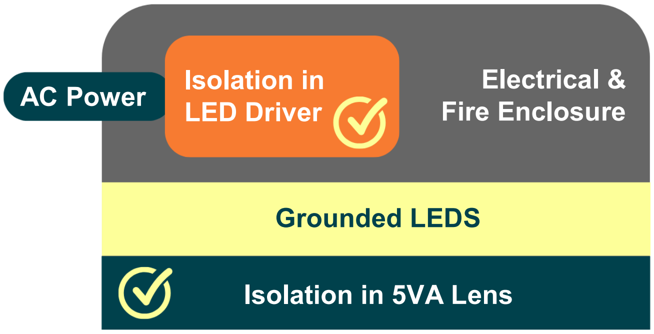


Figure 6: UL Class 2 Luminaire with Isolation in LED Driver and Most Lenient Lens

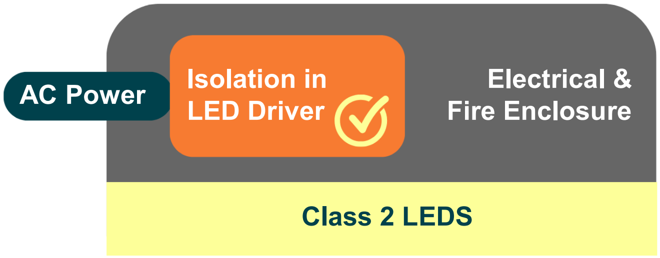
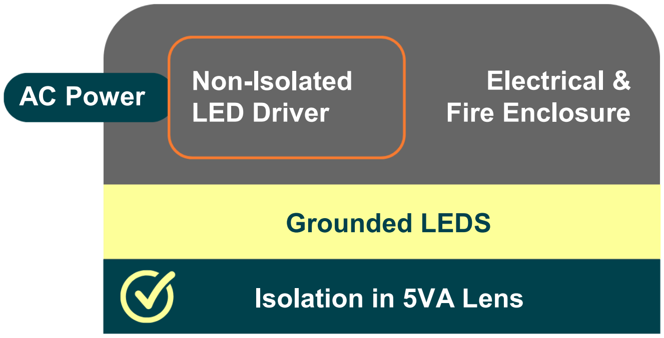


Figure 7: UL non-Class 2 Luminaire with Isolation in Lens Only



Impact to Luminaire

Preventing Electrical Fires

When designing a luminaire that has a UL non-Class 2 driver and outputs over 60V, there are already measures in place to prevent electric shock independent of driver isolation. However, if a non-isolated driver is used, more spacing may be required to avoid electrical fires or component failures due to electrical shorts or arcing.

Spacing requirements consider both creepage distances and clearances. The creepage distance is the shortest distance between two conductive but isolated points along the surface of a component or PCB. This distance is also measured between the shortest conductive point and the ground or accessible dead metal part. The clearance is the distance measured between the same points but across air and is either the same or less than the creepage distance.

The spacing requirements differ most significantly when using low voltage LEDs with a non-isolated driver on 400V AC or 480V AC systems compared to using an isolated driver.

Impact to Luminaire

Referencing UL 8750 and IEC 60598-1 requirements, Table 7 contrasts maximum spacing requirements across two live conductors and between a live conductor to the ground or dead metal part for different input and maximum driver output voltage examples along with the driver isolation type. The maximum driver voltage considers the worst-case, which is generally the open circuit, or no load voltage for constant current drivers. Additional exceptions or logic may exist to reduce these spacing requirements from a safety perspective; please consult with your NRTL. From an LED board reliability perspective, additional spacing may be needed.

Table 7: LED Board Spacing Requirements per Input and Maximum Driver Output Voltage

Spacing Location	Standard	Driver Maximum Output Voltage	Input Voltage	Isolated LED Driver		Non-Isolated LED Driver	
				Clearance Distance (mm)	Creepage Distance (mm)	Clearance Distance (mm)	Creepage Distance (mm)
Between Live Parts	UL8750	60Vdc	277Vac Max	0.50	1.60	1.50	3.00
			480Vac Max	0.50	1.60	3.00	6.10
		170Vdc	277Vac Max	1.50	3.00	1.50	3.00
			480Vac Max	1.50	3.00	3.00	6.10
		305Vdc	277Vac Max	2.25	4.50	2.25	4.50
			480Vac Max	2.25	4.50	3.00	6.10
		600Vdc	277Vac Max	3.00	6.10	3.00	6.10
			480Vac Max	3.00	6.10	3.00	6.10
Between Live Parts and Ground	UL8750	60Vdc	277Vac Max	3.00	3.00	3.90	3.90
			480Vac Max	3.00	3.00	5.60	5.60
		170Vdc	277Vac Max	3.90	3.90	3.90	3.90
			480Vac Max	3.90	3.90	5.60	5.60
		305Vdc	277Vac Max	4.70	4.70	4.70	4.70
			480Vac Max	4.70	4.70	5.60	5.60
		600Vdc	277Vac Max	5.60	5.60	5.60	5.60
			480Vac Max	5.60	5.60	5.60	5.60
	IEC 60598-1	60Vdc	277Vac Max	-	-	1.50	2.80
			480Vac Max	-	-	3.00	4.80
		170Vdc	277Vac Max	1.50	1.80	1.50	2.80
			480Vac Max	1.50	1.80	3.00	4.80
		305Vdc	277Vac Max	3.00	3.10	3.00	3.10
			480Vac Max	3.00	3.10	3.00	4.80
		600Vdc	277Vac Max	3.00	6.10	3.00	6.10
			480Vac Max	3.00	6.10	3.00	6.10

Impact to Luminaire

LED Durability

While the lifetime of isolated and non-isolated LED drivers may be similar, the life of the LED boards may be reduced when using non-isolated drivers. Understanding the LED driver let-through voltage and evaluating whether the LED board or COBs can withstand this voltage is essential. For example, if the let-through voltage is 2kV, qualify the LED load to withstand at least 3kV to allow for tolerances. Also, consider the sustained, higher AC and DC voltage between the output conductors on the board and ground.

LED board durability may be enhanced in several ways. Consider changing the material or construction to increase the board's dielectric withstand voltage or use LEDs with higher ESD ratings. Evaluate if insulation spacings beyond safety requirements are necessary. Add power conditioning or filtering where there is risk for excess electrical noise.

Hipot Testing and Throughput

Some drivers may use lower GDT trigger voltages to help limit let-through voltage. This may require the removal and re-securing of an external screw, nut, or shunt to perform hipot testing, which may impact luminaire assembly and throughput.

Performance

Preventing afterglow requires intentional design and can be highly critical depending on the application. The driver's residual voltage must be lower than the LED's worst-case threshold voltage. Where afterglow exists, typical mitigation methods include selecting a driver with lower residual voltage, altering the LED board layout, using AC relays, or partnering with an LED driver supplier that reliably integrates an output relay.

Validate the performance by testing several drivers and LED board samples together with the driver dimmed-to-off. Use the highest rated input voltage while all lights are also turned off to increase the likelihood of detecting the very faint light.

Connector Selection

While selecting a reliable, high-quality connector is always important, it is critical with non-isolated drivers due to safety. Since there is no backup isolation in the driver, ensuring the integrity of the ground connection throughout the lifespan of the installation is vital to prevent electric shock.

Also consider the connector's ability to maintain a stable connection when exposed to vibrations. This helps prevent arcing in the contacts, which, in turn, reduces electrical noise throughout the distribution system.

Safety agencies require a certified connector supporting the highest voltage in the design and will not accept a commercial or marketed rating. Request and verify the certification file before proceeding with any design and certification work.

Are Non-Isolated Drivers Right For You?

Non-isolated drivers have historically been used where plastic housings are commonplace and also where operators are exceptionally skilled, always taking proper safety cautions. They have been deployed in indoor office and horticulture applications in Europe, imported into high bay applications in North America, and designed into various area lighting applications around the world.

Introducing non-isolated drivers to new applications may bring uncertainty, but the benefits may outweigh the risks depending on the application.

Consider the Application & Target Market

Isolated LED Drivers May be More Beneficial Where *Any* of These Are True:

⇒ Driver is easy to access or likely to be touched while turned ON

⇒ Earth Ground cannot be ensured

⇒ Power required is ≤ Class 2 limits

⇒ LED board protection is most critical

⇒ Connectors are not best-in-class

⇒ Cost to compensate for non-isolated product increases total luminaire cost

⇒ Cost to update luminaire exceeds ROI for remainder of product's lifecycle

Non-Isolated LED Drivers May be More Beneficial Where *All* of These Are True:

⇒ Driver is treated with caution and only handled by trained electrical professionals

⇒ Earth Ground can be ensured

⇒ Power required is > than Class 2 limits

⇒ Efficiency gains or reduction of weight and/or cost are most critical

⇒ Connectors are best-in-class

⇒ Assembly process can accommodate removal of GDT nut, screw, or shunt (if applicable - depends on LED driver)

Are Non-Isolated Drivers Right For You?

If the application and target market do not benefit from redundant safety isolation, the next step for evaluation is to work through a cost-benefit analysis. This will vary significantly on the unique requirements of each design and market served.

The notes in Table 8 provide a very general look at the impact and benefit of converting from an isolated driver to a non-isolated driver based on the UL classification. *(The information in Table 6 and Table 8 is the same.)*

Conduct a Cost-Benefit Analysis

Table 8: Notes on Conversion to Non-Isolated Drivers Based on UL Classification

Both LED Board and Driver Follow	System	Driver Isolation	LED Board Requirement	LED Board Grounding	Installation Limitations & Inspection Complexity
(1) UL Class 2	1	Yes	Most Lenient	Optimal	Low
	2	No	Strict	Required	High
(2) UL non-Class 2 < 60V	3	Yes	Lenient	Optimal	Mid
	4	No	Strict	Required	High
(3) UL non-Class 2 >60V	5	Yes	Strict	Required	High
	6	No	Strict	Required	High

Notes:

1) System 1 is least likely to benefit from switching to a non-isolated driver (System 2). This requires the most resources and change to the luminaire while adding the most system-level cost. The conversion will likely gain some efficiency improvement and weight reduction, but this is generally less meaningful for already compact, lower power drivers.
2) System 3 may or may not benefit from switching to a non-isolated driver (System 4). This requires significant resources and change to the luminaire while total system-level costs may be reduced or remain similar. The conversion will likely gain some efficiency improvement and weight reduction.
3) System 5 is most likely to benefit from switching to a non-isolated driver (System 6). This requires the least resources and change to the luminaire while reducing the most system-level costs. The conversion will likely gain meaningful efficiency improvement and weight reduction.

Are Non-Isolated Drivers Right For You?

While working through the cost-benefit analysis, consider the costs associated with managing any new areas of risk or uncertainty. Include and address questions related to safety, durability, and performance. Non-isolated drivers are the right design choice where it is suitable for the application, and risk can be managed in such a way that the benefits continue to outweigh the costs.

Create a Risk Management Plan

1. How is the integrity of the ground bond maintained in the driver, luminaire, and connector throughout manufacturing and the life of the installation?

2. How is maintenance impacted if the LEDs fail before the driver? What is the PCB's dielectric withstand voltage, the ESD rating of the LEDs, and the let-through voltage of the driver?

3. How is the application impacted by afterglow? What is the minimum threshold voltage that enables current to flow through the LEDs? What is the LED driver's AC residual voltage when powered by the highest rated input? Does this change when connected in the luminaire?

Inventronics offers innovative, non-isolated LED driver solutions that are specifically designed to help mitigate risk of afterglow and excess let-through voltage. To learn more, please contact your local representative today.

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