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White Paper:

Low Voltage Lighting Transformers and LED Retrofit Lamps

To understand the interactions and relationships between low voltage transformers and their use with LED retrofit lamps, an understanding must be established of how each works.

Transformers

Transformers use either a core and coil, or electronic components to transform high (line) voltage into a much lower voltage. There are a number of reasons that using a low voltage system can be desirable, depending on the type of application that it is to be used in.

Types of Transformers

There are several basic types of transformer used in lighting, and they are typically defined by how they convert the line voltage down to low voltage.

Magnetic transformers are very similar, in part, to magnetic fluorescent or HID ballast. They use a core and coil system in order to convert 120V to 12V. This type of ballast is very heat tolerant and relatively simplistic.

Electronic AC (alternating current) transformers again have a similarity to electronic fluorescent ballasts in that they use inverters and other electrical components to convert the voltage from 120V down to 12V. The big difference with these is that they can be much smaller and more efficient by operating at a much higher frequency.

Electronic DC (direct current) transformers are becoming more common for use in driving LED products such as sign backlighting or other system type LEDs, but can also be useful in a general lighting scenario because of the reduced voltage drop over distances. They use a transformer to step down the voltage, a rectifier to convert the AC to DC voltage, a capacitor to smooth out the voltage from the rectifier and a regulator to further smooth the output to get a stable DC power.
**Magnetic (or Electromagnetic) Transformer**

Magnetic transformers use differing numbers of coils in order to reduce the voltage proportionally. An example is a typical 12V transformer drops the voltage of the incoming line voltage by a factor of 10 (120V/12V = 10). This applies if the voltage to the fixture is increased or decreased. Either scenario will translate directly to the lamps. This makes magnetic transformers relatively easy to dim (with the proper dimmer). The transformer also transfers the frequency directly from line voltage, which in the United States is 60Hz.

Some variants of this type of transformer include one designed to accommodate the voltage drop over long runs that are typical of a landscaping application. These typically have multiple circuits which are limited to 300W per circuit to comply with different safety codes. In addition to the multiple circuits, many of these transformers also have multiple “taps”, which have differing voltages depending on the length of the run (or length of wire to the farthest fixture), the wire size used, and the wattage draw of the fixtures on the circuit. Long runs can require a higher initial voltage in order to provide the proper voltage to the fixtures, and there are limits on how much of a load can be placed on a circuit depending on the length of the run and the wire used. This is typically provided by the manufacturer of the transformer.

Magnetic transformers have the advantage of being very heat resistant and do not typically interfere with electronics. Their disadvantage is that they are typically very heavy (consisting mainly of copper and iron), and tend to be larger than electronic transformers.

**Electronic AC Transformer**

Electronic AC transformers use a number of electrical components, including inverters, in order to reduce the voltage. Typically, these transformers are much smaller and lighter than the magnetic version, and this is possible because the transforming capability is not determined by the amount of metal in the coil. By running at very high frequencies, the transformers can use much smaller components and fit a lot of capability into a very small space. These frequencies can be 20,000 Hz and above, compared to the 60 Hz of a magnetic transformer or line voltage. Because they are not as directly reliant on input voltage, the transformers generally translate less of the variation in line voltage to the lamps. This is good for stability, but also means that the transformer has to be designed specifically for dimming, if the dimming characteristic is desired. Many electronic AC transformers also have end of life protection for their lamps, which shut the transformer down if not enough current is being drawn, saving electricity and reducing the already low risk of shock. Their advantages are they are much smaller and lighter, and are more efficient at converting the voltage. Their disadvantages are that being electronics, they are more sensitive to high heat environments, and their frequencies can cause interference or incompatibility with other electronic devices (including LED lamps).

**Electronic DC Transformer**

Electronic DC transformers differ from both magnetic and electronic AC transformers in that each of the two output lines has a dedicated charge. Using electrical components still allows these to be smaller and more efficient than the magnetic transformers, but instead of producing a variable voltage, they produce a constant voltage that is directly wired.
This involves a transformer conversion to the proper voltage, and several steps involving capacitors and rectifiers to smooth the power to a stable DC voltage. DC voltage can help with long runs of wire, but is also helpful in that it is a known quantity for developing other electronics to run on. Many DC transformers are designed more as components for running other types of electronics such as computer parts or as a part of consumer electronics. Their advantages are efficiency and having a known DC output, their disadvantage is that they are usually larger than AC transformers of equivalent wattage, and can be more expensive.

**Effect of Transformer Type on Lighting**

**Halogen or Incandescent Lamps**

Halogen and incandescent lamps are relatively simplistic products and will generally work just as well on any of the types of transformers. The light is generated by the heating of a filament, which will not cool enough during the fraction of a second between cycles (Hz) to make them appear any different on AC or DC. Over extreme lengths of time, the filament of a halogen lamp could theoretically be affected by DC voltage in that one end of the filament would be more prone to “necking” than another, but in practice the effect is negligible. One concern is to ensure that enough of a load is placed on the transformer to operate properly, as increased voltage will shorten the life of these lamps significantly.

**ED Lamps**

LED lamps are not nearly as simple of a product as an incandescent or halogen lamp. Rather than relying on heating of a filament, they create light using special materials and phosphors, run at a very specific voltage and current. In effect, an LED lamp is essentially a self-ballasted product. As such, there are electronics to back up and support the operating environment that an LED is designed to work in. As an example, ProLED products are designed to work on either DC or 60 Hz AC power. While LED lamp replacements will often work on some of the electronic transformers that use differing frequencies, there can be compatibility issues. In addition to frequency issues, there can be challenges in the difference in load that an LED product represents in comparison to the halogen lamps that they replace.

**LEDs**

LEDs are diodes that generate light when operated under the proper conditions, which are very different than line voltage or low voltage typically used by lighting products. Of note is that LED chips run on a very low DC voltage (typically between 3V and 4V) and need a well regulated voltage and current source in order to achieve the long life of which they are capable.

Every lamp replacement product (and every LED fixture) will be made with integrated drivers (appropriate to the application) in order to safely drive the LED components and achieve a long lifespan. What this means is that LED replacement lamps and fixtures are essentially self-ballasted products.

**LED Retrofit Lighting and Transformer Compatibility**

LEDs as a directional light source have only recently been able to start taking the place of halogen lamps, mainly due to the high light output of many of the halogen lamps. Having been on the cutting edge of replacement lamp technology and making lamps that can provide the amount and quality of light output that is expected of halogen lamps, we have significant experience in the challenges of making a new technology work with existing fixtures.
One of the challenges associated with LED retrofit products is producing usable light, driving the LEDs, and managing the heat created by the driver and LEDs in a package that is compatible with the lamp being produced. Retrofit lighting that is of any significant power will have a large portion of its mass made of aluminum (or some other metal) in order to properly dissipate the heat that is generated during operations.

During our experience in the marketplace, we have found that there is sometimes a lack of understanding about how transformers work, and how they can interact with lighting products. Due to the significant difference in consumption between an LED lamp and the lamp that it typically replaces, there can be some compatibility problems. In discussions with many manufacturers of transformers, we have come upon information applicable to LED retrofits.

**LED Retrofit and Magnetic AC Transformers**

Because magnetic transformers require current flow in order to transform voltage from high to low, many magnetic transformers are designed to be utilized above a certain proportion of their maximum capacity. Depending on the manufacturer and wattage of the transformer, in order to function properly the transformer may require between 25% and 50% of their wattage capacity to be utilized. In this instance, functionality is defined as providing the proper (expected) voltage to the lamps. Under driving the transformer typically means that the transformer will put out more voltage / current than is designed for. This is not usually a problem with 12V transformers, as the MR16 LEDs are designed for use on a flexible voltage system up to 18V AC. This can present a problem for higher voltage taps on magnetic multi-tap systems, as the LEDs would be vulnerable to voltage variations from the line voltage, particularly with heavy duty transformers that are designed to run large numbers of halogen lamps. When retrofitting this type of transformer, it is important to know what the wattage rating of the transformer is, and what the minimum load is. Most manufacturers are very helpful if you call and ask about a retrofit scenario, and provide the best guidelines for the operating range of their products.

**LED Retrofit and Electronic AC Transformers**

Electronic AC transformers, as popular and effective as they are with halogen lamps, can present problems when retrofitting to a much lower wattage, electronically regulated product. The most common issue with electronic transformers that we have seen is that the LEDs do not draw enough current. An example would be replacing three 35W Halogen MR16s with three 6W LED MR16s. This is a reduction in apparent current of over 80%. In this case, the transformer’s protection circuit can think that there is a problem with the lamps or the fixture. This scenario can cause lamp flickering, cycling, or having the lamps simply not work at all (by the transformer shutting down). The other problem that can be experienced with an electronic transformer can be with the frequency that the transformer puts out. LED circuitry can usually be designed to accommodate a range of frequencies, but generally not the very wide range of frequencies that can be present in the different types of transformers (from 60Hz in a magnetic to 44kHz or more in an electronic). There are occasions where the two electronic systems just do not mesh. This situation is where the concern comes in, as if the frequencies are mismatched enough, they could damage the LED lamp. Whenever lamps are being considered for use on an electronic AC transformer, they should be tested in a small scale before any large scale replacement occurs.
LED Retrofit and Electronic DC Transformers

Many LED low voltage retrofit lamps will work on AC as well as DC transformers. While DC transformers are not as common, they are typically the best way to run an LED low voltage lamp (depending on manufacturer of the lamp). DC transformers have no frequency issues to worry about, so compatibility is much less of a problem. Generally speaking, these types of transformer run ProLED lamps at their most effective and efficient. The reason for the increase in efficiency is that the circuitry in the LED lamp that typically has to convert AC to DC power and then smooth the power does not have to activate and does not contribute to power losses. This allows the lamp to run cooler and use less energy. The only negative to these is that they are less common in the marketplace than AC electronic transformers. Prior to using LEDs on this type of transformer, ensure that their circuitry is capable of running on DC voltage, and some manufacturers have a different DC voltage rating for their product than AC voltage rating.

Common Low Voltage Lighting Applications

Track Fixtures
For many years any kind of spotlighting or display lighting has been done with track fixtures, and many track fixtures make use of low voltage lighting. MR16s are extremely popular in this application, as they have a very precise beam pattern and are small in size, allowing flexibility of design. Low voltage track products are also found in flood lighting and pendant lighting, sometimes using bi-pin halogen capsules. The major commonality in track lighting is that the light is generally a directed light source, be it a spot light with a very tight beam, or a wall washing or flood lamp.

Halogen Lamps are the traditional light source that is used in a low voltage track type application. Halogen lamps operate more efficiently at low voltage, and provide a higher color temperature for a whiter light than traditional incandescent sources. MR11 and MR16s are commonly used because of the wide range of beam spreads and light levels that they offer. In addition to MR type lamps, AR111s and JC lamps are also used.

LED lamps fit into this area well, as they are, by their nature, a directional light source, and can be directed effectively with optics. Track fixtures offer a challenge in that many will use an electronic transformer in each track head. Sometimes the LED lamps (which are usually under 6W) will not draw enough current to operate the transformer properly, either causing the transformer to shut down (in the case of end of life protection) or by operating outside of the transformer’s rating, which can cause increased voltage to the lamp in magnetic transformers. This can be a problem if the product is a very low wattage incandescent as well, since the increase in voltage will significantly shorten the life of a filament based product.
Landscape Lighting

Landscape lighting falls under different requirements for installation than indoor lighting, and current electrical code favors low voltage lighting in landscape applications. This is because of the differing protection requirements on the wiring to and from the fixture, and low voltage has a significant advantage in the ease of installation, and thus a reduced installation labor cost. The fixtures tend towards directional fixtures, as the desire of the lighting is usually to highlight features of the landscape. They use a special type of transformer that operates a little different and is protected from weather. These transformers are typically specialized to deal with many of the long runs, and have multiple taps from 12V up to 22+V (for very long runs). Calculations are typically required in their installation to ensure the proper voltage is used. The challenge here is that the vast majority of these products are higher wattage magnetic transformers, which typically require a load from 25%-50% of their rated load in order to provide the proper voltage to their terminals. Reducing wattage drawn can, in turn, increase effective voltage, having a negative effect on halogen and incandescent lamps, and requiring consideration on other types of lamps.

Incandescent Lamps are still around in landscape lighting, with PAR36 lamps being common, as well as some miniature lamps. Much of the industry trend has moved towards halogen versions of these lamps, because they are more efficient and tend to last longer.

Halogen Lamps are the most common light source that is used in a low voltage landscape fixture. Halogen lamps operate more efficiently at low voltage, and provide a higher color temperature for a whiter light than traditional incandescent sources, they also tend towards longer life spans. MR11 and MR16s are becoming more commonly used because of the wide range of beam spreads and light levels that they offer. They also allow very compact fixtures, due to their small size. In addition to these, halogen versions of PAR36 lamps have mostly replaced the incandescent versions, and small bi-pin and twist-lock type halogen capsules are used in fixtures where Omni-directional light is desirable.

LED lamps and Fixtures fit into this area well, as they are, by their nature, a directional light source, and can be directed effectively with optics. This is important because a wide beam is necessary when lighting a feature that is short and close, but a narrow beam is needed to reach the tops of trees. Landscape fixtures offer a challenge in that some are sealed for weather resistance, and others the lamp is required to be weather resistant. Open fixtures are good for heat dissipation, but require a lamp that is sealed against the weather. Enclosed fixtures protect the lamp from rain, irrigation, and humidity, but limit the power that an LED lamp can use in the fixture because the heat dissipation must be managed. In many cases (depending on the manufacturer of the LED lamp) an LED can be used in a landscape fixture if it is of all metal construction, as it often allows enough heat transfer to be compatible with LED lamps. If compatible, LED lamps can make landscape lighting applications easier, particularly when they have a flexible operating range of voltages, as voltage drop calculations become less intense. They generally operate well on the 60 Hz magnetic transformers most often used, and can save money by requiring less robust transformers due to their low power draw.
Pool and Water Fixture Lighting
This type of lighting carries a special risk due to the conductivity of water. Low voltage is often preferred, and sometimes required (depending on the locality), for lighting any type of fixture that is submersed in water. This is because low voltage power is much less dangerous to people, although line voltage fixtures are designed with significant safeguards against shock. The challenge with this type of lighting is that it is typically in a sealed fixture, with (obviously) no airflow within the fixture. The potential for energy savings is high; however, as most pool and water feature lighting is very high power consumption. LEDs can take advantage of water’s natural absorption in the red spectrum, and relatively little absorption in the blue and green spectrums by shifting the color temperature higher, allowing light to travel more effectively in water. This is in contrast to a 2600K to 2800K incandescent product, which generate a lot of red in their light, which gets quickly absorbed, and can give the water a green tint.

Downlighting
More recently, there have been miniature downlighting recess cans for general lighting as well as limited highlighting, while maintaining an unobtrusive footprint. These fixtures have capitalized on the small size, multiple light outputs, and the numerous, well controlled beam patterns of an MR type lamp. These types of fixture often include an integrated transformer into the fixture, and more often than not the transformer is an electronic one to keep the size and weight of the fixture down. The MR16 type lamps are most common, since they have a significant capability to produce light, while maintaining a small footprint. MR11s are possible, and can be an even smaller fixture. Either is a good application for the directionality of an LED for saving energy and reducing the amount of projected heat, but there are considerations. First is the transformer compatibility, and the second is whether or not the recessed can is considered totally enclosed. This is the case if the can is rated for insulation contact (IC) or is insulation contact and airtight (ICAT). Either IC or ICAT rated cans will trap too much heat in the fixture for an LED, and the focus should shift to a more efficient halogen type lamp rather than an LED retrofit.

Summary:
LED lamps provide a great deal of potential for reducing energy consumption in fixtures that have been unable to be reached effectively with compact fluorescent technology, and are to the point of providing viable and comparable light in many situations. Much like proper matching of a lamp and ballast, ensuring that the transformer that is currently in the desired retrofit fixture will work properly with the newer lamps is essential to achieving the best energy savings, light and life out of this new technology. This starts with a basic understanding of the types of transformers, and how they can interact with LED lamps.

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**LED and Transformer Compatibility Reference Sheet**

**Magnetic Transformers and LED Lighting:**

Positive:
- They provide a known 60Hz AC power to the LED, which is often accommodated in the design of many LED products.
- They are robust, reliable and are available in many different wattages.
- They are relatively inexpensive, comparatively, for higher wattages.

Negative:
- They provide AC rather than DC current.
- They typically have a minimum load rating to provide the expected voltage, which can be difficult to meet in an existing applications due to the efficient nature of LEDs.
- They translate voltage instability from the incoming power to the output power.
- They are less efficient at power conversion in comparison to electronic transformers.
- They are larger and heavier than the electronic equivalent.

**Electronic AC Transformers and LED Lighting:**

Positive
- Can be designed in a very small package and are often integrated into a fixture.
- More efficient than a magnetic transformer.
- At low wattages, they can have a cost advantage due to less material.
- Less likely to translate voltage instability from incoming power to output power.

Negative:
- Typically operate at high frequencies which can interfere with or damage LED products.
- Often have a minimum load rating that can be triggered by the low draw of LED lamps, causing the transformer to think there is a failed lamp, and either not working, or causing flickering.
- Less tolerant of heat than magnetic transformers.
- Must be designed to be dimmed.

**Electronic DC Transformers and LED Lighting:**

Positive:
- Ideal power supply for most LED products, as almost all LED chips are designed as DC only.
- Provides a very stable power source, often allowing LED products to perform better.
- Smaller and lighter than magnetic transformers.
- Provides less voltage drop on long wiring runs.
- Do not translate voltage instability from incoming power to output power.

Negative:
- DC transformers are less common in existing applications.
- Often more expensive than the equivalent electronic AC transformer.
- Usually larger than electronic AC transformer.
- Must be designed to be dimmed for dimming applications.