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The Challenge of Designing Safer LED Lighting Products

John Showell, Product Safety Consultant at Product Approvals Ltd, considers the health and safety issues related to the current main classes of regulations affecting LED lighting. He then focuses on the highest risk product safety factors; presenting some strategies and methods for designing safer LED lighting products. The challenge of designing LED lighting products that present essentially zero risk of fire and electric shock over their lifetime is raised.

It is important to remember the most fundamental safety related considerations when designing any new product that derives its power from an electrical source, whether that source be from mains grid power, or some kind of off-line supply such as a battery or group of batteries such as for an emergency lighting system. In this article the general term "safety" will be used to represent electrical product safety as the scope of this article does not cover other fields of safety such as photo biological safety considerations.

It is proposed that electrical product safety must be the uppermost consideration when considering the wide range of regulations which affect LED lighting products nowadays. This is simply because the main hazards related to electrical products - fire and electric shock - can and do, tragically, cause fatalities - resulting from products that could potentially contain a design flaw, a manufacturing defect (a "latent" defect as we will assume that 'patent' defects are detected in the manufacturing process); or could be the result of an application error, oversight or misuse.

UK Electrical Safety Council Report

A report by the UK's Electrical Safety Council stated that in 2010/11 in the UK there were 20,284 fires of electrical origin resulting in 48 deaths and 3,324 injuries – the majority caused by products and the remainder by installations. Referring to table 1, lighting was ranked 4th by product category as a cause of fires resulting in 930 fires, 97 injuries and 7 deaths. Defective lighting products and installations cause considerably fewer fires, deaths and injuries than other product types, but it is still an unacceptable state of affairs. LED products and installations are still in the minority but are growing rapidly. We must achieve the goal of zero fire and shock injuries and deaths as we also strive to maximise lumens per watt.

Other Regulations and Hazards

Injuries caused by excessive optical radiation could of course be very serious and must be prevented by competent product design and application. However death or severe injury occurring from excessive non-coherent optical radiation from general lighting would only likely occur as a secondary consequence of some event such as temporary blinding from a light source, causing someone to trip over an obstacle or some other such misfortune.

Other regulations address electro-magnetic emissions and immunity and in most scenarios, the consequences of not complying with legal requirements are essentially nuisance events such as improper operation of equipment and devices in the vicinity of the offending piece of equipment. Even here, of course, one cannot rule out a fatal or serious injury because of an EMC (electro-magnetic compatibility) related malfunction although it is very unlikely.

Environmental regulations come into the category of being a lowest risk short term health hazard for an individual but of course there could be serious longer term health related problems that could occur, for example, due to contamination of a community's water supplies from industrial waste products, chemicals or substances.

Table 1: **Major products involved in electrical fires in 2010/11**

Product [1]	Fires	Injuries	Deaths
Cooking appliances	14,005	2,960	11
Electricity supply - Wiring, cabling, plugs	3,380	314	8
Washing Machines and Tumble Dryers	1,552	74	2
Lighting	930	97	7
Fridge/ Freezer	312	110	4

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Energy efficiency regulations are classed in the arena of environmental regulations and legislation and of course the high energy efficiency of LED lighting is a major factor in the rapid market penetration of solid state lighting. Yet again, a health related factor can be associated with this class of regulations. Because of the prevalence of fossil fuel power generation around the world, if we can reduce energy consumption related to lighting then we will see reduced emissions of airborne pollution and this will benefit people's health. Are there any important regulations that do not have some kind of bearing on human health? Perhaps not, certainly in the key classes of regulations discussed briefly here, they all have some level of potential impact.

Returning to the subject of electrical product safety, the focus of this article, and the area that we can see is most capable of causing rapid or instant serious or fatal injury (instant in the case of an electric shock for example) the article reviews strategies and methodologies to help achieve lighting product designs that will, hopefully, never cause an injury or fatality. A product design that causes zero injury must be the goal. How will you ensure your design and product causes zero injuries over its entire lifetime?

Designers of lighting products may create products that are actually, in themselves, not capable of causing a fire or an electric shock. In this regard the type of product in mind is one that is powered from an energy source that is considered incapable of causing such an event because of its inherently limited available energy - specifically an energy source that is limited as to the electrical current availability, and to the maximum voltage that could be exposed to the human. Consequently, we have the first strategy that could help a product designer create a lighting product that cannot create a fire or electric shock - use of a 'safe' power source.

"Safe" Power Sources

An obvious 'safe' power source is the source created by putting some batteries into an LED flashlight - clearly there is a limited maximum voltage and zero risk of electric shock, and equally there is only a finite maximum current available in a small battery powered product. People tend to think of small batteries as safe power sources and mostly, they will be. Whilst there may be zero risk of electric shock in the example of the flashlight, we could conceive that under a fault condition, it may be possible to achieve a current level high enough to cause a fire. Admittedly, it is highly unlikely - we only tend to hear of fires caused by higher capacity battery sources such as some publicised cases of fires occurring with laptop computer batteries or some incidents with electric vehicles and so on. The factors in defining a safe power source soon become complex so we mostly rely on the body of evidence generated from research in various regions of the world, resulting in published guidance as to what constitutes a power source that presents no risk of fire or shock. Further, we may go to the trouble of performing tests that give us confidence that a fire or shock risk does not exist under any reasonably foreseeable condition (most typically in the world of safety assessment that means consideration and analysis of a single component or material fault occurring in the product or power source).

US Regulations

In the USA for many common applications, there are standards which give guidance on power sources which can be considered to present no risk of fire or electric shock. Generally speaking, the product that is energised by this power source therefore needs no special evaluation or testing to verify that it cannot cause a fire or shock hazard.

NFPA 70 (more commonly known as the NEC or National Electrical Code) is the standard being that is used extensively and applied across US industry, workplaces and also in private homes and other locations. Specifically, the type of power source that is considered to present no risk of fire or shock is a 'Class 2' power supply.

Class 2 inherently limited power supplies are power-limited to 100 VA and have a maximum output voltage of 42.4 V_{peak}. This is not exceeded under any single component fault condition in the power supply, such as the failure of a component in the switched mode power supply regulation circuit, if that topology is used. Definitions can be found in NEC (2011) Article 725 part III.

Another useful standard for the USA is UL1310 standard for safety - 'Class 2 Power Units'. This is a full end-product standard and certain UL1310 agency Listed Class 2 power supplies can be purchased and / or specified for use as a "safe" power source, thus removing the fire and shock hazard analysis from the connected load. It is important to understand the two main categories of UL1310 power supplies - inherently limited and non-inherently limited (definitions in clauses 30.2 & 30.3 respectively of UL1310). Only inherently limited power sources meet the 'safe' level without further

Table 2: **The US National Electrical Code – Class 2 inherently limited – no further protection required**

NEC Class 2 - Overcurrent Protection Not Required			
Source Voltage Vmax (Note 1)	Power Limitations VAmax	Current Limitations Imax	Maximum Overcurrent Protection
Up to and including 20 V_{ac}	-	8 A	-
From over 20 to 30 V_{ac}	-	8 A	-
From over 30 to 150 V_{ac}	-	0.005 A	-
Up to and including 20 V_{dc}	-	8 A	-
From over 20 to 30 V_{dc}	-	8 A	-
From over 30 to 60 V_{dc}	-	150 / V_{max}	-
From over 60 to 150 V_{dc}	-	0.005 A	-
Note 1: Voltage ranges shown are for indoor locations or where wet contact is not likely to occur			

Table 3: The US National Electrical Code – Class 2 non-inherently limited – additional protection required (such as external fusing)

NEC Class 2 - Overcurrent Protection Required			
Source Voltage Vmax (Note 1)	Power Limitations VA_{max}	Current Limitations (I_{max} = Const/V_{max})	Maximum Overcurrent Protection
Up to and including 20 V_{ac}	250 VA (Note 2)	= 1000 / V_{max}	5 A
From over 20 to 30 V_{ac}	250 VA	= 1000 / V_{max}	= 100 / V_{max}
Up to and including 20 V_{dc}	250 VA (Note 2)	= 1000 / V_{max}	5 A
From over 20 to 60 V_{dc}	250 VA	= 1000 / V_{max}	= 100 / V_{max}

Note 1: Voltage ranges shown are for indoor locations or where wet contact is not likely to occur
Note 2: If the power source is a transformer, VA_{max} is 350 or less when V_{max} is 15 or less

measures (outputting up to 42.4 V_{pea} or 60 V_{dc}, and with a maximum current output up to 8 Amps).

Coming down to the UL8750 standard for safety – "Light Emitting Diode (LED) Equipment for Use in Lighting Products" we see there are references to UL1310 Class 2 power units and a LED luminaire evaluated to UL8750 would meet the requirements of UL8750 if it incorporated a Class 2 or equivalent power source without further special evaluation. Note that UL8750 could be applied to a complete piece of LED lighting equipment if the application for that equipment is not covered by an existing UL standard such as UL48 for Electric Signs or UL1574 Track Lighting Systems. Clause 1.3 of UL8750 lists such end application / product standards and if the LED equipment comes under one such standard, it would be evaluated by an agency to the application standard requirements such as UL1574 & UL8750.

In additional to constructional analysis such as verification of electrical spacings (creepage and clearance) and insulating barriers, UL8750 addresses analysis of electric shock and fire hazards by clause 8.5 abnormal tests which include component failure testing and output loading. Other tests may be necessary. A decision must be made at the outset of a new project as to the main strategy to be adopted to prevent risk of electric shock:

Use of an inherently safe power source such as a Class 2 UL1310 or UL60950-1 ITE (Information Technology Equipment) agency certified ('Listed' by a US OSHA-accredited Nationally Recognized Testing Laboratory) power source.

Use of the common principles of protective separation of hazards from users:

- Insulation by use of physical insulation barriers which can provide the entire protection (referred to as double or reinforced insulation), or partial protection supplemented by air gaps or over-the-surface insulation
- Insulation by use of spacings - by through - air (clearance) or over - surface (creepage) distances
- Insulation using a single barrier - basic insulation - plus earth bonding

In applying one of these strategies to achieve prevention of electric shock, one must consider the ability of the solution to continue to provide the required protection in the application over at least the envisaged service life, plus a safety margin. LED drivers are now being advertised for sale with expected lifetimes of 20+ years. One insulation type that will not degrade over time is of course the 'insulation' provided by air (i.e. 'clearance') which is renewable. It's 'counterpart' often used in many designs – 'creepage' (over-the-surface spacing) – will degrade for most materials though, either because of gradual electrical tracking over the surface of the insulating material and possible ultimate breakdown (even potentially causing a fire), and/or due to build-up of pollution on the material surface. This latter degradation mechanism assumes that a PCB for example is not contained in a sealed enclosure, or encapsulated by conformal coating (which itself will have a certain maximum service length).

Solid insulation will often be used but this is susceptible to partial discharging and possible ultimate breakdown of the insulation. Special consideration should be given to so called 'solid' insulation in constructions such as the inner layers of a PCB which may contain multiple voids resulting from the manufacturing process so a margin of safety over the minimum figure stated in applicable standards should be used. PCB delamination risk should also be considered and this could cause loss of adequate insulation between an inner layer track near the edge of a PCB and an adjacent earthed metal enclosure for example.

It is a good idea to draw an insulation diagram such as the one below to record how the separation between humans and hazardous voltage circuits will be achieved.

EU Regulations

SELV (Safe Extra Low Voltage) levels are the equivalent to the US NEC / UL1310 Class 2 maximum safe-to-touch voltages.

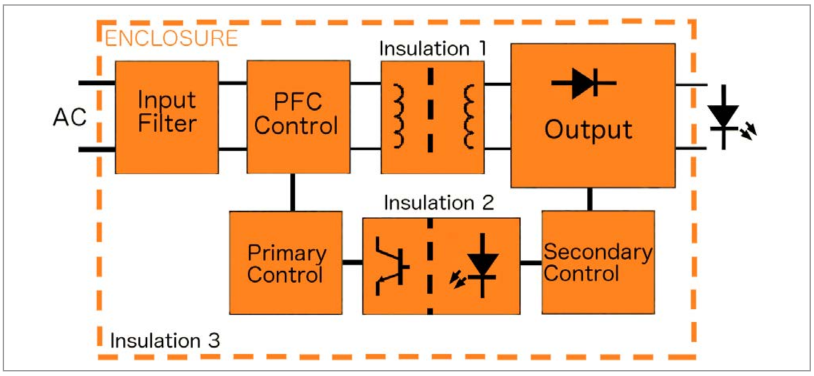

Figure 1: Insulation diagram showing internal and external isolation barriers for a simple LED driver – consider what barriers will be implemented as solid insulation, basic, supplementary or grounded, and whether part of the insulation system may reside in the LED light module for example

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Table 4: **Currently published key LED related safety standards. Note UL 8750 current version is first edition November 18, 2009 with revisions through October 17, 2012**

Area of Application	EN/IEC Standards	UL Standards*
LED modules with and without control gear	EN/IEC 62031:2008	UL 8750**
Separate LED control gear	EN/IEC 61347-2-13:2006	UL 8750**
LED modules with control gear and a lamp cap	EN 60968:2013 IEC 60968:2012	UL 8750**
Connection Systems for LED modules	EN/IEC 60838-2-2:2006+A1: 2012	UL 8750**
LED self-ballasted lamps (>50 V)	EN 62560:2012*** IEC 62560:2011	UL 8750**

* UL 8750 references many other UL Standards
** UL First Edition from 18th November 2009, ANSI Approved
*** The standard is published and for now not mandatory by the OJ of the EU

Note that ELV circuits are not safe to touch because they only have one level of insulation between them and hazardous voltage circuit and there is an un-acceptable electric shock risk if this one barrier fails. In SELV circuits, there is an additional barrier.

Increasingly, there is harmonisation in the standards world and the definitions of safe power sources should increasingly become harmonised across the world. Where there is an IEC safety standard for a particular product type then this is already well advanced. More and more standards in the EU, North America and elsewhere are being derived from the IEC standard, typically with identical base text plus some additional specific national deviations.

EU definition of “safe” power sources

As mentioned, many EU standards now are derived from the recognised IEC standard. For safety in the EU, all LED product types, one should turn to the Official Journal of the EU relating to the Low Voltage Directive 2006/95/EC (which can be accessed via website ec.europa.eu) in order to try to identify a suitable harmonised standard. Conformance to the relevant harmonised standard(s) will give a presumption of conformity to the Low Voltage Directive. The official journal (OJ) lists the standards which have been harmonised under the Low Voltage Directive.

A similar approach could be taken to that described for the US regulations - that is to say choose to contain the hazardous circuits and possible fire source inside a separate power supply thus allowing the LED module or luminaire designer free to concentrate on the light producing part of the design without the burden of much work on analysing and creating the safety case for the power source.

The type of power supply / LED driver needed in Europe for this approach is the SELV type.

A reference to “SELV operated LED modules” can be found in EN 62031 LED modules for general lighting - safety specifications although no definition of SELV is found in this standard. We can however consult EN 60598-1 (Luminaires – general requirements and tests) and SELV is defined as safety extra low voltage in clause 1.2.42.2 of that standard. SELV circuits have double or reinforced insulation between them and hazardous voltage circuits and so are safe to touch and require no insulation. According to EN 60598-1 clause 8.2.3c), an exposed circuit under load must not exceed 25 V_{rms} or 60 V ripple free DC, so at least in DC voltage terms, we see some basic commonality here with the US maximum voltage under UL1310 Class 2 power units. However the SELV definition in the above clause goes on to mention allowable exposed voltages in excess of 25 V_{rms} / 60 V_{dc} but with touch current limits of 0,7 mA (peak) and 2,0 mA for DC. Further, the no-load voltage should not exceed 35 V_{peak} or 60 V_{dc} ripple free (so the excursion above 60 V_{dc} is only allowed under the loaded condition with the imposed touch current limits). These limits are derived from IEC 60364-4-41 Low-voltage electrical installations - Part 4-41: Protection for safety - protection against electric shock.

Clearly the LED product designer potentially has a lot of extra safety related methodology, planning, design, testing and verification work to do if a custom-designed power source is specified for the product. The budget for the project should allow appropriate extra development time and cost plus further costs when it comes to possible third-party test and certification of the overall product.

Simply specifying and incorporating an off-the-shelf ‘safe’ power source is not quite enough, of course. Due diligence must be done to gauge the quality and safety of the bought-in unit, especially if it has not been third-party agency certified.

Finally, in this brief discussion of higher level safety considerations, we come to the EU approach on fire hazard of the power source. There is not a simple equivalent to the US Class 2 current / power limit which in that regulatory scheme has the meaning of not being able to cause a fire. So we must take the approach of analysing the fire risk from the point of view of construction, component and material selection, and testing. This is all necessary for custom designs assessed in accordance with US safety regulations and the safety parameters (such as comparative tracking index, hot wire ignition performance) are similar. However, we don’t have the exact equivalent to the US Class 2 inherently limited power source definition. An EU SELV specification power source is a halfway house (we can buy a power source that won’t cause an electric shock hazard) but work would be needed to show that it cannot cause a fire.

Conclusion

For products destined to be sold into the North American market, it is possible to select a bought-in power supply that provides a 'safe' source of power that is standards compliant (Listed by a US Nationally Recognized Testing Laboratory) and leaves the designer free to concentrate on the other aspects of the LED product design - providing the 100 VA power limit of the inherently limited power source is sufficient for the application (multiple Class 2 power supplies could be used for more LED modules or luminaires - but they must not be connected in parallel or the Class 2 status will be lost).

For the European situation (and several other countries due to the armonisation between EN and IEC standards), we can get a halfway house 'off-the-shelf' safe power source in the form of an SELV rated and certified power supply, which will prevent an electric shock risk being passed into the LED module or luminaire circuit thus potentially eliminating a lot of extra design work.
But we must pay special attention to designing and testing to verify that the SELV source cannot create a fire hazard.

If we cannot use a Class 2 / SELV safe power source, then we must allow significant extra time and thus financial budget in the product development stage to assess and verify the safety of the power source and load circuits. We should also devise the high-level safety case approach as to how a design will be implemented to achieve the goal of zero injuries being caused during the lifetime of the LED module / luminaire. Drawing the first version of the electrical isolation diagram is a good first step to achieving a safe yet cost effective design solution that will also allow safety to be easily assured and verified once in production. ■

References:
[1] UK Electrical Safety Council. Statistics, core data set. http://Www.esc.org.uk/stakeholder/policies-and-research/statistics/
[2] US National Fire Prevention Association, standard no. 70 – US National Electrical Code, 2011.
[3] Underwriters Laboratories UL1310 standard – Class 2 power units
[4] Underwriters Laboratories UL8750 standard – Light Emitting Diode (LED) Equipment for Use in Lighting Products
[5] IEC / EN 62031 standard LED modules for general lighting – safety specifications
[6] EN 60598-1 standard – Luminaires – general requirements and tests

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