PERFORMANCE DIFFERENCES IN AC LED TECHNOLOGY

The Importance of Power Factor and Harmonic Distortion in AC LED Lighting

PowerFactor (PF) and Total Harmonic Distortion (THD) are key performance parameters that can limit the wide acceptance of AC LED lighting in the marketplace. This paper first reviews the importance of both PF and THD to standards setting bodies, the electric utilities, and end users. Next, this paper reviews the PF and THD performance of two existing AC LED solutions, and then compares that performance to the performance of a new AC LED solution that conditions the electric power using selective current diversion (SCD) technology. Finally, this paper summarizes how AC LED lighting can achieve power quality levels necessary to sustain viral growth in the AC LED marketplace.

Power Quality: PF & THD

Despite AC LED[1] lighting's high luminous efficacy and promises to deliver significantly higher energy efficiency than incandescent lighting, power quality of AC LED lighting has been a much less compelling story. Before AC LED lighting can experience viral growth as it replaces billions of incandescent bulbs around the world, the industry will have to address the relatively poor power quality of its existing AC LED lighting solutions[2]. Power quality standards are already being considered, for example, as a prerequisite for AC LED lighting products to receive ENERGY STAR certification.

Power quality for any AC lamp indicates how the lamp draws current when supplied with sinusoidal voltage from the AC mains. Incandescent lamps have a resistance that draws current as a linear load, but AC LEDs have diodes that draw current as a non-linear load.

As a consequence of this non-linear behavior, existing AC LED lighting solutions exhibit poor power quality scores in terms of both ***power factor*** ("PF") and ***total harmonic distortion*** ("THD").

PF is a figure of merit[3] that indicates how effectively energy is transferred from the utility to the lamp. A purely resistive load will draw current at an ideal power factor of 1.0 from the utility. However, the utility must generate and transmit the same amount of electric power to supply 100 watts at PF=0.5 as it must generate and transmit to supply 50 watts at PF = 1.0. To compensate for such increased generation and transmission costs, utilities often charge substantially higher rates for low power factor loads. PF for AC LED lighting is a product of two components: displacement factor (i.e., a phase difference between voltage and current) and a distortion factor[4].

THD is a numeric representation of distortion in the current waveform relative to the sinusoidal voltage waveform on the AC mains. Distortion indicates how much harmonic current is flowing in the power lines. Harmonics are unwanted currents at multiples[5] of the fundamental line frequency (e.g., 50 or 60 Hz). Harmonic currents can create additional voltage and power losses in the transmission lines, heat transformers and capacitors, resonate with power factor correction capacitors, and/or overload neutral conductors. Uncontrolled harmonic currents in commercial facilities can lead to outages and even fires. Any non-linear load, such as an AC LED light engine, will draw a distorted (non-sinusoidal) current waveform when excited by a sinusoidal voltage waveform.

[1] AC LED lighting refers to illumination generated by LED light engines when supplied with a sinusoidal AC voltage source—typically the utility line voltage (e.g., 120 V in the U.S., 100 V in Japan, 220 V in Europe). Because of its high luminous efficacy, AC LED lighting has tremendous potential to become the dominant type of lighting in many applications. Before the full potential for AC LED lighting can begin to be tapped, the AC LED industry must overcome some key barriers: performance, cost, and quality.

[2] Recent history suggests that rapid proliferation of a new technology with a non-linear load will prompt government regulations to address power quality. In the 1980's and 1990's, rapid proliferation of non-linear loads in the form of computer equipment led to international standards such as IEC 555-2 "Harmonic Injection into the AC Mains" in the U.S. and EN61000-3-2 in Europe.

[3] PF values range from 0 to 1, where PF = 1.0 is ideal.

[4] THD is a widely used measure for the distortion factor component of PF.

[5] In the U.S., the fundamental line frequency is 60 Hz with harmonics at 120 Hz, 180 Hz, 240 Hz, 300 Hz, etc…

Comparison of AC LED Technologies

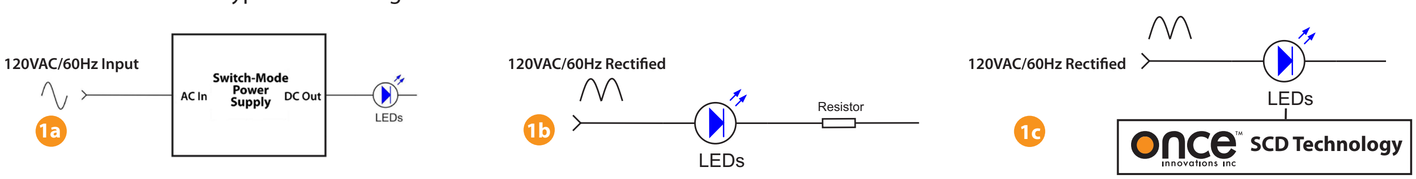
Existing AC LED technologies may be characterized by which type of conditioning circuit topology it has. Existing AC LEDs use a conditioning circuit that is either (i) a switch-mode power supply type, or (ii) a resistor type. This paper also reviews a new, patent pending, type of conditioning circuit for AC LED lighting.

Conditioning Circuit Topologies

Figure 1(a) shows a schematic diagram for a switch-mode power supply (SMPS) type conditioning circuit, which generally converts sinusoidal AC voltage to a regulated voltage and/or current to drive the LEDs. The SMPS type conditioning circuit involves a number of components, including diodes, various capacitors, inductors, resistors, a control processor, and at least one semiconductor switch that modulates current flow by cycling on and off at a high frequency, often in the range of 40-400 kHz.

Figure 1(b) shows a schematic diagram for a resistor type conditioning circuit, which generally rectifies sinusoidal AC voltage to an unregulated voltage that drives the LEDs. The resistor type conditioning circuit requires only a rectifier and a resistor.

Figure 1(c) shows a schematic diagram for a selective current diversion (SCD) type conditioning circuit, which generally rectifies sinusoidal AC voltage to provide conditioned excitation to the LEDs.



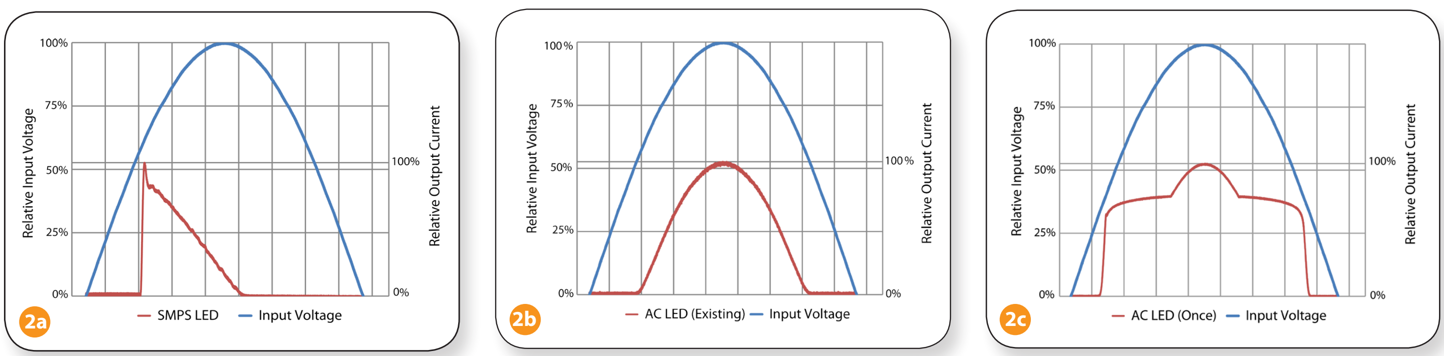


Table 1

Conditioner Type	SMPS	Resistor	SCD	Ideal
PF	0.606	0.92	0.98	1
THD	68.1%	39.5%	15.7%	0.0%

Conditioning Circuit Power Quality

Figures 2(a)-2(c) show plots of measured current waveforms for representative samples of each type of conditioning circuit. These plots help to illustrate the power quality performance for each type in terms of PF and THD.

Figure 2(a) shows that the SMPS type conditioning circuits can draw a very distorted current, and the current is significantly phase-shifted with respect to the sinusoidal voltage wave form. The power quality of a SMPS-based AC LED can be improved, but this generally can come at the cost of adding further complex circuitry (e.g., power factor correction module) to condition and control the current drawn by the load. Although values can vary widely, ***Table 1*** indicates that the tested SMPS conditioning circuit has poor power factor (PF = 0.606) and high distortion (THD = 68.1%).

Figure 2(b) shows that the current drawn by a resistor type AC LED conditioning circuit has alignment of the peak of the current waveform with the peak of the voltage waveform, which helps improve the overall power factor. However, the current waveform is distorted (flattened) at lower voltages. To improve the PF and THD, the conduction angle for the current could be increased by reducing the number of LEDs in series; however, this would require a corresponding increase in series resistance to control current, and the increased resistance would lower the overall efficacy and energy savings potential. ***Table 1*** indicates that the tested resistive type conditioning circuit has good power factor (PF = 0.92) but significant distortion (THD = 39.5%).

Figure 2(c) shows that the current drawn by a SCD type AC LED conditioning circuit also shows alignment of the waveform peaks, but the current waveform is less distorted because it conforms better to the voltage waveform at lower voltages. The increased current at low voltages also boosts luminous efficacy, showing about 15% improvement associated with the reduced distortion. ***Table 1*** indicates that the tested SCD type conditioning circuit has excellent power factor (PF = 0.98) with low distortion (THD = 15.7%).

Conclusions

The new SCD type conditioning circuit for AC LED lighting has achieved breakthrough power quality performance that is superior to currently known AC LED lights. Based on tests of representative sample with existing types of conditioning circuits, AC LED with SCD conditioning technology achieves far better power quaity performance in terms of both power factor and distortion. In particular, the SCD type achieves superior power quality and significantly higher luminous efficacy for very little additional cost relative to the simple resistive conditioning circuit. Moreover, the SCD type achieves much better power quality for far less weight, volume, number of components, and complexity when compared to the SMPS conditioning circuit. The cost of an SCD circuit is estimated to be about 5% of the cost of an SMPS circuit.