APQRC

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Impact of Power Quality on Lighting Technology

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Table of Contents

1. Executive Summary 4

2. Introduction 4

3. Incandescent Lighting 4

3.1 Supply Voltage Magnitude 5

3.2 Flicker 5

3.3 Voltage Sags and Rapid Voltage Change 5

4. Fluorescent Lighting 6

4.1 Supply Voltage Magnitude 6

4.2 Voltage Sags and Rapid Voltage Changes 6

5. Compact Fluorescent Lighting (CFL) 6

5.1 Supply Voltage Magnitude 7

5.2 Voltage Sags and Rapid Voltage Change 7

6. LED Lighting 7

6.1 Supply Voltage Magnitude 8

6.2 Harmonics and Waveform Distortion 9

6.3 Flicker 9

6.4 Voltage Sags and Rapid Voltage Change 9

7. Conclusion 10

8. References 10

1. Executive Summary

This technical note discusses the impact of power quality (PQ) disturbances on different lighting technologies. It mainly focuses on lighting technologies for domestic use; however, much of the technical information is also readily applicable to commercial and industrial lighting technologies. The fundamental operation of modern lighting sources vary depending on the lighting technology. The more recent energy efficient lighting technologies such as compact fluorescent lamps (CFL) and light emitting diode (LED) lighting are much more complex than the traditional incandescent lamp. This has resulted in better immunity to some PQ disturbances but increased susceptibility to others. All lighting technologies are generally sensitive to the magnitude of the input supply voltage whether it be sustained levels or rapid variations. This has effects on both lamp performance and lifespan. The complex interactions between light dimmer, driver circuit and LED lamp for LED lighting systems makes the technology sensitive to voltage waveform distortion in some cases.

2. Introduction

This technical note focuses on the impact of power quality (PQ) disturbances on different lighting technologies. The main emphasis is on domestic lighting technologies. However, many of the same technologies are also used in commercial and industrial applications and hence the PQ impacts of concern in domestic environments become relevant to the lighting in these other applications. The following lighting technologies are examined in this technical note:

- Incandescent lighting – this include traditional vacuum filled incandescent bulbs in all shapes and sizes along with energy saving halogen filled bulbs and all forms of incandescent downlights
- Fluorescent lighting – this includes traditional tubular fluorescent type lighting
- Compact Fluorescent Lamps (CFL)
- LED lighting systems

The impact of the following PQ disturbances on the above lighting technologies is examined:

- Steady state input voltage magnitude – i.e. the magnitude of the supply voltage
- Flicker – periodic modulation of the supply voltage waveform envelope
- Voltage sags and rapid voltage changes – short term variations of the input supply voltage magnitude
- Voltage waveform distortion – including harmonic and other waveform distortion

Not all lighting technologies are impacted by all of the above disturbances and only those disturbances which have major impacts are examined for each lighting technology.

3. Incandescent Lighting

Incandescent lights include traditional vacuum filled lamps along with newer energy saving lamps which are generally filled with halogen gas as opposed to a vacuum. Figure 1 shows an image of a traditional incandescent bulb. Figure 2 shows an image of a halogen downlight. These lighting technologies are mainly impacted by supply voltage variation.

Figure 1: Incandescent Light Bulb [1]

Figure 2: Halogen Downlight [2]

3.1 Supply Voltage Magnitude

Incandescent lighting technology is highly sensitive to the magnitude of the input voltage. The input supply voltage magnitude has a significant impact on both lamp light output and lifespan. A sustained supply voltage magnitude *V* near the rated voltage of the lamp would lead to [1]:

- *Light* output that is approximately proportional to $V^{3.4}$
- *Power* consumption that is approximately proportional to $V^{1.6}$
- *Lifetime* that is approximately proportional to V^{-16}
- *Colour temperature* that is approximately proportional to $V^{0.42}$

This means that a 5% reduction in operating voltage will more than double the life of the bulb at the expense of reducing its light output by about 16%. Conversely, a 5% increase in operating voltage above the rated voltage will halve the lifetime of the lamp albeit with a higher light output as a trade-off.

As listed above, variations in voltage magnitude will also cause the lamp to use more or less energy for higher or lower input voltage levels respectively.

3.2 Flicker

Flicker arises as a result of regular or irregular modulation of the supply waveform envelope causing fluctuations in light output. The human perception of light flicker depends on the individual. This sensitivity may manifest as irritation all the way through to health issues such as headaches and in extreme cases seizures. Modulation of the voltage waveform is easily observable in incandescent lighting as the lamp filament has a very short thermal time constant (for example, a 230V, 60W light bulb will have a shorter time constant compared to that of a 110V, 60W light bulb because of the thinner filament in the former). In fact, standards which apply to flicker have been developed based on the characteristics of incandescent lighting technology.

3.3 Voltage Sags and Rapid Voltage Change

Voltage sags and rapid voltage changes are basically very short term variations of the input supply voltage magnitude. As such, voltage sags or rapid voltage changes will likely produce a noticeable variation in output lighting level. This change in lighting level generally does not damage the lamp; however, it can be highly irritating to some individuals. This is particularly the case when there are many voltage changes per hour caused by a large load such as an air conditioner that cycles regularly. In this case, the inrush current drawn by the load as it switches on causes a voltage drop in the local circuits, leading to many short term changes in light output.

4. Fluorescent Lighting

For the purposes of this technical note, fluorescent lighting is that which uses a basic ballast for starting and current control. Examples include the straight tubes that are installed in office buildings and other commercial premises such as shopping centres. Compact Fluorescent Lamps (CFLs) which use complex electronic ballasts are examined separately. The main power quality disturbances that impact the performance of fluorescent lighting technology are supply voltage magnitude, voltage sags and rapid voltage change.

4.1 Supply Voltage Magnitude

Fluorescent lighting performance can be impacted by the magnitude of the input supply voltage. From [3] the following is a summary of the impact of supply voltage on tubular fluorescent lighting:

- If the supply voltage is too low, the lamp will have difficulty in starting, especially if the humidity level is high. This condition can cause the lamp to flash off and on without starting, which may slowly deteriorate the electrodes of the lamp. Further, because of the reduced energy level in the mercury arc, light output will be reduced.
- With elevated supply voltage levels, preheat or rapid start lamps will sometimes operate as an instant start lamp. As a result, cathode coating of the lamp will deteriorate because of the high-voltage pulses delivered to the cathode. Lumen maintenance will also suffer. At the same time, higher than normal lamp operating currents can cause premature lamp failure and overheating of ballasts.

4.2 Voltage Sags and Rapid Voltage Changes

The main impact of voltage sags and rapid voltage changes on fluorescent lighting is that the lamp may extinguish. "A temporary voltage drop (sag) on the power system, even for a few cycles, will cause a fluorescent lamp to "drop out" [3]. If the voltage drops below 80% of the rated level of a rapid-start ballast lamp (and most other ballasts), the arc stream within the lamp becomes unstable and extinguishes. Fortunately, the lamp will restrike almost immediately upon restoration of full voltage."

5. Compact Fluorescent Lighting (CFL)

With the phasing out of standard incandescent bulbs in many countries, penetration of CFLs, which were the only viable alternative at the time, has increased exponentially. There are many variants of CFL globe both in terms of construction and bulb power rating. CFLs contain a complex electronic ballast for starting. Figure 3 shows images of two different CFL lamps. Figure 4 shows a typical CFL ballast circuit while Figure 5 shows a dismantled CFL with the complex ballast circuit clearly visible. The main power quality disturbances that impact the performance of CFL lighting technology are supply voltage magnitude, voltage sags and rapid voltage change.

Figure 3: CFL Globes

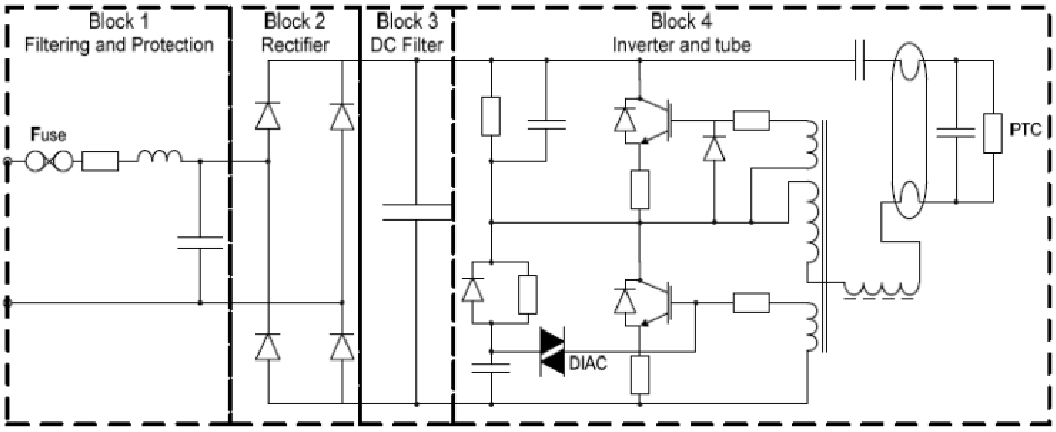

Figure 4: Typical CFL Ballast Circuit [4]

Figure 5: Dismantled CFL showing Complex Ballast Circuit

5.1 Supply Voltage Magnitude

While the electronics in the CFL ballast provide some immunity to variations in light output resulting from the supply voltage, higher voltages will see increased lamp brightness while the opposite is true for reduced supply voltage levels. It is known that the electronic components in the ballast, particularly the DC bus capacitor (Block 3 in Figure 4), are sensitive to supply voltage magnitude and that high levels of supply voltage magnitude will cause a reduction in lamp lifespan particularly if the lamp is switched on and off frequently. However, the precise relationship between supply voltage magnitude and lamp lifespan has yet to be determined.

5.2 Voltage Sags and Rapid Voltage Change

Voltage sags and rapid voltage changes can impact the light output of CFLs. For shallow changes in voltage magnitude, this will manifest as a short term reduction in lamp brightness. Deeper changes in voltage magnitude can cause the lamp to extinguish with the lamp turning back on once the voltage magnitude has returned to an appropriate level.

6. LED Lighting

As the cost of LED lighting technology has decreased over time, LED lighting has become much more popular. At present, LED lighting is the most energy efficient mass produced lighting technology. LED lighting has advantages over CFL lighting in terms of lifespan, simplicity, colour and starting performance. However, LED lighting technology is also the most complex of the lighting technologies examined in this technical note and also may have the most complex integration issues associated with the power supply system. LED lighting cannot be thought of as simply a lamp. Rather, it is a lighting system which contains both an electronic driver circuit designed to condition the input voltage to the required level along with a lamp which may consist of one or more LEDs. In some cases, the electronic driver circuits are integral to the LED lamp, while in other cases, the driver circuit is separate. Given the fact that LED lighting is more than just a lamp, the term LED lighting system is used in this technical note to describe the electronic driver and LED lamp combination. Figure 6 shows a range of LED lamps. Figure 7 shows an example of a 12V, 12W LED driver circuit. Figure 8 shows a photograph of a LED lamp which contains integrated voltage regulation circuitry which demonstrates that both drivers and lamps can be complex arrangements. This figure also shows the three LEDs connected in series which make up the lamp.

The susceptibility of LED lighting systems to power quality disturbances is highly complex and is very much dependant on the design of the driver circuit. Some driver circuits react differently to the various power quality disturbances compared to others. It has been found that some LED lighting systems are highly susceptible to changes in the supply voltage magnitude, while others appear to have high immunity. It has also been found that the complex relationship between LED lamps, driver circuits and dimmers can be highly susceptible to waveform distortion in some cases. Overall, it is difficult to make definitive statements with respect to the impact of power quality disturbances on LED lighting systems.


Figure 6: LED Lamps [5]

Figure 7: Example 12V, 12W Electronic LED Driver

Figure 8: (a) and (b) LED Lamp and Regulation Circuits, (c) 3 LEDs in Series

6.1 Supply Voltage Magnitude

All LED lighting requires conversion of AC voltage to DC voltage to operate. As noted above, this conversion is generally performed by an electronic circuit. As in the case of CFLs, the components in these electronic circuits are sensitive to the magnitude of the supply voltage. Voltage levels which are too high may lead to a decrease in the lifespan of the electronics associated with the LED lighting system. In addition, depending on the performance of the electronic driver, changes in the steady state supply voltage may result in changes in the light output for some LED lighting systems. For those systems that are susceptible, an increased supply voltage magnitude will result in increased light output and vice-versa for decreased supply voltage magnitude.

6.2 Harmonics and Waveform Distortion

The combination of dimmers and LED driver circuits for LED lighting is much more complex than for traditional incandescent lighting. Dimmable LED driver circuits contain complex electronics designed to detect the operation of the dimmer and adjust the output to the LED lamp accordingly. Under certain circumstances, in the presence of waveform distortion, some combinations of dimmer and driver circuits can produce flickering light output. This can particularly be the case during injection of ripple injection load control signals used by distribution utilities. Here, the injected signal causes a rapid change in the voltage output of the dimmer. This in turn causes a change in the output of the driver and fluctuations in the light output of the LED lamp. This interaction between injected control signal and LED lighting has been a major source of customer complaints to distribution utilities. Unfortunately, the problem occurs even when injected voltage levels are within prescribed limits. Further complicating the issue is the fact that some lamp/dimmer/driver combinations appear to be immune to the ripple injection signal while others are highly susceptible. Given the very large number of lamp/dimmer/driver combinations, there is no simple solution to this issue. Indeed, laboratory testing has shown that some dimmers which claim to be specially designed for use with LEDs are not immune to injected ripple control signals as advertised. One possible solution to flickering light output due to waveform distortion is the application of a filter specifically designed to filter the ripple injection system. However, such filters must be used judiciously and if they are applied incorrectly, they can interfere with normal operation of the ripple injection signals, potentially resulting in incorrect operation of off-peak tariff relays, hence impacting hot water heater operation.

6.3 Flicker

Some LED lighting systems appear to be susceptible to flicker. That is, modulation of the supply voltage waveform will result in perceptible changes in the intensity of the light output for some LED lighting systems. Once again, the susceptibility of the LED lighting system to flicker is highly dependent on the design of the electronic driver and will vary with the driver design.

6.4 Voltage Sags and Rapid Voltage Change

Voltage sags and rapid voltage changes can result in changes in light output of LED lighting systems. As for other variations to the magnitude of the supply voltage (e.g. variation in steady state voltage magnitude), the susceptibility of LED lighting systems is dependent on the design of the electronic driver. In general, due to the fact that LED lighting systems contain electronic power supplies and operate at low voltage, they are less susceptible to changes in the input voltage magnitude than in the case of traditional incandescent lamps. Put another way, the same variation in input voltage magnitude will produce a much larger change in light intensity output in a traditional incandescent lamp than in a LED lighting system. In some cases, there is no impact to the LED operation for very large changes in the input voltage as a result of the voltage regulation function of the electronic driver. As for all electronic equipment, if the voltage falls to a low enough level for a long enough time, the LED lamps will extinguish.

7. Conclusion

This technical note has examined the impact of various power quality disturbances on lighting systems. There has been a significant change in lighting technology over the past decade which has led to better immunity to power quality disturbances in some cases but increased susceptibility to power quality disturbances in other cases.

Four lighting technologies have been examined. These are incandescent, fluorescent, compact fluorescent and LED. All of the examined technologies are susceptible to some extent to the magnitude of the input supply voltage, whether it be sustained levels or short term variations such as voltage sags or rapid voltage changes. In general, traditional incandescent lamps are more susceptible to power quality disturbances than modern lighting systems such as CFLs and LED lighting systems. However, the complex nature of LED lighting systems, which include an electronic driver circuit as well as a LED lamp and in some cases a dimmer, has rendered them susceptible to some forms of waveform distortion. In many cases, the complexity of this problem makes it difficult to define and rectify.

8. References

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