The Impact of LED Lighting Systems to the Power Quality and Recommendations for Installation Methods to Achieve the Expected Energy Efficiency

THE IMPACT OF LED LIGHTING SYSTEMS TO THE POWER QUALITY AND RECOMMENDATIONS FOR INSTALLATION METHODS TO ACHIEVE THE EXPECTED ENERGY EFFICIENCY

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ABSTRACT

In this paper, the impact of LED lighting systems to the power quality (PQ) of the electrical network are analyzed. The paper compares the effect for PQ in respect with the old fluorescent tube lights (FTL). Moreover, the alternative installation methods for LED lights are analyzed and recommendations for the installations of LED lights will be given to achieve the expected energy efficiency.

INTRODUCTION

The lighting systems are currently changing radically. Lighting accounts 20-25 % of the total electrical energy consumption of the world, hence energy efficiency of lighting is crucially important [1]. The LED lights will gain market share and replace other lighting devices in all aspects of lighting. According to EU regulation, incandescent (IC) lamps with power higher than 7 W have been forbidden to sell since year 2012 [2]. In addition, the ferromagnetic connection devices of fluorescent tube lights (FTL) were banned to sell since 13th of April 2017 [3].

The capacitive reactive power is an expanding issue due to replacement of overhead lines by underground cables also in rural areas in Finland. The forecasting reveals the continuous reduction of inductive loads leading to the need to invest in reactors and the changes in the consumer load types are accelerating the procurement. The consumption of reactive power is proportional to the load current, but the production of reactive power is dependent with the voltage level.

Experimental measurements of lighting systems influence on the electrical networks power quality are presented in this paper. FTL with magnetic and electronic ballasts as well as three LED products are compared. The power quality was measured using power quality analyzer Dranetz PX5. Earlier the effect of single LED lights and compact fluorescent lamps (CFL) to the power quality has been analyzed in the laboratory [4, 5, 6, 7, 8]. According to the results, LED lights consume the least energy compared to ICs and CFLs, hence LED is the most energy efficient lighting type. In this paper, the lighting system and its effect on power quality with various lighting types are analyzed.

LED LIGHTS

LED lights are solid-state lighting devices, i.e. semiconductor emits the light unlike in fluorescent lamps, where electric current is applied and the gas inside the tube produces short-wave ultraviolet (UV) light. The UV light is turned into visible light by phosphor coating inside the tube. LEDs are p-n junction diodes, which emit light when proper voltage is applied. Even a slight raise in voltage will increase the current flowing through LED exponentially. The LED lights have many advantages e.g. long lifetime, no toxic components and high energy efficiency. However, LEDs are operated by using DC voltage, hence electronic connection device is required to rectify AC power supply into DC. There are various electronic connection device topologies for LED lights, but the basic operating principle is described in Figure 1.

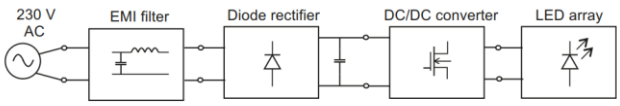


Figure 1. Operating principle of LED ballast circuit

Usually a diode rectifier is used to convert AC supply voltage to DC. DC capacitor is added to smooth produced DC voltage and EMI filter is connected between the electrical network and the rectifier to filter out the harmonics of AC current. Commonly used DC/DC converter topologies are boost, flyback, resonant and buck, which produce the required constant current for the LED array. The power factor correction (PFC) circuit may or may not be included in the DC circuit. The commercial ballasts are built with the cheapest possible way, which still meets the IEC 61000-3-2 Class C standard requirements for lighting.

Power Quality

LED lights behave as non-linear loads because of the electronic connection device shown in Figure 1 unlike conventional IC lamps. Non-linear loads produce high frequency current harmonics, which can lead to power quality degradation in the distribution network. The harmonics increase the power losses in cables and transformers. In addition, harmonics may cause flickering, imbalance and core saturation of transformers and thermal aging of induction motors [4]. High frequency emissions of LED lights in the 2…150 kHz range may also cause problems for power line communication (PLC) used e.g. in smart meters. The harmonics of the diode rectifier can be limited by using PFC circuit. Therefore, the produced harmonics highly depend on the type and quality of the electronic connection device used with the LED light.

MEASUREMENTS

This study concentrates on the experimental measurements of lighting system level influence on the power quality when FTLs with magnetic or electronic ballasts are replaced with LED technology. The replacing light can be either a completely new LED luminaire or replacement of LED tube for the old fluorescent light frame with or without additional modifications. For example in Finland, the configuration changes will remove the responsibility from the original manufacturer concerning safety or other features. The original rating plate and other certifications are no longer valid. The person performing the modifications will become responsible for the safety and other features [9]. The electrical behavior of the lighting before and after the change of lighting technology was observed using power quality meter Dranetz PX5. The general measurement setup for all the measurements is illustrated in Figure 2.

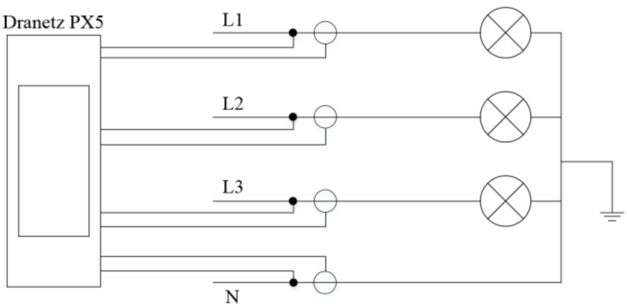


Figure 2. Measurement setup.

The setup includes voltage and current measurements of three phases (L1, L2 and L3) and neutral wire (N). The voltages were measured by power quality analyzer from the terminal blocks or mains of the group switchgear and the currents were sensed using current probes. The whole three-phase lighting group was measured at a time and the loads were selected to be only lighting. Since the measured lighting groups were connected in wye and grounded at the group switchgear, the measuring unit was measuring phase voltages. The neutral of the main busbar of the group switchgear offered the reference point for the measurements due to the grounding. The neutral current measurement was specific for the investigated lighting group. The measurement setup was kept identical for every case to retain the correspondence of the measurements. Each of the phases in the lighting groups had 3-5 lamps per phase (2 × 58 W fluorescent tubes per lamp), loading of the phase varied based on type, model and number of lights. The lighting was fed by the local distribution network (400 V, 50 Hz) through the switchboards of the building. The phase voltages are presented in Figure 3 revealing the condition of the prevailing electrical system because of the practical measurement environment. The currents are strongly distorted when passive components are utilized with FTL as shown in Figure 3a.

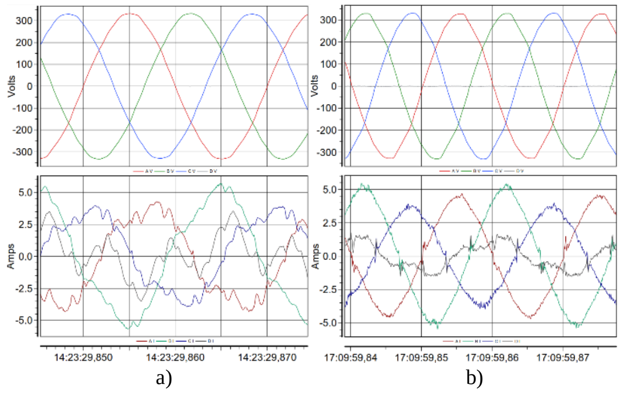
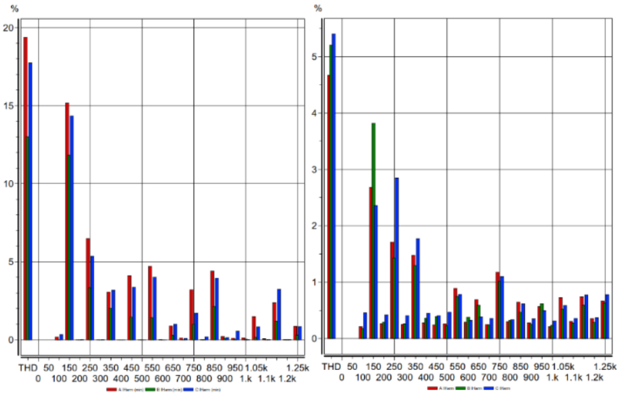


Figure 3. Phase voltage and current waveforms from FTLs with magnetic ballast (a) and electronic ballast (b). L1 is red, L2 is green, L3 is blue and grey is neutral.

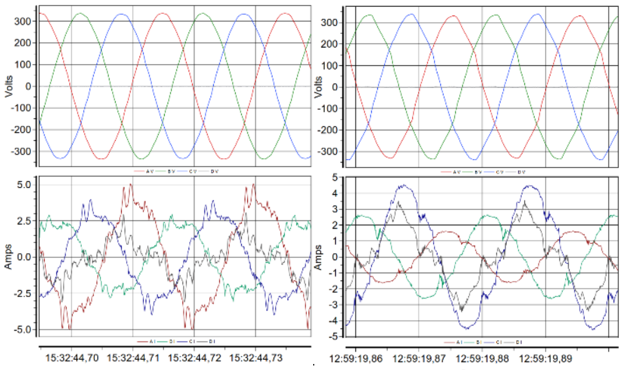
The neutral wire current amplitude is almost as high as the phase current amplitude with magnetic ballast as shown in Figure 3a. Instead, the electronic ballast is able to manage the harmonics and decrease the neutral wire current as well as phase difference as shown in Figure 3b. Total Harmonic Distortion (THD) has been calculated up to 40th harmonic component as the limitations for voltage and current harmonics are set similarly in the standards IEC 61000-3-2 Class C and EN 50160. The overall current THD is significantly higher, 18 % when FTL with magnetic ballast is used compared to 5 % with electronic ballast as shown in Figure 4. The use of magnetic ballast leads to significant amount of third harmonics, which can be eliminated with the use of electronic ballast.



a) b)

Figure 4. Measured current THD of FTL with magnetic (a) and electronic ballast (b). L1 is red, L2 is green, and L3 is blue.

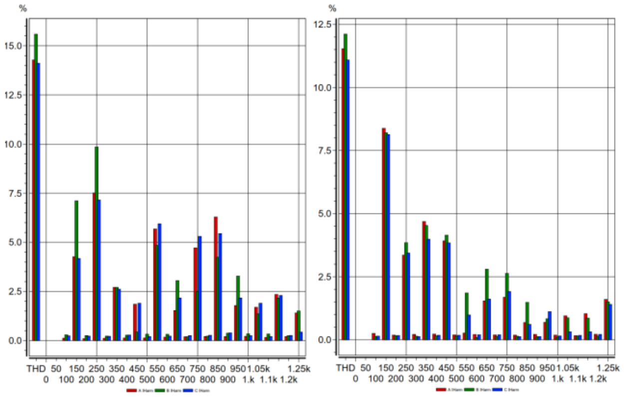
In FTLs, the compensation capacitors are designed to keep the unity power factor with the inductive ballast. However, the lamps are almost purely capacitive when the capacitors are still in use with LED tubes. In Figure 5a, is presented the voltage and current waveform from the measured lighting group, where FTLs have been replaced with LED tubes but the choke and compensation capacitors remain coupled. In Figure 5b, the choke and compensation capacitors are also removed during the installation of LED tubes, however there is imbalance between phases, which increases the neutral wire current. The electronic rectification is evidently observed from the waveforms of currents in Figure 5a.



a) b)

Figure 5. Phase voltage and current waveforms from LED tubes with the old FTLs capacitors (a) and without capacitors (b). L1 is red, L2 is green, L3 is blue and grey is neutral.

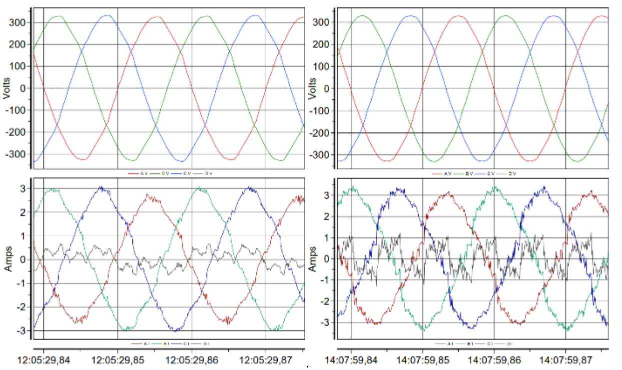
Removal of the capacitors decreases the phase difference significantly. When the capacitors remain coupled, the phase difference between current and voltage is almost 90º. When the capacitors are also removed with the lighting update, phase difference is only 25º. The percentage of harmonics decreases from 14 % to 12 % when the capacitors are removed as shown in Figure 6. The amount of third harmonics remains the same but fifth harmonic decreases from 10 % to 3 %. It can be concluded that special attention to the additional passive compensation devices is required when the lights are replaced with LEDs. PFC circuit of the LEDs controls the power factor close to one, but the effect of separate capacitors is beyond control. The active power is reduced but the apparent power and RMS current remains almost unchanged. Therefore, with the defective replacement practice LEDs may cause more issues than benefits and the expected energy efficiency is lost. In addition, the neutral current amplitude is almost 75 % of the phase current amplitude, as shown in Figure 5a.



a) b)

Figure 6. Measured current THD of LED tubes with capacitors (a) and without capacitors (b). L1 is red, L2 is green, and L3 is blue.

The currents are more sinusoidal when the whole luminaire is changed and not only the tubes as shown in Figure 7 compared to Figure 5. The current amplitude is lower, 3 A, compared to the previous cases, 5 A. In addition, the neutral wire current amplitude is very low especially with the LEDs from manufacturer 1 as shown in Figure 7a.



a) b)

Figure 7. Phase voltages and currents from LED luminaire manufacturer 1 (a) and manufacturer 2 (b). L1 is red, L2 is green, L3 is blue and grey is neutral.

The overall current THD is almost doubled from 6 % to 12 % with the LED light by manufacturer 2 compared to the light by manufacturer 1 as shown in Figure 8.

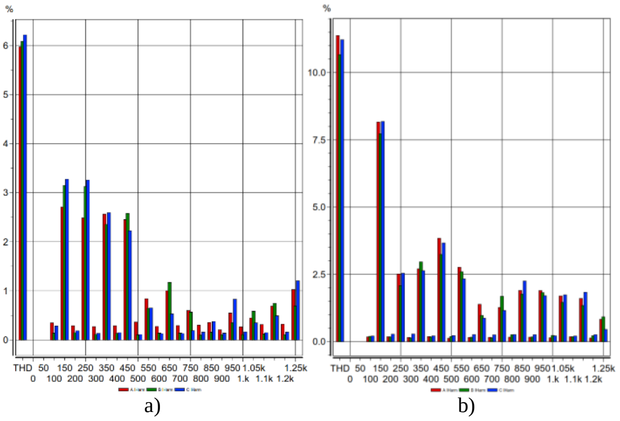


Figure 8. Measured current THD from LED luminaire manufacturer 1 (a) and manufacturer 2 (b). L1 is red, L2 is green and L3 is blue.

The amount of third harmonic component is doubled with the light from manufacturer 2 compared to the manufacturer 1 as shown in Figure 8. The percentages of higher harmonics are almost the same with both lights. High harmonic current content causes derating of the distribution transformers and accelerates aging [10].

Transient analysis

The most important possible problem with LED lights is the start-up transient. Transient current with the LED luminaires from manufacturer 2 is presented in Figure 9. The duration of the transient is very short (microseconds) but the amplitude is almost 200 A, i.e. 60 times higher than nominal phase current, 3 A. When these lighting groups are switched on, the peak current can cause malfunctions, for example unwanted tripping of circuit breakers [11]. The series inductance of the conductors and the capacitors of the LED power supply units (PSU) are forming a series resonance circuit and the resonance frequency is dependent on the features of the PSU. Because of the series resonance, significantly high voltages can occur over the PSU's internal capacitances. This effect may be part of the reason for the shortened lifetime of some LED lights. Verification of this hypothesis would require further research.

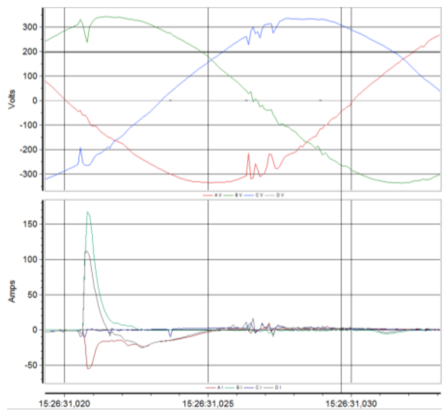


Figure 9. Start-up transient from the same luminaires as in Figure 7b. L1 is red, L2 is green and L3 is blue.

The disturbance in the network voltage may cause problems to some devices. In the Figure 9 the transient current leads to voltage oscillations. When this oscillation occurs around zero, it may cause problems with power electronic devices using simple PLL-technology, e.g. zero crossing detection.

There is a need for further improvement of the lighting system. The proper operation of protection devices needs to be verified. The amount of lights may vary from the old system with FTL for example, if B-type 16 A circuit breakers are used, the amount of lights is reduced by 50 %. The use of circuit breakers with C-type tripping curves can solve this problem and some manufacturers are providing their recommendations for the protection settings. Some manufacturers are also providing soft-starters for their LED lighting systems.

CONCLUSION

The experimental study of the lighting system influence on the power quality has been performed. The effect of the FTL lights with magnetic and electronic ballasts as well as the LED lights from four companies are compared. According to the results, replacing of FTL with LED tubes is not straightforward from the power quality point of view. It is very usual to replace only the FTL tube to LED tube without removing the additional capacitors. According to the presented results, the increase in energy efficiency and power quality is not achieved. The produced reactive power is significant with the defective replacement practice. The issue is accelerated with the continuous reduction of inductive loads and the increase of the capacitive reactive power production.

The power quality of LED lights from different manufacturers highly varies. In commercial or residential building with district heating, lighting and other power electronic loads constitute a considerable part of the apparent power consumption. The transformation from inductive to capacitive load with increase in distortion may lead to PQ problems. LED lights behave as non-linear loads producing high frequency current harmonics, which can lead to PQ degradation, increased power losses of cables and transformers, flickering, imbalance and core saturation of transformers, thermal aging of induction motors and malfunction of power line communication.

When replacing old FTLs with LEDs, the protection and the start-up transient must be considered. The protection device may require update, for example slower circuit breaker. The use of soft-starter is also an option to solve these problems. If no updates for the supply side are made, there may be a need to reduce the amount of lights when FTLs are replaced with LEDs.

According to the measurements, LEDs are remarkable factor in the change of capacitive reactive power production. However, this can be prevented by considering the whole lighting system, when the lighting is planned to be renovated. In the future, there should be more detailed instructions and requirements for the lighting system renovation. For example, the installation instructions should include the removal of the capacitors. However, electromagnetic compatibility of the modified lighting equipment cannot be ensured straightforwardly. The best practice for lighting update is to change the whole luminaire. At the moment, this is the only way to ensure the designed operation.

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