BEHAVIOUR OF STREET LIGHTING FEEDERS SUPPLYING TRADITIONAL AND NEW LED LAMPS

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ABSTRACT

This paper aims at the investigation of street lighting feeders and the technical issues which are caused by the substitution of the traditional lamps with the LED ones. Three types of lamps are investigated: fluorescent, high pressure discharge and LED lamps. Load static behaviour and the total harmonic distortion are examined experimentally, while lighting feeder behaviour is investigated numerically. Experimental results show that the THD and power factor of LED lamps are significantly higher than that of traditional lamps. Numerical investigations have shown that the total lighting feeder behaviour is independent from the lamp types.

INTRODUCTION

Street lighting is an important service provided by public authorities. Lighting ensures visibility in the dark and is essential for pedestrian and road safety. Street lighting technologies have progressed gradually over the years and now the new electronic equipments, i.e. LED lights combined with their electronic ballast and the flexible adjustment of luminous flux settings, show an extremely high performance. Their energy consumption and losses are remarkable low. Additionally, they allow a continuous adjustment of the consumed electric power and as a consequence a very high efficiency of light control. According to the European Commission, energy savings through more efficient street and office lighting for the period 2009 - 2020 could be in the magnitude of 38 TWh. Mandating LED lighting for traffic signals and street lights could significantly contribute to the EU's 20-20-20 strategy [1].

Additionally nowadays the detailed power flow calculations even in the low voltage grid is becoming more and more inevitable. The accuracy of these calculations strongly depends on the load modelling precision. The component based analyses is widely used for modelling of the load in the low voltage grid [2]. Load composition is an important part of this method. It describes the load type such as heating, induction motor, lighting, etc.

This paper aims the investigation of street lighting feeders and the technical issues which are caused by the substitution of the traditional lamps with the LED ones. Three types of lamps are investigated: fluorescent, discharge and LED lamps. Firstly is performed an experimental investigation of the electrical behaviour of different street lamps including the harmonic analyses. Secondly is performed a numerical analyses of the street lighting feeders.

ELECTRICAL BEHAVIOUR OF STREET LAMPS

Static load characteristic is the most popular modelling approach of loads for power flow and steady state estimation calculations in distribution networks. In this study the static load characteristic were extracted experimentally for different streetlamp types. Harmonics are also measured additionally.

Lamp types

The measurements were performed for 3 lamp types:
- Fluorescent; NARVA; 64 W; 230 V; magnetic ballast
- High pressure discharge; OSRAM; 230 V; electronic ballast
- Light emitting diodes; Philips; BRS419; 15.35 W; 230 V; electronic ballast.

Fluorescent lamps

Fluorescent lamps consists of a discharge tube which is filled with argon, neon or mixed gas and saturated mercury vapour at a low pressure [3]. The discharge process radiates ultraviolet rays through the generation of electrical field between the two electrodes. The phosphor layer on the inside of the glass tube converts the ultraviolet rays to the visible light. Fluorescent lamps are equipped with a ballast, which is necessary for it stable and continuous operation.

High pressure discharge lamps

High pressure discharge lamps consist of a discharge tube which is filled with gas at higher pressure and have a higher ignition voltage than fluorescent lamps.

Light emitting diodes (LED)

Light emitting diodes consists of some semiconductors, which emit light when an electrical field id applied. Electroluminescence panels and light emitting diodes belong to this category. They consist of microcrystalline powder phosphor based II_VI compounds, such as zinc sulphide. They are suitable for high voltage and low current density, while light emitting diodes and high current density devices operate at low voltage [3].

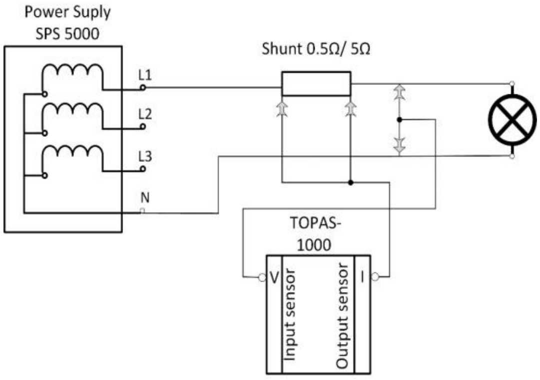


Figure 1. Measurement arrangement

Measurement arrangement

The load measurements of different lamps were performed using the laboratory facilities of the Institute of Energy Systems and Electrical Drives, TU Wien. The equipment used for measurements are shown in Figure 1. Lamps are supplied with electricity by the power supply SPS-5000, which fulfils the requirements (voltage and frequency stability, low total harmonic distortion and ideal internal resistance) according to IEC/EN 61000-3-2. The power network analyser TOPAS 1000 has been used for the measurements of electrical characteristics like current, voltage, active and reactive power, and harmonics. To detect and measure very low current values the output sensor was connected via a shunt (0.5 and 5 Ohm). Measurements have been performed for different supply voltage values i.e. from 209V to 253V (0.9 – 1.1 U/U_n). All measurements are performed in room temperature 22°C±1°C.The fluorescent and LED lamps are measured over a fifteen minutes interval, because all electrical parameters have been stabilised after one minute. While the high pressure discharge lamps are measured over thirty minutes interval, because the electrical parameters were stabilised after 7 minutes.

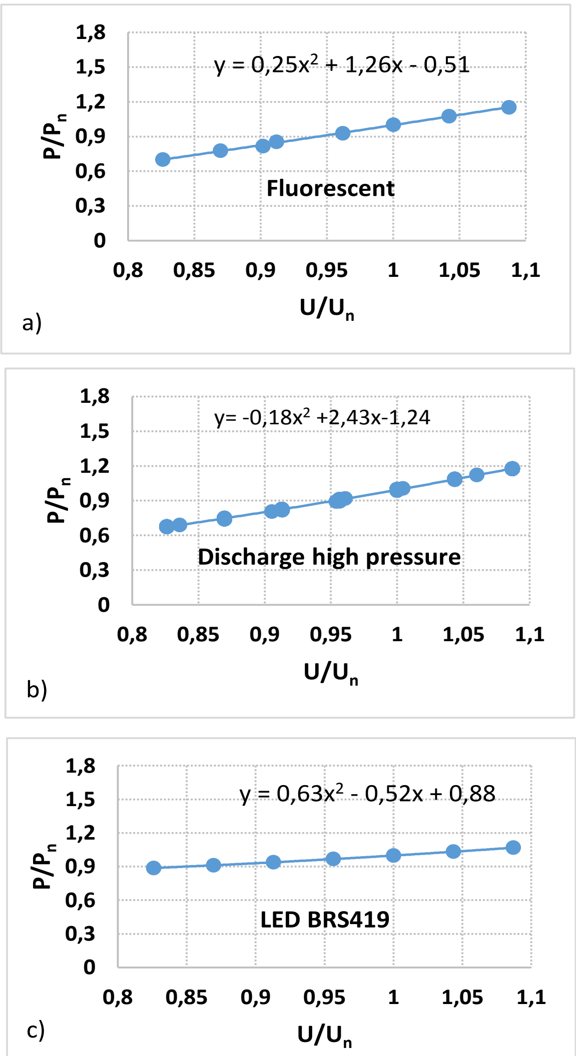


Figure 2. Active power of load versus applied voltage for different lamp types: a) fluorescent; b) discharge high pressure; and c) LED BRS419. Preferred analytical function and smoothed data curve.

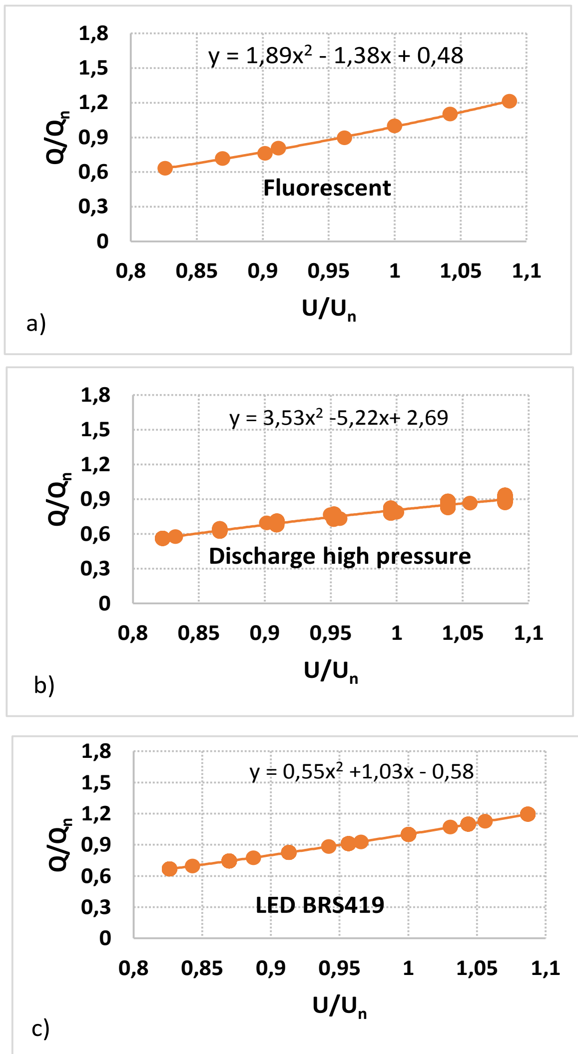


Figure 3. Reactive power of load versus applied voltage for different lamp types: a) fluorescent; b) discharge high pressure; and c) LED BRS419. Preferred analytical function and smoothed data curve.

Lighting load behaviour

Load model represents the mathematical relationship between the active and reactive power to voltage and frequency. ZIP load model is the most popular one [4].In this case the load is represented by the following analytical functions:

$$P = P_n\left[K_2^P\left(\frac{V}{V_n}\right)^2 + K_1^P\left(\frac{V}{V_n}\right) + K_0^P\right] * (1 + K_P\Delta f) \quad (1)$$

$$Q = Q_n\left[K_2^Q\left(\frac{V}{V_n}\right)^2 + K_1^Q\left(\frac{V}{V_n}\right) + K_0^Q\right] * (1 + K_Q\Delta f) \quad (2)$$

where $K_2^P, K_1^P, K_0^P, K_2^Q, K_1^Q, K_0^Q$ are coefficients, which describe the load-voltage dependency. These coefficients have the feature $K_2^P + K_1^P + K_0^P = 1$ and $K_2^Q + K_1^Q + K_0^Q = 1$ correspondingly for active and reactive power [3, 5]. P_n and Q_n are active and reactive power values at nominal voltage V_n. K_P and K_Q describe the load-frequency dependency. The last one is not in focus of this work.

Equations (1) and (2) describe different load behaviours as follows:

- Mostly constant impedance load where

$$K_2^P > K_1^P + K_0^P \quad (3)$$

In this case active power varies with voltage square.

- Mostly constant current load where

$$K_1^P > K_2^P + K_0^P \quad (4)$$

In this case active power varies proportional with voltage.

- Mostly constant power load where

$$K_0^P > K_1^P + K_2^P \quad (5)$$

In this case voltage change does not impact active power.

Experimental results

Figure 2 shows the active power of load versus applied voltage for different lamp types: a) fluorescent; b) discharge high pressure; and c) LED BRS419. Preferred analytical function and smoothed data curve. In this case polynomial coefficients for different lamps are:

Fluorescent $K_2^P = 0.25,\ K_1^P = 1.26,\ K_0^P = -0.51$
Di.high pressure $K_2^P = -0.18,\ K_1^P = 2.43,\ K_0^P = -1.24$
LED $K_2^P = 0.63,\ K_1^P = -0.52,\ K_0^P = 0.88$

It is interesting to note that based on equation (4) fluorescent and discharge high pressure lamps mostly behave conform to the constant current model. While based on equation (5), LED lamps mostly behave conform to the constant power model.

Figure 3 shows the reactive power of load versus applied voltage for different lamp types: a) fluorescent; b) discharge high pressure; and c) LED BRS419. Preferred analytical function and smoothed data curve. In this case polynomial coefficients for different lamps are:

Fluorescent $K_2^Q = 1.89,\ K_1^Q = -1.38,\ K_0^Q = 0.48$
Di.high pressure $K_2^Q = 3.53,\ K_1^Q = -5.22,\ K_0^Q = 2.69$
LED $K_2^Q = 0.55,\ K_1^Q = 1.03,\ K_0^Q = -0.58$

It is interesting to note that based on equation (3) fluorescent and discharge high pressure lamps mostly behave conform to the constant impedance model. While based on equation (4), LED lamps mostly behave conform to the constant current model.

Figure 4 shows the power factor as a function of voltage for different lamp types. LED lamps show over the all measured voltage band a significantly higher power factor than the fluorescent and discharge high pressure lamps over the all measured voltage. With the voltage increase power factor of LED lamps decreases by ca. 7%. Discharge high pressure lamps show an almost constant power factor over the all voltage band. Fluorescent lamps shows the lowermost power factor. It decreases by ca. 9% by voltage increase.

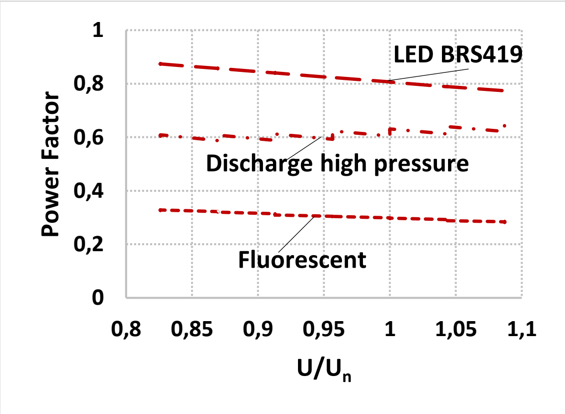


Figure 4. Power factor as a function of voltage for different lamp types.

Harmonic analysis

Figure 5 shows the Total Harmonic Distortion, THD, as a function of voltage for different lamp types. LED lamps or more precisely, the electronic light generation as a whole, show a considerable increase of THD, more than 3 times, compared to fluorescent lamps. Compared to discharge lamps, LED lamps shows a higher THD in the lower voltage range. The THD increase is quoted to 20%. While on the higher voltage area the THD increase is quoted to 0.6%

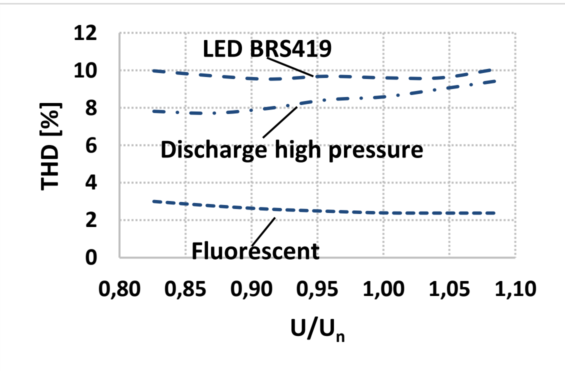
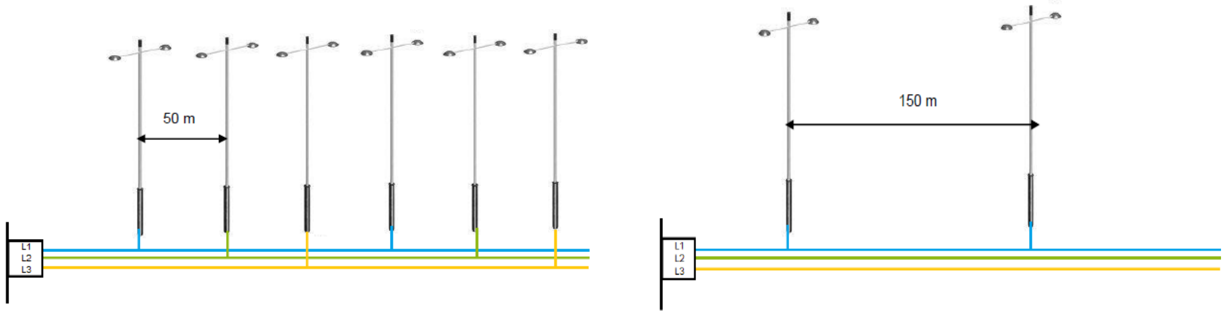


Figure 5. THD according to IEEE 1035 as a function of voltage for different lamp types.

ELECTRICAL BAHAVIOUR OF STREET LIGHTING FEEDERS

Streets lighting are usually connected on three phase feeders. Figure 6. shows an overview of the connection of street lighting. Figure 6a) shows the connection on a three phase. Lamps are connected in an alternated way to the different phases to guarantee a balanced load. Therefore, street lighting is operated balanced and single phase power flow simulations are sufficient for the investigation of the electrical behaviour of street lighting feeders.

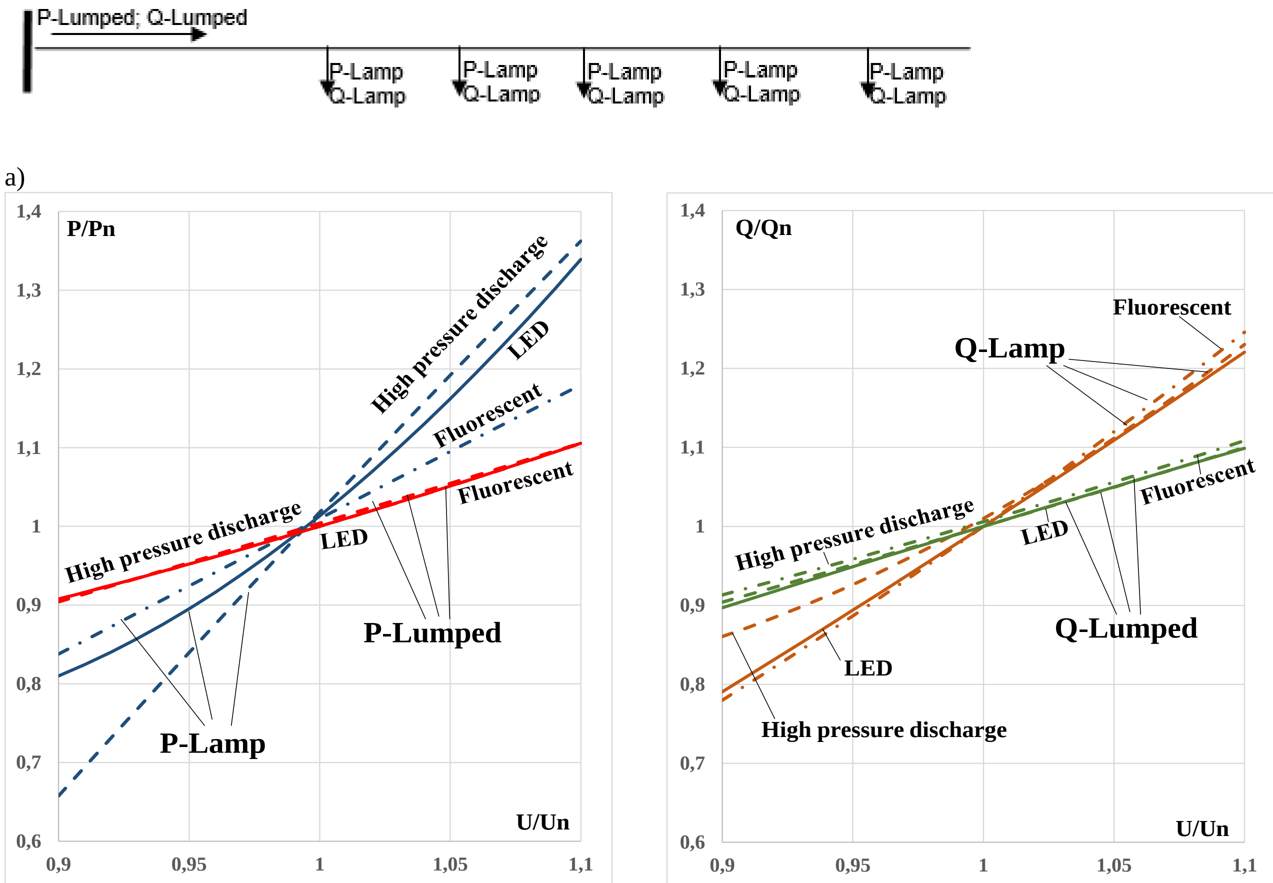
Figure 7 shows the power components of the static load



a) b)

Figure 6. Overview of the connection of street lighting: a) on a three phase feeder and b) on a specific phase.

phase feeder. The geographical distance of two subsequent lamps is in average about 50m [6]. The distance of two subsequent lamps connected at the same phase is 150m. Figure 6b) shows the connection of the lamps on a specific characteristic for the individual lamp loads and lumped load at feeder head for different lamp types. Figure 7a) shows the single line diagram of a lighting feeder. The load at feeder head is referred to as lumped load and



b) c)

Figure 7. Power components of the static load characteristic for the individual lamp loads and lumped load at feeder head for different lamp types: a) Lighting feeder; b) active power; c) reactive power.

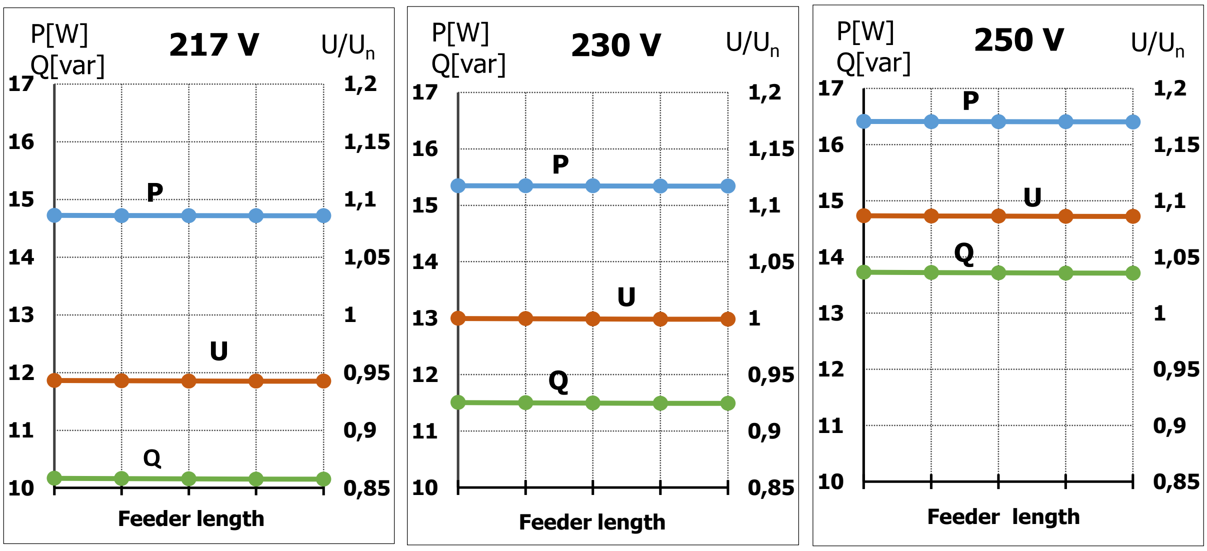


Figure 8. Active-, reactive power lamp consumption and voltage over the length of a feeder for LED lamps BRS419, for different voltage values at feeder head: a) 207V; b) 230V and c) 250V.

is calculated as follows:

$$P^{Lumped} = \sum_{k=0}^{n} P_i^{Lamp}(V_i) + \Delta P \quad (6)$$

$$Q^{Lumped} = \sum_{k=0}^{n} Q_i^{Lamp}(V_i) + \Delta Q \quad (7)$$

where P^{Lumped}, Q^{Lumped} are active and reactive power at the lighting feeder head. P_i^{Lamp}, Q_i^{Lamp} are the active and reactive power consumption of the individual lamps, which are connected at position i to the feeder. V_i is the voltage at the position i at lighting feeder. n is the number of the lamps connected on the feeder. ΔP and ΔQ are active and reactive power feeder losses. The ZIP model (1) and (2) are used to model the load. The polynomial coefficients where defined experimentally as described above.

Numerical investigations have shown that the feeder – i.e. the lumped load seen at feeder head – behaves differently than the individual lamps themselves. Figure 7b) shows the active power component of the static load characteristic for each individual lamp type and lumped load at feeder head. Static load characteristic of lumped load versus applied voltage at the feeder begin is hardly influenced by lamp types. Almost the same conclusion can be find out for the reactive power component of the static load characteristic, Figure 7c.

A voltage increase at feeder head from 217V to 250V provokes an increase of active power consumption of about 35.8% for the fluorescent lamps; 44% for the discharge high pressure sodium lamps and only 11.4% for the LED lamps. The associated reactive power consumption increases by 51.9%, 28.6% and 35% correspondingly. Figure 8 shows the lamps active-, reactive power consumption and the voltage over the length of a feeder for LED lamps BRS419, for different voltage values at feeder head: a) 207V; b) 230V and c) 250V.

CONCLUSIONS

Nowadays the replacement of traditional street lighting lamps by the new electronic equipment's - i.e. LED lights combined with their electronic ballast and the flexible adjustment of luminous flux settings - is in ongoing, because they are quite efficient. But they show a significantly higher THD and power factor than the traditional ones. Power factor depends slightly from the applied voltage i.e. it decreases with the voltage increase. Independent from the lamp type power consumption of lighting feeders increases with the increasing of supplying voltage at feeder head. Numerical investigations have shown that the static load characteristic of lumped load at feeder head is hardly influenced by lamp types. However more experimental and numerical investigation are necessary to generalize these results.

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