Chapter

Improvement the Efficiency of Distribution Network Using an Efficient Lighting System of Streets

Nassim Iqteit and Khalid Yahya

Abstract

Nowadays, improve the efficiency and reduce active loss are very important target for any electric company. One of the methods to reach this target is using appropriate street lighting and tunnel lighting systems. Control of lighting, appropriate products of lighting system, and management of the luminaire dimming will used to improve the efficiency of lighting network. Studying the lamp efficiency of low pressure sodium, LED, high pressure sodium, compact fluorescent lamps, etc. Case study and calculations of active losses in lighting system of 30 luminaire are presented in this chapter. The results discuss the impact of type and number of luminaires, distance between poles, and dimming ratio on the outdoor lighting efficiency and values of active loss in lighting network which is part of distribution networks.

Keywords: lighting network, streets, efficiency, active losses, LED, dimming, products for lighting

1. Introduction

The active power loss in a street lighting system depends on the complexity of the grid, types of luminaires, the number of luminaires, the unit of dimming used, the reactive power level in the network, etc. Using regulated devices, lighting dimming systems [1, 2] and reducing the reactive power [3] are usually used for reduction active power losses in lighting networks. Another aspect for improving the energy efficiency of a lighting road system is that it is designed to maximize the efficiency of the light flux emitted in the surrounding area whereas minimizing its losses [4]. The increase in power losses leads to increase in active power then the consuming of electricity will increase. Until now, calculating the power losses in lighting system in distribution grid, assumes that the network receive constant power from the rated light sources or luminaires throughout the lighting period. Throughout lighting operation, the rated power of luminaires may change within their lifetime. Additionally, at night time, the voltage of source may be higher than the rated grid voltage, which means greater active power consumption, higher power currents and higher power losses [5].

Decreasing operating hours, where it is depending on the hours of darkness and amount of daylight. Photoelectric switching is usually used to attain the minimum hours of street lighting operation. Diminution the number of lamps operating in streets; the amount of light requisite on the road depends on legal requirements, tarmac, traffic volume, type of road, speed limit and surroundings. Any change in these parameters assist to minimize the active loss in the lighting system. Installation of more efficient light sources assists to reduce the number of lamps operating and provide the same levels of illumination. Modern control system of street or tunnel lighting system contains; control unit in lighting fixture/luminaire, CPU and GSM module in switchboard of the installation, and remote data processor for management and controlling the individual installations [6]. Moreover, opening up the tunnel roof reduces the number of luminaire use in tunnels, but shadows, insufficient of lighting and difficulty in guiding the sunlight are critical points for limiting the lighting of tunnels by daylighting. In addition, all lighting installations require to be preserved to perform at maximum efficiency. Dirt on lens on panels and reflectors leads to reduced output from the luminaire [6].

Lamp types usable in street and tunnel lighting; high pressure sodium lamps, low pressure sodium lamps, metal halide lamps with quartz arc tube, metal halide lamps with ceramic arc tube, high pressure mercury lamps, linear fluorescent lamps, compact fluorescent lamps with integrated ballast, compact fluorescent lamps with non-integrated ballast, and LEDs [7].

LED technology is quickly becoming competitive with high-intensity discharge light sources for outdoor space lighting. Most LED manufacturers describe useful life based on the estimated time at which LED light output will depreciate to 70% of its initial rating; often the target is 100,000–150,000 hours for outdoor luminaires. As with all LED products, careful data gathering and research is required to assess quality, performance, and overall value. The following steps are provided as a quick summary of the outdoor lighting system [8]:

- Need to photometric test reports based on the IESNA LM-79-08 test procedure.
- Required warranty; 3–5 years is reasonable for outdoor luminaires.
- Check ingress protection (IP) ratings, and choose an appropriate rating for the intended application.
- Ask for operating temperature information and how this data relates to luminaire efficacy and lumen depreciation.
- Check color temperature for suitability in the intended application.
- Assess glare, preferably with the luminaire at intended mounting height and under typical nighttime viewing conditions, compared to incumbent technology.
- Evaluate economic payback, based on applicable energy, equipment, maintenance, and control costs for the site.

The quality, type, maintenance requirements and average annual daily traffic volume are critical in the selection of the street and tunnel lighting system. LEDs and electrode-less lamps are newer technologies on their way to be potential future tunnel lighting systems [9].

2. Street lighting technologies

2.1 Street light sources

There are distinct luminaires families that are used for lighting streets of cites, where these technologies are shown in **Figure 1** [10]. Additionally, the power of these technologies and their applications are given in **Table 1**. **Table 2** illustrates other technologies of lamps and their powers, luminosities. LED technologies are also used for lighting streets of cities. The life of LED technologies are defined by estimated time at which LED light output will depreciate to 70% of its initial rating; often the life time is 100,000–150,000 h for outdoor luminaires [8]. As clarified in **Figure 2**, LEDs resort to dim over time rather than tragically failing, like other technologies [11].

2.2 Street light lamp characteristics

Table 3 illustrates the characteristics of road light lamps usually used [11].

The main technologies of street lighting system are high pressure sodium lamps (HPS) and electronic ballast, HPS and electromagnetic ballast, and LED lamp. The comparison between these main technologies is shown in **Table 4**.

2.3 Distributions, spacing and height of luminaires in the streets

Table 5 shows the relation between the category of roads and the type of street lighting system and spacing to height ratio (SHR) [7].

Figure 1.
12 of different luminaires technologies in the streets of cites.

Luminaire type	Power/type	Application
1	70 W, 100 W HPS	Residential street lighting
2	200 W, 250 W, 310 W, 400 W HPS	Arterial and/or collector street lighting
3	70 W, 100 W, 150 W, 200 W HPS	Collector and/or residential street lighting
4	400 W HPS (street side) 150 W HPS (house side)	22” Luminaire—Arterial and/or collector street lighting 17” Luminaire—Sidewalk side pedestrian lighting
5	35 W, 100 W, 150 W, 250 W HPS	Domus DMS50—Arterial and/or collector street lighting. Domus DOS—Residential street lighting and/or Sidewalk side pedestrian lighting.
6	35 W, 70 W HPS	Residential street lighting and/or pedestrian lighting
7	150 W, 250 W HPS	Arterial and/or collector street lighting
8	35 W, 50 W, 70 W HPS	Collector and/or residential street lighting
9	35 W, 50 W, 70 W HPS	Residential street lighting and/or pedestrian lighting
10	150 W, 200 W, 250 W HPS	Arterial, collector, or residential street lighting
11	70 W HPS	Residential street lighting and/or pedestrian lighting
12	70-100 W HPS	Residential street lighting and/or pedestrian lighting

Ballast voltage: multi-tap 120/240 V, HPS: high pressure sodium.

Table 1.
The power and the applications of technologies in ***Figure 1****.*

Type of lamp	Power range (W)	Luminosity (lm/m^2)
Incandescent	15–150	9–15
Fluorescent tube	18–58	43–76
Mercury vapor	50–400	30–49
High pressure sodium	50–400	67–128
Low pressure sodium	18–180	69–152

Table 2.
Lamp types and their powers and luminosities [6].

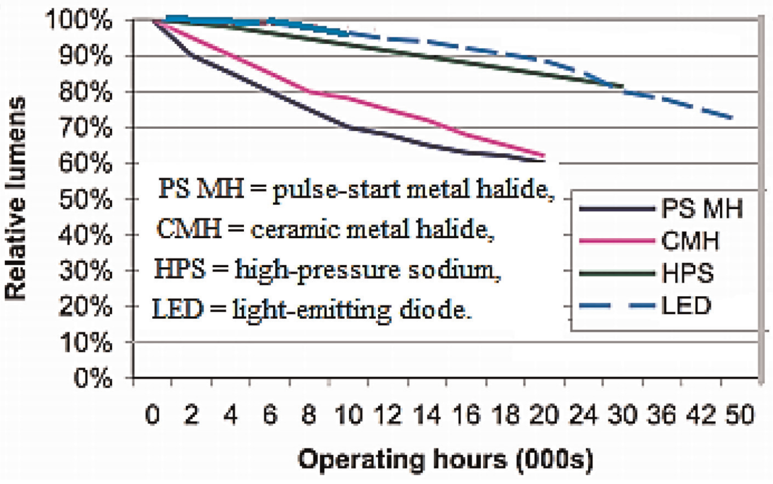

Figure 2.
Lumen depreciation rate for different lighting technologies.

Type of lamp	Luminous efficacy (lm/W)	Color rendering properties	Lamp life (h)	Remarks
High-pressure mercury vapor (MV)	35–65	Fair	10,000–15,000	High energy use, poor lamp life
Metal halide (MH)	70–130	Excellent	8000–12,000	High luminous efficacy, poor lamp life
Low-pressure sodium vapor	100–190	Very poor	18,000–24,000	Energy-efficient, very poor color rendering
Low-pressure mercury fluorescent tubular lamp (T12 and T8)	30–90	Good	5000–10,000	Poor lamp life, medium energy use; only available in low wattages
Energy-efficient fluorescent tubular lamp (T5)	100–120	Very good	15,000–20,000	Energy-efficient, long lamp life; only available in low wattages
Light-emitting diode (LED)	70–160	Good	40,000–90,000	High energy savings, low maintenance, long life, no mercury; high investment cost, nascent technology

Table 3.
Typical streetlight lamp characteristics.

LED lamp	HPS lamp and electronic ballast	HPS and electromagnetic ballast
• Long operating life (50,000 h life with 70–80% lumen maintenance) • Very low power consumption • Low installation and maintenance costs • Harmonized illumination • High efficiency • Dimming possibilities • Contain no hazardous materials • Low temperature and function well in cold temperatures • Good vibration resistant characteristics • Quick start and re-start (do not need to firstly cool the system as with HID) • Low glare and strobe-free • Free from ultraviolet or IR • Possible use with renewable energies	• Long lifetime (from 40,000 to 60,000 h) • Increased lamp life (on average up to 30% longer lamp life) • No flickering effect • Dimmable • High efficiency (up to 15% savings) • Non audible noise • Low weight • Energy saving (up to 13%) • Relatively expensive • Not environmentally friendly	• Long lifetime (>30 years at 105°C) • Low cost • Suitable for extreme weather conditions (humidity, temperature variation, lightning) • Recyclable materials (magnetic chokes are recyclable) • Self-recovery feature (when the ac mains voltage recovers after a disturbance) • Very low maintenance costs • Not dimmable • Not energy saving • Flickering effect • No constant light output

Table 4.
Characteristics of lamp technologies [12].

Replacing lighting fixture/luminaire; new fixtures are generally luminous more efficient, which allows light sources with lower power to be used. **Figure 3** shows IESNA outdoor fixture types classifying the distributions for spacing luminaires [8].

Road category specification	Fast traffic	Mixed traffic	Slow traffic
Lamps used	almost uniquely sodium lamps	Mainly sodium and high pressure mercury lamps	Mainly sodium and mercury lamps are used and to lesser degree compact fluorescent and metal halide lamps
Power of lamps used	150 W, 250 W HPS and 131 W, 135 W and 180 W LPS	250 W, 400 W HPM and 100 W, 150 W, 250 W HPS	125 W HPM, 50 W, 70 W HPS, 70 W MH and 36 W CFL
Spacing/height of pole ratio (SHR)	Approximately equal to 4 (e.g., 90/20, 60/15, 48/12, 40/13)	Varies between 4.5 and 3 (e.g., 45/10, 50/12,5, 35/11)	Between 5 and 4 (e.g., 40/8, 36/8, 25/5, 30/7, 20/4)

Table 5.
Type of street lighting system and spacing of poles to their height.

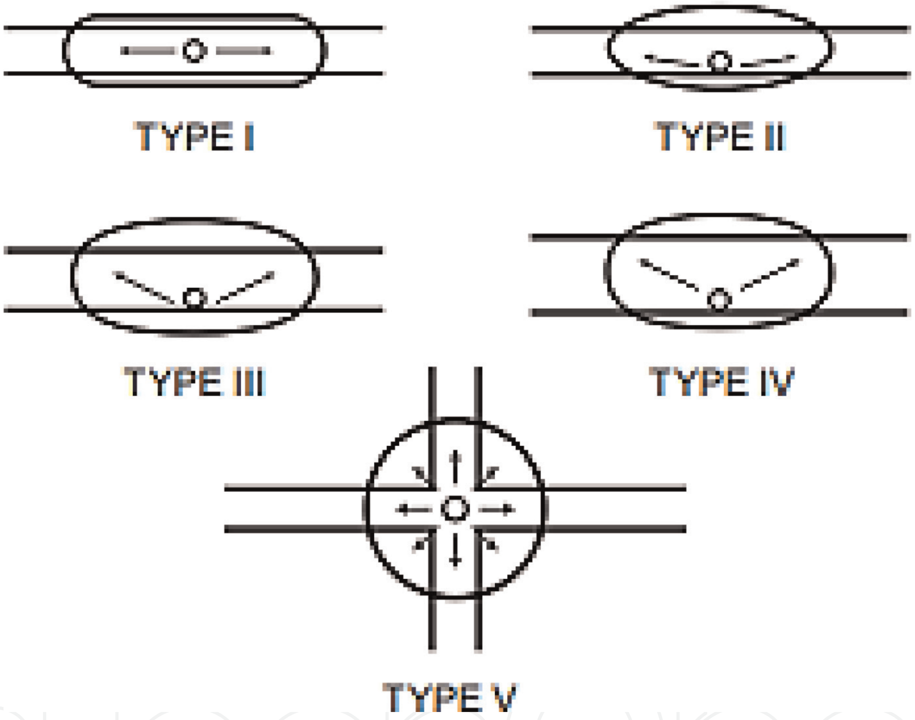

Figure 3.
IESNA outdoor lighting distribution types I—V.

3. Streets and tunnel lighting control

The block diagram of street light system as given in **Figure 4** composes of microcontroller, LDR, and photoelectric sensor. By using the LDR we can control and drive the lights of streets. The system of a smart street lighting system is illustrated in **Figure 5** by a simplified block diagram. The system includes a microcontroller module for regulating, sensing and controlling the lighting system. This system also has different sensors, a voltage regulation circuit, a LCD and GSM/GPRS module.

With a view to meet the demands of tunnel lighting and energy-saving preferable, stepless control method is arranged in the tunnel lighting control system. The control system is formed of vehicle detectors, data converters, luminance detectors, lighting control computer, dimming controllers and LED lamps. **Figure 6** shows the block of the tunnel control system [15].

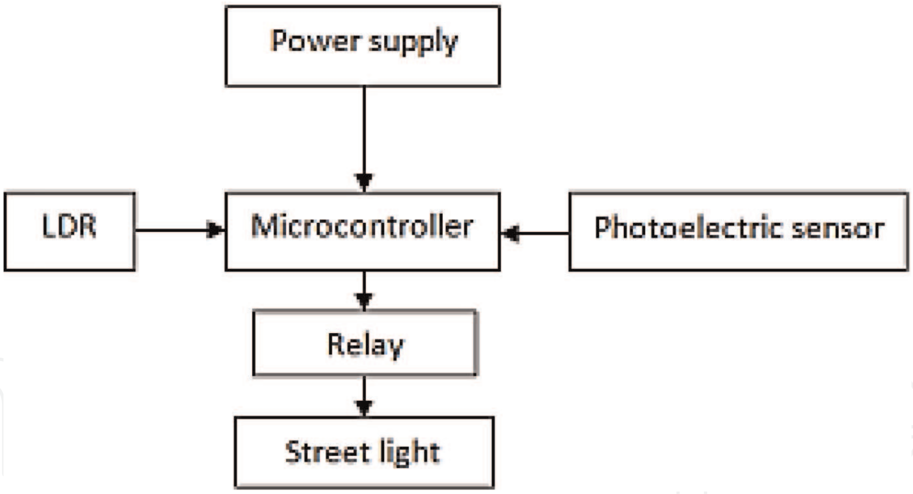

Figure 4.
Block diagram of the control of street light system [13].

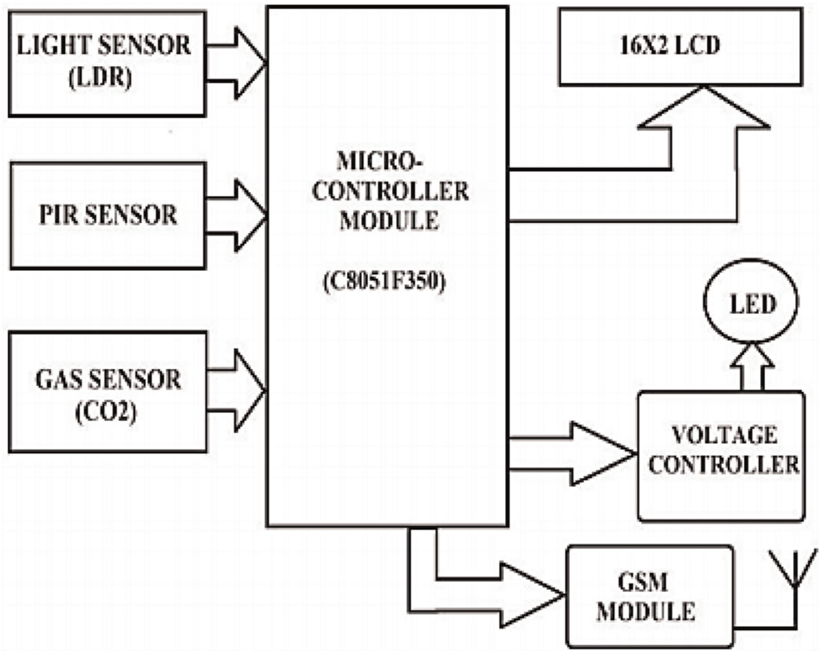

Figure 5.
Block diagram for control smart street lighting system [14].

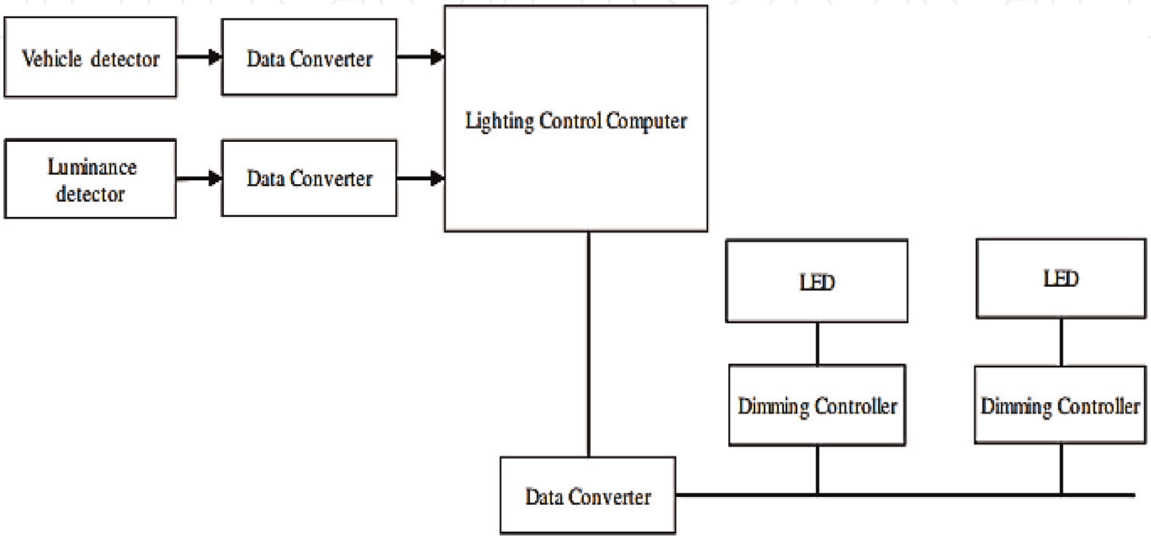

Figure 6.
Block diagram of tunnel lighting control system.

4. Active power losses in road lighting installation

The lighting circuit consists of the following components: the power cable protection in the lighting panel board, relay dimming by astronomical clock (or other dimming device), three-phase feeder wiring, the pole protection, the wire connecting the pole plate with luminaire, and the luminaire. **Figure 7** shows, schematically, an example of a road lighting installation with the main components [5].

The total power loss of the lighting installation ΔP_{TOTAL} can be determined from the following relationship:

$$\Delta P_{TOTAL} = \Delta P_{CABLE} + \Delta P_{NEUTRAL} + \Delta P_{WIRE} + \Delta P_{PPB} + \Delta P_{PPOLE} + \Delta P_{RELAY} \quad (1)$$

where, ΔP_{TOTAL} total losses of active power, (W); ΔP_{CABLE} losses of active power in three (one) phase feeder wiring, (W); $\Delta P_{NEUTRAL}$ losses of active power in neutral conductor, (W); ΔP_{WIRE} losses of active power in wire in the pole, (W); ΔP_{PPB} losses of active power in protection in the lighting panel board, (W); ΔP_{PPOLE} losses of active power in protection in the pole, (W); ΔP_{RELAY} losses of active power in relay, (W).

The following factors have a decisive influence on the network losses: level of luminaries dimming, network configuration (single or three phases) and number of light points. Thus, the total losses in the lighting system for the three-phase network, as defined by the Eq. (1), can be estimated as:

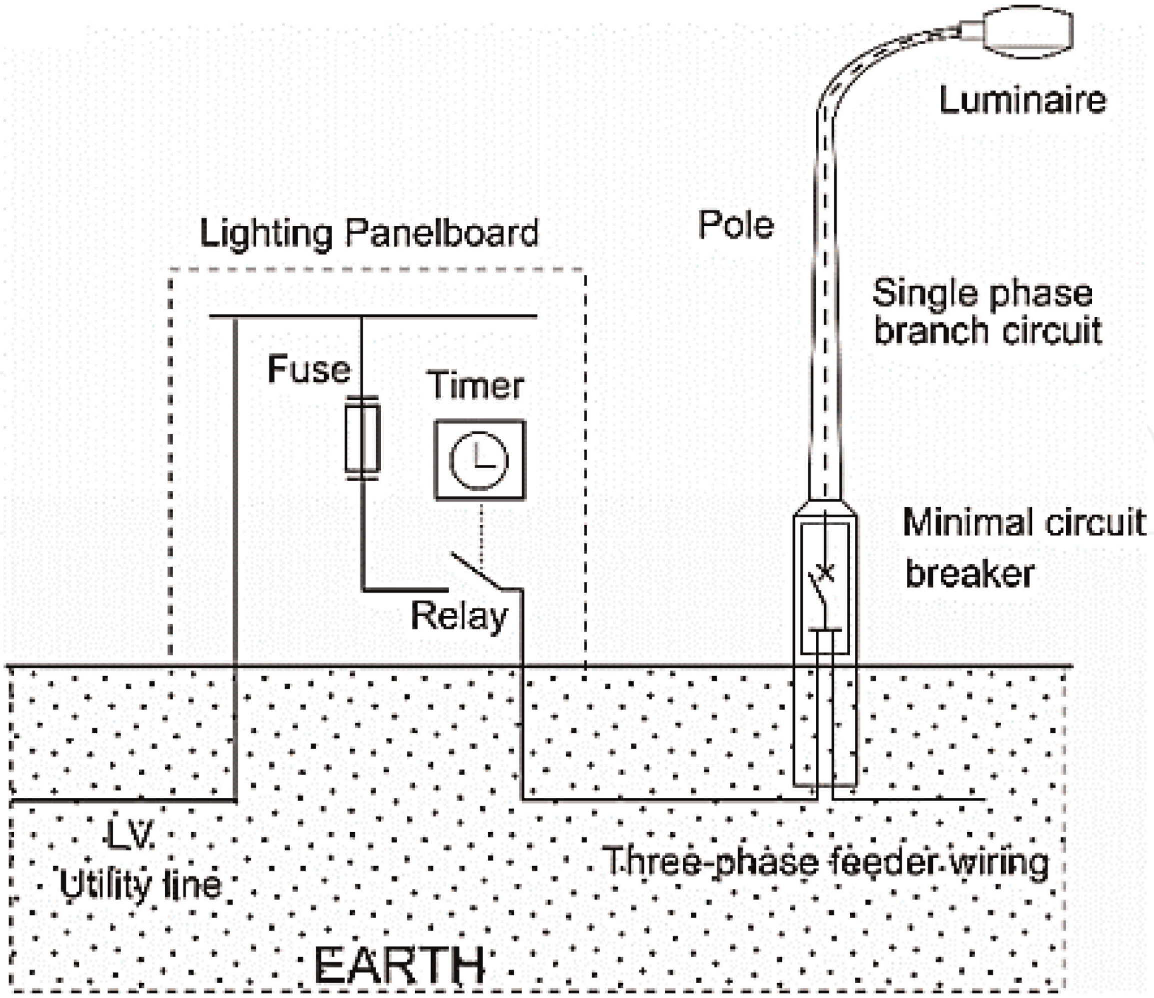

Figure 7.
Example of a road lighting installation.

$$\Delta P_{TOTAL} \cong k_{red}\bullet\left[\frac{3l}{\gamma_C S_C}\left[n^2\left(\frac{l_{01}+l}{l}\right)+\frac{n(n-1)(2n-1)}{2}\right]I_{Lum}^2+\frac{2l_{PW}}{\gamma_{PW}S_{PW}}I_{Lum}^2\right] \text{ for } n_p \le 3 \tag{2}$$

$$\Delta P_{TOTAL} \cong k_{red}\bullet\frac{3l}{\gamma_C S_C}\left[n^2\left(\frac{l_{01}+l}{l}\right)+\frac{n(n-1)(2n-1)}{2}\right]I_{Lum}^2 \text{ for } n_p>3 \tag{3}$$

In the case of single-phase networks,

$$\Delta P_{TOTAL} \cong k_{red}\bullet\left[\frac{2l}{\gamma_C S_C}\left[n^2\left(\frac{l_{01}}{l}\right)+\frac{n(n-1)(2n-1)}{6}\right]I_{Lum}^2+\frac{2l_{PW}}{\gamma_{PW}S_{PW}}I_{Lum}^2\right] \text{ for } n_p \le 3 \tag{4}$$

$$\Delta P_{TOTAL} \cong k_{red}\bullet\frac{2l}{\gamma_C S_C}\left[n^2\left(\frac{l_{01}}{l}\right)+\frac{n(n-1)(2n-1)}{6}\right]I_{Lum}^2 \text{ for } n_p>3 \tag{5}$$

where the reduction factor k_{red} is the coefficient of slope of the dimming characteristic. The dimming characteristic of the luminaire are the relation of the active power of the luminaire to the degree of dimming. l_{01} is the distance of the first luminaire from the lighting switchboard, (m); l is the distance between poles, (m); γ_C is the electrical conductivity of feeder wiring, (m/Ωmm^2); S_C is the cross-section of feeder wiring, (mm^2); n is the number of luminaires per phase; n_p is the number of lighting points (luminaires); I_{Lum} is the RMS value of luminaire current, (A); l_{PW} is the length of the wire that connects the pole switchboard to the luminaire, (m); γ_{PW} is the electrical conductivity of the wire connects the pole switchboard to the luminaire (m/Ωmm^2); and S_{PW} is the cross-section of the wire connecting the pole switchboard to the luminaire, (mm^2).

Figure 8 shows an example of daily dimming characteristic. The times of switching on (t_{on}) and off (t_{off}) the luminaires were determined using astronomical tables of sunrises and sunsets in an installations area for luminaires.

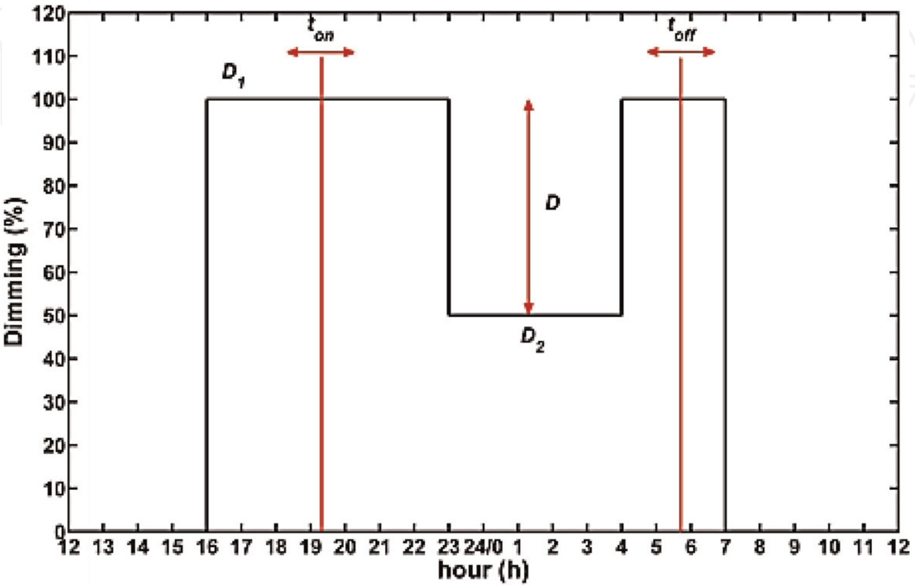

Figure 8.
Daily dimming characteristic of luminaire.

5. Case study and results

5.1 Case study

A luminaire LUM has rated power of 140 W was equipped with a wireless power and luminous flux dimming system. The dimming was carried out using a program implemented on the server. The program enabled the dimming of the luminaire in the range from 10 to 100%. The electrical and photometric curves of tested luminaire is given in **Figure 9**. The calculations presented in Sections 5.2 and 5.3 are made for a given distance between the poles reaching to 30 m.

5.2 Active power losses calculation results of three-phase lighting system

The dependence of the percentage of total active power losses on the number of luminaires and dimming is shown in **Figure 10**. Losses at the point of light are greater in the entire dimming range than the total losses in other parts of the installation. The total percentage of ΔP_{TOTAL} in a system of 30 luminaires ranges from 0.55% for dimming 10% to 1.17% for dimming 100%.

5.3 Active power losses calculation results of a single-phase lighting system

The dependence of ΔP_{TOTAL} as a function of the number of luminaires and dimming is shown in **Figure 11**. The total percentage of ΔP_{TOTAL} in a system of 30 luminaires range from 2.850% for dimming = 10% to 6.689% for dimming = 100%.

5.4 Estimation of active power losses for different distances between poles

The results of power losses for street lighting systems with 3 and 30 luminaires as function of distance between the poles are given in **Figures 12** and **13**,

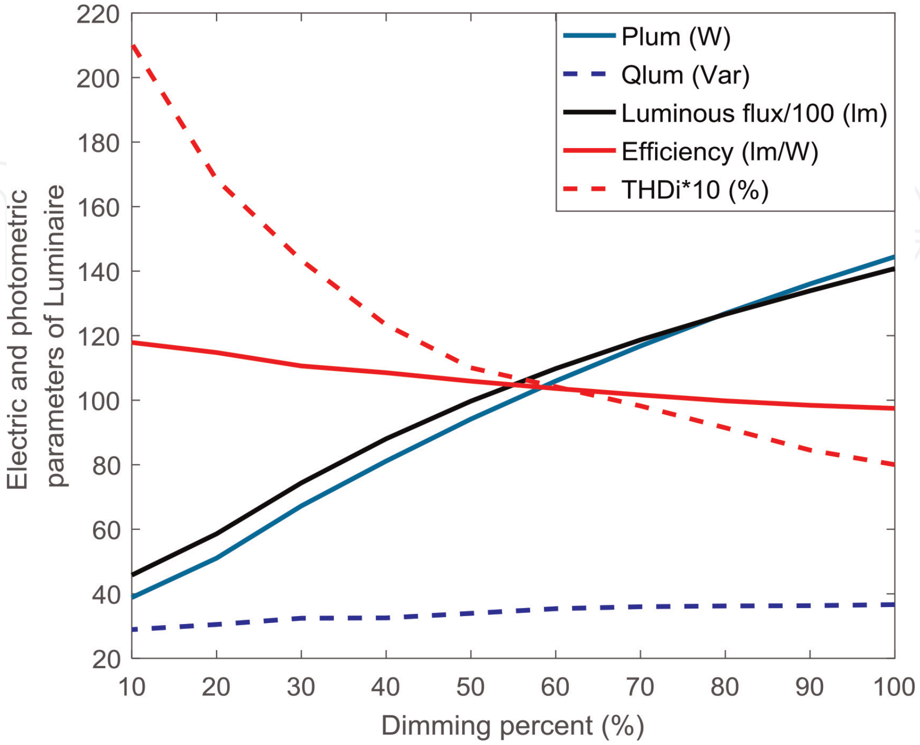

Figure 9.
Electrical and photometric curves of tested luminaire (LUM).

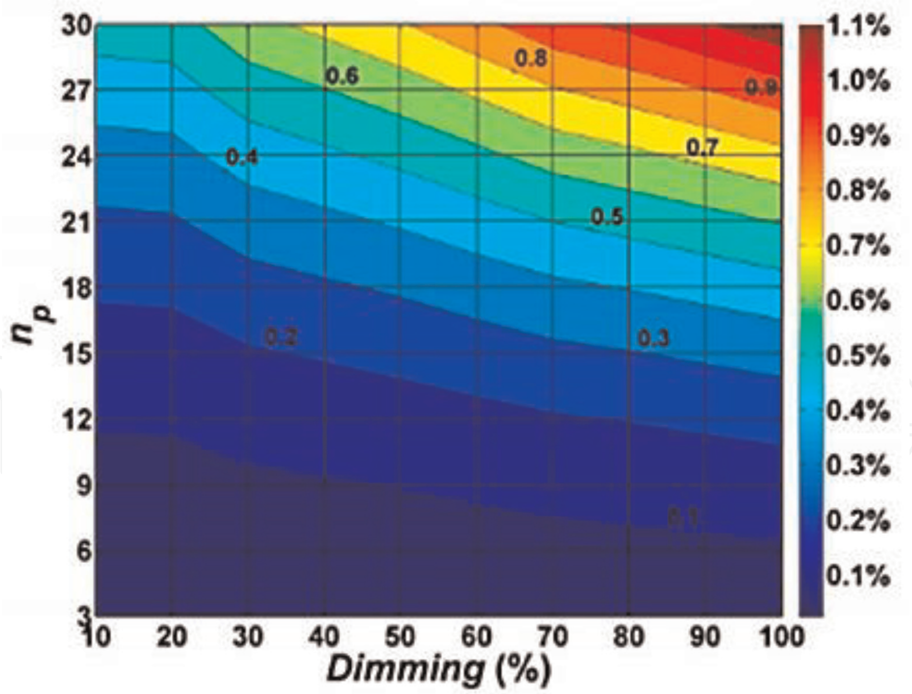

Figure 10.
Dependence of total active power losses ΔP_{TOTAL} *in relation to the dimming and the number of poles* n_p *for LUM [5].*

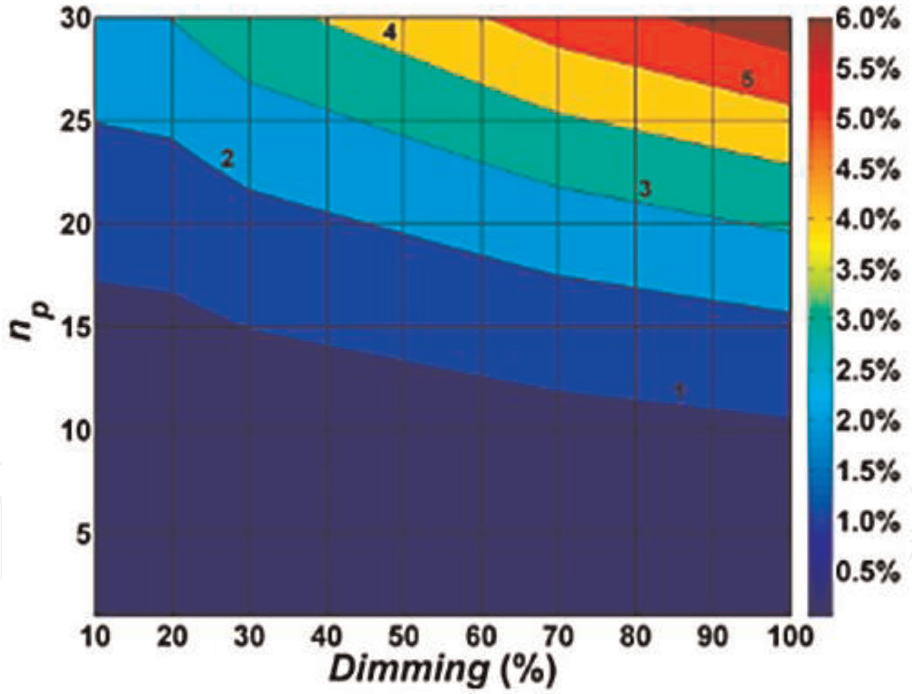

Figure 11.
Dependence of total active power losses ΔP_{TOTAL} *in relation to the dimming and the number of poles* n_p *for LUM [5].*

respectively. The total losses percentage increase by increasing the distance between the poles as well as increasing in the dimming value lead to increase the active loss. In addition three phase lighting system has losses less than single phase system. **Table 6** shows the relation between rated power of luminaires and total power losses in single and three phase system, where the number of lighting in streets is 30 luminaire at dimming 100% and l = 10 = 30 m. SC = 4 × 25 mm^2, γC = 34 m/Ω.mm^2.

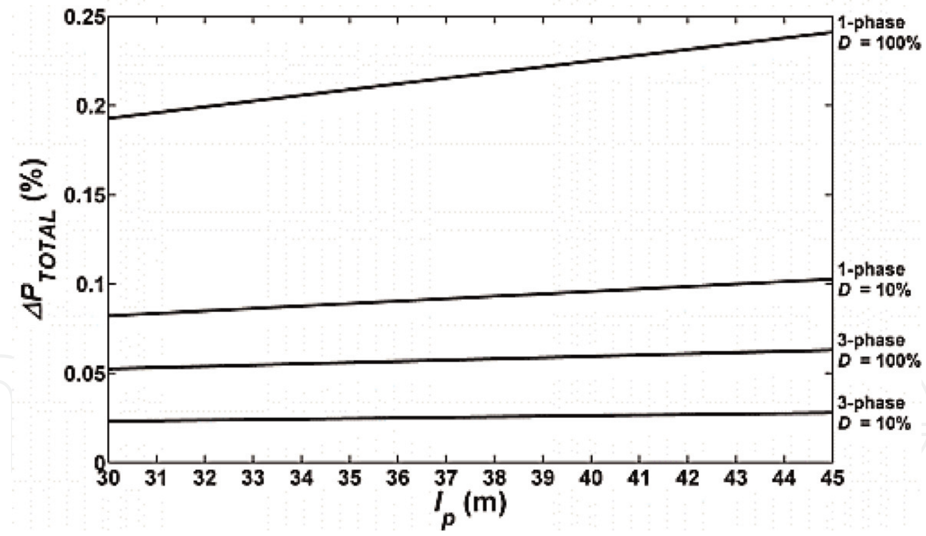

Figure 12.
Relative total power losses in relation to the distance between poles for circuit consisting of three luminaires [5].

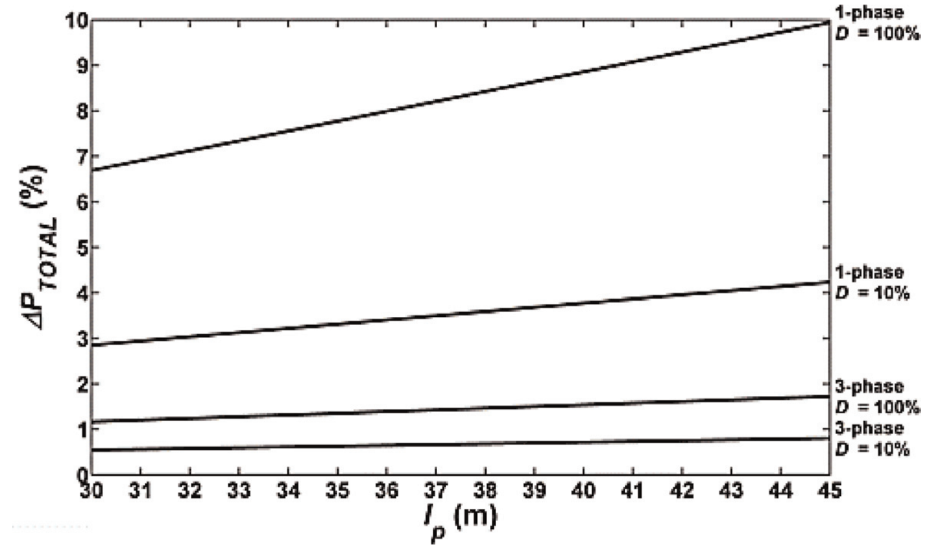

Figure 13.
Relative total power losses in relation to the distance between poles for circuit consisting of 30 luminaires [5].

Rated power of luminaire (W)	ΔP_{TOTAL} three phase system (W)	ΔP_{TOTAL} single phase system (W)
32	2.851	16.023
85	16.308	92.687
140	50.608	289.914

Table 6.
Active power losses for lighting street by 30 luminaire at dimming 100% and $l = 10 = 30$ *m,* $SC = 4 \times 25$ *mm*^{2}*,* $\gamma C = 34$ *m/Ω.mm*^{2}*.*

6. Conclusion

Increasing the efficiency and reduction the active loss are very significant aim in each distribution network. Lighting grid is a one of main parts in distribution grid and reduction active loss in it is the main aim of this chapter. Different technologies for lighting streets and tunnels were discussed in this chapter, while the results indicate the sodium lamp and LED are the efficient technologies. Control unit for management the dimming of luminaire and using three phase lighting system instead of single phase get better the efficiency of street lighting system. The numbers of luminaire, the distance between poles, wires conductivity, environmental conditions, and category of streets are other factors can effect on the value of active loss reduction.

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