Public Lighting Control Systems

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In recent years great progress has been made in developing the modern public lighting control systems for controlling and reducing energy consumption. These range from controlling the circuits of public lighting and/or individual control with special lamps and ballasts with appropriate network operating protocols. This may include sending and receiving instructions via a separate data network, as a high frequency signal injected into the voltage waveform or wireless. Public lighting costs can be a significant expense for city utilities, it is therefore important to take all the opportunities for efficiency improvements. The paper will describe public lighting system with special emphasis on control and its impact on the distribution network.

Keywords public lighting; lighting fixture; control systems; ripple control

1. Introduction

High quality public lighting at night enables the safe flow of traffic and the smooth operation of the various activities, meetings, sports and more. Control and supervision of public lighting includes adjusting and monitoring parameters of light such as light intensity, time and period of operation, the state of deterioration and condition of the lamp elements. These parameters of light are introduced primarily to reduce the cost of electricity and maintenance costs, reducing the intensity of illumination during part of the night, and achieving the desired lighting conditions at each lighting fixture.

The system control is closely linked to system regulation that further improves the lighting system itself. Regulation of lighting means regulation of electrical parameters (current, voltage) needed to operate the lamp. Regulation is introduced in order to achieve optimal lighting conditions at each lighting fixture and in extending the life of elements of lighting equipment. As a result a significant reduction in maintenance costs and electricity costs is achieved [1]. Increasing the efficiency of public lighting can be achieved in several ways: by using energy efficient light sources [2], electronic ballasts, instead of electromagnetic ballasts, energy-efficient sources with good colour rendering index, regulation of street lighting, reducing light pollution, etc.

2. The basic of public lighting

With increasing amount of motor traffic public lighting becomes a great necessity for safe traffic of pedestrians and motor vehicles [3]. Public lighting can be divided according to purpose on: road lighting (lighting of roads, tunnels and intersections), urban lighting (lighting of squares and pedestrian zones), and reflector lighting (lighting facades and important buildings). The basic elements that makes up the modern system of public lighting can be divided into: electric light sources (light bulbs), lamps (used to control and distribute the luminous flux of one or more light sources), the elements of the installation of public (street) lighting (lamp brackets, wall brackets, poles, bearing wires) devices for power supply and distribution, control and regulation, cables and power lines and protection systems. Light sources of high luminous intensity based on arc discharge are typical for use in public lighting. They include: high-pressure mercury lamps, high pressure sodium lamps or high pressure metal halide lamps. Lamps based on arc discharge have negative resistive characteristic and unstable behaviour if supplied with constant voltage [4]. All these lamps require specific ballasts and sometimes igniters for the achievement and maintenance of the working conditions. The ballasts are commonly used devices for control and regulation in the existing system of public lighting. They are also used to regulate the electrical parameters needed for the lamp working conditions. Ballast characteristics must match the characteristics of the light source, because otherwise large deviations of luminous parameters are present. Ballast always consumes power and therefore reduces the energy efficiency of the entire system.

3. Public lighting control systems

Control and supervision of public lighting includes setting and monitoring the parameters of lighting and it is introduced primarily to reduce costs of energy and maintenance costs. Control system enables the achievement of desired lighting conditions at each lighting fixture. In order to achieve optimal lighting conditions, the intensity of illumination can be changed throughout the day depending on weather conditions, such as extending the lighting time when it is rain or fog. Dispatch Centre has a photo sensor which, depending on the intensity of daylight, generates a signal and public lighting is turned on if visibility is reduced even before the defined time.

There are two basic control systems: centralized and local control system. Centralized control system of public lighting send control commands to the entire system from one centre. The local control system allows selective control of certain parts of public lighting system. Measuring elements, control elements, switching devices and elements for the transmission signals are an integral part of public lighting control systems. Measuring elements have the task of measuring different values of illumination in specific areas which enables the control of public lighting. Elements for the public lighting control are processors based on the specific algorithms that automatically control the lighting in the manner of commands implementation, collecting the parameters on operating conditions, alarms in case of errors and failures, and more. The device can operate in conjunction with a remote control system and independently. Switching devices and elements of the lighting system are all necessary control signals, protective and safety devices and lighting controllers. Transmission systems signals can be classical, where the transmission of electrical impulses is carried by relays and contactors, or modern, with electronic equipment for data transmission and processing [3].

According to technical performance, control systems are divided as: time-based control of lighting fixture, control based on zone lighting controllers, ripple control from distribution remote control system and processor control of public lighting.

3.1 Time-based control of lighting fixture

The purpose of time-based control of lighting fixture is to achieve a savings in power consumption by dimming the luminous flux during the part of night: all-night or half-night mode.

Table 1 The example of switching times for the pubic lighting for local receivers[5]

January	on [h]	off [h]	May	on [h]	off [h]	September	on [h]	off [h]
1. week	16:30	7:45	1. week	20:15	6:15	1. week	20:10	6:45
2. week	16:45	7:45	2. week	20:30	6:15	2. week	19:55	6:45
3. week	17:00	7:45	3. week	20:45	6:00	3. week	19:35	7:10
4. week	17:15	7:45	4. week	20:45	6:00	4. week	19:15	7:30

Usually, the lighting dims to 50% power for a period from 23 h to 5 h depending on the season, latitude, etc. Besides grounding and phase zero, two phase wires are connected to a lighting fixture, the so-called C (all-night) and P (half-night) wire. The old wiring method for half-night regulation was based on connection of the P wire which would be left without power supply around 23 hours, so that the lamp would not operate up to 5 hours when it would be turned up again and worked until the final demise. Today, the used regulation is through ballast, embedded in the lamp. Ballasts are wired to work with the two outputs i.e. work with two impedances: nominal and increased. Using the increased impedance active current of power source is reduced and consequently the emitted luminous flux. Both phases (P and C) are connected to the lamp. P wire is then used as a control wire, i.e. it is used as a signal to switch the lights into a reduced mode. When both of the phases are connected to a power supply the lamp light is at full power. When the power supply at P wire is absent (about 23 hours), the lamp switches to work in a reduced mode (e.g. 250 W to 150 W). This is a two-step regulation, not continuous, but for the purposes of street lighting that is sufficient in most cases.

3.2 Control based on zone lighting controllers

One of the main reasons for the use of zone lighting controllers is to collect the data on the state of elements of the public lighting system. Condition monitoring of each lighting fixture allows a planned and timely maintenance of public lighting elements, which can significantly reduce maintenance costs.

According to the regulation method applied, control based on zone lighting controllers can be divided into: group control voltage regulation, control through control circuits and control using communication when every lighting fixture has electronic ballasts. Communication between the zone lighting controller and lighting fixtures is possible over existing power lines, additional communication lines and wireless with radio or GSM.

3.3 Ripple control from distribution remote control system

Ripple control systems is an information system that transmits messages from the control centre to all points of the power system. Information flow is unidirectional and runs from one or more ripple control transmitting points to all receiving points. The control signal (audio frequencies between 100 Hz and 1500 Hz, e.g. Elektroprimorje 216.65 Hz) is injected into the voltage waveform of the network as a sequence of short pulses in a defined frequency so that the encoded message consists of one or more commands. The ripple control receiver is located in a distribution substation in a field for public lighting. By order of the Croatia Electrical Utility centre the commands are sent to all ripple control receivers. The activation signal is sent when horizontal illumination level measured by luxomat in command center of the Croatia Electrical Utility is 5 lx (turning on), or 15 lx (turning off). The basic elements that make up the ripple control of public lighting are: ripple control transmitter with the lighting relay and timer, the existing power network which serves as a communication system, the ripple control receiver, and the switching elements. The basic elements that make this system are central unit within the PC with appropriate applications, GSM modem in order to achieve uniform application of communication with the remote local unit, remote unit or ripple control transmitter that controls the data received from the central unit as well as information about the status of the lamp and fuses collected by ripple control regulator and the power grid as a transmission medium.

The system has the ability to transmit messages but it also allows receiving them from the lowest point of control, for example, a lamp post. Basic data that can remotely edit and send to a ripple transmitter consists of local time and date, list of defined times of turning the lighting on and off, program priorities, weekly activities, a list of commands and instructions, the transmission parameters etc. Ripple control regulator which is actually a special ripple control receiver regulates the intensity of the light bulbs. It also has the ability to detect the status of the lamp and send the alert to the command centre by the corresponding local units.

3.4 Processor control of public lighting

This public lighting control system is primarily used for lighting the tunnel. Supervision of the tunnel lighting system performs local processor while the control of the lighting system operation and other systems in the tunnel (ventilation, traffic signalization, etc.) performs processor device that is an integral part of the remote control and supervision.

Any automatic control system must have the ability to manually turn on or turn off the lighting in a tunnel. The tunnel lighting is uninterrupted, i.e. it is in operation day and night, and its control is based only on changing the road surface luminance of the tunnel in relation to the access zone luminance [3]. The changes are achieved in three ways: continuous control, and continuous change in luminous flux of installed light sources, intermittent control, or discontinuous change in luminous flux of installed light sources, and combined control of mentioned types of control.

4. The impact of public lighting on distribution network

Public lighting systems spatially occupy a large area and although consumption per individual lighting fixture is not significant, a total distribution network load by public lighting is not negligible. For example, the public lighting of the city of Rijeka has a total output of 2.13 MW. This load must be taken into account in creating a daily distribution load curve, and switching the public lighting on must be designed so that it does not activate simultaneously.

Directives relating to electromagnetic compatibility are particularly useful in using the widespread low-voltage equipment that has become a significant source of interference. The fact that all electricity users are connected over the electric power network means that the same network is becoming a channel through which users become influenced by interference, which in most cases originate from the equipment of other users. Ensuring power quality is mainly related to the monitoring of voltage, with the emphasis on higher harmonics. Best known and valid regulation in the European Union that defines the power quality in low and medium voltage networks is the EN 50160 [6].

Equipment whose operation is based on the use of power conversion components and power electronics circuits (rectifiers and inverters) are typical examples of voltage and current harmonic generators. Harmonic current flows in the network which results in distortion of ideal sinusoidal voltage, i.e. voltage distortion. Generators of higher harmonics can be grouped into three categories according to the source, the size and predictability: a small and predictable (households, public lighting), large and random (electric arc furnace) and a large and predictable (static converters) [4]. Lighting fixtures are non-linear loads due to the arc characteristics. Harmonic currents generated by this specific lighting are defined by the type of ballasts that are used. Although the lighting fixtures with electromagnetic ballasts also produce harmonics, much bigger problem are the electronic ballasts. Gas-discharge light sources are high harmonics generators and have relatively poor power factor. Energy saving lamps can have a total harmonic distortion of 15%, crest factor typically 1.6 to 1.7. A small number of these light bulbs in one place does not produce significant harmonic problem. In cases where in a small area in the electric power network a greater number of light bulbs is concentrated it is necessary to install devices to filter the harmonics. Usually, unfiltered single phase non-linear loads like gas discharge lamps produce current distortions that contain large amounts of 3rd, 5th, 7th, 9th,…, 15th harmonic and so on. Harmonic filters correct poor power factor, while avoiding potential dangerous resonance points, particularly associated with the 5th and 7th harmonic. This is necessary if the same source (distribution substation) supply the consumers that are sensitive to higher harmonics [2].

Although the effect of individual load to the total harmonic distortion of current and voltage in power network is not large, diverse operating conditions of loads and their cumulative effect does represent a significant source of odd harmonics distortion. Unlike the modern single-phase rectifier, older technology rectifiers contained a transformer with inductance that aligned the current waveform, which decreased the content of the harmonic distortion. The newer electronic devices that typically have a switch mode power supply [4] are highly nonlinear loads because they take electricity from the grid in just a small part of each semi period of nominal voltage (usually at maximum voltage). The local distribution network does not feel such a burden for the most part semi period, but in that small part semi period feels like a big problem. The consequence of many such devices operating on a local network (e.g., zones with more street lighting lamps with modern electronic ballasts), results in the deterioration of power quality. Usually it appears as "clipping voltage", which leads to increased harmonic content (mostly the third harmonic). In addition to generating harmonics, public lighting equipment causes a short-term voltage dips, especially if they are required to operate with igniters. Loads with nonlinear characteristics, while burdening the small portion of each semi period, have substantially reduced impedance, which causes an increase in voltage drop on that part of the network. In addition, power transformers are saturated and therefore their output voltage is reduced. The consequence of all this is cutting sinusoidal voltage at a maximum, and in severe cases even higher voltage drop. An additional problem in connecting the device with switch mode power supply is a big increase in third harmonic currents in the neutral which can cause its overload, especially if such devices are connected to existing wiring [7]. If this is a relatively old distribution network it is very likely that the neutral are inappropriate dimensioned for connection of such devices. In addition, transformers, from which the network is powered is further heated.

To explain the increase of voltage distortion on the LV side of MV/LV transformers, during the switching of the public lighting, the very simple model is proposed [8]. All the circuit elements are referred to a given harmonics of order *k*. The voltage $V_{(k)}$ is the voltage on the LV side of the transformer, whose level of deterioration is under observation. The other loads fed by the same substations, can be included in Thevenin parameters $V_{N(k)}$ and $Z_{(k)}$. Thevenin impendence $Z_{(k)}$ is sum of source and network impendence:

$$Z_{(k)} = (R_{L(k)} + R_{N(k)}) + j(X_{L(k)} + X_{N(k)}) \tag{1}$$

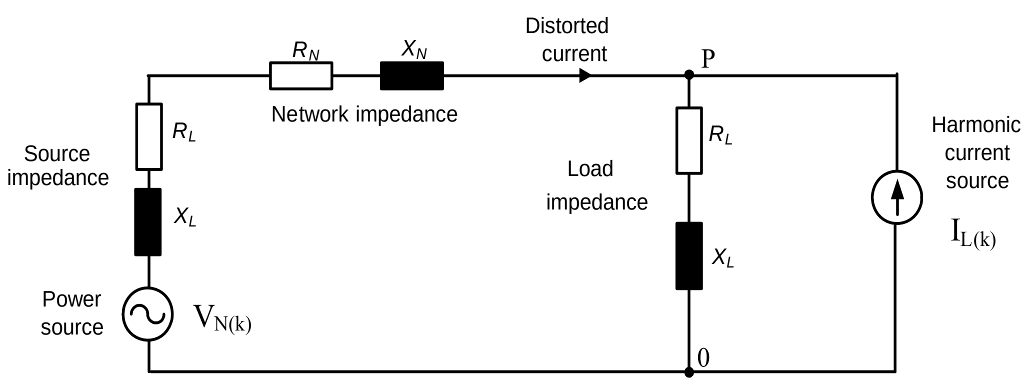

Fig.1 *Non-linear load impact on distribution network*

The generic k^{th} harmonic voltage phasor at the point P can be expressed as [7]:

$$\bar{V}_{(k)} = \bar{\alpha}_{(k)} \bar{V}_{N(k)} - \bar{\beta}_{(k)} \bar{I}_{L(k)} \tag{2}$$

The first part of the equation represents the influence of the MV network distortion level, while the second takes the contribution of the lamps into account. Both influences can compensate each other, so that total distortion due to k^{th} harmonic can decrease. The complex coefficients $\alpha_{(k)}$ and $\beta_{(k)}$ are defined as:

$$\bar{\alpha}_{(k)} = \frac{1}{1 + \bar{Z}_{(k)} \cdot \bar{Z}_{L(k)}} \tag{3}$$

$$\bar{\beta}_{(k)} = \frac{\bar{Z}_{(k)}}{1+\bar{Z}_{(k)} \cdot \bar{Z}_{L(k)}} = \bar{\alpha}_{(k)}\bar{Z}_{(k)} \qquad (4)$$

Taking into account (3) and (4), (2) can be written as:

$$\bar{V}_{(k)} = \bar{\alpha}_{(k)}(\bar{V}_{N(k)} - \bar{Z}_{(k)}\bar{I}_{L(k)}) \qquad (5)$$

Reactive part of load impendence is mostly equivalent admittance of all the power factor correction capacitor installed on the lamps. The coefficient $\alpha_{(k)}$ allows to put the role played by capacitors into evidence. If there are no capacitors ($B_{(k)} = 1$) than $\alpha_{(k)} = 1$, otherwise, for the most important harmonics (5^{th} and 7^{th}) $\alpha_{(k)} > 1$, which leads to amplification of the voltage distortion of the network $V_{N(k)}$ even without the contribution of the load current $I_{L(k)}$ [9]. Some possible remedies to the problem are the public lighting load reduction with respect to the rated power of the MV/LV transformer, or the increase in the rated power of the transformer with fixed public lighting load, the partial elimination of the lamp capacitors, the addition of capacitors (with reactor in series) with or without the corresponding elimination of lamp capacitors [4,9].

5. Conclusion

The main role of the external lighting is that lighting reduces the number of accidents and increase road safety. It also ensures the visibility of pedestrians and cyclists and increases overall safety and security of people and objects. In recent years great progress has been made in developing the modern public lighting, widening the possibilities of their control and maintenance methods with positive impact on the energy efficiency.

A large number of public lighting control systems have been developed for controlling and reducing energy consumption. These range from controlling the circle of public lighting and/or individual control with special lamps and ballasts with matching network operating protocols. This may include sending and receiving instructions via a separate data network, at high frequencies over the top low voltage or wireless.

The majority of light sources in public lighting are HID (High Intensity Discharge) lamps using electromagnetic or electronic ballasts and every lighting grid contains a great number of such single-phase loads. In order to balance the distribution network, they try to connect the same number of lamps on every phase of supply system; however, very often, the whole tree-phase load can appear to the supply network as unbalanced load at the fundamental and at the harmonics. Ways of solving the problems caused by public lighting as nonlinear loads are: installation of special transformers with features tailored to nonlinear load, creating the distribution networks while taking into account the parameters of nonlinear loads, mounting switching equipment to compensate for the effects of switching modes and the consumer's request to comply with regulations on electromagnetic compatibility. Public lighting costs can be a significant expense for city utilities, so it is also important to take all the opportunities for efficiency improvements.

New solutions are being developed for all applications, but, increasing traffic, demand of residents for safety, many regulations and an ever tightening budget creates wide area for continuous research.

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