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ONE APPROACH IN STREET LIGHTING SYSTEM RECONSTRUCTION REGARDING ENERGY EFFICIENCY

JEDAN PRISTUP REKONSTRUIRANJA SUSTAVA ULIČNE RASVJETE S OBZIROM NA ENERGETSKU UČINKOVITOST

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Abstract: This paper will present an approach for reconstruction of street lighting system regarding energy efficiency. Today, most street lighting systems are based on gas discharge lamps. LED lighting is energy efficiency lighting, which consumes less energy than lighting based on gas discharge lamps but, initial investment is still high. Methodology described in this paper includes analysis of the existing street lighting and gives guidelines for selection of equivalent LED lighting instead of the non-efficient existing one. Methodology includes economic evaluation of investment and saving ratio. This approach shortens calculation time, especially luminance calculations, due to lighting classification (on streets and areas) in clusters. This approach is especially appropriate for great systems of street lighting (city areas, cities and so on.).

Keywords: public street lighting, energy efficiency, LED system, clustering

Sažetak: U referatu će biti predstavljen jedan pristup (metodologija) za rekonstruiranje sustava ulične rasvjete s obzirom na energetsku učinkovitost. Naime, današnji sustavi ulične rasvjete bazirani su na svjetiljkama s izbojem u plinu. LED rasvjeta je energetski učinkovita rasvjeta koja troši manje električne energije, ali je početno ulaganje znatno. Metodologija opisana u referatu uzima u obzir analizu postojećeg stanja ulične rasvjete i daje smjernice za izbor ekvivalentne LED rasvjete umjesto postojeće neefikasne rasvjete. Metodologija uzima u obzir ekonomske parametre odnosa ulaganja u LED rasvjetu i potencijalne uštede. Ovakav pristup skraćuje vrijeme proračuna, posebno svjetlotehničkih, jer je rasvjeta po ulicama i naseljima svrstana u klastere. Ovaj pristup je posebno prikladan u prvom redu za velike sustave ulične rasvjete (gradska naselja, gradovi i sl.).

Ključne riječi: javna rasvjeta, energetska učinkovitost, LED sustav, klasteriranje

INTRODUCTION

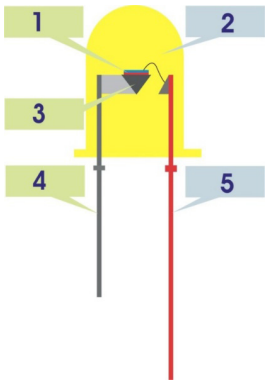
First loads were lamps (bulbs). The first power plants fed the street lighting systems back in 19th century. Street lighting systems today have a major influence on [1]: traffic safety, protection from robbery, normal movement of people and vehicles and more. All roads with a large number of vehicles, pedestrians and intersections should be illuminated at night. It is because of lower visibility during the night and lower concentration of all participants in traffic. At these occasions, the positive impact of street lighting is obvious. Deactivation of street lighting contributes to [1]: 13% increase in vehicle stealing, 25% more forays and 65% more burglaries. Street lighting is a developed area of business today. Back in 2005, in EU, 2.1 million of luminaires and 18.3 million of lamps were sold. These expends increased with maintenance expends contributing to billions of cash flow in the street lighting business [2]. Luminaire is the most important parameter of street lighting system due to its expensiveness. Quality luminaire has a long life span. The degree of luminaire protection from solids and liquids is a very important parameter that directly affects the life span of a luminaire. The degree of luminaire protection from solids varies from IP1 to IP6. IP6 is full protection - protection against dust entry in luminaire. The degree of luminaire protection from liquids varies from IP0 to IP8 where IP8 presents waterproof luminaire for permanent immersion up to 5 meters. IK parameter presents protection from mechanical damage of luminaire. It varies from IK00 – no protection at all, to IK10 – protection from 5 kg body impact when falling from 400 mm in height. A very important parameter for luminaires is luminaire optic, too. Optic is important for utilization of light without unnecessary loss and for reduction of light pollution. Light pollution

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is every unnecessary light emission out of the zone of luminance (streets, squares etc.). Additionally, luminaires contain ballasts for proper function.

1. LED LIGHTING TECHNOLOGY

LED lighting technology presents future in lighting technology. LED lights have a long life span, high degree of utilization and lower light pollution. The only problem, although non-technical, is a high price of this system. LED lighting started being developed in the 1960s, but its full development started only 10-20 years ago. LED lighting consists of a LED diode assisted by the chip (CREE, EPISTAR etc.). LED is a solid physical body that, as a semiconductor element, converts electrical energy directly into light, unlike the types of bulbs known so far, which must produce heat that gives light emission. LED converts electrical energy into photons which are visible as light. Semiconductor is fed by DC current and whole LED system is closed in special plastic. It gives luminaire a strength and manipulative usability. Basic parts of LED system are given in Figure 1 [1]. All materials used to make LEDs have a very high refractive index. This means that most of the light will be reflected back to the material. This fracture occurs at the transition of material and air. Efficiency of LED system increases with time. In 2002 Philips manufactures 5W LED. Utilization of this system was between 18-22 lm/W. For illustration, classic incandescent bulbs of 60-100W power range have an efficiency of 15 lm/W. For fluo lights, utilization increases up to 100 lm/W. In 2010, company Cree Inc. manufactured 208 lm/W chip prototype (at a room temperature). In practice, LED chips of higher power are used. For those chips, current values are 350 mA or 700 mA. The declared life span of an LED ranges between 25000 and 100000 operating hours, depending on LED power and manufacturer. Ambient temperature and quality of supply have a great influence on an LED's life span. Additionally, LED life span is in correlation with the rated luminous flux. When luminous flux decreases under 50% of rated value, LED life span is over [2].



Legend:

1. LED chip
2. Plastic housing with optic
3. Reflector
4. Cathode
5. Anode

Figure 1: Main elements of LED light [1]

Advantage of LED lighting is an almost instantaneous response to a voltage change. Figure 2 presents relation between efficiency of LED and sodium lighting. LED lighting luminous flux is more directional than with sodium lamps [1].

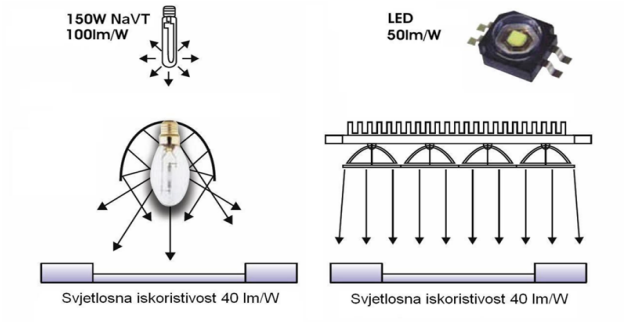


Figure 2: Relation between efficiency of LED and sodium lighting [1]

2. BASICS OF STREET LIGHTING DESIGN

CEN 13201-(1-5):2004 [3] is a referent norm in street lighting design. In street lighting design, there are several important parameters. The main term is luminance. The light from the luminaire falls on the road and reflects from its surface into the eye of the viewer, who perceives it as light. This is called luminance - L (cd/m^2). Overall uniformity (of road surface luminance, illuminance on a road area or hemispherical illuminance) (U_0) is ratio of the lowest to the average value. Longitudinal uniformity (U_L) is the lowest of the longitudinal uniformities of the driving lanes of the carriageway. Threshold increment (TI) is measure of the loss of visibility caused by the disability glare of the luminaires of a road lighting installation. Surround ratio (SR) is average illuminance on strips just outside the edges of the carriageway in proportion to the average illuminance on strips just inside the edges [3].

Criteria for street lighting design must fit set conditions: L, U_0, U_L, TI and SR [3]. Optimal luminance for street lighting is 2.0 cd/m2. This value is justified for highways, so luminance of 0.5 cd/m^2 to 2 cd/m^2 is recommended, depending on the type of road [3]. Luminance depends on: photometric characteristics of the lamp, the position of the lamps in relation to the road, the reflective properties of the carriageway and the position of the observer. For street lighting systems lighting classes from M1 (local roads) to M6 (highways) are defined. Values of U_0 are divided in four categories: 0.4, 0.5, 0.6 and 0.7 [3]. Requirements for U_0 are increasing with maximum permitted speed, traffic density and possible dangerous situations. The U_L should not be less than 0.4, thus avoiding dark areas and ensuring that the driver can see pedestrians entering in his line of driving [3]. Today, lighting design calculations are mostly performed in one of the available software solutions (RELUX, DIALUX etc).

3. DESIGN METHODOLOGY

This chapter presents methodology for street lighting system reconstruction in view of energy efficiency. Methodology consists of more steps, described below.

3.1. Step 1 – System inspecting and data base creation

This step consists of inspection of street lighting system. Each pole with luminaire and additional equipment gets its own ID number. Properties for each pole are as follows:

- Pole properties: material type (concrete, wood or metal), height (in meters), pole distance from edge of carriageway (in meters) and pole orientation (left or right);
- Luminaire properties: type, number of luminaires per pole, boom length (in meters) and luminaire or boom rotation (in degrees);
- Lamp properties: type of light source, number of lamps per luminaire, power (in watts);
- Road: carriageway coating (asphalt, concrete, ground etc.), carriageway width (in meters);
- Route: distance between poles (in meters).

Using the above presented inspection, data base of lighting system can be created.

3.2. Step 2 – Data analysis

Generally, luminance calculation for great street lighting systems (e.g. towns) is quite a long-term job if it is done street by street. An idea is to divide calculation area in clusters based on their similarities. This means that in one area (e.g. town) all the same street light scenes would be one cluster. The condition to carry out clustering is a completed inspection of street light system as described in 3.1. Since there are numerous different street light scenes in great street lighting systems, clustering is an appropriate method for data analysis. Additionally, this method decreases luminance calculation time (unlike doing luminance calculation street by street). Simplified, the idea is to find the same streets in targeted area after inspection and classify them in appropriate clusters. Then, calculations must be performed for clusters. In practice, one town can have numerous streets but only a few clusters.
Clusters are created on basis of:

- Width of carriageway (in meters),
- Height of street light pole (in meters),
- Distance between two poles (in meters).

These parameters are the most responsible for luminance results. Additionally, other parameters must be met: distance of pole from carriageway edge (in meters), carriageway coating etc.

3.3. Step 3 – Luminance calculation

In this part, methodology of luminance calculation for defined clusters will be described. Calculation methodology is composed of a series of sub-steps. Current state of luminance (mercury, fluo and sodium luminaires) has not been analysed. Referent Norm is CEN 13201-1(5):2004 [3].

3.3.1. Sub-step 1 – Grouping of lighting situations

A lighting situation can be classified within a group in terms of the base parameters given in [3], which identify the appropriate set of lighting situations for each group. Lighting situations are divided in term of: typical speed of main user (in km/h) and user types in the same relevant area (main user, other allowed user and excluded user). Selected lighting situations contribute to selection of set of lighting situation (A1-A3, B1-B2, C1, D1-D4 or E1-E2).

3.3.2. Sub-step 2 – External influence

For each lighting situation there are external influences which must be taken into consideration. Main external influences, which can impact the luminance, are: conflict area, complexity of visual field, parked vehicles, ambient luminance and cyclists flow.

3.3.3. Sub-step 3 – Recommended lighting class

Lighting class can be determined on the basis of external influence. Lighting classes are generally: ME1, ME2, ME3, ME4, ME5 and ME6. In practice, ME1 presents highways and ME6 local roads. For each lighting class, boundary values are required for: L (cd/m2), U0 (min.), UI (min.), SR (min.) and TI (max.). The most difficult fulfilment of conditions is for ME1.

3.3.4. Sub-step 4 – Carriageway coating and maintenance factor

Maintenance factor can be defined based on experience. Carriageway coating is usually, but not necessary, asphalt.

Luminance calculations can be performed based on the proposed steps and sub-steps. It is the first step of reconstruction. It is a condition for optimal selection of LED luminaire.

Luminance calculation, after inclusion of all needed inputs, can be optimally performed. Constrains in optimization can be defined on different manners. For example, boom can be included/excluded, boom rotation can be allowed/not allowed etc.

4. ECONOMIC EVALUATION

Methods for economic evaluations of project profitability can be divided as [4, 5]:

- Methods ignoring time value of money (simply and easy to understand),
- Methods including time value of money.

Ignoring time value of money is not appropriate for project evaluation. There are several methods regarding time value of money in techno-economic analysis. Time value of mon-

ey describes the relation between the value of money today and in the future. Discounting (calculation of present value of future sum of money) and compounding (calculation of future value of present sum of money) are generally two methods for computing time value of money [6]. The usual methods for economic profitability determination are: *NPV*, *IRR*, *PI* and *DPB* [7], [8]. If these methods do not give the same result, investor must choose to which they will give preference.

NPV is a discounted difference between the net present value of project benefits and project expends (costs). *NPV* requires discounting to the initial year of the project [7]. *NPV* equation is given by:

$$NPV = \sum_{t=1}^{n} \frac{GT_t}{(1+k)^t} - I_0 \tag{1}$$

where I_0 is initial investment in year 0 (cash flow in t=0), GT_t is expected net cash flow in period t, k is capital cost and n is time of project analysis. The goal is to obtain as great as possible *NPV* value. If *NPV*, a project must be rejected.

Simply, *IRR* is a discount rate for which *NPV*=0. So, *IRR* must be greater or equal to the project's discount rate. If that is so, the project should be accepted. Otherwise it should be rejected [9]. The value of *IRR* is in percentage value. Greater *IRR* means better project. *IRR* is defined with:

$$0 = \sum_{t=1}^{n} \frac{GT_t}{(1+r)^t} - I_0 \tag{2}$$

where r presents *IRR*.

PI or benefit-cost ratio of a project is the ratio of the present value of future net cash flows and initial cash outflow. *NPV* equation defines these parameters. If $PI \geq 1$, the project should be accepted. *PI* is given with equation:

$$PI = \frac{\sum_{t=1}^{n} \frac{GT_t}{(1+k)^t}}{I_0} \tag{3}$$

DPB is a time period (in years) required for payback of initial cash outflow. This parameter gives the number of years for investment return. Shareholders must define number of years acceptable for the project's payback period. If project's discounted payback period is less than that number of years, project should be accepted [9]. *DPB* can be presented by:

$$DPB = N_p + \frac{UE_S}{CF_y} \tag{4}$$

where N_p presents number of periods before full expends have been covered, UEs uncovered expends at the start of the year and CFy cash flow in the year of expends being covered. Calculations consider the interest rate. This rate is difficult to determine and it can be differently interpreted.

4.1. Application in street lighting

Expends in street lighting can be divided as:
- Investment in new street lighting system,
- Expends due to electricity costs,
- Maintenance of installed street lighting system.

Investment in a new street lighting system understands investments for luminaires and additional equipment, if necessary. Those expends are obtained by luminance calculation and appropriate bill of costs.

Expends for the cost of electricity for the street lighting system on yearly basis can be obtained as:

$$EC = \sum_{\substack{i=1,2..,m \\ j=1,2,..,n}} P_{inst} \cdot T_i \cdot d_i \cdot c_j \tag{5}$$

where i presents the number of seasons on yearly basis, j number of seasons with different cost of electricity per season on yearly basis. EC is money consumption of street lighting system in monetary value (EUR), T_i is working hours of street lighting in a season period, d_i is number of days in one season and c_j is electrical energy price in EUR/kWh.

For maintenance cost of the installed street lighting system, factor deterioration (F_S) of luminaire should be introduced as:

$$F_S = 1 / l \tag{6}$$

where l is lifespan of light source in years.
Number of replaced luminaires annual (n):

$$n = F_S \cdot N \tag{7}$$

where N presents total number of luminaires in exploitation. Total exploitation cost of street lighting system is sum of investment costs, electricity costs and maintenance costs.

5. EXAMPLE – CASE STUDY

In this part, example case study will be presented. It is a case study of urban area of the Široki Brijeg City in Bosnia and Herzegovina. Luminaires in urban area for this case study are divided in street lights and other lights. Other lights are lights for parking places, parks, etc. Those are the places without intense vehicle traffic. They are excluded from this analysis.

There are 949 luminaires in this urban area. These luminaires are divided according to source as follows:

- Mercury source of following rated power: 125 W, 250 W and 400 W;
- Sodium source of following rated power: 70 W, 100 W, 150 W and 250 W.

Source division is presented in Figure 3. High share of mercury sources is visible.

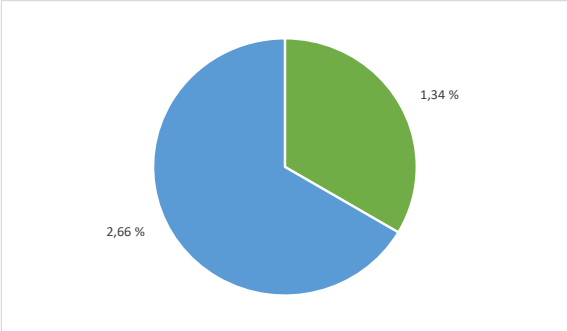


Figure 3: Percent ratio of mercury sources (1) and sodium sources (2)

The results presented above have been obtained by system inspection according to 3.1. Using the collected data, data analysis is performed. As described in 3.2., clusters are created. Cluster overview is presented in Table I. There are 23 different clusters.

Table I: Clusters overview

Cluster no.	Carriageway width (in meters)	Pole height (in meters)	Distance between poles (in meters)
1	5	7,5	30
2	6	10	20
3	4	7,4	30
4	6	6	20
5	6	10	35
6	4	7,5	25
7	4	6	20
8	7	6	20
9	4	5	20
10	7	7,4	27
11	4	7	30
12	6	6	25
13	8	10	25
14	4	6	28
15	7	8	30
16	8	12	30
17	6	7,5	35
18	5	8	40
19	5	8	20
20	6	8	39
21	7	6	25
22	7,5	7	30
23	7,5	10	30

Urban area is divided in more areas (settlements) according to the street light systems (metering points). Settlements are divided into streets going through the given settlement. Each settlement has its own cluster or more clusters depending on different street light scenes. It is presented in Table II.

Table II: Overview of clusters for street light systems

Area/Street light system	Cluster no.
Burića Brig	1
Sveta obitelj	2
Ličtica 3 – Kino	3
Ovčiji Brod - Škola Trn	4
Obilaznica	5
Bivši ZAP – Policija	6
Kosa	7, 8, 9, 10
Stadion	3, 8, 11
Zorićevina 1	4, 9
Dječiji Vrtić Puringaj	4
Hotel Park	8, 12, 13
Brijeg kod SŠ Gimnazija	14
Bakamuša	8, 15
Pribinovići Brijeg 2	3
Škola Klanac	7
Trn Ovčiji Brod	16
Trn Stipelić	16
Vagan	17
Jelići	18
Njivice 2 Puringaj	7
Njivice 1	3, 19
Oklaji 1	20
JR Jošotić	3
LR Ličtica 1	3, 13, 21
JR Lise 1	12, 18, 21, 22, 23

Now, luminance calculation can be performed for each cluster.

A lighting situation can be classified according to 3.3.1. as B2. B2 is obtained on basis of:
- Typical speed of main user (km/h): >30 and ≤60;
- Main user: motorised traffic, slow moving vehicles, cyclists;
- Other allowed users: pedestrians.

Main external influences which can have influence on luminance are:
- Conflict area: no;
- Complexity of visual field: normal;
- Parked vehicles: not present;
- Ambient luminance: low (suburban area), high (urban area);
- Traffic flow cyclists: normal.

Now, recommended lighting classes can be obtained as follows:
- Main weather type: dry;
- Geometric measures for traffic calming: no;
- Intersection density (intersections/km): ≥3;
- Difficulty of navigational task: normal;
- Traffic flow vehicles: <7000 (suburban area), ≥7000 (urban area).

Additionally, obtained lighting classes are:
- ME4b – suburban area,
- ME3c – urban area.

Luminous needs for the obtained lighting classes are presented in Table III [3].

Table III: Luminous level for obtained lighting classes [3]

Class	Parameters				
	L [cd/m^2]	U_0 min.	U_l min.	TI max.	SR min.
ME3c	1	0,4	0,5	15	0,5
ME4b	0,75	0,4	0,5	15	0,5

Carriageway coating is asphalt. Maintenance factor is 0.8.

On the basis of the performed sub-steps, luminance calculations are made. Those calculations are performed for each cluster. Later, clusters are attributed to streets and settlements. Calculations are performed with DIALUX software. Its optimization toolbox is used.

Constraints are set (project task):
- Boom length: max. 1.5 meter (preferred no boom if it is possible);
- Angle of luminaire rotation: <15 ° (preferred 0 ° if it is possible).

Rated power of LED light luminaires is obtained as follows: 41 W, 57 W, 65 W, 77W, 88 W and 106 W. Luminaires had different optic, on basis of ratio pole height/carriageway width. Optimal optic for each cluster is set by DIALUX software optimization tool.

Quantities of LED light luminaires for installing are presented in Table IV.

Table IV: Quantities of LED light luminaires

Rated power (W)	Quantities(pcs.)
41	124
57	529
65	26
77	123
88	50
106	97

Figure 4 shows rated power of installed street light system before replacement, after replacement and savings.

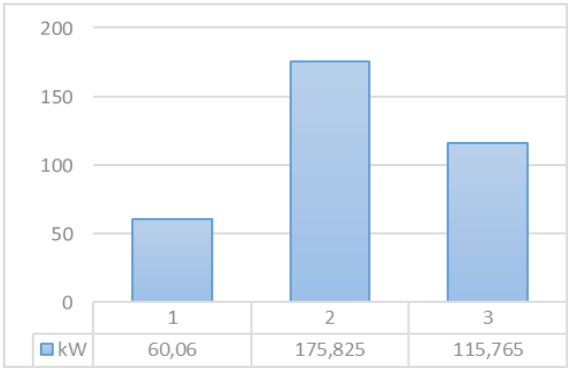


Figure 4: Rated power of street light system: 1- new system, 2-system before replacement and 3-savings

It is visible that decrease in the rated power is more than 50% after the replacement of conventional light system with LED system.

Input data necessary for economic evaluation:
- Seasons with different time work of street lighting system: summer - 9 hours (122 days), winter – 15 hours (120 days) and autumn/spring - 11 hours (123 days);
- Analysed time period: 12 years;
- Investment in new LED street light system: 270000 EUR.
- Discount rate: 4%;
- Equity: 100%;
- Expend of replacement of luminaire: 30 EUR/pcs (conventional) and 130 EUR/pcs (LED);
- Price of electric energy: winter: 0.1097 EUR/kWh, rest of year: 0.0843 EUR/kWh;
- Luminaire lifetime: LED: 50000 h, mercury: 18000 h and sodium: 25000 h.

After implementation of economic evaluation described in section 4, results are obtained. Those results are presented in Table V.

Table V: Economic evaluation results

Economic parameter	Evaluation results
NPV (EUR)	164051.39
IRR (%)	12.33
IP	1.61
DPB (in year)	8

According to [4]-[8], obtained results are very satisfying. There is obvious benefit of replacing existing lighting system with new LED lighting system.

6. CONCLUSION

This paper presents one approach for a large street lighting system reconstruction. Reconstruction means replacement of the existing conventional luminaires with

the new ones. Those new are appropriate LED luminaires. Methodology of this replacement is described in this paper. This methodology consists of system inspection, creation of data base, clustering, calculations and economic evaluation. This methodology is especially applicable for large street lighting systems. Contribution of paper is in shortening of luminance calculations using clustering. Methodology is applicable for every street lighting system. Economic evaluation can be conducted using modern dynamic economic methods. This all is accompanied with one case study. Economic evaluation conducted for case study showed great benefits of installing new LED lighting system.

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BIOGRAPHY

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Drago Bago both graduated and completed postgraduate PhD studies from the Faculty of Electrical Engineering and Computing, University of Zagreb. Since 2000 he has been employed at JP "Elektroprivreda HZ HB" d.d. Mostar in Distribution Power Division and Development Division. At the moment, he is a member of the Board and the Executive Director for Development in JP ''Elektroprivreda HZ HB" d.d. Mostar. He completed a professional study ''Energy Efficiency" organized by the Institute of Energy Technology in Kjeller (Oslo), Norway and the Faculty of Electrical Engineering and Computing. He is the author or co-author of several scientific and professional papers in the field of overvoltage protection for medium voltage lines, the correlation of events data from the power system and data from the system of professional organization IEEE. He is also a member of the Study Committee of the International Council on Large Electric Systems CIGRÉ in Paris, Study Committee C6 - Distribution Systems and Dispersed Generation. He is the President of the International Conference of CIRED for Bosnia and Herzegovina and president of Study Committee C6 BH K CIGRÉ - Distribution Systems and Dispersed Generation. He is a member of the Board of BH K CIGRÉ. He is a member of the Board BAKE - BH Council for Electrical Engineering. He is a member of the Editorial Council of the magazine ''BH Elektrotehnika". He is the member of the Croatian Association of Engineers - AMAC.