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Measurement Analysis of an Advanced Control System for Reducing the Energy Consumption of Public Street Lighting Systems

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***Abstract*--The paper proposes a measurement analysis method of the performances of an advanced control system which are used in public street lighting systems. It is presented the hardware implementation of DIMM Light advanced system and the measurement analysis of this system using a Lab VIEW application. By use of the DIMM Light for controlling the switch on points of the public street lighting system we increase the power efficiency and quality of lighting level, and, in the same time, the costs are decrease.**

***Index Terms*—Electric Control Equipment, Measurement System, Public Street Lighting, Power efficiency.**

I. Introduction

FROM the electrical energy consumer categories, with an important weight, 10% is owned by the public lighting. The public lighting is one of the quality criterions of the modern civilization. The outdoor lighting is one of the power consumer where the light-technical, energy, economic and esthetical aspects have to be analyzed together, important being yet the lighting level on traffic road and pavement.

The public street lighting has the part to ensure not only the direction and safe circulation of the vehicles and pedestrians in the night but also a corresponding surrounding during the lack of the daylight luminance. One solution that could open new development trend in the public street lighting is to make use of the advanced system for controlling the switch on point. An important equipment of a public street lighting system is the switch on point, which ensures the correct supply of the lamps on an hour interval imposed by the beneficiary and thus also provides the energy economy [1]-[6].

Many present switches on points have no automated systems, starting to function and disconnecting, most often, at the manual action of a person. The new intelligent equipments used in this paper to increase the efficiency of the public street lighting must include more functions: switch on/off depending on the local lighting state; the possibility of switch on/off depending on the functioning preliminary schedule; the knowledge from distance of the functioning state of the respective electric network, the signaling at the appearance of some possible defects; the possibility of remote controlling the switch on/off commands; the knowledge possibility from a central point of the energetic consumptions in each switch on point and the state of the respective network, especially that the measured quantities are most often non-sinusoidal; the possibility of establishing economic functioning regimes, inclusive at voltages lower than nominal voltages; the endowment with a distance transmitting device of the command and measuring information: radio, wireless etc.

Ones of these new functions can be implemented using hardware and software specialized elements, such as programmable automats DIMM Light with the ZDM 3500/3000/2500/2000 family.

This paper proposes the introduction of an advanced control system which uses the programmable automat DIMM Light, and which leads an automat system for control the switch on points in public street lighting systems. It is presented the hardware implemented application and the measurement analysis method of the performances of proposed system using a Lab VIEW application.

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II. Architecture of Proposed Application

A. Advanced Control System Configuration

In practical application we use the ZDM 2500 device of DIMM Light (Fig. 1), for controlling a practical public street lighting system which contains 10 sodium vapor lamps shown in Fig. 2, each of lamp has the nominal power 250W [7]-[11]. To configure the DIMM Light innovative solution for the application related to the control of switch on points in public street lighting, we take into account the next requirements [12]:

- connecting the automat consumer, depending on the lighting state, through the agency of a solar radiation transducer or through manual command;
- connecting the lighting network using an hour program,

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Fig. 1. The DIMM Light device family ZDM 3500/3000/2500/2000.

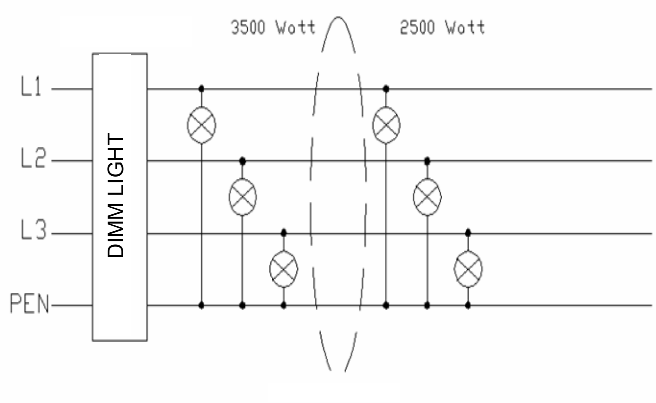

Fig.2 The DIMM Light 5 KW cascade connection in a 4 – wire system.

depending on the day from the week;

- supplying the network through the agency of voltage/frequency converter;

- supplying the lighting through the agency of an autotransformer, in order decrease the lighting intensity between certain hours (the reduction of the luminous flux).

The ZDM 2500 has a simple installation and a simple programming with a computer or laptop. The input analogical signals, received from the twilight transducer are compared with the values imposed in the lighting controller. Depending on this comparison the automat will decide if it's the moment to command the connection of the public street lighting. Depending on the chosen automation variant through the autotransformer or through the converter, the current and voltage protections automatically modify their working parameters. The automation working in the autotransformer variant is realized when at ones of the input of ZDM 2500 a digital signal is applied. The working takes place when three signals are simultaneously applied with the programming clock signal. With the help of this clock we can program the period in which the luminous intensity will reduce (between what hours and what days). Thus, during the night, we can cut off light totally or cut off light partially with 50%, 33% or 67% of the lighting level.

The automation functioning with the help of the frequency converter is realized when at the input a digital signal is applied to the integrator blocks [13]-[19].

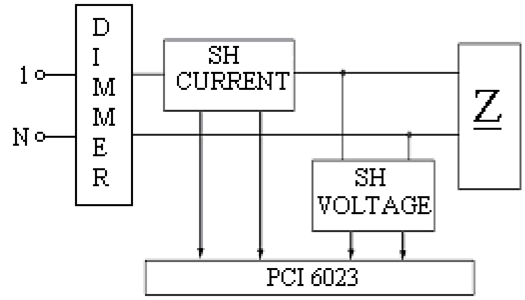

Fig.3. The LabVIEW application.

B. *Configuration of the Lab VIEW application*

Lab VIEW is one of the most used virtual instrumentation Environment [20]-[21]. The virtual instrumentation (VI) represents the association between flexible hardware equipment (data acquisition systems or programmable measurement instruments) attached to a microcomputer and an application soft which implements the functions of the instrument and represents the interface between the human operator and the instrument. VI transparently combine computer resources, measurement and control possibilities of the hardware equipment (electric signal transducers, signal conditioning circuits, A/D and D/A converters, interfaces e.a.), data analysis software, data processing, result presentation and process leading. In LabVIEW, the VI is a module developed through the programmer. It consists of an interface with the user ('front panel'- the front part of the instrument's panel) and a block program (the part behind the panel, the diagram, which is available only to the programmer).

Organizing the program module with VI offers to the users a strongly graphical oriented interface, easy to use, which offers high accuracy and flexibility.

In order to proves the technical and economical advantages of the DIMM Light control system we design and implement a Lab VIEW application, shown in Fig. 3. In our laboratory, we used two blocks, SH current and SH voltage, for the measurements of the current and voltage.

C. *Analysis of the Measurements Results*

In order to consider the Lab VIEW application in our laboratory the load ($\underline{Z}$) consists in a 250 W sodium vapor lamp with capacitor for discharge lamp circuits [22].

First step of the measurement method is to consider the lamp without the ZDM 2500-DIMM Light device. In this case, we make the measurements for the current and voltage at the lamp terminals (shown in Fig. 4), for the power factor (shown in Fig. 5), and for the active power (shown in Fig. 6). In the same time we implemented a Fourier method analysis for the voltage and current measurement, shown in Fig. 7, respectively in Fig. 8.

Second step in the measurement analysis method is to know the behavior of the DIMM Light. From this reason we make the measurements of current and voltage at the input (shown in Fig. 9) and output of the ZDM 2500 device of

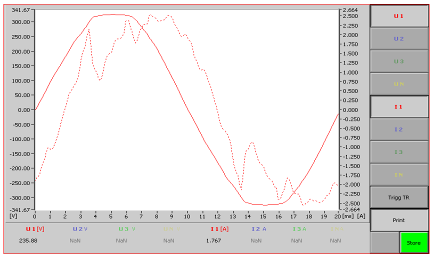

Fig. 4. The variation of current and voltage at the lamp terminals without ZDM 2500-DIMM Light.

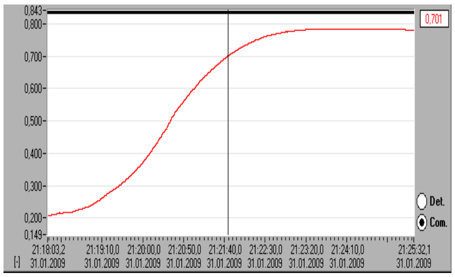

Fig. 5. The variation of the power factor at the lamp terminals without ZDM 2500-DIMM Light.

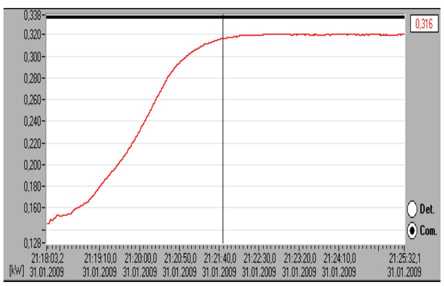

Fig. 6. The variation of the active power at the lamp terminals without ZDM 2500-DIMM Light.

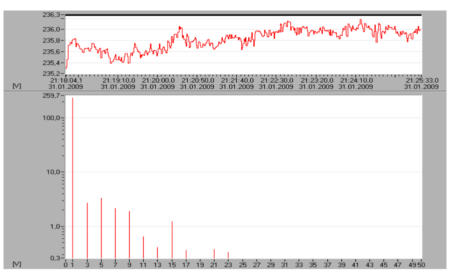

Fig. 7. Fourier analysis of the voltage at the lamp terminals without ZDM 2500-DIMM Light.

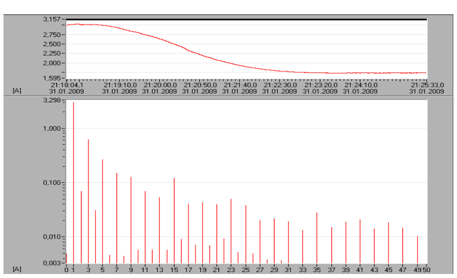

Fig. 8. Fourier analysis of the current at the lamp terminals without ZDM 2500-DIMM Light.

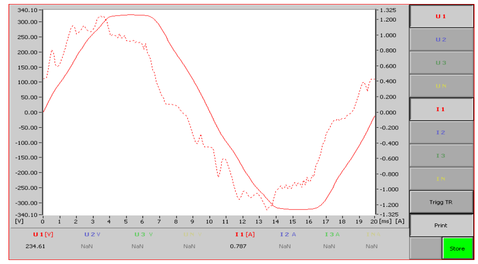

Fig. 9. The variation of current and voltage at the ZDM 2500-DIMM Light input.

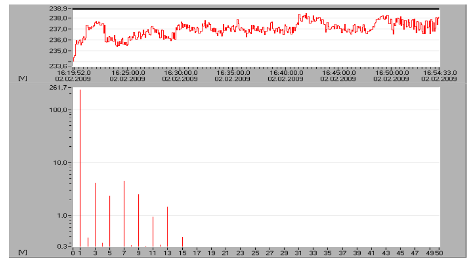

Fig. 10. Fourier analysis of voltage at the ZDM 2500-DIMM Light input.

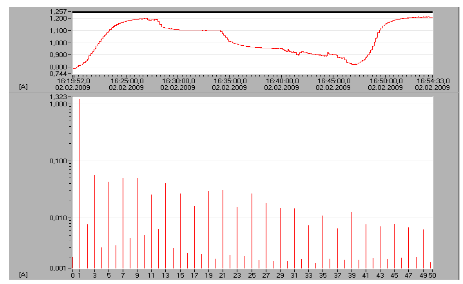

Fig. 11. Fourier analysis of current at the ZDM 2500-DIMM Light input.

DIMM Light family. The variation of the current and voltage at the input of ZDM 2500 device are normally for the steady-state electro-energetically system, that results from the Fourier analysis of these signals shown in Fig. 10 (for the voltage input) respectively in Fig. 11 (for the current input).

For the output device measurements, we choose two different practical situations of public street lighting systems:

a) the lighting level is normal, consequently ZDM 2500 device of DIMM Light hasn't an action, and the variation of voltage and current are shown in Fig. 12;

b) the lighting level is cut off partially the with 67% y the ZDM 2500 device of DIMM Light, and the variation of voltage and current are shown in Fig. 13.

The case b) is analyzed by using the Fourier transform, and their results are shown in Fig. 14, for the voltage harmonics analysis, respectively in Fig. 15, for the current harmonics analysis [23], [24].

Generally, we can expressed the voltage and the current at the device ZDM 2500-DIMM Light output by using the Fourier series, so that

$$u(t) = \sum_{p=0}^{m} U^{(p)} \sqrt{2} \sin(p\omega t + \varphi^{(p)}) \qquad (1)$$

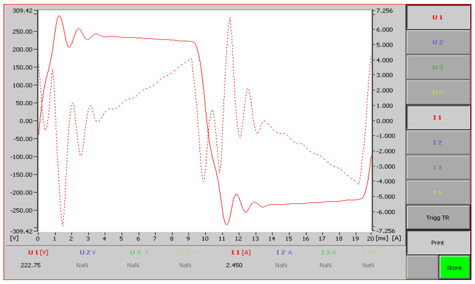

Fig. 12. The variation of current and voltage at the ZDM 2500-DIMM Light output when the reduction of the lighting level is 0%.

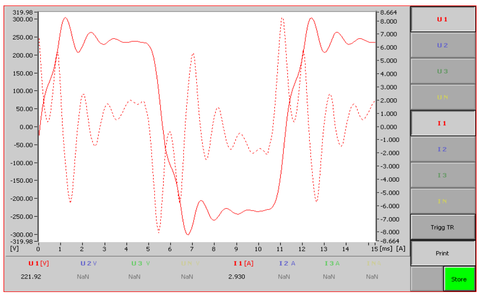

Fig. 13. The variation of current and voltage at the ZDM 2500-DIMM Light output when the reduction of the lighting level is 67%.

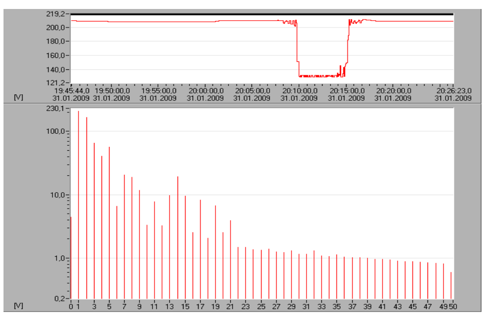

Fig. 14. Fourier analysis of voltage at the ZDM 2500-DIMM Light output when the reduction of the lighting level is 67%.

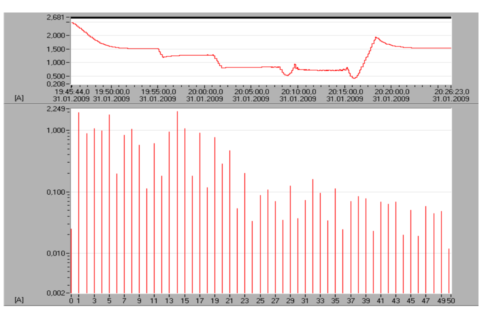

Fig. 15. Fourier analysis of current at the ZDM 2500-DIMM Light output when the reduction of the lighting level is 67%.

$$i(t) = \sum_{p=0}^{m} I^{(p)} \sqrt{2} \sin(p\omega t + \varphi^{(p)} - \gamma^{(p)}) \qquad (2)$$

where m is the finite number of harmonics considered, $U^{(p)}$ and $I^{(p)}$ represent the RMS values of the p^{th}-harmonic of

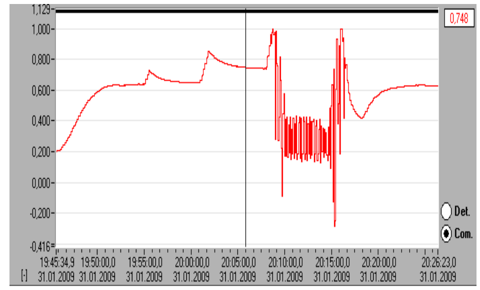

Fig. 16. The variation of the power factor when the reduction of the lighting level is 67%.

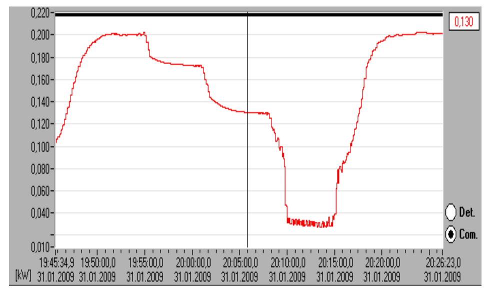

Fig. 17. The variation of the active power when the reduction of the lighting level is 67%.

voltage and current, respectively, while $\varphi^{(p)}$ and $\varphi^{(p)} - \gamma^{(p)}$ represent the phase angle of the p^{th}-harmonic of voltage and current, respectively.

We remark the keeping of the voltage harmonics content and the variation of voltage in both cases a) and b). The distortion of the voltage, especially in case b), compared with the voltage at the lamp terminals during the absence of the ZDM 2500-DIMM Light device, can be observed. In case b) the content and the amplitude of voltage harmonics increase: new even harmonics appear, and the amplitude of odd and even harmonics are with 10-50% bigger.

A similar observation can be extracted by analyzing the current variation. In case b) the content and the amplitude of current harmonics are bigger compared with case a), and especially with the current at the lamp terminals during the absence of the ZDM 2500-DIMM. Thus new even harmonics appear, and the amplitude of odd and even harmonics are with 20-60% bigger.

The distortion of voltage and current characteristics when the ZDM 2500 device cuts off the lighting level with 67% is explained through the existence of the non-linearity of the autotransformer in this device.

Other important measurements consist in the analysis of the variation of power factor and absorbed active power for case b). We can observe an important variation of power factor (Fig. 16) which decreases when the autotransformer of the device starts to work and cuts off partially the lighting level. The active power has the same variation, shown in Fig, 17, so it decreases when the lighting level is partially cut off. If we compare and analyze the measurements accomplished when the ZDM 2500-DIMM Light is, and isn't in the system, we can observe:

- the variation of the current and voltage when the DIMM Light isn't in the system (Fig. 4) is the same with the variation at the input of the ZDM 2500-DIMM Light (Fig. 9);
- the power factor and the absorbed active power ((Fig, 5 and Fig. 6) increase when the ZDM 2500-DIMM Light is absent, and have an important decrease when the ZDM 2500-DIMM Light is present, and it reduce the lighting level with 67% (Fig. 16 and Fig. 17).

In conclusion when the lighting level is cut off partially with 67%, the ZDM 2500-DIMM Light reduce the power factor and the absorbed active power with 30%, but the device introduces a distortion at the current and voltage.

In the final step of the Lab VIEW application we made the comparative measurements of the lamp parameters: illuminance (lighting level), current, and the absorbed active power in two situations, without ZDM 2500-DIMM Light, and in presence of ZDM 2500-DIMM Light when this device cuts off partially the lighting level of lamp with 0%, 20%, 40%, and 67%.

The illuminance (E) of the 250 W sodium vapor lamp decreases (Fig. 18) when the ZDM 2500-DIMM Light cuts off partially with 0%, 20%, 40%, and 67% the lighting level. In the absence of the device the maximum value of E is 3580 lx, and when ZDM 2500 cuts off partially the lighting level with 0%, 20%, 40%, and 67% the values of E are respectively 2280 lx, 1820 lx, 1103 lx, and 275 lx (shown in Table 1). The opinion polls showed that this demand-orientated brightness controlling for these limits of the illuminance in public street lighting is accepted by the local communities and the residents.

The efficiency of ZDM 2500-DIMM Light results if we compare the values of the current and the absorbed active power in the absence of the device and when the device works.

The variations of current and absorbed active power are shown in Fig. 19, and their values are presented in Table 1. In the absence of the device the nominal current of lamp is 1.73 A. We can observe an important decrease of current when the ZDM 2500 is connected in circuit compared with the nominal current, between 87.2% and 40.4%. In the same time a strong decrease has the absorbed active power. The nominal value without ZDM 2500 is 320 W and, when the device is connected in circuits, the absorbed active power is smaller, with values between 62.6% and 10%.

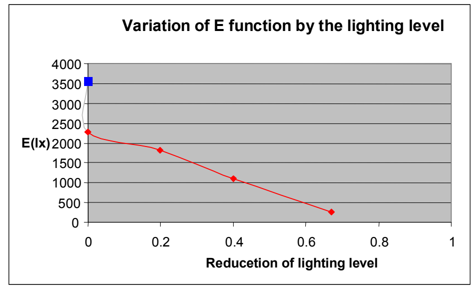

Fig. 18. The variation of the illuminance of lamp when ZDM 2500-DIMM Light cut of partially 0%, 20%, 40%, and 67% the lighting level.

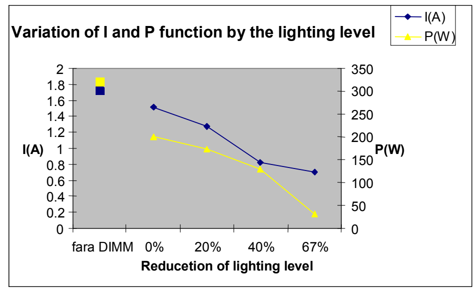

Fig. 19. The variation of current and absorbed active power when ZDM 2500-DIMM Light cut of partially 0%, 20%, 40%, and 67% the lighting level.

TABLE 1
VALUES OF ILLUMINANCE, CURRENT AND ACTIVE POWER FOR A LAMP WITH AND WITHOUT ZDM 2500-DIMM LIGHT

Lamp 250W	**without DIMM**	with DIMM	with DIMM	with DIMM	with DIMM
Reducing of lighting level	**0**	0%	20%	40%	67%
E(lx)	**3580**	2280	1820	1103	275
I(A)	**1.73**	1.51	1.27	0.82	0.7
P(W)	**320**	200	173	130	32

By use of the DIMM Light for controlling the street lighting system we increase the power efficiency and quality of lighting level, and in the same time the economic results are better.

It obtains an essential reduction of performance and energy costs (more than 30%), the device has a simple installation and programming, the amortization in less than 5 years.

III. Conclusions

At the Hanover fair in 2006 and 2007 and at the Frankfurt lighting fair in 2008 was noticed a tendency of introducing, as part of public lighting systems, of different equipments endowed with the latest microprocessors or programmable automats.

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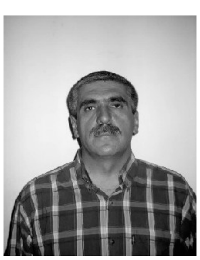
IV. BIOGRAPHIES



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His present research interest includes the sensor interface systems, analogue circuit design and signal processing, measurement theory and power quality. He has published more 600 technical papers and 60 books and has been involved in numerous government and industrial projects in area of measurements and instrumentation.

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