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Analysis of Energy Efficiency and Power Quality in Use of LEDs in Traffic Signaling System: The Case Study – Cuiabá – Mato Grosso

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***Abstract* — The main focus of this paper is to analyze the process of replacing the incandescent light bulbs with enhanced filament which have low electrical efficiency, by one of the most modern techniques of lighting, LED (light emitting diode), and the impacts on efficiency energy and power quality. Thus, in search of solutions aimed at energy efficiency and power quality, this article offers reviews and comparisons of measurements taken on the field during the replacement of incandescent bulbs by LEDs in all traffic and pedestrian lights in the city of Cuiabá /MT.**

Key words: Electrical efficiency, Demand, Incandescent Lamps, LED, Power Quality, Reduce.

I. Introduction

As provided by law n°.9991 of July 24, 2000, the concessionaires or permittees of distribution of electricity, hereinafter referred as Enterprises should apply a minimum percentage of net operating revenues in Energy Efficiency Programs - PEE, according to regulations of the National Electric Energy Agency - ANEEL.

The energy saved, measured in MWh/year and the reduction in peak demand, measured in kW, are the main quantitative indicators for energy efficiency projects. The values were gathered through diagnostic or pre-registered diagnosis. After the project conclusion, these values must be measured through practices appropriate of measurement and verification (M & V). The measurement campaigns on energy efficiency projects play a key role in the evaluation of real reductions in energy consumption achieved by the project and are the focus of the projects evaluations by ANEEL.

The proposed measurement campaigns should be underpinned on the International Protocol of Measurement Performance and Verification (PIMVP), which provides an overview of the best practices currently available to measure and verify the results of energy efficiency projects.

Taking into account that one cannot manage what is not measured, well-defined measurement methodology and verification can help to understand the real needs and priorities of Energy Efficiency Programs implemented in the country, leading to regulations more in line with the reality and contributing to the efficiency and effectiveness of the resources implementation and achievement of results [1], [2], [3].

The preparation of this measurement plan is critical for the appropriate determination of economic obtained and is also the basis for the subsequent results verification, both by those involved agents as well as the supervision of the Regulatory Agency.

When a company invests in energy efficiency, its executives generally want to know the amount of saved energy with the implementation of the efficiency program and the time of return of investments. Thus, the determination of energy savings requires precise measurements and methodologies that can be reproduced. More globally, the conservation of electricity ends up benefiting society in general, because its effects are felt in different ways. Promotes the reduction, postponement or even elimination of new investments for the construction of power plants and power grids. Decrease prices of products and services. Ensures the availability of electric energy supplied and service to new consumers. The benefits mentioned are even of greater importance in a state with the characteristics of the state of Mato Grosso, where there is a population growth and industrial heating with rates higher than the average of the other units of the federation. Thus, it is necessary to "increase" the availability of electricity, through the processes of energy efficiency, postponing the larger investments required for the construction of new generation sources and transmission lines, and also, contributing to the reduction of environmental problems caused by such developments. It is imperative, therefore, the study of methods to reduce the losses caused by inadequate equipment and/or misused [4].

In this context, this paper presents the results obtained from field measurements, in the process of replacing incandescent bulbs with low efficiency, used in traffic and pedestrian lights, by one of the most modern techniques of lighting, LED, and impacts of energy efficiency and power quality with both types of lighting.

II. ENERGY DIAGNOSIS

This energetic diagnosis aims to replace incandescent sets of low energy efficiency and reduced service life (2,000 hours), currently used in traffic lights signs in the city of

Cuiabá/MT, for sets that use LEDs (Light Emitting Diodes) of high energy efficiency and of long useful life (100,000 hours), thus, reducing the active power consumption and active power demand at peak hours of the electric system. The city of Cuiabá has approximately 550,000 inhabitants and 150,000 vehicles resulting in motorization rate of 3.66 people/vehicles. Your traffic signaling system has around 109 semaphore crossings, which were installed in about 1419 incandescent lights on main vehicular semaphores blocks, pedestrian and repeaters. Traffic control is performed by the Coordination of Traffic Signaling, located at Headquarters of the Municipal Urban Transport, the Road No 13 June 1289, Porto neighborhood. The Traffic Control Centre (TCC) of Cuiabá divides the city into 14 major sub areas, called "Area CTA and Area Non-CTA, and the CTA has international significance for Area Traffic Control. The focus groups, also called semaphore's blocks currently used for traffic control are divided into three categories, namely:

- Main vehicular semaphore's Block; that used incandescent lamps of 100 W;
- Vehicular repeater semaphore's Block, which used incandescent lamps of 100 W and
- Pedestrian semaphore's Block, which used incandescent lamps of 100 W.

Incandescent light bulbs are used by CCT with the filament reinforced type, which has an estimated life of 2000 hours, operating at voltage of 120V alternating current. The blocks vehicular semaphore's block have three lamps (focus) witch lens that can be red, yellow or green.

Pedestrians black have two focuses, with red and green lenses. The system implemented using incandescent bulbs, presents high energy consumption, and also frequent burning lamps, burdening maintenance costs and causing conditions of extreme risk of collisions and pedestrian accidents. Another major problem is the effect caused by direct sunlight and high heat generated by incandescent lamps, which cause deterioration over time of the lenses and color filters, hampering the understanding of the signaling traffic signal colors. Because of the prevalence of tropical weather, many roads in the city of Cuiabá had unsatisfactory security conditions, where vision was impaired drivers.

The actions of energy efficiency performed in 14 Sub-Areas in which were replaced around 1419 light bulbs installed in main vehicular semaphore's block, pedestrian and repeaters by LEDs were well distributed:

- 488 (five hundred and ten) LED modules, 200 mm, color green of 10W; on the replacement of 488 incandescent light bulbs of 100W;
- 361 (three hundred and sixty-one) LED modules, 200 mm, color yellow of 11W; on the replacement of 361 incandescent light bulbs of 100W;
- 352 (three hundred and fifty two) LED modules, 200 mm, color red of 8W; on the replacement of 352 incandescent light bulbs of 100W;
- 20 (twenty) LED modules, 300 mm, color green of 14W; on the replacement of 20 incandescent light bulbs of 100W;
- 20 (twenty) LED modules, 300 mm, color yellow of 13W; on the replacement of 20 incandescent light bulbs of 100W;
- 178 (one hundred and seventy-eight) LED modules, 300 mm, red color of 9W; on the replacement of 178 incandescent light bulbs of 100W.

In the installation of the new technology were replaced modules composed of socket, reflector, lamps and tinted lenses for new compounds of light elements circuit boards with LEDs and lenses. The goals of reducing energy consumption and active power demand, obtained by estimation, are shown in Table I.

TABLE I
ESTIMATION OF REDUCING ACTIVE ENERGY CONSUMPTION AND PEAK DEMAND FOR ACTIVE POWER

Final use	Saved Energy (MWh/ano)	Demand Withdrawal (kW)
Semaphore System	332,64	110

III. MEASUREMENTS PERFORMED IN FIELD

In order to validate the values to reduce energy consumption and peak demand for active power shown on Table I, obtained by estimated calculations, measurements were made at various traffic crossings that had lights of vehicles and pedestrians in the city of Cuiabá/MT, before and after the implementation of the energy efficiency project. Figures 1, 2, 3 and 4 illustrate measurements made, initially with incandescent lights on and subsequently, with LEDs lamps.

Fig. 1. Measurements performed on vehicle traffic lights with incandescent light bulbs before replacing.

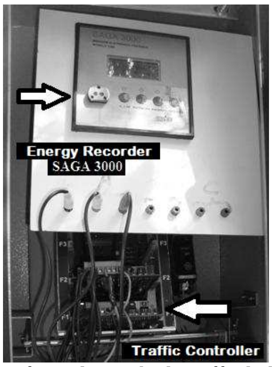

Fig. 2. Measurements performed on vehicle traffic lights after replacing with LEDS.

Fig. 3. Measurements made at pedestrian lights with incandescent lamps before replacing.

Fig. 4. Measurements made at pedestrian lights with LEDs after replacing.

The instrument used for measurements was the SAGA 3000, illustrated in Figures 1, 2, 3 and 4. The SAGA 3000 is an electronic register of electrical quantities in real-time, for single-phase electrical systems, two-phase and three-phase balanced or not, for portable use in distribution grids and installation in primaries booths or in several low voltage circuits. It has three input channels for voltage signals and three for current signals. From the input signals of voltage and current the device calculates and show on display values of phase voltages, line voltages, currents, power factor per phase and total active power, reactive and apparent power per phase and total, active power, reactive and apparent per phase and total, total active energy (provided or consumed), capacitive/inductive reactive total power, etc..

With the values obtained from the measurements were plotted graphs that demonstrate the behavior of demand of active power at the traffic lights in crossings located in the city of Cuiabá, before and after replacement of conventional lighting with the new technology. To illustrate, Figures 5, 6 and 7 illustrate the values obtained of demand for semaphores of 6, 12 and 16 lamps.

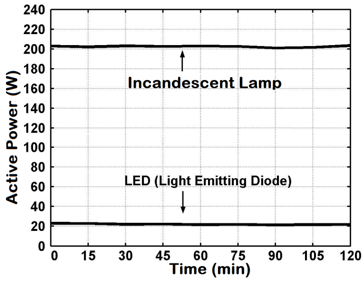

Fig. 5. Curve of active power demand for traffic lights of 6 lamps.

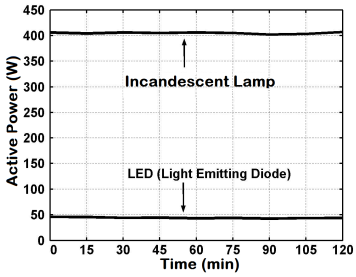

Fig. 6. Curve of active power demand for traffic lights of 12 lamps.

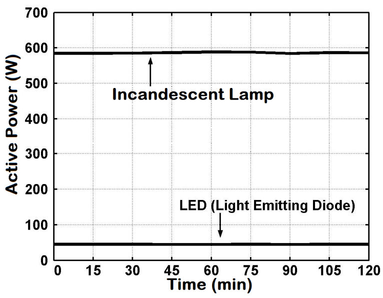

Fig. 7. Curve of active power demand for traffic lights of 16 lamps.

Using data from measurement campaigns made on the field, was drafted Table II that shows values of the active power demands and energy consumption before and after the process of energy efficiency at the traffics lights of vehicles and pedestrians in the city of Cuiabá / MT.

TABLE II
RELATIONSHIP OF CONSUMPTION OF BOTH TYPES OF LAMPS AT TRAFFIC LIGHTS IN THE CITY OF CUIABÁ.

Lights Consumption Cuiabá (Divided by nº Lamps)				
N° of Crosses	Total N° of Lamps		Demand (W)	Annual Consumption (MWh/year)
3	9	Inc	313,02	2,74
		LED	30,6	0, 268
9	54	Inc	1878,12	16,452
		LED	183,6	1,608
2	14	Inc	486,92	4,26
		LED	53,6	0, 469
2	16	Inc	556,48	4,87
		LED	54,4	0, 476
10	90	Inc	3130,2	27,42
		LED	306	2,68
7	70	Inc	2434,6	21,32
		LED	238	2,08
1	11	Inc	382,58	3,35
		LED	37,4	0, 327
30	360	Inc	12520,8	109,68
		LED	1224	10,72
2	26	Inc	905,8	7,93
		LED	88,4	0, 774
10	140	Inc	4869	42,65
		LED	476	4,17
5	75	Inc	2608,5	22,85
		LED	255	2, 233
5	80	Inc	2872,4	25,16
		LED	272	2,38
1	17	Inc	591,26	5, 179
		LED	57,8	0, 506
3	54	Inc	1878,12	16,45
		LED	183,6	1, 608
4	80	Inc	2782,4	24,37
		LED	272	2,38
1	21	Inc	730,38	6,39
		LED	71,4	0, 625
2	46	Inc	1599,88	14,01
		LED	156,4	1,37
4	96	Inc	3338,88	29,24
		LED	326,4	2,86
1	25	Inc	869,5	7,61
		LED	85,0	0, 744
1	27	Inc	939,06	8,22
		LED	91,8	0, 804
1	29	Inc	1008,62	8,83
		LED	98,6	0, 863
1	31	Inc	1078,18	9,44
		LED	105,4	0, 923
1	48	Inc	1669,44	14,62
		LED	163,2	1, 429
TOTAL	1419	Inc	49404,14	433,041
		LED	4830,6	42,297

Using the values reported in Table II were calculated the reduction of active demand power and reduction of electricity consumption in kW and annual MWh/year, respectively, shown in Tables III and IV.

TABLE III
RELATIONSHIP OF DIFFERENCE OF DEMAND BETWEEN THE TECHNOLOGY TYPES.

	Total Demand (kW)	**Avoided Demand in Ponta Time (kW)**
LED	4,830	44,573
Incandescent Light bulb	49,404	

TABLE IV
RELATIONSHIP OF DIFFERENCE BETWEEN CONSUMPTION OF TYPES OF LAMPS.

	Total Consumption (MWh/YEAR)	**Total Consumption Avoided (MWh/YEAR)**
LED	42,297	390,744
Incandescent Light bulb	432,041	

Thus, analyzing the data obtained in measurements before and after the replacement of lamps shown in Tables III and IV, can be observed that was a significant reduction in the values of consumption of active energy and on the peak active power demand. The active energy and total active power required by the system LEDs stayed around 42.29 MWh/year and 4.83 kW respectively, representing approximately 10% of active energy and power demand for the technology represented by the conventional incandescent requesting the system an energy of 432.04 MWh/year and a total power of 49.4 kW. The results obtained in measurement campaigns in relation to reductions in energy consumption and active power demand active diverged from the values obtained by the estimation of load installed from the lamps, thus demonstrating the importance of a plan for measuring and verifying performance on the field to obtain the real values of the energy savings and demand of active power. The results also demonstrated great benefits of LED lamp technology for energy efficiency, with total economic feasibility.

IV. MEASUREMENT OF VOLTAGE AND CURRENT IN INCANDESCENT LAMPS AND LEDS

To analyze the impact of replacing incandescent lamps by LEDs on power quality tests and comparisons were performed in the laboratory with the two types of technology.

Initially were monitored in laboratory electrical currents required by the bus phase of the new technology LED bulbs in order to verify the quality of electricity. The lamps used in the assay, were the same used in the substitution process in this design for energy efficiency, lenses possessed hard coating and uniform, contained transient suppressor incorporated for protection, an operating range of -40 ° C to 74 ° C, power factor greater than 0.9 and Total Harmonic Distortion (THD) less than 20%, whose technical characteristics were supplied by *Dialight*, its manufacturer. The LEDS being tested contained different sizes of 8"(200mm) and 12" (300mm) and colors green (14W), red (6W) and Yellow (12W).

Figure 8 depicts the experimental measurement scheme used to check the characteristics of the electrical current requested bus by this new technology.

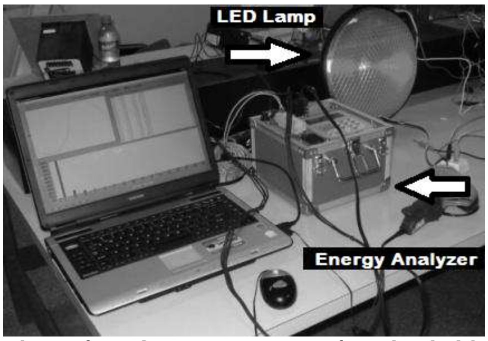

Fig. 8. Scheme of LED lamp measurement performed in the laboratory.

After the measurements of LEDs, was made the monitoring of incandescent light bulb of reinforced filament. The measurement scheme is depicted in Figure 9. The Incandescent lamps used in the tests, were the same that were replaced in this energy efficiency project, had nominal power of 100W and were constituted by a doubly coiled tungsten filament, so the name of IFR (Incandescent Filament Reinforced). They have such an enhancement to obtain a longer life, and had a greater resistance to shock and vibration, which are subject to the semaphore.

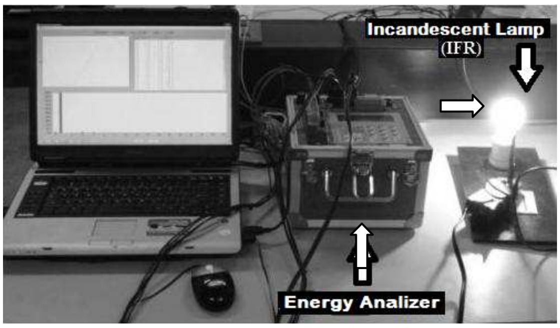

Fig.9. Measurement Scheme of Incandescent Lamp (IFR Incandescent Filament-Reinforced).

After the laboratory test, it was found that the three colors of LEDs showed the same characteristics in relation to the current request bus phase. Thus, for a simplified analysis, we compared the results of only red LED lamp with the incandescent lamp, whose waveforms are shown in Figures 10, 11 and 12.

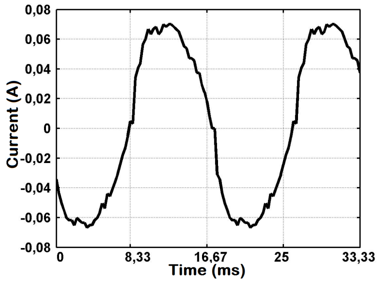

Fig.10. Current waveform of the small lamp of red LED.

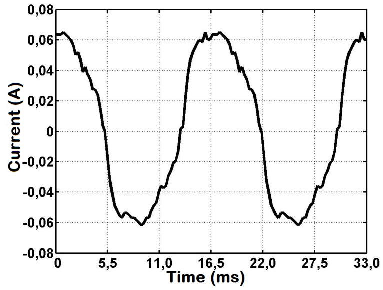

Fig.11. Current waveform of the big lamp of red LED.

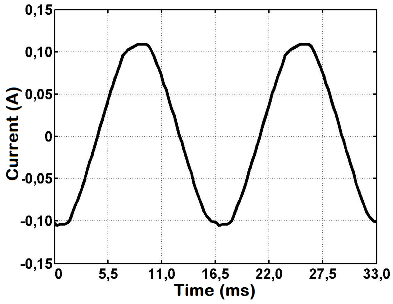

Fig.12. Current waveform of incandescent lamp.

By inspection of Figures 10, 11 and 12, it is evident that the signal current required by the LED lamp bus has a small harmonic distortion relative to the current signal of the incandescent lamp, which can best be seen in harmonic spectra illustrated in Figures 13 14 and 15.

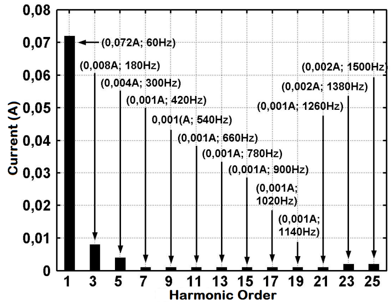

Fig.13. Harmonic spectrum of small red LED lamp.

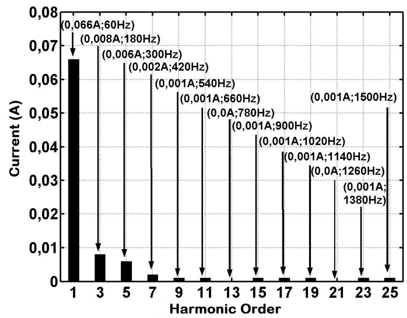

Fig.14. Harmonic spectrum of big red LED lamp.

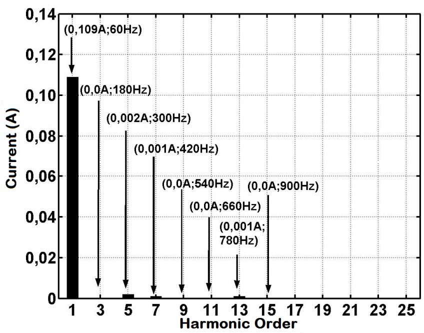

Fig.15. Harmonic spectrum of the incandescent lamp of filament reinforced.

By the graphs in Figures 13, 14 and 15 shows that the difference between the characteristic of the LED lamps used in the assay relative to incandescent light bulbs, when it comes to electric energy quality, is pretty small because the LED injected low amount of distortion harmonics in the system, causing the waveform of the current to maintain its characteristic having a sinusoidal current value of THD around 14.43% for the LEDs 12 "and 16.2% for the LEDs 8" as shown in Tables V and VI, and these values were very close to the technical data provided by the manufacturer.

TABLE V
INDIVIDUAL AND TOTAL HARMONIC DISTORTION FOR LED OF 12”

LED 12” Lamp			
Harmonic Order		Harmonic Distortion	
		DIT (%)	DTT (%)
Green (14W)	3	12,87	14,47
	5	5,71	
Yellow (12W)	3	11,11	12,47
	5	4,08	
Red(6W)	3	12,55	16,34
	5	7,62	

TABLE VI

INDIVIDUAL AND TOTAL HARMONIC DISTORTION FOR LED OF 8”

Lamp LED 8”			
Harmonic Order		Harmonic Distortion	
		DIT (%)	DTT (%)
Green (7W)	3	14,03	17,15
	5	8,62	
Yellow (7W)	3	14,71	17,54
	5	7,86	
Red (6W)	3	11,10	13,95
	5	5,97	

Analyzing the results obtained it was found that current technologies of LEDs already has technical resources that reduce distoções harmonics introduced into the system, not providing significant losses in power quality and considerably increasing the gain in energy efficiency of the system.

V. CONCLUSION

This paper presents the results obtained through the implementation of an energy efficiency project in the systems of vehicle and pedestrian traffic lights in the city of Cuiabá/MT, which were replaced reinforced filament incandescent light bulbs with LEDs lamps and analyzes process of the impacts on consumption active power, active power demand, improving the functioning of the system and the quality of electricity.

The results achieved through campaigns of field measurements show that with respect to active power consumption and demand of active power the gains were quite significant with the use of the new technology of LEDs, while providing high reliability, better conditions traffic safety, lower maintenance costs and increased visibility in adverse situations. Using this new technology, such as shows quite reduce of active power consumption, it also allows power systems of traffics lights through batteries when there are technical problems in energy supply by the utility distribution network.

As for power quality, the results obtained from experimental tests carried out in laboratories in various LED lamps, shows a low harmonic spectrum for currents required by this new technology, representing a small percentage of interference in the quantities present in the electrical system.

Thus, LED lamps used in this design efficiency despite using components with nonlinear characteristics, showed a good technology for minimizing harmonic distortions, and the knowledge of these disturbances present in the electrical systems requires special attention and must be taken preventive measures, thereby ensuring safe projects, avoiding risky situations for users and equipment.

Therefore, the technology of using LEDs presents one of the most promising options for the future of lighting, including already existing studies and experiences for its application also in street and decorative lighting, because of their small size, high reliability, low losses and high useful life.

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