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Performance and measurement of power quality due to harmonics from street lighting networks

Manzano E.R.[1], Carlorosi M.[2],Tapia Garzón M.[3]

[1] Depto. Luminotecnia Luz y Visión, FaCET, Universidad Nacional de Tucumán, Av. Independencia 1800, 4000, Tucumán, Argentina, Phone/fax: +543814361936 **emanzano@herrera.unt.edu.ar**,

[2] Depto. Ingeniería Eléctrica, FaCET, Universidad Nacional de Tucumán, Av. Independencia 1800, 4000, Tucumán, Argentina. **vmcarlorosi@herrera.unt.edu.ar**

[3] Electrocivil S.A., San Miguel de Tucumán, Argentina. **electrocivil@arnet.com.ar**

Abstract. The municipality government of San Miguel de Tucumán city in Argentina is interested in applying energy saving policies to street lighting facilities. In this frame, devices like astronomical programmable clocks and electronic control gear (ballast) will be used to replace photocells and inductive control gear. Also luminaries in use could be replaced by more efficient ones. A technical-economical evaluation was necessary and the technical aspect was request to the Lighting Department of Tucumán University. The performance of the devices and the power quality impact in the lighting networks evaluation was also necessary to evaluate.

The study carried out involved outdoor and laboratory test. During 1,5 month six lighting networks with 273 semi-cutoff luminaires were tested. Network selected belong to residential areas which represent more than 60% of total city lighting facilities (26.000 luminaires). In addition laboratory test were conducted with a sample of inductive (in use) and electronic control gear, for high pressure sodium discharge lamps (HPS) 150W. Performance varying voltage input for aged was analyze.

Some results from tests points out that:

- The use of programmable astronomical clocks instead of photocell produces 11% of energy saving because of actual time on and off schedule set.
- Electronic control gear instead of inductive control gear produces 28% energy saving.
- Luminaire replacement of current HPS 150W by HPS 100W with Electronic control gear and photocell control produces 43% in energy saving.

Outdoor test results from measurement of electrical input parameters and harmonics of existing inductive control gear in street lighting, indicate that: while THD V voltage is about 2,8%, THD A current can be reduced from 38% to 6,5% even when electronic control gear is set to the lower output power step (70% of power output and 60% of initial average illuminance value).

The results obtained will be used as arguments for the widespread replacement in the city which would involve considerable investment and a new experience in the region.

Key words

Energy saving, lighting networks, power quality, harmonics.

1. Introduction

The electrical power supply quality in Argentina is regulated by ENRE where standards from IEC were used as reference [1,2,3]. It is also the national organization responsible of ensuring the energy supply quality. Quality controls originally where applied to energy companies mainly to assure voltage standard levels and continuity supply on time. On the other hand, consumers are demand to have a Power factor (FP) with inductive load above 0,9. When the consumers has nonlinear loads, compensation capacitance for the fundamental component is insufficient and harmonics filters are required.

Urban lighting networks and lighting installations in Argentina are municipality property and responsibility. Excepting Buenos Aires city all other big cities have independent networks from other users and are directly connected to a three-phase power transformer with join star connection and with ground neutral (TT, air line or underground line). Lighting load power is usually compose by high pressure sodium (HPS) 70% and high pressure mercury (HPM), 25% with inductive control gear with capacitor power factor correction. These type of loads produce harmonics on lighting networks depending on control gear quality and lamp age.

Since the energy crisis experimented in Argentina, efficiency programs like PRONURE for municipalities have emerged as a financial support sources for recycling inefficient facilities. The use of devices like:

- electronic control gear for high pressure discharge lamps with voltage stabilization output and flux output regulation by reduction output power,
- astronomical programmable clocks as switching on and off devices, and
- more efficient luminaries,

are attractive possibilities for energy efficiency and savings. Recycling of standard inductive control gear by electronic control gear, photocell by astronomical clocks and new luminaries can be done with these financial programs.

Independent networks with non linear concentrated load can introduce distortions in the energy wave shape. Standard inductive control gear and electronic control gear without filters can be a source of distortions. A technical and economical evaluation of convenience needs tests of performance and impact over lighting network. The technical aspects were request to the Lighting Department of Tucumán University where outdoor test and laboratory test done are described in the paper.

2. Outdoor test

In order to evaluate energy saving and electric power quality, six lighting net´s with 273 luminaires were selected from streets and avenues of residential areas. At the beginning of each network, at the control and switching board, electric measurements where monitored during 1,5 month. For each network four different set-ups were arrange in order to measure the energy consumed while using the different devices under test. The test time period was the same in all cases and environmental and electrical conditions were the actual situations expected.
The set-ups arranged for each network were:

a) Lighting facilities unmodified, with existing luminaires, provided with HPS 150W lamps, inductive control gear with individual power factor compensation and switched on-off by a single photocell located at the switching board.

b) Lighting facilities modified, with the existing luminaires unmodified, but switched on-off by a single programmable astronomical clock located at the switching board.

c) Lighting facilities modified, with luminaires modified provided with HPS 150W lamps, electronic control gear from a local manufacture and switched on-off by a programmable astronomical clocks.

d) Lighting facilities modified, with luminaires modified provided with HPS 100W lamps, electronic control gear and switched on-off by a programmable astronomical clocks.

In all set-ups, average and uniformity of illuminance were measured in order to guarantee levels requirements recommended by Argentine national standard [4].

To measure the active energy consumption for all set-ups and all the lighting networks, readings from the energy meters were done at the evening before street lights switching on and at the morning after, after switching off. These routine was repeated night by night. It was also record the switching on and off times, counting of lamps outages during night time and networks that during daytime could be running on. In table I, as an example, the energy records for the switching board 1 connected to network 1 with set-up "***a***" are indicated. Estimations of the kWh consumed by lamps (number and power al already known) according to the burning time record are done in order to estimate looses and to have an indicator to check results consistence. Estimations of the kWh consumed by lamps (number and power al already known) according to the burning time record are done in order to estimate looses and to have an indicator to check results consistence.

TABLE I: Energy records for the switching board 1 connected to network 1 with set-up "***a***"

Switching board	**1**	Energy meter N°	2232683					
Address	**ESTEBAN DE ECHEVERRIA corner with SAN JUAN**							
Lighting facilities								
Lantern	STRAND JC TUC 250							
Lamp	HPS 150W							
Control gear	**inductive with PF correction**							
Switching device	**Photocell**							
Luminaires	30							
Arrangement	One side row, metal columns 7m high, 3m bracket							
Energy measurement set-up A								
Record Number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Switch on		28/08 18:50	29/08 18:45	30/08 18:50	31/08 18:50	01/09 18:50	02/09 18:55	03/09 18:55
Switch off			29/08 7:30	30/08 7:30	31/08 7:30	01/09 7:30	02/09 7:30	03/09 7:25
Period running on			12:40	12:45	12:40	12:40	12:40	12:30
Meter record kWh	**42123.4**	**42180.0**	**42237.5**	**42293.5**	**42349.5**	**42405.0**	**42460.5**	**42516.5**
Lamps outages	1	1	1	1	1	1	1	1
Lamps daytime running	0	0	0	0	0	0	0	0
Estimated kWh		56.6	57.5	56	56	55.5	55.5	56
W/lamp estimated		154.1	155.5	152.5	152.5	151.1	153.1	154.5
Losses estimated		3%	4%	2%	2%	1%	2%	3%

Results from active energy measurements points out that:

- The use of programmable astronomical clocks instead of photocells produces 11% of energy saving because of better adjustment to actual on and off schedule time set.
- The use of electronic control gear instead of inductive control gear produces 28% energy saving.
- Luminaire replacement of current HPS 150W by a more efficient Luminaire with HPS 100W with electronic control gear and control by programmable astronomical clocks produces 43% in energy saving.

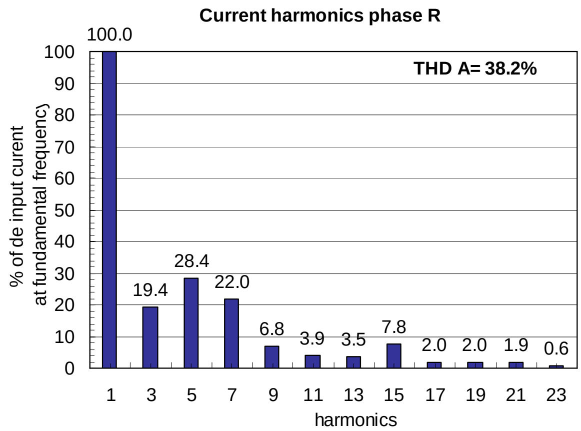

Fig. 1: Current harmonics from inductive control gear of street lighting facilities.

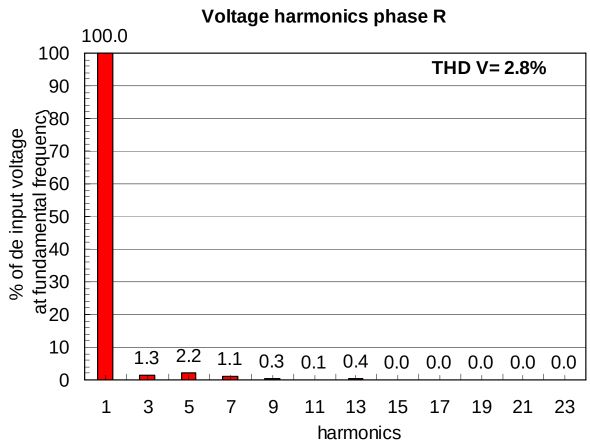

Fig. 2: Voltage harmonics from inductive control gear of street lighting facilities.

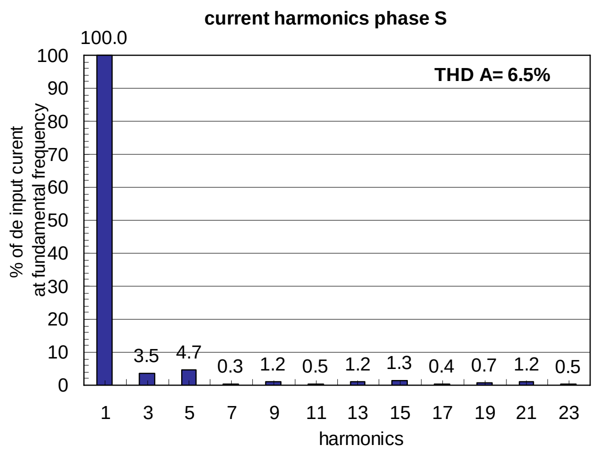

Fig. 3: Current harmonics from inductive control gear of street lighting facilities.

Power quality electric parameters and harmonics were measured with portable Class B equipment [5] for set-up´s "***b***" and "***c***". As a result of replacement of inductive control gear by electronic control gear, harmonics measurements [5] of THD current shows reductions from 38% to 6,5% even at the lowest power step reduction (70% of active power output and 60% of initial average illuminance value). Voltage THD remains about 2,8% in all cases.

3. Laboratory test

Ten samples, five of inductive (capacitive compensated to PF=0,9) and five of electronic control gear with their lamps (HPS 150W) were taken from the lighting facilities after the outdoor test and individually tested in laboratory. Two type of tests were done:

I) under controlled electrical conditions with AC supply THD V voltage lees than 3% as outdoor test

II) under controlled electrical conditions with AC supply source THD V voltage less or equal than 0,1% and harmonics in agreement with IEC 61000-3-2 [7].

The equipment used for electric parameters and harmonics measure was Class A [6] .

Each of these tests were done setting the input voltage to five different levels: 80%, 90%, 100% , 110%, 115% (last value was approximate in test II) of the rated voltage (called U_N) from the samples. For each level and after lamp lumen steady state was reached, electric parameters and lamp lumen output were measured. The lamps tested were those used with the luminaires samples and lumen output was measured in a integrating sphere using a photometer sensor with V(λ) filter [8]. As the electronic control gear has three power steps of lamp power output: 100% during 1h, 83% reduction after 1hr and 70% after 2hs of non stop lamp burning, the test II was repeated for the last two power steps.

From test I, performance results with inductive control gear for input voltage at 100% U_N level are indicated:

- voltage and current waveform in figure 4
- current harmonics components in figure 5 and
- input electric parameters (voltage, current, active power, power factor PF) and lamp outputs (lumen output Lm and efficacy Lm/Watts) for 5 voltage levels as a ratio of the measured value to the value at U_N, are indicated in figure 6.

As can be appreciated current waveform suffers an important distortion similar as in the outdoor test because of intrinsic device characteristics and because of source supply voltage harmonic components. The THD A current average value is 34% at 100% U_N level. This test agrees with the results obtained from outdoor test when input voltage was higher or lower than U_N as can be appreciated from figure 6.

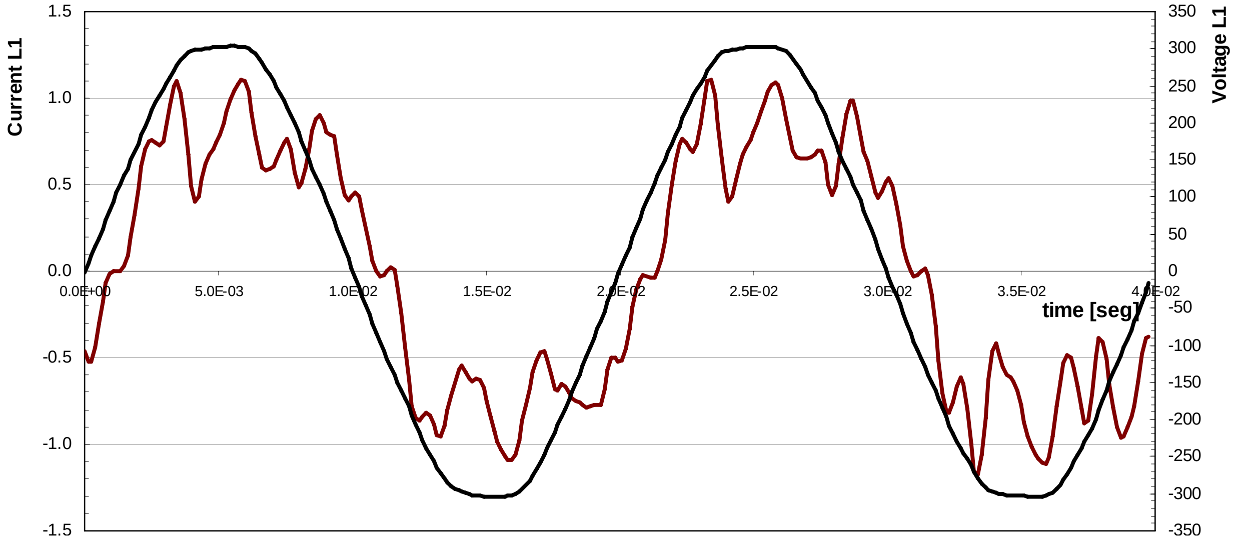

Fig. 4: Voltage and current waveforms from HPS 150W with inductive gear control and input voltage set to U_N using AC source THD V ≤ 3%.

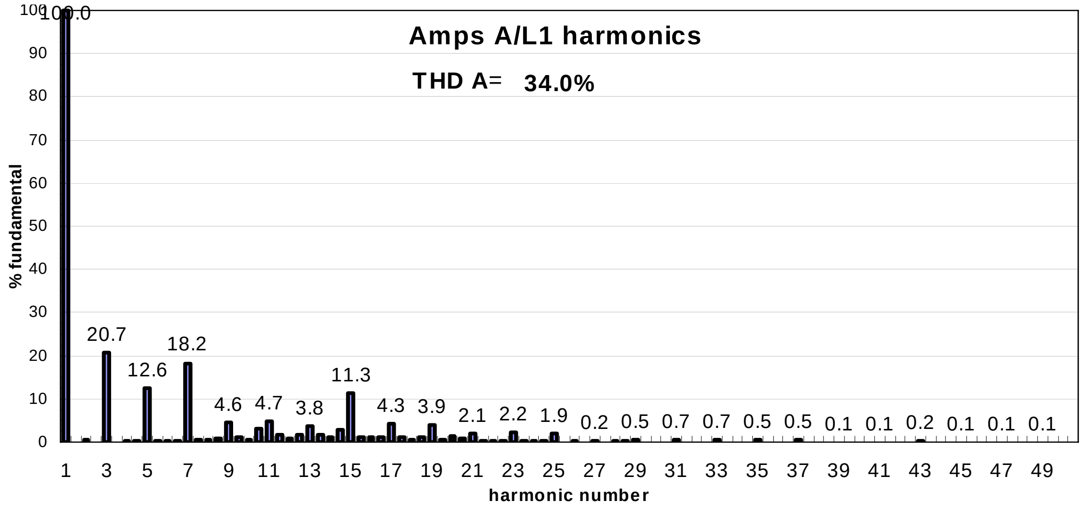

Fig. 5: Current harmonics from HPS 150W with inductive control gear at voltage U_N level and THD V ≤3%

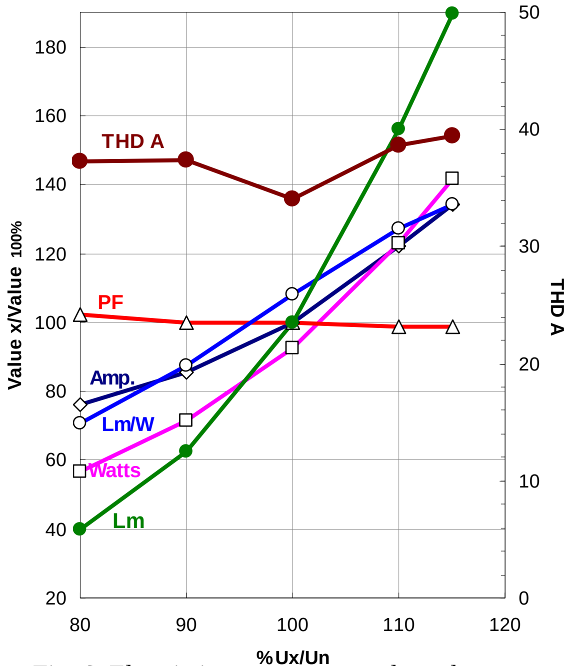

Fig. 6: Electric input parameters, lamp lumen output and efficacy, for inductive control gear at 5 voltage levels and supply THD V ≤3%.

In a similar way, from test I, performance results with electronic control gear are indicated:

- voltage and current waveform in figure 7 for input voltage at 100% U_N level
- input electric parameters (voltage, current, active power, power factor PF) and lamp outputs (lumen output Lm and efficacy Lm/Watts) for 5 voltage levels as a ratio of the measured value to the value at U_N, are indicated in figure 8.

Current waveform this time does not suffers significant distortion as in the outdoor. The worst THD A current average value is 6,6% at 115% U_N level. When input voltage rises 230V lumen output and efficacy are nearly the same for inductive and electronic control gear.

Under test II, performance results with inductive control gear are indicated:

- voltage and current waveform in figure 9 for input voltage at 112% U_N level
- current harmonics components in figure 10, for input voltage at 112% U_N level, and
- input electric parameters and lamp outputs for 5 voltage levels, in figure 11.

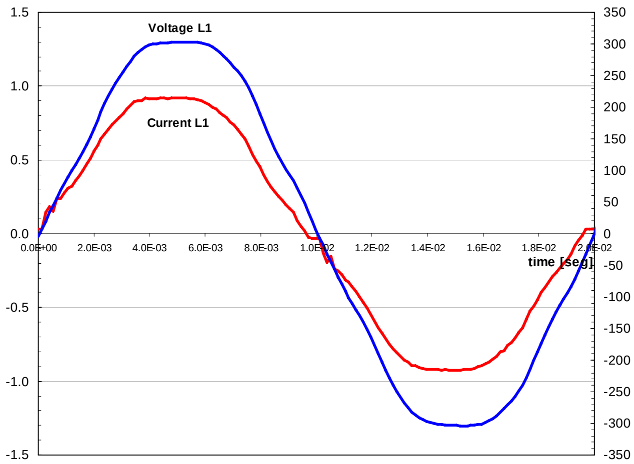

Fig. 7: Voltage and current waveforms from HPS 150W with electronic control gear at input voltage 100% of U_N level and supply source THD V ≤ 3%

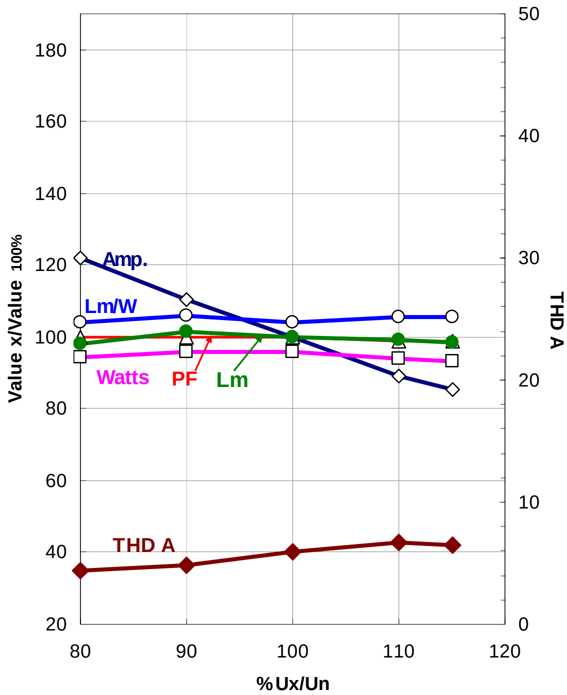

Fig. 8: Electric input parameters, lamp lumen output and efficacy, for electronic control gear at 5 voltage levels and supply source THD V ≤3%

As can be appreciated current waveform suffers a distortion because of intrinsic device characteristics but in this test not because of source supply voltage harmonic components. At 112% U_N level the THD A current average value is 28,4% and harmonics are the highest, except for the 3rd harmonic (PF=0,9), all others are under the limit value according to IEC 61000-3-2 Class C. However IEC limits are for voltage 100% U_N level, nevertheless voltage in street lighting networks are usually above U_N after 22:00h and could reach easily 115% U_N.

With electronic control gear performance results in figure 12 are indicated for input electric parameters and lamp outputs for 5 voltage levels when output power step is set to 100%. Current waveform (not indicated) suffer no distortion at all and at 112% U_N level the THD A current average value is 5,1%. Even in the worst case: lowest

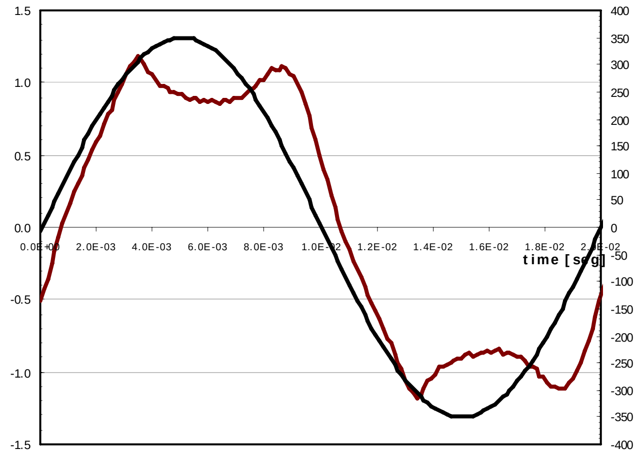

Fig. 9: Voltage and current waveforms from HPS 150W with inductive gear control and input voltage set to 112% of U_N using supply source THD V ≤ 0,1%.

output power step and highest input voltage THD A is 6,5%.

4. Conclusions

The paper describes a study of energy saving testing tree devices: electronic control gears, astronomical clocks and more efficient luminaires. As any energy saving policy should maintain power quality, this last was tested in relation to harmonics. Outdoor test and laboratory test were carried on studding the device performance and comparisons were made with the devices in use that are willing to be replaced. The energy saving obtained from the use of these devices is significant and the harmonics reductions are significant as well, moreover if is consider that actual voltage in lighting networks is usually higher than the rated device value after 22:00. Remains to weigh energy saving cost against economical investment. In this case actual energy values cost needs to be consider without government subsidise in order to weight correctly each factor.

From outdoor and laboratory tests, two main advantages for the electronic control gear are concluded:

- When input voltage is above the nominal value, fact that is usually found after evening in residential areas, input power does not increase, consequently energy consumption does not increase as well. This fact is a disadvantage with inductive control gear.
- Harmonics with the make of electronic control gear tested were not a problem as it was firstly supposed, moreover inductive control gear could be a problem that needs to be evaluated in terms of additional power looses and power quality in electric lines and transformers.

Further studies will be aim to evaluate electric power quality in residential houses with compact fluorescent lamps and industrial installations.

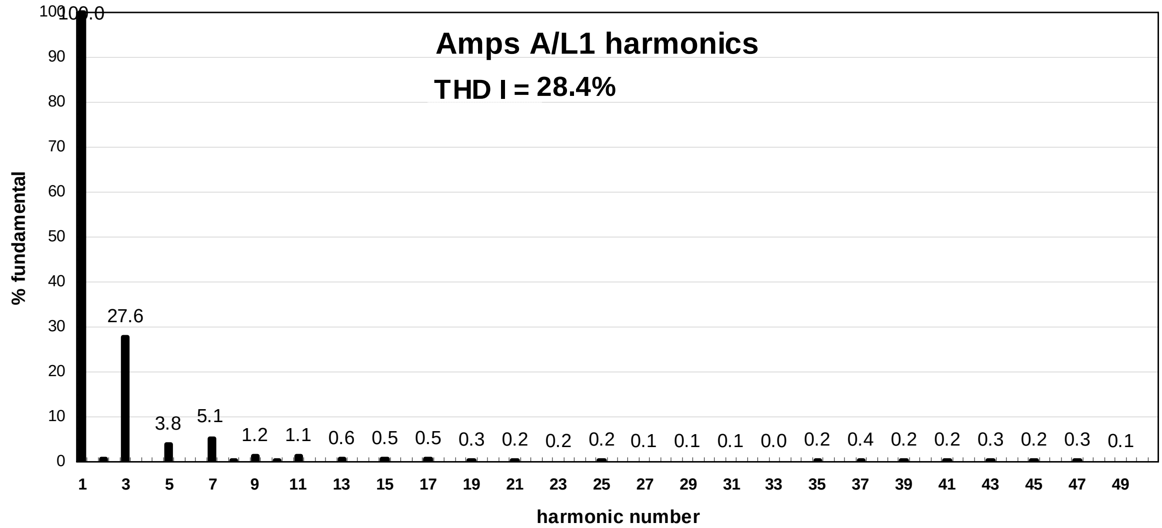

Fig. 10: Voltage and current waveforms from HPS 150W with inductive gear control and input voltage set to 112% of U_N using supply source THD V ≤ 0,1%.

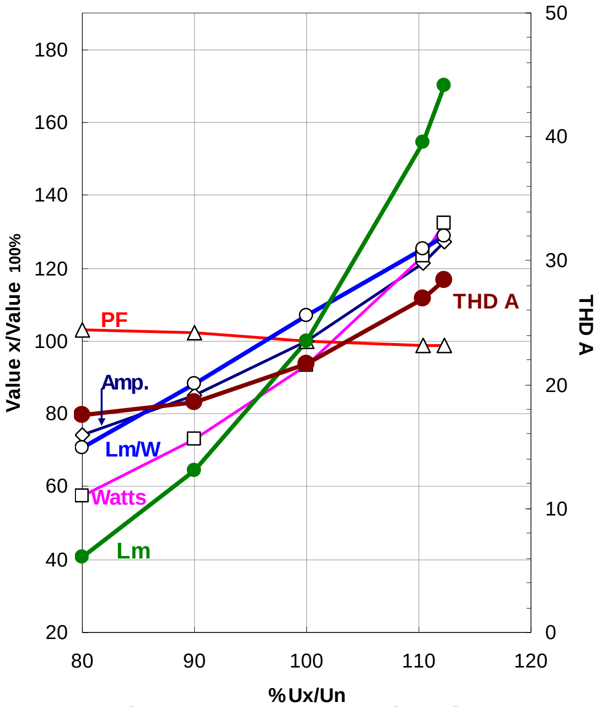

Fig. 11: Electric input parameters, lamp lumen output and efficacy, for inductive control gear at 5 voltage levels and supply source THD V ≤1%

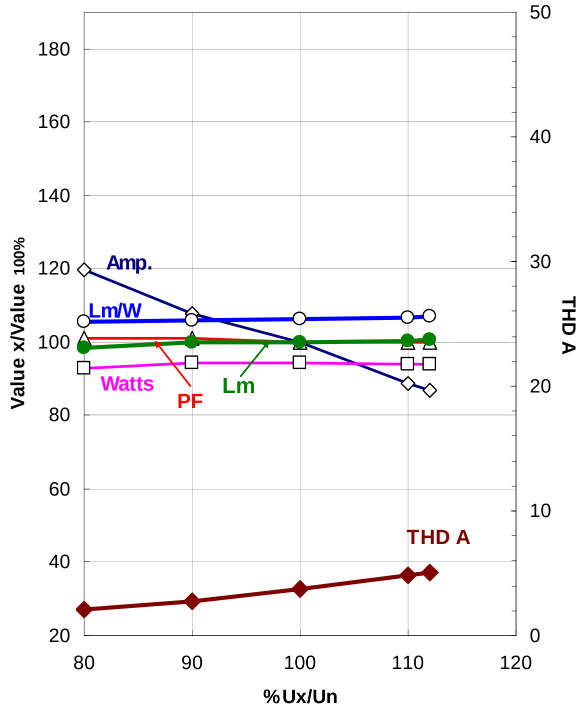

Fig. 12: Electric input parameters, lamp lumen output and efficacy, for electronic control gear at 5 voltage levels and supply source THD V ≤1%

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