A Real Life Light Flicker Case-Study with LED Lamps

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Abstract— **This paper shows the results of a real life case-study which demonstrates also that there is a need for new Flickermeters able to cope with new lamps' technologies different from standard incandescent, in particular with LED lamps. The case-study refers to a LED lamp that was visibly flickering even if measurements taken onsite with a standard PQ instrument reported neither THD nor Pst issues. Numerical tests using a new Flickermeter proposed by some of the authors and laboratory experiments by means of an objective light Flickermeter have demonstrated the reasons of this singular case.**

Index Terms— **Flickermeters, LED lamps, Light Flicker, Power Quality.**

I. INTRODUCTION

It is well known that IEC compliant Flickermeters (FM) are capable of measuring fast voltage fluctuations in terms of Pst that is a good indicator of the amount of Light Flicker (LF) produced by a standard incandescent lamp which is sensible to RMS time variations [1]. Recent literature have demonstrated the sensitivity of the new lamps (CFL and LED) in terms of Light Flicker to interharmonic frequencies lower and higher than the double of the system frequency even in absence of harmonics [2]-[13]. Moreover, the CIGRE WG C4.111 [14] has recently reviewed additional available research regarding lamp sensitivities to make recommendations for possible future ways to manage voltage fluctuations. Finally, the IEEE Standard P1453 "Recommended Practice for the Analysis of Fluctuating Installations on Power Systems [15], contains the Annex A (informative) titled "Impact of interharmonics on flicker related to non-incandescent lamps".

In the relevant literature, recent examples of new FM are reported in [16]-[22]. In particular, [20]-[22] remove the demodulator and modify weighting filters of the IEC FM in order to evaluate LF directly from fluctuations of lamp light flux evaluating temporal flicker severity of any lamp at any voltage condition very accurately but are not practical, since the measurement methodology needs laboratory tests with real lamp placed in opportune test chambers.

In [22] a tunable flickermeter based on a generalized lamp model able to account for lamp technologies different from incandescent is presented. The generalized lamp model is based on the use of only three input parameters derived from the type of the lamp and its electrical circuit that have to be selected to emulate the behavior of a specific lamp. Starting from the measurement of the instantaneous input line voltages (L1, L2, L3) as for the classical IEC FM, the Pst and Plt outputs can obtained.

This paper shows the results of a real life case-study which demonstrate that there is a need for new Flickermeters able to cope with new lamps' technologies different from standard incandescent, in particular with respect to LED lamps. The case-study refer to a LED lamp that was visible flickering even if measurements taken onsite with a standard PQ instrument reported neither THD nor Pst issues. The flickering lamp was substituted with another model and the Light Flicker problem fixed. In this paper, after a preliminary description of the case-study, measured line voltage waveforms are analysed in order to deeply characterize their spectral content. Finally, numerical tests using a new Flickermeter proposed by some of the authors and laboratory experiments by means of an objective light Flickermeter have demonstrated the reasons of this singular case.

II. CASE-STUDY DESCRIPTION

A. Circuit Description

A chicken house served by an electric utility complained about flickering lights inside their facilities after recently changing over to LED lights as a means to reduce energy cost.

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The facilities in question consisted of a total of 12 chicken houses. Each house is approximately 500ft long by 50ft wide and contains 100 LED lights (120V) per house of which, only 70 are on a dimmer system. There are also outside LED area lights around the chicken houses that are not on a dimmer system.

Figure 1. Photoorto map of the houses

Electrically, the site is slightly over 13 miles from the substation and connected to a 23kV circuit feeding three separate single phase 100kVA transformers providing 60Hz 120/240V service. Each 100kVA transformer serves 4 houses. The service conductor going to each of the four chicken houses and circuit breaker panel is 2/0 Aluminum Triplex. The 70 dimmable lights are served from a LED dimmer system controller which is in turn fed from the panel. The remaining 30 lights are straight off a breaker from the panel. Upon inspection of the facility visible flicker phenomenon was present in all LED lights served from the 100 kVA transformer.

B. *Measurement Instrument and waveforms measured*

A power quality recorder was connected to the service conductors at the transformer to measure the variations in voltage, current, flicker, power, and to capture waveforms of the phenomenon. Originally the service transformer location was chosen due to the fact that all four chicken houses were seeing the flicker effects however when the RMS data for the voltage and current were graphed there appeared to be no fluctuations in either that would account for the visual fluctuation in the light. Fig. 2 shows an RMS Voltage Plot recorded at the site with a nominal of 120 V phase to neutral.

Flicker Values never went above 0.32 Pst while the phenomenon was occurring. Fig. 3 shows a plot of the Pst values obtained at the transformer. The waveforms of the voltage and current however showed a repetitive transient that was occurring at the peak of the voltage waveforms due to a high speed current draw of the LEDs on the dimmer circuit. A waveform of the voltage and current is shown in Fig.4. This high speed current draw was found to be the root cause of the flickering LED lights however, why this phenomenon caused the LED lights to flicker and why the existing flicker indices model did not align with the observed phenomenon needed further investigation. The problem was fixed substituting the original LED lights (LED_OLD) with another model from another manufacturer (LED_NEW).

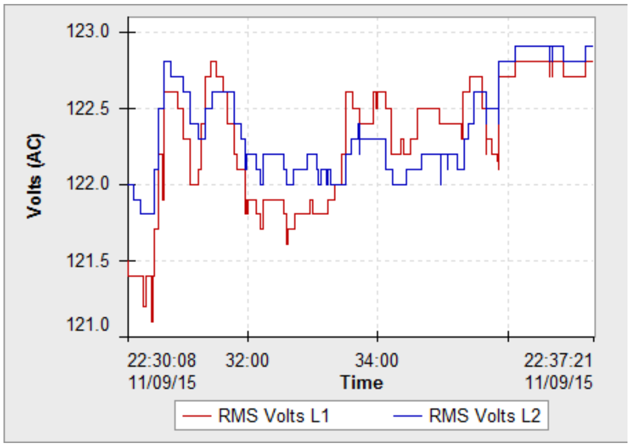


Figure 2. Voltage RMS versus the time measured on site.

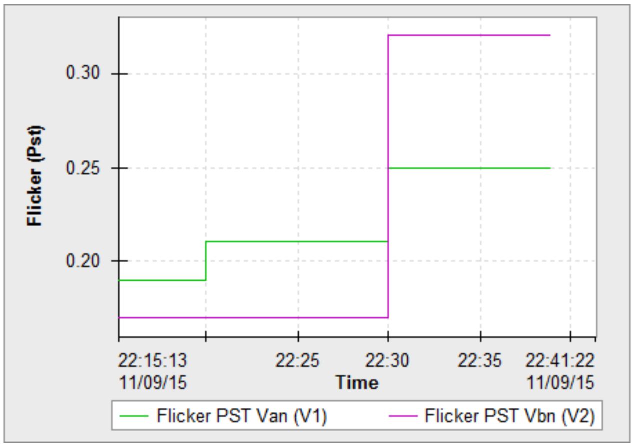


Figure 3. Flicker severity index, P_{st}, versus the time measured on site.

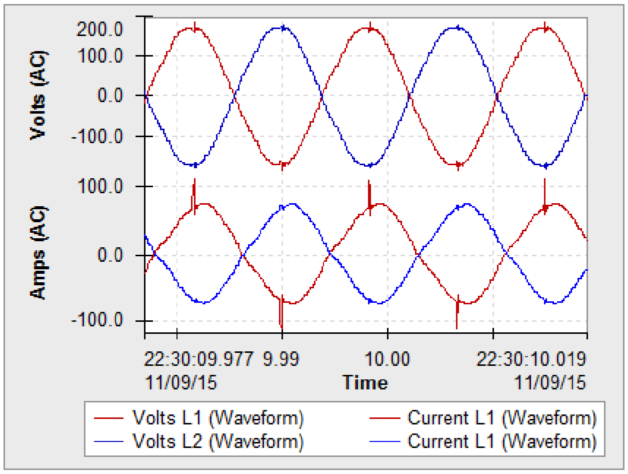


Figure 4. Time waveforms measured on site: line to neutral voltages; line currents.

III. DISTORTION ANALYSYS

This section reports a very accurate spectral analysis of the line voltage measured on the field in order to the origin of the phenomenon and its simple analytical explanation using the theory of inter-modulation.

A. Distrotion analysis of experimental data

Fig. 5 shows the zoom of the absolute value of the line voltage versus the time where it is evident the phenomenon of the peak modulation that seems to be the cause of the flickering of the LED lamps.

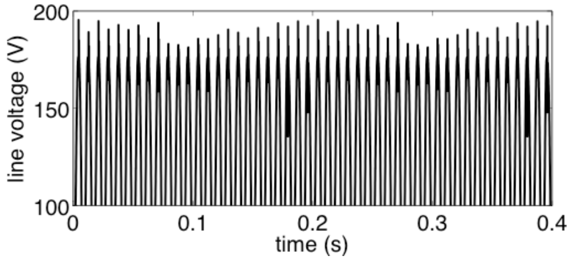
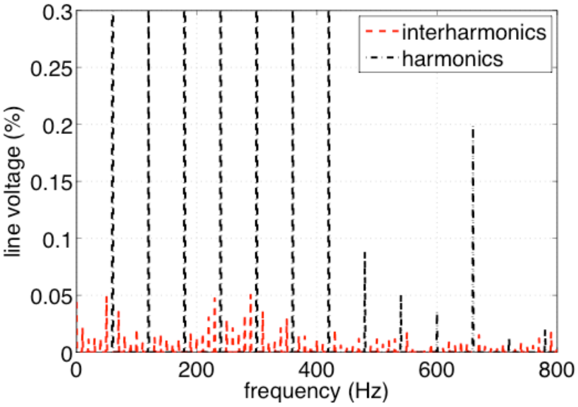
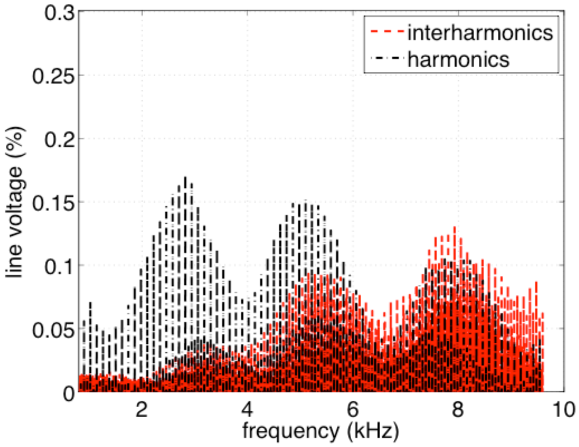


Figure 5. Zoom of the absolute value of the line voltage versus the time.



a) Spectrum in the range from dc to 0.8 kHz.



b) Spectrum in the ranges from dc to 0.8 kHz to 10 kHz.

Figure 6. Line voltage spectrum versus frequency: a) range from dc to 0.8 kHz; b) range from 0.8 kHz to 10 kHz (red dashed lines refer to interharmonics, black dash-dotted lines refer to harmonics).

Fig. 6 shows line voltage spectrum versus frequency: a) range from dc to 0.8 kHz and b) range from 0.8 kHz to 10 kHz (red dashed lines refer to interharmonics, black dash-dotted lines refer to harmonics). It is possible to observe that in the low frequency range (Fig. 6a)) some interharmonics are present but their amplitude is too small to produce LF. On the contrary, in the high frequency range (Fig. 6b) frequency tones characterized by an amplitude triple with respect to the abovementioned interharmonics are present. The richness of this spectrum evidences the presence of an intermodulation phenomenon in the line voltage.

B. Theoretical analysis to show the origin of the peak modulation

Let's consider an ideal sinusoidal voltage at fundamental frequency, $v_1(t)$, with a superimposed high frequency signal composed by a couple of harmonics and a couple of interharmonics, $v_{HF}(t)$:

$$v_1(t) = 100\,sin(2\pi \cdot 50 \cdot t), \tag{1}$$

$$\begin{aligned} v_{HF}(t) &= 2 \cdot sin(2\pi \cdot 2500 \cdot f_1 t) + 1 \cdot sin(2\pi \cdot 5000 \cdot f_1 t) + \\ &+ 0.75 \cdot sin(2\pi \cdot 6090 \cdot f_1 t) + 2 \cdot sin(2\pi \cdot 8090 \cdot f_1 t). \end{aligned} \tag{2}$$

Then, let's consider a modulating signal, $M(t)$, that intermodultes the HF voltage in correspondence of peaks of the fundamental voltage so that the resulting signal, $v_{res}(t)$, will be in the form:

$$v_{res}(t) = v_{res}(t) + |M(t)| \cdot v_{HF}(t). \tag{3}$$

Fig. 7 shows the abovementioned quantities $v_1(t)$, $v_{res}(t)$ and $M(t)$ versus the time, respectively. Fig. 8 shows the waveform of the resulting signal $v_{res}(t)$ and the zoom of its absolute value while Fig. 9 shows the spectrum of $v_{res}(t)$.

From Figs. 8 and 9 it is possible to observe the similarities with Figs. 5 and 6 which demonstrate that the richness of the spectrum is caused by the intermodulation of the high frequency disturbance (which is characterised by only four spectral lines) by the signal $|M(t)|$.

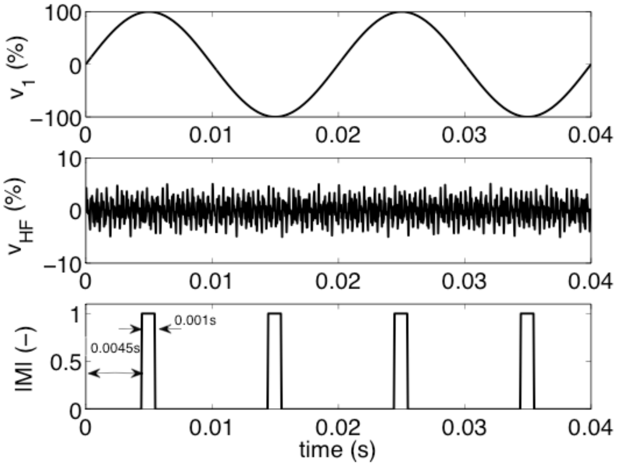


Figure 7. $v_1(t)$, $v_{res}(t)$ and $M(t)$ versus the time.

In other words, going back to the real case-study, it is reasonable to say that the high frequency disturbance is "triggered" in correspondence of the peaks of the line voltage. This seems due to the control strategy adopted by the LED connected to the mains.

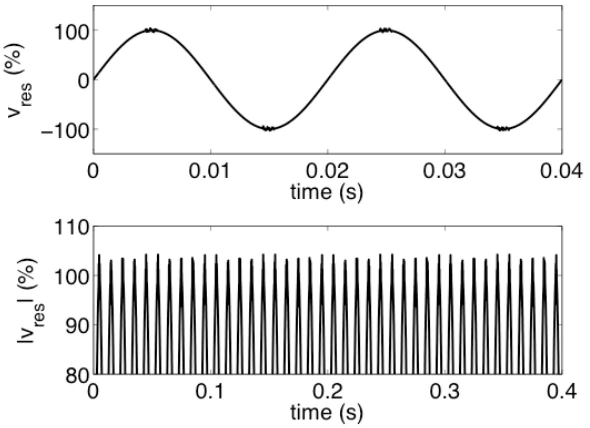


Figure 8. Waveform of the resulting signal $v_{res}(t)$ and zoom of its absolute value.

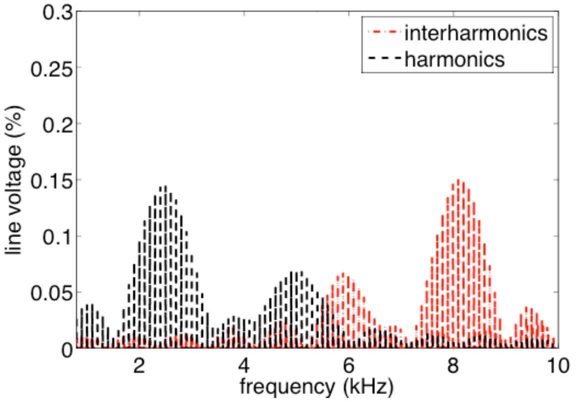


Figure 9. Spectrum of the resulting signal versus frequency.

IV. NUMERICAL CASE-STUDY

Numerical experiments have been conducted applying the measured line voltage to the new Flickermeter proposed by some of the authors [23].

Being the recorded line voltage only 400 ms long, this waveform was taken and applied in loop but since this waveform is not periodic, small phase jump between consecutive segments are caused producing some additional flicker that was demonstrated to be negligible.

Fig. 10 shows the instantaneous flicker level, P_{inst}, versus the time when the Flickermeter is set using the three constants corresponding to the standard incandescent lamp (60 W, 120 V, 60 Hz). It is confirmed what was measured onsite: the measured was Pst=0.26 that is to say the standard FM is not able to measure LF for non-incandescent lamps.

On the contrary, Fig. 11 shows P_{inst} versus the time when the FM is set using the three constants corresponding to the LED lamp referred to as LED 06 in [13]. It is possible to observe that P_{inst} oscillates around 20 which corresponds to a flicker severity level, P_{st} equal to 3.24. This further demonstrates the ability of the new FM to assess LF produced by LED lamps in the case-study analyzed.

Finally, Fig. 12 shows the results of a parametric analysis conducted using the same values of τ_L and K of LED 06 but varying the τ_C in the range from 10 ms to 100 ms. It is possible to observe that growing τ_C the P_{st} saturates around a value equal to 3.6.

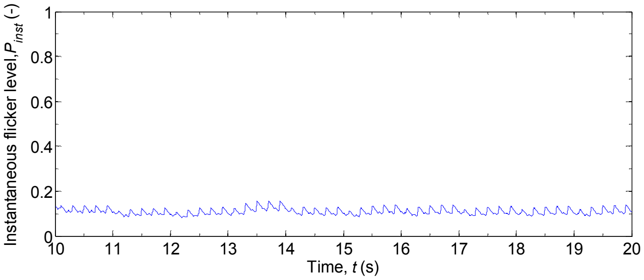


Figure 10. Incandescent bulb τ_C=0 ms, τ_L =29.3 ms, K=3.52).

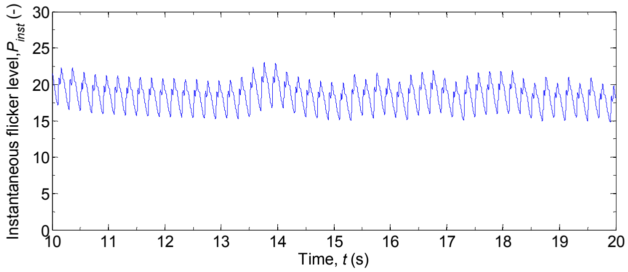


Figure 11. LED lamp (τ_C =28 ms, τ_L =2 ms, K=1).

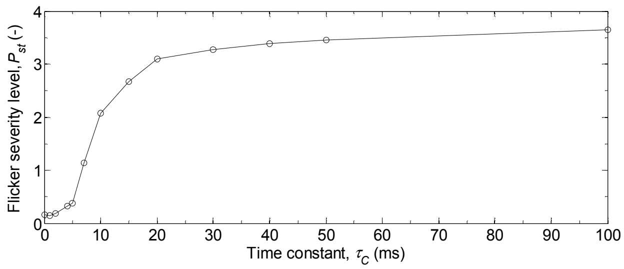


Figure 12. LED lamp (τ_C ariable, τ_L =2 ms, K=1).

V. EXPERIMENTAL LABORATORY ANALYSIS

Experimental activities have been conducted in the laboratories of the Brno University of Technology where an objective light FM is available. Details about the test setup used are contained in [21]. The lamps utilized during the experiments are LED a, LED b and LED c, further on, obviously, LED_OLD and LED_NEW, with classification according to [24] in Table I..

A. Lamps Charachterization by means of standard tests

Lamps characterization has been firstly conducted applying the following standard test procedures for steady state disturbances (fundamental voltage 120 Vrms @ 60 Hz):

- Gain factor curves due to interharmonics [13] (Fig. 13);
- Pst gain curves due to interharmonics [23] (Fig. 14);
- Interharmonic-flicker curves [23] (Fig. 15);

Both the lamps have shown very good performances demonstrating their quality and a quite low sensitivity in terms of Light Flicker.

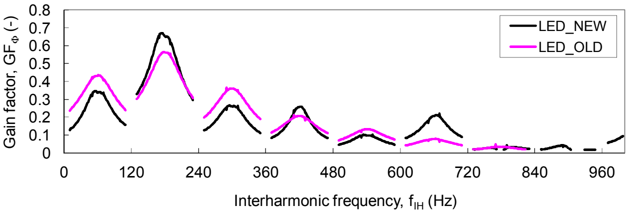


Figure 13. Gain Factors curves for the two tested lamps.

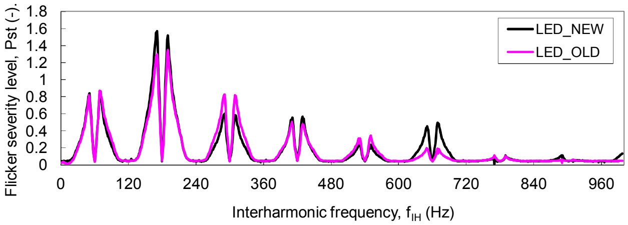


Figure 14. Pst gain curves for the two tested lamps.

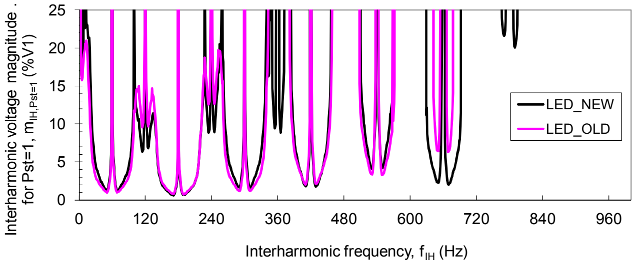


Figure 15. Interharmonic flicker curves for the two tested lamps.

B. *Application of measured line voltages*

As done for the numerical case-study, measured line voltages have been generated by a controllable power generator and applied in loop to the two lamps described in Section II and to three other LED lamps available in the laboratory equipped with a driver which is free of any constant output regulation loop.

The results in terms of Flicker sensitivity level, P_{st}, evaluated in 10 s, are reported in Table I. It is possible to observe that the three LED lamps without regulation loops do show flicker issues as it is expected for their circuit simplicity that reflects on the inability to react to supply voltage changes. LED_NEW does not suffer at all. On the contrary, for LED_OLD two values of P_{st} are reported: the first refer to the response of the lamps when it was still cold which is equal to 2.80 while the second refers to the response of the lamps after some minutes of operation which was 0.55. In other words, the LED_OLD lamps flickers due to momentary failure in the driver control to stabilize output related to operation conditions when subject to the test voltage waveform.

TABLE I. P_{ST} RESULTS APPLYING MEASURED LINE VOLTAGES

Lamp	LED a	LED b	LED c	LED_NEW	LED_OLD
Type [24]	B	B	A1	D1a	D1a
Pst (10s)	3.76	2.6	1.21	0.52	2.80 - 0.55

Fig. 16 shows the measured P_{st} behavior for LED_OLD during the test for 15 minutes. It is clearly visible that at the beginning the LED_OLD produces very high values P_{st} but after a minute a regulation action starts to compensate the input voltage fluctuations. This control action becomes effective after 7-8 minutes when the corresponding P_{st} becomes lower than 1. This is also shown in Fig. 17 in terms of Instantaneous flicker level, P_{inst}.

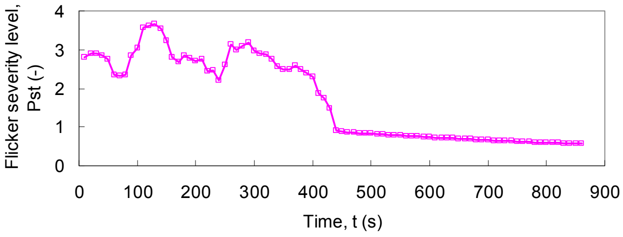
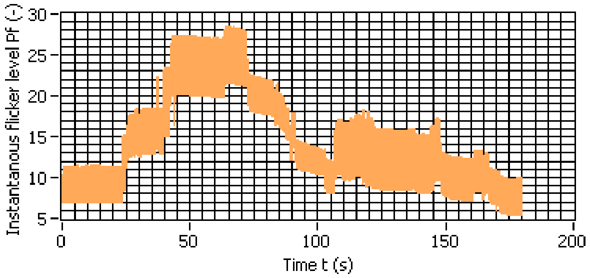
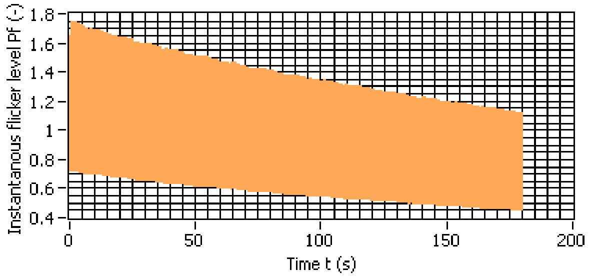


Figure 16. LED_OLD Flicker severity level, , P_{st} versus time.



a) cold lamp



b) hot lamp

Figure 17. LED_OLD instantaneous flicker level, P_{inst} versus time.

It is also possible to observe that if input voltage distortion is not constant, some changes happen in consecutive segments of supply voltage and the driver tends to fail in stabilization and the lamp starts to flicker again, but for shorter intervals. Thus if there are repetitive changes in supply (stochastic time variations), the lamp can strongly flicker continually.

Finally, it is possible to conclude that both the lamps used in the chicken farm are of very good driver topology. Their immunity is one of the best, namely in range of LED lamps dedicated for household applications. However, the LED_OLD lamp driver control tends to fail under certain operation conditions, such as ambient temperature and permanent changes in time varying fluctuations. The same was not found in case of the LED_NEW lamp.

VI. CONCLUSIONS

This paper has shown the results of a real life case-study which has demonstrated the there is a need for new Flickermeters able to cope with new lamps' technologies different from standard incandescent, in particular with LED lamps. The case-study refers to a LED lamp that was visibly flickering even though measurements taken onsite with a standard PQ instrument reported neither THD nor Pst issues. The flickering lamp was substituted with another model and the Light Flicker problem ceased. Numerical tests using a new Flickermeter proposed by some of the authors and laboratory experiments by means of an objective light Flickermeter have been used to investigate the reasons of this singular case.

Finally, it is possible to conclude, that LED_NEW, being equipped with high quality driver, is able to "compensate" for voltage variations even if they are due to such time varying spikes as recorded in the field measurements. However, the behavior of LED_OLD, even if its driver topology is more or less the same of LED_NEW, is sometimes, under specific conditions, different. Through investigation, it was discovered that the control circuit of the driver in LED_OLD is not able to stabilize output when the driver is cold. Once the driver is warmed up, after a certain time interval, and in a few evident steps, the control loops starts to work properly. Therefore, it has been found in the LED_OLD lamp that there is a strong relation to temperature of the driver and to a slightly lesser extent sharp changes in supply voltage (still containing modulated spikes) to flicker.

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