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An alternative strategy to improve the flicker severity measurement

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ABSTRACT

The IEC 61000-4-15 standard defines a flickermeter that is universally accepted as the meter used for the objective measurement of a disturbing light flicker. The accurate results provided by the IEC flickermeter under uniform fluctuations stand in contrast with its unpredictable behavior under real conditions when voltage fluctuations are not uniform over time. Under nonuniform fluctuations, the IEC flickermeter can indicate wrong values, and this could explain the absence of users' complaints at sites where high flicker levels were measured. This work presents a new strategy for flicker measurement that overcomes the deficiencies presented in the IEC flickermeter, properly relating flicker severity values and temporal evolution of the fluctuation. The manuscript describes in detail the functional and design specifications of the new strategy, as well as the results obtained during the validation process in which the IEC flickermeter and the new strategy were subjected to input signals with different temporal fluctuation patterns. The manuscript also presents a comparison between the response of the two strategies to real voltage signals, which are complex and nonuniform in nature. The results confirm the differences between both strategies, despite both meet the same requirements established by the standard.

Introduction

The supply voltage may vary under changes in load conditions or in the operation of the generation systems, and these variations produce flicker of the lighting equipment. Flicker is understood as the disturbing sensation that is experienced by the human visual system when subjected to these light fluctuations, leading to potential complaints. A flickermeter must objectively quantify the discomfort produced by a reference light source when its supply voltage fluctuates, in order to reduce the expense of corrective measures for both the owner of the disturbing equipment and the electrical company. Thus, the effective calculation of flicker severity becomes essential in the monitoring performed by the metering equipment [1].

The universally accepted flicker measurement method was developed by the International Union for Electricity Applications (UIE) during the 1980s [2] and was first published as the standard IEC 868 in 1992. This standard established the functional and design specifications for the International Electrotechnical Commission (IEC) flickermeter and defined short-term flicker severity, P_{st}, as the fundamental parameter used to evaluate the discomfort. Afterwards, the specification was classified as the IEC 61000-4-15 standard, and its last edition was published in 2010 [3] with the objective of a greater convergence in the results provided by different commercial implementations. During the last 10 years, the unpredictable behavior of the IEC flickermeter under real conditions has put its accuracy in assessing the perceived flicker severity under question [4,5]. The main argument in clarifying this issue points to the extensive use of efficient lighting technologies that are less sensitive to flicker than the incandescent one that is used as the reference lamp in the current standard [5,6]. There is also a concern about the idea that the IEC flickermeter needs improvement when dealing with interharmonics that cause flicker [7]. However, according to the findings presented in [8], the most convincing explanation for the poor behavior of the IEC flickermeter in real scenarios comes from the inherent deficiencies in its specification. The response of the IEC flickermeter is not correct when the fluctuations are not uniform over time. The design of its complex specification did not particularly consider the dependence of flicker severity on temporal evolution of the fluctuation. In fact, the final specification was adjusted for a set of uniform rectangular fluctuations, a simple model of the fluctuations in real scenarios. However, the nonuniform characteristics of the real fluctuations in some locations lead the IEC flickermeter to provide wrong values. In these cases, the assessed flicker severity differs from the actual perception of the users, explaining the poor correlation with their complaints [8].

The current work presents a new strategy for measuring flicker severity. This strategy provides an alternative to the IEC flickerme-

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ter as it suggests a method that properly correlates flicker severity and temporal evolution of the fluctuation, complying with the accuracy requirements of the IEC 61000-4-15 standard. The work describes the new strategy and sets out the reasons for its success in evaluating the flicker severity produced by nonuniform fluctuations. The new strategy is described as a simple outline that can be easily adapted from the current configuration specified by the IEC 61000-4-15 standard. The work provides all the details required for the design and the implementation of the new strategy. Finally, the work presents a comparison between the two strategies when subjected to analytical input signals both with uniform and non-uniform temporal fluctuation patterns. Moreover, the work shows the different behavior of the two strategies with real voltage signals, due to the complexity and irregularity of their fluctuations.

Description of the IEC flickermeter

Fig. 1 shows the block diagram of a flickermeter according to the specification defined in IEC 61000-4-15. In Block 1, the input voltage $u(t)$ is scaled to an internal reference value to make flicker measurements independent of the input voltage level.

In Block 2, the scaled input voltage $u_1(t)$ is demodulated by means of a squaring multiplier, thereby simulating the behavior of an incandescent lamp.

Block 3 comprises three cascaded filters. The first two filters complete the demodulation process and consist of a 1st-order high-pass filter (3 dB cutoff frequency $f_{co} = 0.05$ Hz) and a 6th-order low-pass Butterworth filter (3 dB cutoff frequency $f_{co,50} = 35$ Hz for 50 Hz systems). The third filter is a band-pass filter that models the behavior of the lamp-eye system. Its design was defined from experiments carried out by De Lange and Ailleret in the 1950s [9,10] and its transfer function is given in the standard [3]. The output of Block 3 is $u_3(t)$, which represents the weighted demodulated voltage-change signal.

Block 4 of the flickermeter implements the *eye–brain* model proposed by Rashbass and Koenderink [11,12]. This block includes a squaring multiplier that simulates the nonlinear eye–brain response, followed by a low-pass filter that accounts for the perceptual storage effects in the brain. The low-pass filter is specified to be a sliding mean filter with a time constant of 300 ms. The filtered signal is then multiplied by a scaling factor to obtain P_{inst}. The unit of P_{inst} corresponds to the reference human flicker perceptibility threshold, experimentally obtained through subjective tests [2].

Block 5 evaluates the flicker severity by applying a multipoint algorithm that uses the percentiles obtained from the cumulative probability function (CPF) over a short period (usually 10 min) of P_{inst}. The adjustment of the algorithm was carried out by using the experimental curve of the flicker severity threshold, $P_{st} = 1$ [13], obtained for different frequencies of rectangular voltage fluctuations. Once the values of the coefficients and percentiles were calculated, all the points of the curve for $P_{st} = 1$ fitted with errors under 5%. Initially, the selected percentiles were $P_{0.1}$, P_1, P_3, P_{10} and P_{50}. Later, some of these were substituted by other smoothed percentiles, P_{1s}, P_{3s}, P_{10s} and P_{50s}, each of them obtained from a set of *unsmoothed* percentiles. Consequently, the standard [3] obtains a flicker severity value from a total of 15 *unsmoothed* percentiles as:

$$P_{st} = \sqrt{0.0314 \cdot P_{0.1} + 0.0525 \cdot P_{1s} + 0.0657 \cdot P_{3s} + 0.28 \cdot P_{10s} + 0.08 \cdot P_{50s}} \quad (1)$$

Deficiencies of the IEC flickermeter

The evolution of the IEC 61000–4-15 standard has been aimed at increasing the accuracy of flicker measurement. The most significant progression corresponds to the 2.0 edition, which includes a new set of functional tests in order to restrict the implementation margins. This improvement has contributed to the convergence of the results from the commercial implementations under the same input conditions [14]. However, during the last years, several studies have warned about the unpredictable behavior of the IEC flickermeter under real conditions [15,16]. Additionally, in many networks that supply industrial areas, the real flicker severity values are much higher than the planning levels without causing complaints by residential customers. However, other loads that generate flicker that is clearly over the planning levels, but quite close to the former cases, lead to complaints by customers, requiring corrective actions [4,5]. In fact, different working groups created for the improvement of the electric power system have studied the possibility of modifying the IEC 61000–4-15 standard to solve those problems. On the one hand, the working group C4.108 of CIGRE (International Council on Large Electric Systems)

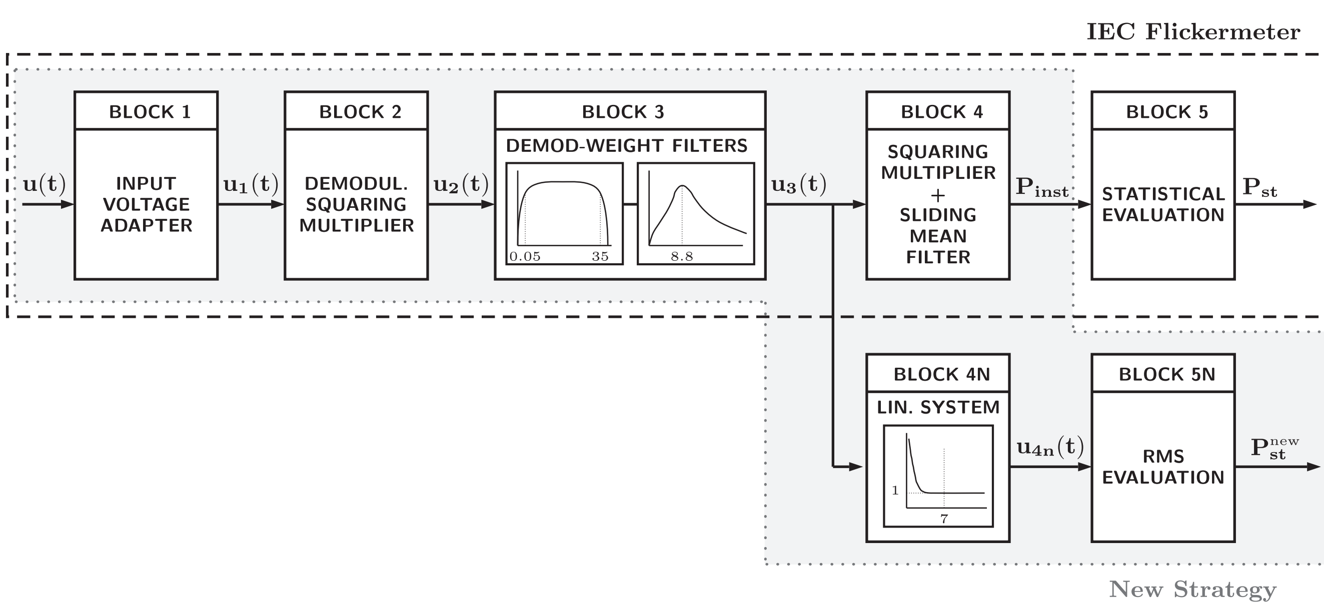

Fig. 1. Block diagrams of the IEC flickermeter and the new strategy.