

A REVIEW OF FLICKER OBJECTIVES RELATED TO COMPLAINTS, MEASUREMENTS, AND ANALYSIS TECHNIQUES

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ABSTRACT

Recent anecdotal and technical evidence exists regarding the difficulty in coordinating measured flicker levels with customer complaints. This potential poor correlation is particularly observed with regard to measurements made in HV and EHV systems and, to a lesser extent, to measurements made in MV systems. A recently completed report from CIGRE/CIRED C4.07 documented measured levels of P_{st} (or P_{lt} where used) above planning levels while no complaints were received from LV users. Similar reports were also received throughout the work of CIGRE/CIRED C4.103 in revising IEC 61000-3-7, culminating in new annex material offering possible options for managing this situation. To develop further understanding of the possible causes of the observed lack of correlation, CIGRE/CIRED C4.108 was convened first in 2007. This paper documents the preliminary findings of that group.

INTRODUCTION

During the completion of the work of two previous CIGRE/CIRED JWG's, namely C4.07 and C4.103, significant indications of poor correlation between measured flicker levels and customer complaints were received. As part of C4.07, these cases were documented to the greatest extent possible at that time [1]. Furthermore, as a part of the work of C4.103 during the revision of IEC 61000-3-7, the concept of reallocation of planning levels while maintaining LV compatibility levels was proposed and demonstrated in new annex material [2].

The work of C4.07 and C4.103 has been augmented by a new CIGRE/CIRED JWG initially convened in 2007. This new JWG, C4.108 "Flicker Objectives," was charged with three main responsibilities (as relevant to this paper). These are:

1. Gather information on and document cases of correlation (or lack thereof) between flicker levels measured throughout power systems (including MV, HV, and EHV locations) and customer complaints received. Furthermore, reasonable explanations for lack of correlation should be offered when possible.

2. Evaluate the technical issues associated with flicker transfer coefficients between EHV, HV, MV, and LV with particular emphasis on the attenuating effects of common system and load equipment.
3. Evaluate the sensitivities of modern lighting technologies with regard to flicker susceptibility and, where possible, provide discussion of the possible impact of new lamps on the issue of poor measurement/complaint correlation.

MEASUREMENT-COMPLAINT CORRELATION

As stated in the introduction, significant evidence exists indicating that P_{st} and P_{lt} levels are significantly greater than planning levels in HV and EHV systems. The correlation between these measurements and customer complaints related to flicker have been inconsistent. In Table 1 is shown a limited international summary of cases taken from available literature. Note that significant additional data is available in a largely anonymous format in the report produced by C4.07 [1].

Table 1. Measured Flicker Levels and Complaint Histories

Country	Index and Percentile	$P_{st/lt}$ Level	Voltage (kV)	Complaints
Norway	P_{st99}	2.0	132	Numerous
Sweden	P_{st99}	1.59	400	Some
	P_{st99}	2.84	145	Some
Slovenia	P_{lt95}	up to 2.8	110	1 per 1000 customers
	P_{st95}	2.78		
Australia	P_{lt95}	2.14	132	None
	P_{st99}	3.10		
	P_{lt99}	2.23		

In Table 2 is shown a short summary of planning levels presently in use in various countries. Only companies/countries using P_{st}/P_{lt} concepts are included to maintain clarity. This information has been taken from [3] and gathered by the C4.108 JWG.

Table 2. Sample of Adopted Planning Levels

Country	Index and Percentile	P _{st/lt} Level	Voltage (kV)	Remarks
England	P _{stmax}	1.0	≤132	
	P _{ltmax}	0.8	≤132	
	P _{stmax}	0.8	>132	
	P _{ltmax}	0.6	>132	
Russia	P _{st}	1.3		Percentile and voltage level not specified
Brazil	P _{st95, daily}	1.0/TF		Transfer factors (TF) used to account for attenuation
	P _{lt95, weekly}	0.8/TF		
IEC 61000-3-7	P _{st}	0.9	MV	
	P _{lt}	0.7	MV	
	P _{st}	0.8	HV/EHV	
	P _{lt}	0.6	HV/EHV	

The purpose of Tables 1 and 2 is to document that flicker levels significantly greater than established planning levels may exist in practical networks without customer complaints regarding flicker. There is evidently no general correlation between flicker level at HV/EHV and customer complaints. This result appears conflicting with the basis for the flicker meter in IEC 61000-4-15 [4]. However, the research behind the flicker measurement standard considers LV compatibility levels instead of HV/EHV planning levels [5]. Addressing this gap between the well-correlated LV situation and the poorly-correlated HV/EHV situation is the main task of C4.108, "Flicker Objectives."

FLICKER ATTENUATION AND TRANSFER FACTOR ANALYSIS

A significant possible contributor to poor correlation between measured flicker levels and customer complaints is the fact that measurements are often made at HV and EHV levels whereas complaints are received from customers observing LV lamp output. Significant attenuation, incorporated in 61000-3-7 using transfer factors, is possible and indeed likely between HV/EHV and LV. Results from C4.07 and C4.103 recommend transfer factors between HV/EHV and MV and MV and LV to be 0.8 and 1.0, respectively [1,2]. Taking these factors into account together with recommended planning levels and an ultimate compatibility level of P_{st}=1.0 at LV, it is straightforward to show how P_{st} levels much greater than 1.0 (and therefore even greater than the recommended planning levels) can exist at HV/EHV [2].

As an example, consider a situation where the planning level at LV is taken as the compatibility level, P_{st}=1.0. Assuming the global contribution of all LV loads is 0.5 and the transfer coefficient between MV and LV systems is 1.0, the planning level at MV can be derived as shown in (1).

$$G_{PstLV} = \sqrt[3]{L_{PstLV}^3 - T_{PstML}^3 \cdot L_{PstMV}^3}$$

$$0.5 = \sqrt[3]{1^3 - 1^3 \cdot L_{PstMV}^3}$$

$$L_{PstMV} = 0.96$$
(1)

Further assuming the global contribution of MV loads is 0.5 and a HV to MV transfer coefficient of 0.9, the allowable planning level at HV can be derived as shown in (2).

$$G_{PstMV} = \sqrt[3]{L_{PstMV}^3 - T_{PstHM}^3 \cdot L_{PstHV}^3}$$

$$0.5 = \sqrt[3]{0.96^3 - 0.9^3 \cdot L_{PstHV}^3}$$

$$L_{PstHV} = 1.01$$
(2)

Continuing this process from MV to HV assuming a global HV level of 0.5 and an HV to MV transfer coefficient of 0.8 gives L_{PstHV}=1.21. This clearly demonstrates that flicker levels in excess of 1.0 (compatibility level at LV) can exist at HV/EHV without leading to any complaints at these voltage levels. The key issues in this rationale are that flicker-producing loads may not be present at all voltage levels and that flicker levels are attenuated between voltage levels, particularly between HV/EHV and LV.

The specification of planning levels and the determination of emission limits is part of the pre-connection planning process. Considering the attenuation phenomena in pre-connection assessments is one of the most problematic issues to address accurately. During system flicker studies, two approaches are recommended that offer different compromises between available data, modelling complexity, and accuracy requirements. In general, the two approaches use standard modelling techniques for power delivery equipment and differ in the way in which load response to voltage fluctuations is handled:

1. Model load equipment using dP/dV and dQ/dV terms with some time dependence so that different types of loads may respond differently to voltage fluctuations.
2. Model load equipment, particularly motor loads, using either appropriate frequency-dependent impedance parameters or time-domain models.

For the first approach, research results are available that indicate widely-varying load response characteristics across the spectrum of load equipment. A summary of characteristics for industrial, commercial, and residential load categories is shown in Table 3 [6,7]. The time response characteristics can be modelled using a first-order high-pass filter with a time constant ranging from 0.1-1.0 second depending on the specific nature of the load considered. The disadvantage of this method lies in the requirement of a mixture of load flow calculations and time simulation techniques in a single study.

Table 3. Load Response Characteristics

Load Sector	dP/dV	dQ/dV
Industrial	0.18	6.0
Commercial	1.3	3.1
Residential	1.5	3.2

To avoid the difficulties of this first approach, it is possible to use a linear approximation of the attenuating effects of a combined load which exhibits documented attenuation characteristics ($T_{Pst}=0.8$ for HV→MV considerations, for example). Because the attenuation is a function of the amount of load present, a reasonable approach is to express attenuation not as a constant but as a function of the amount of load. Equation (3) is developed based on expressing the amount of load as a percentage of the HV→MV load-serving transformer rating. Using a full-load transfer factor $C_f=0.8$, the results of (3) are plotted as shown in Figure 1.

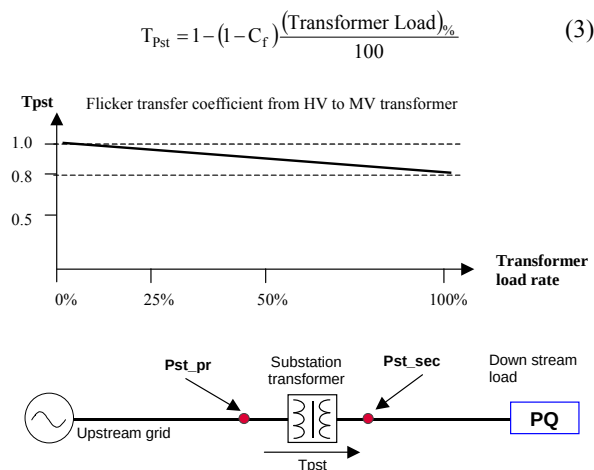


Figure 1. Expression of Transfer Factor as a Function of Percentage Transformer Load Level

For the second approach, initial research indicates that a motor may be replaced by a frequency dependent impedance that is valid over the range of interest for flicker studies (0-100 or 120 Hz) [8,9]. This impedance should not simply be a multiple of the (normalized) frequency and the short-circuit reactance (as is common in harmonic studies). Rather, the impedance used should take into account the transition from subtransient (short-circuit) to synchronous (rated frequency) characteristics over the appropriate frequency range, particularly within ± 20 Hz of the power frequency. The disadvantage of this approach is the fact that a general relationship regarding motor impedance frequency dependence does not exist—the relationship depends on many factors including motor size, mechanical load, etc.

As an alternative to frequency-dependent impedances, load response characteristics may be included in a time-domain simulation using detailed rotating machine models. These

models will most accurately capture the attenuation effects of motor loads. The disadvantages of this most detailed approach are the possible lack of data and the extended simulation study times required.

Laboratory experimental results show that induction motor loads impact flicker attenuation as shown in Figure 2. Note that T_{PstAB} denotes the flicker transfer factor from an upstream source “A” to a downstream location “B” where the motor load is considered to be downstream. It is clear from Figure 2 that it could become difficult to specify frequency dependent load model parameters to capture the full range of the effects. Such difficulty would be increased by noting that different sizes and types of motors will have different response characteristics. (A small motor was used in the development of Figure 2.)

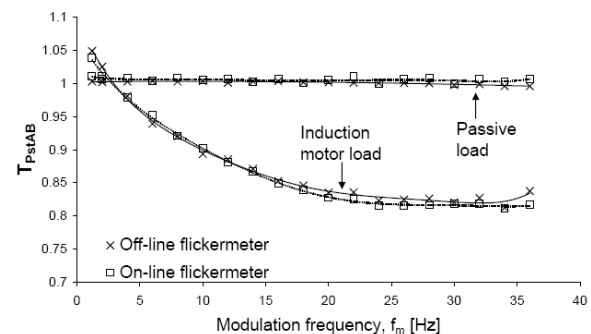


Figure 2. Flicker Attenuation due to Induction Motors vs. Passive Loads

IMPACT OF NON-INCANDESCENT LIGHTING TECHNOLOGIES

It has long been recognized that different types of lamps will respond differently to input voltage fluctuations. This knowledge has led some to call for the elimination of the flicker meter as described in IEC 61000-4-15 as the accepted measurement instrument. Such calls are, however, premature because of the extensive technical and physiological research that supports the present specification [5]. The only portion of the flicker meter that depends on the characteristics of the lamp are those involved in the well-known “lamp-eye-brain” filter polynomials in Block 3. While it is beyond the scope of C4.108 to propose flicker meter modifications, the response of different lamp technologies to voltage fluctuations is a major potential contributor to poor correlation between measurements and complaints. Some of these different response characteristics are summarized in the following paragraphs.

Figure 3 is a comparison plot showing the sinusoidal voltage modulation level required to produce an instantaneous flicker sensation (P_{inst}) of 1.0. It is clear that the 60 W incandescent lamp that forms the basis of the

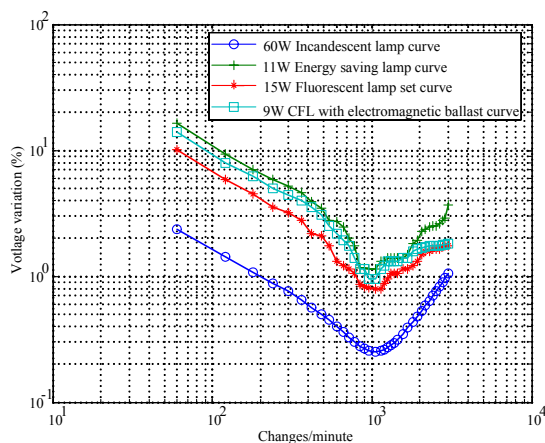


Figure 3. Instantaneous Flicker Sensation Curves for Sinusoidal Input Voltage Modulation

characteristics of the present IEC 61000-4-15 is by far the most sensitive to input voltage fluctuations.

In order to specifically isolate the characteristics of different lamp types, tests were also done on individual lamps. Using the luminance variation of a 230V, 60W incandescent lamp (under sinusoidal voltage modulation conditions required to produce $P_{inst}=1.0$) as a base (reference), the normalized luminance variations of other technologies were measured in a laboratory environment. The results are shown in Figure 4. As in Figure 3, it is clear that modern lighting technologies are less susceptible to flicker than the 230V, 60W incandescent lamp on which IEC 61000-4-15 is based.

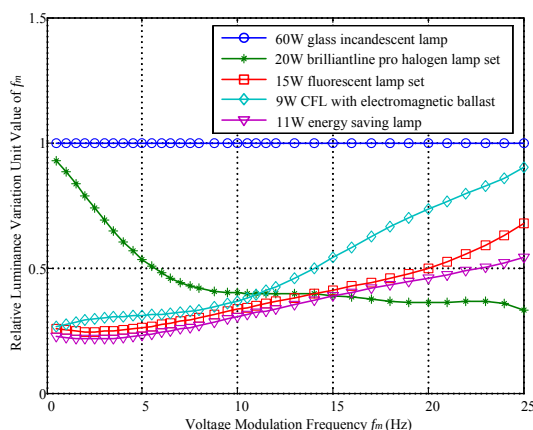


Figure 4. Luminance Variation for Modern Lamps

Preliminary work by active researchers has shown that similar differences in susceptibility are to be expected for P_{st} levels. A decrease in lamp sensitivity which translates into a reduced P_{st} value for a given voltage fluctuation could be a major reason that high P_{st} measurements have been recorded with no correlating customer complaints. Further work by relevant organizations is necessary to consider

possible modifications to the flicker meter specification to incorporate different lighting technologies so that this proposal can be further evaluated by field measurements.

CONCLUSIONS

This paper represents a summary of the work completed to date by CIGRE/CIRED JWG C4.108, "Flicker Objectives." This JWG is essentially charged with addressing the well-known situation wherein flicker measurements in HV and EHV systems are well above established planning levels yet no LV customer complaints exist. It has been shown that documented cases of excessive flicker levels (excessive with respect to planning levels) in HV/EHV systems exist yet customer complaints are not necessarily received.

Two major hypotheses for this apparent inconsistency are being addressed by the JWG C4.108 and have been summarized in this paper. Firstly, excessive flicker levels at HV/EHV may well be significantly attenuated before reaching an observer at LV. Secondly, the observer at LV may be utilizing modern lighting technology which could be up to 4-6 times less likely to lead to objectionable lamp intensity fluctuations and LV customer complaints.

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