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Flickermeter - Part 0: Evaluation of flicker severity

Flickermeter -- Part 0: Evaluation of flicker severity

Flickermeter -- Teil O: Beurteilung der Flickersctärke

Flickermètre -- Partie 0: Evaluation de la sévérité du flicker

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Flickermeter
Part 0: Evaluation of flicker severity

(IEC 868-0:1991)

Flickermètre
Partie 0: Evaluation de la séverité du flicker
(CEI 868-0:1991)

Flickermeter
Teil 0: Beurteilung der Flickerschärfe
(IEC 868-0:1991)

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CENELEC

European Committee for Electrotechnical Standardization
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Foreword

The CENELEC questionnaire procedure, performed for finding out whether or not the Technical Report IEC 868-0:1991 could be accepted without textual changes, has shown that no common modifications were necessary for the acceptance as European Standard.

The reference document was submitted to the CENELEC members for formal vote and was approved by CENELEC as EN 60868-0 on 9 December 1992.

The following dates were fixed:

—	latest date of publication of an identical national standard	(dop) 1993-12-01
—	latest date of withdrawal of conflicting national standards	(dow) 1993-12-01

Annexes designated "normative" are part of the body of the standard. In this standard, Annex ZA is normative.

Contents

1 Statistical evaluation

The UIE/IEC flickermeter simulates the process of physiological visual perception and gives a reliable indication of the reaction of an observer to any type of flicker, which is independent of the source of the disturbance.

The flickermeter monitors individual and sequential flicker occurrences in units of perceptibility; it is necessary to evaluate its output by a method that indicates severity level for regular and irregular type of flicker. The output of the instrument is one unit, at the threshold of perceptibility.

The concern of UIE is to achieve a unique method for flicker evaluation using an evaluation procedure that is equally applicable to any kind of fluctuating load. The specification of limits for the disturbances generated by the various categories of equipment is the task of the appropriate standardization bodies.

To take account of the mechanisms of vision and the building up of annoyance, the flicker shall be evaluated over a sufficiently representative period of time. Moreover because of the random nature of flicker caused by some loads it must be assumed that during this time its instantaneous level can be widely and unpredictably variable. It is important to check not only the maximum attained levels but also for what percentage of a significant observation period any given flicker level has been exceeded. To cover all cases, a statistical approach is essential and this requires a function to be established relating flicker sensation levels and the corresponding percentages of duration, over the observation period.

The steps to establish this function are the following:

— first the measured instantaneous flicker sensation levels at the output of Block 4 of the flickermeter are classified according to their value, thus obtaining their frequency distribution;

— when the observation period expires, the cumulative probability function (CPF) is established.

This method has been called "time at level classification" and is illustrated in Figure 1.

Figure 2 shows the graphical representation of a CPF curve where, for clarity, only a small number of classes has been used.

Figure 3 to Figure 5 give examples of CPF curves obtained for different disturbing loads. It can be seen that the shapes of the curves are dissimilar, yet a common criterion is required to describe them in a concise and meaningful way and so assess flicker severity quantitatively and objectively.

If all CPF curves followed a standard type of distribution, such as Gaussian, they might be characterised by a few parameters such as mean, standard deviation and so on. This not being the case, a multipoint method which could be used to characterise any CPF curve was developed.

A suitable algorithm for use with various shapes of CPF curves can be expressed as follows:

$$P_{st} = \sqrt{K_1 P_1 + K_2 P_2 + \dots K_n P_n}$$

where:

P_{st} is the value of short-term flicker severity;

K_1 to K_n are weighting coefficients and

P_1, P_2 to P_n are CPF curve levels with an assigned probability of being exceeded.

The weighting coefficients were determined in such a way as to indicate the flicker severity correctly for a wide range of frequencies of rectangular modulation of the input voltage but the response to other waveshapes was also taken into account.

A stable solution can be obtained using five gauge points or percentiles, namely:

$P_{0,1}$	the level exceeded by only	0,1 %	of the observation period
P_1	" " "	1 %	" " "
P_3	" " "	3 %	" " "
P_{10}	" " "	10 %	" " "
P_{50}	" " "	50 %	" " "

The 50 % reference point is the median level of flicker, giving a general indication of the order of magnitude of the disturbance. The other points am taken toward the low end of the probability scale to weight the higher sensation levels appropriately, because these are more significant in assessing the severity of the disturbance.

It should be noted that the maximum flicker level observed during the selected time interval is not included because a single peak level of very short duration cannot be representative of a flicker occurrence. The foundation of the CPF concept is that time at a given level gives the more useful indication; the choice of 0,1 % as a minimum percentile provides a suitable response for large, Infrequent flicker amplitudes.

A suitable observation period should be chosen. This could be selected to match the duty cycle of a specific disturbing equipment but it is desirable to adopt a common time, independent of the specific type of disturbing source being considered.

In fulfilling this objective it has been necessary to consider again the physiology of flicker perception and the results of tests on human subjects and to try to determine what time interval would be appropriate to represent the reaction of the average observer to a wide range of flicker characteristics.

An interval of 10 min has been selected as a good compromise. It is long enough to avoid giving too much importance to isolated voltage changes. It is also long enough to allow an unaware subject to notice the disturbance and its persistence, but at the same time it is short enough to allow a detailed characterization of a disturbing equipment with a long lasting duty cycle. It is an important advantage that the same interval is the observation time specified in IEC 555-3.

2 Short-term flicker severity assessment

2.1 Choosing the multipoint algorithm

In choosing a suitable multipoint algorithm, another problem had to be resolved, that of relating the multipoint evaluation to flicker severity.

A limited number of human subjective response test results was available, which could be used to relate flicker severity with non-linear CPF curves. However, from investigations made into earlier work concerning human subjective response measurements, it appeared that the higher frequency part of the limit curve given in IEC 555-3 (Figure 6a) corresponds fairly well to the experimental results which relate flicker severity to consumer complaints for rectangular disturbance waveforms.

On the other hand it appeared that the part of the limit curve over the range 1 to 0,1 changes per minute was not a true measure of flicker severity but the 3 % limit of voltage change had to be introduced for reasons other than that of limiting flicker annoyance. A realistic relationship for flicker evaluation requires that the severity curve be extented to the 7,5 % voltage change level at 0,1 changes per minute (Figure 6b). It was therefore decided to determine a multipoint algorithm from this modified rectangular response curve and then to test its validity from results of subsequent human subjective response measurements.

The following values were obtained for the K coefficients:

K for 0,1 % level = 0,0314
K for 1 % " = 0,0525
K for 3 % " = 0,0657
K for 10 % " = 0,28
K for 50 % " = 0,08

All chosen coefficients are positive, which ensures that the resulting values for flicker severity remain stable i.e. they do not appear to be oscillatory in relation to variations on the voltage changes per minute scale.

For the agreed short-term assessment period of 10 min, the flicker severity was therefore expressed by the equation

$$P_{st} = \sqrt{0{,}0314\,P_{0,1} + 0{,}0525\,P_1 + 0{,}0657\,P_3 + 0{,}28\,P_{10} + 0{,}08\,P_{50}}$$

To check the accuracy of this flicker severity assessment and to ensure that the results were stable for regularly repeated fluctuations, the multipoint algorithm was used to evaluate every limit level given in the IEC table for the specified period of 10 min. The results are shown in Table 1 under the sub-columns "unsmoothed" and in Figure 6a.

It can be seen in Figure 6a that the greatest difference between the severity curve and the right-hand part of the IEC limit curve is about 10 %, which is a satisfactory result. A still better fit is however not possible the mason for that is probably the empirical origin of the IEC curve. The precision of such a curve is evidently limited and it is not suitable for exact mathematical representation.

2.2 Practical checking of the P_{st} evaluation

The next requirement was to demonstrate that the multipoint algorithm gave correct responses for different types of supply disturbance. The first test was related to arc furnace disturbances and the results were checked against gauge point voltages obtained from the ERA flickermeter. Good correlation was obtained with test results obtained at different installations.

Next, it was decided to demonstrate correlation with disturbances associated with motor starting. This demonstration was carried out in the United Kingdom by arranging for human subjective response tests to be made with simulated shapes of disturbance and was performed for test conditions representing six changes per minute. The measurements also included rectangular disturbances. The results obtained from the flickermeter concorded with the test subject opinions and, incidentally, the rectangular disturbance had a voltage variation which agreed closely with the IEC curve.

Further experience in flicker severity evaluation showed that if there were a need to modify the curve of equal severity as a function of voltage fluctuation frequencies, then the P_{st} coefficients could easily be adapted to fit a new curve.

Therefore the UIE proposes that this multipoint evaluation of flicker severity should be used, not only for household and similar appliances under the test conditions of IEC 555-3, but that the same evaluation should be used for voltage fluctuations caused by industrial loads, including arc furnaces.

The quantity P_{st} is proposed only as a means to gauge the level of flicker severity, its main purpose being to provide an international method of flicker severity assessment. The UIE does not propose a limiting value for P_{st}, this is recognized to be the responsibility of the various International and National Standards Committees.

The UIE, however, is mindful of the need to give some guidance on how to use the flickermeter for evaluating limit values for flicker severity.

A limit value for P_{st} could be set as greater or less than unity according to the application, taking into account the fact that in laboratory tests a substantial proportion of observers report flicker as annoying when $P_{st} = 1$.

2.3 Agreement between simplified assessment methods and evaluation

The above-mentioned difference between the $P_{st} = 1$ curve and the right-hand part of the IEC 555 curve will cause a small discrepancy (maximum 10 %) between simplified assessment methods and measurements.

The present practice is to use a simplified assessment method as a first step and to perform measurements in case of doubt (when the results are within 10 % of the limit). It may, however, cause, problems if measurements are difficult or even impossible to carry out.

As a better solution, the UIE recommends to the IEC to revise the right-hand part of the IEC 555 limit curve slightly, so as to be identical to the $P_{st} = 1$ curve. Measuring P_{st} (with the additional requirement that the voltage changes shall not in any case exceed 3 %) will then give results identical to those obtained using the analytical method.

3 Accuracy of the P_{st} evaluation

The classification method used to obtain the CPF may introduce errors due to the fact that in a practical implementation of the statistical evaluation block the number of classes shall be limited, as shall the resolution of the analogue-to-digital converter that is used for both digital and analogue designs of flickermeter.

This usually means that the true values of the level associated with any of the selected percentiles, P_k (k = 0,1; 1; 3; 10; 50), is not given directly but lies between two known values in the classified distribution.

Table 1 — Voltage changes just permitted by IEC 555-3 compared with those giving one unit flicker severity ($P_{st} = 1$) for various changes of voltage per minute using unsmoothed and smoothed 5 point algorithm

Column 1 Changes per minute	Column 2 Relative voltage changes $\Delta U/U$ %	Column 3 Voltage change for unit flicker ($P_{st} = 1$) $\Delta U/U$ %		Column 4 Percentage difference $\frac{\text{Column 3} - \text{Column 2}}{\text{Column 2}} \times 100\,\%$	
		Unsmoothed	Smoothed	Unsmoothed	Smoothed
0,1	3,00	7,46	7,391	—	—
0,2	3,00	4,52	4,584	—	—
0,3	3,00	3,88	3,842	—	—
0,4	3,00	3,52	3,540	—	—
0,5	3,00	3,34	3,350	—	—
0,6	3,00	3,14	3,196	—	—
0,76	3,00	2,97	2,979	− 1,0	− 0,7
0,84	2,90	2,90	2,867	0,0	− 1,1
0,95	2,80	2,79	2,765	− 0,3	− 0,4
1,06	2,70	2,70	2,679	0,0	− 0,8
1,20	2,60	2,60	2,579	0,0	− 0,8
1,36	2,50	2,49	2,484	− 0,4	− 0,6
1,55	2,40	2,38	2,394	− 0,8	− 0,3
1,78	2,30	2,26	2,294	− 1,7	− 0,3
2,05	2,20	2,16	2,193	− 1,8	− 0,3
2,39	2,10	2,07	2,091	− 1,4	− 0,4
2,79	2,00	1,97	1,989	− 1,5	− 0,6
3,29	1,90	1,88	1,893	− 1,0	− 0,4
3,92	1,80	1,78	1,789	− 1,1	− 0,6
4,71	1,70	1,70	1,679	0,0	− 1,2
5,72	1,60	1,57	1,571	− 1,9	− 1,8
7,04	1,50	1,47	1,456	− 2,0	− 2,9
8,79	1,40	1,37	1,348	− 2,1	− 3,7
11,16	1,30	1,24	1,244	− 4,6	− 4,3
14,44	1,20	1,14	1,150	− 5,0	− 4,2
19,10	1,10	1,04	1,062	− 5,5	− 3,5
26,60	1,00	0,97	0,975	− 3,0	− 2,5
32,00	0,95	0,93	0,942	− 2,1	− 0,8
39,00	0,90	0,89	0,906	− 1,1	− 0,7
48,70	0,85	0,86	0,866	+ 1,2	+ 1,9
61,80	0,80	0,83	0,824	+ 3,8	+ 3,0
80,50	0,75	0,78	0,782	+ 4,0	+ 4,3
110,00	0,70	0,72	0,725	+ 2,9	+ 3,6
175,00	0,65	0,63	0,635	− 3,1	− 2,3
275,00	0,60	0,55	0,551	− 8,3	− 8,2
380,00	0,55	0,50	0,500	− 9,1	− 9,1
475,00	0,50	0,48	0,476	− 4,0	− 4,8
580,00	0,45	0,43	0,423	− 4,4	− 6,0
690,00	0,40	0,37	0,367	− 7,5	− 8,25
795,00	0,35	0,32	0,321	− 8,6	− 8,3
1 052,00	0,29	0,28	0,276	− 1,1	− 4,8
1 180,00	0,30	0,29	0,283	− 3,3	− 5,7
1 400,00	0,35	0,33	0,331	− 5,7	− 5,4
1 620,00	0,40	0,40	0,402	0,0	+ 0,5
1 800,00	0,45	0,47	0,480	+ 4,4	+ 6,7

If each percentile P_k is estimated using the mean value of the corresponding class the maximum error on P_k will be:

$$\left| \varepsilon_{i_{\max}} \right| = \frac{1}{2} \frac{F_s}{N}$$

where:

N is the number of classes in the classifier

F_s is the measuring range

Assuming that all percentiles coincide with a class interval end point the calculated P_{st} values will be:

$$P_{st} = \sqrt{P^2_{st_{true}} \pm \frac{1}{2} \frac{F_s}{N} \sum_{i=1}^{5} K_i} = \sqrt{P^2_{st_{true}} \pm 0{,}2548 \frac{F_s}{N}}$$

The maximum possible value of P_{st} will occur when all percentiles P_k fall into the highest level class, M_{max}, that approximately corresponds to the full scale value, F_s of the range being used:

$$P_{st_{max}} = \sqrt{M_{max} \sum_{i=1}^{5} K_i} = 0{,}7139 \sqrt{M_{max}}$$

If the actual calculated P_{st} is a fraction α of $P_{st_{MAX}}$, the maximum relative error will be expressed by:

$$\varepsilon_{max}\% = \frac{P_{st} - P_{st_{true}}}{P_{st_{true}}} 100 = 100 \left(\sqrt{1 + \frac{1}{2N\alpha^2}} - 1 \right)$$

It can be seen that the maximum relative error is independent of the range and depends only on α and N.

Figure 7 gives the maximum error as a function of α and for different values of N.

Table 2 shows the minimum P_{st} values measurable with a maximum error of 5 %, for different flickermeter ranges and classifier sizes.

Table 2 — Minimum measurable P_{st} values with an error of 5 % for each range and three classifier sizes

p.u. flickermeter range		4	16	64	400	1600	6400
Classes	$P_{st}/P_{st_{max}}$	$P_{st_{max}}$					
		1,42	2,85	5,7	14,2	28,5	57
64	0,275	0,39	0,784	1,567	3,9	7,837	15,68
128	0,19	0,27	0,542	1,083	2,698	5,415	10,83
256	0,125	0,192	0,385	0,77	1,92	3,85	7,695

It can be seen that to avoid the need for too many classes the estimate of percentiles had to be improved and the benefits obtainable by an interpolation technique were examined. The first possibility was that of using a linear interpolation within the class interval in which a percentile of interest was included, e.g. 0,1; 1; 3; 10 and 50 %.

4 Interpolation

4.1 Linear interpolation

If the classifier is arranged as shown in Figure 8a, so that the full scale value, F_s, of the measuring range is divided into N equal steps, the width of each step will be F_s/N. If the classes are numbered 1 to n to N, class n will have a maximum level $P_n = nF_s/N$ and Y_n % of the output will be equal to or greater than the level P_n.

Similarly, y_{n-1} % of the output will be equal to or greater than (n-1) F_s/N. If the CPF curve can be considered as linear over this range, then, by linear interpolation, the level of output that is equal to or exceeded by y_k % of the output, is given by:

$$P_k = \frac{F_s}{N} [n - (y_k - y_n) / (y_{n-1} - y_n)]$$

4.2 Non-linear interpolation

Linear interpolation gives accurate results when the CPF is reasonably linear, otherwise a more complex non-linear interpolation may be necessary. One technique which has been adopted successfully is to fit a quadratic formula to the levels corresponding to the upper end points of three consecutive classes, n–1, n and n + 1 on the CPF.

In this case, a quadratic formula can be used to define the value P_k required, which lies in class n.

Referring to Figure 8b the CPF level is obtained from the relationship:

$$P_k = \frac{F_s}{N} [n - 1 + \frac{1}{2H_2} (H_1 - \sqrt{H_3})]$$

where:

F_s/N = class width

$$H_1 = \frac{1}{2} y_{n+1} - 2y_n + \frac{3}{2} y_{n-1}$$

$$H_2 = \frac{1}{2} y_{n+1} - y_n + \frac{1}{2} y_{n-1}$$

$$H_3 = H_1^2 - 4 H_2 (y_{n-1} - y_k)$$

where y_n is the percent probability at the right-hand end point of class n and so on.

4.3 Pseudo zero interpolation

It may happen that one or more percentiles of interest P_k lie in the interval of the first class of the classifier. Experience has shown that interpolating between zero and the upper end point of the first class gives poor results, because this makes the implicit assumption that a level of zero will be exceeded with a 100 % probability.

In practice, a typical cumulative probability function (CPF) can meet the probability axis well below the 100 % mark and then move vertically up the axis. This is shown in Figure 5 for an arc furnace and for infrequent voltage step changes which are typical of domestic appliances. A way of reducing errors in this region is to extrapolate back the CPF points to provide a pseudo zero intercept value. An algorithm suitable for this purpose consists of fitting a quadratic function on the first three values of the classification y_n (n = 1, 2, 3) using weighting coefficients of 3, – 3 and 1, respectively (Figure 9):

$$y_0 = (3y_1 - 3y_2 + y_3)$$

where y_0 is the pseudo zero intercept value.

5 Smoothing percentile points

When studying loads that produce a constant disturbance when in operation but follow an on/off duty cycle it was noted that a small change in duty cycle could cause an abrupt change in one of the five percentile points and a significant change in the evaluated flicker severity, P_{st}.

As an example a load that produces, when working, a sinusoidal modulation of the supply voltage at 4 Hz was studied. It was first postulated that the load operated for 61 s and was switched off for the remainder of the observation period of 10 min. Calculation using a simulation programme showed that the corresponding flicker severity, P_{st} was 0,62 units. Changing the "on" period from 61 s to 59 s reduced P_{st} to 0,39. This was mainly because the change of duty cycle reduced P_{10} from 0,866 to 0,031.

Although such severe effects would probably seldom occur in practice, it is important that the method of flicker evaluation should be able to handle the widest possible range of fluctuating loads. The following procedure is recommended. The derivation of P_{st} from the five percentile points, $P_{0,1}$, P_1, P_3 P_{10} and P_{50}, discussed above, is unchanged but smoothed values of each of these points are derived from subsidiary percentile points as follows:

$$P_{50\,s} = (P_{30} + P_{50} + P_{80})/3$$

$$P_{10\,s} = (P_6 + P_8 + P_{10} + P_{13} + P_{17})/5$$

$$P_{3\,s} = (P_{2,2} + P_3 + P_4)/3$$

$$P_{1\,s} = (P_{0,7} + P_1 + P_{1,5})/3$$

The 0,3 s memory time-constant incorporated in the flickermeter circuit ensures that $P_{0,1}$ cannot change abruptly and no further smoothing is needed.

The algorithm for obtaining P_{st} flicker severity remains compatible with that already proposed by the IEC and allows consistent results to be obtained from five smoothed gauge points.

The effect of using the smoothed percentile points on the example given above was examined and the following results obtained:

(on-off/s)		
Duty cycle	**Unsmoothed** P_{st}	**Smoothed** P_{st}
61/539	0,622	0,542
59/541	0,392	0,497
57/543	0,380	0,495

Studies have been repeated for all the rectangular disturbances derived from the IEC 555 curve, but using the smoothed percentile points. The results are given in Table 1 — alongside those obtained without smoothing. It can be seen that there is no degradation of the fit to the IEC curve.

6 Non-linear classification

From a practical point of view the use of classifier intervals of equal width requires a correct selection of the measuring range and sometimes this is not easy to do because the maximum flicker levels are not predictable.

A way of overcoming this difficulty is to use non-linear classification over a suitably high measuring range. This also allows errors to be reduced when only a few registers of the classifier are affected by the incoming data. It is advantageous to use a logarithmic distribution of the class widths. This method offers a complete coverage of the specified measuring ranges and permits the specified accuracy to be achieved while using linear interpolation between classes. Thus the flickermeter can always be used at the highest measuring range since logarithmic scaling associated with linear interpolation will typically keep the classifying errors below 0,5 % without the need of pseudo zero extrapolation.

It has been suggested that a linear classifier could be used on the output 3 of the flickermeter, which gives the square root of the instantaneous flicker sensation but this still requires selection of the correct range.