FLICKER ASSESSMENT: INDIVIDUAL CONTRIBUTION OF AN ARC FURNACE AND FLICKER TRANSMISSION

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SUMMARY

The flicker generated by Arc Furnaces is a complex phenomena generated by the irregular behaviour of the electric arc in the furnace and is transmitted to the public network.
The load flow calculation does not represent exactly the flicker transmission, making necessary statistical approaches to calculate the flicker transmission, specially when several Arc Furnaces are connected to the same network.
This article presents a practical method to assess the contribution of one Arc Furnace independently of the flicker generated simultaneously by other Arc Furnaces, based in actual measurements. Furthermore, it will be showed the flicker transmission through different MV systems.

1.- INTRODUCTION

The flicker is a disturbance which affects only to lighting, and accordingly its effect is only relevant in Low Voltage systems.
Welders or compressors are typical disturbing loads in LV, although they only affect to a few customers, usually those connected in the same feeder. The calculation of the influence of this kind of loads is easy, and investment needed to correct these situations is not too big.
For the purposes of enabling connection of arc furnaces to power company networks, calculations are made of the forecast flicker level produced by each type of furnace.
The formulae which enable the forecast flicker emission to be estimated for a given type of furnace are based on the experimental measurements made when the furnace is already in operation.

As has been shown, the flicker emitted by arc furnaces, depends on many different factors which may vary randomly, and exact prediction is therefore very difficult; consequently we must of necessity make a forecast which contains a certain margin of uncertainty.
In any case, the aim is to define viability of the proposed connection without exceeding the limits of the standard and to accept the connection subject to any corrective measures considered necessary and at an individual emission limit as a contractual condition.

Once the furnace is installed and in operation as agreed, the individual flicker it produces must be measured.

Measurement of the flicker in the Common Connection Point must last one week and what we measure is the flicker produced by all the furnaces impacting this PCC.

The method set out below allows the flicker produced by one particular furnace to be distinguished from among several furnaces operating in electrical proximity.

2.- MEASUREMENTS TAKEN

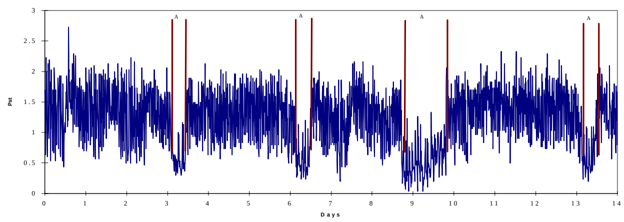
The measurements set out below were made with a flicker meter in accordance with CEI 60868, with a total measurement period of 2 weeks.
In the three channels available, the flicker has been recorded for the following phase-phase voltages.

- V_{12} of Furnace 1 (30 kV step bars)
- V_{12} of Furnace 2 (30 kV step bars)
- V_{12} of the connection point at 220 kV

The 30 kV bars are mutually independent, although they are supplied from the same 220 kV line.

The result of the flicker measurement is shown in Figure 1. The Pst99% recorded is 2.327 and corresponds mainly to the flicker generated by the arc furnaces of Customers A, B and C, with small contributions from Customer D and 4 large furnaces in a neighbouring province.

Figure 1: Flicker measured over 2 weeks



During most of the measuring period, Customers A and B's operations coincided, and the flicker generated by the two is therefore mixed. Only at peak times on working days and on 1 May can the flicker generated by Customer A alone be distinguished.
In order to evaluate the flicker generated by Customer A, without including the flicker generated by other customers, the following factors were taken into account:

- Flicker recorded at Customer A's connection point.
- Flicker recorded in Customer A's 30 kV 30 kV step bars.
- Evolution of short-circuit power in Customer A.
- Electric load of Customers A, B, C and D during measurement, obtained from Iberdrola's database.

3.- METHODS FOR ESTIMATING INDIVIDUAL FLICKER

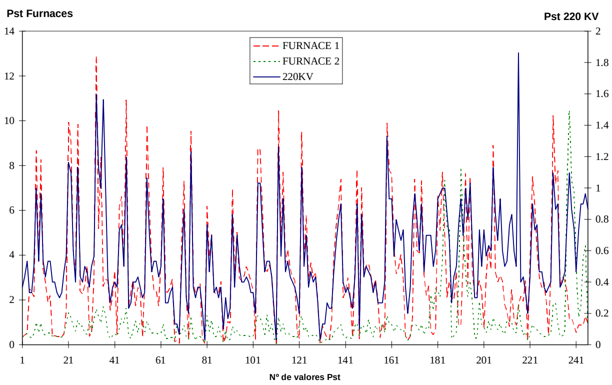
Three methods have been considered for calculating the flicker generated by Customer A.

3.1 Considering only times at which the other customers were not operating

For this purpose, times at which load of other customers was negligible were considered. It should be borne in mind that consumption never falls to zero, since other lower-power processes continue to operate, and the database uses a one-hour integration period.

Figure 2 shows the Pst in Customer A's connection point and 30 kV step bars at times when consumption by other customers was less than 20 MWh. The flicker values for 41 hours can thus be obtained.

Figure 2: Customer A flicker on the basis of load

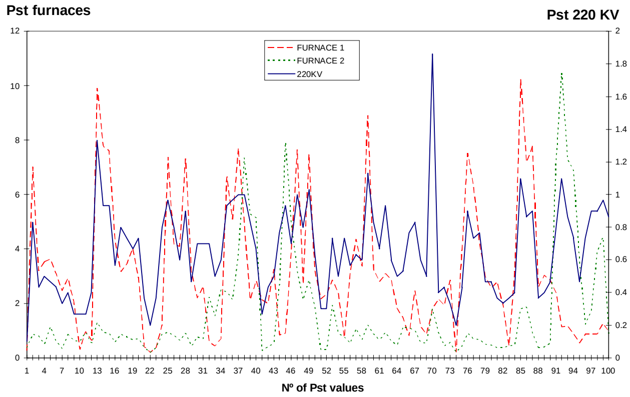


In general, a clearly visible correlation can be seen between the flicker in the 30 kV and 220 kV levels.

Nonetheless, some discrepancies exist, as we can see in Figure 3, which shows a detail of part of Figure 2. Flicker values can be seen at 220 kV which do not correspond to flicker generation at 30 kV. In particular, we can see:

- High flicker values in 220 kV (over 1.8) without generation of flicker by Customer A, since it can be seen in the 30 kV. These are caused by the nearby furnaces, over periods of time which are so short that when the load figures are integrated in periods of one hour, the result is very low. In order to prevent this problem, the minimum consumption limit would have to be lowered. Given that consumption never falls to zero, due to other loads in the factory, this would mean taking into account only a few dozen values, which would not be enough to evaluate the flicker emitted.
- Medium flicker values in 220 kV (between 0.4 and 0.9). These mainly come from other flicker sources which have not been taken into consideration, especially arc furnaces in neighbouring provinces.

Figure 3: Detail of Figure 2, last 100 Pst values



In conclusion, it can be seen that in practise, this is not a useful way of making a precise flicker evaluation, since it requires:

- Measurement of all flicker sources in electrical proximity, whether or not they are from the same area, power company or voltage level. In this case in particular, it would be necessary to take measurements for at least 9 different arc furnaces.
- Measurement of consumption by the other furnaces independently of the rest of the factory loads.
- A very long period of time in order to obtain sufficient flicker values. The figure 2 shows the measurement with the greatest solo operating period recorded. Over 6 weeks of measurement, this case has arisen in less than 100 hours (approximately 4 days). In addition, it must also be taken into account that the values thus obtained do not represent normal operation of the furnace over the week, since in general they correspond to the same time bands on weekdays.

3.2 From the measurement in 30 kV and the short-circuit power

The flicker values in 30 kV step bars may be divided up into low and high ratio damping.
This ratio can be calculated in two ways, on the basis of the short-circuit power or from the flicker measurements.
The short-circuit power in 220 kV was obtained from the cases of a Power System Simulator PSS/E recorded by the Power System State Estimator, giving 1,683 values:

- The short-circuit power at the connection point, calculated during the measurement, varied between 4,358 and 5,298 MVA.
- The power in 30 kV, calculated from the 220 kV data, varied between 850 and 880 MVA.
- The flicker damping would lie between 5.13 and 6.02.
- Figure 4 shows the evolution of all these values. The stripe across the damping values that appears in Figure 5 represents the standard deviation of these values, with a minimum of 5.39 and a maximum of 5.66. The average value is 5.52.

Figure 4: Short-circuit power

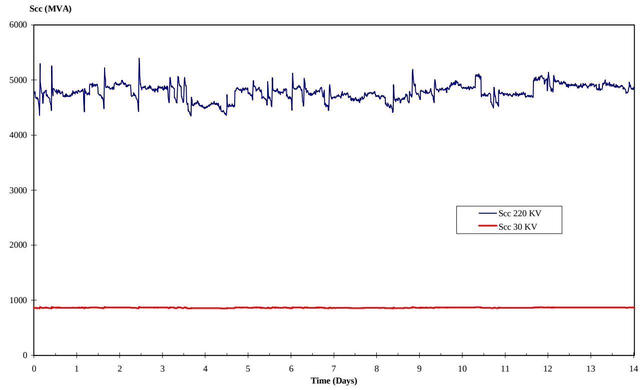


Figure 5: Short-circuit power ratio

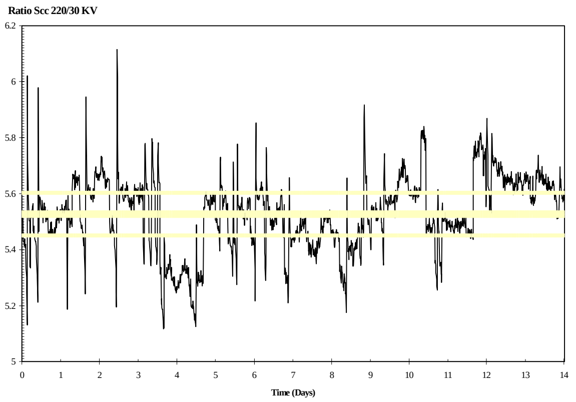
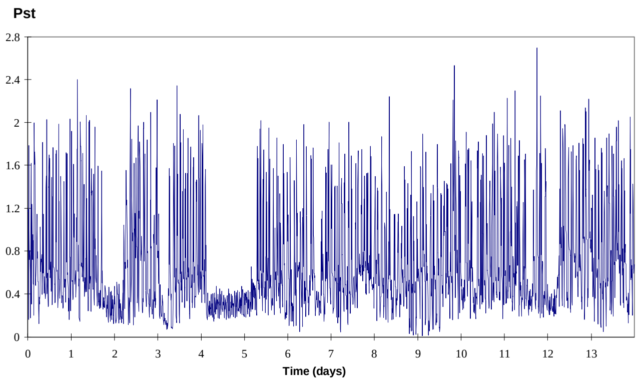


Figure 6: Flicker calculated on the basis of Scc



Using this data and presuming the sum of the flicker from Customer A's two furnaces to have α=3, the flicker shown in Figure 6 was calculated.

It can clearly be seen that the flicker calculated is very much greater than that measured at times when Customer A was operating alone, shown in Figures 1, 2 and 3.

Errors of about 50% can be seen and these are entirely unacceptable.

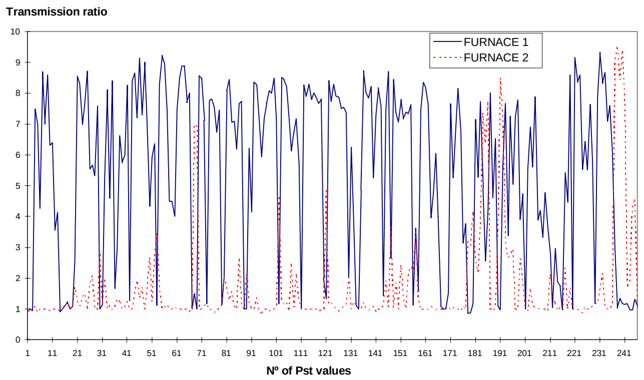
3.3 From the damping from 30 kV to 220 kV resulting from the measurement

Figure 7 shows the ratios of 30 kV step bars flicker to 220 kV flicker (Pst 30/Pst 220) at times when no flicker is coming from other sources.

A clear pattern can be seen in the damping for both Furnace 1 and Furnace 2.

- When they are not in operation, the damping is very close to 1.
- When they are in operation, they usually tend towards values higher than those calculated using the short-circuit powers.

Figure 7: Flicker damping (Pst) from 30 kV to 220 kV when only Customer A is operating



The values given are for times when only Customer A is operating, and cannot be considered representative of the entire measurement period. In addition, this type of study requires a more complex examination of the consumption of all flicker sources, as mentioned in the point above.

In order to solve this problem, this following starting points were taken into account:

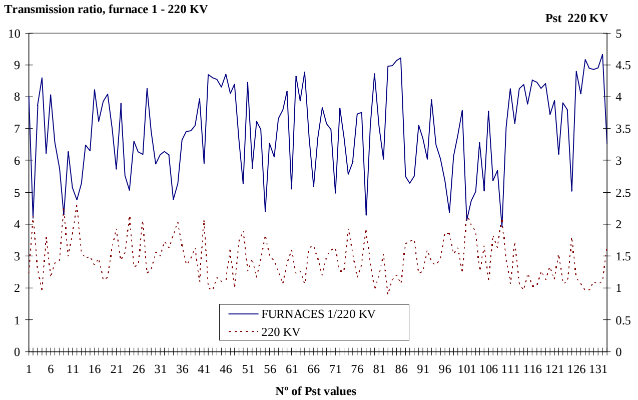
- The high flicker values in 30 kV step bars (Pst values of nearly 14 were reached) are independent of the network.
- Flicker coming from other customers may increase the flicker in 220 kV or leave it approximately equal, but never reduce it.
- From these two points it may be deduced that the influence of other customers can only lead to a reduction in the ratio of 30 to 220 kV flicker. The higher ratios are therefore the more reliable ones, because they are less influenced by the other 220 kV flicker sources.

Figure 8 shows the flicker damping for Furnace 1 and the 220 kV flicker, when the 30 kV flicker is greater than 8.

- Maximum damping rates similar to those of Figure 7 are obtained (up to 9.55).
- The minimum damping values coincide in all cases with Pst values of over 1.5 in 220 kV. They correspond to times at which various furnaces are operating simultaneously.
- The performance of Furnace 2 is similar.

It is clear that there is a damping of the flicker resulting from other loads in the network, is greater than the corresponding to the ratio of the short circuit powers. The damping will therefore be variable, depending on the loads connected to the network, and the maximum value may not be taken directly, given that even if it is exact, it represents a specific moment.

Figure 8: Flicker damping (Pst) from 30 kV to 220 kV over two weeks



This phenomenon needs to be examined in more general terms. In order to avoid coincidence with the operation of other furnaces, only the times at which the high flicker is lower than the values normally provided by other furnaces will be taken into consideration.

Figure 9 shows the damping for a Pst in 30 kV greater than 8, and a Pst in 220 kV less than 1.1. The resulting values correspond to different days and different times.

Other limits have likewise been set within the range:

- Pst in 30 kV between 3 and 14
- Pst in 220 kV between 0.4 and 1.3

In all cases distribution was similar to that in Figure 9, with a practically identical standard deviation, whenever 10 - 30 values are taken for each interval.

In all cases, the result is independent of the date and time and consistent with the values recorded at the times when – according to consumption – Customer A was operating alone.

Figure 9: Flicker damping (Pst) from 30 kV to 220 kV over 2 weeks

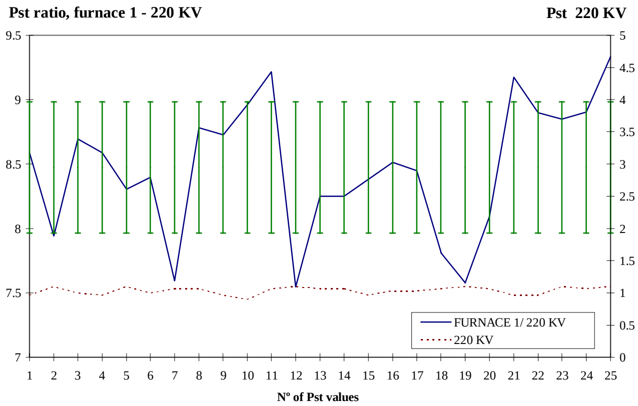
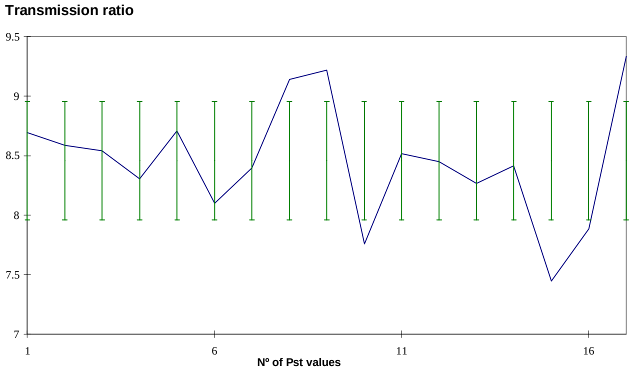


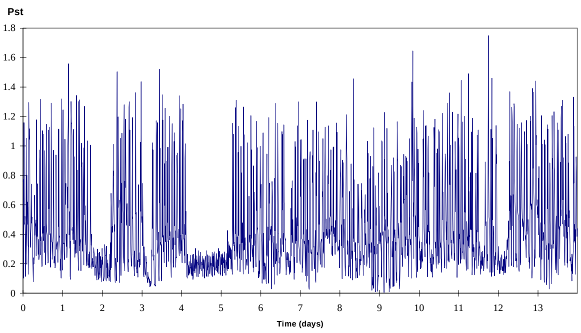
Figure 10: Flicker damping (Pst) from 30 kV to 220 kV with only Customer A operating



With the damping values obtained, the 220 kV flicker may be calculated by measuring the 30 kV values. This may be done without taking into account other flicker generators and only requires simultaneous measurements in both voltage levels, which can be performed with a single unit with more than one channel.

The values shown in Figure 11 were calculated in this way, taking a damping value of 8.5, which is the average of the values under consideration and ensures a maximum error rate of about 5% (precision margin required from a flicker meter by CEI 60868).

Figure 11: Flicker calculated on the basis of Damping = 8.5



4.- FLICKER TRANSMISSION TO MV SYSTEMS

Simultaneous measurements were taken using the same three-phase equipment in three voltage levels in a substation adjacent to several arc furnaces:

- 220 kV: supplies arc furnaces and transformers at 132 kV
- 30 kV: supplied from 132 kV. Meshed. Industrial use and for transformation to other 13 kV systems
- 13 kV: supplied from 132 kV. Small industry and domestic use.

Figure 12 compares the flicker in 220 kV (Pst) with the transmission ratios to the 30 and 13 kV systems. For greater clarity, only the first 100 values are shown, although the behaviour over the whole week is the same.

We can see:

- No flicker in 220 kV (Pst No. 1 at 66):
  - The ratio of flicker transmission to the 13 kV system lies either around 1 or around 1.3:
    - Transmission ratio of around 1: No important flicker in any of the systems.
    - Transmission ratio of around 1.3: The flicker in 13 kV is higher than that of 220 kV because the flicker in 132 kV is higher than that of 220 kV as a result of Customer D's operation.
  - The transmission ratio at 30 kV is generally 0.1 to 0.3 points below that of 13 kV, despite the fact that both are supplied from the same 132 kV system.

- With flicker in 220 kV (Pst No. 67 at 100):
  - The ratio of flicker transmission to the 13 kV system falls to values below 0.8.
  - The ratio of flicker transmission to the 30 kV system falls to values of about 0.6.

Given that the transmission values are only relevant when there is flicker generation in 220 kV, we shall take the values for the times at which the 220 kV makes the flicker coming from the other points negligible. For this purpose a value of Pst > 1.8 has been taken.
Figure 13 shows the transmission ratios in these cases, with a fourth degree polynomial trend line. The transmission ratios can be seen to be as follows:

- from 220 kV to 13 kV: 0.75
- from 220 kV to 30 kV: 0.6

Figure 14 compares the flicker in 13 and 30 kV, showing the ratio between the flicker in the two systems over the complete measuring period (1 week).

It can be seen that most of the time the ratio of the Pst values of the two systems lies between 1.1 and 1.3.

Figure 12: Flicker transmission generated in 220 kV at lower levels.

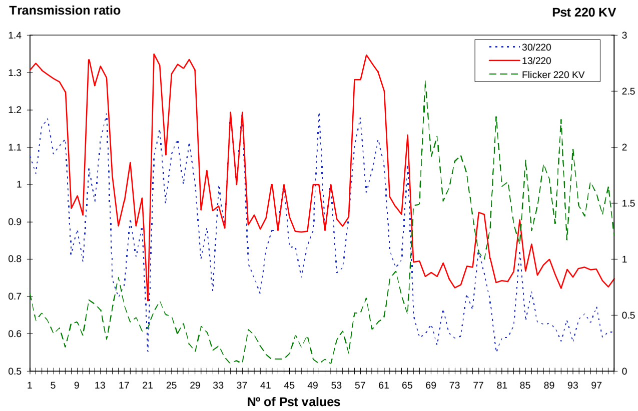


Figure 13: Transmission ratio

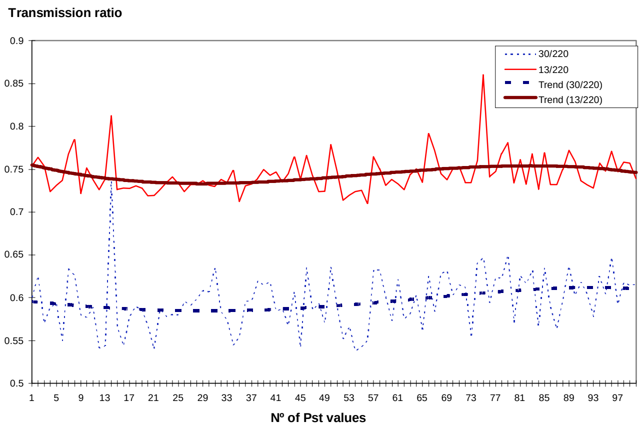
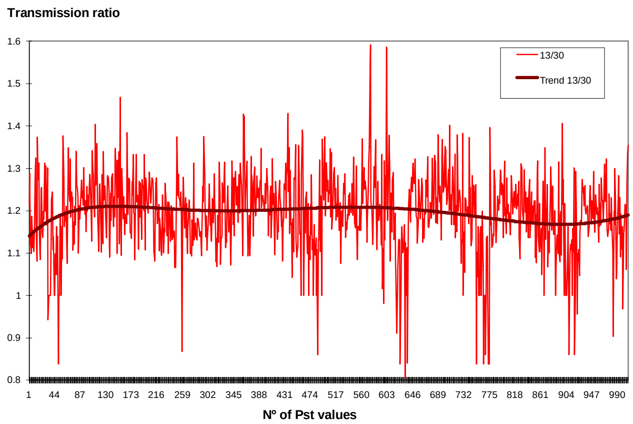


Figure 14: Ratio of 13 to 30 kV flicker (Pst). Measurement taken over 1 week.



From the above it may be deduced that the industrial loads, which predominate in 30 kV, damp the flicker around 20% more than the domestic and small industry loads supplied by the 13 kV system.

5.- CONCLUSIONS

The flicker generated by Arc Furnaces is a complex phenomena and affects to HV and EHV systems and, as a result, to several MV and LV systems fed by them. The flicker is generated by the irregular behaviour of the electric arc in the furnace and is transmitted to the public network.

This type of flicker is not a single voltage modulation, as in the case of LV loads, but a combination of various components. It has been proved that the load flow calculation does not represent exactly the flicker transmission, making necessary statistical approaches to calculate the flicker transmission.

When several Arc Furnaces are connected to the same network there is a flicker addition in the network, that follows complex summation laws. Since most of the Arc Furnaces are usually of a similar sizes and use similar technologies the flicker emitted by each of them is similar too. Likewise, most of them work simultaneously.

Moreover, the contribution of each Arc Furnace to the HV system is not necessarily the same as its contribution to the MV or the LV systems, since there is a flicker reduction in the transmission, due mostly to the loads connected to MV.

All these circumstances, make very difficult to assess the part of the flicker corresponding to each Arc Furnace.

Three methods have been presented for calculating the flicker generated by a customer.

- Considering only times at which the other customers were not operating is not a useful way of making a precise flicker evaluation, since it requires very long and complex measurement of all flicker sources in electrical proximity.
- The flicker values calculated from the measurement in MV and the short-circuit power of HV and MV are much greater than actual values, with unacceptable errors of about 50%.
- The most accurate results can be achieved taking into account the damping from MV step bars to HV resulting from the measurement. With the damping values obtained, the HV flicker may be calculated by measuring the MV step bars values. This may be done without taking into account other flicker generators and only requires simultaneous measurements in both voltage levels.

The flicker transmission to MV depends on the behaviour of system loads:

- The ratio of flicker transmission to a MV system that feeds domestic and small industry falls to values about 0.75.
- The ratio of flicker transmission to a MV system that feeds medium and heavy industry falls to values of about 0.6.