CUSTOMER FLICKER EMISSION ASSESSMENT: A NEW METHOD BASED ON RMS VALUE MEASUREMENTS

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ABSTRACT
The present paper presents a simple and novel method for flicker source assessment. The method needs small volume of on-site data recordings; it is based on electromagnetic transient simulation with recorded customer load impedance variations and simplified IEC flicker meter emulator. The method makes it possible to assess flicker emission with fast monitoring electric RMS values. It may be used by system operators to perform flicker assessment with their available power quality monitoring data.

Index Terms - IEC flicker meter emulator, full wave detector, flicker assessment, flicker source models, Pst, Plt.

INTRODUCTION
The authors [2][3][4] have studied a number of methods in flicker assessment and shared their rich experience in determination of customer flicker emission levels. These methods include simple flicker on-site measurement, correlation with power measurement, direct on-line voltage and current measurements.

In this paper, we propose another flicker source detection method based on RMS value measurements and IEC flicker meter algorithms. The method uses numeric simulation of upstream grid, recorded customer impedance variations and simplified IEC flicker meter emulator integrated in a power quality software. This method estimates flicker value with taking into account grid impedance, customer active and reactive power variations. In the following sections, the proposed method will be presented and analyzed with an actual case study.

FLICKER SOURCE DETECTION BY ON-SITE MEASUREMENTS AND SIMULATION

Principle of the method
This approach includes two actions: on-site measurement and electromagnetic transient simulation with IEC flicker meter emulation. Firstly, on-site measurement is carried out at PCC of the investigated customer in order to record RMS electric values: voltage $U$, active power $P$ and reactive power $Q$. An electromagnetic transient simulation is then performed on an artificial simulation circuit including a fictitious equivalent upstream grid model seen from PCC, a flicker meter emulator and a dynamic load impedance defined by the recordings (Fig. 1). During the simulation, the flicker meter emulator will compute flicker severity in $Pst$ values that correspond to the customer contribution on flicker level at the PCC.

![Fig. 1. Principle of flicker assessment with measured customer powers and equivalent grid model](image)

During electromechanical transient simulation, the variation of customer equivalent impedance $R_c + j X_c$ will cause voltage variation $U_c$ at PCC.

$$U_c = U_0 - \tilde{I}_c \cdot (R_g + j X_g)$$  

(2)

where $\tilde{I}_c$ is the current vector caused by customer power in the equivalent upstream circuit.

In fact, the voltage $U_c$ is the voltage that would appear at the PCC if the customer’s installation were the only disturbing installation in the system. As an IEC61000-4-15 flicker meter emulator is used to compute $Pst$ from $U_c(t)$, on-site recording duration should cover at least 10 min. However, if the customer load variation has a fast repeating profile, the on-site measurement duration could be shorter than 10 min. In this case, the flicker meter will extrapolate
the phenomenon to 10 min in order to get one Pst value.

The principle of this method is based on the following basis and assumptions:

- No resonance with grid at flicker’s frequencies because flicker phenomenon concerns only the voltage fluctuation whose frequencies are lower than 35 Hz.
- A reasonable grid background flicker level can’t cause important variations on customer powers P and Q as grid voltage fluctuation is normally low. Consequently, customer power variation resulted from upstream voltage fluctuations is considered as neglected.
- Voltage change crossing grid impedance is purely calculated by simulation tool with measured customer voltage, active and reactive powers and equivalent grid model at PCC. This voltage change is then used to calculate flicker level that is considered the customer contribution.

**Application procedure**

Application of this method needs on-site measurements and IEC flicker meter emulator in a power flow or frequency domain software with electromechanical transient analysis (time domain software is naturally compatible, but computation time will be longer in flicker assessment). The main idea here is to obtain, by simulation with on-site measurements, the emission voltage that would appear at main point of common coupling (PCC) if the upstream voltage were pure sinusoidal wave form. The emission voltage is then fed into the flicker meter emulator in the same simulation circuit in order to get customer flicker contribution level Pst_ct.

Following steps show how to use the proposed method in flicker source assessment:

- Record voltage U, powers P and Q every cycle or every half cycle (for example, 10ms for 50Hz system) during a significant period. This is a key point to get customer impedance variation profiles. Customer load variation can be also modeled by manufacturer’s data if it is available. In this case, on-site measurement is not necessary.
- Build all necessary components of upstream grid (case where a grid database is available) or create a fictitious grid: a Thévenin equivalent circuit with an ideal sinusoidal voltage source and an impedance calculated by short-circuit powers at PCC. The magnitude of the voltage source should be defined by load flow simulation with rated voltage and powers at PCC (phase angle of this voltage source don’t play any role in this assessment method),
- Define angle of upstream impedance according to grid characteristics if using a fictitious grid model,
- Insert an IEC flicker meter emulator at PCC,
- Create customer dynamic load model: variable impedance calculated by measured voltage U at PCC and measured customer powers P and Q,
- Start simulation with measured U, P and Q as input values and the emission voltage U_e will be calculated at PCC,
- Finally, the emission voltage is applied to the embedded IEC flicker meter emulator to obtain the flicker emission level Pst_ct.

**Simplified IEC61000-4-15 flicker meter emulation**

Another key point in implementing this method is the use of an IEC flicker meter emulator that is composed of all blocks of IEC61000-4-15 [1] (Fig. 2).

The original input of block 2 of IEC flicker meter must be instantaneous voltage value. Necessary modifications have to be done in order to accept directly RMS value at block 2. As a matter of fact, if using RMS values as input, the original squaring demodulator becomes inefficient. For this reason, we have added a full wave bridge detector in block 2 of IEC flicker meter in order to complete the original squaring demodulator. Full-wave bridge detector is an envelope detector used in AM radio receiver since long time. Its principle is the same as a full bridge rectifier. In practice, a numeric full wave demodulation needs just an absolute value computation followed by original LP and HP filters in block 3, so that computation time is shortened and particularly there is no extra double frequency component as in a squaring demodulation process [5]. This is the key point to extend IEC flicker meter into a general power quality assessment tools.

![Fig. 2: Function blocks 2 to 5 of IEC61000-4-15 flicker meter](image)

![Fig. 3: Principle of squaring detector and full-wave detector in block 2 of modified IEC flicker meter emulator](image)
IEC compliance tests of proposed flicker meter emulator

Table 1 gives Pst values of the two types of flicker meter emulator tested with recommended Pst=1 square wave signals by IEC61000-4-15. The flicker meter emulator with RMS value input is almost compliant with IEC61000-4-15.

<table>
<thead>
<tr>
<th>Voltage changes per min</th>
<th>Amplitude dV/V in %</th>
<th>With wave form input</th>
<th>With RMS value input</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.715%</td>
<td>0.9997</td>
<td>0.9999</td>
</tr>
<tr>
<td>2</td>
<td>2.191%</td>
<td>1.0009</td>
<td>1.0019</td>
</tr>
<tr>
<td>7</td>
<td>1.45%</td>
<td>1.0038</td>
<td>1.0170</td>
</tr>
<tr>
<td>39</td>
<td>0.894%</td>
<td>1.0025</td>
<td>1.0183</td>
</tr>
<tr>
<td>110</td>
<td>0.722%</td>
<td>1.0037</td>
<td>1.0018</td>
</tr>
<tr>
<td>1620</td>
<td>0.407%</td>
<td>1.0018</td>
<td>1.0105</td>
</tr>
<tr>
<td>4000</td>
<td>2.343%</td>
<td>1.0007</td>
<td>0.9013</td>
</tr>
</tbody>
</table>

In the last test of 4000 voltage changes per min (33Hz), Pst error is about 10%. This is owing to the low sampling frequency in RMS value recordings (i.e. 100Hz for half cycle RMS measurements in 50Hz system). Pst computation error increases when flicker frequency is greater than 25 Hz. In power grid flicker assessment, it is acceptable as the main frequency range of most industrial flicker loads such as motor starting and welding machine is lower than 25Hz.

Needs in on-site measurements

In order to guarantee the necessary accuracy in flicker assessment, RMS values should be recorded with sampling period as small as possible, one RMS value each half cycle of fundamental frequency if possible. In practice, some power quality monitoring systems have already high sampling rate in RMS value recordings (one cycle value, 10 cycle value for example). It may be possible to use directly the proposed method to perform flicker assessments by analyzing power quality monitoring data. For low frequency repetition phenomenon as motor starting, even 100 ms RMS value can be used in flicker assessment.

Back ground flicker estimation

As another benefit of the proposed method, it would be possible to calculate grid background flicker level. During the site recording of customer voltage and powers, if the total flicker value Pst_tl at PCC is measured or calculated with measured voltage variation. The background flicker level Pst_bg could be estimated by cubic summation law (3) as recommended by IEC61000-3-7.

\[
Pst_{\text{bg}} = \sqrt[3]{Pst_{\text{tl}}^3 - Pst_{\text{ct}}^3} \quad (3)
\]

**Upstream short-circuit power checking**

With measured total flicker level Pst_tl and simulated customer flicker contribution Pst_ct, it would be possible to check the certitude of short-circuit power Ssc_u used in the simulation.

Case 1: back ground flicker level is negligible

If the back ground flicker at PCC is very small (Pst < 0.35 for instance), it is practically negligible. In fact, with a constant load power variation, simulated Pst_ct is inversely proportional with upstream short-circuit power. We can use Pst_ct and Pst_tl to check the actual short-circuit power Ssc_a at PCC:

\[
S_{sc-a} = S_{sc-u} \frac{Pst_{\text{ct}}}{Pst_{\text{tl}}} \quad (4)
\]

Case 2: back ground flicker level is not negligible

If simulated customer flicker emission Pst_ct is greater than measured total flicker at PCC, upstream impedance value should be checked, its magnitude or angle may be incorrect. That means the used short-circuit power Ssc_u at PCC may be wrong. In this case, if doing extrapolation simulation compared to the measured flicker level Pst_tl, we can estimate actual grid short-circuit power Ssc_a at PCC:

\[
S_{sc-a} \geq S_{sc-u} \frac{Pst_{\text{ct}}}{Pst_{\text{tl}}} \quad \text{if } Pst_{\text{ct}} > Pst_{\text{tl}} \quad (5)
\]

However, (5) can’t be applied if Pst_ct < Pst_tl. In this case, it is impossible to know whether this difference in Pst value comes from an incorrect upstream short-circuit power value or a high back ground flicker level.

**Case study**

A number of case studies have been performed by ExpertEC (EDF R&D software for power quality assessment and mitigation [6]) with embedded flicker meter in order to validate the proposed method. Following case study is to estimate flicker level at PCC (MV level) caused by a LV welding machine of a customer (Fig. 5). On-site measurements have been performed at secondary side of customer transformer during 10 min; sampling cycle of RMS values is 20 ms (one cycle for 50 Hz system).

- Power supply of the customer at PCC: 20kV, 50Hz, short-circuit power Ssc = 50MVA, upstream impedance angle R/X=0.18,
- Customer transformer: 1000 kVA, 20kV/410V, short-circuit impedance Zsc=6%,
- Customer flicker load: welding machine, 650kVA.
The customer load is modeled by a dynamic impedance calculated from on-site measurements $U$, $P$ and $Q$ at LV bus bar. The customer transformer has to be modeled between PCC and LV measuring point in order to calculate customer flicker emission level at PCC.

At the moment of the site recording, total flicker value at PCC ($P_{st\_tl}$ in Fig. 4) has been measured by an on-site IEC flicker meter, it may be possible to estimate background flicker level $P_{st\_bg}$ by (3). For this case study, $P_{st\_tl}$ is about 1.37 at the moment of on-site recording. The back ground flicker level is estimated:

$$P_{st\_bg} = \sqrt[3]{1.37^3 - 1.353^3} = 0.455$$

**Which voltage should be used in load model calculation**

In the above case study, both of customer RMS voltage and fundamental voltage has been recorded during the on-site investigation. The flicker assessment indicated in Fig. 5 have been obtained by using measured fundamental voltage. Another simulation has been performed with measured RMS voltages including all frequencies. The maximum $P_{st}$ difference between these two sets of simulation is lower than 0.2% at MV level. It is concluded that the choice of RMS voltage or fundamental voltage has no significant influence on flicker estimation for this type of load profile.

The method has been applied to flicker assessment in several load profiles: spot welder, direct-line motor starter and electric arc furnace with promising results. In case of application on high harmonic content loads, the flicker assessment error may be important because this method only computes voltage changes at fundamental frequency. If harmonic powers are not negligible, multi-frequency computations are necessary, i.e., to perform at each simulation step multi-frequency computation to get adequate voltage variation.

**CONCLUSION**

The proposed assessment method based on RMS values has been detailed and applied to some actual case studies with promising results. The method is a mixed approach using both on-site measurements and IEC flicker meter emulation. This method makes it possible for utilities to perform flicker assessment with their available monitoring data with very low computing burden.

Flicker meter with RMS input is a modified version of IEC flicker meter and its accuracy is sufficient in grid flicker assessment. The modified flicker meter can be easily integrated into a power quality or a load flow software.

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**REFERENCES**