Determination of Flicker Source at the Point of Common Coupling Using Flicker Energy

In this paper a new method for determination of flicker source in power system is proposed. This method is based on the energy of flicker signal; therefore, an expression for flicker energy signals is defined, which can be successfully utilized for detection of the flicker source. The main advantage of this method is its simplicity which can be implemented in time domain and no transformation to frequency domain is required. The validity and performance of this method is verified by simulation and experimental results.

Keywords: Flicker, Flicker Energy, Flicker Source.

1. INTRODUCTION

Flicker has been described as the impression of fluctuating luminance or color occurring when the frequency of the variations of the light stimulus lies between a few Hertz and fashion frequency of images. The fashion frequency of images varies from person to person and depends on many factors. Fluctuations in the system voltage can effectively create perceptible (low frequency) light flicker depending on the magnitude and frequency of the variation. The main causes of the flicker are loads that drawing large magnitude with high current harmonic contents variable due to the impedance of power system. These changes produce amplitude modulation of the voltage at the load bus and even at remote buses. Another common source of flicker is sudden starting up and shutting down of large electrical machines. The flickering of lights causes annoyance to human observers. Other reported effects of voltage flicker include: reduction life of electronic equipments, incandescent fluorescent and cathode-ray tube devices. Malfunction of phase-locked loops and loss of synchronism in Uninterruptible Power Supplies (UPS). Malfunction of electronic controllers and protection devices.

Voltage fluctuations caused by loads which vary repeatedly with a frequency between 0.001 Hz and 25 Hz cause irritating flicker phenomena. Voltage fluctuation is described as a cyclical variation of the voltage envelope or a series of random voltage changes. The amplitude of which does not exceed the range of permissible operational voltage changes mentioned. This phenomenon is one of the power quality problems which are measured according to various standards such as EN 50160 [1].

The so called short term and long term flicker severity $P_{st}$ & $P_{lt}$ in the standards gives information about the flicker level but it gives no information about the direction of the flicker source. Identification of the direction (upstream or downstream) of the flicker is of great interest for power quality researchers. The aim of this study is to develop analytical methods to determine the direction of flicker source with respect to measuring point in power systems. In [2] a method for separation of the flicker caused by customers has been proposed. Inserting a known reactance series in the current path and measuring the flicker of the voltage drop along the known reactance and knowing the short circuit impedance of the network, the flicker caused by this customer can be calculated. In [3] a method for identification of flicker source is proposed. In [4] few mathematical methods to determine the direction of flicker source are reviewed. According to relative amplitude of current and
voltage signals a simple method for determination of flicker source with respect to measurement point is presented in [5]. Using inter harmonic power direction a method to determine flicker source is suggested in [6]. Also [7]-[9] proposed an algorithm to detection of flicker direction based on flicker power. Authors of this paper propose mathematical methods to determine the direction of flicker at the point of common coupling in [10]-[12]. In this paper a fast and simple method for calculation of the direction to the flicker source is proposed which can be easily implemented in measuring instruments. One of the major advantages of this method is processing of data in real-time and therefore no transformation from time domain to frequency domain is required.

2. DESCRIPTION OF THE PROPOSED METHOD

The measurement methods for the model developed in [12] based on the following facts:

1) A flicker source will cause changes in the envelopes in both voltage and current at the monitoring point, in other words:
A flicker source will cause an amplitude modulation (AM) of the voltage and current signals at the monitoring point.

2) Changes in the voltage and current envelopes are 180 degrees out of phase if the flicker source is located below the monitoring point (flow direction of flicker is downstream).

3) Changes in the voltage and current are in phase if the flow direction of flicker is upstream.

Points 2 and 3 suggest it is possible to develop measurement methods, which can determine the direction of flicker source with respect to the monitoring point.

3. FLICKER ENERGY

The modulating signals \( m_u(t) \) and \( m_i(t) \) are represent the envelopes of the amplitude modulated signals, which are used for calculation of the flicker energy \( E \) which is defined as:

\[
E(t) = \int_{0}^{t} m_u(t)m_i(t) \, dt
\]  
(1)

For periodic signals \( m_u(t) \) and \( m_i(t) \) considering discrete-time sampled data, Equation.1 can be written as:

\[
E = \sum_{j=1}^{n} m_{uj}(t)m_{ij}(t)
\]  
(2)

The sign of \( E \) gives information about the direction of flicker. If the flow direction of flicker is upstream then the waveforms of \( m_u(t) \) and \( m_i(t) \) are in phase and flicker energy is positive. If the flow direction of flicker is downstream in regard to the monitoring point, the waveforms of \( m_u(t) \) and \( m_i(t) \) are 180 degrees out of phase and the flicker energy is negative.
4. THE METHOD FOR CALCULATING THE FLICKER ENERGY

This measurement method can be done in time domain. Fig.1 shows the proposed method, which is based on IEC 61000-4-15.

Blocks (1) and (2) are identical for both voltage and current signals. The modulating signals are recovered by square demodulation performed in block (1). The analogue transfer function of the band-pass filter used in block (2) is given in expression (3) and its coefficients are given in Table I.

\[
H(s) = \frac{K \omega_1 s}{s^2 + 2 \lambda s + \omega^2} \cdot \frac{1 + \frac{s}{\omega_2}}{(s + \frac{1}{\omega_2})(s + \frac{1}{\omega_4})}
\]

(3)

<table>
<thead>
<tr>
<th>(K)</th>
<th>(\lambda)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.477802</td>
<td>2\pi \times 4.05981</td>
</tr>
<tr>
<td>(\omega_1)</td>
<td>(\omega_3)</td>
</tr>
<tr>
<td>2\pi \times 9.15494</td>
<td>2\pi \times 1.22535</td>
</tr>
<tr>
<td>(\omega_2)</td>
<td>(\omega_4)</td>
</tr>
<tr>
<td>2\pi \times 2.27979</td>
<td>2\pi \times 21.9</td>
</tr>
</tbody>
</table>

The band-pass filter is implemented as a digital equivalent by bilinear transformation. Its transfer function is given by:

\[
H(z) = \frac{0.041 - 0.041z^{-2}}{1 - 1.9561z^{-1} + 0.9584z^{-2}} \times \frac{0.0292 + 0.003z^{-1} - 0.0289z^{-2}}{1 - 1.8852z^{-1} + 0.8858z^{-2}}
\]

(4)

A block diagram of the transfer function in Equation 4 is shown in Fig.3. The outputs of the band-pass filter are modulating signals weighted with the amplitude spectrum of the band-pass filter and then multiplied together which finally give the flicker energy.
5. SIMULATION

The Simulations of the proposed method have been done using the Simulink as shown in Fig.4.

The modulating voltage signals are used as reference signals with a phase of 0°. For the modulating current signals, the phases 0° and 180° are chosen. The modulating signal is a sinusoidal waveform with a frequency of 8.8 Hz corresponding to the peak response of the lamp-eye flicker in the standard IEC-61000-4-15. The input data sequence to the model consists of time discrete sampled data of voltage $u[n]$ and current $i[n]$ with sampling frequency $f_s$ of 409.6Hz. Simulations are presented in four different classes. It is notable that in Figs.5-8, the source of flicker has been correctly identified by the measurement. In Figs. 5 and 7 the flow direction of flicker is upstream as the flicker energy is positive and in Figs. 6 and 8 the flow direction of flicker is downstream as the flicker energy is negative.
Fig. 5-1. Voltage of high level modulation (30%) phase diff=0 degree

Fig. 5-2. Current of high level modulation (30%) phase diff=0 degree

Fig. 5-3. Flicker Energy of high level modulation (30%) phase diff=0 degree

Fig. 6-1. Voltage of high level modulation (30%) phase diff=180 degrees
Fig. 6-2. Current of high level modulation (30%) phase diff=180 degrees

Fig. 6-3. Flicker Energy of high level modulation (30%) phase diff=180 degrees

Fig. 7-1. Voltage of low level modulation (3%) phase diff=0 degree

Fig. 7-2. Current of low level modulation (3%) phase diff=0 degree
Other simulation model of the ON-OFF load is performed as shown in Fig. 9.
In this model a square wave generator (0V and 1V with 50% duty cycle) simulates the on-off-state load. The same square wave generator is also used as the modulating signal to the voltage. The results of the simulation are shown in Fig.10 and Fig.11. In the first simulation the envelopes of voltage and current signals are 180 degrees out of phase (producing negative flicker energy (Fig.10). In a second simulation, flicker energy is positive because the square wave signal, which modulates the voltage signal, is multiplied by (-1) which means the envelopes of voltage and current are in phase (Fig.11).

Fig. 10. Result of simulated flicker energy of the ON-OFF load. When envelopes of the voltage and the current signals are 180 degrees out of phase

Fig. 11. Result of simulated flicker energy of the ON-OFF load. When envelopes of the voltage and the current signals are in phase
6. EXPERIMENTAL RESULTS

To show the validity and effectiveness of the proposed method the experimental test has been done. The experimental results respectively obtained for two cases.

One case related to the data which registered at 19 December 2006 in the Chodan Pars feeder by ION7600 instruments. We know that in this case the source of flicker is the power network and it is shown from Fig.12 that this method can determine the flicker direction, correctly.

![Fig.12.a. Flicker voltage of phase A at 19 Dec. 2006](image)

![Fig.12.ab Flicker Energy of phase A at 19 Dec. 2006](image)

To consider another case which the flicker source is customer, we implement the presented method on the data registered at 28 November 2006 in the Nassaji feeder. In this case as it is shown in Fig.13 the flicker direction is downstream and the presented method can detect the source of flicker correctly.

![Fig.13.a. Flicker voltage of phase B at 28 Nov. 2006](image)
7. CONCLUSION

In this paper, a method for identifying the flow direction of flicker has been described. In this method, the monitoring point is defined as the point where waveforms of voltage and current are measured. By studying the modulating signals of voltage and current, the direction of the flicker source can be determined. In this paper a quantity called flicker energy is defined. The sign of flicker energy gives the flow direction of flicker. This algorithm is developed in time domain and simulation & experimental results prove the accuracy of this method.

References