Assess of the Flicker Caused by Electric Arc Furnace Using Simulation Method*

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Abstract. In order to assess the flicker caused by electric arc furnace, the simulation method to assess flicker and its application in electric arc furnace power system is studied. Firstly, based on the Flicker Meter functional and design specifications recommended by IEC, an IEC Flicker Meter is designed concretely; Secondly, an IEC Flicker Meter model is established in SIMULINK, and a special M file which can be used to calculate the short term flicker sensation indicator (P_{st}) is compiled, according to the IEC criterion, the Flicker Meter model is tested; Finally, assess of the flicker caused by an actual electric arc furnace is achieved, the instantaneous flicker sensation *S(t)* in the point of common coupling is gained. The results show that application of simulation method to assess the flicker caused by electric arc furnace is an effective way.

Keywords: Electric arc furnace, voltage fluctuation and flicker, Flicker Meter, simulation.

1 Introduction

When impact load of high power connected to power grid of relatively small capacity, such as electric arc furnace, mine hoist, heavy merchant mill, heavy electric welding machine as well as electric locomotive, voltage fluctuation will be caused, which will undermine other electric equipments which are connected to the point of common connection. With the wide application of the above mentioned impact load of high power, as ref. [1], voltage fluctuation and flicker has become one of the key indicators to measure the power quality of the grid.

Electric arc furnace (EAF) is not only a major facility in steel factory but also one of the super impact loads of single capacity in the power supply system. The components of voltage fluctuation frequency due to EAF is mainly distributing in 4~14Hz band,

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which is precisely in the visually sensitive areas of human beings. Therefore, among all sorts of impact load, EAF has the most severe impact on voltage fluctuation and flicker as shown in ref. [2]. The regulations from home or abroad on voltage fluctuation and flicker limits are specific about EAF. Generally, the terms can be applied to all the other types of loads if they can meet the requirements of EAF. In order to improve or inhibit the voltage fluctuation and flicker caused by EAF, some relevant compensation facility such as SVC which is needed to be used in the power grid. Because accurate flicker values are needed for the research and setting of these devices, the accurate measurement or estimation to flicker value is the prerequisite for solving the problem of voltage fluctuation and flicker.

The flicker severity caused by EAF can be directly measured by Flicker Meter or estimated by simulation method. As shown in ref. [3-7], the research and application of Flicker Meter has been the focus of experts from home and abroad. In recent years, there are literatures (ref. [8-11]) on flicker simulation method emerged, but most of them are only focusing on the simple simulation method research. And literatures of further studies on application have been rarely involved, so they are not supposed to guide the practical application. In addition, the accurate signal of voltage fluctuations which can be obtained through simulation system is a prerequisite for the application of simulation method. The accuracy of the signal depends on the mathematical model of load characteristics. The signal can also be obtained through analysis of field measurement data. When the waveform of voltage fluctuations is recorded, waveform of any time-domain can be divided into a series of residential section of signals which are input to the flicker simulation measurement system for data processing. And finally get the results of instantaneous flicker sensation level $S(t)$ and other short-term flicker value P_{st}.

2 IEC Flicker Meter

The designing standards of the Flicker Meter recommended by IEC only provides schematic diagram and design specifications, without mention of the specific design details and design parameters. Therefore, understanding the physical sense of the input and output signals of each part in the flicker measurement system correctly and setting specific technical details in each part become the priority of the research of flicker measurement system. The schematic diagram of the Flicker Meter recommended by IEC61000-4-15 (ref. [12]) is shown in Figure 1.

In figure 1, the frame 1 is an input adapter link with fluctuant voltage signal input. It is used to reduce the input voltage of different levels to the level applying to internal circuits.

The frame 2-4 simulate of the reaction of light- eye-brain to the voltage fluctuation. Among which, frame 2 simulate the function of light, realizing square demodulation to the voltage fluctuation component and obtaining the voltage signal in linear relation with component of the voltage fluctuation.

The band-pass weighting filter part of the frame 3 is made up with a band pass filter and a visual sensitivity weighting filter in series, which reflect the sensitivity of the illuminance change of tungsten filament lamp of 60w, 230v in the voltage fluctuations

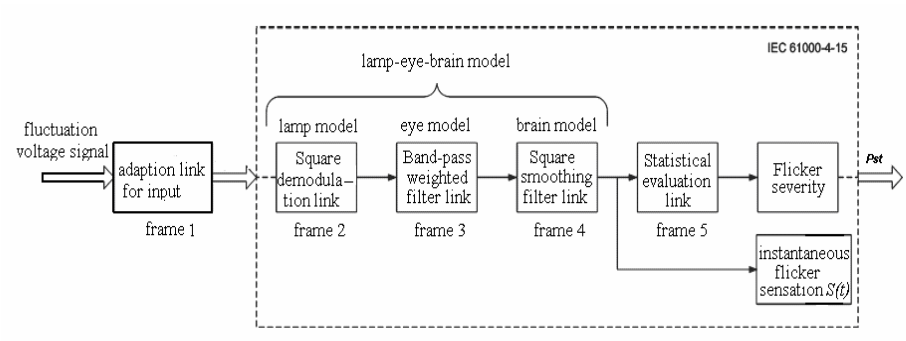

Fig. 1. Schematic diagram of IEC flickermeter

of different frequencies. The band-pass filter consists of a high-pass filter and a low-pass filter with the frequencies 35Hz and 0.05Hz correspondingly. The transfer functions of the two filters are listed in equations (1) and (2). The transfer function of the first-order high-pass filter with the cutoff frequency of 0.05Hz is as follows.

$$H_P(s) = \frac{s/\omega}{1+s/\omega} \tag{1}$$

Where, ω=2π0.05. The transfer function of the low-pass filter with a cut-off frequency of 35Hz which select the 6-order Butterworth filter is shown in equation (2).

$$Bw(s) = [1+\sum_{i=1}^{6} b_i (\frac{s}{\omega})^i]^{-1} \tag{2}$$

Where, ω=2π×35, b1=3. 864, b2=7. 464, b3=9. 141, b4=7. 464, b5=3. 864, b6=1.

The visibility weighting filter in frame 3 is used to simulate the frequency selectivity of the human eyes. The center frequency is 8.8 HZ and the transfer function is shown in equation (3).

$$F(s) = \frac{k\omega_1 s(1+s/\omega_2)}{(s^2+2\lambda s+\omega_1{}^2)(1+s/\omega_3)(1+s/\omega_4)} \tag{3}$$

Where, k=1.74082; λ=2π4.05981; $\omega 1$=2π9.15494; $\omega 2$=2π2.27979; $\omega 3$=2π1.22535; $\omega 4$=2π21.9.

Frame 4 contains a square and a low-pass smoothing filter with the time constant of 300ms. The transient and nonlinear response and memory effect to the illuminance of the light are simulated for the light-eye-brain parts. The low-pass smoothing filter transfer function is shown in equation (4).

$$L_p(s) = \frac{1}{1+0.3s} \tag{4}$$

It should be noted that in order to obtain the instantaneous visual sensitivity *S(t)*, which reflects the flicker of the voltage fluctuations of human's, further processing for the output signal from the first order low-pass smoothing filter is needed.

Cumulative Probability Function (CPF) method is used in frame 5 to make statistical estimation of the flicker. Flicker value of P_{st} in short time (10 min measurement time) is commonly used as indicator to flicker evaluation, the value of which defined by IEC is shown in equation (5).

$$P_{st} = \sqrt{0.0314P_{0.1} + 0.0525P_1 + 0.0657P_3 + 0.28P_{10} + 0.08P_{50}} \tag{5}$$

Where, P0.1, P1, P3, P10, P50 are all visual sensitivity values *S(t)* obtained within 10 minutes by using CPF values exceeding 0.1%, 1%, 3%, 10% and 50% of the time respectively.

3 Simulation Models and Verification of the IEC Flicker Meter

According to the transfer function and specific parameters in each part of the above IEC Flicker Meter, the Flicker Meter simulation model is established using SIMULINK, which is showed in Figure 2. The system input of the figure is the component of the amplitude modulated wave signal of the fluctuation voltage, the output of which is the instantaneous flickering sensitivity *S(t)*.

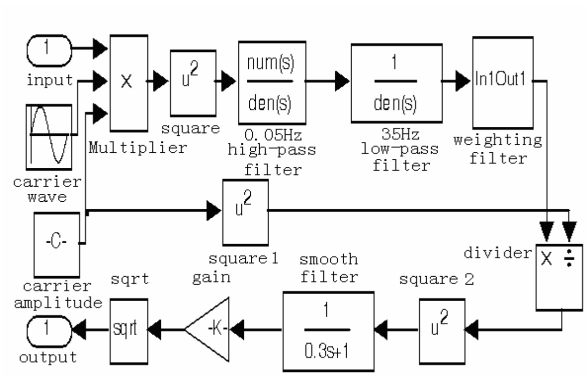

Fig. 2. Simulated model of Flicker Meter

To verify the validity of simulated model of the Flicker Meter, the input signal of the voltage signal is assumed as u (t), which is shown in (6).

$$u(t) = 230\sqrt{2}\left[1 + m\cos(\Omega t)\right]\cos(\omega t) \tag{6}$$

Where, m is the ratio between the peak amplitude modulated wave value and the peak rated voltage value, whose value equals to half the value of the voltage fluctuations $\Delta U/U$; *Ω* is the frequency of the amplitude modulation wave angular whose value equals to $2\pi k$, where *k* is the wave frequency and *ω* is the frequency of the power frequency angular .

With the system simulation testing time of 10 minutes, and the data of the voltage fluctuation of the sine amplitude modulates wave when *S(t)* =1 according to IEC, the input signal of the voltage fluctuation is constructed to verify and simulate the value of $S(t)$ shown in table1. According to the calculated relative errors between the simulation results and the theoretical value of $S(t)$, the relative errors remains between $\pm 5\%$ that is well compliant with the accuracy requirements listed in the standard of IEC. Therefore, the validity and availability of the simulation system model of the Flicker Meter is proved.

Table 1. Proof of the IEC Flicker Meter model

Fluctuation frequency	Fluctuation Value (%)	simulation value S(t)	Relative error (%)
1.0	1.432	0.952	-4.8
3.0	0.654	0.985	-1.5
5.0	0.398	0.997	-0.3
6.0	0.328	0.998	-0.2
6.5	0.300	0.998	-0.2
7.0	0.280	0.998	-0.2
7.5	0.266	0.998	-0.2
8.0	0.256	0.998	-0.2
8.8	0.250	0.998	-0.2
9.5	0.254	0.998	-0.2
10.0	0.262	0.997	-0.3
10.5	0.270	0.997	-0.3
11.0	0.282	0.996	-0.4
11.5	0.296	0.995	-0.5
12.0	0.312	0.997	-0.3
13.0	0.348	0.997	-0.3
16.0	0.480	0.997	-0.3
18.0	0.584	0.999	-0.1
20.0	0.700	0.999	-0.1
25.0	1.042	1.011	1.1

By outputting the sample value of $S(t)$ obtained from the flicker testing system to “sw.mat” file by the “To File” module, the P_{st} value is calculated based on the method of CPF and M file compiled by MATLAB.

4 Evaluation of the Flicker Severity Caused by Electric Arc Furnace Using Simulation

By applying the established model of Flicker Meter and the stochastic model of the arc furnace proposed by the author, the voltage fluctuation and the flicker severity caused by the arc furnace can be evaluated in a simulate way. Then the instantaneous flicker sensitivity value *S(t)* of a common connection point (PCC) of the power supply system with arc furnace in a certain steel mill is obtained.

Based on the sampling value *S(t)* from the "sw.mat" file, five eigenvalues of the instantaneous flicker sensitivity are obtained when running the M file. The five P_{st} are as followed: P0.1, P0.2, P0.3, P0.4, P0.5, are respectively 1.7130, 1.6299, 1.5301, 1.3305, 1.0146. The value of P_{st} obtained by composing above figures into equation (5) is 0.8328. It is obvious that the flickering value of P_{st} in short-time caused by the arc furnace is a little higher than international standard (On the condition of HV, the limited value of P_{st} is 0.8) .Therefore, proper measures are needed to take to inhibit the question of voltage fluctuation and flicker caused by the arc furnace.

5 Conclusion

Based on the flicker measurement principle recommended by IEC, the transfer function and specific parameters of each session in the IEC Flicker Meter are designed to facilitate understanding the physical meaning of the input and output signals of each session in the IEC Flicker Meter. In the flicker measurement system model established in SIMULINK, the simulated value of *S(t)* is obtained by constructing the input voltage fluctuation signal according to the inspection standards recommended by IEC. And the relative error between the simulated value and the theoretical value keeps below $\pm 5\%$, which is absolutely accords with the requirement mentioned in the standard of IEC. Meanwhile, the experimental results show that this simulated system model of the Flicker Meter is valid and effective.With reference to the stochastic models of the AC arc furnace, flickering severity caused by arc furnace is researched. It is shown that it's available and effective to evaluate the flicker severity caused by arc furnace by using the simulation method, which also provides a new effective way to evaluate the flickering severity.

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