Establishment of Inter-harmonic Flicker Curve for Fluorescent Lamp

Cao Huiyan, Wu Tong, Tao Shuyi, Sun Jie, Tian Zhili, Zhao Qiang, Cui Jia, Gao Linze

Fushun Power Supply Company, Liaoning Electric Power Company Limited, State Grid, China

Keywords: inter-harmonic; flicker; curve; experimental platform; fluorescent lamp

Abstract. In order to analyze the inter-harmonic affections on the voltage flicker, the relationship between the inter-harmonics and flicker analysis are carried out. In order to be able to accurately determine the level of inter-harmonics to make the electric light flicker, inter-harmonic-flicker limit curve drawing method based on the voltage flicker constraints is established. Analog tester flicker and inter-harmonic-flicker experimental platform are built; limit curve can be drawn through the experimental data. The 2 kinds of harmonic-flicker limit curves for the 220 V, 50 Hz fluorescent lamp are drawn by the 2 methods separately, and the analysis results show that the accuracy of the results obtained by the two methods, the level of inter-harmonics whether lead to fluorescent flicker can be determined by the curves. The methods have the small amount of calculation, and are practical and easy to implement.

Introduction

With the extensive use of nonlinear and fluctuating load in power system, the inter-harmonic generated by which adversely affect to power system increasingly, and the most representative is the impact of inter-harmonic on voltage fluctuation and flicker [1-3].

The research on the impact of inter-harmonic on voltage fluctuations can be taken by superimposing inter-harmonic frequency signal on the voltage signal and examining the quantitative changes of voltage fluctuation and voltage frequency [4, 5]. However, flicker is the lighting illumination instability and thereby causing the human eyes discomfort caused by voltage fluctuations. Whether the electric light flicker occurred depends on the size of voltage fluctuation and voltage fluctuation frequency. Experiments show that the human eyes sensitivity to the flicker frequency is different. Generally human eye is most sensitive to flicker frequency of 8.8Hz [6]. Compared with the influence of inter-harmonics on voltage fluctuations, the value of flicker caused by inter-harmonics needs assessment to determine, therefore, quantitative analysis is more difficult.

Currently flicker evaluation is by IEC flicker meter based on voltage modulation to incandescent flicker effect [7]. Since the nature of the composite signal of the inter-harmonic and the fundamental is not amplitude modulated signal, and the incandescent flux ripple effects caused by the composite signal and fluctuating load are different, there the traditional IEC flicker meter is not suitable for voltage fluctuations and flicker caused by inter-harmonics computing and evaluating issues [8]. Therefore, inter-harmonics flicker curve can be used to evaluate the impact of inter-harmonics to flicker. Inter-harmonics flicker curve can reflects the functional relationship of the maximum acceptable amplitude and harmonic frequency and describe generating inter-harmonic amplitude threshold, and determine whether an inter-harmonic components can cause flicker [9, 10]. If the magnitude of specific frequency inter-harmonic component is higher than the relative magnitude of the inter-harmonic curve, the inter-harmonics will cause flicker, on the contrary the possibility of the flicker generated by the corresponding voltage fluctuations will be small.

A variety of inter-harmonics flicker limit curve developing methods have been proposed for different rated voltages 60 Hz incandescent. On the basis of IEC flicker meter principle, the 0~100 Hz inter-harmonic flicker curve based peak fluctuations has been formulated by adopting synchronous demodulation substituted by square demodulation and 10 order Butterworth low-pass filter substituted by 6-order Butterworth low-pass filter and calculating the inter-harmonics and flicker caused by voltage fluctuations [8]. For 120V/60 Hz incandescent Tayjasanant T. proposed the inter-harmonics flicker curve based IEC flicker meter and the curve based RMS and peak voltage values obtained by the IEEE flicker [9]. YONG JING proposed the relationship between the standard based on IEC flicker meter and luminous flux fluctuation characteristics and parameters of the harmonics and developed an inter-harmonics flicker limit curve [10]. Emanuel A. noted that RMS voltage fluctuations likely to cause flicker of incandescent lamps and voltage peak fluctuations prone to a fluorescent lamp flicker [11].

Two methods of fluorescent inter-harmonic flicker curve based peak voltage fluctuations have been developed by analyzing the influence of inter-harmonic on flicker in this paper. The first method is the use of inter-harmonics and flicker constraints; the other is the actual test method through the use of inter-harmonics - flicker test platform. The 220 V / 50 Hz fluorescent lamp inter-harmonic flicker limit curves have been developed by the two methods and compared analyzed each other and compared with the IEC flicker curve; and the accuracy and usefulness of the curves were verified.

Influences of interharmonics on flicker

Whether flicker occurred depends on many factors such as voltage fluctuation, voltage fluctuation frequency and the type of lighting, etc. When an inter-harmonic is superimposed on the power frequency voltage, voltage fluctuation will be resulted in because the two signal cycles are not synchronized. When the volatility is greater than a certain value, a specific frequency flicker will happen.

The impact of harmonics on flicker can be explained by a voltage signal containing fundamental and inter-harmonics.

$$u(t) = U_1\left[\sin(2\pi f_1 t) + m\sin(2\pi f_{\mathrm{IH}} t + \theta_{\mathrm{IH}})\right] \quad (1)$$

Where, U_1 is the fundamental amplitude, f_1 is the fundamental frequency, m is the inter-harmonic relative amplitudes, f_{IH} and θ_{IH} are respectively the inter-harmonic frequency and initial phase.

The signal wave of an inter-harmonic superimposed on the power frequency voltage is shown in Figure 1. The voltage signal envelope significant fluctuation can be seen. In which $U_1 = 100\mathrm{V}$, $f_1 = 50\mathrm{H_Z}$, $m = 0.1$, $f_{\mathrm{IH}} = 97\mathrm{Hz}$, $\theta_{\mathrm{IH}} = 0$.

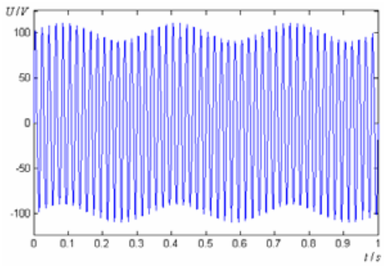

Fig. 1 The waveforms of a voltage containing 97 Hz inter-harmonic

Assume $f_{\mathrm{IH}} = hf_1 + \Delta f$, h is the harmonic order closed to f_{IH}, and the initial phase of the inter-harmonic is $\theta_{\mathrm{IH}} = 0$, so this voltage signal can be expressed as

$$u(t) = U_1\left[\sin(2\pi f_1 t) + m\cos(2\pi\Delta f t)\right]\sin(2\pi h f_1 t) + U_1 m\sin(2\pi\Delta f t)\cos(2\pi h f_1 t) \quad (2)$$

If $\Delta f = 0$, only the harmonic components are contained in the signal, the amplitude of the voltage will not change; If $\Delta f \neq 0$, the asynchronous inter-harmonics are contained in the voltage signal, and cause voltage fluctuations.

Influence of Inter-harmonic on Voltage Fluctuation Peak

When $t = \dfrac{n}{4f_1}$, $n = 1, 3, 5\cdots$, the expression (1) has extreme value. When $m << 1$, the peak voltage is expressed as

$$U_{\text{peak}} = U_1\left[1 \pm m\sin\left(\frac{n\pi}{2}\frac{f_{\text{IH}}}{f_1} + \theta_{\text{IH}}\right)\right] \tag{3}$$

Thus, the voltage fluctuates between $U_1(1+m)$ and $U_1(1-m)$, the peak voltage fluctuating level is $d_{\text{peak}} = m$, and regardless of the inter-harmonic frequency.

Figure 2 shows the voltage fluctuation levels caused by a relative voltage peak variation $d = 1\%$, the frequency of 0 ~ 300Hz inter-harmonics. As can be seen from the figure, the relative voltage peak variation is substantially constant and independent of inter-harmonics frequency.

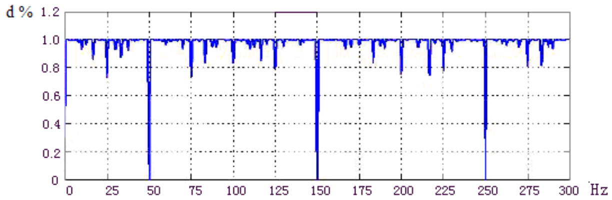

Fig. 2 Relative voltage peak fluctuation with 1% inter-harmonic magnitude distortion

Influence of Inter-Harmonic on Flicker Frequency

Usually the voltage variation frequency is called modulation frequency, beat or flicker frequency. The flicker frequency caused by inter-harmonics is

$$f_{\text{flicker}} = \left| f_{\text{IH}} - hf_1 \right| \tag{4}$$

Where, f_{IH} is the inter-harmonic frequency; h is the nearest odd harmonic frequency to f_{IH}. The flicker frequencies that 0~300Hz inter-harmonic frequencies corresponding to are shown in Figure 3.

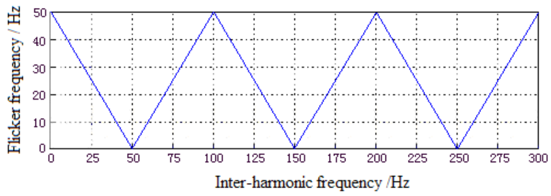

Fig. 3 Relationship between inter-harmonic and flicker frequencies

The approach based on voltage flicker constraint

Inter-harmonic flicker curve describes the function of the acceptable maximum inter-harmonic amplitude and inter-harmonics frequency. Its function is expressed as

$$m = F(f_{\text{IH}}) \tag{5}$$

Where, m is the relative amplitude of inter-harmonic, f_{IH} is the inter-harmonic frequency.

Inter-harmonic constraints can be derived by using of voltage flicker constraints and the inter-harmonic flicker curve can be developed by inter-harmonic constraints according the analysis of inter-harmonic influencing on flicker.

The concrete steps to draw out inter-harmonic flicker curve:

(1) The voltage change value corresponding to a flicker frequency will be obtained through the standard flicker curve, and its relational expression is

$$d = \psi(f_{\text{flicker}}) \tag{6}$$

Figure 4 is a unit of the periodic rectangular voltage fluctuation flicker (Pst = 1) curve, through which a voltage change corresponding to a flicker frequency can be obtained.

(2) The minimal inter-harmonic amplitude to produce flicker can obtained by using equation (4) and jointing equation (6). The relationship between voltage fluctuation and inter-harmonic amplitude and frequency is

$$d = g(m, f_{\text{IH}}) \tag{7}$$

(3) The different critical voltage variation amplitude corresponding to each inter-harmonic frequency will be obtained by repeating the above steps, and the curve drawing will be completed.

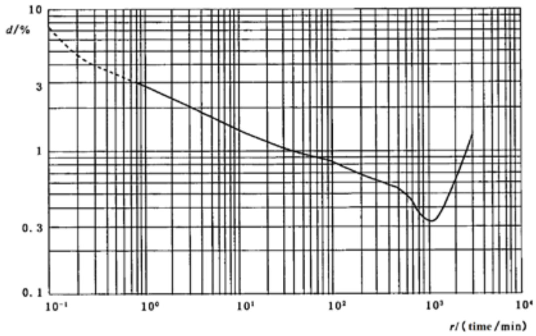

Fig. 4 Unit flicker(Pst=1) curve caused bys relative voltage change

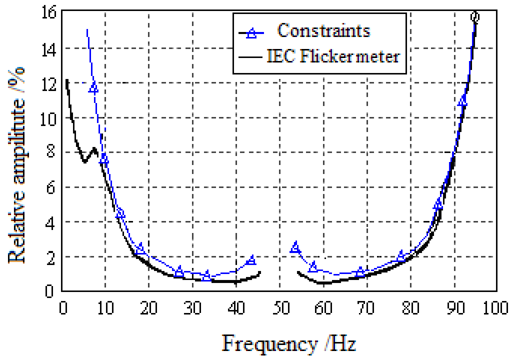

Fig. 5 The fluorescent lamps inter-harmonics flicker curve based on constraint conditions

A 220V /50 Hz fluorescent lamp inter-harmonic flicker curve in the range of 0~100Hz based on the peaks fluctuations is obtained by the above methods, and is shown in Figure 5. The inter-harmonic flicker curve is approximately symmetrical, and the fluorescent is more sensitive to the inter-harmonic frequencies closed odd times. Thus, the minimum threshold limit value caused of the inter-harmonic levels by flicker occurs in the vicinity of the fundamental frequency. Compared with the IEC flicker meter incandescent standard curve, the inter-harmonic amplitude causing flicker is relatively larger, it indicates that the tolerance degree of the fluorescent light to voltage fluctuation caused by inter-harmonic.

The approach based on test

Inter-harmonic flicker curve can be developed by using the actual measurement method. The relative magnitude of a inter-harmonic frequency required to generate unit flicker is measured, and this value will be treated as the critical amplitude. Then the inter-harmonic amplitude to frequency curve can be synthesized by getting the different critical amplitudes of harmonic frequencies. So, the inter-harmonic flicker experimental platform was built, the structure is shown in Figure 6.

Two single-phase 220V, 50Hz frequency voltage are input signals. One branch is series connected with the other voltage signal isolated by transformer through a regulator, a step-down transformer, a diode bridge and a single phase H-bridge inverter. The first branch is used for generating an inter-harmonic voltage signal. By adjusting the input voltage of the regulator thereby changing the diode full bridge rectifier output DC voltage the inter-harmonic voltage amplitude of H-bridge inverter output is controlled and the inter-harmonic frequency of the output is up to the function generator. The second branch is used as the power source.

The inter-harmonic signal is applied on the frequency signal to supply power to the electric light by two voltage path series connection. The collection and analysis of voltage signal for detecting flicker are completed by the analog flicker meter, and the inter-harmonic is measured by inter-harmonic detector.

For the specific inter-harmonic frequency, the flicker will be caused by increasing the inter-harmonic amplitude to threshold value.

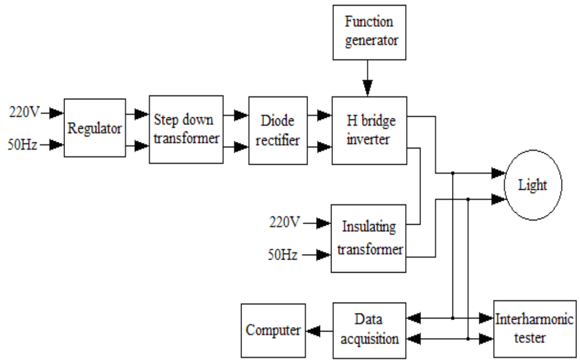

Fig 6 The schematic diagram of the inter-harmonic flicker laboratory station

According to the literature [8] flicker meter principles the analog flicker meter is established as a standard measurement system by using MATLAB / Simulink simulation software.

A specific frequency inter-harmonic is chosen, and its amplitude is increased until causing flicker. The frequency and amplitude are recorded for curve drawing. The curve drawing will be completed by changing the inter-harmonic frequency and repeating the above steps. With this experimental platform, the inter-harmonics and flicker of different electric light sources can be tested to obtain their inter-harmonic flicker curve.

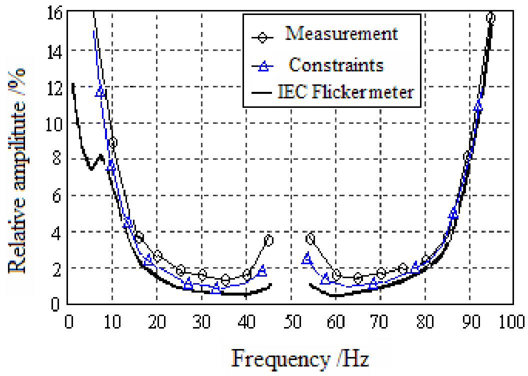

Fig 7 Inter-harmonics flicker curve comparison

The 0 ~ 100Hz inter-harmonic flicker curve based on the peak fluctuations of 220 V / 50 Hz fluorescent is obtained by testing is shown in Figure 7 and the part test data is in Table 1.

Table 1 The data of inter-harmonic flicker curves

Inter-harmonic frequency Hz	Flicker frequency Hz	Relative amplitude m/%	Inter-harmonic frequency Hz	Flicker frequency Hz	Relative amplitude m/%
5	45	16.20	95	45	15.73
10	40	8.86	90	40	8.04
15	35	3.50	85	35	3.78
20	30	2.63	80	30	2.26
25	25	1.87	75	25	2.01
30	20	1.64	70	20	1.85
35	15	1.56	65	15	1.78
40	10	1.82	60	10	1.82
45	5	3.74	55	5	3.81

Figure 7 shows that the trends of the inter-harmonic flicker curve obtained by experiment and the curve based on the IEC flicker constraint is consistent. Since the measurement error, the flicker threshold of experimental curve is only slightly higher than the deduced curve. The results obtained by the two methods are basically same.

Conclusion

Inter-harmonic will have an impact on voltage fluctuation and flicker; inter-harmonic content will affect voltage changing value, inter-harmonic frequency will affect flicker frequency. By using the relationship of voltage flicker frequency, inter-harmonic frequency and inter-harmonic amplitude, the flicker minimum amplitude caused by a specific frequency can be determined, and further develop inter-harmonic flicker curve. The established inter-harmonics flicker experimental platform can measure the value of inter-harmonics and flicker, and the platform appropriate for different kinds of electric light. With this experimental platform, a variety of electric light inter-harmonic-flicker curve can be developed easily.

References

[1] GB/T 24337-2009 Power Quality Public Power System Interharmonics. Beijing: Standard of China, 2009.

[2] LIN Haixue. Origin of Interharmonic and Its Effects on Power System [J]. Power Supply Technologies And Applications,Vol.13, May, 2010, pp. 1-6.

[3] HAO Jiangtao, Liu Nian, Xing Jinyu, at el. The Sources and Harms of Interharmnics in Power System． Sichuan Power Technologies,February, 2005, pp. 11-14.

[4] ZHU Ke, YONG Jing, Thavatchai Tayjasanant. Quantifying Flicker Impact of Interharmonics. Proceedings of the CSEE, Vol.28, October, 2008, pp. 113-118.

[5] HU Jie, CHEN Ni. The Analysis of Interharmonics Affection on The Voltage Fluctuation. Electrical Power Application, Vol.29, May, 2010, pp. 46-49.

[6] XIAO Xiangning. Power Quality Analysis and Control. Beijing: China Power Press, 2010.