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Voltage Flicker Estimation Based on Pair of Inter-harmonics Analysis Method

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ABSTRACT

This paper presents a voltage flicker estimation based on a pair of inter-harmonics analysis method. The proposed algorithm is able to estimate flicker frequency and amplitude changes of a voltage waveform. The correlation of the pair of inter-harmonics, flicker frequency, and amplitude changes are presented and their formulas highlighted. .Experimental results indicate the amplitude of pair of inter-harmonics can detect the voltage flicker. Furthermore, the experimental results are compared with the measurement results obtained by using the Fluke power analyzer (Pst).

Keywords: voltage flicker, inter-harmonics, FFT

INTRODUCTION

Nowadays, utilization of nonlinear loads with asymmetrical current-voltage characteristics such as arc motor drive and arc furnace creates voltage fluctuation to the power system (Grady & Santoso, 2001). Specifically, voltage fluctuation with certain frequency value is considered as voltage flicker (Tayjasanant, Wencong, Chun, & Wilsun, 2005). Moreover, unsteadiness light luminance may occur due to the aforementioned voltage flicker. Practically, International Electrotechnical Commission (IEC) flickermeter is introduced by IEC standard for voltage flicker severity measurement ("Electromagnetic compatibility (EMC) - Part 4-15: Testing and measurement techniques - Flickermeter - Functional and design specifications.," 2011). Instantaneous flicker sensation (P_{inst}), Short Term Perceptibility (P_{st}) and Long Term Perceptibility (P_{lt}) are the voltage flicker severity measurement's indicators which are covered by IEC flickermeter. Pst and Plt are referred to voltage flicker severity indicators under observation of 10 minutes and 2 hours respectively.

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Some of research works have been conducted to improve the accuracy of the IEC flickermeter (Virulkar & Aware, 2012) and voltage flicker mitigation have also been done by many researchers (Michel & de Preville, 2004; Routimo et al., 2008). Analysis on reducing the observation time of Pst (Tan & Ramachandaramurthy, 2012) has also been done by researchers. Interrelationship between inter-harmonics and voltage flicker has been investigated by many researchers too (Dahai, Wilsun, & Nassif, 2005; Keppler, Watson, Arrillaga, & Shiun, 2003; Langella, Liccardo, Marino, Testa, & Triggianese, 2007; Tayjasanant et al., 2005; Wilsun, 2005). Voltage flicker detection has been proposed by many researchers such as atomic method (Ning, Linchuan, & Qingquan, 2012), wavelet Fourier transform (WeiHui & ShiPing, 2011), Chirp-z transform (Kang, Guo, Li, & Yan, 2010), and new modified S-transform algorithm (Huang, Xu, Shi, & Zhang, 2014). The atomic method is considered not practical since it needs a special voltage flicker dictionary which is generated by matching pursuits algorithm. The voltage flicker detection based on wavelet Fourier transform is mathematically considered cumbersome as the measured waveform needs to be filtered by wavelet transform, and then use a long window is required to identify the voltage flicker amplitude and flicker frequency. Other than that, the Chirp-z transform is only tested in simulation and it is not practical as the algorithm is not tested with noise condition. Then, the modified S-transform for voltage flicker detection algorithm is able to detect duration time of voltage flicker effectively but it cannot detect severity of voltage flicker.

Basically, there are some changes on the amplitudes of pair of inter-harmonics due to intrinsic characteristic of a voltage flicker waveform (Jing, Tayjasanant, Wilsun, & Caixin, 2008). This proposed algorithm is able to estimate flicker frequency and amplitude changes in a voltage waveform based on pair of inter-harmonics analysis method. Firstly, amplitudes of pair of inter-harmonics are detected by signal processing method. Then, the amplitudes of particular inter-harmonics are substituted in the formulas that have been generated in this paper. Subsequently, the flicker frequency and amplitude changes of a voltage flicker waveform are detected and are compare with the flicker reference curve in order to detect the voltage flicker.

A number of signal processing algorithms based on different techniques for inter-harmonics detection such as Discrete Fourier Transform (DFT), Fast Fourier Transform (FFT), Short-Time Fourier transform (STFT) (Wright, 1999) and spectrogram (Abdullah, Peng, Ghani, & Jopri, 2014) have been reported over the past years (Coppola, Qian, Buso, Boroyevich, & Bell, 2008). The FFT is considered direct improvement of the DFT which is able to perform faster conversion from time to frequency domain, but number of samples must fulfil 2n where n is an integer number. Otherwise, operation of the FFT may lead to inaccurate result due to phenomena of aliasing (Hsiung-Cheng, 2008), leakage (Chang, Chen, Liu, & Wu, 2008), and picket fence effects (Chang et al., 2008). Meanwhile, STFT is considered improvement of the FFT as it is generated based on sliding FFT process. The sliding FFT is done by dividing the measurement signal into many small divisions and FFT is applied to these tiny divisions. Next, spectrogram is considered as squared magnitude of the STFT and the output of spectrogram are plotted in spectrograph. Subsequently, the STFT and spectrogram are considered mathematical burden due to many times of applying FFT. Therefore, directly using FFT is merited, to be utilized in the proposed algorithm due to its speed capability to convert time domain to frequency domain. The correlation between voltage flicker and inter-harmonics are presented in Section II.

Sections III discusses the background of the FFT. Section IV presents the proposed algorithm. The experiments are presented in Sections VI. Lastly, the conclusion is contained in Section VI.

CORRELATION BETWEEN INTER-HARMONICS AND VOLTAGE FLICKER

Basically, modulated waveform can occur following the appearance of inter-harmonics in a power system. The fluctuation frequency of the instantaneous voltage is considered as voltage flicker frequency. The voltage flicker frequency (Jing et al., 2008), fflicker can be calculated by

$$f_{flicker} = \left| f_{IH} - f_f \right| \quad (1)$$

where, f_{IH} and f_f are considered as inter-harmonic frequency and fundamental frequency respectively of the power system. By considering a 50 Hz power system which consists of 3 Hz of voltage flicker frequency, then the related inter-harmonics are 47 Hz and 53 Hz. Essentially, the voltage flicker may occur due to pair of inter-harmonics (47 and 53 Hz together) or single inter-harmonic (47 or 53 Hz). In practical situation, voltage flicker waveform occurs mainly due to pair of inter-harmonics. Therefore, the derivation of formula for aforementioned situation is shown as follow (Zai Peng, Radzi, Hizam, & Abdul Wahab, 2015):

$$v_2(t) = \alpha_3 e^{j\omega_3 t} + \alpha_1 e^{j\omega_1 t} + \alpha_2 e^{j\omega_2 t} \quad (2)$$

$v_2(t)$, α_1, and ω_1 are represented as the instantaneous voltage, fundamental amplitude, and angular frequency (fundamental) respectively. Meanwhile, α_2, and ω_2 are symbolized as the first inter-harmonic amplitude, and its angular frequency. Next, α_3, and ω_3 are represented as the second inter-harmonic amplitude, and its angular frequency respectively. The relationship of ω is assumed as $\omega_3 < \omega_1 < \omega_2$.

After that, the aforementioned instantaneous voltage becomes,

$$v_2(t) = e^{j\omega_1 t}(\alpha_1 + \alpha_2 e^{j(\omega_2 - \omega_1)t} + \alpha_3 e^{j(\omega_3 - \omega_1)t}) \quad (3)$$

$e^{j\omega 1}t$ is represented as factorized exponential form of fundamental frequency. The amplitude is represented as α_1+ α2 $e^{j(\omega 2- \omega 2)t}$+ α_3 $e^{j(\omega 3- \omega 2)t}$. Therefore, the amplitude can be calculated as following:

$$Amp._{2H} = \left| \alpha_1 + \alpha_2 e^{j(\omega_2 - \omega_1)t} + \alpha_3 e^{j(\omega_3 - \omega_1)t} \right| \quad (4)$$

After the expansion,

$$Amp._{2H} = \begin{vmatrix} \alpha_1 + \alpha_2 \cos(\omega_2 - \omega_1)t + j\alpha_2 \sin(\omega_2 - \omega_1)t \\ +\alpha_3 \cos(\omega_3 - \omega_1)t + j\alpha_3 \sin(\omega_3 - \omega_1)t \end{vmatrix} \quad (5)$$

The calculation for the amplitude is as follow:

$$Amp_{\cdot 2H} = \sqrt{\begin{bmatrix}\alpha_1 + \alpha_2 \cos(\omega_2 - \omega_1)t + \\ \alpha_3 \cos(\omega_3 - \omega_1)t\end{bmatrix}^2 + \left[\alpha_2 \sin(\omega_2 - \omega_1)t + \alpha_3 \sin(\omega_3 - \omega_1)t\right]^2} \tag{6}$$

Further elaboration is:

$$Amp_{\cdot 2H} = \sqrt{\begin{bmatrix}2\alpha_1\alpha_2 \cos(\omega_2 - \omega_1)t + 2\alpha_1\alpha_3 \cos(\omega_3 - \omega_1)t + 2\alpha_2\alpha_3 \cos(\omega_2 - \omega_1)t \cos(\omega_3 - \omega_1)t + \\ \alpha_1^2 + \alpha_2^2 \cos^2(\omega_2 - \omega_1)t + \alpha_3^2 \cos^2(\omega_3 - \omega_1)t + \alpha_2^2 \sin^2(\omega_2 - \omega_1)t + \\ 2\alpha_2\alpha_3 \sin(\omega_2 - \omega_1)t \sin(\omega_3 - \omega_1)t + \alpha_3^2 \sin^2(\omega_3 - \omega_1)t\end{bmatrix}} \tag{7}$$

Since

$$\omega_3 \text{ p } \omega_1 \text{ p } \omega_2 and \omega_3 - \omega_1 = \omega_2 - \omega_1 \tag{8}$$

Then,

$$Amp_{\cdot 2H} = \sqrt{\begin{bmatrix}2\alpha_1\alpha_2 \cos(\omega_2 - \omega_1)t + 2\alpha_1\alpha_3 \cos(\omega_3 - \omega_1)t + 2\alpha_2\alpha_3 \cos^2(\omega_2 - \omega_1)t + \alpha_1^2 + \\ \alpha_2^2 \cos^2(\omega_2 - \omega_1)t + \alpha_3^2 \cos^2(\omega_3 - \omega_1)t + \alpha_2^2 \sin^2(\omega_2 - \omega_1)t + \\ 2\alpha_2\alpha_3 \sin^2(\omega_2 - \omega_1)t + \alpha_3^2 \sin^2(\omega_3 - \omega_1)t\end{bmatrix}} \tag{9}$$

By simplifying using trigonometry identity:

$$Amp_{\cdot 2H} = \sqrt{\left[2\alpha_1\alpha_2 \cos(\omega_2 - \omega_1)t + 2\alpha_1\alpha_3 \cos(\omega_3 - \omega_1)t + 2\alpha_2\alpha_3 + \alpha_1^2 + \alpha_2^2 + \alpha_3^2\right]} \tag{10}$$

Therefore, the simplified version is:

$$Amp_{\cdot 2H} = \sqrt{\left[2\alpha_1(\alpha_2 + \alpha_3)\cos(\omega_2 - \omega_1)t + 2\alpha_2\alpha_3 + \alpha_1^2 + \alpha_2^2 + \alpha_3^2\right]} \tag{11}$$

The maximum of the instantaneous voltage is:

$$Amp_{\cdot 2H}\, max = \sqrt{\left[2\alpha_1(\alpha_2 + \alpha_3)(1) + 2\alpha_2\alpha_3 + \alpha_1^2 + \alpha_2^2 + \alpha_3^2\right]} \tag{12}$$

The minimum of the instantaneous voltage is:

$$Amp_{\cdot 2H} \min = \sqrt{\left[2\alpha_1(\alpha_2 + \alpha_3)(-1) + 2\alpha_2\alpha_3 + \alpha_1^2 + \alpha_2^2 + \alpha_3^2\right]} \tag{13}$$

The substitution of the $\cos(\omega_2\text{-}\omega_1)t$ to 1 and -1 is for calculating the maximum and minimum values of the instantaneous voltage respectively. Figure 1 shows voltage flicker waveform for 50 Hz voltage supply with presence of pair of inter-harmonics, in which 47 Hz (ω_3) and 53 Hz (ω_2) with amplitude of 0.1 p.u. (α_3) and 0.2 p.u. (α_2) respectively. The maximum and minimum values of the instantaneous voltage in Figure 1(b) are 1.3 and 0.7 p.u respectively. Assuming the amplitudes of α_3, α_1 and α_2 are determined to be 0.1, 1 and 0.2 p.u. respectively Eq. (12) and

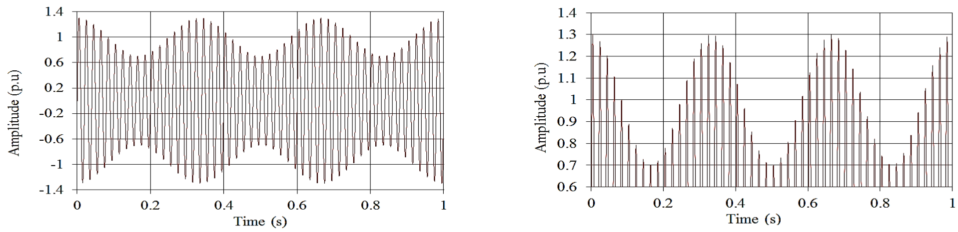

Figure 1. Voltage flicker waveform caused by pair of inter-harmonics: (a) zoom-out version, and (b) zoom-in version

eq. (13) is used to calculate the maximum and minimum values of the instantaneous voltage, which are 1.3 and 0.7 p.u. respectively. To evaluate severity of the voltage flicker, relative fluctuation voltage (Δv/v) has to be calculated based on the following formula:

$$\Delta v / v = \frac{Amp_{2H}.\max - Amp_{2H}.\min}{\alpha_1} \times 100 \tag{14}$$

For Figure 1, Δv/v is 60%. Again, the amplitudes of fundamental (α1) and two inter-harmonics (α_2 and α_3) are the key values to identify Δv/v.

To summarize, a generated voltage flicker may produce significant effect on the amplitudes of a pair of inter-harmonics (Jing et al., 2008). The amplitudes of fundamental (α_1) and pair of inter-harmonics (α_2 and α_3) is found to be crucial in order to identify Δv/v and is discussed in the next section.

BACKGROUND OF FFT

Based on standard IEC 61000-4-7, the general formula for FFT is

$$X(k) = \sum_{n=1}^{N-1} x(n) e^{-j\omega_k n} \tag{15}$$

where,

$$\omega_k = \frac{2\pi k}{N} \tag{16}$$

N is number of samples in time domain; k is number of samples in frequency domain (Bin number returned by FFT); x is data in time domain and X is data in frequency domain. Since

$$e^{-j\omega_k n} = \cos\left(\frac{2\pi kn}{N}\right) - jsin(\frac{2\pi kn}{N}) \tag{17}$$

Then, the output of the FFT in frequency domain is

$$X(k) = \sum_{n=1}^{N-1} \left[x(n)\cos\left(\frac{2\pi kn}{N}\right) - jx(n)sin(\frac{2\pi kn}{N}) \right] \tag{18}$$

It can be written as

$$X(k) = \sum_{n=1}^{N-1}\left[real - j\_imaginary\right] \tag{19}$$

After that, the amplitude and phase values of the desired signal can be extracted via following equation:

$$A = \sqrt{real^2 + imaginary^2} \tag{20}$$

$$\theta = \tan^{-1}\frac{imaginary}{real} \tag{21}$$

Based on previous works, optimized sampling frequency for FFT is 12.8k Hz (Leelajindakrairerk & Chompoo-Inwai, 2012; Yamada, 2013) for detecting signal with fundamental frequency of 50 Hz. Specifically, the frequency resolution (eq. (22)) is needed for this proposed algorithm is 0.1. Therefore, the window size is 128k samples (12.8k/0.1). Consequently, 10s is needed for processing a single output data.

$$Frequency\_resolution = \frac{Sampling\_frequency}{Window\_size} \tag{22}$$

PROPOSED ALGORITHM

As discussed earlier , the amplitudes of pair of inter-harmonics and fundamental frequency are the key values to determine the voltage flicker. Principally, FFT is utilized as the amplitudes detector due to its advantages as mentioned in the introduction section. The particular amplitudes' values are substituted into eq. (12) and eq. (13) to determine the maximum and minimum values of the fluctuation voltage and the relative fluctuation voltage (Δv/v) calculated via eq. (14). The voltage flicker can be detected by comparing Δv/v with voltage flicker reference curve. Specifically, voltage flicker is detected when then Δv/v is positioned above the flicker reference curve (Figure 3) and vice versa. The voltage flicker reference curve is generated based on IEC standard (Albistur, Aravena, Moran, & Espinoza, 2014). The block diagram of the proposed algorithm is shown in Figure 2.

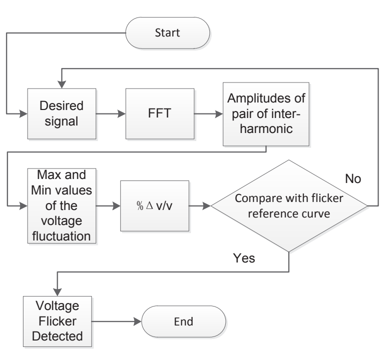

Figure 2. VBlock diagram of the proposed algorithm

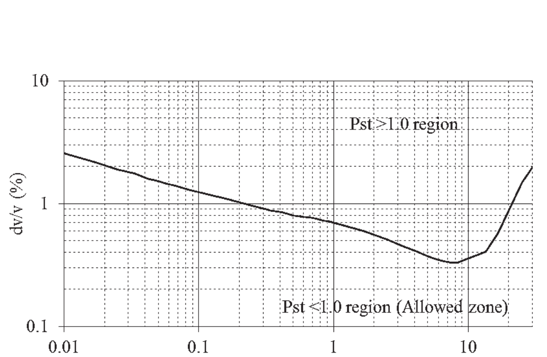

Figure 3. Voltage flicker reference curve

EXPERIMENTAL RESULTS

Figure 4 shows the experimental setup to perform this proposed algorithm. Programmable AC source model 6590 is utilized as voltage flicker waveform generator for this experimental setup. Furthermore, several voltage flicker waveforms are considered in this experimental work for further evaluating robustness of the proposed algorithm. The benchmarking tool used is Fluke power analyzer (P^{st}). Data acquisition is assessed using differential probe Gw Instek GDP_025 and Ni USB 6212. Sampling frequency of 12,800 Hz is utilized for this experimental work. The window width is 128k samples. Therefore, 10 seconds are needed for single experimental data. Finally, the data is exported to Matlab Simulink to further be analysed by the proposed algorithm as shown in Figure 2.

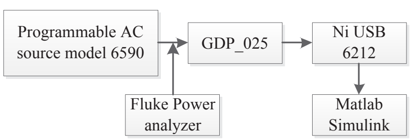

Figure 4. Configuration block for the experimental work

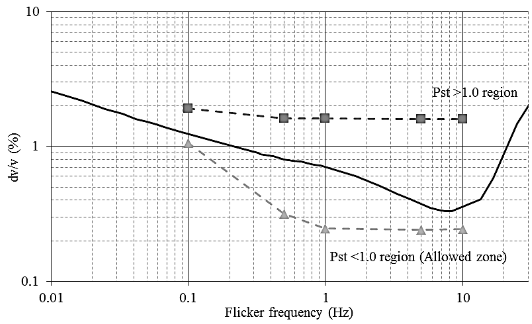

Figure 5. Data analysis for the experimental work

The programmable AC source is supplied by a voltage (rms) of 240 V and the aforementioned voltage waveform is interrupted by various envelope pulse levels which are generated by the programmable AC source too. Two types of envelope pulses level voltage (rms) are utilized in this experimental setup, which are 239.5 and 237 V. In addition, single envelope pulse level is programmed with various pulse frequencies such as 0.1, 0.5, 1, 5 and 10 Hz. Subsequently, 10 sets of experimental data are used for testing. Table 1 is a summary of the data analysis related to this experimental work. FFT is utilized to capture and analyse the voltage flicker waveform generated by the programmable AC source and the maximum, minimum and relative fluctuation voltages are generated by substituting the outputs of the FFT to eq. (12), eq. (13) and eq. (14) accordingly. The voltage flicker is detected, when the value of relative fluctuation voltage (eq. (14)) is located above the flicker reference curve (Figure 5). The Fluke power analyzer (P_{st}) is utilized for benchmarking purposes where the voltage flicker is detected when the P_{st} is greater than 1. The voltage flicker is successfully detected via the proposed algorithm, which is compared with the Fluke power analyzer (P_{st}) to ensure 100% detection accuracy.

Table 1
Summary of data analysis for the proposed algorithm (Experimental

Pulse level (Vrms)	Pulse frequency/ Flicker frequency (Hz)	Number of test	FFT			Calculation by proposed algorithm				FLUKE		Detection Accuracy (%)
			50 Hz- Pulse frequency	50 Hz	50 Hz+ Pulse frequency	Max (Vpeak)	Min (Vpeak)	%Δv/v	Flicker detection	(P_{st})	Flicker detection (Pst>1)	
239.50	0.10	1	1.03	336.90	0.77	338.70	335.10	1.07	No	0.16	No	100
237.00		2	1.65	335.10	1.56	338.31	331.89	1.92	Yes	1.05	Yes	100
239.50	0.50	3	0.27	336.90	0.26	337.43	336.37	0.32	No	0.23	No	100
237.00		4	1.42	335.10	1.28	337.80	332.40	1.61	Yes	1.53	Yes	100
239.50	1.00	5	0.14	336.90	0.28	337.31	336.49	0.25	No	0.26	No	100
237.00		6	1.33	335.10	1.37	337.80	332.40	1.61	Yes	1.78	Yes	100
239.50	5.00	7	0.19	336.90	0.21	337.30	336.50	0.24	No	0.45	No	100
237.00		8	1.30	335.10	1.38	337.78	332.42	1.60	Yes	3.02	Yes	100
239.50	10.00	9	0.22	336.90	0.19	337.31	336.49	0.24	No	0.65	No	100
237.00		10	1.35	335.10	1.34	337.79	332.41	1.60	Yes	4.36	Yes	100

CONCLUSION

This paper has presented voltage flicker detection based on pair of inter-harmonics analysis method. The amplitudes of pair of inter-harmonics and fundamental frequency are shown to be the key values for determining the voltage flicker. The amplitude of the aforementioned inter-harmonics was substituted into the formula that have been derived in this paper accordingly. Subsequently, The voltage flicker can be detected when the relative fluctuation voltage is located above with the flicker reference curve. According to experimental results, the amplitudes of pair of inter-harmonics are able to detect the voltage flicker. The experimental results were compared with those obtained by using the Fluke power analyzer (P_{st}).

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REFERENCES

Abdullah, A. R., Peng, G. Z., Ghani, S. A., & Jopri, M. H. (2014, March 24-25). A new vector draft method for harmonic source detection at point of common coupling. In *Power Engineering and Optimization Conference (PEOCO), 2014 IEEE 8th International*.

Albistur, C. F., Aravena, P. A., Moran, L. A., & Espinoza, J. R. (2014). A Simple Predictive Method to Estimate Flicker. *IEEE Transactions on Industry Applications, 50*(3), 2150-2155.

Chang, G. W., Chen, C. I., Liu, Y. J., & Wu, M. C. (2008). Measuring power system harmonics and interharmonics by an improved fast Fourier transform-based algorithm. IET Generation, *Transmission and Distribution, 2*(2), 193-201.

Coppola, L., Qian, L., Buso, S., Boroyevich, D., & Bell, A. (2008). Wavelet Transform as an Alternative to the Short-Time Fourier Transform for the Study of Conducted Noise in Power Electronics. *IEEE Transactions on Industrial Electronics, 5*5(2), 880-887.

Dahai, Z., Wilsun, X., & Nassif, A. (2005, May 1-4). Flicker source identification by interharmonic power direction. *Canadian Conference on Electrical and Computer Engineering, 2005*.

Electromagnetic compatibility (EMC) - Part 4-15: Testing and measurement techniques - Flickermeter - Functional and design specifications.IEC 61000-4-152011.

Goh, Z. P., Radzi, M. A. M., Hizam, H., & Abdul W. N. I. (2015). A Simple Predictive Method of Critical Flicker Detection for Human Healthy Precaution. *Mathematical Problems in Engineering, 2015*.

Grady, W. M., & Santoso, S. (2001). Understanding Power System Hannonics. *IEEE Power Engineering Review, 21*(11), 8-11.

Hsiung, C. L. (2008). Inter-Harmonic Identification Using Group-Harmonic Weighting Approach Based on the FFT. *IEEE Transactions on Power Electronics, 23*(3), 1309-1319.

Huang, Y. H., Xu, J. J., Shi, H., & Zhang, Y. S. (2014, May 31 2014-June 2 2014). Effective voltage flicker detection approach based on a new modified S-transform algorithm. *Control and Decision Conference (2014 CCDC), The 26th Chinese*.

Jing, Y., Tayjasanant, T., Wilsun, X., & Caixin, S. (2008). Characterizing Voltage Fluctuations Caused by a Pair of Interharmonics. *IEEE Transactions on Power Delivery, 23*(1), 319-327.

Kang, W., Guo, J., Li, H., & Yan, X. (2010, 28-31 March 2010). Voltage Flicker Detection Based on Chirp-z Transform. In *Power and Energy Engineering Conference (APPEEC), 2010 Asia-Pacific*.

Keppler, T., Watson, N. R., Arrillaga, J., & Shiun, Chen. (2003). Theoretical assessment of light flicker caused by sub- and interharmonic frequencies. *IEEE Transactions on Power Delivery, 18*(1), 329-333.

Langella, R., Liccardo, F., Marino, P., Testa, A., & Triggianese, M. (2007, May 21-23). On the Assessment of Light Flicker due to the Interharmonic Distortion Produced by Wind Turbines. *International Conference on Clean Electrical Power, 2007. ICCEP '07*.

Leelajindakrairerk, E. J. S. C. M., & Chompoo-Inwai, C. C. (2012, 12-14 Dec. 2012). Optimal technique for total harmonic distortion detection and estimation for smart meter. *IPEC, 2012 Conference on Power and Energy.*

Michel, D., & de Preville, G. (2004, 31 March-2 April 2004). Mixed topology for flicker mitigation. *Power Electronics, Machines and Drives, 2004. (PEMD 2004). Second International Conference on (Conf. Publ. No. 498)*.

Ning, W., Linchuan, L., & Qingquan, J. (2012, 21-24 May 2012). Detection of voltage flicker based on atomic method. *Innovative Smart Grid Technologies - Asia (ISGT Asia), 2012 IEEE*.

Routimo, M., Makinen, A., Salo, M., Seesvuori, R., Kiviranta, J., & Tuusa, H. (2008). Flicker Mitigation With a Hybrid Compensator. *IEEE Transactions on Industry Applications, 44*(4), 1227-1238.

Tan, R. H. G., & Ramachandaramurthy, V. K. (2012, June 6-7). Tolerance analysis of flicker Pst short term perceptibility assessment for one minute observation time. In *Power Engineering and Optimization Conference (PEDCO) Melaka, Malaysia, 2012 Ieee International*.

Tayjasanant, T., Wencong, W., Chun, L., & Wilsun, X. (2005). Interharmonic-flicker curves. *IEEE Transactions on Power Delivery, 20*(2), 1017-1024.

Virulkar, V. B., & Aware, M. V. (2012, 25-28 Oct. 2012). Power system flicker analysis, modeling and prototype implementation. *IECON 2012 - 38th Annual Conference on IEEE Industrial Electronics Society.*

WeiHui, Z., & ShiPing, S. (2011, September 16-18). Voltage flicker detection based on wavelet fourier transform. *International Conference on Electrical and Control Engineering (ICECE), 2011*.

Wilsun, X. (2005, June 12-16). Deficiency of the IEC flicker meter for measuring interharmonic-caused voltage flickers. *Power Engineering Society General Meeting, 2005. IEEE*.

Wright, P. S. (1999). Short-time Fourier transforms and Wigner-Ville distributions applied to the calibration of power frequency harmonic analyzers. *IEEE Transactions on Instrumentation and Measurement, 4*8(2), 475-478.

Yamada, T. (2013). High-Accuracy Estimations of Frequency, Amplitude, and Phase With a Modified DFT for Asynchronous Sampling. *IEEE Transactions on Instrumentation and Measurement, 62*(6), 1428-1435.