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Generation of Power Spectrum of Power Quality Disturbances using MATLAB

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Abstract
The aim of this paper is to present power spectrum of electrical power quality disturbances obtained by mathematical modeling. Signals considered for analysis are transients, harmonics, interruption, voltage sag, voltage swell, voltage fluctuations and voltage flicker. These power quality disturbances affect the continuity of supply and results in reduction of stability of the power system. So there is a necessity for an analysis of power quality disturbances in different perspectives. Power spectrum representation of the different disturbance signals is obtained. The values of power in Decibels and frequency in Hertz are obtained which gives more information about the signals in time domain. Power spectrum gives useful information about the variations in signals. Waveforms for transients, interruption, sag, swell, harmonics, voltage fluctuations, and voltage flicker are generated using mathematical equations and their corresponding power spectrum representations are obtained in MATLAB environment.

1. Introduction

Electric power is produced at the generating stations and then transmitted and distributed through transmission and distribution systems for industrial and domestic load applications. Different types of power system loads are electric heating loads, lighting loads, motor loads and power electronics based loads. Electricity is supplied to the loads with an assurance of continuity of supply under normal and contingency conditions. In order to produce high quality electric power supply certain standards must be convened with regard to the factors of level of reliability. Continuity of service is to be provided by utilities to load by keeping the magnitude of voltage constant. The paper is organized as section 2 with the description about power quality disturbance signals and section 3 with time domain signals and power spectrum the obtained results in MATLAB and section 4 draws the conclusion.

2. Power Quality Disturbances

Power quality is concerned with deviation of either voltage or current from their respective ideal voltage or current and this deviation is termed as power quality disturbance. The Institute of Electrical and Electronics Engineers (IEEE) dictionary states that “power quality is the concept of powering and grounding sensitive equipment in a matter that is suitable to the operation of that equipment” [1,13]. The power produced must be free of any interruption or disturbance that affects normal operation of electrical equipment. The International Electrotechnical Commission (IEC) definition of power quality is as follows: “Characteristics of the electricity at a given point on an electrical system, evaluated against a set of reference technical parameters” [2,12]. In order to improve electric power quality, the sources and causes of disturbances must be known. Preventive measures can only be taken by proper recognition of the disturbances. IEEE standard 1159-1995 [3,11], “IEEE recommended practice for monitoring electric power quality” describes all power quality disturbances and their standard definitions. By analyzing voltage disturbance waveforms, power quality events can be recognized. Power quality is the combination of voltage quality and current quality [4,14]. Power quality disturbances are generated for an evaluation to find possible solutions for each of these disturbances. The fundamental voltage component characterization approach is qualified to power quality disturbances featured in remarkable magnitude changing situations, such as sags, swells, and interruptions [5,15]. A numerical model framework to generate various power quality waveforms is proposed in [6,16].

3. Power Spectrum of Power Quality Disturbances

Power spectrum is the method used to analyze the frequency content of a signal and is computed by using Fast Fourier Transform (FFT). Power spectrum represents the distribution of power of a signal for different frequency components. The two steps involved in the calculation of power spectrum are:

1. Fast Fourier Transform algorithm is used to convert the time-domain power quality signals into the frequency domain.
2. The power spectrum of power quality signals is calculated by taking the square of magnitude of the FFT result. As FFT result is complex, absolute values are considered by taking square of the magnitude

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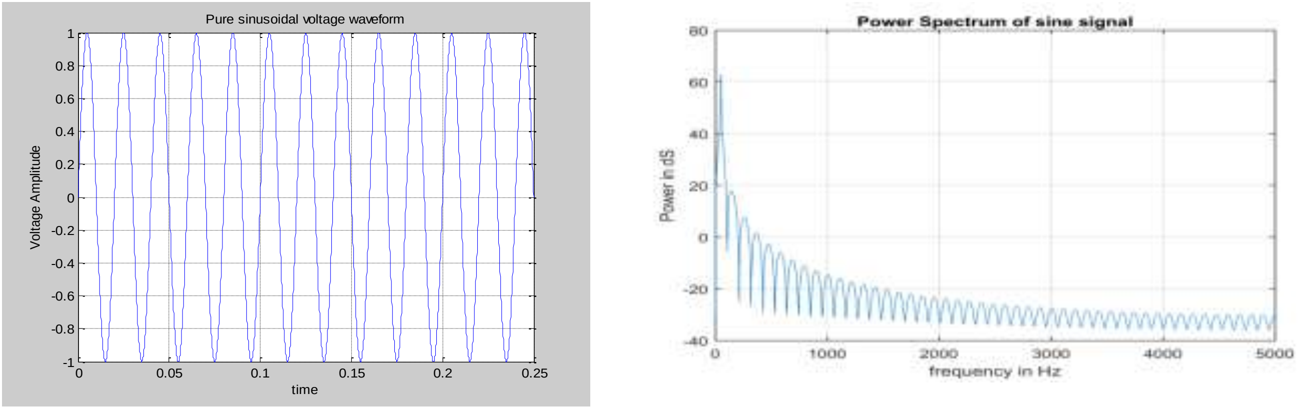
5. This gives power at each frequency component and power spectrum of power quality disturbances can be generated
6. Peaks in the power spectrum indicate dominant frequencies in your signal

In all the defined equations, the term A represents the maximum value of the supply voltage $V(t)$. Equation (1) represents the mathematical equation of pure sinusoidal supply voltage without any distortions as depicted in Fig.1(a) given as:

$$V(t) = Asin(\omega t) \qquad (1)$$

The power spectrum of sinusoidal signal is shown in fig. 1(b).



(a) Pure sinusoidal voltage waveform (b) Power Spectrum of sine signal

Fig.1 Sinusoidal voltage signal and its power spectrum

Different power quality disturbances considered for analysis are:

A. Transient
B. Interruption
C. Sag
D. Swell
E. Harmonics
F. Fluctuations
G. Flicker

A. Transient

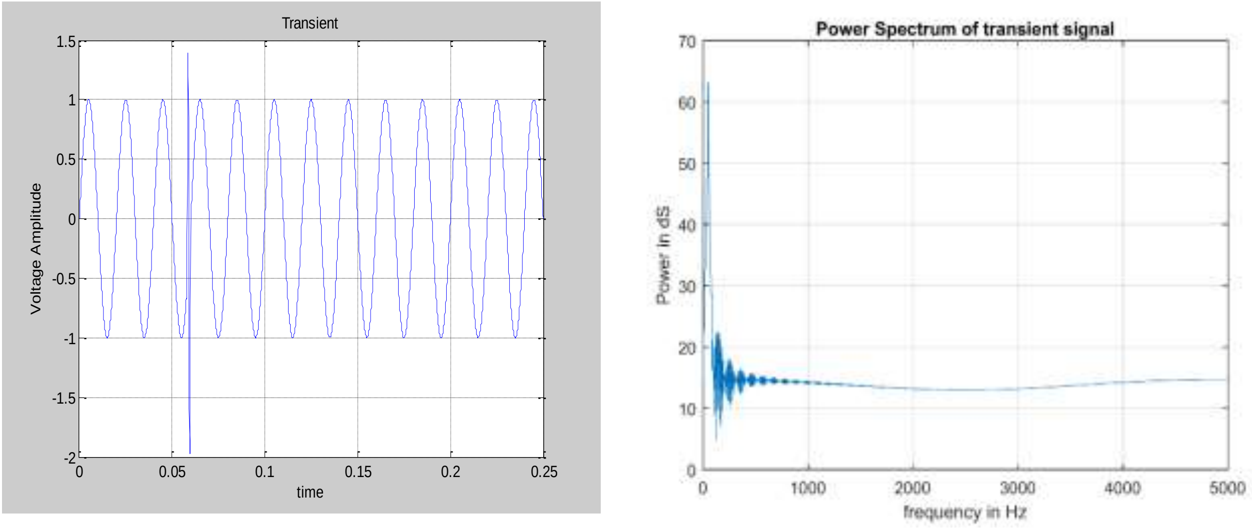
A transient can be a unidirectional impulse of either polarity or a damped oscillatory wave with the first peak occurring in either polarity [3]. The possible causes of transients are lightning, ESD

(Electrostatic Discharge), utility fault clearing, and switching of inductive or capacitive loads [7]. Oscillatory transients are numerically modelled for $V(t)$ and is given in [8] as:

$$V(t) = A\left[\sin\omega t + \alpha e^{\frac{-(t-t_1)}{\tau}} \sin\omega_n(t-t_1)(u(t_2)-u(t_1))\right] \quad (2)$$

The controlling parameters α, τ and f_n which are transient magnitude, transient settling time and transient oscillatory frequency respectively given in parametric equation (2),.

Fig.2(a) and (b) depicts transient, simulated in MATLAB using (3) and its power spectrum.



(a) Transient signal waveform (b) Power Spectrum of transient signal

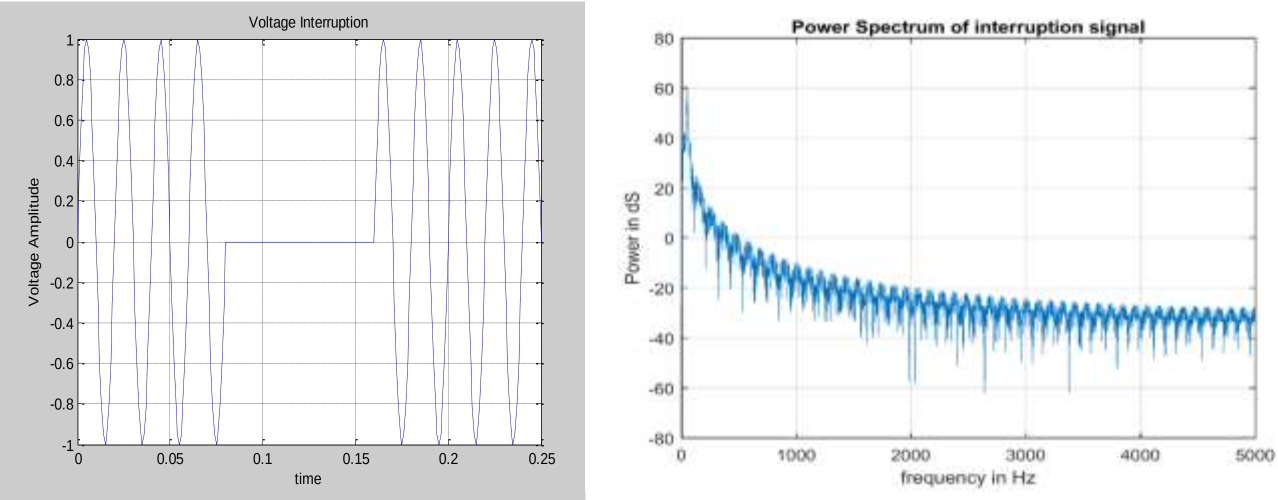
Fig.2 Transient signal and its power spectrum

B. Interruption

An interruption occurs when the supply voltage or load current decreases to less than 0.1 pu for a period of time not exceeding 1 minute [3]. The possible causes of voltage interruption are switching, utility faults, circuit breaker tripping, and component failures [7]. Interruption is numerically modeled based on parametric equation as in [8]:

$$V(t) = A\left(1-\alpha\left(u(t-t_1)-\alpha\big(u(t-t_2)\big)\right)\right)\sin\omega t \quad (4)$$

By simulating (4) in MATLAB, voltage waveform with interruption is shown in Fig.3(a) and its power spectrum in fig.3(b).



(a) Interruption signal waveform (b) Power Spectrum of interruption signal

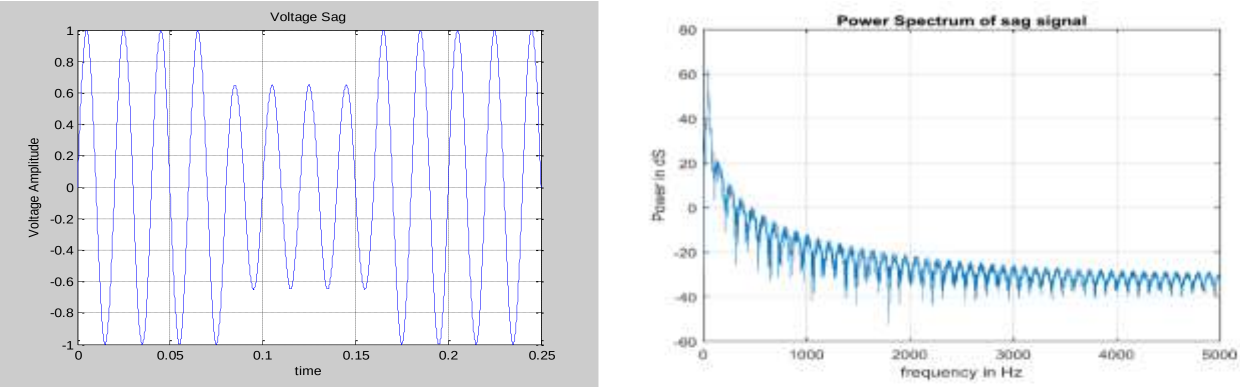
Fig.3 Interruption signal and its power spectrum

C. Voltage sag

A sag is a decrease in rms voltage to between 0.1 pu and 0.9 pu for durations from 0.5 cycles to 1 minute [3]. The possible causes of voltage sags are startup loads and faults [7]. Voltage sag is numerically modeled as in [8]:

$$V(t) = A\left(1 - \alpha\left(u(t - t_1) - \alpha\left(u(t - t_2)\right)\right)\right)\sin\omega t \qquad (5)$$

Voltage sag, shown in Fig.4(a) is obtained by simulating (5) in MATLAB and indicates a sudden decrease in voltage for a certain duration.



(a) Sag signal waveform (b) Power Spectrum of sag signal

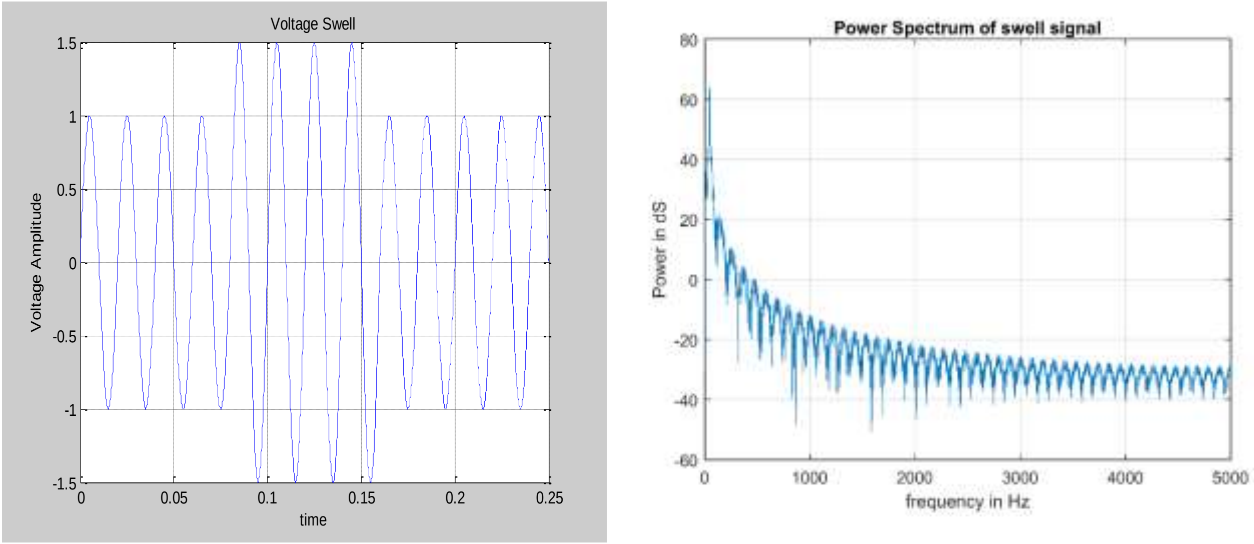
Fig.4 Voltage sag signal and its power spectrum

D. Voltage Swell

A swell is an increase in rms voltage above 1.1 pu for durations from 0.5 cycle to 1 minute [3]. The possible causes of voltage swells are load changes and utility faults [7]. Voltage swell is numerically modeled as in [8]:

$$V(t) = A\left(1 + \alpha\left(u(t - t_1) - \alpha\big(u(t - t_2)\big)\right)\right)\sin \omega t \qquad (6)$$

Voltage swell, shown in Fig.5(a), is obtained by simulating (6) in MATLAB and its power spectrum shown in fig.5(b).



(a) Swell sigma waveform (b) Power Spectrum of swell signal

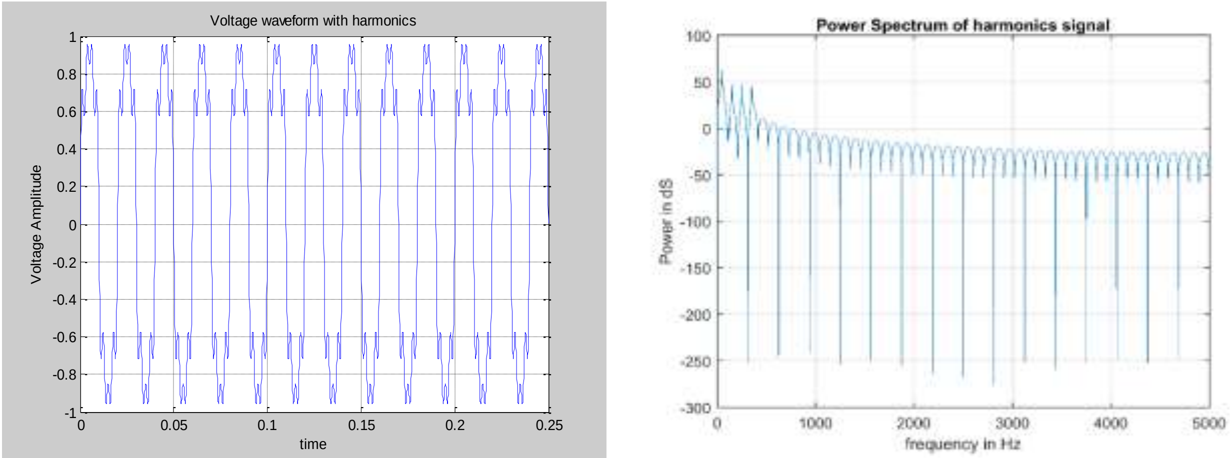
Fig.5 Voltage swell signal and its power spectrum

E. Harmonics

Harmonics are sinusoidal voltages or currents having frequencies that are integer multiples of the frequency at which the supply system is designed to operate (termed as fundamental frequency) [3]. Harmonics produce waveform distortion. Harmonics are numerically modeled as in [8],

$$V(t) = A\sum \alpha_n \sin(n\omega t), 1 \leq n \;\&\; \textstyle\sum_{i=1}^{n} \alpha_i^2 = 1 \qquad (7)$$

α_n is the magnitude of the nth order harmonic which is the summation of amplitudes of harmonic components. By simulating equation (7) for harmonics, in MATLAB, voltage waveform with harmonics as shown in Fig.6(a) and its power spectrum is obtained.



(a) Harmonics signal waveform (b) Power Spectrum of harmonics signal

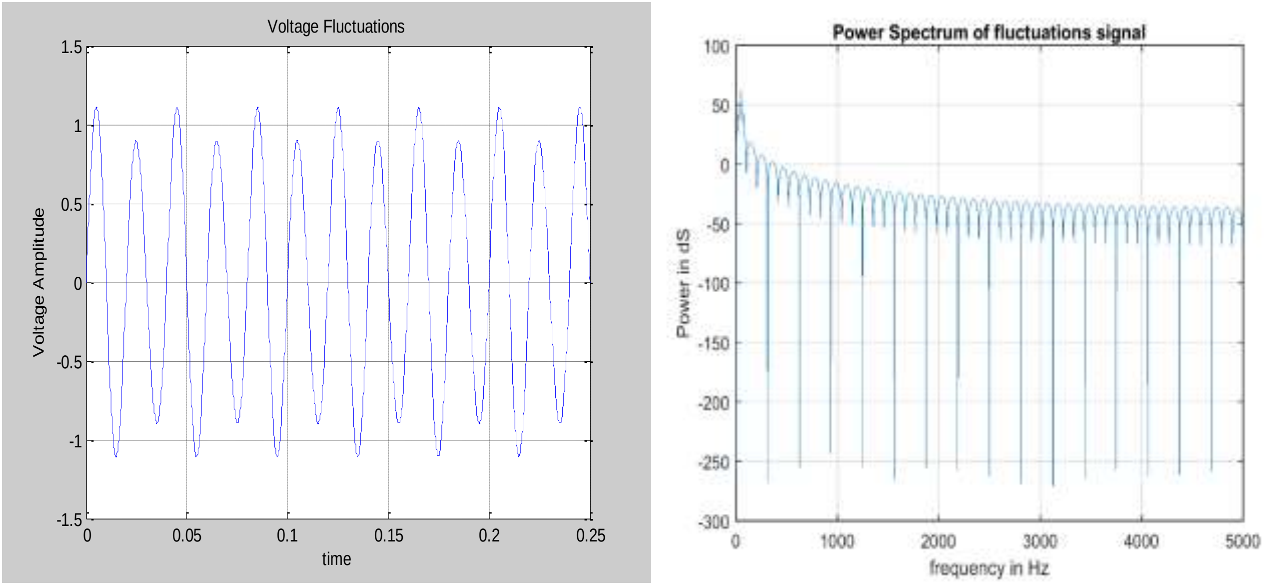
Fig.6 Harmonics signal and its power spectrum

F. Voltage fluctuations

Voltage fluctuations are systematic variations of the voltage envelope or a series of random voltage changes for voltage ranges of 0.95 pu to 1.05 pu [3].

$$V(t) = A(1 + asin(b\omega t))sin(\omega t) \qquad (11)$$

The controlling parameters a and b correspond to the magnitude and integer multiple of frequency respectively. The possible causes of voltage fluctuations are radio transmitters, faulty equipment, ineffective grounding, and proximity to EMI or RFI source [7]. Fig.9(a) shows the waveform of voltage fluctuations obtained in MATLAB by simulating (11) and fig. (b) its power spectrum.



(a) Fluctuations signal waveform (b) Power Spectrum of fluctuations signal

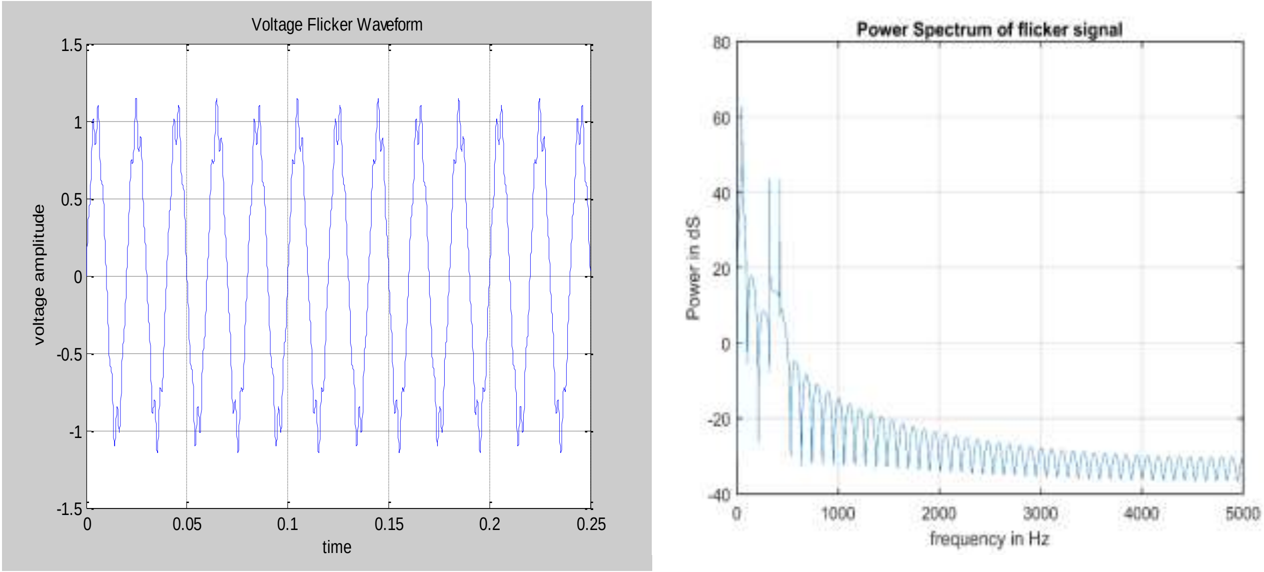
Fig.7 Fluctuations signal and its power spectrum

.G. Voltage flicker

Loads that exhibit continuous, rapid variations in load current magnitude can cause voltage variations erroneously referred to as “flicker” [3]. The sinusoidal voltage signal in terms of flicker signal [10], is given by:

$$V(t) = \left[A_1 + \sum_{i=1}^{I} A_{fi} \sin\left(\omega_{fi} t + \Phi_{fi}\right)\right] \sin(\omega_1 t + \Phi_1) \quad (12)$$

A_1,ω_1 and Φ_1 are amplitude, angular frequency and phase angle of fundamental component of voltage. A_{fi},ω_{fi} and Φ_{fi} are amplitude, angular frequency and phase angle of flicker component of voltage. I is the number of flicker components. Waveform as shown in Fig.8(a), is generated in MATLAB and fig.8(b) shows its power spectrum.



(a) Flicker signal waveform (b) Power Spectrum of flicker signal

Fig.8 Flicker signal and its power spectrum

The results shown from Fig.1 to Fig.8 are obtained in MATLAB by using suitable code based on parametric equations and corresponding power spectrum for each of the power quality disturbances. All the power quality disturbance signals represent variations in pure sinusoidal voltage waveform in time domain and frequency content information is obtained from power spectrum.

4. Conclusion

The power quality disturbances results in disconuity and variations in supply. To obtain frequency information from the time domain sigbals, Fast Fourier Transform is used Power spectrum gives the frequency content present in the signal for different frequency sections. This information can be used for power quality evaluation as the disturbance signals are transformed into frequency domain.

Power spectrum gives power in dB values for different frequencies in Hz As the type of disturbance changes. Power values also changes. The extent of distortion can be depicted from power spectrum values. Disturbances considered for analysis are transients, voltage interruption, voltage sag, voltage swell, harmonics, voltage fluctuations, and voltage flicker. Waveforms are generated using a suitable code based on parametric equations and power spectrum in MATLAB environment.

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