SUGGESTED FLICKER MONITORING SYSTEM BASED ON WAVELET TRANSFORM

Amal F. ABD El-GAWAD
Zagazig University - Faculty of Eng., Egypt
amgawad2001@yahoo.com

ABSTRACT

The present paper suggests two routines to diagnosis the Flicker by using discrete Wavelet analysis. The routines aim to classify the Flicker voltage limits of studied signals as acceptable or not, according to the standard limits. The first routine depends on the values of details and approximations due to the wavelet analysis. The second depends on separating the residuals (the amount of deformation on the studied signals due to Flicker) by wavelet analysis, and then determine the residuals' stored energy by applying FFT transform to evaluate it. The suggested two routines can be implemented for different types of loads (Lamps, Arc Furnace and Induction Motors). Comparisons between the two routines are reported with the complete investigations. Under Matlab - Toolboxes, the results are verified with many demonstrations.

INTRODUCTION

Voltage Fluctuations are described by IEEE as systematic variations of the voltage waveform envelope, or a series of random voltage changes, the magnitude of which falls between the voltage limits set by ANSI C84.1. Generally, the variations range from 0.1% to 7% of nominal voltage with frequencies less than 25 Hz. Subsequently, the most important effect of this power quality problem is the variation in the light output of various lighting sources, commonly termed as Flicker.

The International Electrotechnical Commission (IEC) along with the Union for Electroheat (UIE), the Electric Power Research Institution (EPRI) and the Institute of Electrical and Electronics Engineers (IEEE) have made corporative efforts to allow the IEC standard to be modified for a variety of lighting technologies and promote a universal standard [1]. This universal standard approach has been adopted for voltage flicker and AS/NZ standard has conformed to this norm. It is indicated that Europe has also accepted this norm and it is implemented as a standard [2].

Voltage flickering can be extremely harmful to sensitive electronic equipment. Computerized equipment requires stable voltage to perform properly. For this reason, voltage flicker is a major power quality problem. The magnitude of the voltage flicker depends upon the size and type of the electrical load that is producing the disturbance. So, flicker is a symptom of voltage fluctuation which can be caused by disturbances introduced during power generation, transmission or distribution, but are typically caused by the use of large fluctuating loads, i.e. loads that have rapidly fluctuating active and reactive power demand like some types of lamps, arc furnace and induction motors. Procedure for determining the requirements for connecting large fluctuating loads to medium voltage (MV) and high (HV) levels are explained in IEC 61000-3-7. Flicker emission planning levels provided by IEC must be always less than or equal to the compatibility levels for low voltage (LV) and medium voltage (MV) systems. The IEC 61000-3-3 provides and explains voltage flicker emission limits for the equipments connected to LV systems.

In this paper it is required to investigate voltage flicker due to fluctuating loads for example due to induction motors as they are huge number extended all over the network. The voltage signals under study that represent the effect of induction motors can be obtained by two different methods. The first one, depends on employing signify mathematical equation as an example for LV loads [3]. It is generated by using *m-file in MATLAB*. Also, the second one is produced with *MATLAB* but by implementing a dynamic model of induction motor via *Simulink toolbox* as an example for MV loads [4].

To obtain the high degree of frequency resolution, wavelet transform is suggested to be implemented for well judge between acceptable and unacceptable flicker level due to the international standards. More over discrete wavelet transform (DWT) is recommended against Continuous wavelet transform (CWT). If it is intended to build intelligent monitoring system, generally, Continues wavelet transform (CWT) is not recommended to be utilized to construct a vector to train an intelligent classifier for detecting of voltage flickers as calculating wavelet coefficient at every possible scale is a fair amount of work, and it generates an awful lot of data that will be hard to train any type of intelligent classifier like neural networks or fuzzy logic. The present paper proposes two routines to diagnosis the Flicker by using discrete Wavelet analysis. The first routine depends on the values of details and approximations due to the wavelet analysis. The second depends on capturing the energy spectrum of the residuals that result due to processing the compression features of a certain wavelet basis. Investigations and comparisons between the two routines are studied to get the best one.

The results obtained can be considered as the basis for a flicker monitoring system based on Wavelet Transform that in future it may be produced and handled in the market.

WAVELET TRANSFORM

The main advantage of wavelet is its capability of providing accurate transient information in both frequency domain and time location.

Basic Concepts

Wavelets are functions that satisfy certain requirements. The term *Ψ(t)* is the wavelet function 'mother wavelet' and its dilation and translation are simply 'wavelets' in Eq. (l). Wavelet transform of sampled waveforms can be obtained by implementing the discrete wavelet transform, which is given by:

$$DWT(m,n) = \frac{1}{\sqrt{a_0^m}} \sum_k f(k) \Psi^*\left(\frac{n - ka_0^m}{a_0^m}\right) dt \qquad (1)$$

Where, a_0^m and ka_0^m are the scaling (dilation) and translation (time shift) constants, respectively. Actual implementation of the discrete wavelet transform, involves successive pairs of high-pass and low-pass filters at each scaling stage of the wavelet transform. This can be thought of as successive approximations of the same function, each approximation providing the incremental information related to a particular scale (frequency range), the first scale covering a broad frequency range at the high frequency end of the spectrum and the higher scales covering the lower end of the frequency spectrum however with progressively shorter bandwidths. Conversely, the first scale will have the highest time resolution and higher scales will cover increasingly longer time interval. Depending on *Ψ(t)* many families of wave let can be named like *Haar, Daubechies* (dbN), *Symlets, Coiflets, Gaussian and Mexican hat wavelets*. For Daubechies, it is established that N is the order and db is the surname. Some of these families are suitable for the applications using *CWT* and the others for *DWT*. The transform by *Daubechies* wavelets is more convenient in analyzing various frequency components of a signal. For this study of voltage flickers, after many revises and investigations, *(db5)* is selected to be implemented with decomposition of level 5.

Multiple Level Decomposition and Reconstruction

This process involves two aspects: breaking down a signal into many lower resolution components or coefficients depending on the desired level 'N' (decomposition process), and reassembling the signal from the coefficients (reconstruction process). Of course, there is no point breakin up a signal merely to have the satisfaction of immediately reconstructing it. It is possible to modify the wavelet coefficients before performing the reconstruction step. The wavelet coefficients may be divided into the smoothed version (called the approximation) 'aj' and the detailed version 'dj'; where 'j' takes successively the values from ' 1' to 'N'. This is called the wavelet decomposition tree.

Data Compression

The compression features of a given wavelet basis are primarily linked to the relative scarceness of the wavelet domain representation for the signal. The notion behind compression is based on the concept that the regular signal component can be accurately approximated using the following elements: a small number of approximation coefficients (at a suitably chosen level) and some of the detail coefficients. Compression procedure contains three steps: decompose, threshold detail coefficients and reconstruct. One can set a global threshold, compression performance, or a relative square norm recovery performance. The compression process removed most of the noise, but preserved nearly all the energy of the signal. The remaining wavelet coefficients represent very small ratio and called residuals.

ESTIMATION OF INDUCTION MOTOR VOLTAGE FLICKER

Flicker may be produced, for example, if a steel mill uses large electric motors or arc furnaces on a distribution network, or frequent starting of an elevator motor in an office building, or if a rural residence has a large water pump starting regularly on a long feeder system. The likelihood of flicker increase as the size of the changing load becomes larger with respect to the prospective short circuit current available at the point of common connection. In the first part of this paper, mathematical equation for generated voltage of induction motor is formed as an example for LV loads that cause flicker. It is generated by using *m-file in MATLAB*. In the second part of the paper, dynamic model for an induction motor using *MATLAB/ (Simulink)* is presented as an example for MV loads that connected to the electric network.

The resulting signals from both approaches are implemented for using wavelet transform to judge the flicker voltage level.

Mathematical Equation

Voltage flicker is usually expressed as a percent of the total change in voltage with respect to the average voltage over a specified time interval. The corresponding instantaneous voltage can be expressed as:

$$V(t) = V_P\,(1 + m \sin(2\pi f_m t)\cos(2\pi f_0 t)) \qquad (2)$$

Where, V_P: Peak amplitude of the fundamental ac voltage

f_m : Modulation frequency

f_0 : Fundamental frequency,

$m = \Delta V/2\ V_P$: Modulation depth

In this case, the induction motor represent LV load then the required signals are generated through this equation by choosing suitable parameters as the inputs to *m-file in MATLAB.*

Dynamic Model

To simulate the induction motor behavior using *simulink/Matlab*, it is suggested to use an uncomplicated electrical network shown in Fig.1.

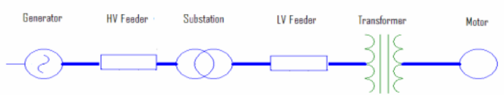

Fig. 1. Induction Motor Network.

By choosing suitable values for the elements of the network and also for the resistance and reactance of both stator and rotor for the 22 kV induction motor, the simulation model can be built as shown in Fig.2.

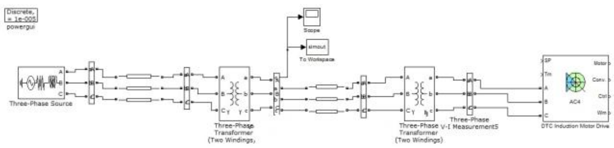

Fig. 2. MATLAB diagram of simulated model of Induction Motor Network.

RESULTS

Results for mathematical equation and dynamic model using *DWT* are reported as follows.

Results for Mathematical Equation

Table I contains the parameters required for generating the normal voltage signal. Also, it contains the parameters required to create the flicker at the generated signals.

TABLE I
GENERATED CASES FORM MATHEMATICAL EQUATION

Case	No	Varying parameter	D1	FFT
Normal	0	V_P=220 volts, f_0=60 Hz	-0.25:0.4	15.8*10^7
Acceptable	1	f_m =5, 10 ,30 ΔV =0.125, 0.5, 0.375	-200:200	9.5*10^7
	2	f_m =5,10,30 ΔV =0.5,1,1.5	-450:400	12.2*10^7
	3	f_m =3,5,10 ΔV =0.5,1,1.5	-500:500	10.5*10^7
	4	f_m =8,15,30 ΔV =0.5,1,1.5	-400:200	14.5*10^7
Unacceptable	5	f_m =35,45,55 ΔV =2.5,5,7.5	-2000:2000	2.8*10^9
	6	f_m =100,150,200 ΔV =2.5,5,7.5	-1200:1200	2.5*10^9

With choosing suitable the values of the parameters, acceptable and unacceptable flicker level voltage can be determined according to the standards discussed before.
It also, contains the 1st detail coefficients D1, which describes the flicker level condition resulting from applying discrete wavelet transform (DWT) with function db5 with decomposition of level 5. Values of D1 are the most obvious items that clarify the needed distinguish.

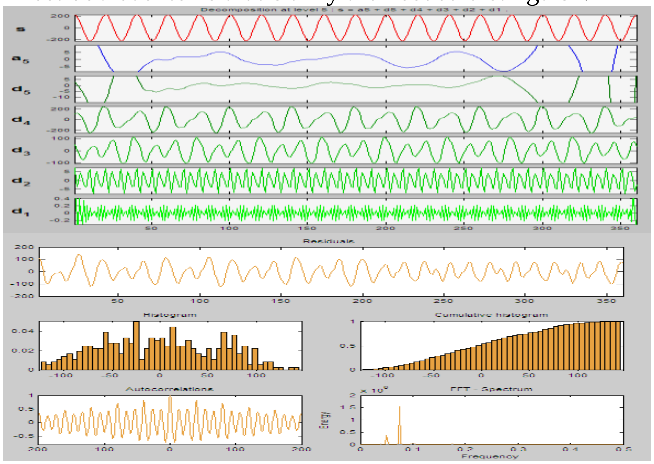

Fig. 3. DWT analysis for normal case.

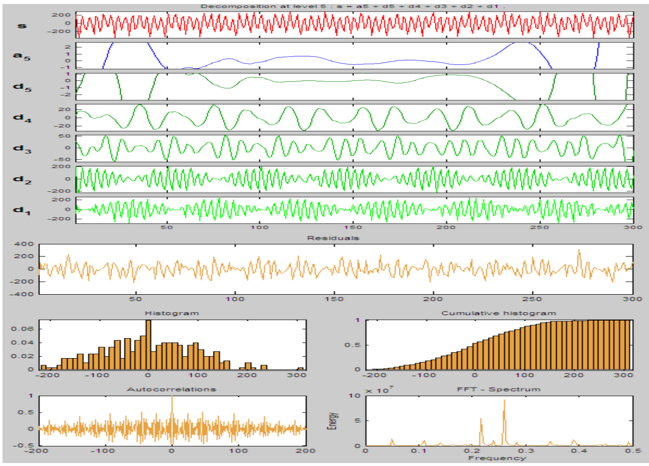

Fig. 4. DWT analysis for case 1 (acceptable).

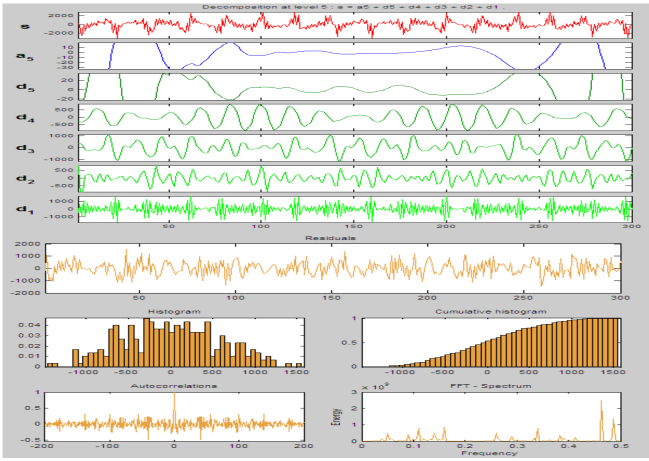

Fig. 5. DWT analysis for case 6 (unacceptable).

So, the first routine of diagnosis depends on comparing the value of D1 for normal case and other cases. It is found that their values are very small for normal case as shown in fig.3. For acceptable cases the values are relatively bigger for D1, as shown in fig.4. In addition, for unacceptable case, values of D1 are evidently big, as shown in fig.5.

So, by using this analysis it can be discriminated clearly between acceptable and unacceptable manners. Also, as D1 picks up the high frequency component of the signal, it is clear that its shape at case 6 (unacceptable) is more distorted than this of case 1 (acceptable). Table I contains also values of FFT which represents the stored energy in the residuals resulting from the compression process as discussed before. So, the second routine of diagnosis depends on comparing the value of FFT for normal case and other cases. It is clear that one cannot distinguish between normal case and the other acceptable cases. On the other hand unacceptable cases are relatively different. So, this sort of diagnosis is not efficient. Figs. 3, 4 and 5 show some more information about the compression process like the shape of residuals, their histogram, their cumulative histogram, autocorrelations and the required FFT- spectrum.

<u>Results for Dynamic Model</u>

Simulated the electrical network MATLAB / (simulink), is implemented by connecting the suggested induction motor to through sinusoidal medium voltage source of 22 kV – 50Hz, taking into account choosing suitable values for the resistance and reactance of both stator and rotor. Then the proposed two routines are implemented.

TABLE II
GENERATED CASES FORM DYNAMIC MODEL

Case	No	Varying parameter	D1	FFT
Normal	0	V=22 kV ,f=50 Hz	-30 :30	4*10^8
Flicker	1	Stator: R=0.435Ω & X=0.002 Ω Rotor: R=0.816 Ω & X=0.002 Ω	-200 :400	4*10^15
	2	Stator: R=2.0 Ω & X=0.0005 Ω Rotor : R=0.9 Ω & X=0.001 Ω	-200 :400	4*10^15

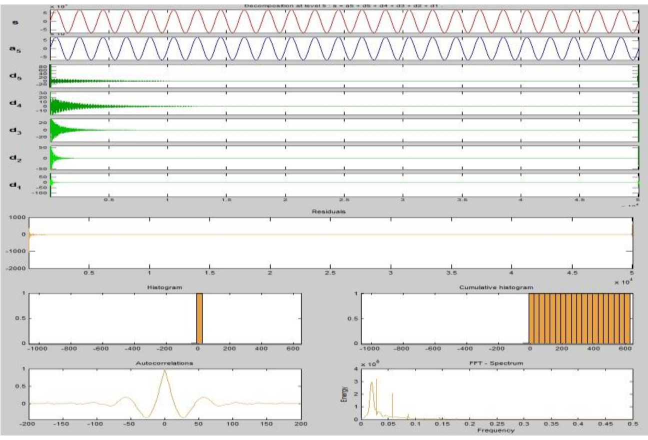

Fig. 6. DWT analysis for normal case.

From table II, it is clear that one can distinguish evidently between normal and flicker cases for the values of both D1 and FFT. In other words both routines can diagnose the cases impeded by flicker, but still the first one is more efficient as shown in Figs. 6 and 7.

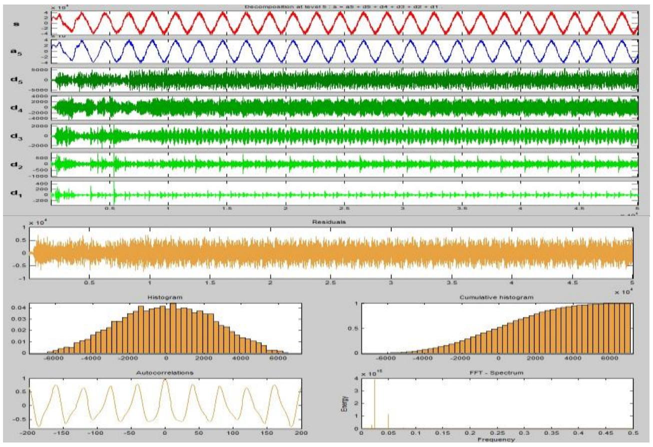

Fig. 7. DWT analysis for voltage flicker.

CONCLUSION

From the previous donations along the paper, it can be concluded that:

- To generate the Flicker Signals two approaches are introduced, mathematical equation and dynamic model of electric network using *MATLAB*.
- Wavelet transform with (db5) is suggested to be employed for well judging between acceptable and unacceptable flicker level due to the international standards.
- It is evident to mention that as the degree of flicker is increased as the residuals are increased.
- The first routine is better than the second routine in this situation as the determined residuals' stored energy after applying FFT transform is relatively small. It is small because the amount of deformation on the studied signals due to Flicker is small compared with other sources of deformations like voltage dip or swell.
- The results obtained can be considered as the basis for a flicker monitoring system based on Wavelet Transform that in future it may be produced and handled in the market.

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