International Journal of Computer Applications (0975 – 8887)
Volume 71– No.24, June 2013

Analysis of Harmonics of Electric Traction System using Wavelet Transform

Vasanthi V, Ashok S
Department of Electrical Engineering
National Institute of Technology,
Calicut, Kerala, India

ABSTRACT

Wavelet Transform is a mathematical tool for time frequency analysis of non stationary signals like the current waveform in electric traction system. The locomotives used in traction system have different types of traction motors –dc and three phase ac motors with different methods of speed control. Hence technologies will be different depending on the type of locomotives. The nature of the load in electric traction system is very dynamic due to the acceleration, constant speed operation and deceleration of the locomotives. Due to the variation in the type and running pattern of locomotives harmonics induced into the system varies with time. In this paper, wavelet transform is applied to find out the total harmonic distortion of the measured current from a traction substation. Also a comparison is made by applying discrete Fourier transform to the instantaneous values of measured current.

Keywords
Electric traction, locomotive, harmonics, wavelet transform.

1 INTRODUCTION
Wavelet transform is a signal processing tool for analyzing harmonics in power system applications. Electric traction is one of the power system applications with non-stationary current waveform. Electric traction system consists of different locomotives fed from traction substations (TSS). The presence of power electronic circuits in locomotives affects the quality of line current of traction system. It is required that the line current should be thoroughly analyzed for harmonics, which will otherwise affects the quality of power supplied by the utility. The locomotives are different in the type and technology for speed control. Also a traction substation feeds more than one locomotive at the same time. The locomotives in a TSS can have different running pattern such as acceleration mode, constant running mode or regenerative braking mode. All these factors together cause time dependency in the current waveform at the TSS.

Fourier transform (FT) performs well with time invariant signals, but does not perform well for detection of sudden or fast changes in the waveform. For non-stationary signal analysis, short time Fourier transform (STFT) can be used. It gives frequency and time information but the resolution is fixed due to the fixed window [1-4].The mentioned limitations of FT and STFT are overcome by wavelet transform (WT), which has been proposed by several authors. A wavelet is an effective time–frequency analysis tool for analyzing non-stationary signals. The signal is represented by the combination of wavelets and its scaled and translated version. The discrete wavelet transform (DWT) analyzes the signal at different frequency bands with different resolutions by decomposing the signal into a coarse approximation and detail information. The DWT employs two sets of functions called scaling functions and wavelet functions, which are associated with low pass and high pass filters, respectively. The decomposition of the signal into the different frequency bands is simply obtained by successive low pass and high pass filtering of the time domain signal [4, 5].A lot of work has been done in power quality assessment using wavelet transforms. Reference [6] presents the application of wavelet transform in power system transient and harmonic analysis.The analysis related to a four quadrant ac converter of a particular locomotive is performed in reference [7]. DWT and wavelet networks are applied to classify the power quality events in reference [8]. Comparison has been made between short time Fourier transform and wavelet transform for the analysis of power quality events in a 12 bus system [9]. Power quality indices are developed based on the wavelet decomposition coefficients [10].

In this paper, the wavelet transform (WT) is applied to the current waveform measured from a traction substation to determine the harmonic distortion. Total harmonic distortion and harmonics in different level of decomposition are determined. The results are compared with those given by the power analyzer of fluke make.

2 THEORY OF WAVELET
Wavelet transform is a tool for analysing the signals with time varying characteristics. Fourier transform (FT) identifies all the spectral components present in the signal without giving information about the time localisation. Short time Fourier transform (STFT) gives both time and frequency information but due to the fixed window size, a good time and frequency resolution cannot be achieved simultaneously. Any one should be compromised for the other. This problem of STFT can be solved by wavelet transform. Wavelet transform decomposes the signal in both time and frequency domains without any reduction in resolution by using variable window size. The different frequency components can be extracted from the signal by the method of multi-resolution analysis (MRA) of discrete wavelet transform (DWT). The basic building blocks of MRA are wavelet and scaling functions. They are used to decompose the signal into different frequency bands and reconstruct the original signal. The decomposed signal consists of two types of coefficients namely detail (generated by wavelet function) and approximation (generated by scaling function). The mathematical expression for any signal x (t) canbe given as a sum of wavelet and scaling functions in DWT as given in (1).

$$x(t) = \sum_k a_0(k)\emptyset(t-k) + \sum_{j=0}^{N} \sum_k d_j(k) 2^{j/2} \psi(2^j t - k) \quad (1)$$

Where $\emptyset(t)$ and $\psi(t)$ are the scaling function and wavelet function respectively and a_0 is the '0' level scaling coefficient, d_j represent the detail coefficients and k is the translation coefficient [6].

DWT is implemented by using multistage filter bank with low pass and high pass filters. The output of the filters is down sampled by two so that the wavelet function is scaled by two. The approximation coefficients: low frequency components and detailed coefficients: high frequency components are represented by a (k) and d (k) respectively.

2.1 Calculation of THD

Total harmonic distortion (THD) is defined as the ratio of root mean square value of harmonics to root mean square value of fundamental component.

$$THD = \sqrt{\frac{\sum_{j=1}^{m-1}(\sum_{k=1}^{N_j} 2^{j-1} d_j^2(k)/N_j)}{(\sum_k 2^{m-1} a_m^2(k)/N_m)}} \qquad (2)$$

where k is the coefficient number at level j, m the highest level of decomposition, N_j , N_m the number of coefficients at level j, m and d and a corresponds to detail and approximation coefficient respectively[5].

2.2 Signal captured from substation

The authors measured the readings at low voltage side of traction substation (110/25 kV) using the power analyzer of fluke make. The root mean square value of load current and load voltage waveforms measured using power analyzer at the TSS for a day are plotted in fig 1 and fig2 respectively. The low voltage side of the traction has two feeders supplying power to opposite side of the substation. The readings were taken continuously at the feeder of the substation. The substations have identical parameters with two traction transformers of power capacity 21.6 MVA and frequency of 50Hz operating one at a time. There is slight variation in the readings day by day depending on the load pattern. The traction substation considered is the one through which the above type of locomotives are passing. The low voltage side of the traction has two feeders supplying power to opposite side of the substation. The readings were taken continuously at the feeder of the substation. They have identical parameters with two traction transformers of power capacity 21.6 MVA and frequency of 50Hz operating one at a time. There is slight variation in the readings day by day depending on the load pattern [11].

2.3 Selection of wavelet

Unlike Fourier transforms which has got single basis function, wavelets have different basis functions. The first step in analysing signals using wavelet transform is finding a wavelet whose shape is very close to the signal under consideration. One method of finding suitable wavelet is depending on the correlation coefficient. High value of correlation coefficient implies the mother wavelet is very suitable to the signal. In this work, different wavelets namely db2 to db10, sym 2-8, coif 2-6 were included in the analysis for selecting the wavelet with very close shape to the signal. Finally coif 5 was having the highest root mean square value of the coefficients and was found to be the most suitable wavelet and so it was selected for analysing purpose.

.

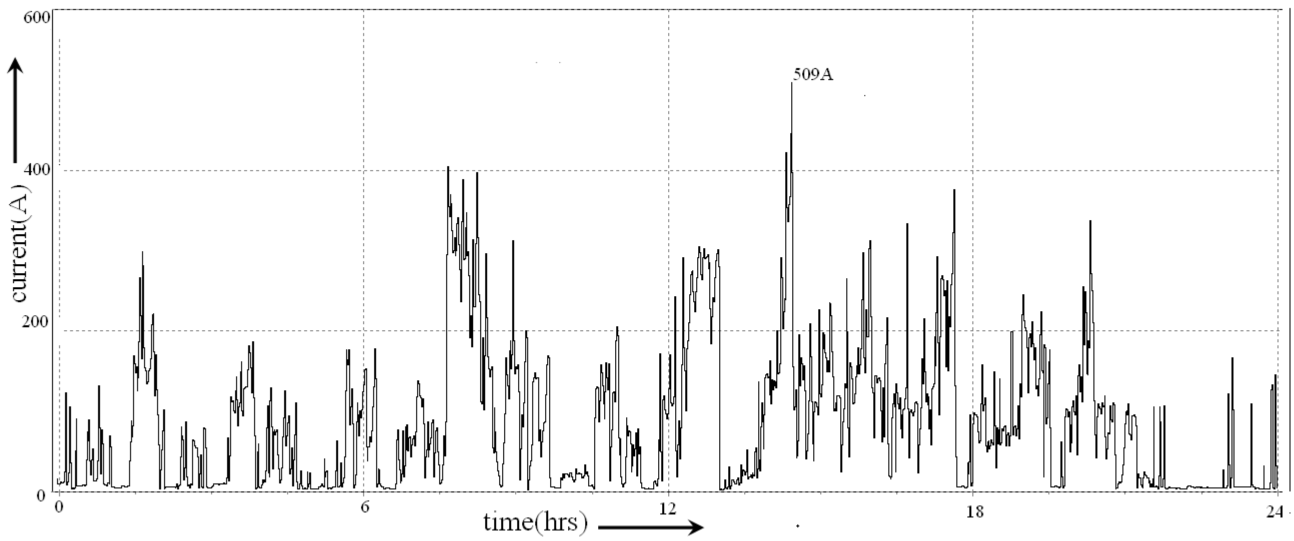

Fig 1: Load current measured at the feeder for a typical day [11]

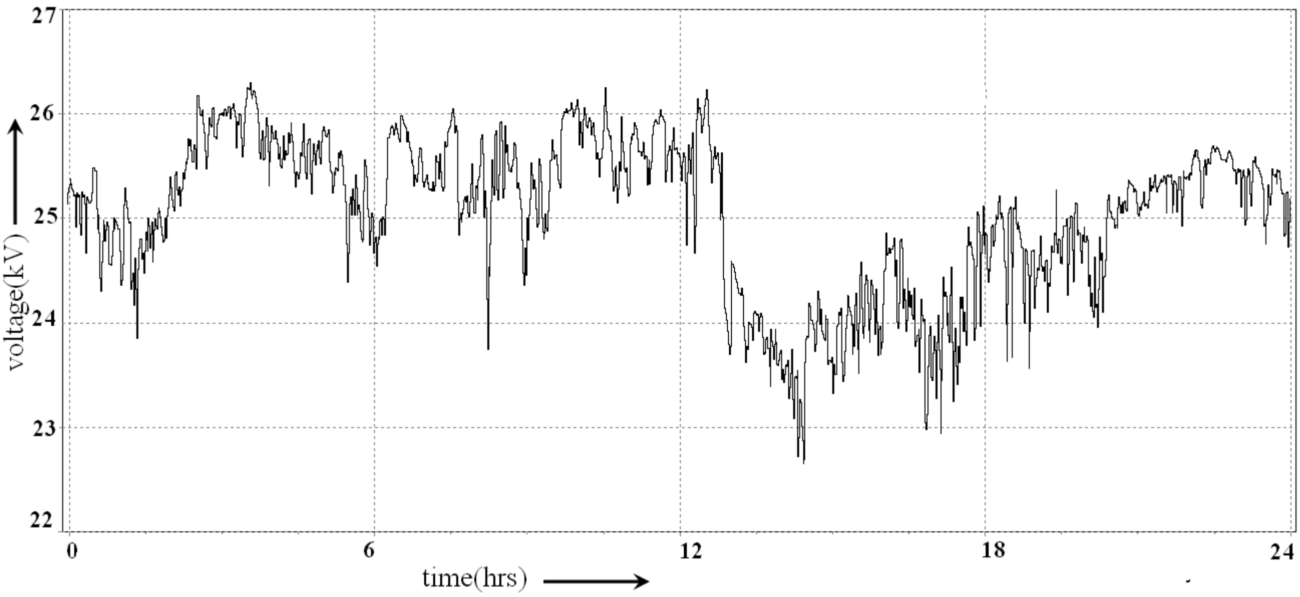

Fig 2: Voltage measured at the feeder for a typical day [11]

2.4 Harmonic analysis

The sampling frequency of the instrument used for current measurement at the traction substation is 10.4 kHz. The maximum harmonic frequency of the signal that is of interest is 2.5 kHz. According to Nyquist theorem, the sampling frequency should be greater than or equal to twice the highest frequency content in the signal. The fundamental frequency of the system is 50 Hz. DWT is applied to the signal for 5 level decomposition with different wavelet functions. The frequency band and harmonics for 5 level decomposition is given in table.1**.**

In order to determine the frequency band containing 2nd and 3rd harmonics separately, coefficients of D5 level is again decomposed. Similarly the band containing 4th, 5th and 6th is decomposed into separate out the above frequencies. As a ratio of fundamental frequency, the band containing 3rd and 5th comes to 0.2233 and 0.10 respectively.

Table 1. Frequency range and order of harmonics for 5 level decomposition

Level of decomposition	Frequency range(Hz)	Order of harmonic	Harmonics in ratio of fundamental
D1	1250-2500	25-50	0.0365
D2	625-1250	13-25	0.0683
D3	312.5-625	7-12	0.1093
D4	156-312.5	4,5,6	0.1500
D5	73-156	2,3	0.2227
A5	0-73	1	1

THD=0.30

3 SIGNAL ANALYSIS BY DFT

The current waveform was captured from a traction substation for a number of days. The measured data for a typical day is processed by discrete fourier transform (DFT) with sampling interval of one minute duration. It was assumed that signal is constant in the one minute duration. By applying DFT, individual harmonics and THD can be determined for each sample taken per minute. The average of all the instantaneous total harmonic distortion and individual harmonics for a typical day is calculated. The results are tabulated in table.2

.
.

Table.2 Average harmonics and THD by DFT

THD	0.33
1	1
3	0.26
5	0.17
7	0.08
9	0.044

The tabulated results show that the total harmonic distortion obtained by DWT and average value of THD for a typical day obtained from DFT are very close to each other. The slight difference is due to the presence of negligible even harmonics in DWT method of analysis. Similarly the harmonics in different bands also show closeness in values.

4 CONCLUSION

Wavelet transform is applied to determine the harmonics of the current waveform measured at a traction substation for a typical day. The harmonics in different bands of decomposition is determined and finally the total harmonic distortion is also found out by multi resolution technique. Discrete Fourier transform is applied to the data measured at a sampling interval of one minute duration. The instantaneous value of total harmonic distortion and individual harmonics are obtained by applying DFT to the current data. Then average value for a typical day was calculated. The tabulated results show closeness in values of THD and harmonic contents obtained in both methods.

5 ACKNOWLEDGMENTS

The authors thank Indian railway for the help in taking measurements at the traction substation.

6 REFERENCES

[1] Wilkinson WA, Cox MD, Discrete wavelet analysis of power system transients, IEEE Trans Power Systems (1996)11:2037–44.

[2] Santoso S, Grady WM, Powers EJ, Lamoree J, Bhatt SC. Characterization of distribution power quality events with Fourier and wavelet transforms, IEEE Trans Power Deliver 2000,15:247–54

[3] Gu Y, Bollen MHJ. Time–frequency and time–scale domain analysis of voltage disturbances. IEEE Trans Power Delivery 2000; 15:1279–83.

[4] A.SerdarYilmaz ,AbdulhamitSubasi a, Mehmet Bayrak, Vedat M. Karsli, Ergun Ercelebi. Application of lifting based wavelet transforms to characterize power quality events.Energy Conversion and Management 48 (2007) 112–123

[5] A.H. Ghaemi , H. AskarianAbyaneh , K. Mazlumi. Harmonic indices assessment by Wavelet Transform.Electrical Power and Energy Systems 33 (2011) 1399–1409.

[6] Tongxin Zheng, Elham B Makram, Adly AGirgis,"Power System transient and harmonic studies using wavelet transform", IEEE transactions on power delivery, Vol.14, No.4, October 1999

[7] P.Fedrigo, A Gandeli, S Leva, A P Morando, "Wavelet analysis of line current for a four quadrant locomotive" IEEEIndustry application conference,2000, Page(s): 1917 - 1922 vol.3

[8] M.A.S. Masoum, S. Jamali N, Ghaffarzadeh. Detection and classification of power quality disturbances using discrete wavelet transform, and wavelet networks. IET Sci. Meas. Technol., 2010, Vol. 4, iss. 4, pp. 193–205.

[9] Francisco Jurado a, Jose´ R. Saenz, Comparison between discrete STFT and wavelets for the analysis of power quality events.Electric Power Systems Research 62(3) (2002)183-190.

[10] Walid G. Morsia, M.E. El-Hawary, Novel power quality indices based on wavelet packet transform for non-stationary sinusoidal and non-sinusoidal disturbances , Electric Power Systems Research 80 (2010) 753–759.

[11] Vasanthi V,Ashok S,Harmonic issues in electric traction system, in proceedings of IEEE int.conf. energy,automation and signals,dec 2011.