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Estimation of Interharmonics Using Exponential Wave Fitting Algorithm

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Abstract: In this paper, exponential wave fitting algorithm is proposed for the estimation of harmonics and interharmonics in power system. A appropriate control approach must be provided to ease the harmonics. To obtain suitable control parameter, the harmonics present in the system is to be estimated. In this work, the estimation of interharmonics was done with and without noise. Interharmonics can be thought of as the inter-modulation of the fundamental and harmonic components of the system with any other frequency components and can be perceived in an increasing number of loads. These loads include static frequency converters, cycloconverters, sub-synchronous converter cascades, induction motors, arc furnaces and all loads not pulsating synchronously with the fundamental power system frequency. International Electro technical Commission (IEC) which is the international body recognized as the curator of electric power quality standards (IEC-1000-2-1) officially defined this terminology as 'Between the harmonics of the power frequency voltage and current, further frequencies can be observed which are not an integer of the fundamental, They can appear as discrete frequencies or as a wide- band spectrum'. A recent IEC-61000-2-2 draft redefines interharmonic as 'Any frequency which is not an integer multiple of the fundamental frequency'. IEEE Interharmonic Task Force adopted this definition. As harmonics and interharmonics have much adverse effects on the equipment, a proper control strategy must be provided to alleviate the harmonics.

Keywords: Exponential Wave Fitting Algorithm; Frequency Estimation, Power System; Noise; Harmonics Mitigation; Power Quality.

I. INTRODUCTION

With increasing use of power electronic drives and non-linear loads, the generated power harmonics and interharmonics have resulted in serious power line pollution. Power supply quality is therefore provoked. Harmonics are spectral components at frequencies that are integer multiples of the ac system fundamental frequency. Interharmonics are spectral components at frequencies that are not integer multiples of the system fundamental frequency. Traditional harmonics may cause overheating and useful life reduction, interharmonics create overheating and useful life reduction, interharmonics create some new problems, such as voltage fluctuations, and light flicker, even for low-amplitude levels.The noise on data transmission line is also related with harmonics. At some special systems, harmonic current components may cause effect of carrier signals, and thus affect other carrier signals. Moreover, harmonics may also produce transformer and capacitor overheating, thus reducing their working life. The resulting rotor heating and pulsating output torque will drop the driver's efficiency.

Interharmonics can be pragmatic in an increasing number of loads in addition to harmonics. There are two basic contrivances for the generation of interharmonics. The first is the generation of components in the sidebands of the supply voltage frequency and its harmonics as a result of changes in their magnitudes and/or phase angles. These are produced by rapid variations of current in equipment and installations, which can also be a source of voltage fluctuations. Disturbances are caused by loads operating in a transient state, either continuously or temporarily, or, in many more cases, when an amplitude modulation of currents and voltages occurs. The second way is the asynchronous switching (i.e. not synchronised with the power system frequency) of semiconductor devices in static converters.

The occurrence of interharmonics strongly rises difficulties in modelling and evaluating the distorted waveforms. This is mainly due to: 1) very low values of concerns of interharmonics (about one order of magnitude less than for harmonics), 2) the erraticism of their frequencies and amplitudes, 3) the variability of the waveform periodicity, and 4) the great sensitivity to the spectral leakage phenomenon.

I. CONCEPT AND EFFECTS OF INTERHARMONICS

When a sinusoidal voltage is applied to a certain type of load, the current drawn by the load is proportional to the voltage and impedance and follows the envelope of the voltage waveform. These loads are referred to as linear loads. Examples of linear loads are resistive heaters, incandescent lamps, and constant speed induction and synchronous motors.

In contrast, some loads cause the current to vary disproportionately with the voltage during each half cycle. These loads are classified as nonlinear loads, and the current and voltage have waveforms that are nonsinusoidal, containing distortions, whereby the 50 Hertz waveform has numerous additional waveforms superimposed upon it, creating multiple frequencies within the normal sine wave. Examples of such loads are battery chargers, electronic ballasts, variable frequency drives, and switching mode power supplies. In these devices harmonics are generated due to following factors

- non-linear characteristics of the load
- Inrush current at the time of switching
- Saturation of core
- Use of solid state switching devices

Interharmonic currents cause interharmonic distortion of the voltage depending on magnitudes of the current components and the supply system impedance at that frequency. Among the most common, direct, effects of interharmonics are:

- Thermal effects
- Low-frequency oscillations in mechanical systems
- Disturbances in fluorescent lamps and electronic equipment operation.

- Interference with control and protection signals in power supply lines.
- Overloading passive parallel filters for high order harmonics
- Telecommunication interference
- Acoustic disturbance
- Saturation of current transformers.

The most common effects of the presence of interharmonics are variations in rms voltage magnitude and flicker.

Table 1 Voltage distortion limits

Bus voltage	Maximum individual harmonic component	Maximum total harmonic distortion (THD)
69kv and below	3.0	5.0
Above 69kv to 161kv	1.5	2.5
Above 161kv	1.0	1.5

Table 2 Influences on Equipments

EQUIPMENT	INFLUENCE
Capacitors and reactors	Overheating, burn out, generation of vibration and capacitor bank failure because of reactive power overload, resonance.
Neutral cables	Overheating of neutral lines, skin effect losses.
Rectifier	Faulty operation due to phase shifting of control signals
Relays and	Faulty operation due to excess of setting level or phase variation
Synchronous machines	Overheating in coils and cores, excessive losses, rise in torsional stresses
Communication lines	Generation of noise voltage
Audio equipment and home	Defects ,influence on life and on performance of components such as diodes, transistors and capacitors
Power fuses	Blowing out due to excessive harmonic current.
Transformers	Generation of beat noise, increased losses in the core. Generation of harmonic fluxes and increase in flux density.
Computer	Adverse influence on performance
Watt-hour meter	Measuring error due to non-linear characteristics of effective voltage and current flux

The harmonics are normally measured on the point of common coupling (PCC). It is defines as the electrical connecting point or interface between the utility distribution system and the customer's or user's electrical distribution system.

II. METHODOLOGY

Exponential wave fitting method is most widely used in practice. It is a mathematical method and with its help a trend exponential curve is fitted to the data in such a manner that the following two conditions are satisfied.

$\sum (Y - Y_c) = 0$ . . . .(1)

$\sum (Y - Y_c)^2$ is least. . . . .(2)

Where Y is the actual data.

Y_c is the computed value.

Thus it is a mathematical method in which a trend curve is fitted to the data in such a manner the sum of the squares of the deviations of the actual and the computed values is least. Residue R is given by, $R = (X_{actual} - \text{assumed signal})^2$. This is the function to be minimized. According to least square method, a set of equations are obtained by differentiating the residue with respect to the unknowns and equating them to zero.

Inputs required

Inputs required to estimate the harmonics are as follows

- Number of samples (n).
- Time and its corresponding magnitude (mag).
- Number of harmonics to be estimated (h).

Steps involved

- Formulate residue R which is the difference between actual output and estimated signal.
- Differentiate R with all unknown parameters and equate it to zero.
- The equations are expressed in matrix form as AX =B and solved.
- The magnitude and phase angle of individual harmonics are determined.

PROBLEM FORMULATION

Let the assumed signal structure be,

$X(t) = \sum A_k \cos(w_k t + \varphi_k)$ . . . .(3)

Where, k = 1,2…….N

N : number of inter harmonics

A_k : amplitude of kth inter harmonic.

W_k : angular frequency of kth inter harmonic.

Φ_k : phase angle of kth inter harmonic.

We know,

$e^{jt} = \cos t + j \sin t$ . . . .(4)

let $y = A \cos(wt + \varphi)$

$= A/2\, (e^{j(wt+\varphi)} + e^{-j(wt+\varphi)})$

$= A/2\, (e^{jwt} . e^{\varphi} + e^{-jwt} . e^{-\varphi})$

$= X e^{jwt} + X^* e^{-jwt}$ . . . .(5)

where $X = A/2\, e^{\varphi}$

In our problem we need the values of A_k and φ_k . They can be estimated from the values of X.

The residue function is defined as follows:

$R = [mag - (A_1 e^{j2\pi ft} + A_1^* e^{-j2\pi ft} + A_2 e^{j4\pi ft} + A_2^* e^{-j4\pi ft} + \ldots + A_n e^{j2n\pi ft} + A_n^* e^{-j2n\pi ft})]^2$ . . . .(6)

From least square technique,

$\partial R/\partial A_k = 0$ . . . .(7)

$\partial R/\partial A_k^* = 0$ . . . .(8)

where k = 1,2……n

n: order of harmonics

Then, $\partial R/\partial A1 = 2[mag - (A_1 e^{j2\pi ft} + A_1^* e^{-j2\pi ft} + A_2 e^{j4\pi ft} + A_2^* e^{-j4\pi ft} + \ldots + A_n e^{j2n\pi ft} + A_n^* e^{-j2n\pi ft})]\,[-e^{j2\pi ft}] = 0$ . . . .(9)

$\partial R/\partial A1^* = 2[mag - (A_1 e^{j2\pi ft} + A_1^* e^{-j2\pi ft} + A_2 e^{j4\pi ft} + A_2^* e^{-j4\pi ft} + \ldots + A_n e^{j2n\pi ft} + A_n^* e^{-j2n\pi ft})]\,[-e^{-j2\pi ft}] = 0$ . . . .(10)

$\partial R/\partial A2 = 2[mag - (A_1 e^{j2\pi ft} + A_1^* e^{-j2\pi ft} + A_2 e^{j4\pi ft} + A_2^* e^{-j4\pi ft} + \ldots + A_n e^{j2n\pi ft} + A_n^* e^{-j2n\pi ft})]\,[-e^{j4\pi ft}] = 0$ . . . .(11)

$\partial R/\partial A2^* = 2[mag - (A_1 e^{j2\pi ft} + A_1^* e^{-j2\pi ft} + A_2 e^{j4\pi ft} + A_2^* e^{-j4\pi ft} + \ldots + A_n e^{j2n\pi ft} + A_n^* e^{-j2n\pi ft})]\,[-e^{-j4\pi ft}] = 0$ . . . .(12)

…….

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$$\partial R/\partial A_n = 2[mag - (A_1e^{j2\pi ft} + A_1^*e^{-j2\pi ft} + A_2e^{j4\pi ft} + A_2^*e^{-j4\pi ft} + \ldots + A_ne^{j2n\pi ft} + A_n^*e^{-j2n\pi ft})] [-e^{j2n\pi ft}] = 0 \quad \ldots.(13)$$

$$\partial R/\partial A1^* = 2[mag - (A_1e^{j2\pi ft} + A_1^*e^{-j2\pi ft} + A_2e^{j4\pi ft} + A_2^*e^{-j4\pi ft} + \ldots + A_ne^{j2n\pi ft} + A_n^*e^{-j2n\pi ft})] [-e^{-j2n\pi ft}] = 0 \quad \ldots.(14)$$

Then we get,

$$A_1\sum e^{j4\pi ft} + A_1^*\sum e^{0} + A_2\sum e^{j6\pi ft} + A_2^*\sum e^{-j2\pi ft} + \ldots + A_n\sum e^{j2(n+1)\pi ft} + A_n^*\sum e^{-j2(n-1)\pi ft} = \sum mage^{j2\pi ft} \quad \ldots.(15)$$

$$A_1\sum e^{0} + A_1^*\sum e^{-j4\pi ft} + A_2\sum e^{j2\pi ft} + A_2^*\sum e^{-j6\pi ft} + \ldots + A_n\sum e^{j2(n-1)\pi ft} + A_n^*\sum e^{-j2(n+1)\pi ft} = \sum mage^{j2\pi ft} \quad \ldots.(16)$$

$$A_1\sum e^{j6\pi ft} + A_1^*\sum e^{j2\pi ft} + A_2\sum e^{j8\pi ft} + A_2^*\sum e^{0} + \ldots + A_n\sum e^{j2(n+2)\pi ft} + A_n^*\sum e^{-j2(n-2)\pi ft} = \sum mage^{j2\pi ft} \quad \ldots.(17)$$

$$A_1\sum e^{-j2\pi ft} + A_1^*\sum e^{-j6\pi ft} + A_2\sum e^{0} + A_2^*\sum e^{-j8\pi ft} + \ldots + A_n\sum e^{j2(n-2)\pi ft} + A_n^*\sum e^{-j2(n+2)\pi ft} = \sum mage^{j2n\pi ft} \quad \ldots.(18)$$

$$A_1\sum e^{j2(n+1)\pi ft} + A_1^*\sum e^{j2(n-1)\pi ft} + A_2\sum e^{2(n+2)\pi ft} + A_2^*\sum e^{2(n-2)\pi ft} + \ldots + A_n\sum e^{j4n\pi ft} + A_n^*\sum e^{0} = \sum mage^{j2n\pi ft} \quad \ldots.(19)$$

$$A_1\sum e^{-j2(n-1)\pi ft} + A_1^*\sum e^{-j2(n+1)\pi ft} + A_2\sum e^{-j2(n-2)\pi ft} + A_2^*\sum e^{-j2(n+2)\pi ft} + \ldots + A_n\sum e^{0} + A_n^*\sum e^{-j4n\pi ft} = \sum mage^{j2n\pi ft} \quad \ldots.(20)$$

Thus, we get similar 2n number of equations. By solving these equations the required solution is obtained. In this work, these equations are represented by means of matrix and complex values of A_1, A_1^*, A_2, A_2^*,……A_n, A_n^* are obtained. Then magnitude and phase angle of individual frequency components are determined.

FREQUENCY (Hz)	MAGNITUDE (p.u)	PHASE ANGLE (rad)
50	0.96	0.0000
125	0.05	-0.7854
180	0.045	1.5708
250	0.02	0.0000

Magnitude X = magnitude (A) *2

Phase angle φ = angle (A)

The problem formulation is similar to the previous discussion. The difference lies in the value of frequency (f) that is used in the equation 6. In this case, the number of terms to be estimated is given as input. For example, for 25 Hz resolution, if the number of terms to be estimated 10, then it means estimating magnitudes and phase angles corresponding to the frequencies 50, 75,100, 125….275.As the input is concerned, the data for one cycle is not sufficient. To estimate the magnitude and phase angle of 25 Hz signal, we require data for 2 complete 50 Hz cycles.

IV. ESTIMATION OF INTERHARMONICS

The signal to be estimated is assumed as,

$$mag = .96\cos(2\pi 50t)+.05\cos(2\pi 125t-\pi/4)+.045\cos(2\pi 180t+pi/2)+.02\cos(2\pi 250t) \quad \ldots.(21)$$

To obtain interharmonics component, we have to choose initially a suitable window size. In our problem we require 5Hz frequency resolution and cycles required are 10. Hence the data for 10 cycles is given as input.

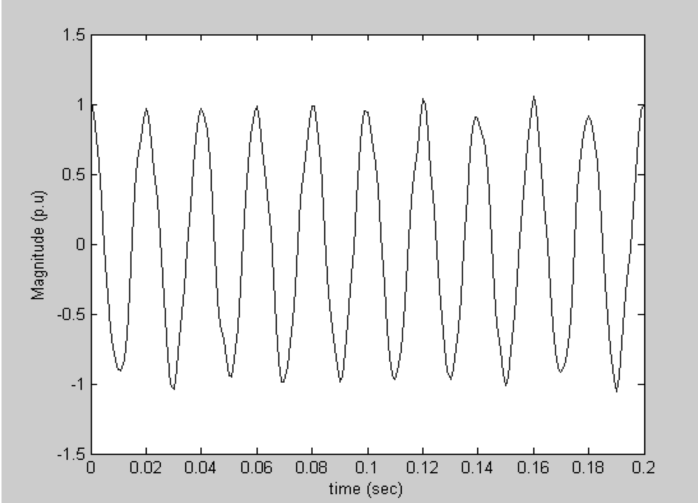

Figure 1 Input signal without noise

Table 3 Magnitude and phase angle of interharmonics in test signal

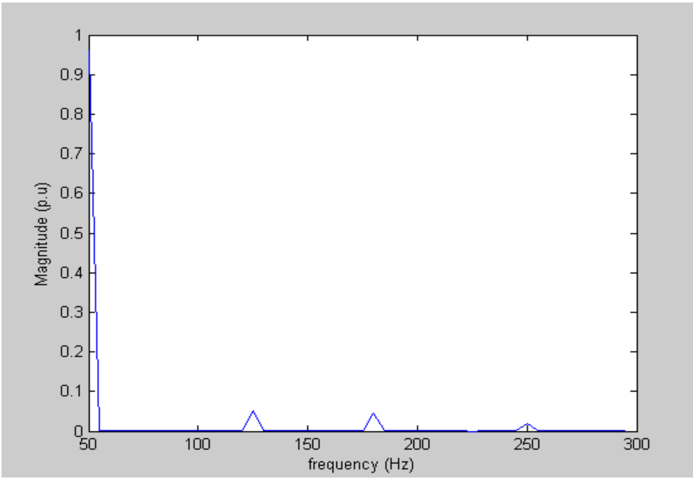

Figure 2 Frequency spectrum of the signal

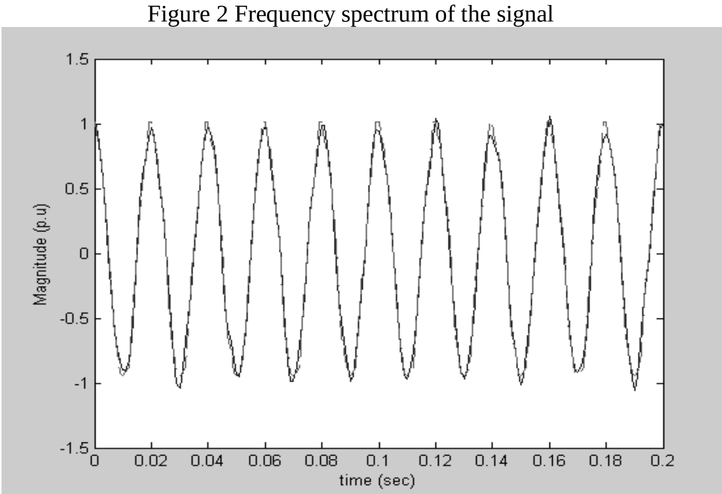

Figure 3 Comparison between original and estimated waveform

Then the estimation was carried out in the presence of noise with signal to noise ratio 20db and the results are shown below.

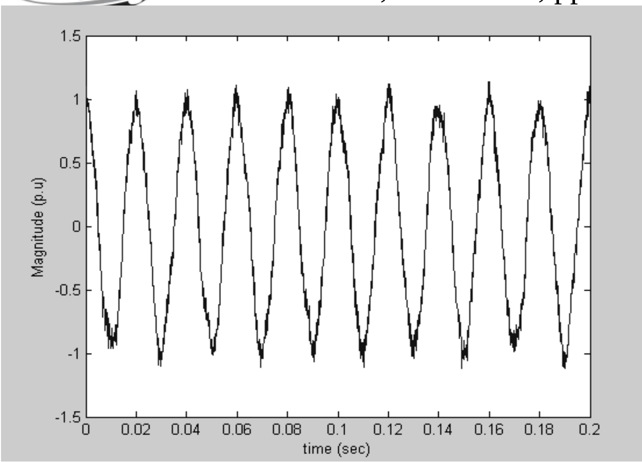

Figure 4 Input signal with noise

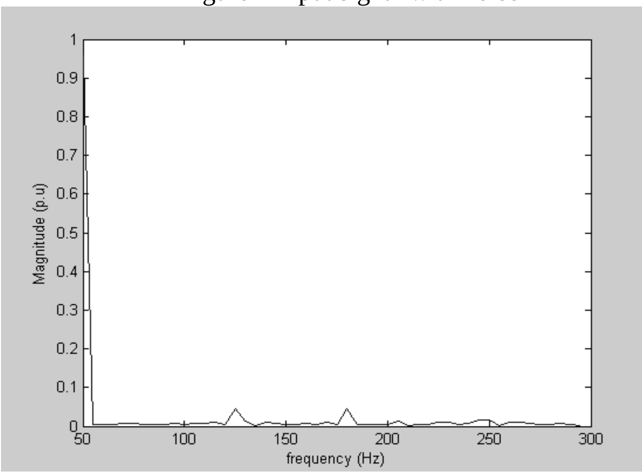

Figure 5 frequency spectrum of noise signal.

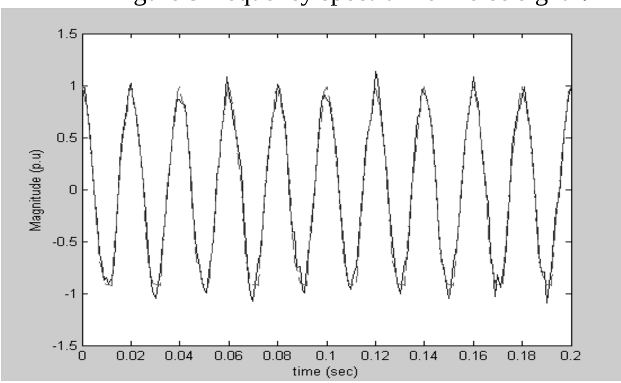

Figure 6 Comparison between original and estimated waveform.

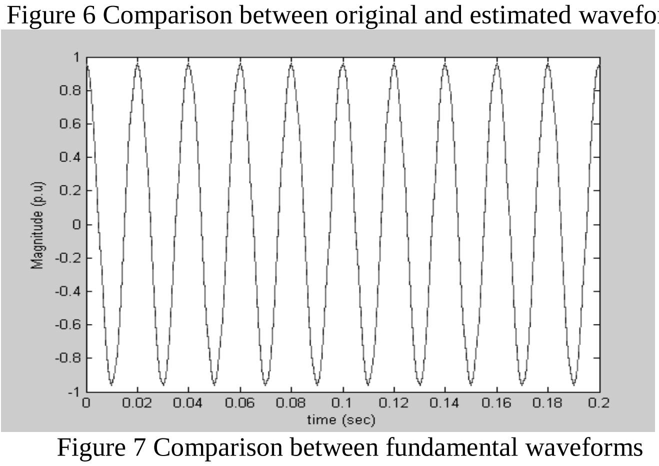

Figure 7 Comparison between fundamental waveforms

V. CONCLUSION

Least square technique can be effectively applied to the problem of estimation of harmonics and interharmonics in power system. This method can be used on line to estimate harmonics nearly up to 50 terms. But to estimate high switching frequencies (>2.5 KHz) in the power frequency (50 Hz) signal, this method takes more time and hence it cannot be applied on line in such cases.

In this work, the estimation of interharmonics was done with and without noise. In the case of providing input without noise, accurate results were obtained. In the presence of noise, the results obtained were satisfactory with the tolerable error less than 4%. As harmonics and interharmonics have much adverse effects on the equipment, a proper control strategy must be provided to mitigate the harmonics**.**

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