

## A Distinctive Scheme for Extraction of Symmetrical Components along with Harmonics

Md. Rayhanus Sakib<sup>1</sup>, Syed Naser Hasnain<sup>2</sup>, Ahmed Sabit Faisal<sup>3</sup>

<sup>1</sup>(Lecturer, Department of EEE, IBAIS University, Dhaka, Bangladesh)

<sup>2</sup>(Dept. of EEE, Ahsanullah University of Science and Technology, Dhaka, Bangladesh)

<sup>3</sup>(Dept. of EEE, American International University of Bangladesh, Dhaka, Bangladesh)

**Abstract:** Symmetrical components are very excellent tools for the analysis of three phase unbalanced power system.. In this paper, a software program has been developed in C++ Builder to extract the positive, negative components along with harmonics from the three phase current of a simulated three phase system. This software is user defined. The developed software has been tested on simulated system under balanced, unbalanced, faults and harmonics condition and a satisfactory result have been found.

**Keywords:** Filter, Harmonics, Harmonic Extraction, Symmetrical Components, Software.

### I. INTRODUCTION

A number of techniques have been proposed to estimate the symmetrical components of a three-phase voltage and current. In particular, techniques such as the Kalman filter [1], [2], the fast Fourier transform (FFT) [3]– [5], adaptive line combiner [6], [7], stochastic estimation theory [8], and the concept of state observer [9] have been employed to estimate the instantaneous symmetrical components. Furthermore, phase-locked loop (PLL) based algorithms [10]–[14], filtering algorithms [15]–[18], and the decoupled double synchronous reference frame PLL (DDSRFPLL) [19] have been introduced to extract the symmetrical components in order to handle the unbalance phenomenon. For harmonic extraction there are many methods such as Discrete Fourier Transform and Fast Fourier Transform [20],[ 21], synchronous reference frame (dq) Theory [22] and instantaneous power (pq) theory [23]. Harmonic extraction using Fourier Transform is a useful method for specific harmonic component compensation. However Fourier Transform requires one more cycle of the voltage waveform data and corresponding time such that the delayed harmonic canceling can be occurred [24]. There are some potential problems for pq method in harmonic extraction [25]. The pq theory can determine the harmonic components under load conditions only. The dq technique which is widely used for voltage sag extraction does not respond fast or does not give accurate results to the voltage harmonics because the inaccuracy which is associated with the PLL and passive filters used in this technique [26]. In This Paper, A software program is introduced to extract the harmonics and symmetrical components by using digital filter from the power system.

### II. SYMMETRICAL COMPONENTS AND HARMONICS

The method of symmetrical components is a mathematical technique that allows the engineer to solve unbalanced systems using balanced techniques. A balanced system is composed of three phasors equal in magnitude and displaced by 120 degrees from the others, and the direction of positive rotation is counterclockwise. On the other hand, in an unbalanced system, the three phasors magnitudes are not equal and the three phase angles are not necessarily 120 degrees. The basic premise of symmetrical components is that an unbalanced network of three related vectors can be resolved into three sets of vectors. Two of the sets have equal magnitude and are displaced 120 degrees apart while the third set has equal magnitude, but zero phase displacement. The three sets are known as the positive, negative, and zero sequence components of the electrical system [27].

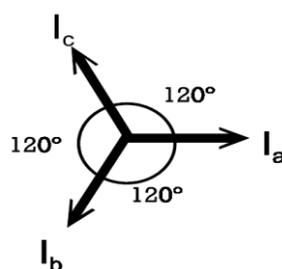


Fig. 1 A balanced, three-phase system of phasors

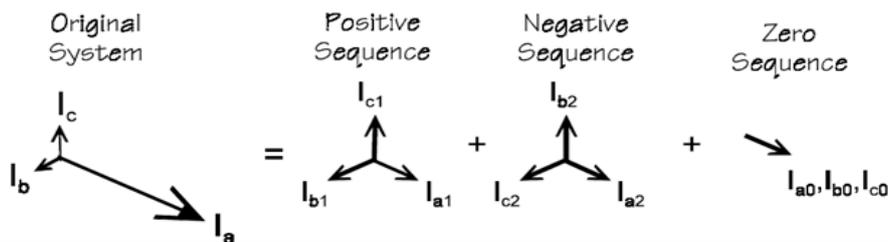


Fig. 2 An unbalanced, three-phase system of phasors

Fig. 1 illustrates a balanced, three-phase system of phasors. Note that each of the three phasors is equal in magnitude and displaced by 120 degrees from the others. Further, the direction of positive rotation is counterclockwise. Fig. 2, on the other hand, shows an unbalanced system where the three phasors magnitudes are not equal and the three phase angles are not necessarily 120 degrees. The phasors labeled as the Original System in Fig. 2 are typical of the currents in a three phase system with a short circuit to ground on phase A [28]. The sinusoidal shape of the voltage waveforms gets deformed due to the flow of current signals other than those at fundamental frequency, which are mostly generated by non-linear loads connected to the system. These steady-state periodic waveforms, which deform the supply signal, are termed as harmonics. Recent few years have witnessed rapid growth in harmonic voltages and currents injected into the power system due to the increased utilization of non-linear loads. In addition, devices employing high frequency switching, such as switch mode power supplies (SMPS) in televisions, computers and compact fluorescent lighting add a significant level of harmonics to the supply system. Although voltage distortion at the transmission level is typically much less than 1.0 percent, this distortion increases closer to the load point.

### III. FILTERS

A digital filter is a system that performs mathematical operations on a sampled, discrete-time signal to reduce or enhance certain aspects of that signal. Discrete Fourier Transform (DFT) and Fast Fourier Transform (FFT) are usually used for calculating the harmonic content of a periodic signal. Although the FFT is fast in terms of computing speed, it needs data points sampled over one cycle of the signal to accurately calculate the harmonic components. The frequency response of a filter consists of its magnitude and phase responses. The magnitude response indicates the ratio of a filtered sine wave's output amplitude to its input amplitude. The phase response describes the phase "offset" or time delay experienced by a sine wave passing through a filter .

Since the fundamental frequency of electrical power system signals is 50 Hz or 60 Hz typically, harmonic extraction takes 20 ms or 16.67 ms, respectively. However, many applications, such as harmonic monitoring, may require extraction of a limited number of individual harmonics. For an example, in many cases only the 5th and 7th harmonics are of interest as the levels of other harmonic components are significantly low. There are mainly two categories of digital filter: the recursive filter and the non recursive filter. These are often referred to as infinite impulse response (IIR) filters and finite impulse response (FIR) filters, respectively. Time domain techniques for harmonic extraction mainly uses digital filter techniques such as Infinite Impulse Response (IIR) filters. Although, these can be used to extract individual harmonic components, the ripple and time delay inherited in these filters make them less appealing [29].

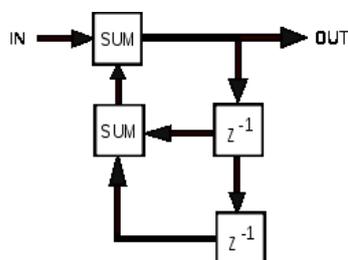


Fig. 3 Simple IIR filter block diagram

A typical block diagram of an IIR filter looks like the above. The  $z^{-1}$  block is a unit delay. The coefficients and number of feedback/feed forward paths are implementation-dependent [30]. Most recursive filters have an infinite impulse response, because of the feedback of previous outputs. Practical Infinite-Impulse-Response (IIR) filters are usually based upon analogue equivalents (Butterworth, Chebyshev, etc.), using a transformation known as the bilinear transformation which maps the s-plane poles and zeros of the analogue filter into the z-plane. However, it is quite possible to design an IIR filter without any reference to analogue

designs, for example by choosing appropriate locations for the poles and zeroes on the unit circle (Remember:  $G(e^{j\omega T})=0$  wherever there is a zero on the unit circle, i.e. complete attenuation of that frequency; on the other hand,  $G(e^{j\omega T}) \rightarrow \infty$  when there is a pole near the unit circle, i.e. high gain at that frequency). The technique of digitizing an analogue design is the most popular IIR filter design technique, since there is a large amount of theory on standard analogue filters available. The bilinear z-transform is a mathematical transformation from the s-domain to the z-domain which preserves the frequency characteristics and is defined by:

$$s = \frac{2}{T} \frac{1-z^{-1}}{1+z^{-1}} \quad (1) \quad ; \text{ where } T = \text{ sampling period}$$

Under this mapping, the entire  $j\omega$  axis in the s-plane is mapped onto the unit circle in the z-plane; the left-half s-plane is mapped inside the unit circle and the right-half s-plane is mapped outside the unit circle. The bilinear transformation gives a non-linear relationship between analogue frequency  $\omega_a$  and digital frequency  $\omega_d$ . Since the frequency response of a digital filter is evaluated by setting  $z = e^{j\omega T}$ :

$$s_a = j\omega_a = \frac{2}{T} \frac{1-e^{j\omega_d T}}{1+e^{j\omega_d T}} = \frac{2}{T} \tanh \frac{j\omega_d T}{2} \quad (2)$$

$$\text{i.e. } \omega_a = \frac{2}{T} \tan \frac{\omega_d T}{2}$$

The form of this non-linearity is shown in Fig. 4 for the case  $T = 2$ . For small values of  $\omega_d$ , the mapping is almost linear; for most of the frequency scale, however, the mapping is highly non-linear.

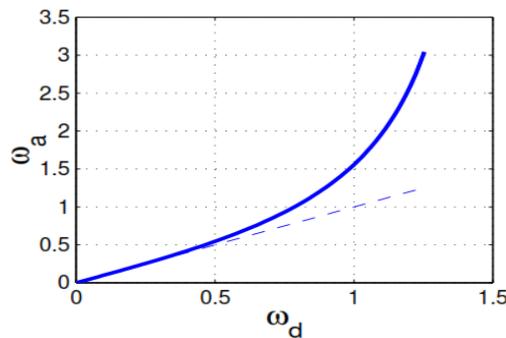


Fig. 4 The Bilinear mapping function

#### IV. PERFORMANCE EVALUATION AND DISCUSSION

3-Phase System at Balanced Condition:

$$I_a = A \sin \omega t \quad (3) \quad ; \quad A=10$$

$$I_b = B \sin \left( \omega t - \frac{4\pi}{6} \right) \quad (4) \quad ; \quad B=10$$

$$I_c = C \sin \left( \omega t - \frac{4\pi}{3} \right) \quad (5) \quad ; \quad C=10$$

In Fig. 5, blue line represents phase  $I_a$ , red line represents phase  $I_b$ , green line represents phase  $I_c$

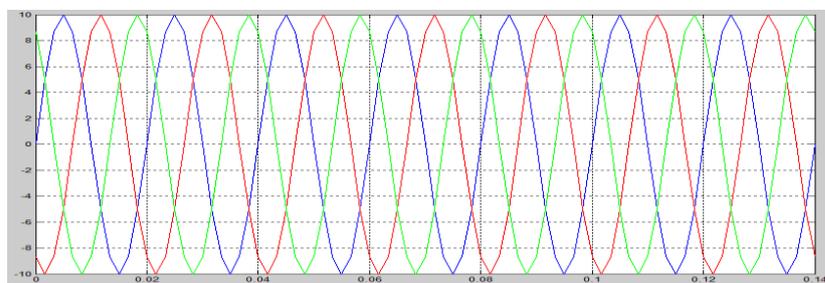


Fig. 5 3-Phase System at balanced condition

3-Phase System at Unbalanced Condition:

$$I_a = A \sin \omega t \quad (6) \quad ; \quad A=10$$

$$I_b = B \sin \left( \omega t - \frac{4\pi}{6} \right) \quad (7) \quad ; \quad B=8$$

$$I_c = C \sin\left(\omega t - \frac{4\pi}{3}\right) \quad (8) \quad ; \quad C=6$$

In Fig. 6, blue line represents phase  $I_a$ , red line represents phase  $I_b$ , green line represents phase  $I_c$ .

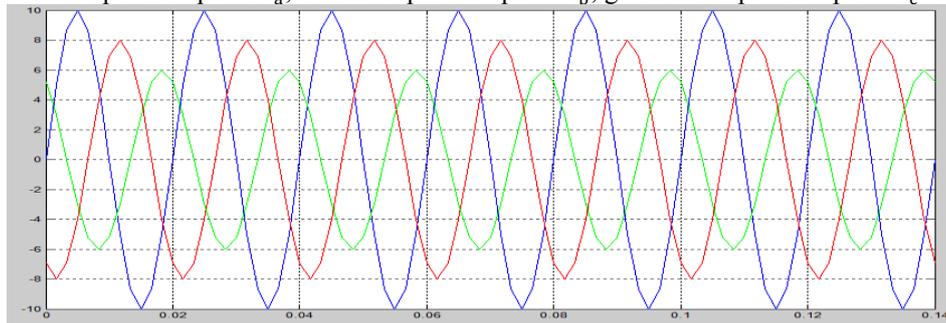


Fig. 6 3-Phase System at unbalanced condition

Harmonics at 3-Phase System at Balanced Condition:

$$I_a = A \sin(\omega t) + A_1 \sin\left(3\omega t + 15\right) \quad (9) \quad ; \quad A=10, A_1=11$$

$$I_b = B \sin\left(\omega t - \frac{4\pi}{6}\right) + B_1 \sin\left(3\omega t - \frac{4\pi}{6} + 15\right) \quad (10) \quad ; \quad B=10, B_1=14$$

$$I_c = C \sin\left(\omega t - \frac{4\pi}{3}\right) + C_1 \sin\left(3\omega t - \frac{4\pi}{3} + 15\right) \quad (11) \quad ; \quad C=10, C_1=16$$

Here, third harmonics is presented in the system, adding harmonics with the fundamental sine wave (balanced condition) may unbalance the system. In Fig. 7, blue line represents phase  $I_a$ , red line represents phase  $I_b$ , green line represents phase  $I_c$ .

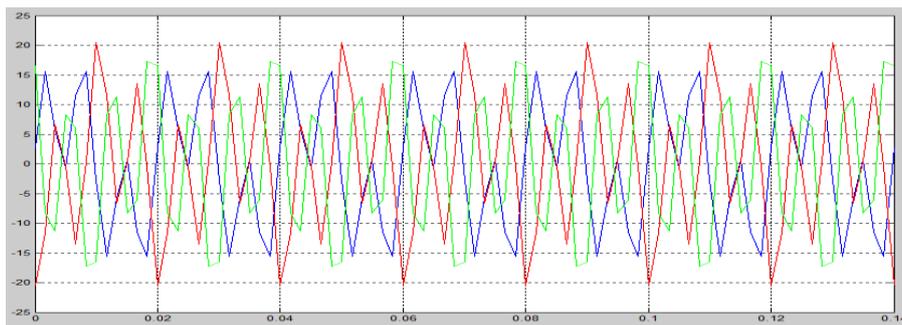


Fig. 7 Harmonics at 3-Phase System at balanced condition

Harmonics at 3-Phase System at Unbalanced Condition:

$$I_a = A \sin(\omega t) + A_1 \sin\left(3\omega t + 15\right) \quad (12) \quad ; \quad A=10, A_1=11$$

$$I_b = B \sin\left(\omega t - \frac{4\pi}{6}\right) + B_1 \sin\left(3\omega t - \frac{4\pi}{6} + 15\right) \quad (13) \quad ; \quad B=8, B_1=14$$

$$I_c = C \sin\left(\omega t - \frac{4\pi}{3}\right) + C_1 \sin\left(3\omega t - \frac{4\pi}{3} + 15\right) \quad (14) \quad ; \quad C=6, C_1=16$$

Here, third harmonics is presented in the system, adding harmonics with the fundamental sine wave (unbalanced condition) may unbalance the system. In Fig. 8, blue line represents phase  $I_a$ , red line represents phase  $I_b$ , green line represents phase  $I_c$ .

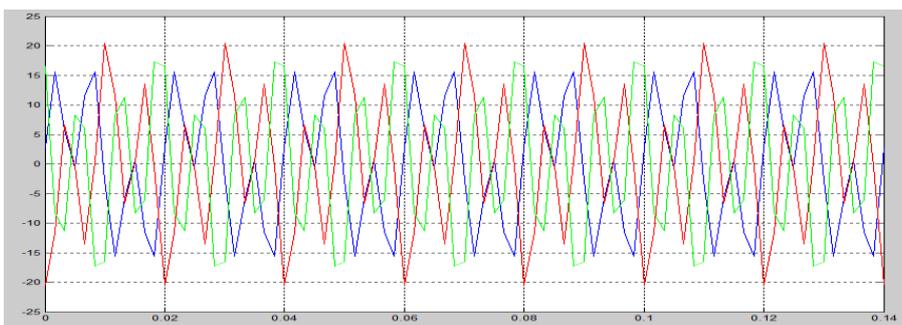


Fig. 8 Harmonics at 3-Phase System at unbalanced condition

Positive & Negative Sequence Current at Balanced Condition:

$$I_a = A \sin \omega t \quad (15) \quad ; \quad A=10$$

$$I_b = B \sin \left( \omega t - \frac{4\pi}{6} \right) \quad (16) \quad ; \quad B=10$$

$$I_c = C \sin \left( \omega t - \frac{4\pi}{3} \right) \quad (17) \quad ; \quad C=10$$

In Fig. 9, blue line represents phase positive phase sequence current, red line represents phase negative phase sequence current.

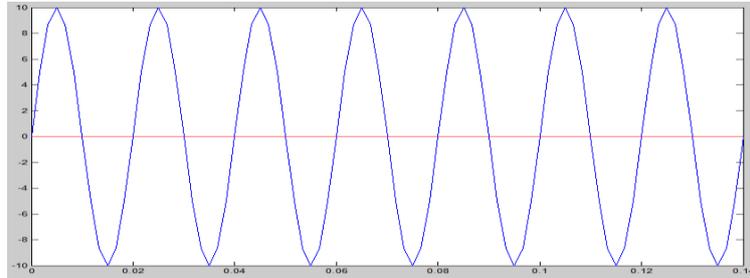


Fig. 9 Positive & Negative sequence current at balanced condition

Positive & Negative sequence current at unbalanced condition:

$$I_a = A \sin \omega t \quad (18) \quad ; \quad A=5$$

$$I_b = B \sin \left( \omega t - \frac{4\pi}{6} \right) \quad (19) \quad ; \quad B=3$$

$$I_c = C \sin \left( \omega t - \frac{4\pi}{3} \right) \quad (20) \quad ; \quad C=2$$

In Fig. 10, blue line represents phase positive phase sequence current, red line represents phase negative phase sequence current.

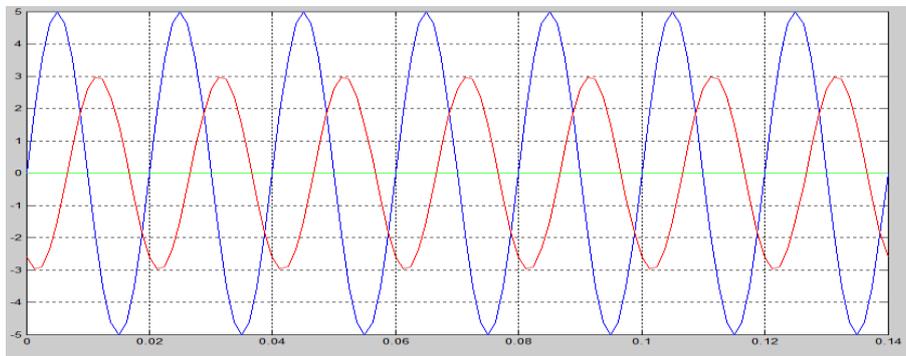


Fig. 10 Positive & Negative sequence current at unbalanced condition

#### IV.1 Single line to ground fault of an unloaded generator

At this condition the faults are expressed by the following condition  $I_b=0, I_c=0, V_a=0$ . Let  $Z_1 = .25pu, Z_2=0.35pu, Z_3=0.10pu$ , on a base of 20MVA, 13.8KV,  $E_a=1.0pu$  since the internal voltage is equal to the terminal voltage at no load. Using above data, the sub transient current in line 'a' is,  $I_a = -j3.59$  KA. The current in phase A, B, C before fault are calculated as,  $I_a = I_b = I_c = .837$  KA. After fault, the current at phase A (line 'a') is  $I_a=3.59$ , and  $I_b=I_c=0$ . In Fig. 11, blue line represents phase  $I_a$ , red line represents phase  $I_b$ , green line represents phase  $I_c$

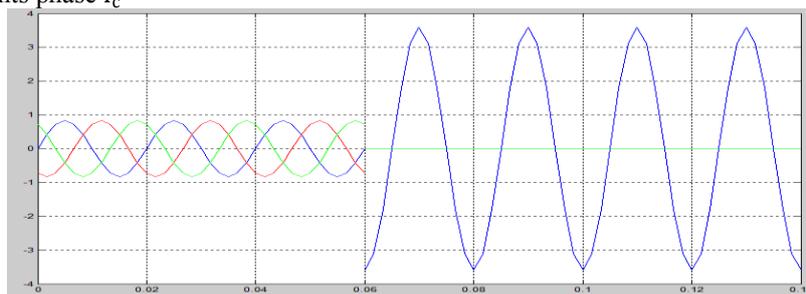


Fig. 11 Single line to ground fault of an unloaded generator

#### IV. 2 Line to line fault of an unloaded generator

At this condition the faults are expressed by the following condition  $I_a=0, I_b=-I_c, V_b=V_c$ . So, calculating the sub transient current,  $I_a=0$ , and  $I_b=I_c=2.416$ . The current in phase A, B, C before fault are,  $I_a=I_b=I_c=.837$  KA. After fault, the current at phase A (line 'a') is  $I_a=0$ , and  $I_b=I_c=2.416$  KA. In Fig. 12, blue line represents phase  $I_a$ , red line represents phase  $I_b$ , green line represents phase  $I_c$

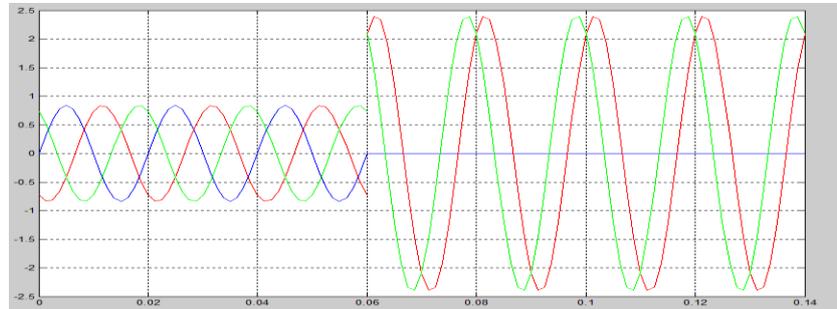


Fig. 12 Line to line fault of an unloaded generator

#### IV.3 Single line to ground fault of an unloaded generator (positive & negative sequence extraction)

The current in phase A, B, C before fault are,  $I_a=I_b=I_c=.837$  KA. After fault, the current at phase A (line 'a') is  $I_a=3.59$ , and  $I_b=I_c=0$ . In Fig. 13, blue line represents phase positive phase sequence current, red line represents phase negative phase sequence current.

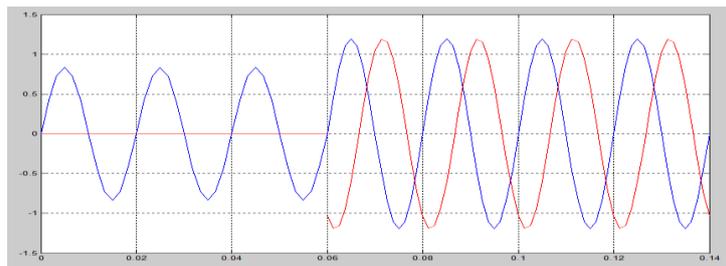


Fig. 13 Positive & negative sequence extraction

### V. CONCLUSION

This system is capable of extracting positive, negative sequence currents and harmonics from the samples of phase currents of three phases balanced and unbalanced systems. Containing different harmonics, the software has been tested on different sampled system and a satisfactory result has been obtained. There might be few possibilities with this system such as if half cycle window were used in the filtering algorithm then the decision of the tripping time would have been reduced. Although there might have some sort of risk in giving the decision so fast; because there might have a wrong decision due to presence of transients in the sequence current.

### REFERENCES

- [1] S. A. Soliman and M. E. El-Hawary, "Application of Kalman filtering for online estimation of symmetrical components for power system protection," *Electr. Power Syst. Res.*, vol. 38, 1997, pp. 113–123.
- [2] A. A. Girgis, W. Chang, and E. B. Makram, "Analysis of high-impedance fault generated signals using a Kalman filtering approach," *IEEE Trans. Power Del.*, vol. 5, no. 4, Oct. 1990, pp. 1714–1724.
- [3] A. Campos, G. Joos, P. D. Ziogas, and J. F. Lindsay, "A DSP-based real-time digital filter for symmetrical components," in *Proc. Athens Power Tech. Joint Int. Power Conf. (APT 1993)*, vol. 1, pp. 75–79.
- [4] T. Lobos, "Fast estimation of symmetrical components in real time," *Proc. Inst. Electr. Eng. C*, vol. 139, no. 1, Jan. 1992, pp. 27–30.
- [5] G. Andria and L. Salvatore, "Inverter drive signal processing via DFT and EKF," *Proc. Inst. Electr. Eng. B*, vol. 137, no. 2, Mar. 1990, pp. 111–119.
- [6] P. K. Dash, D. P. Swain, A. C. Liew, and S. Rahman, "An adaptive linear combiner for on-line tracking of power system harmonics," *IEEE Trans. Power Syst.*, vol. 11, no. 4, Nov. 1996, pp. 1730–1735.
- [7] M. I. Marei, E. F. El-Saadany, and M. A. Salama, "A processing unit for symmetrical components and harmonics estimation based on a new adaptive linear combiner structure," *IEEE Trans. Power Del.*, vol. 19, no. 3, Jul. 2004, pp. 1245–1252.
- [8] K. M. El-Naggar, "A fast method for identification of symmetrical components for power system protection," *Electr. Power Energy Syst.*, vol. 23, 2001, pp. 813–817.
- [9] S. Chen and G. Joos, "A novel DSP-based adaptive line synchronization system for three-phase utility interface power converters," in *Proc. Power Electron. Spec. Conf.*, 2001, vol. 2, pp. 528–532.
- [10] D. Jovic, "Phase-locked loop system for FACTS," *IEEE Trans. Power Syst.*, vol. 18, no. 3, Aug. 2003, pp. 1116–1124.

- [11] G. M. Lee, D. C. Lee, and J. K. Seok, "Control of series active power filters compensating for source voltage unbalance and current harmonics," *IEEE Trans. Ind. Electron.*, vol. 51, no. 1, Feb. 2004, pp. 132–139.
- [12] M. Karimi-Ghartemani and H. Karimi, "Processing of symmetrical components in time-domain," *IEEE Trans. Power Syst.*, vol. 22, no. 2, May 2007, pp. 572–579.
- [13] P. Rodriguez, A. V. Timbus, R. Teodorescu, M. Liserre, and F. Blaabjerg, "Flexible active power control of distributed power generation systems during grid faults," *IEEE Trans. Power Electron.*, vol. 57, no. 5, Oct. 2007, pp. 2583–2592.
- [14] M. R. Iravani and M. Karimi-Ghartemani, "Online estimation of steady state and instantaneous symmetrical components," *Proc. Inst. Electr. Eng.*, vol. 150, no. 5, Sep. 2003, pp. 616–622.
- [15] A. Yazdani and R. Iravani, "A unified dynamic model and control for the voltage source converter under unbalanced grid conditions," *IEEE Trans. Power Del.*, vol. 21, no. 3, Jul. 2006, pp. 1620–1629.
- [16] S.-J. Lee, J.-K. Kang, and S.-K. Sul, "A new phase detecting method for power conversion systems considering distorted conditions in power system," in *Proc. 34th IAS Annu. Meeting Ind. Appl. Conf.*, 1999, vol. 4, pp. 2167–2172.
- [17] S. Hong-Seok and K. Nam, "Dual current control scheme for PWM converter under unbalanced input voltage conditions," *IEEE Trans. Ind. Electron.*, vol. 46, no. 5, Oct. 1999, pp. 953–959.
- [18] P. Rodríguez, J. Pou, J. Bergas, I. Candela, R. Burgos, and D. Boroyevich, "Double synchronous reference frame PLL for power converters control," in *Proc. IEEE PESC*, 2005, pp. 1415–1421.
- [19] P. Rodriguez, J. Pou, J. Bergas, I. Candela, R. Burgos, and D. Boroyevich, "Decoupled double synchronous reference frame PLL for power converters control," *IEEE Trans. Power Electron.*, vol. 22, no. 2, Mar. 2007, pp. 584–592.
- [20] Asiminoaei L, Blaabjerg F, Hansen S, "Evaluation of harmonic detection methods for active power filter applications". *Applied Power Electronics Conference and Exposition*, 2005. APEC 2005. Twentieth Annual IEEE Volume 1, 6-10 March 2005 Page(s):635 – 641 .
- [21] Tianjun D, Guangju C, Yong L, "Frequency domain interpolation wavelet transform based algorithm for harmonic analysis of power system." *Communications, Circuits and Systems, ICCAS 2004. 2004 International Conference on Volume 2, 27-29 June 2004 Page(s):742 – 746*.
- [22] Gannett RA, Sozio JC, " Boroyevich D Application of synchronous and stationary frame controllers for unbalanced and nonlinear load compensation in 4-leg inverters". *Applied Power Electronics Conference and Exposition*, 2002. APEC, Seventeenth Annual IEEE. Volume 2, 10-14 March 2002 Page(s):1038 - 1043.
- [23] Czarnecki Ls Instantaneous reactive power p-q theory and power properties of three-phase systems. *Power Delivery, IEEE Transactions on Volume 21, Issue 1, Jan. 2006 Page(s):362 – 367* .
- [24] Pecharanin N, Mitsui H, Sone M "Harmonic detection by using neural network". *Neural Networks*, 1995. Proceedings., IEEE International Conference on Volume 2, 27 Nov.-1 Dec. 1995 Page(s):923 – 926.
- [25] Srinivasan D, Ng WS, "Liew AC Neural-Network based signature recognition for harmonic source identification". *Power Delivery, IEEE Transactions on Volume 21, Issue 1, Jan. 2006 Page(s):398 – 405*.
- [26] Elnady A, Salama MMA, " Mitigation of voltage disturbances using adaptive perceptron-based control algorithm" . *Power Delivery, IEEE Transactions on Volume 20, Issue 1, Page(s):309 – 318*.
- [27] Charles L. Fortescue, "Method of Symmetrical Co-Ordinates Applied to the Solution of Polyphase Networks". Presented at the 34th annual convention of the AIEE (American Institute of Electrical Engineers) in Atlantic City, N.J. on 28 July 1918. *AIEE Transactions*, vol. 37, part II, 1918, pages 1027-1140 .
- [28] S. G. Johnson and M. Frigo. "A modified split-radix FFT with fewer arithmetic operations," *IEEE Trans. Signal Processing* 55 (1), 2007, pp-111–119.
- [29]. Westinghouse Corporation, *Applied Protective Relaying*, 1976, Westinghouse Corporation, no ISBN, Library of Congress card no. 76-8060 - a standard reference on electromechanical protective relays.
- [30] S.W.A. Bergen and A. Antoniou, "Design of Nonrecursive Digital Filters Using the Ultraspherical Window Function", *EURASIP Journal on Applied Signal Processing*, vol. 2005, no. 12, 2005, pp. 1910–1922.