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IMPROVED WALSH FUNCTIONS ALGORITHM FOR SINGLE PHASE POWER COMPONENTS MEASUREMENT

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ABSTRACT
This paper presents an improved Walsh function (IWF) algorithm for power components measurement in linear and nonlinear, balanced and unbalanced sinusoidal load system. It takes advantage of the Walsh Functions' simple procedure to develop an algorithm to determine the active, reactive and distortion powers. The increasing use of non-linear loads causes distortion of the power supply system leading to voltage and current waveforms to become non-stationary and non-sinusoidal. As a result measurement using the IEEE standard 1459-2000 which is based on fast Fourier transform FFT is no longer realistic in non-sinusoidal load condition due to its sensitivity to the spectral leakage phenomenon. The proposed Improved Walsh function algorithm which has the features of being simple, and having high accuracy rate for measurement of both sinusoidal and non-sinusoidal signals was tested using a model created on Matlab 2011. The results were compared with the FFT approach and Wavelet transform technique and it showed that the algorithm has the potential to effectively determine the active and reactive powers of a network under different distortion load conditions better than the FFT. The algorithm is computationally less cumbersome when compared with the Wavelet transform.

Keywords: improved Walsh function, reactive power, fast Fourier transforms, wavelet transform.

INTRODUCTION

Power electronics technology has been increasingly used in many fields in recent years. The proliferation of non-linear loads on distribution systems has resulted in the deterioration of power quality in a substantial way [1]. These distortions increase the reactive power of the system and lower the power factor which invariably has negative consequences on the power quality of the supply system. Accurate measurement and evaluation of the power components is of utmost importance for effective planning, billing, monitoring, maintenance and further development of the power supply system [2]. The deregulation of the power sector has lead electricity operators to seek for ways to make the best use of the supply systems [3]. With several competing electric power vendors, power quality indices play a significant role as consumers will naturally select or subscribe to the provider with the highest power quality indices [4].

In the billing of electricity based only on the value of the integral of the load active power measured using kilowatt-hour meter, the electric utility board incurs losses in revenue for energy delivered to current harmonic generating customers and also those that cause current asymmetry so accurate estimation of the active and reactive power is of immense important [5].

The conventional or classical method of determining power consumption for linear sinusoidal power system is to evaluate using measured values of the voltage (V), current (I) and power factor (Pf). The apparent power S, active power P, and reactive power Q are defined as in [6]. This classical way of power evaluation needs accurate measurement of the root mean square (RMS) values of the voltage and current before performing the multiplication operation so as to determine the apparent power S. Precise determination of RMS values of voltage and current is complex and poses a serious challenge in electric measurement [7]. These conditions are not easily attainable in the real practical world due to the nature of the loads most of which are nonlinear [8].

There are clear definitions for power components like active power, reactive power, apparent powers, and distortion power, for a linear sinusoidal network as provided by the IEEE standard 1459-2000 which is based on fast Fourier transform FFT [9] but as a result of the increasing use of harmonic generating loads the voltage and current waveform becomes nonlinear and non-sinusoidal so the results obtained using this standard in nonlinear and non-sinusoidal load conditions are no longer realistic. Fast Fourier transform FFT which is a frequency domain based algorithms was presented for evaluating power components without the requirement for a phase shift operation. It algorithm has the advantage of effectively measuring the power components for a stationary sinusoidal voltage and current waveforms, but large error which makes it unfit for use occur when the network become nonlinear and non-sinusoidal due to spectral leakage and picket fence phenomenon. Fourier transform is still computational complex, not easy to apply for compensation purpose and it also loss time information. The resolution of the FT is fixed as a result of fixed window size. [10-11]

In-phase quadrature approach which is a time based technique decomposes the current waveform into active component and a residual or non-active component. The voltage interacts with the active current component to yield the active power while the interaction with the non-active current produces the non-active power. Though the technique effectively determine the active and non-active powers; however, other power components cannot be measured as information concerning frequency cannot be provided using the time domain approach. It has the

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advantage of being simple, accurate, easy to implement and real time decomposition of the distorted waveform, though it cannot be used alone as a comprehensive approach for measuring the power component as defined by the IEEE Standard 1459-2010, also it losses frequency content information [12]

The symmetrical component method for the analysis of unbalanced three phase system was used [13-14] for fault studies, power system protection/control and power measurement under sinusoidal invariant conditions while recursive estimation method was proposed in [15]. The limitation of these approaches is the heavy mathematical burden associated with them. A Kalman filter algorithm which requires a fixed and specified frequency of the harmonic in advance was proposed in [16]. The approach is hard to achieve thereby limiting its' application for the estimation of symmetrical components especially under nonlinear non-sinusoidal operating conditions.

To surmount the deficiencies of the above approaches the Wavelet transform was proposed by several authors [17-20]. Wavelet transform which is a time-frequency representation of any stationary or non-stationary waveform using functions that when analyzed produce set of scaled and translated function called baby Wavelet, measures the similarity between the original distorted waveform and the basic function of the wavelet transform known as mother wavelet through Wavelet coefficient computation. It has the advantage of preserving both the time and frequency domain information without any effect on the resolution. Also, it is use in analyzing physical situations where the signal contains discontinuities and sharp spikes. The algorithm is cumbersome and prone to error [17-20].

A method that simplifies the multiplication procedure required for the evaluation of power components from instantaneous power signal using peculiar properties of the Walsh function was presented [21], while a modified approach using the Walsh function WF for the measurement in both sinusoidal and non-sinusoidal conditions was proposed in [22]. Also in [23] a Walsh function (WF) based method for measuring of reactive power (RP) in unbalanced three-phase system was proposed, the influence of the harmonics to the measurement results which is not accounted for in the studies is the main drawback of the algorithms. In [24] an advanced algorithm based on Walsh function method for harmonic elimination to obtain switching angles that permits full regulation of the fundamental amplitude with only a switching interval vector for a single-phase system was presented. The technique which is only for harmonic estimation does not involve power component measurement and has the drawback of obtaining a great number of solutions that make difficult the selection process of the better cases thereby, increasing the computation time.

The advantages of the Walsh function based approach to power components evaluation are;

- Multiplication of the signal by corresponding order WF is performed simply by alteration of sign of the signal from +1 to -1, it analyzes signal into rectangular waveforms rather than sinusoidal ones and computation is faster when compared with other techniques like FFT and Wavelet transform. It contained only addition and subtraction hence much simpler.
- It eliminates the IEEE/IEC requirement for a phase shift of π/2 between the voltage and the current signals.
- It is simple and has the advantage of better accuracy and reliability.
- Walsh function presents intrinsic high level accuracy due to coefficient characteristics in energy staircase representation and has good mathematical tools to analyze energy meter output behaviour for in-depth error detection.

A methodology based on Improved Walsh functions (IWF) algorithm that is devoted to the evaluation of power components by estimation and correction of the influence of the higher order harmonic distortion on the earlier proposed evaluation algorithms using simple but effective algorithm is presented and compared with the existing FFT and Wavelet approaches in this paper. The improved algorithm serves as better alternative for power components measurement; it take into consideration among others, elimination of the effect of harmonic on reactive power measurement and it can be used on any type of energy meter testing. Harmonic current affects the reactive power measurement, the dominant harmonic frequencies produced by most consumers are the odd integer multiple of the fundamental frequency, and among them the third order harmonic is the most prevalent.

The remaining of this paper is organized as follows. Section two, is a survey of the IEEE standard 1459-2000 and Wavelet transform algorithms for the measurement of power component, section three presents the proposed Walsh function algorithm for measurement, while section four is the modeling, simulation discussion and comparison of the proposed improved algorithm for measurement using the Walsh function. Lastly, section five is the conclusions.

IEEE STANDARD 1459-2000 DEFINITIONS FOR POWER COMPONENTS

The definition of the power components according to the IEEE standard 1459-2000 which is based on fast Fourier transform for a single phase power network [25].

Instantaneous voltage $v(t)$ and current $i(t)$

$$v(t) = v_1(t) + v_H(t), \quad i(t) = i_1(t) + i_H(t) \tag{1}$$

Fundamental instantaneous voltage $v_1(t)$ and current $i_1(t)$

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$$v_1(t)=\sqrt{2}V_1\sin(\omega t-\alpha_1)$$
$$i_1(t)=\sqrt{2}I_1\sin(\omega t-\beta_1) \quad (2)$$

Instantaneous harmonic voltage $v_H(t)$ and current $i_H(t)$

$$v_H(t)=\sqrt{2}\sum_{h\neq 1}V_h\sin(h\omega t-\alpha_h)$$
$$i_H(t)=\sqrt{2}\sum_{h\neq 1}I_h\sin(h\omega t-\beta_h) \quad (3)$$

Where V_1 and I_1 are the fundamental RMS values of the phase voltage and current, subscript 1 indicates the fundamental components with H and h referring to the non fundamental components and the harmonic order. α_1 and β_1 are the fundamental voltage and current phase angle.

The fundamental active power P_1, harmonic power P_H , total active power P are;

$$P_1=V_1I_1\cos\theta_1,\ P_H=\sum_{h\neq 1}V_hI_h\cos\theta_h,\ \theta_1=\alpha_1+\beta_1$$

$$P=P_1+P_H \quad (4)$$

The RMS value for the voltage and current are;

$$V=\sqrt{\frac{1}{T}\int_0^T v^2(t)dt},\ I=\sqrt{\frac{1}{T}\int_0^T i^2(t)dt} \quad (5)$$

$$V^2=V_1^2+V_H^2,\ V_H^2=\sum_{h\neq 1}V_h^2 \quad (6)$$

$$I^2=I_1^2+I_H^2,\ I_H^2=\sum_{h\neq 1}I_h^2 \quad (7)$$

The fundamental reactive power Q_1, Budeanu's harmonic reactive power Q_{BH} and Budeanu's reactive power Q_B are defined as;

$$Q_1=V_1I_1\sin\theta_1\ Q_{BH}=\sum_{h\neq 1}V_hI_h\sin\theta_h,\ Q_B=Q_1+Q_{BH} \quad (8)$$

The apparent power S, non-active power N and Budeanu's distortion power D_B are;

$$S=VI,\ N=\sqrt{S^2-P^2},\ D_B=\sqrt{N^2-Q_B^2}$$

$$S^2=P^2+Q_B^2+D_B^2 \quad (9)$$

WAVELET PACKET TRANSFORM (WPT)

Wavelet Packet transforms WPT algorithm for calculating and measuring the active, reactive, non-active, distortion and apparent power. WPT is favored over the other forms of Wavelet transform i.e., discrete wavelet transform DWT and stationary wavelet transform SWT because it provides a uniform frequency bands and offers flexible decomposition through merging splitting process of the nodes. Also, it is considered a generalization of the Wavelet transform such that DWT is a special case of the WPT and can be obtained by suitable merging of the details while keeping the decomposition process being applied on the approximations only [26]. The major disadvantage of the Wavelet transform is its computational burden. In the time-frequency domain voltage and current waveform with 2^n sample point can be expressed using the WPT coefficient.

$$v(t)=\sum_{k=0}^{2^{N-j-1}}d_j^0(k)\phi_{j,k}(t)+\sum_{m=1}^{2^{j-1}}\left(\sum_{k=0}^{2^{N-j-1}}d_j^{2m}(k)\psi_{j,k}^m(t)\right) \quad (10)$$

$$=v_j^0+\sum_{m=1}^{2^{j-1}}v_j^m \quad (11)$$

The RMS value of the voltage

$$V=\sqrt{\frac{1}{2^N}\sum_{k=0}^{2^{N-j-1}}(d_j^o(k))^2+\frac{1}{2^N}\sum_{m=1}^{2^{j-1}}\sum_{k=0}^{2^{N-j-1}}(d_j^m(k))^2} \quad (12)$$

$$=\sqrt{(V_j^o)^2+\sum_{m=1}^{2^{j-1}}(V_j^m)^2} \quad (13)$$

Likewise the current is expressed in the time-frequency domain as,

$$i(t)=\sum_{k=0}^{2^{N-j-1}}d_j^{'0}(k)\phi_{j,k}(t)+\sum_{n=1}^{2^{j-1}}\left(\sum_{k=0}^{2^{N-j-1}}d_j^{'2n}(k)\psi_{j,k}^n(t)\right) \quad (14)$$

$$=i_j^0+\sum_{n=1}^{2^{j-1}}i_j^n \quad (15)$$

The RMS value of the current

$$I=\sqrt{\frac{1}{2^N}\sum_{k=0}^{2^{N-j-1}}(d_j^{'0}(k))^2+\frac{1}{2^N}\sum_{n=1}^{2^{j-1}}\sum_{k=0}^{2^{N-j-1}}(d_j^{'n}(k))^2} \quad (16)$$

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$$= \sqrt{(I_j^0)^2 + \sum_{n=1}^{2^{j-1}} (I_j^n)^2} \quad (17)$$

Where d_j^n and $d_j^{'n}$ are the WPT coefficient for voltage and current at level j, m is the voltage node and n the current node.

The active Power P is given by:

$$P = P_j^0 + \sum_{\substack{m=1,n=1,\\ m=n}}^{2^{j-1}} P_j^m \quad (18)$$

P_j^0 is the active power at node zero and level j.

$$P_j^0 = \frac{1}{2^N} \sum_{k=0}^{2^{N-j-1}} d_j^0(k) d_j^{'0}(k) \quad (19)$$

While the active power at any other node m=*n*;

$$P_j^m = \frac{1}{2^N} \sum_{k=0}^{2^{N-j-1}} d_j^m(k) d_j^{'n}(k) \quad (20)$$

In WPT, the current is decomposed into two components, the active component I_{aj}^n which produces the active power transmission and the residual current component I_{resj}^n which represent the non-active power that should be compensated.

$$I = \sqrt{(I_{aj}^0)^2 + (I_{resj}^0)^2 + \sum_{n=1}^{2^{j-1}} (I_{aj}^n)^2 + \sum_{n=1}^{2^{j-1}} (I_{resj}^n)^2} \quad (21)$$

Where

$$I_{aj}^0 = \sqrt{\frac{1}{2^N} \frac{\sum_{k=0}^{2^{N-j-1}} (d_j^0(k))(d_j^{'0}(k))^2 \sum_{k=0}^{2^{N-j-1}} (d_j^0(k))^2}{\sum_{k=0}^{2^{N-j-1}} (d_j^0(k))^4}} \quad (22)$$

$$I_{aj}^n = \sqrt{\frac{1}{2^N} \frac{\sum_{k=0}^{2^{N-j-1}} (d_j^n(k))(d_j^{'n}(k))^2 \sum_{k=0}^{2^{N-j-1}} (d_j^{2n}(k))^2}{\sum_{k=0}^{2^{N-j-1}} (d_j^n(k))^4}} \quad (23)$$

$$(I_{resj}^0)^2 = \frac{1}{2^N} \sum_{k=0}^{2^{N-j-1}} (d_j^{'0}(k))^2 + \frac{\sum_{k=0}^{2^{N-j-1}} (d_j^0(k))^2 (d_j^{'0}(k))^2 \sum_{k=0}^{2^{N-j-1}} (d_j^0(k))^2}{\sum_{k=0}^{2^{N-j-1}} (d_j^o(k))^4}$$

$$-2\left(\sum_{k=0}^{2^{N-j-1}} d_j^{'0}(k)\right) \frac{\sum_{k=0}^{2^{N-j-1}} d_j^0(k) d_j^{'0}(k)}{\sum_{k=0}^{2^{N-j-1}} (d_j^0(k))^2} \sum_{k=0}^{2^{N-j-1}} d_j^0(k) \quad (24)$$

$$I_{resj}^n = \frac{1}{2^N}\left[\sum_{k=0}^{2^{N-j-1}} (d_j^{2n}(k))^2 + \frac{\sum_{k=0}^{2^{N-j-1}} (d_j^n(k))^2 (d_j^n(k))^2 \sum_{k=0}^{2^{N-j-1}} (d_j^{2n}(k))^2}{\sum_{k=0}^{2^{N-j-1}} (d_j^n(k))^4}\right.$$

$$\left. X\left(\sum_{k=0}^{2^{N-j-1}} (d_j^{2n}(k)\right) \frac{\sum_{k=0}^{2^{N-j-1}} d_j^n(k) d_j^{'n}(k)}{\sum_{k=0}^{2^{N-j-1}} (d_j^n(k))^2} \sum_{k=0}^{2^{N-j-1}} d_j^{2n}(k)\right] \quad (25)$$

The apparent power can be expressed as:

$$S^2 = \sum_{m=0}^{2^{j-1}} (V_j^m)^2 (I_{aj}^m)^2 + \sum_{m=0}^{2^{j-1}} (V_j^m)^2 (I_{resj}^m) +$$

$$\sum_{\substack{m=0,n=0\\ m\neq n}}^{2^{j-1}} (V_j^m)^2 (I_{aj}^n)^2 + \sum_{\substack{m=0,n=0\\ m\neq n}}^{2^{j-1}} (V_j^m)^2 (I_{resj}^n)^2 \quad (26)$$

$$S^2 = \left[\left(\sum_{m=0}^{2^{j-1}} V_j^m I_{aj}^m\right)^2\right] + \left[\left(\sum_{m=0}^{2^{j-1}} V_j^m I_{resj}^m\right)^2\right] +$$

$$\left[\left(\sum_{\substack{m=0,n=0\\ m\neq n}}^{2^{j-1}} V_j^m I_{aj}^n\right)^2 + \left(\sum_{\substack{m=0,n=0\\ m\neq n}}^{2^{j-1}} V_j^m I_{resj}^n\right)^2\right] \quad (27)$$

$$S^2 = \left[P^2\right] + \left[Q^2\right] + \left[D^2\right] \quad (28)$$

Where P is the total power, Q is the reactive power and D the distortion power using the WPT.

Non-active power $N = \sqrt{S^2 - P^2} = \sqrt{Q^2 + D^2}$ (29)

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IMPROVED WALSH FUNCTION ALGORITHM

From the fundamentals definition in IEEE 1459-2000 the instantaneous voltage $u(t)$ in a single phase power system is [25];

$$u(t) = \sqrt{2}U \sin(wt) \tag{30}$$

This will have an instantaneous current $i(t)$ defined as;

$$i(t) = \sqrt{2}I \sin(wt - \theta) \tag{31}$$

The instantaneous active power p of the phase is

$$p = u(t) * I(t) = \sqrt{2}U \sin(wt) * \sqrt{2}I \sin(wt - \theta) \tag{32}$$

Where U and I are the root mean square RMS value of the voltage and current respectively, $w = 2\pi/T$ is the angular frequency, T is the cycling period of U, while θ is the phase angle between the voltage and the current waveform. Substituting and solving equation (32) trigonometrically gives expression for the instantaneous power as;

$$p = P - (P\cos 2wt + Q\sin 2wt) \tag{33}$$

Where

$P = UI\cos\theta$ and $Q = UI\sin\theta$ are average active power and fundamental reactive power of the phase.

To obtain the algorithm for the active power equation (33) is multiplied with the zero order Walsh function and integrated over the time T. Zero order Walsh function $Wal(0,t)$ is a constant 1 over the period of T so all the integral multiple of $Wal(0,t)$ with $\cos 2wt$ and $\sin 2wt$ approach to zero [27]. Thus,

$$\frac{1}{T}\int_0^T p(Wal(0,t))dt = \frac{1}{T}\int_0^T P(Wal(0,t))dt \tag{34}$$

Solving for active power P the Walsh function algorithm for active power measurement in linear and nonlinear, sinusoidal or non-sinusoidal conditions is obtained as shown in (35). Harmonic distortion has no much effect on the active power measurement but it has significant effects on the reactive power measurement.

$$P = \frac{1}{T}\int_0^T p(Wal(0,t))dt \tag{35}$$

The Walsh function algorithm for the reactive power measurement can be obtained by multiplying equation (33) by the third order Walsh function $Wal(3,t)$ and integrate over the period T. 3rd order Walsh function is a periodic function.

$$\frac{1}{T}\int_0^T p(Wal(3,t)) = \frac{1}{T}\int_0^T P(Wal(3,t))dt - \frac{1}{T}\int_0^T P\cos 2wt(Wal(3,t))dt - \frac{1}{T}\int_0^T Q\sin 2wt(Wal(3,t))dt \tag{36}$$

On the right side of (36) the integral of the 3rd order Walsh function $Wal(3,t)$ with the constant P is equal to zero since $Wal(3,t)$ is a dynamic function, also the integral of $Wal(3,t)$ with $P\cos 2wt$ is zero as they are orthogonal so (36) is re-written as

$$\frac{1}{T}\int_0^T p(Wal(3,t)) = -\frac{1}{T}\int_0^T Q\sin 2wt(Wal(3,t))dt \tag{37}$$

Solving for Q

$$Q = -\frac{\pi}{2T}\int_0^T p(Wal(t))dt \tag{38}$$

Equation (38) is the Walsh function algorithm for measuring the reactive power of a single phase linear sinusoidal load power system [27].

The dominant harmonics in power distribution system are the odd integer multiples of the fundamental frequency. The third order harmonic is the most common. In order to measure power component in the presence of harmonic distortion, assuming that the voltage waveform is sinusoidal and the load current waveform is contaminated with the third order current harmonic as

$$i_{3h} = I_{3h}\sin(3wt - \phi_{3h}) \tag{39}$$

Where i_{3h} is the instantaneous harmonic current, I_{3h} the RMS value of the harmonic current, $Ø_{3h}$ is the phase angle between the voltage and the harmonic current.

The new instantaneous power under this harmonic current is;

$$p = P + (P_{3h} - P)\cos 2wt + (Q_{3h} - Q)\sin 2wt - P_{3h}\cos 4wt - Q_{3h}\sin 4wt \tag{40}$$

To obtain the algorithm for reactive power under this condition we multiply (40) with the third order Walsh function $Wal(3,t)$ and integrate over the period ***T*****.** In it, the integrals that involve the multiplier

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of $\cos 2wt$, $\cos 4wt$, $\sin 4wt$ and the constant P with $Wal(3,t)$ are all equal to zero so.

$$\frac{1}{T}\int_0^T p(Wal(3,t)) =$$
$$-\frac{1}{T}\int_0^T (Q_{3h}-Q)\sin 2wt(Wal(3,t))dt \quad (41)$$

The product of the 3rd order Walsh function with $(Q_{3h}-Q)\sin 2wt$ produces the full wave rectification of the term hence;

$$\frac{1}{T}\int_0^T p(Wal(3,t)) = -\frac{1}{T}\int_0^T (Q_{3h}-Q)\sin 2wtdt \quad (42)$$

Solving for Q yields;

$$Q = \frac{\pi}{2T}\int_0^T pWal(3,t)dt + Q_{3h} \quad (43)$$

The Q_{3h} represent the effect of the 3rd order harmonic current i_{3h} to the reactive power measurement. The last term of (40) is the distortion power term and its oscillating with the frequency of $4w$ which is similar to the oscillating frequency of the 7th order Walsh function $Wal(7,t)$. To be able to estimate the distortion power term we multiply (40) by $Wal(7,t)$ and then take the integral over the time T. The product of the $Wal(7,t)$ with $\cos 2wt$, $\cos 4wt$, $\sin 2wt$ and the constant P are equal to zero so,

$$\frac{1}{T}\int_0^T p(Wal(7,t)) = -\frac{1}{T}\int_0^T Q_{3h}\sin 4wt(Wal(7,t))dt \quad (44)$$

while the product of $Wal(7,t)$ and $Q_{3h}\sin 4wt$ result in the rectification of the term of the $Q_{3h}\sin 4wt$ so (12) is written as shown;

$$\frac{1}{T}\int_0^T p(Wal(7,t)) = -\frac{1}{T}\int_0^T Q_{3h}\sin 4wtdt \quad (45)$$

Solving for Q_{3h},

$$Q_{3h} = \frac{\pi}{2T}\int_0^T p(Wal(7,t))dt \quad (46)$$

Equation (46) is the Walsh function algorithm for measuring the distortion power in a single phase power system. Substituting (46) into (43) yields;

$$Q = \frac{\pi}{2T}\int_0^T pWal(3,t)dt + \frac{\pi}{2T}\int_0^T pWal(7,t)dt \quad (47)$$

A further simplification of (47) by adding the 3rd and 7th order Walsh function algebraically gives the new algorithm for reactive power measurement.

$$Q = \frac{\pi}{T}\int_0^T pWal(3;7,t)dt \quad (48)$$

Apparent power S

$$S^2 = P^2 + Q^2 + D^2 \quad (49)$$

MODELING AND SIMULATION OF THE ALGORITHM

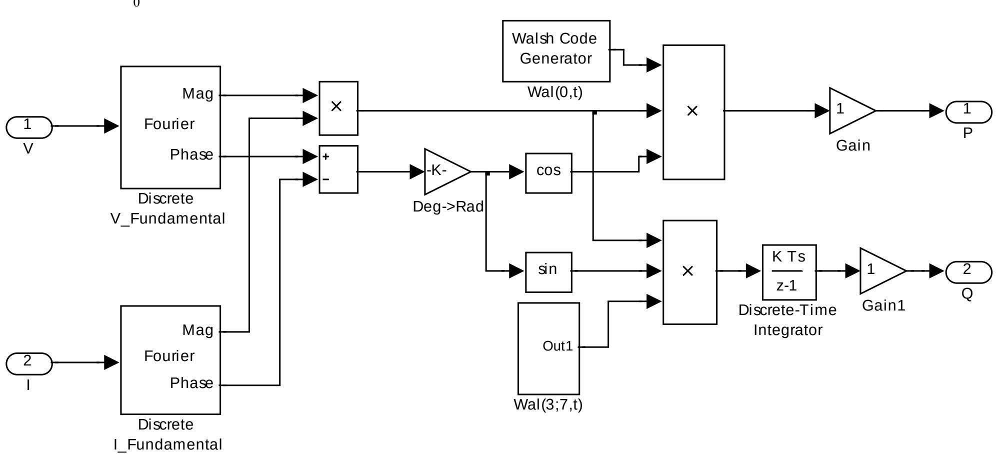

Figure-1. The subsystem of the model.

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Two case studies were used to validate the proposed improved Walsh function IWF algorithm. That is, case one linear sinusoidal load waveform and case two nonlinear non-sinusoidal waveform conditions. Power components were evaluated using the three different algorithms; the fast Fourier transform FFT, Wavelet packet transform WPT and the proposed IWF algorithms. The results were compared and errors resulting from each method were determined in order to observe the effectiveness of the proposed improved algorithm for power component measurement in both cases.

Case-A: Linear sinusoidal waveform

The voltage and current waveforms are linear and sinusoidal. The IEEE standard 1459-2000 which is based on FFT algorithm was used as the benchmark for comparison. The FFT approach has been proven to give excellent result when use for power component measurement in a linear sinusoidal load system. Assuming that the fundamental voltage component is 50V sinusoidal and fundamental current component is 25A. The voltage component leads the current component by 40^o and the sampling frequency is 32 samples per 50Hz of fundamental frequency. The simulation is implemented for FFT with window of 10 cycles and WPT with mother wavelet of 10db in this study. The true values of the power component are computed using time domain formula.

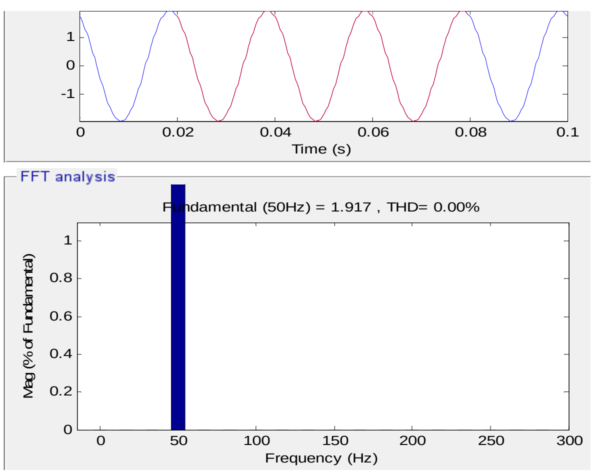

Figure-2. Current waveform and harmonic spectrum of linear and sinusoidal load system.

Table-1. The result of case A.

Power quantity	Real values	FFT	WPT	Walsh FT
Active power P	478.80	478.78	478.03	478.80
Reactive power Q	401.74	401.74	408.48	408.50
Apparent power S	673.16	673.14	670.71	670.70
Distortion power D	Nil	250.00	235.43	235.40

The result shows that the FFT spectrum measures the component of the linear waveform of the voltage and current more accurately for the linear power quality disturbance waveforms giving the best result when compared with WPT and the proposed WFT. When the network is stationary there is no effect of the spectral leakage associated with the FFT technique so it gives the most accurate result though also WPT and the proposed IWF algorithms give near accurate result with the little differences being mainly due to approximation error.

Case-B: Nonlinear non-sinusoidal waveform

The same as case one except that the current is contaminated with a third order current harmonic of 10A that has time varying amplitude. From the result shown in Table-2 the FFT due to spectral leakage and picket fence effect phenomenon associated with the FFT algorithm as a result of the nature of the network which is nonlinear and non-sinusoidal it record significant error. The WPT and the proposed improved Walsh function give near accurate values. The improved Walsh function algorithm was able to effectively measure the power component even under nonlinear load condition.

CONCLUSIONS

An improved Walsh function algorithm was proposed and implemented in this study for power component measurement in a single phase linear and nonlinear load system. The algorithm was simulated and the result compared with that of IEEE standard 1459-2000 based of FFT algorithm and Wavelet packet approach for power component measurement. The FFT approach gives accurate result when the network is linear and sinusoidal but when distortion is introduces large error occur in the reading. The WPT gives accurate result for both linear and nonlinear system but the computational burden is great, thereby increasing the possibility for error. The proposed Walsh function is simple with less computation and it gives accurate result for both linear and nonlinear system measurement as the algorithm has eliminated the effect of harmonics due to the nonlinear load system. The algorithm can be effectively implemented to accurately measure power component in power distribution Network.

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