Measurement of Power in Distribution System using DTCWT Based Signal Processing Technique

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Abstract. Power Quality is the Major Concern in modern Electrical Distribution System. Supplying Un Interrupted Power to the customers is the first priority of distribution companies. In recent days, raise of un balanced loads the voltage levels are deviated, further causing many power quality issues. There is a constant need of monitoring the voltage, current levels of the distribution system. To achieve this, these parameters like voltage, current and power are continuously measured. Decomposed Signals are more effective than the Original Signals to analysis the Signal for detecting Power Quality disturbances. So, Signal Processing techniques are affective techniques to measure the voltage, current and Power. In this Paper, dual tree complex wavelets transform (DTCWT) is used to decompose the signal. A formula is proposed measure the power in distribution system using dual tree complex wavelet transform. The Proposed formula Validated by taking different cases and it is carried out in MATLAB Software.

Keywords: Power Quality, Power Measurement, Wavelet, Dual Tree Complex Wavelet Transform, RMS Value, Wavelet Transform, PQ disturbances.

1. Introduction
In the Power Industry, monitoring of quality voltage and power is challenging issue to the Electrical Engineers. There are many disturbances that affect the regular flow of power, which leads to temporary to permanent outage of power in the system. In some cases, it leads to loss of equipment and loss of human life. There are many different types of disturbances, some are harmonics, voltage sag, voltage swell caused be the fault and unbalanced loads, flickering etc. These power quality disturbances occurred in Electrical distribution system are furthermore explained by Srkjoga et.al [1]. In order to monitor these disturbances in the Power System, the monitoring devices need to measure the voltage and current. These monitoring devices help engineers to identify the previous problems and forthcoming problems through the measured data. These Power Quality monitoring systems are discussed by B.A. Ahmad et.al [2]. In order to analyse these voltage and current signals, it is necessary to calculate the value by investigating the signal. Calculation of power is most important task in power quality monitoring. It is necessary to monitor active and reactive power values when any sudden change in load or fault occurred in the system. There are many signal decomposing methods are there to analyse the signal. Wavelet transform is one of the finest signal analysis tools. As the Voltage and Current signals are non-stationary signals, wavelet transform is perfect tool to analyse these signals as mentioned by P. M. Bentley et. al [3]. Wavelets are perfect to analyse the transient signals occurred in the power system and it is discussed by Hariharan et. al [4]. Detection of these Power Quality disturbances are detected by Prakash et.al [5] using dual tree complex wavelet transform. Mishra [6] reviewed various methods of power quality disturbances and classifications and discussed in their
study. To analyse the power system, the voltage and current signals should be decomposed to sub band levels. The Power formula was first measured by Yoon et.al [7] by using wavelet transform in 1998. Poisson et. al. [8] proposed measures and detect the quality of power disturbance signals. Sinha et. al [9] proposed a method to identify the harmonic source in the electrical distribution system by using wavelet transform technique. Ying-Yi Hong et. al [10] proposed a method to detect arc faults by measuring the voltage and current. Compared to active power, measuring the reactive power is difficult task as it is concerned with the phase shift. This was also achieved by Yoon et.al [11]. Lin et. al [12] discussed the power measurement using recursive group-harmonic power minimizing algorithm and it is discussed in. In this Paper, a formula is proposed to measure the Power Distribution System based on dual tree complex wavelet transform technique. Harmonic Source also included validating the proposed formula. The proposed formula is used for the real time purposes to detect the power quality disturbances that occur.

2. Proposed Formula

The average ac power is measured by the multiplication of RMS value of voltage and current signals. These Signals are decomposed to analysis further for finding disturbances in the circuit. There are many signal processing techniques are there to do this task, for example like Fourier Transform, S-Transform, Wavelet Transform etc. Wavelet Transform is the one of the efficient methods to analyse the signal. Dual tree complex wavelet transform is advance signal processing tool than the ordinary wavelet transforms. In dual tree complex wavelet transform there are two wavelet trees, one wavelet tree denotes the real value of complex wavelet and another wavelet tree denotes the imaginary value of complex wavelet. Let $\delta(k)$ is complex wavelet. The real wavelet is denoted by $\Phi(t)$ and imaginary wavelet is denoted by $\Omega(t)$. Then the complex wavelet formula can be written according to Kingsbury as [13].

$$\delta(k) = \Phi(t) + j \Omega(t). \quad (2.1)$$

The values of real and imaginary coefficients are such that, the phase angle of one wavelet coefficients shifted to $90^\circ$. It forms a perfect Hilbert transform. This Hilbert transform is very essential in the calculation of energy and power signals. The energy density value will be same even the signal is shifted. This property added the advantage to the dual tree complex wavelet transform to achieve the shift invariance. The amplitude will be unchanged even any change in the shift. This property added the advantage to the dual tree complex wavelet transform to achieve the perfect reconstruction property. Auto correlation factor is same for both the signals, as it is one of the important factors to validate the performance of the signal decomposition. The other advantages of the dual tree complex wavelet transform is discussed by srkjoga et.al [14]. The approximate and detail coefficients of $x(t)$ signal is derived as follows

$$A_{P(Re)} = 2^{P/2} \int_{\inf}^{\inf} x(t) \rho(h)(2^P t - k) dt \quad (2.2)$$

Where $P=1,2,3,\ldots,J$ and $\rho(h)$ is scaling factor

$$D_{P(Re)} = 2^{1/2} \int_{\inf}^{\inf} x(t) \zeta(h)(2^P t - k) dt \quad (2.3)$$
Where $J=1, 2, \ldots, P$ and $\zeta(h)$ is scaling factor

The Structure of Dual Tree complex wavelet transform signal decomposition of signal $x(n)$ is shown in below Figure 1. In the below diagram the $x(n)$ signal is decomposed up to 3 levels. There are two wavelets to form a complex wavelet. The upper tree is the real tree, where $h_0(n)$ are the approximation coefficients of original signal at different levels and $h_1(n)$ are the detail coefficients of original signal at different levels. The lower tree is imaginary tree, where $g_0(n)$ are the approximation coefficients of original signal at different levels and $g_1(n)$ are the detail coefficients of original signal. The scaling factor is chosen such a way that coefficients of upper tree are Hilbert transform to the lower tree of the decomposed signal. The inverse decomposition should give accurate value of the original signal, as the DTCWT outperform discrete wavelet transform in the perfect reconstruction of original signal.

![Figure 1. Structure of Dual Tree Complex Wavelet Transform](image)

The Sinusoidal Voltage and Current signal, which undergone decomposition is shown in Figure 2

![Figure 2. Sinusoidal Voltage/Current Signal](image)

The Voltage Signal is denoted as $v(t)$ and Current Signal is denoted as $i(t)$ respectively. Consideration of Time Period is the important tasks in the dual tree complex wavelet transform based signal decomposition method. Numbers of decomposition levels are chosen according to number of signal samples for the decomposition. The complex coefficients values are considered as absolute values for the calculation purpose. This will increase the speed of the calculation in performing the task with
very minimum error in the output value. The voltage signal detail coefficients and approximation coefficients are considered. Similarly, the current detail and approximation coefficients are considered. Fahri Vatansever proposed a methodology to measure the rms value of power through dual tree complex wavelet transform and it is more discussed in [15]. Fahri Vatansever rearranged the detail and approximate coefficients of wavelet transform of a signal, such a way that it is suitable to dual tree complex wavelet transform. Considering the one-sided decomposition signal, the formula proposed by Fahri Vatansever is given as

\[
P = \left\{ \left\{ \frac{1}{N} \sum_{k=1}^{N} a^v_s[k] \right\} \right\}^{2} + \sum_{m=1}^{s} \left\{ \frac{1}{N} \sum_{K=1}^{N} d^v_m[k] \right\}^{2}
\]

Where \( N \) is Number of Values
\( s \) is decomposition level
\( d^v_m[k] \), \( d^v_m[k] \) are the detail coefficients of the signal
\( a^v_s[k] \), \( a^v_s[k] \) are the approximate coefficients of the signal

The Proposed Formula for Power Calculation through dual tree complex wavelet transform is given below.

\[
P = \left( \frac{2}{T} \max_{J \geq 0} \sum_{J=0}^{J_{\text{max}}} \left| \text{abs}(K_J) \right| \left| \text{abs}(L_J) \right| \right)
\]

Where
\( T = \text{No. of Samples} \) (It should be even number and in the form of \( 2^N \), where \( N = 0, 1, 2, 3 \ldots N \)).
\( J = \text{Level of Decomposition} \)
\( K_J = \text{detail coefficients of Voltage Signal at level } J \)
\( L_J = \text{detail coefficients of Current Signal at level } J \)

The Proposed formula is verified through different in cases in the next section of this Paper.

3. Results and Discussions

The above derived formula is tested for different signals to validate it. The time period should always in the form of \( 2^N \), where \( N = 0, 1, 2, 3 \), up to \( N \) as signal is getting decomposed by the dual tree complex wavelet transform signal analysis process. While in the process of validating different cases are considered, they are

Case: 1

In this Case, two sine waves are considered. Let the signals are taken as voltage signal and Current Signal.

\[
V = 100 \text{ Sin (wt)} \quad (3.1)
\]
\[
I = 50 \text{ Sin (wt-30)} \quad (3.2)
\]
The Power Occurred from these two signals is \( P = 100 \times 50 = 5000 \) watts. These signals are decomposed to 9 levels (\( J = 9 \)). The time period considered for the decomposition is 2048 (\( T = 2048 \)). The Entire code is written in MATLAB software. The sum of details is calculated and tabulated in Table 1.

| Level of Decomposition (J) | Sum of Details (D) |
|---------------------------|--------------------|
| 1                         | 8.9890             |
| 2                         | 2233.6             |
| 3                         | 4416               |
| 4                         | 580390             |
| 5                         | 4531400            |
| 6                         | 375.80             |
| 7                         | 1313.3             |
| 8                         | 91760              |
| 9                         | 1                  |
| **TOTAL**                 | **5211888.3**      |

The Sum of Details (D) is 5211888.3. Now the Power value is calculated by the proposed formula.

\[
\text{Power (} P \text{)} = \frac{2}{T} \times (5211888.3)
\]

\[
\text{Power (} P \text{)} = \frac{2}{2048} \times (5211888.3)
\]

\[
= 5096 \text{ Watts.}
\]

The Value got from the derived formula is almost equal to the calculated value in the Case 1

Case: 2

In this Case, two sine waves with harmonics are considered. Let the signals are taken as voltage signal and Current Signal

\[
V = 100 \sin (wt) + 50 \sin (3wt) \quad \text{(3.3)}
\]

\[
I = 75 \sin (wt) + 25 \sin (3wt) \quad \text{(3.4)}
\]

The Power Occurred from these two signals is \( P = 100 \times 50 + 75 \times 25 = 6875 \) watts. These signals are decomposed to 9 levels (\( J = 9 \)). The time period considered for the decomposition is 2048 (\( T = 2048 \)). The Entire code is written in MATLAB software. The sum of details is calculated and tabulated in Table 2.

| Level of Decomposition (J) | Sum of Details (D) |
|---------------------------|--------------------|
| 1                         | 1734.2             |
| 2                         | 12931              |
| 3                         | 1580700            |
| 4                         | 925750             |
The Sum of Details (D) is 7054401.2. Now the Power value is calculated by the proposed formula.

\[
\text{Power (P)} = \frac{2}{T} (7054401.2)
\]

\[
\text{Power (P)} = \frac{2}{2048} (7054401.2) = 6989 \text{ Watts}.
\]

The Value got from the derived formula is almost equal to the calculated value in the Case 2.

**Case: 3**

In this Case, two sine waves are considered. Let the signals are taken as voltage signal and Current Signal. Now the Case: 1 verified with different time period to test the reliability of the proposed formula.

\[V= 100 \sin (wt)\] (3.5)

\[I=50 \sin (wt-30)\] (3.6)

The Power Occurred from these two signals is \(P= 100 \times 50 = 5000 \text{ watts}\). These signals are decomposed to 9 levels (\(J=9\)). The time period considered for the decomposition is 2048 (\(T=1024\)). The Entire code is written in MATLAB software. sum of details is calculated and tabulated in Table 3.

**Table 3.** Sum of Details at different levels for Case: 3

| Level of Decomposition (J) | Sum of Details (D) |
|----------------------------|--------------------|
| 1                          | 146.64             |
| 2                          | 1924.9             |
| 3                          | 290120             |
| 4                          | 2265300            |
| 5                          | 161.54             |
| 6                          | 484.30             |
| 7                          | 0.0143             |
| 8                          | 0.5501             |
| 9                          | 1                  |
| **TOTAL**                  | **2557952**        |

The Sum of Details (D) is 2557952. Now the Power value is calculated by the proposed formula.
\[
\text{Power (P)} = \frac{2}{I} \times (2557952)
\]
\[
\text{Power (P)} = \frac{2}{1024} \times (2557952)
\]
\[= 4996 \text{ Watts.}
\]

The Value got from the derived formula is almost equal to the calculated value in the Case 3.

**Case 4:**

In this Case a real time Simulink model is considered for validating the proposed formula. In this a single phase voltage source with 500V peak amplitude is considered. Resistive Load of 50 ohms connected across the voltage source. The voltage Signal and Current Signal are collected to workspace for further investigation. The Simulink model is shown in below Figure 3.

![Simulink Model](image)

**Figure. 3 MATLAB Simulink Model to Verify Case: 4**

The Power Occurred from these two signals is

\[P = \frac{500 \times 10}{\sqrt{2}} \times \sqrt{2} = 2500 \text{ watts.}
\]

These signals are decomposed to 9 levels \((J=5)\). The time period considered for the decomposition is 128 \((T=128)\). The Entire code is written in MATLAB software. sum of details is calculated and tabulated in Table 4.

| Level of Decomposition (J) | Sum of Details (D) |
|---------------------------|--------------------|
| 1                         | 30.64              |
| 2                         | 1000               |
| 3                         | 7000               |
| 4                         | 151000             |
| 5                         | 6.36               |
| **TOTAL**                 | **159937**         |
The Sum of Details (D) is 2557952. Now the Power value is calculated by the proposed formula.

\[
\text{Power (P)} = \frac{2}{T} \times 159937
\]

\[
\text{Power (P)} = \frac{2}{128} \times 159937
\]

= 2499 Watts.

The Value got from the derived formula is almost equal to the calculated value in the Case 4.

4. Conclusions

The Proposed formula is validated with four different cases. In all the cases the proposed formula gave accurate value to the calculated Value. The Entire Cases are compared with Existed method and tabulated in Table 5.

| Case | Calculated Value | Measured Value | Error % (Existed Methodology) | Error % (Proposed Methodology) |
|------|------------------|----------------|-------------------------------|-------------------------------|
| 1    | 5000             | 5096           | 1.9                           | 1.8                           |
| 2    | 6875             | 6989           | 1.2                           | 1.6                           |
| 3    | 5000             | 4996           | 0.09                          | 0.008                         |
| 4    | 2500             | 2499           | 0.009                         | 0.004                         |

In the Table 5, the error percentage is so minimal in all the cases. In the case 1 and case 2, the error percentage is 1.8 and 1.6 respectively. In the Case 3 and Case 4, the error percentage is 0.008 and 0.004 respectively. The proposed formula is accurate formula than any previous formulae derived for the power calculations through dual tree complex wavelet transform signal processing technique. The Proposed Formula is compared with existed formula and it performed almost same result within less time. It is tabulated in Table 6.

| Method                | Complexity         | Response Time               |
|-----------------------|--------------------|-----------------------------|
| Existed Method        | High Computation   | Slow Response Time          |
| Proposed Methodology  | Low Computation    | Faster compared to          |
|                       | Required           | Existed method with         |
|                       |                    | response time               |
|                       |                    | 0.0000000001 sec.           |

This Proposed Methodology is also cost effective compared to the Existed method. The Response time is very fast compared to existed method.
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