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Identification of Power Quality on EAF using Wavelet Transform based on Actual Recorded Data

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Abstract— **This paper presents disturbance voltage identification based on actual data recorded of electric arc furnace load. The identification of disturbance used wavelet transformation. The proposed method can precisely identify disturbance caused by operation of an electric arc furnace (EAF). The identification procedure consists of 4 steps: measurement of voltage eaf, normalization of actual data recorded, transformation wavelet and wavelet energy calculation. The result of transformation wavelet analyzed for identification of disturbance which occurrence. The types disturbance detected are unbalance voltage. From calculation of energy wavelet, shown the wavelet energy average *Va, Vb* and *Vc* are 0.14842, 0.04884, and 0.09926 respectively.**

Keywords- Power Quality; Disturbance of Voltage; Wavelet Transform; Wavelet Energy; Eaf

I. INTRODUCTION

Electrical disturbance problem often occurs on the distribution system, especially in industrial areas. The disturbances can disrupt the production process internally or outside sources. Electrical disturbances associated with power quality, which include blackouts, power factor, harmonics, sags, swells, and unbalanced conditions [1][2][3][4]. A satisfied quality of power is required for sensitive equipment to work normally. When the quality of power reduced below the standard, the circuit breaker opens so can reducing the power factor [5]. The importance disturbances that are considered include voltage stabilization, continuity, and waveform. The voltage stability is identified such as under-voltage, over-voltage, voltage sag, voltage swell, phase shift, flicker and frequency. The continuity problems terms the momentary interruption, temporary interruption, and sustained interruption, transient, three phase voltage unbalance, harmonic voltage, current notch [6]. Voltage sags are reduction the rms value of voltage with short duration, it can be characterized by residual voltage and duration[4]. IEEE Standard 1159 defines voltage sag as reduction in the rms voltage between 0.1 and 0.9 p.u. of the nominal voltage, for duration of 0.5cycle to 1 min.[7]. Power quality problems causes equipment damage, under and over voltage. The under voltage and over voltage occurs in long duration voltage variation or in short-duration voltage variation. Electric arc furnace (eaf) is a typical furnace used in many steel making company. The furnace is fed by sponge steel, scraps steel, or recycled steel to form steel processed [8]. Three fundamental changes in the operation of electric arc furnace, which can produce disturbance voltage in the power system, like short-circuit, open circuit condition, and normal operation [9]. The operation of the eaf causes electrical short circuit internally between phase and scrap. This process can decrease the quality of electricity. Voltage sags and swells frequently occur. The harmonic distortions also appear due to the process in EAF. Power transformers become overheating, dips on lighting systems, and failure if the dip voltage is deeper than 35% . To identify the internal short circuit process in EAF become very interesting topics, followed by action for compensation. Researchers have published topics in improvement of power quality in weak grid system and weak grid characteristics [10][11]. This paper discusses a method to identify power quality due to Electric Arc Furnace operation. It analyses the power quality characteristics using wavelet transformation. The WT approach prepares a window that simultaneously gives proper resolutions in both the time and the frequency domain [12]. The wavelet transforms disturbance signals into approximate signal and detail signal [13]. The wavelet method is suitable for transforming event which occurs in a short duration.

II. IDENTIFICATION METHOD

The short circuit, which occurs inside the EAF, is identified applying 4 steps: measurement of voltage in eaf system using power quality analyzer, normalized data recorded, discrete wavelet transformation, calculation wavelet energy. The flowchart is illustrated in Figure 1.

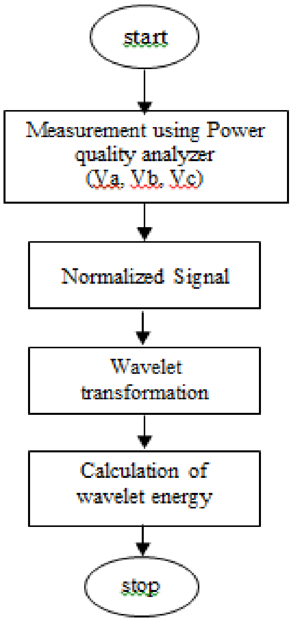


Fig. 1. Flowchart System

A. *Recorded Data*

The data which use in this study obtain from measurement at the PCC using power quality analyzer.

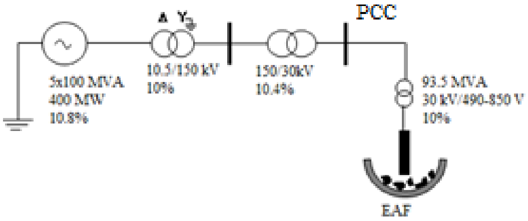


Fig. 2. Electrical Circuit Of Electric Arc Furnace

The Electric Arc Furnace in this study has a capacity 130 tons, 50 MW, 30 kV [14]. The melting process of steel inside the EAF is due to the heat generated from short circuit among the electrodes. .

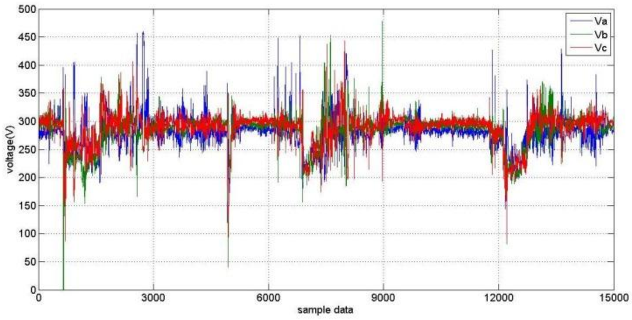


Fig. 3. Recorded Data of Voltage EAF

Data obtained in raw form corresponding read on power quality analyzer. to simplify the simulation process, the data should be in the range of 0 and 1.Therefore, it is necessary to process the raw data by:

$$d_n = \frac{d_x - d_{min}}{d_{max} - d_{min}} \tag{1}$$

B. *Wavelet Transformation*

Wavelet transformation has the objective to detect any disturbance. This paper used discrete wavelet transform (DWT) with wavelet daubechies as mother wavelet. Transformed signal is voltage V_α (positive sequence phasor). Original signal is decomposed into approximation and detail signals [7][9]. Wavelet orthogonal consist scaling function $((\emptyset(x))$ and wavelet function $((\psi(x))$ in equation (2)

$$\phi(x) = \sum_{t=0}^{J-1} a_k \phi(2x - t)$$
$$\psi(x) = \sum_{t=0}^{J-1} b_k \phi(2x - t) \tag{2}$$

$(a_0 - a_{J-1})$ is scaling sequence and $(b_0 - b_{J1})$ is wavelet sequence. Scaling function is assosiated with low-pass filterswith coefisient $\{h(n), n \in z\}$, and wavelet function is asssosiated with *high-pass filter* with coeficient $\{g(n), n \in z\}$,(Figure 4)

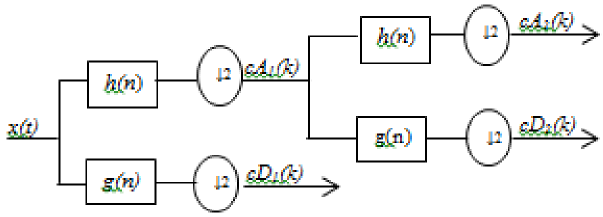


Fig. 4. Wavelet Decomposition 2 Levels

Some important traits for low pass filter and high pass filter are:

1. $\sum_n h(n)^2 = 1$ and $\sum_n g(n)^2 = 1$ (3)
2. $\sum_n h(n) = \sqrt{2}$ and $\sum_n g(n) = 0$ (4)
3. Filter *g(n)*is alternative from filter *h(n)*, which is an odd integer N so:

$$g(n) = (-1)^n h(N - n) \tag{5}$$

Based on implementation from figure 4, correlation of approximation coefficient with detail coefficient defined as:

$$cA_j(k) = \sum_n h(2k - n) cA_{j-1}(n) \tag{6}$$
$$cD_j(k) = \sum_n g(2k - n) cA_{j-1}(n) \tag{7}$$

cA_j and cD_j represent approximation coefficient and detail coefficient from signal to the level-j.

C. *Wavelet Energy*

The wavelet energy is the sum of square of detailed coefficients. To distinguish the disturbance signal can be viewed by the energy distribution of the wavelet transform. Energy values for each detail signal and approximation signal can be calculated by equation(8) and (9).[15]

$$E_{dj} = \sum_n \left| d_{j(n)} \right|^2 \tag{8}$$

$$E_{ai} = \sum_n \left| a_{i(n)} \right|^2 \quad (9)$$

E_{dj} is energy of detail signal to-*j* and E_{ai} is the energy of approximation signal to-*i* for n-level decomposition.

Scales of the wavelet energy coefficients varying depending on the input signal. The distorted signal has energy can be partitioned at different resolution levels and in different ways depending on the power quality problems [16].

III. Result and Discussion

Data obtained from the voltage measurement, normalized using equation (2) and the results are as shown in figure 5.

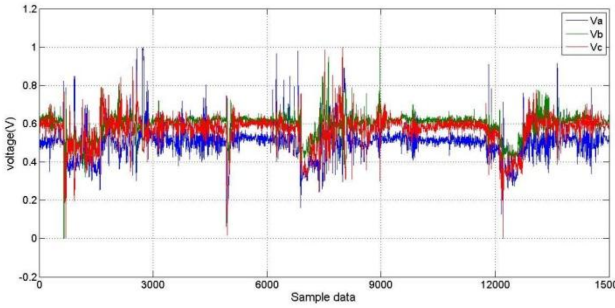
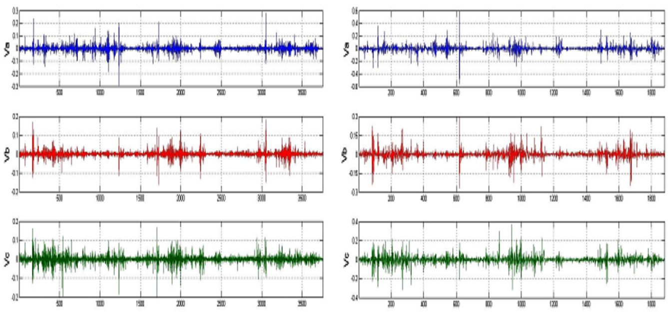


Fig. 5. Result Normalized of Measurement EAF Voltage

Data normalization as shown in Figure 4 is then transformed using wavelet transform. Discrete Wavelet Transformation divides the original signal into two parts, namely the approximation and detail. Approximation has the same shape of the signal with the original signal are signal *Va*, *Vb* and *Vc*. In this research, the wavelet transform up to 5 levels, the results can be seen in Figure 6 and Figure 7.

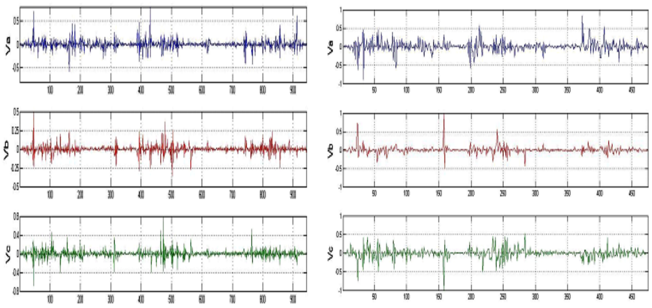
Details are observed signal, detail generate shape of the signal corresponding to the mother wavelet when fault occurs.



(a) (b)

Fig. 6. Wavelet Transformation (a) Detail-2 (*Va*, *Vb*, And *Vc*) and (b) Detail -3 (*Va*, *Vb*, And *Vc*)

Figure 6 are the result of wavelet transformation for detail 2 and detail 3 for signals *Va*, *Vb*, and *Vc*.



(a) (b)

Fig. 7. Wavelet Transformation (a) Detail-(*Va, Vb*, And *Vc*) and (b) Detail -5 (*Va*, *Vb*, And *Vc*)

Figure 7 are the result of wavelet transformation for detail 4 and detail 5 for signals *Va*, *Vb*, and *Vc*. From Figure 6 and Figure7, shown there are disturbance of voltage, i.e. unbalance voltage.

The value of detail signal which obtained from Figure 5 and Figure 6 are used to calculate the wavelet energy on each voltage (*Va*, *Vb*, and *Vc*).

The calculation result of wavelet energy the detail signal, indicate that the signal detail of *Va*, *Vb* and *Vc* have an average value ($Ed_{average}$) 0.14842, 0.04884, and 0.09926 respectively.

Table 1. Wavelet Energy Of Three Phase Voltage EAF

	Ea	Ed1	Ed2	Ed3	Ed4	Ed5
Va	99.2578	0.0245	0.0596	0.1496	0.2334	0.2750
Vb	99.7559	0.0076	0.0226	0.0497	0.0639	0.1004
Vc	99.5038	0.0159	0.0388	0.0908	0.1560	0.1948

From Table 1, it can be explained that in the event of voltage at phase-b (*Vb*) has the largest *Ed* value among other voltage. This suggests that the higher the value of *Ed*, the energy loss is also higher.

IV. Conclussion

In this study, method of disturbance identification with wavelet analysis has been developed and tested. The test result show powerful capabilities of the proposed method based on wavelet transform to detect disturbance voltage occurs is unbalance voltage. Based on the value of wavelet energy, it is known that the energy value greater in one of voltage (*Va*) than another voltage (*Vb* and *Vc*).

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