

SAG VOLTAGE IDENTIFICATION ON 30 KV SYSTEMS AFFECTED BY ELECTRIC ARC FURNACE USING WAVELET TRANSFORMATION METHOD

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ABSTRACT

This paper presents sag voltage identification on 30 kV system with electric arc furnace load. The identification of disturbance using wavelet transformation. The proposed method can precisely identify sags caused by 3 disturbances: single-phase, two-phase, and three-phase short circuits, which occur in internally process of an electric arc furnace (EAF). The identification procedure consists of 3 steps: preparation, wavelet energy calculation, analysis for identification. The types of short circuit are detected from the amount of energy during the EAF operation. The highest energy required indicates a three-phase short circuit; however the lightest is for single-phase short circuit. Simulation results from a typical data show that a sag voltage in 0.55-0.75 pu for 0.201 seconds, containing wavelet energy average 0.434733, is caused by 3 types of short circuit in certain subsequent time.

Keywords: *Power Quality, 30 kV System, Electric Arc Furnace, Short Circuit disturbances, Wavelet transformation*

1. INTRODUCTION

Problems of electrical disturbances are commonly faced on distribution system in a typical industry area. The disturbances may disrupt the production process internally or outside of the source. The disruptions will affect to the costs. The electric disturbances relate to the power quality, which include outage, power factor, harmonics, sags, swells, and unbalanced conditions[1][2][3].

A satisfied quality of power is required for sensitive equipment to work normally. When the quality of power reduces below the standard, it operates the circuit breaker, and also reducing the power factor[4]. Three important disturbances that are considered include voltage stabilization, continuity, and waveform. The voltage stabilization 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 [5].

Voltage sags are the rms value of the voltage reduction with short duration. It can be characterized by residual voltage and duration[2][6]. According 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 0.5 cycle to 1 min.[2].

Unsatisfied power quality causes equipment damage and under-overvoltage. The permitted under or over voltage shall be in the range of -10% - 5% . This under – 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, scrap steel, or recycled steel to form a steel processed [7]. Three fundamental changes in the operation of electric arc furnace, which can produce disturbance voltage of the power system, i.e. short-circuit conditions, open circuit condition, and normal operation [8]. The operation of EAF causes electric short circuit internally between phase and steel. This process then decreases the quality of electricity. Voltage sags and

swells frequently occur. High harmonic distortions may also appear due to the internal process of EAF [9]. This will affect the equipment surrounding the disturbance sources. Power transformers may be overheating, dips on lighting systems, or failure if the dip voltage is deeper than 35% [10]. To identify the internal short circuit process in EAF become very interesting topics, followed by action for compensation.

This paper discusses a method to identify sag voltage due to Electric Arc Furnace operation. It analyses the sag characteristics using wavelet transformation. The wavelet transforms disturbance signals into detail signal and approximate signal [11]. Then, the signals are categorized as formed by single phase, inter phase, or three phase short circuits. The wavelet method is suitable for transforming event which occurs in a short duration.

2. SYSTEM MODELING

The system study is modeled as an infinite bus 150 kV with short circuit capacity 7702 MVA supplying a step down transformer 30 kV with short circuit capacity 1607 MVA, through transmission line, as shown in Figure 1.

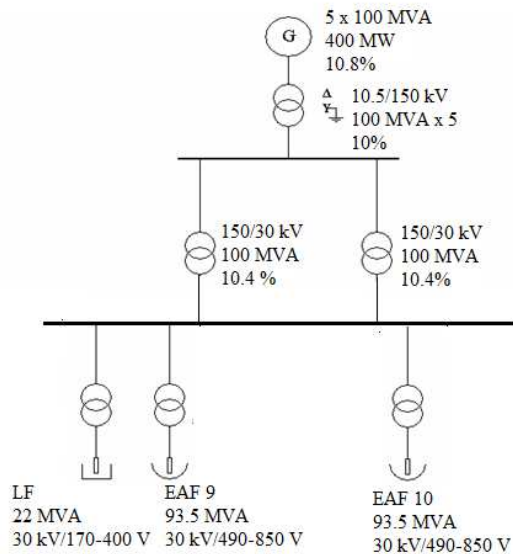


Figure 1: Single line diagram

The Electric Arc Furnace in this study has a capacity 130 tons, 50 MW, and modeled as an inductive load 45 MVAR, 30 kV. The melting process of steel inside the EAF is due to the heat generated from short circuit among the electrodes.

The short circuits types include 1-phase, 2-phase, and 3-phase. It appears according to the stages of melting process and position of the electrode-iron.

3. IDENTIFICATION METHOD

The short circuit, which occurs inside the EAF, is identified applying 4 steps: modeling of distribution system, Clark transformation, discrete wavelet transformation, calculation wavelet energy, analysis. The flowchart is illustrated in Figure2.

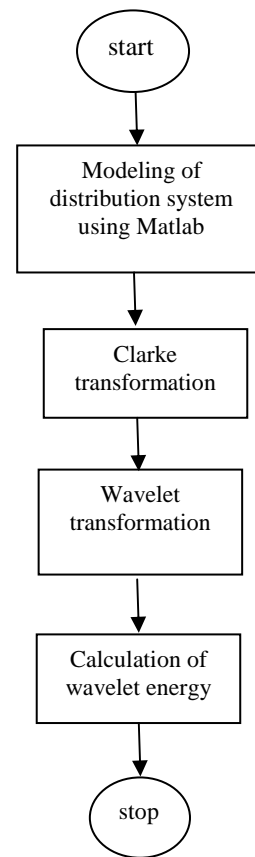


Figure 2: Flowchat system

3.1 Modeling of Distribution system

Single line diagram in Figure 2 is modeled using Matlab version 7.8.0 (R2009a). By using existing data in section 2, it can be modeled as in Figure 3. The results of the model simulations will be obtained the data of three-phase voltages are known V_a , V_b and V_c .

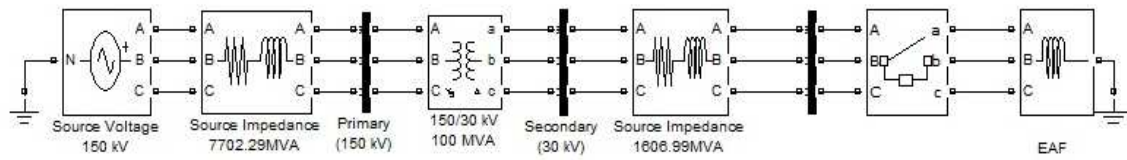


Figure 3: Modeling of distribution system

3.2 Clarke Transformation

Clarke transform is for converting voltage or current waveform in time domain into alpha, beta axis. This simplified the analysis from 3 phase into single calculation [12]. In this study, three-phase voltage (V_a , V_b and V_c) are converted into two-phase voltages i.e V_α and V_β . Clark transformation is calculated using matrix as follows:

$$\begin{bmatrix} V_\alpha \\ V_\beta \\ V_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad (1)$$

3.3 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 ($\phi(x)$) and wavelet function ($\psi(x)$) in equation (2)

$$\begin{aligned} \phi(x) &= \sum_{k=0}^{J-1} a_k \phi(2x - t) \\ \psi(x) &= \sum_{k=0}^{J-1} b_k \psi(2x - t) \end{aligned} \quad (2)$$

$(a_0 - a_{J-1})$ is scaling sequence and $(b_0 - b_{J-1})$ is wavelet sequence. Scaling function is associated with low-pass filters with coefficient $\{h(n), n \in Z\}$, and wavelet function is associated with high-pass filter with coefficient $\{g(n), n \in Z\}$, (Figure 4).

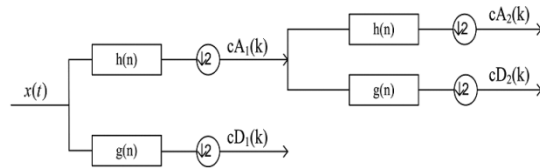


Figure 4: Wavelet decomposition 2 levels

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

$$1. \sum_n h(n)^2 = 1 \text{ and } \sum_n g(n)^2 = 1 \quad (3)$$

$$2. \sum_n h(n) = \sqrt{2} \text{ and } \sum_n g(n) = 0 \quad (4)$$

3. Filter $g(n)$ is alternative from filter $h(n)$, which is an odd integer N so:

$$g(n) = (-1)^n h(N - n) \quad (5)$$

Based on implementation from figure 5, correlation of approximation coefficient with detail coefficient defined as:

$$cA_j(k) = \sum_n h(2k - n) cA_{j-1}(n) \quad (6)$$

$$cD_j(k) = \sum_n g(2k - n) cA_{j-1}(n) \quad (7)$$

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

3.4 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).[14][15]:

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

$$E_{aj} = \sum_n |a_{j(n)}|^2 \quad (9)$$

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].

4. RESULTS AND DISCUSSION

Simulation result of Single line diagram before the EAF operation is shown in figure 4. Voltage 3-phase signal is transformed Clarke with equation 1, the result is as Figure 5. Then V_α (Figure5) is decomposed into approximation and detail signals using wavelet transform 3-level as shown in figure 8(a).

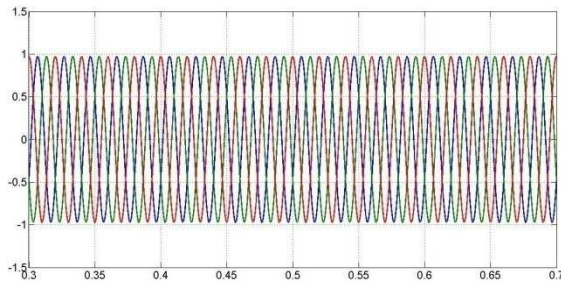


Figure5: Simulation result before EAF operation

The simulation results before the EAF operation is a pure sine wave, these results transformed Clarke (Figure 6).

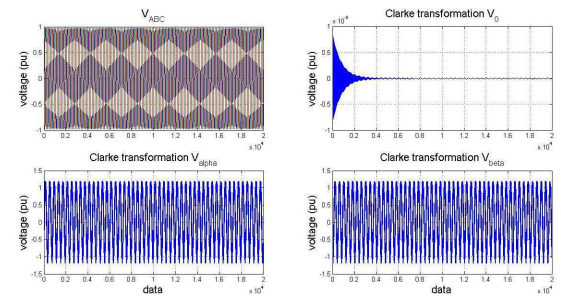


Figure 6: Clarke Transformation signal before EAF operation

Clarke transformation results, obtained V_0 , V_α and V_β . Then V_α is transformed using wavelet transform to detect the disturbance.

After EAF operation, the electrode reaches the surface of the scrap with the same gap and assumed 3-phase short circuit. The simulation results shown at Figure 7, Figure 8, and Figure 9(b).

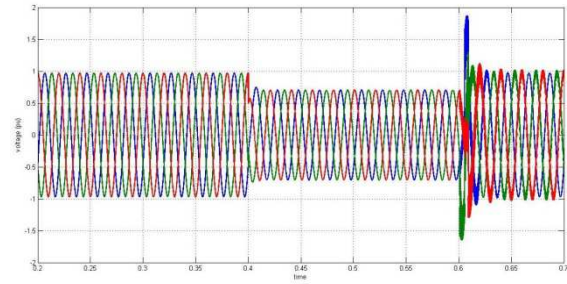


Figure 7: Simulation result after EAF operation

Figure 7. Signal of simulation result when EAF has been operated and assumed a three-phase short circuit fault.

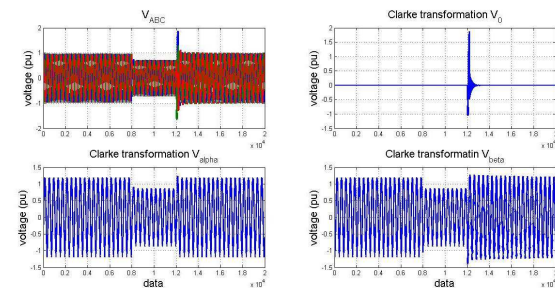


Figure 8: Clarke Transformation after EAF operation

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 is a signal V_α . Details are observed signal, detail generate shape of the signal corresponding to the mother wavelet when fault occurs. Scales of the wavelet transform generated during disturbances are 0.0683, 0.0393, and 0.0835 on the data to 8006, 12026, and the data to 12122. Scale to determine the value of the wavelet the time of the disturbance, can be seen in Figure 9 (b). Seen that detail in the event of short circuit of 3-phase voltage disturbance is identified decrease the voltage to 0.55 pu-0.75 pu with duration of events around 0.2010s. So the type of disturbance occurred can be referred to as voltage sag, due to the large drop voltage and duration of disruption.

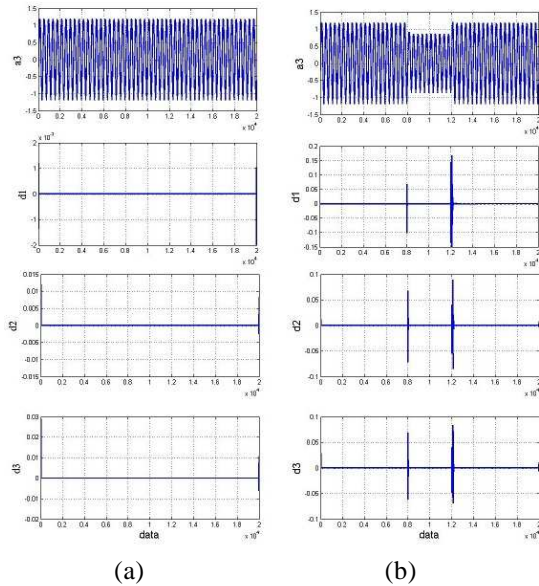


Figure 9: Wavelet transformation 3-level (a) before EAF operation (b) after EAF operation (short circuit 3-phase)

The calculations results of wavelet energy detail signals (Table 1), show that the conditions before EAF operated and after the EAF operated (3-phase short circuit) has an average wavelet energy detail signals ($E_{d\text{average}}$) 6.67×10^{-7} and 0.434733 , respectively.

Table 1. Wavelet energy for some conditions of EAF operation

	Before EAF operation	Short circuit type during EAF operation		
		1-phase	2-phase	3-phase
E_a	99.9999	99.9998	99.997	99.9945
E_{d1}	0.3×10^{-6}	10.5×10^{-6}	153.1×10^{-6}	4.2×10^{-3}
E_{d2}	6.1×10^{-6}	10×10^{-6}	10×10^{-6}	0.4
E_{d3}	13.6×10^{-6}	141.1×10^{-6}	141.1×10^{-6}	0.9

From Table 1, it can be explained that in the event of a short circuit of 3-phase has the largest E_d value among other conditions. This suggests that the higher the value of E_d , the energy loss is also higher.

5. CONCLUSION

In this paper, disturbance voltage detection method with wavelet analysis has been developed and tested. The test result show powerful capabilities of the proposed method based on wavelet transform to detect sag voltage occurs at 0.55-0.75 p.u for 0.201 seconds. Based on the value of wavelet energy, it is known that the energy value greater in the occurrence of short circuits than without short circuits. This value will be greater in multi phase short circuits.

In the next experiment, wavelet transform is used to detect disturbance of power quality (harmonic, flicker, etc) at electric arc furnace based on the measurement data.

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