

Ferroresonance Signal Analysis with Wavelet Transform on 500 kV Transmission Lines Capacitive Voltage Transformers

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Abstract— This paper deals with ferroresonance detection on a transmission line utilizing wavelet transform. The ferroresonance involving linear capacitor and non-linear inductor was triggered by the disturbances of power system, such as lightning strike, switching operation and ground fault. The primary voltage of capacitive voltage divider (CVT) was observed as response of the triggered ferroresonance. The voltage signal was processed using wavelet daubechies (db5) until 9 levels. The cyclic cumulative energy for each condition was then calculated and compared. The result shows that the cyclic cumulative energy ratio and duration of period of cumulative energy deviation can be used as ferroresonance detection parameters.

Keywords—ferroresonance; capacitive voltage divider, wavelet transform

I. INTRODUCTION

In modern era, electric power has been one of the fundamental needs. Consequently, reliability and stability of power system must be presented. On the other hand, the condition of power system is affected by performance of electric apparatus, such as transformer to convert voltage level. The occurrence of disruption can degrade performance of the transformer. Overvoltage is one of the disruption kinds that often contributes to this degradation.

Ferroresonance characterized by overvoltage is a result of interaction between linear capacitor and non-linear inductor [1-2]. The overvoltage due to ferroresonance belongs to abnormal overvoltage since its amplitude is very high with harmonics distortion [3]. Eventually, this effect leads to not only damage of transformer but also failure of power system. The complexity in detection of ferroresonance still becomes an important issue at this moment. As a result, ferroresonance cannot be mitigated effectively.

In this paper, the discrete wavelet transform was applied to obtain the ferroresonance detection parameters. The transient disturbances due to lightning strike, ground fault and switching operation were chosen as triggers of ferroresonance. The response of ferroresonance observed was primary voltage of

capacitive voltage transformer (CVT) of 500 kV transmission line. The result can be evaluated as a ferroresonance detection method based on wavelet [4-8].

A. Ferroresonance

Ferroresonance, also known as a non-linear resonance, is a complex non-linear disturbance of power system. One of the characteristic of this phenomenon is its abnormal overvoltage endangering transmission line, insulation, protection, apparatus and operator. If the power system is subjected by an unknown complex disturbance, the suspicion is ferroresonance contributing to this condition.

The term of ferroresonance was known in 1920 [1]. This oscillation phenomenon involves non-linear inductor, linear capacitor and sinusoidal voltage source. The non-linear inductor origin from power transformer, voltage measuring transformer and shunt reactor, whereas the linear capacitor is sourced from line charging of transmission line and grading capacitance of circuit breaker.

Ferroresonance reduces impedance to its lowest value. As a result, the current flowing to transformer will rise significantly. Later, this high current increases flux density of the transformer until its iron core is saturated. Under this condition, the interaction between nonlinear inductance of transformer, capacitor, and iron core result in an abnormal response, such as overvoltage and overcurrent with its harmonic distortion.

B. Wavelet Transform

There are 2 types of wavelet transform, namely continuous wavelet transforms (CWT) and discrete wavelet transforms (DWT). By giving a function of wave, $f(t)$, CWT provides many wavelet transform coefficients that leads to excessive output data. DWT is able to overcome this problem since it uses only some of wavelet transform coefficients.

DWT is composed based on Mallat decomposition algorithm, in which the input signal is decomposed to be 2 signal types. The one is high frequency signal and the other

one is an approximation with its low frequency. In application of mother wavelet, DWT analyzes the detail using high frequency, whereas low frequency is used to analyze approximation. The mechanism can be explained more detail in the following. The input signal is divided to be 2 sub-signal types, that are high frequency and low frequency. The sub-signal is then divided to be 2 sub-signals with different frequency. This mechanism takes a place continuously in accordance with level of wavelet transform used [4]. Wavelet transform develops a method to sample dynamics characteristic of non-stationary signal using short data. Wavelet transform is similar with fourier transform that is a signal classifier in sinusoidal form with variety of frequency.

In this paper, detection of ferroresonance was conducted using high frequency daubechies wavelet transform. This mother wavelet is very crucial in detection of ferroresonance's characteristic. The order and level of this mother wavelet can be determined based on criteria of voltage signal extraction and mother wavelet itself [5]. The calculation of cumulative energy would be used as ferroresonance detection parameters.

II. MODELLING OF FERRORESONANCE AND DETECTION METHOD

CVT is a voltage measuring transformer of transmission line, as modelled in Fig. 1. The measured voltage, V_u , is in order of kilovolt hundreds. By using capacitive voltage divider, the capacitor voltage of C_2 will be in order of kilovolt tens, such as 5, 10, 15 and 20 kV. Later, magnetic transformer will decrease the voltage to be standard secondary voltage, that is 100 or $100\sqrt{3}$. The parameters of CVT is explained in detail as shown in Table 1.

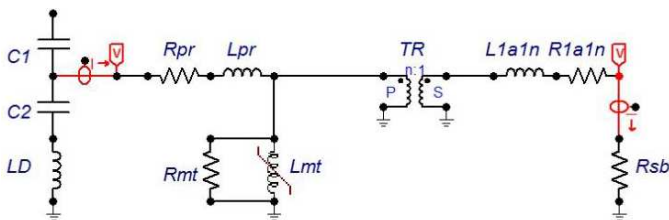


Figure 1. Model of CVT using ATPDraw.

TABLE 1. COMPARISON BETWEEN SIMULATION

Parameter	Value
Rated voltage	$500\sqrt{3}$ kV
Frequency	50 Hz
Voltage divider capacitor	$C1 = 3300$ pF, $C2 = 79700$ pF, load coil = 10 mH
Step down transformer	$R1 = 220 \Omega$, $L2 = 0.007$ mH, ratio = 200
Burden	75Ω

In this study, 4 conditions of transmission line were simulated as depicted on Fig 2. The result of simulation was primary voltage of CVT for 1 s with 100 kHz sampling frequency. The voltage signal was processed using wavelet daubechies (db5) until 9 levels. After that, cyclic cumulative energy for each condition was calculated and compared.

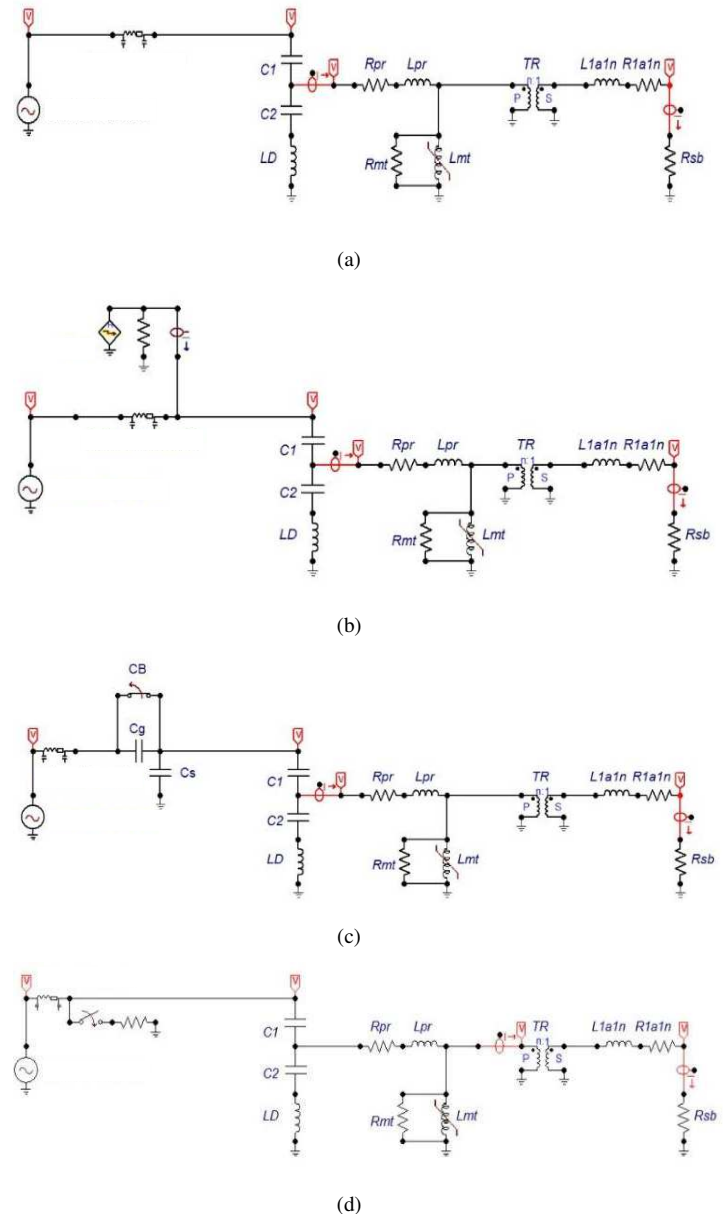


Figure 2. Model of simulated condition: a) normal b) lightning strike c) switching operation d) ground fault.

III. RESULT AND ANALYSIS

The comparison of CVT's primary voltage response for each scheme can be seen in Fig. 3. The amplitude of voltage for normal condition is 16.23 kV, as shown in Fig. 3 (a). The amplitude of the voltage for the other conditions is higher than normal condition. Moreover, their voltage amplitude experiences increasing both on ferroresonance response and on non-ferroresonance response, as depicted on Fig. 3 (b-d). The daubechies (db5) wavelet transform for 9 levels is then applied to all simulation results. The output of signal processing can be seen in Fig. 4.

The difference of wavelet daubechies for each conditions can be seen visually at level 8 of wavelet daubechies (d8), as depicted in Fig. 4. The d8 signal is relatively normal and unchanged for normal condition. This result is contrary with the other conditions. The d8 signal is then calculated its cumulative energy for each cycle using (1). The obtained cumulative energy is then compared at period of before and after disturbance, as shown in Fig. 5. The detail information of the cumulative energy in Fig. 5 can be explained in Table 2.

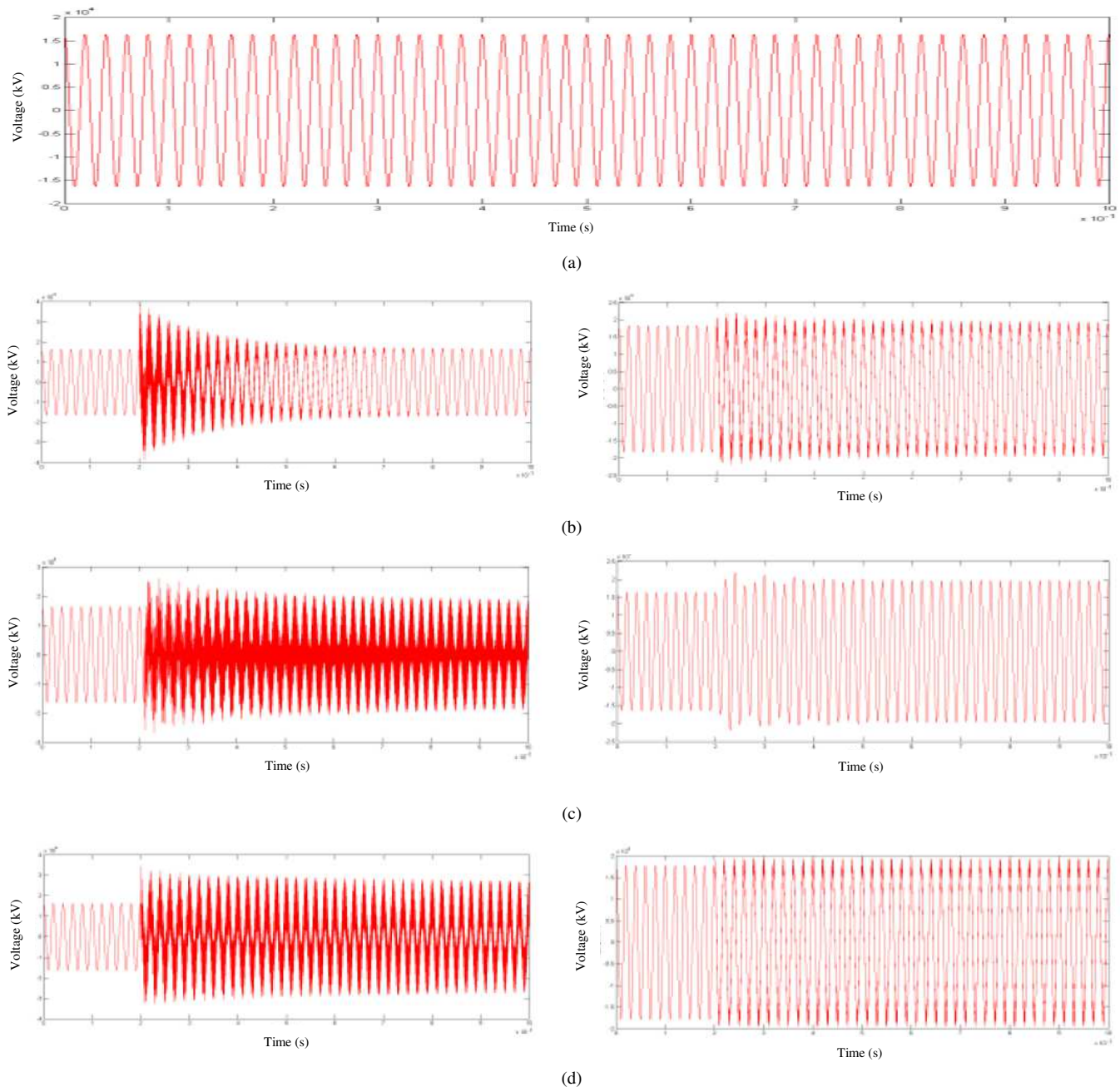
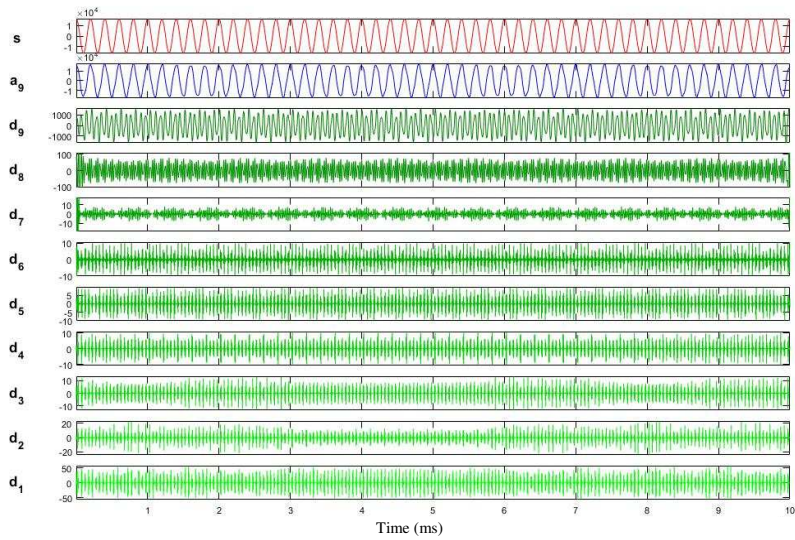
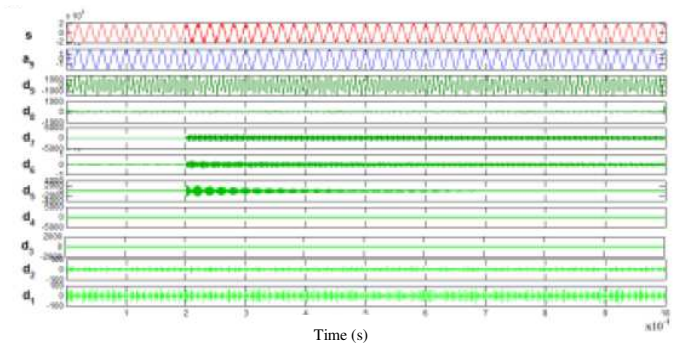
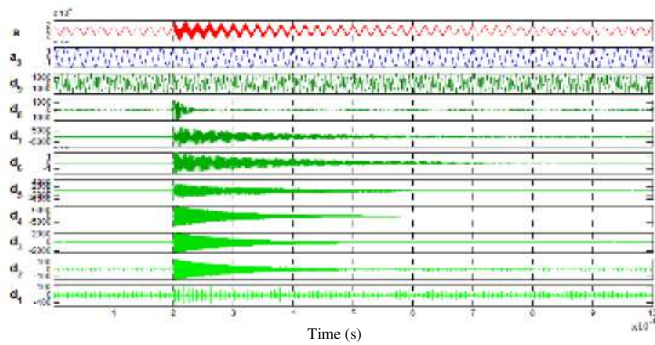


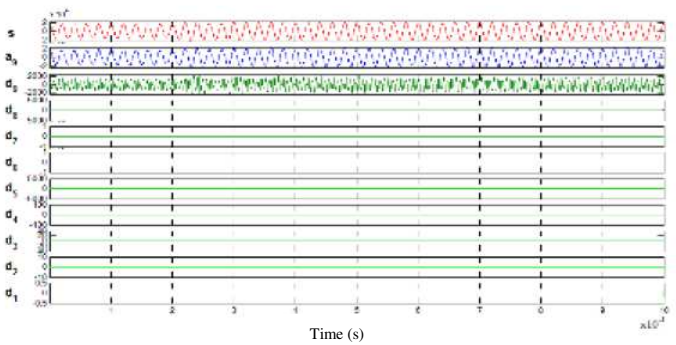
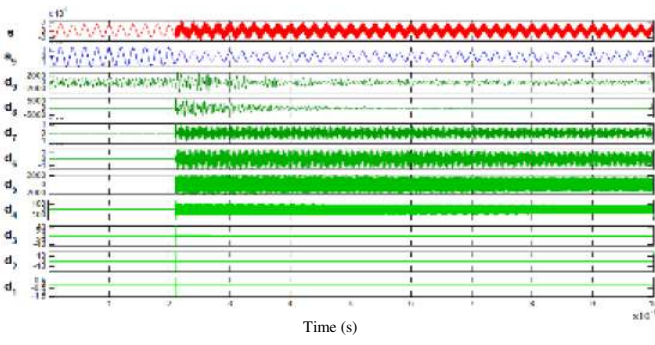
Figure 2. Model of simulated condition: a) normal b) lightning strike c) switching operation.



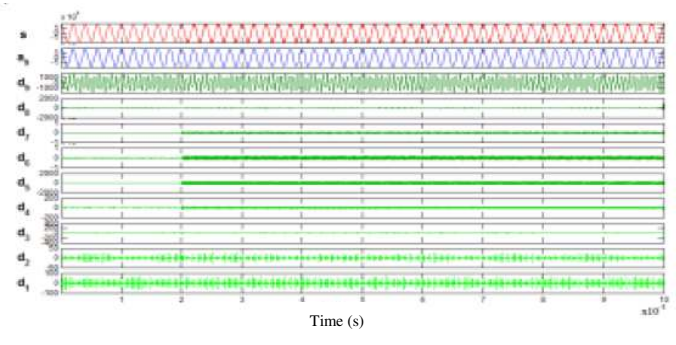
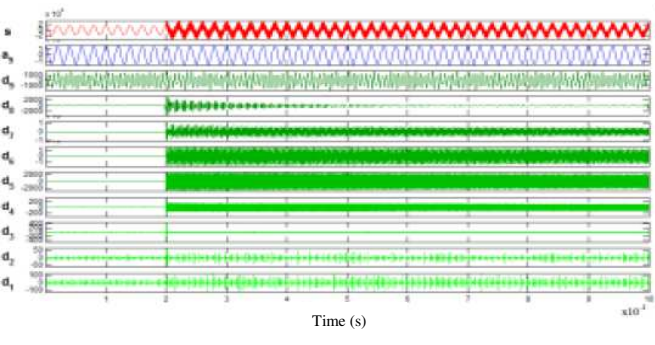
(a)



(b)



(c)



(d)

Figure 4. Result of wavelet daubechies (db5) for 9 levels: a) normal b) lightning strike c) switching operation d) ground fault.

TABLE 2. COMPARISON OF CYCLIC CUMULATIVE ENERGY FOR EACH CONDITION

Time (s)	Normal	Lightning Strike		Switching		Ground Fault	
		Ferroresonance	Non-Ferroresonance	Ferroresonance	Non-Ferroresonance	Ferroresonance	Non-Ferroresonance
0.16-0.18 (T ₂)	2.948	2.96	2.904	2.84	2.841	2.928	2.913
0.18-0.2 (T ₁)	3.196	13.363	3.258	2.664	2.719	3.987	3.739
0.2-0.22 (T ₁)	3.422	2534.2	14.49	10199	3.573	4447.7	13.294
0.22-0.24 (T ₂)	3.141	648.29	10.5	18853	6.911	2995.7	6.273
0.24-0.26 (T ₃)	2.602	113.44	8.224	11974	6.806	2075.8	5.18

$$E(t) = \frac{\sum_{i=0}^n (A)^2}{F_s} \quad (1)$$

with,
E = cumulative energy
A = amplitude
F_s = frequency rate (100 kHz)

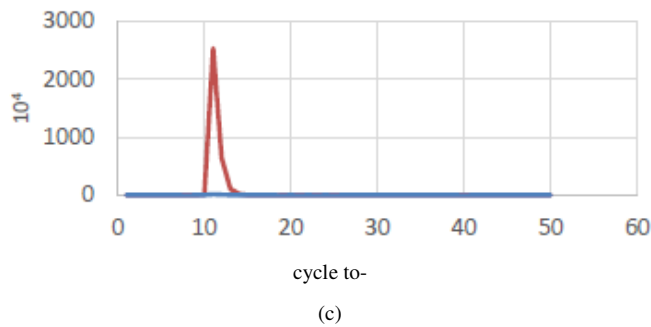
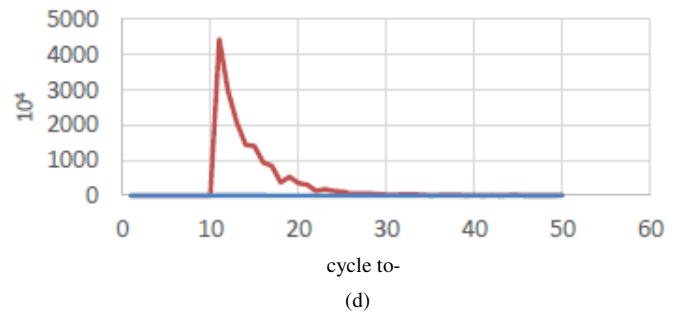
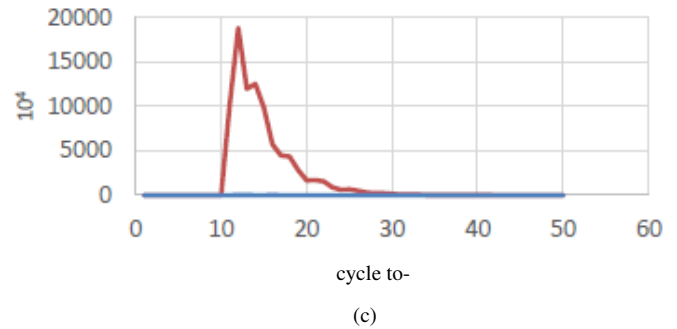
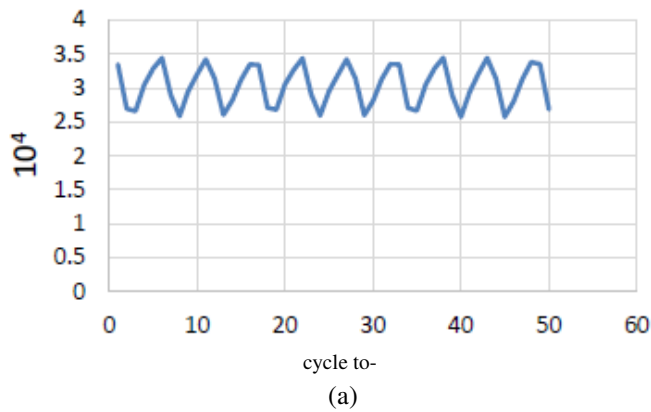


Figure 5. Comparison of cumulative energy: a) normal b) lightning strike c) switching operation d) ground fault. The ferroresonance response is colored as red, while the non-ferroresonance is blue.

The average value of cyclic cumulative energy for normal condition was 3.035×10^4 . This value was then used as a reference value showing the system was normal. The cyclic cumulative energy at period in which the disturbance taken a place deviated significantly from the reference value. Otherwise, the cyclic cumulative energy at period in which the disturbance had not occurred was near with the reference value. The present of ferroresonance could also be recognized by duration of period of cumulative energy deviation

IV. CONCLUSION

The present of ferroresonance due to lightning strike, switching or ground fault can be detected by its cyclic cumulative energy. It can be conducted by observing of cyclic cumulative energy ratio. Moreover, the duration in which deviation of cyclic cumulative energy from the reference value (the average value of cyclic cumulative energy for normal condition) is presented can be used as a ferroresonance detection parameter. For ferroresonance response, the amplitude and duration of the deviation in the case of lightning strike condition was 2534.2×10^4 for 6 cycles, switching condition was 10199×10^4 for 33 cycles and ground fault was 4447.7×10^4 for >40 cycles. For non-ferroresonance response, the amplitude and duration of the deviation in the case of lightning strike condition was 14.49×10^4 for 5 cycles, switching operation was 6.91×10^4 for 4 cycles and ground fault was 13.294×10^4 for 5 cycles, with average value in normal condition was 3.035×10^4 .

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