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High Impedance Fault Detection Algorithm using Frequency-Based Principal Component Analysis

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Abstract: An exposed energized conductor may cause fire, a huge release of energy and a high risk to human life and the undetectable fault is a serious issue to the public safety hazard and risk of arcing ignition of fires especially when it comes in contact with trees, structure or fall to the ground. However, it is undetectable by the conventional overcurrent protection system as the current maintained at low level. This particular project focuses on modelling high impedance fault (HIF) using Emanuel arc model constructed in MATLAB Simulink and applied it to the IEEE 13 node test feeder circuit model. Principal Component Analysis (PCA) algorithm is developed and implemented to the system in order to detect the HIF in the system based on the change in frequency of the current. It is proven that the presence of HIF in the system caused high frequency in current value. Hence, it is concluded that the presence of HIF in the system results in the PC3 value to be low ($-0.1 \leq PC3 \leq 0.1$) and spike in frequency to be more than 60Hz. The characteristics of HIF for power system is analyzed and the HIF has been successfully modelled based on its characteristics in time-domain simulation. The occurrence of HIF in power system is successfully detected using the time-series analysis method.

Keywords: Fault Detection, High Impedance Fault, Principal Component Analysis

1. Introduction

Conventional overcurrent protection relay in transmission line is important in protecting from any potentially dangerous effects of overcurrent. The main goal is to isolate the fault from the rest of the system to avoid damaging other equipment in the line. In addition, it should protect the circuit conductor against overload condition and from short-circuit or ground-fault condition, preventing and minimizing the unnecessary power loss [1]. There are several types of faults and condition that may take place such as overvoltage or undervoltage, overloads and short circuits. Thus, safety measures must be implemented to protect the power grid from these unwanted operating conditions. However, a conventional overcurrent protection relay may not be able to detect and identify a high impedance fault

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(HIF) as its characteristics of current are low magnitude, unstable and wide fluctuation. According to the literature, HIF is the unwanted electrical contact between an energized conductor and a high impedance object such as road, trees or grass [2]. These are the kinds of fault that are difficult to be detected by normal monitoring equipment since their presence result in just a slight increase in phase to ground current and phase to ground voltage [3].

Based on the survey findings in [4], HIF can be divided into four classes according to their analysis domain which are time-domain analysis, frequency-domain analysis, time-scale analysis and time-frequency analysis. The study focuses more on the time-domain analysis. The characteristics of HIF for power system modelling purposes are analysed and HIF is modelled based on its characteristics in the time-domain simulation. The occurence of HIF is determined using a time-series analysis method and PCA technique is used in distinguishing the data.

2. Methodology

This project will be carried out according to the methodology to obtain the results of the study.

2.1 Methodology

The project is carried out according to the flowchart as shown in Figure 1, 2 and 3. Literature review is done and data information are analyzed. Next, HIF is modelled and applied in the simulation system in MATLAB Simulink in IEEE 13 node test feeder circuit model. The HIF model according to the Emanuel arc model is shown in Figure 4. Table 1 shows the value of the parameters in the HIF subsystem. The HIF is applied each at every phase. Once the HIF is accurately modelled, the performance of PCA technique is tested and evaluated as shown in Figure 2. Figure 3 shows the process flow of the evaluation of PCA at three different conditions and the results are compared to show the effectiveness of PCA in detecting HIF.

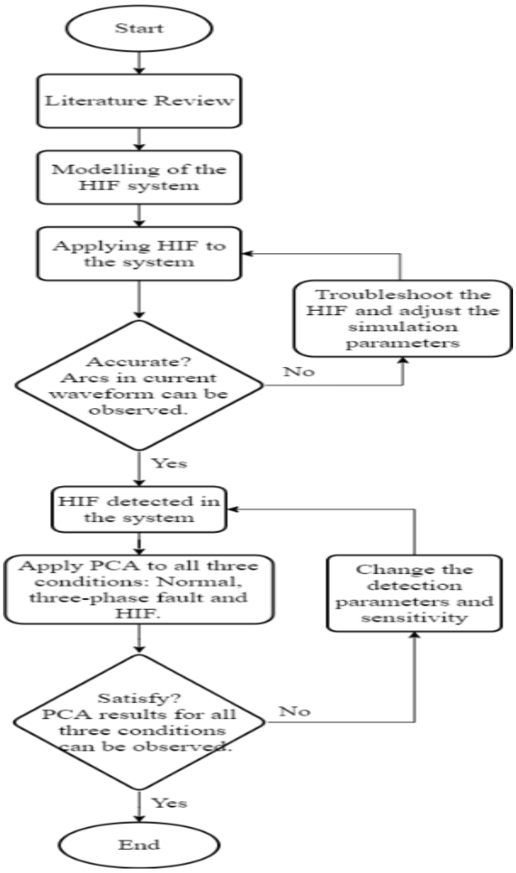

Figure 1: The flowchart of the project

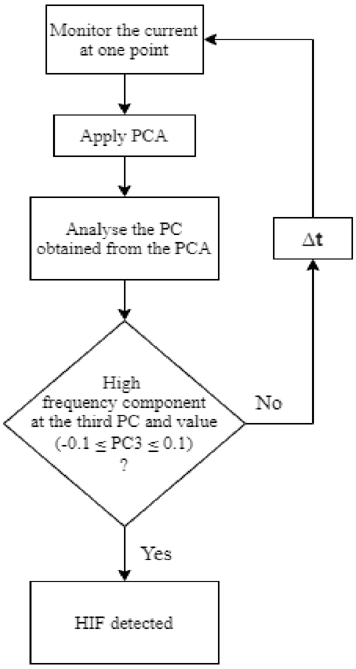

Figure 2: Process flow of the PCA algorithm

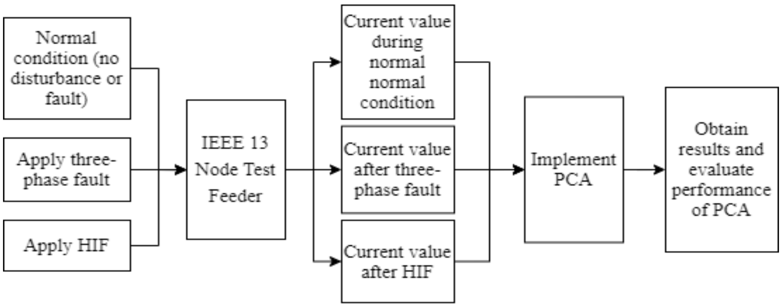

Figure 3: Process flow of evaluating PCA

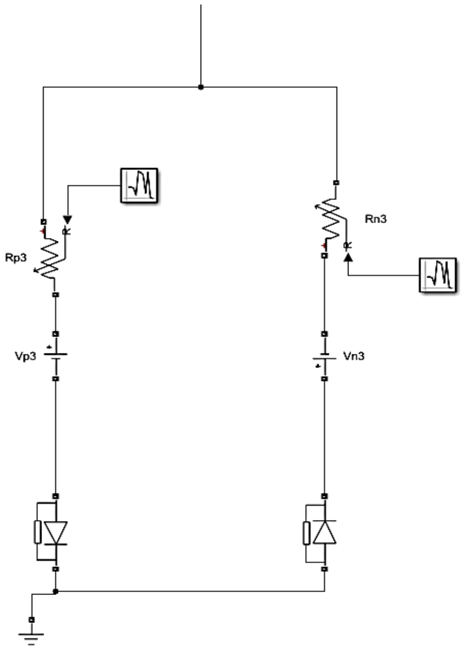

Figure 4: HIF model according to Emanuel arc model

Table 1: Parameter values for the Emanuel arc model

Parameters	Value
Rp	189.09 Ω
Rn	189.09 Ω
Vp	1134.43V
Vn	7556.28V

2.3 Equations

The three phase current measurement data sets near Bus 692 are taken from the simulation test system and used as the prospect to test the PCA. In order to ensure better performance of PCA the rate in which a discrete system sample its input, sampling time is 100001 with three variables indicating three-phase current. The data sets are taken at 3 different conditions which are at normal condition with no fault, after three-phase fault is applied and after HIF is applied. The PCA results of these 3 conditions are then compared. The data is arranged into row vector are initially summarized and the sample mean vector and sample standard deviation vector is calculated. The mean, $\bar{x}$ and standard deviation, σ are given by Eq. 1 and Eq. 2

$$\bar{\mu}_j = \frac{1}{n}\sum_{i=1}^{n} X_{ij} \quad \textit{Eq. 1}$$

$$\sigma = \sqrt{\frac{\sum(x_j - \mu^2)}{n}} \quad \textit{Eq. 2}$$

The data are then standardized by subtracting the sample mean from each observation and dividing it with the sample standard deviation. This will center and scales the data. The mean of a variable is moved to zero when it is centered, and the scales of magnitude are adjusted when it is standardized. The new data, Z, is calculated as Eq. 3 will be used to generate the PCA.

$$Z = \frac{(X - \mu)}{\sigma} \quad \textit{Eq. 3}$$

The PCA is then implemented and graph of principal components for all three conditions are generated. The PCA method is used to divide the measured data of X into multiple orthogonal time trends.

$$X = A_{mixingmatrix}\ x\ PC \quad \textit{Eq. 4}$$

Eq. 1-4 are turned into a set of coding constructed in MATLAB and the results of the current waveforms from the three conditions are used as the input for the coding to analyze.

3. Results and Discussion

In this section, the PCA approach is applied to the IEEE 13 node test feeder. Non-linear dynamic simulation at the test system is performed in MATLAB software. PCA is applied at 3 different conditions to the current value near Bus 692. The conditions considered in this study are:

a) Normal operating condition – used as reference variables as the current waveform has no spike or disturbance.
b) Three-phase fault – supposedly contain spike of current when fault is applied.
c) HIF – the current is at normal level but the current contains electric arcs undetected by the conventional overcurrent relay.

In this particular study, PCA is used to determine the optimum number of principal component (PC). It minimizes the overwhelming number of dimensions by developing PCs. It describes the variation and account for the original features' various effects. The duration time window taken to monitor the system behavior is one second. The PCA decomposes the original signal into mono component signals in order to obtain instantaneous frequency information for every mode of oscillation, making it a more efficient approach for detecting power quality problems.

Figure 5 shows the case of normal operating condition when PCA is applied. PC1 and PC2 have 59.95Hz and 59.70Hz respectively. The peak value for PC1 and PC2 are approximately 2 and 1 respectively. PC3 shows the reading is zero which means PCA detected no signs of change in frequency showing no signs of HIF in the system.

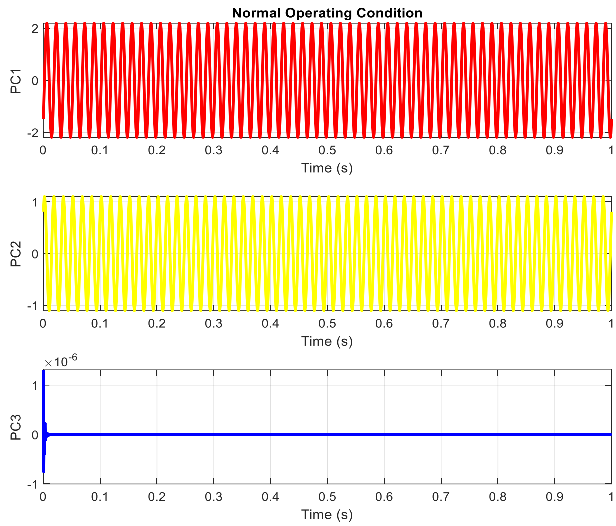

Figure 5: PCA during normal operating condition

While in Figure 6, a significant increase in value of PC1, PC2 and PC3 at 0.3 second which indicate a spike of current in the system when three-phase fault is applied. The behavior of three PCs is similar but different in value. At 0.3 second, value of PC1 is almost 12 while value of PC2 and PC3 shows 6.63 and 7.24 respectively. From this result, the current respond is proven to be accurate as the current near Bus 692 does have a temporary spike as shown in Figure 6.

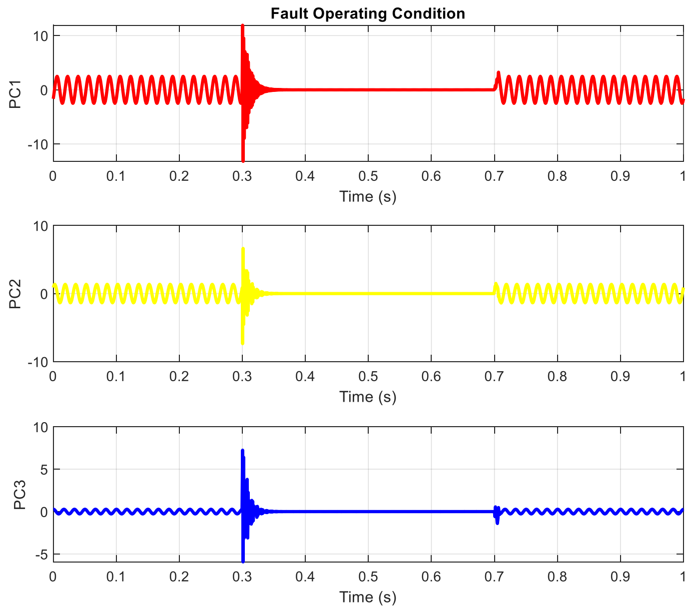

Figure 6: PCA during three-phase fault operating condition

Figure 7 shows when PCA is applied to HIF condition. PC3 is able to detect the presence of HIF in the system as it shows unique results compared to the other two. The magnitude of PC3 during HIF is completely different than PC3 during normal condition and three-phase fault. When HIF is applied, PC3 detected unknown frequency at 0.3 seconds to 0.7 seconds pointing out the presence of HIF during the time frame as it displays the most significant data.

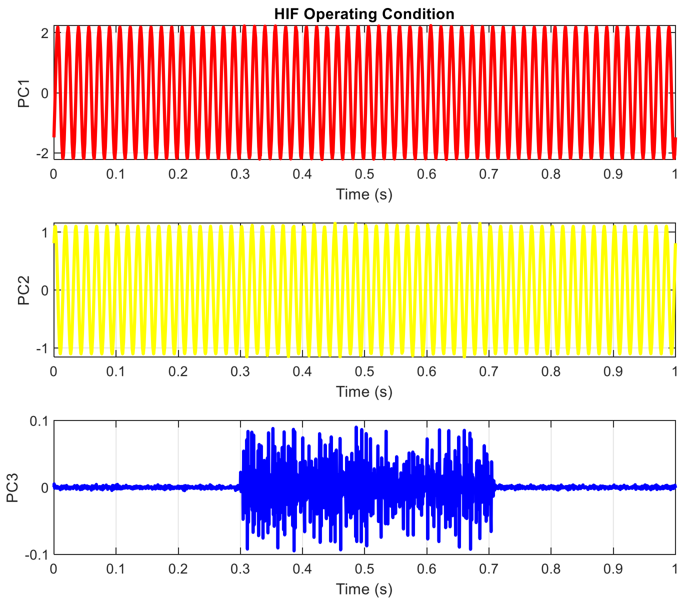

Figure 7: PCA during HIF operating condition

PC3 at all three conditions are analyzed and it is observed that PC3 during HIF have the highest frequency from 0.3 second to 0.7 second at approximately 530Hz and the waveform were unstable the whole time. While PC3 frequency during normal condition is zero during the same time. PC3 during three-phase fault had a spike before maintaining at zero from 0.3 second and goes back to normal frequency right after 0.7 second at 59.5Hz.

The PC3 peak comparison between the three conditions shows a significant difference. During normal condition, three-phase fault and HIF the value of the peak PC3 are 7.24, less than 0.00001 and almost 0.1 respectively. The value of peak PC3 during HIF is quite low in comparison to the peak value of PC3 during three-phase fault. The detection criteria for HIF fault are low PC3 peak value and high in frequency.

While for three-phase fault, the value of the peak PC3 might be high because of the spike in current but it only lasts for 0.06 second before maintaining at zero. It also has normal frequency. Thus, it will not be considered as HIF. This shows the accuracy of the PCA technique as only the PC3 during HIF is high compared to the others.

The current and voltage measurement during the three-phase fault at four different points are observed. Based on the results, after HIF is applied, the normal current protection scheme will not be able to operate as it is unable to detect the presence of HIF since the current value remain under the limit. The current measurements during HIF observed and analyzed. HIF has been successfully modelled and the current waveforms are recorded. PCA is applied and the criteria for HIF in the power system is observed.

4. Conclusion

The characteristics of HIF in power system has been analyzed for modelling purposes and the HIF based on its characteristics in the time-domain simulation has been successfully modelled in this study as the current waveform shows non-linearity and arcing with no spike in current value. The HIF occurrence in the power system is detected by implementing PCA in time domain.

The current waveforms during three different conditions are observed at the same point. It shows that during three-phase fault is applied to the system, it caused significant increase in current level and current during HIF maintain at the same level with change in frequency and arcing.

The detection criteria for HIF are concluded to be low in PC3 value ($-0.1 \leq PC3 \leq 0.1$) and high in frequency which is more than 60Hz. The effectiveness of PCA in detecting HIF in the system is simple yet useful and beneficial for the power system protection. Thus, it is proven that by implementing PCA to the system, HIF can be detected faster as it eliminates linked variables and shrinks the data space dimensions. Not only that, it also improves in terms of visualization.

Acknowledgement

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