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On the Use of Vibration Analysis for Contact Fault Detection in High-Voltage HVCBs

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HIGHLIGHTS

- A methodology to detect contact fault in HVCB using vibration analysis is proposed.
- A real experimental setup is used to validate the methodology.
- The results show that is possible not only identify failures but also to assess its intensity.

Abstract: As high-voltage circuit breakers (HVCBs) are responsible for switching off the load in the event of anomalies, they suffer various wear and tear, both on their main contacts and on the other actuation mechanisms. Not only load maneuvers but also weather conditions can bring factors that contribute to deterioration and, consequently, contribute to failures of this component that is so important for energy supply. Both failures and maintenance shutdowns generate costs for substations, something that could be minimized if there was monitoring of the condition of the HVCBs. This paper shows a methodology to analyze the vibration signal of HVCB in order to identify and quantify contact failures. The proposed methodology is verified through an experimental setup. The results show that it is possible not only to identify the fault but also to assess its intensity using vibration analysis.

Keywords: High-voltage HVCBs; Vibration analysis; Signal processing; Fault detection; Predictive Maintenance.

INTRODUCTION

High-voltage circuit breakers (HVCBs) are one of the most crucial components of protection and control in power systems. As a result, its reliability is critical for ensuring the stability and security of these systems [1-3]. HVCBs must be examined and checked on a regular schedule to prevent incorrect operation. Because HVCBs are made up of various mechanical and electrical components, such as dampers, latches, springs, and coils, flaws can occur for a variety of reasons [4-5].

The most common methods for performing HVCB condition checks are measuring contact resistance, contact timing, travel motion, velocity, and coil current [6-7]. However, conventional methods require that the system be stopped to perform the measurements, which generates a cost both in money and time, in addition to possible damage due to excessively invasive maintenance [8-9].

As a result, tests for monitoring and diagnosing the health of HVCBs, particularly using non-invasive procedures, were developed with the goal of easing maintenance and lowering costs. The premise is that it is possible to detect faults in HVCB by measuring other magnitudes that contain fault information without having to turn off the equipment. Vibration analysis, a well-established technique for defect analysis that has been used in rotary engines [10], composites [11], and other applications, is now being used to detect faults in HVCBs. HVCB vibration signals, on the other hand, are significantly non-stationary and non-linear, making feature extraction more challenging than for other vibration signals, such as those from rotating motors [3].

Vibration analysis utilized in HVBC research could be categorized according to the manner of extracting signal characteristics, like the domain of analysis: time domain, frequency domain, and time-frequency domain. Most of the tools identified in this domain for monitoring HVBC are derived from research that attempts to extract characteristics from vibroacoustic sounds [12].

Many causes of vibration can be recognized during the closing or opening action, with the working mechanisms including more than half of all potential faults in HVCB [13]. Each vibration source has a unique vibration signature, which may be used to detect not just the problem but also which component has the issue. This is also a non-invasive procedure, and all measurements can be performed online. Although HVCBs are not the type of equipment with the highest book value in the electrical system, they are the main protection element for other equipment that has a higher price.

In this paper, a diagnostic method based on analyzing the vibration signals in HVCB is proposed. For this, firstly, the vibration signals of a HVCB in healthy condition are collected to serve as a baseline. After collecting the signals, damages are made to the HVCB contacts, and then the vibration signal is measured in order to compare it with the baseline. The results show that the vibration signal is sensitive enough to detect the induced fault in the HVCB.

The article is organized as follows: The next section presents the experimental setup used as well as the entire methodology used in the HVCB failure test. The follow section presents the main results and discussions. Finally, the last section concludes the paper.

MATERIAL AND METHODS

To analyze HVCB failures, two basic approaches can be used. The first involves monitoring an active HVCB and analyzing all changes until it fails. In the second approach, the defects are inserted on purpose in order to be able to compare the faulty HVCB with the healthy one. In this paper, the second approach was adopted, that is, inserting the fault.

Circuit breakers can use air, oil, or gas as an insulating medium. However, circuit breakers using air or oil have a relatively slow arc extinguishing force after contact separation movement, which in the case of high voltage circuit breakers is a negative since they require the shortest possible extinguishing time in order to avoid an increase in tension harmful to the equipment. Hence, for high voltages, SF6 circuit breakers are widely applied.

HVCBs that use SF6 are split into two types (live tank and dead tank) based on their extinguishing chambers. The switching device of the live tank type is in an insulator bushing that is live at line voltage (or some voltage above ground). Living tank circuit breakers are less expensive and take up less space than dead tank breakers. The switching device in the dead tank is housed within a metallic container that is kept at earth potential. Because the incoming and outgoing wires are routed through insulated bushings, current transformers can be installed on them (with a live tank arrangement, this is not possible and separate CTs are required).

SF6-insulated HVCBs are manufactured following the IEC 62271-100 standard, also known as "High Voltage - Part 100: High Voltage Circuit Breakers -- Power Circuit Breakers", which establishes the requirements for HVCBs used in alternating current electrical power systems with a frequency of 50 Hz or 60 Hz. Some of the topics covered by the standard include:

- General performance and safety requirements for power circuit breakers;
- Design and construction requirements, including specifications for materials, dimensions, and tolerances;
- Requirements for type tests, routine tests, and special tests;
- Criteria for selecting power circuit breakers for specific applications;
- Guidelines for Maintenance, Inspection, and Repair of Power Circuit Breakers.

The IEC 62271-100 standard is widely recognized as an important international standard for the manufacture and safe operation of high-voltage circuit breakers.

Experimental setup

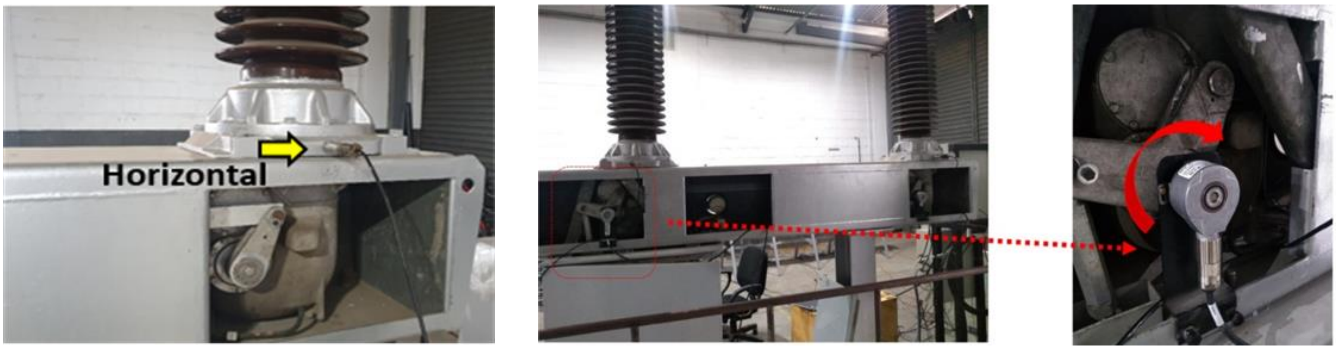
This subsection presents the equipment used in the HVCB failure test. The HVCB used was the GL312 Alstom/GE 145 kV, insulated with SF6 gas, and of the live tank type. Figure 1 shows the HVCB used in the tests, and Table 1 shows its main characteristics.

Figure 1. GL132 Alstom/GE test HVCB.

Table 1. GL312 Alstom/GE Technical Characteristics

Characteristic	
Rated voltage	145 kV
Rated frequency	50 / 60 Hz
Rated normal current	Up to 3150 A
Rated short-circuit breaking current	Up to 40 kA
Rated short-circuit making current	104 kA
Rated duration of short-circuit	3s
Opening time	28 ms
Break time	50 ms
Closing time	≤ 70 ms

For the vibration measurements, the SI110A PHD accelerometer was used (Table 2), and for the drive mechanism angle measurements, the high-resolution incremental-type encoder DFS60A SICK was used (Table 3). The accelerometer was installed at the base of each pole, in the horizontal direction, in order to eliminate signal saturation and provide a better response in amplitude and frequency, as shown in Figure 2a. The encoder was installed on the axes of the pole, as illustrated in Figure 2b. All signals are collected using the Preditor 4.0® acquisition system, which has an analog–digital converter with 24-bit resolution and a sampling frequency of 46.875 kHz.



(a) (b)

Figure 2. (a): installed accelerometer position. **(b):** installed incremental encoders position.

Table 2. SI110A PHD Technical Characteristics

Characteristic	
Sensitivity	100 mV/g
Maximum amplitude	80 g
Frequency response	0.7 to 15,000 Hz

Table 3. DFS60A SICK Characteristics

Characteristic	
Pulses per revolution	65,536
Measuring step	90°
Error limit	± 0.03°

Methodology

This subsection presents the methodology used to carry out the tests. The tests carried out consist of measuring the vibration through the accelerometer and the angle of the driver mechanism through the encoder. The tests are carried out during the HVCB operation, that is, closing and opening the contacts. Before inserting the faults, five vibration signals were collected in healthy operating conditions to serve as a baseline in the analysis. Once collected, faults can be inserted into breaker contacts. Faults were simulated by causing a contact finger failure in two different ways. The first time, we removed 5 of the 40 contact fingers (fault 1), and the second time, we removed 11 of the 40 contact fingers (fault 2). Thus, it will be possible to evaluate not only the detection of the fault but also the sensitivity to the intensity of the fault. As in the healthy condition, 5 signals were also collected in each fault condition. In summary, Figure 3 presents the flowchart of the proposed methodology, also, Figure 4 shows the HVCB contact fingers.

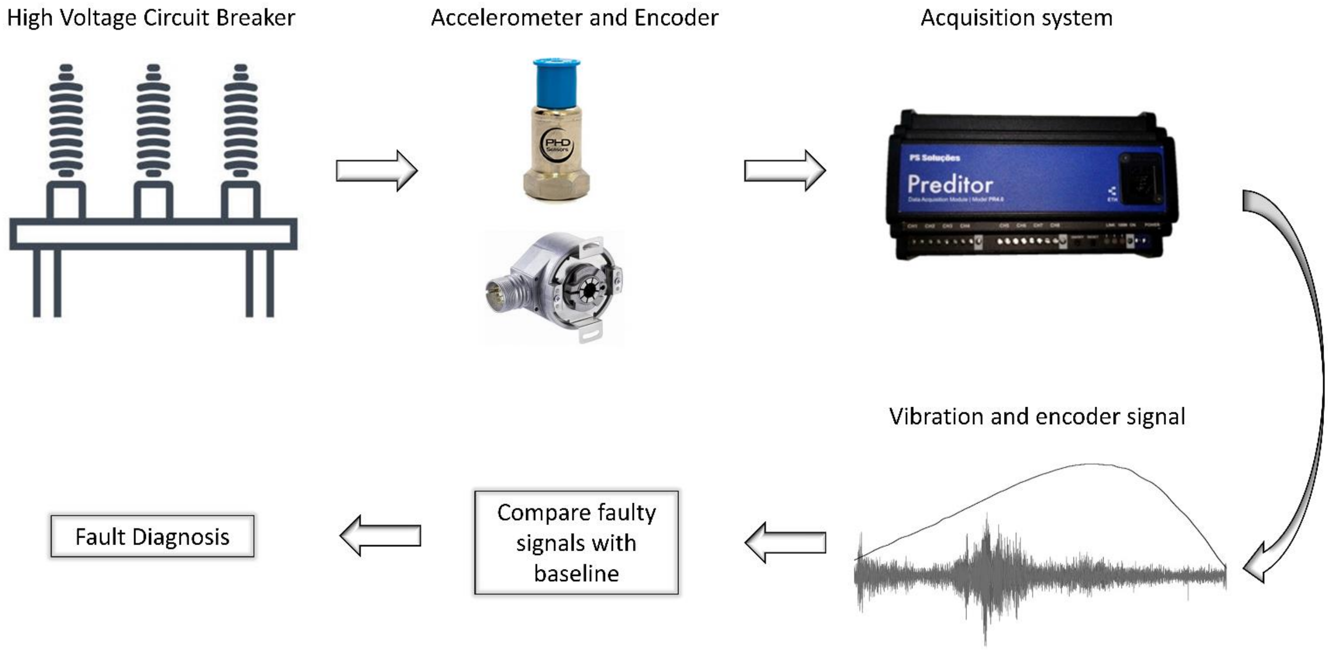


Figure 3. Methodology flowchart.

Figure 4. HVCB contact finger.

RESULTS AND DISCUSSION

In this section, the results obtained through vibration analysis techniques will be discussed. As mentioned, the analysis will be carried out by comparing the vibration signal of a healthy HVCB with that of another with a fault (2 levels of intensity). To aid the interpretation, the angle of the HVCB activation mechanism will also be presented. With this information, it is possible to infer the closing and opening moments of the HVCBs.

Figure 5 shows the signals collected in the 5 vibration tests for the HVCB in healthy condition. These signals will be used as a baseline to compare with the fault signals. Figure 6 shows the signals for the HVCB with fault 1. In the highlighted region, it is possible to perceive a significant increase in amplitude for all tests. It is also possible to notice that this increase in amplitude occurs close to the moment of closing the contacts. This occurs due to the variations caused by the failure inserted in the contact fingers. Figure 7 shows the signals for the HVCB with fault 2. In the highlighted regions, it is also possible to see a significant increase in the amplitude of vibration for all tests. In addition, he notices that this increase is greater than in the case of failure 1, which shows that in addition to being able to detect the defect, it is also possible to measure how serious it is. Finally, in the same way as for fault 1, the increase in vibration amplitude occurs during the closing of the HVCB contacts.

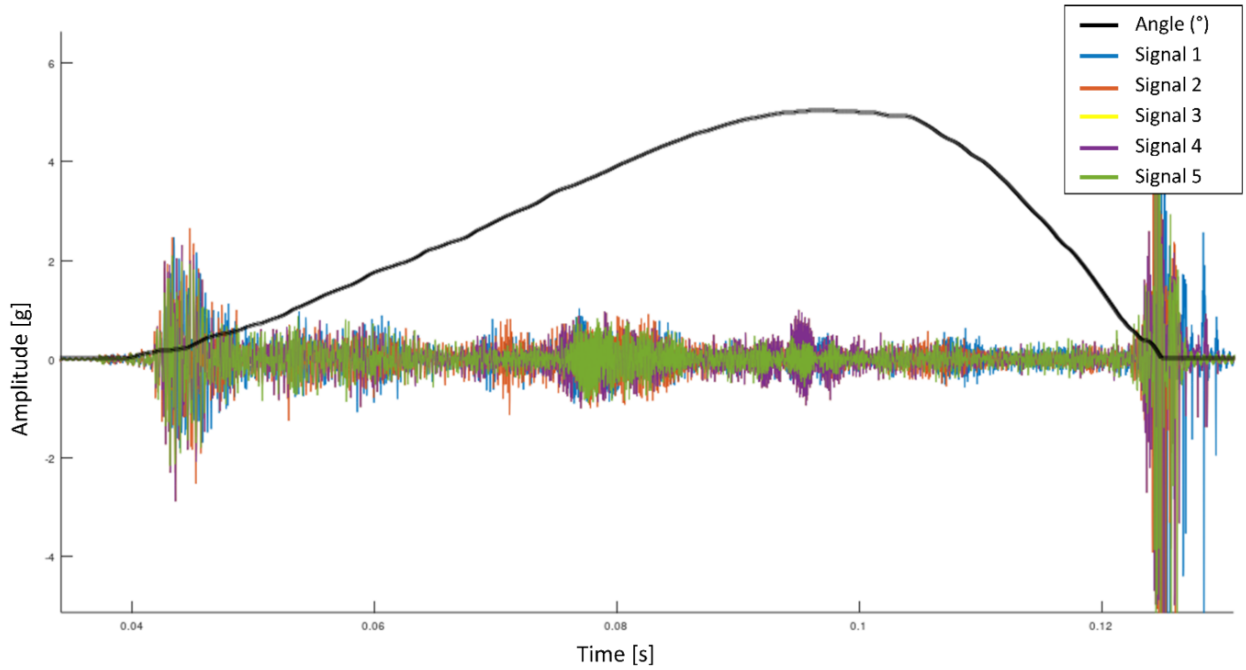


Figure 5. HVCB vibration signals in healthy condition.

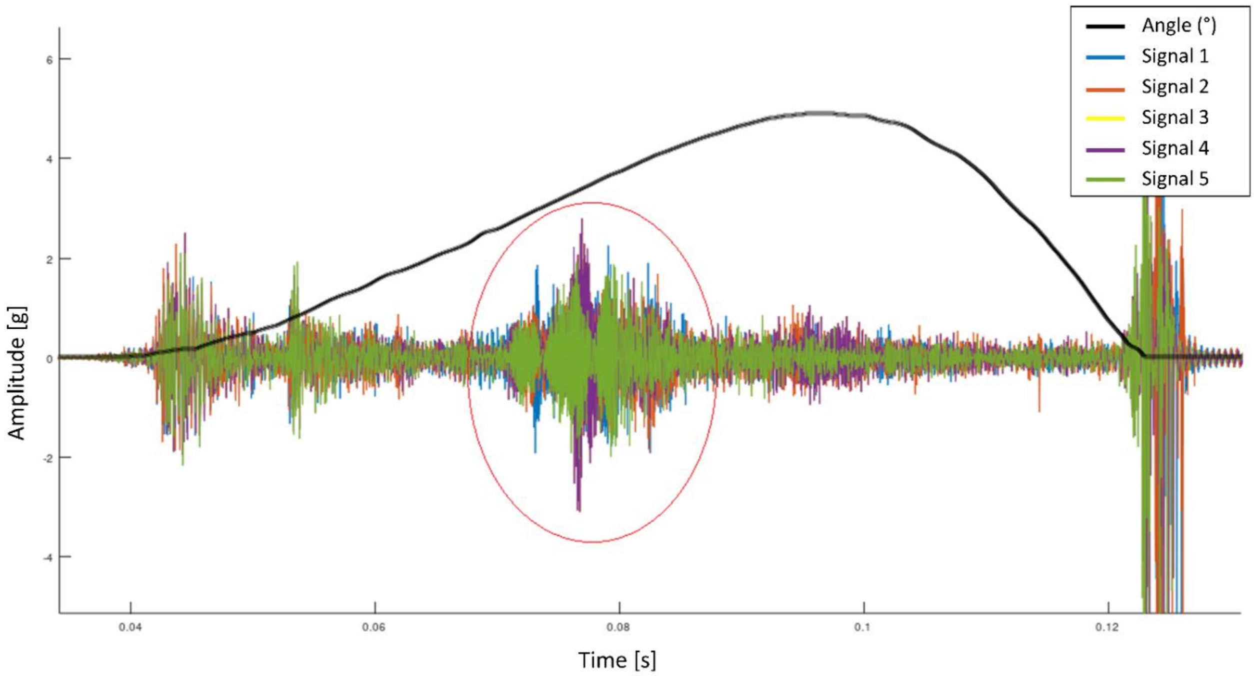


Figure 6. HVCB vibration signals in fault 1 condition.

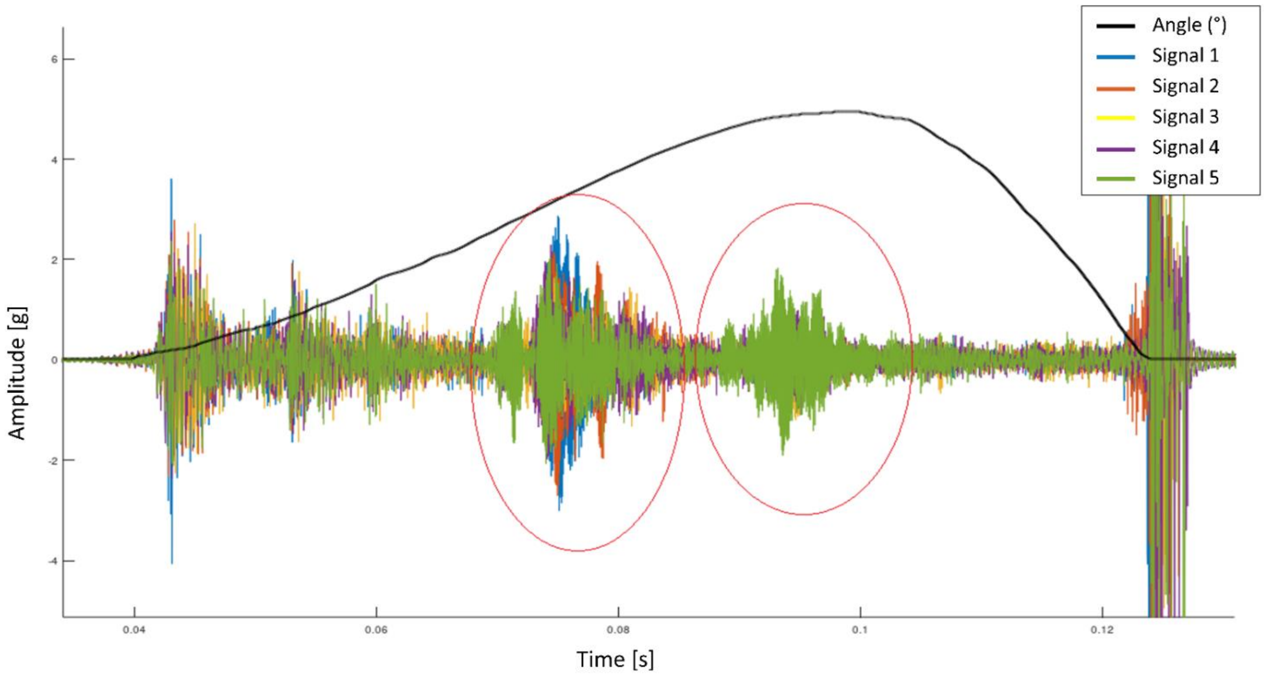


Figure 7. HVCB vibration signals in fault 2 condition.

Figure 8 was used to help compare the signals. In it, all the signals 1 from tests were chosen and placed together to better assess the difference between them. With the same thought in mind, Figure 9 was also created, which shows the percentage variation of the vibration signal of the defects in the selected region based on the baseline.

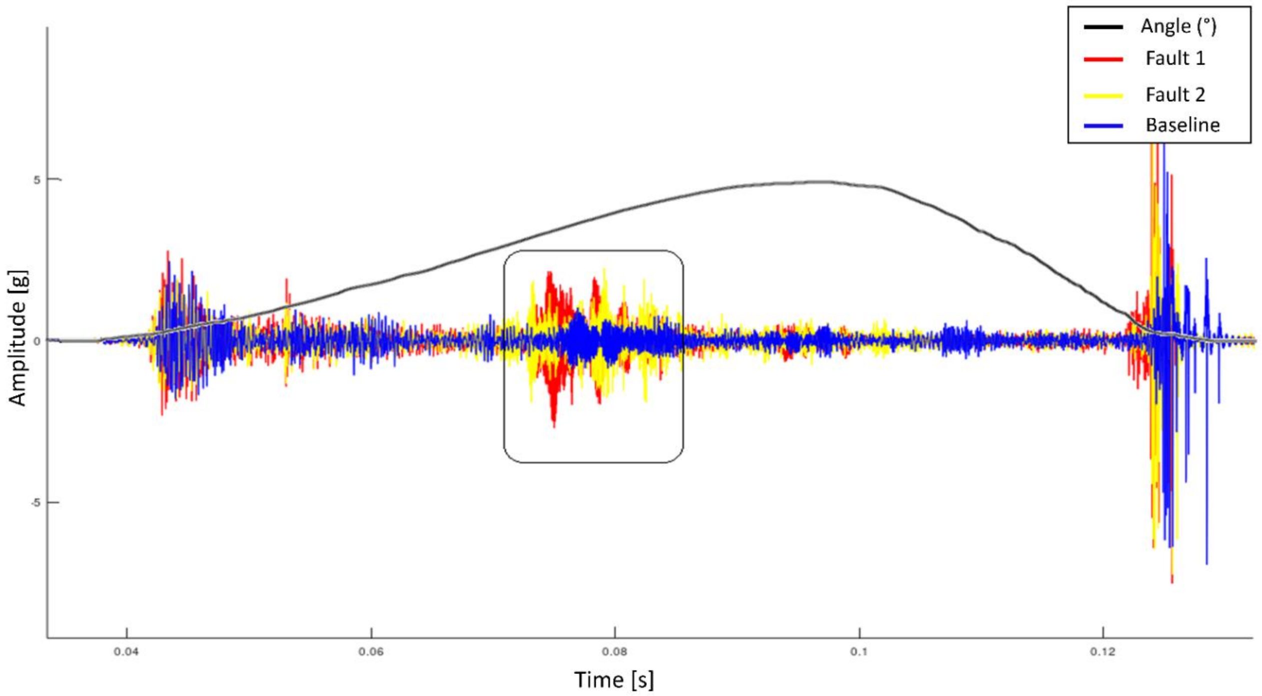


Figure 8. Comparison between signal 1 for all conditions.

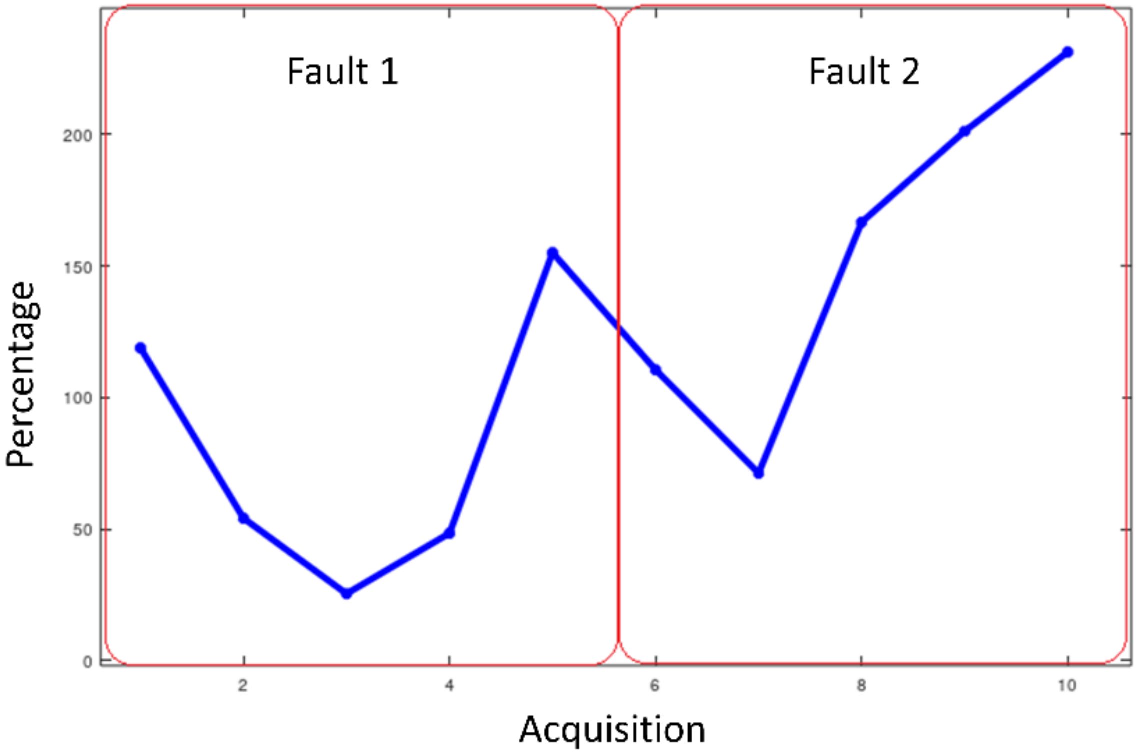


Figure 9. Percent variation of the signals in the zone of interest for all tests.

CONCLUSION

This paper presents the application of vibration analysis to detect and quantify faults in HVCBs. The usage and application of vibration analysis methodologies were explored and validated by an experiment. The results show that it is possible not only to identify the fault but also to assess its intensity.

Furthermore, the study is industry-relevant. Through vibration analysis, it is possible to access the condition of the HVCB non-invasively and possibly online. This all generates greater availability and safety in the HVCB, in addition to a reduction in cost. Even though it is very efficient and practical, it must be said that tests have not been carried out on all possible defects that may occur in a HVCB.

Future work will include more tests and evaluate other types of faults that occur in HVCBs. Furthermore, with a larger database, it is possible to develop AI techniques to automate the diagnosis of faults in HVCBs.

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Conflicts of Interest: The authors declare no conflict of interest.

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