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Experimental Verification of the Contacts of High Voltage Disconnect Switches when Subjected to Forced Harmonic Vibration

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Abstract

The present study aimed to find, through field tests, the dynamic response of a high voltage disconnect switch when exposed to forced vibration. A unidirectional motovibrator was used to generate harmonic vibration at three different frequencies and to measure the response through accelerometers and the displacement of the moving contact in relation to the fixed contact in the closing direction of the disconnector. Among the frequencies tested are 24 Hz, 34 Hz and 43,5 Hz, being the frequency of 34 Hz the one that best used the energy generated by the motovibrator, presenting positive results in closing, except for the excessive time to do so. The frequency of 43,5 Hz had the best performance for the correct closing of the disconnector, taking little time to complete closing, however the values of g force were high, which could jeopardize the structural integrity of the disconnector, in addition to the lower usage of the energy generated by the vibrator.

Keywords: Dynamic response; experimental trial; vibrator; disconnector.

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1. Introduction

Disconnect switches are mechanical switching devices responsible for the actions of opening, closing or transferring the connection of an electrical circuit. They are of extreme importance for the transmission system, and can be classified as one of the most important equipment inside an electrical power substation because they operate with or without load, with the purpose of opening and closing the circuits [1]. Disconnect switches allow control of the interruption on power supply, as well as expansion and maintenance works on components [2].

A survey that included 25 countries, which sent information related to 935,204 disconnectors and earthing switches/years of operation. In this research, it is indicated that the voltage level that most fails in the disconnectors is between 300 kV and 500 kV, followed by levels above 500 kV, the failures being most commonly found in air-insulated equipment [3].

It was verified that the equipment that presented the highest failure rate were switches installed before 1974, followed by the range from 1974 - 1983, with the highest failure rate being knee-type disconnect switches. The most common failures, for air insulated equipment, are "does not close after command", followed by "loss of mechanical integrity", "locked in open or closed position", "dielectric breakdown" and "others", with 72%, 13%, 7%, 2% and 6% respectively [3;4]. These percentages are illustrated in Figure 1.

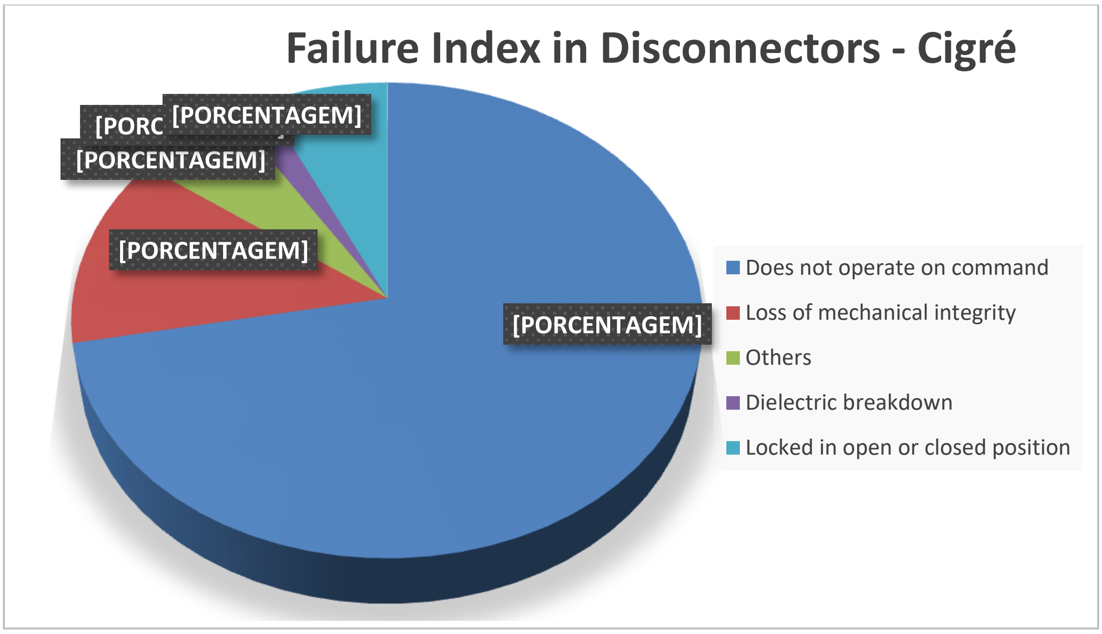

Figure 1: Failure index in disconnectors

Through the graphic we can observe the list of failures caused by the position lock. The mentioned cause can generate a hot spot in the disconnector, making it unusable and, consequently, causing a failure in the power supply.

A switch-disconnector operating at voltages of 500 kV and currents of 3000 A, presents an ideal closing resistance of around 150 μΩ, which in itself generates a power of up to 1.35 kW for a current of 3000 A. In case of a bad closing of this switch, the resistance grows, causing an excessive heating in the contacts. With greater heating, the electrical resistance increases, causing the contact to heat up more, raising the temperature again, which can melt and destroy the key. Due to this problem, the operations of high voltage disconnect switches require on-site supervision [5]. In Figure 2, you can identify the problem with the main blade contacts.

Figure 2: Problem in contacts due to bad closing

Aiming to reduce the percentage of influence from this type of failure, forced harmonic vibration was used. Movement frequency is known as the natural frequency or resonant frequency of the system. Any physical structure has natural vibration modes that basically depend on the material they are made of and the boundary conditions of the system [6; 7].

The general goal of the present study is to indicate the ideal accelerations that contacts must be subjected to in order to improve the quality of the performed maneuvers and to reduce inefficiency that comes from the blocking in opening or closing position. Besides, the displacement of one contact in relation to another through an LVDT will be presented and, finally, the use of the energy generated by the vibrator and transmitted to the disconnector's structure.

When the excitation applied to a structure is close to the natural frequency, vibration amplitude tends to infinity, and the energy is dissipated only by the damping present on the structure. Therefore, posible excitations that come close to the natural frequency must be carefully dealt with in order to avoid disastrous incidents [8; 9].

In order to improve the disconnector's opening and closing maneuvers, a forced harmonic vibration was used to reduce friction between the contacts and thus ensure the correct maneuver. This solution had its state of the art validated in previous studies carried out by [10;11; 12].

- Performed tests on a DA-type high-voltage disconnect switch, where he found that when using forced harmonic vibration in the disconnector, the torque request of the electric motor used in the maneuvers was lower. It was also observed that the electrical resistance of the contacts was lower after turning off the vibration that was used to facilitate the maneuver [10].

- Experimentally evaluated, on a test bench, the use of forced harmonic vibration in two models of high voltage disconnect switches, one of the AV type and the other of the VR type, both used in 230 kV lines. In this study, the loosening of the screws when exposed to vibration, the frequencies that helped the correct closing of the disconnector, the mechanical tension and the deformation of the disconnector components when exposed to vibration were verified. To carry out the tests, he used a digital torquemeter to verify the loosening of the screws, accelerometers to verify the behavior of the vibration and strain gauges to measure the tensions and deformations. The same concluded that the screws of the structure did not loosen when subjected to vibration, that the tension and mechanical deformation of the components when subjected to vibration were within the elastic regime of the materials and that the opening and closing maneuvers presented better quality when it was under excitation of vibration [11].

- Reverse-engineered the same two disconnectors mentioned above, where he performed tests for dynamic analysis of the two disconnectors using the finite element method. The two computer models of the high voltage disconnect switches were calibrated using experimental data, obtained through impacts and forced harmonic vibration. To carry out the experimental measurements, he used accelerometers at the points of interest. His study concluded that the stress values of the switches under the effects of vibrations, with some exceptions, remained at acceptable levels, being mostly below the yield limits of the materials considered for the mechanical components [12].

Such loads were applied to the disconnector by using a unidirectional vibrator, which generates a controlled vibration in only one direction, making it possible to vary frequencies and loads from a frequency inverter and change the rotating masses respectively, altering the centrifugal force of the vibrator.This way, when applying an excitation with frequency close to the natural frequency of the switch and in perpendicular direction to the contact, the friction between fixed and moving contacts is reduced [13]. Figure 3 shows the disconnector's contact and indicates the excitation direction.

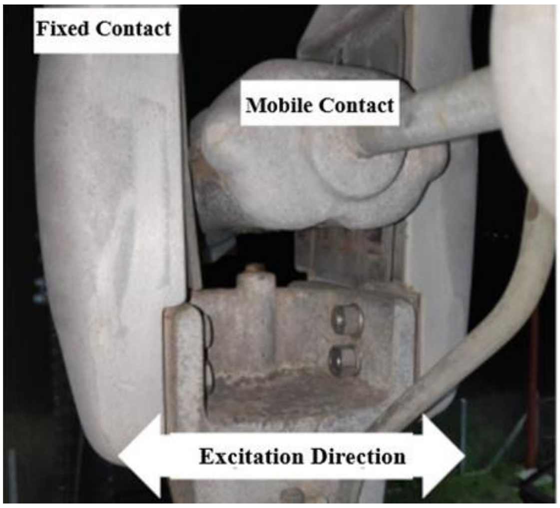

Figure 3: Direction of excitation in relation to contacts

2. Materials and methods

In order to validate the concept of forced vibration system for friction relief in maneuver procedure on disconnect switches, experimental tests were carried out in real scale, under the condition of no electric current passing. Experimental tests were carried out in disconnect switches which were installed on the Testing Bench of the Laboratory of Technological Innovation in Design Manufacturing and Materials at the University of Passo Fundo – Lintec UPF. The disconnect switch used in this experiment is called Lorenzetti 242 kV, which is used in lines of 230 kV and can support a rated current of 1600 A. This is a three-phase disconnect switch with a two-stage vertical opening, that is, after closing it rotates within the fixed contact. In Figure 4 it is possible to see the disconnect switch used for the study, given that all the tests were carried out in only one pole of the disconnector.

Figure 4: Testing Bench Lintec UPF

To carry out the tests, the vibrator was positioned below the insulator chain, as it is instructed in ABNT NBR IEC 60694 [14]. To make the structure of the vibrator switches, four bars and two angle brackets were used. Two end keys of the threaded bars were screwed together with a fixed end like two angles exerting a pressure system, in the form of a vibrator, next to a fastened end structure.

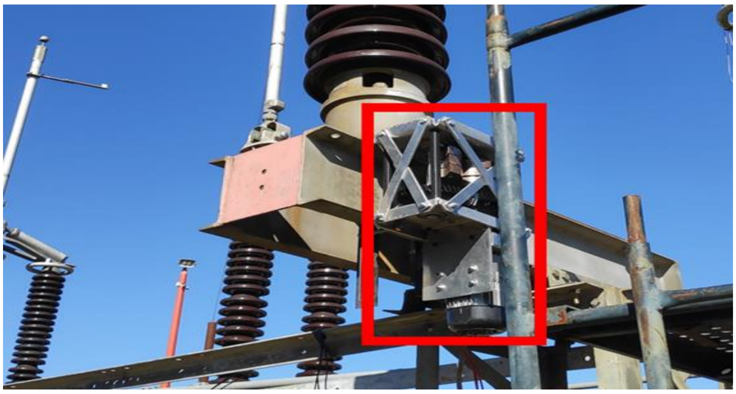

Figure 5: Vibrator positioned in the disconnector

To carry out the tests, the contacts were tightened so that the mobile contact was approximately 20mm away from the fixed contact, thus creating an incorrect maneuver when the disconnect switch was closed. The opening can be seen in Figure 6.

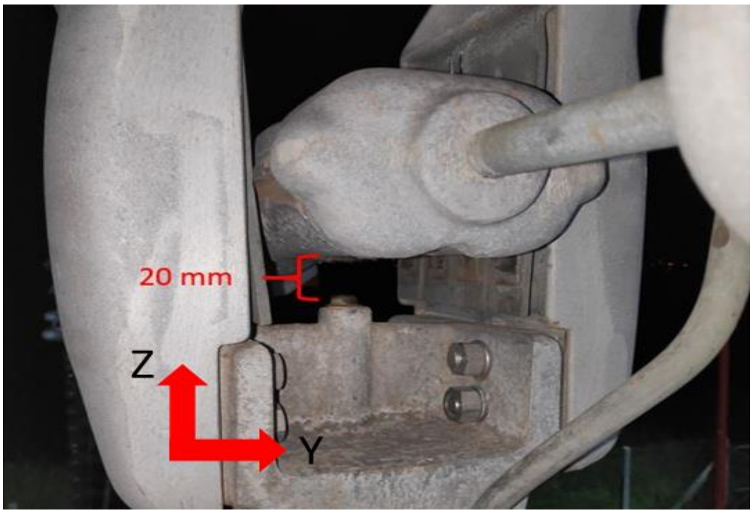

Figure 6: Contact opening (20mm opening)

After fixing the vibrator to the structure and tightening the contacts, the accelerometer was then positioned in order to measure the vibration excitation on the rod of the mobile contact and, this way, data for the behavior of the switch when subjected to vibration at different excitation frequencies were collected. The measuring equipment used for this test was a Teknikao NK620 vibration collector and dynamic balancer, with a measuring frequency range of 5 Hz to 2 kHz, and an amplitude of 200mm/s². Its accelerometer has a resolution of 0,01 m/s².

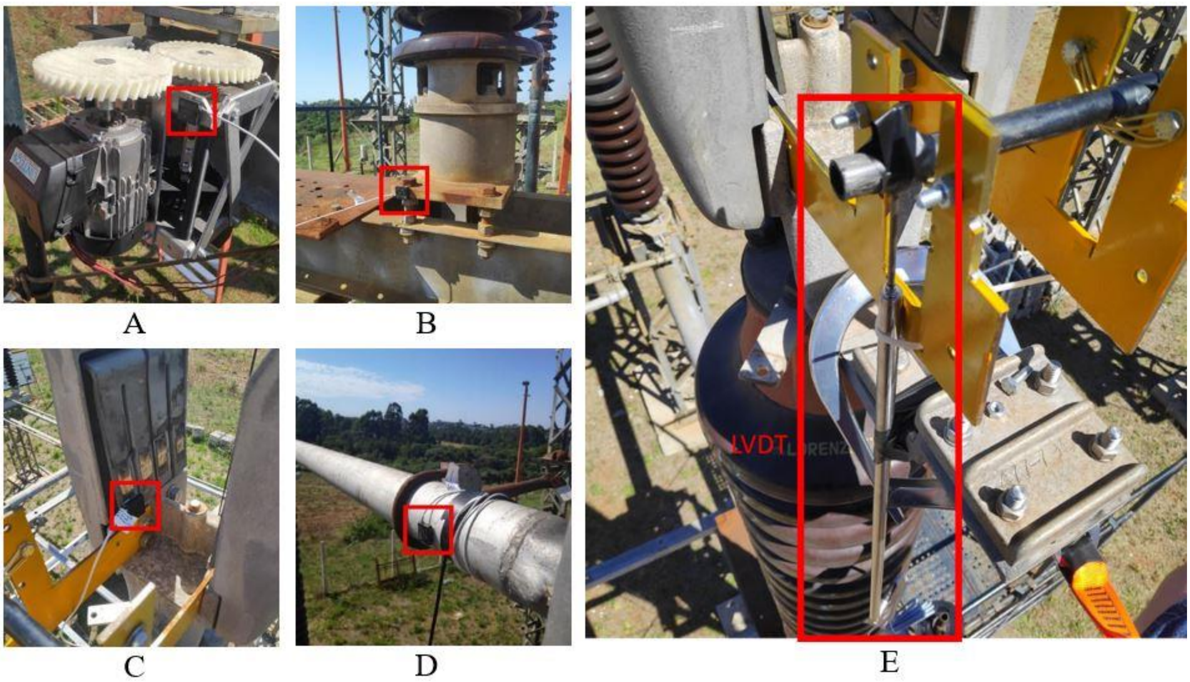

Figure 7: Positioning of accelerometers

Accelerometers and a LVDT were also used for other tests where the accelerometers were positioned to measure the acceleration in four different points, one being attached to the vibrator itself (Figure 7 – A), the other to the base of insulators (Figure 7 – B) and the two other accelerometers were attached to the fixed and mobile contacts of the disconnector (Figure 7 – C and D respectively). Also, it is worth pointing out that the accelerometers were positioned to measure acceleration towards the vibration point (see Figure 3) for all four points. The LVDT (Figure 7 - E) was positioned to measure the displacement of the mobile contact's rod in relation to the fixed contact.

All four accelerometers used were Silicon Designs MEMS accelerometers, being the models 2210-025 for 25g, 2220-050 for 50g, 2210-100 for 100g and 2210-400 for 400g. The LVDT used is an HBM WA500, having 500 of Travel and a maximum linearity deviation of less than 0.1%.

3. Results

As previously mentioned, an accelerometer attached to the rod of the mobile contact was used to check the behavior of the disconnect switch when subjected to vibration. The data obtained from this can be checked in Figure 8.

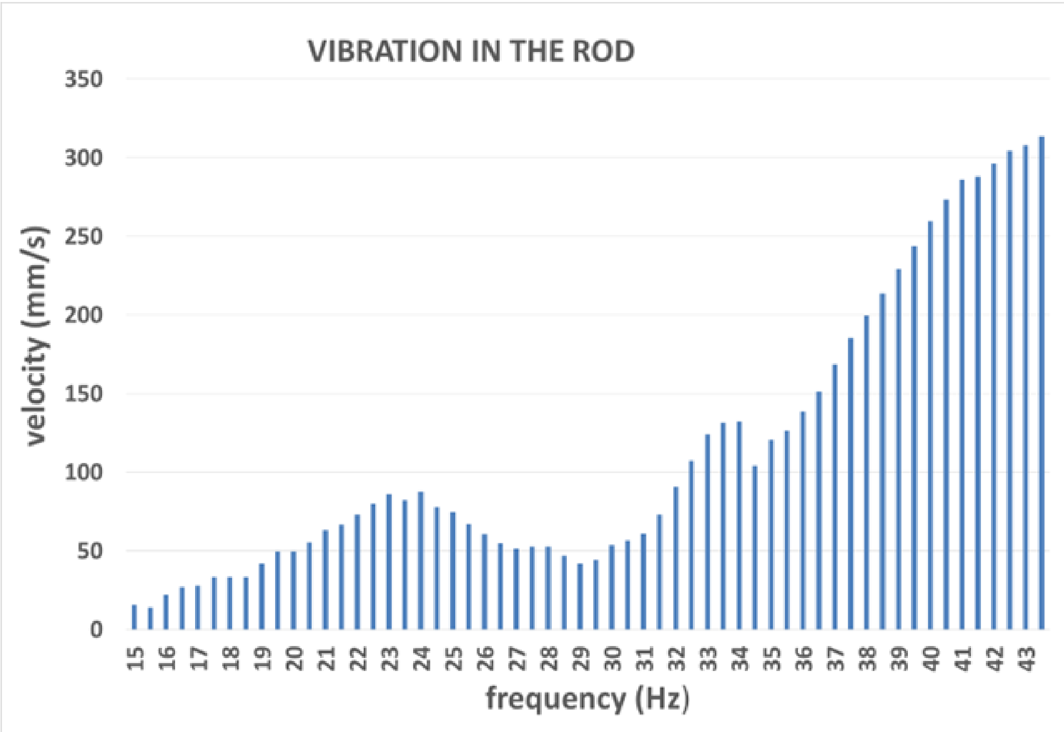

Figure 8: Behavior of the mobile rod

Excitation frequency of the vibrator ranged from 0,5 Hz to 0,5 Hz starting from 15 Hz to 43,5 Hz and the data obtained was the RMS speed in which the rod was moving.

By looking at Figure 5 it is possible to see that the frequencies that cause excitation peaks in the switch are 24

Hz, 38 Hz e 43,5 Hz and, for this reason, other tests were carried out in order to check the behavior of the vibration system, of the structure where it was attached to, of the two contacts and a LVDT was added to the fixed contact in order to check if the switch was closing during vibration as indicated before.

3.1. Frequency 24 Hz Data

Initially, the tests were carried out with a frequency of 24 Hz and, to do so, 30-second tests were done. With the data obtained, the efficiency in the transmission of the energy from the vibrator to the structure where it was fixed was then checked. The data from the two accelerometers were superimposed and acceleration peaks for the same instants were checked.

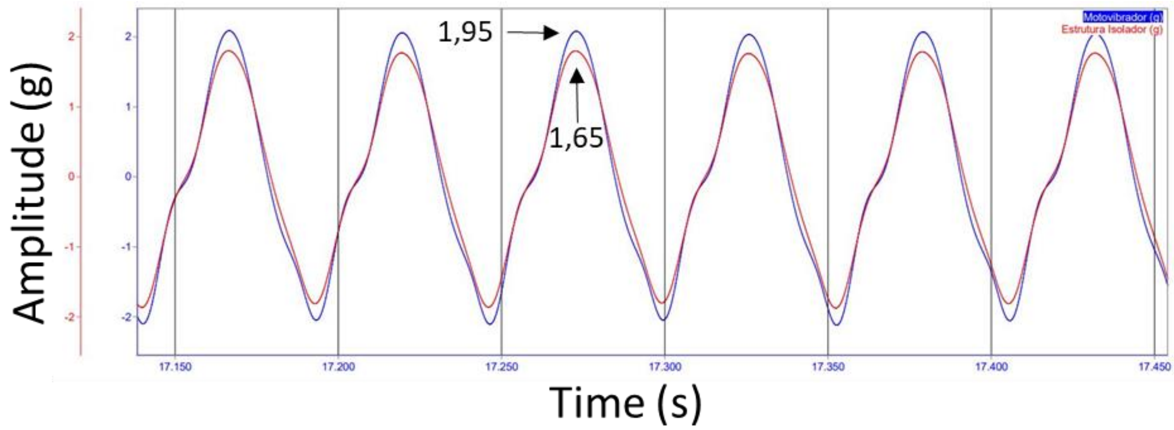

Figure 9: Comparison between the vibration of the vibrator (blue) and the base of the insulators (red) in 24Hz

As we can see in Figure 9, there is a difference in acceleration peaks, being 1,95g for the vibrator and 1,65g for the structure. This way, the transmission of energy using approximately 85% could be noted.

Subsequently, the LVDT displacement was checked, where a displacement of approximately 3mm in the first 6,5 seconds of testing and 0,5mm od displacement in the rest of the testing time was noted, as it can be seen in Figure 10.

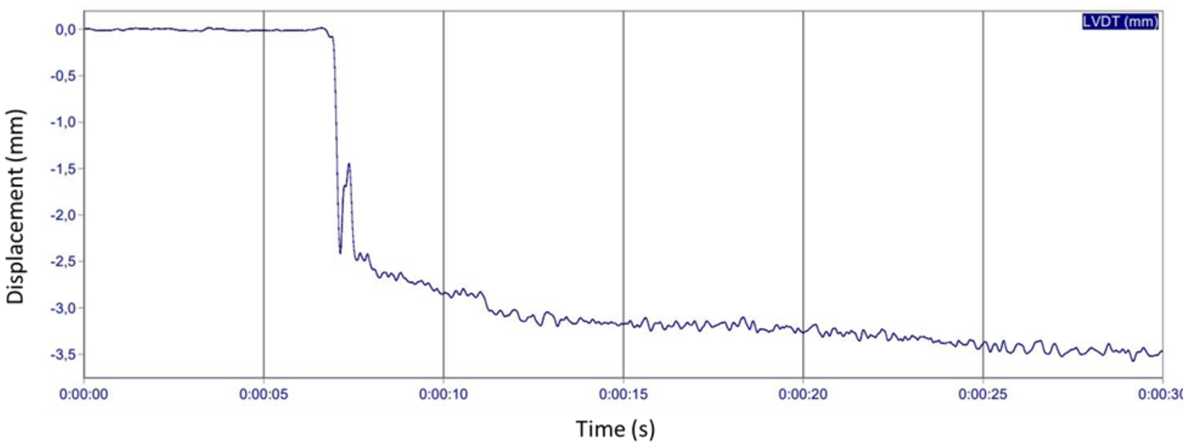

Figure 10: LVDT 24Hz displacement

Finally, for this test, a difference in the acceleration of the disconnector contacts was noted, where a maximum difference of 4g between signals can be seen, according to Figure 11.

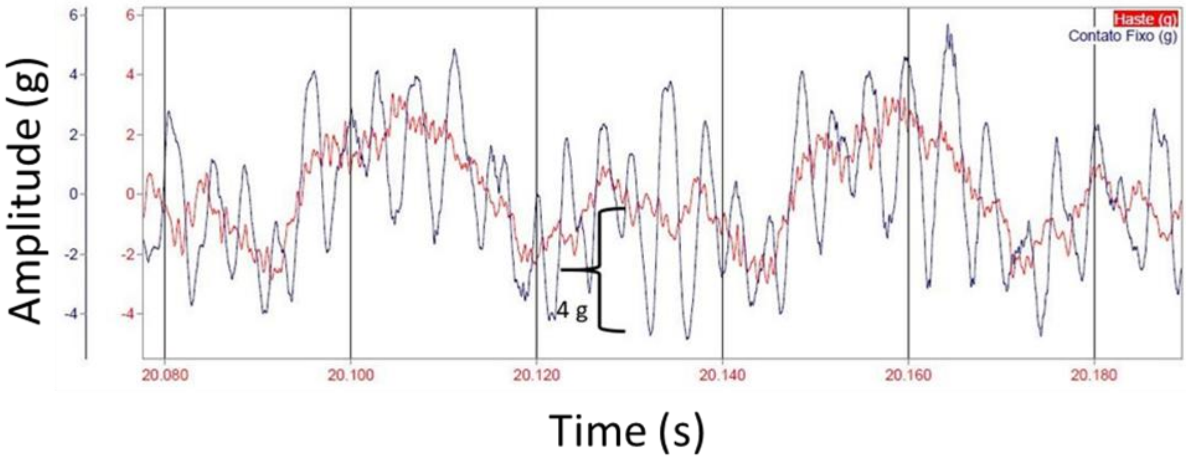

Figure 11: Comparison between 24Hz contacts, mobile contact (red) and fixed contact (blue)

3.2. Frequency 34 Hz Data

As done for the tests on 24 Hz frequency, 30-second tests were also carried out for the 34 Hz frequency and the same comparisons between signals were done. When comparing the vibration from the vibrator with the structure, peaks of 1,96 g for the vibrator and 1,75 g for the structure are noted, indicating a use of 89% of the generated energy, as shown in Figure 12.

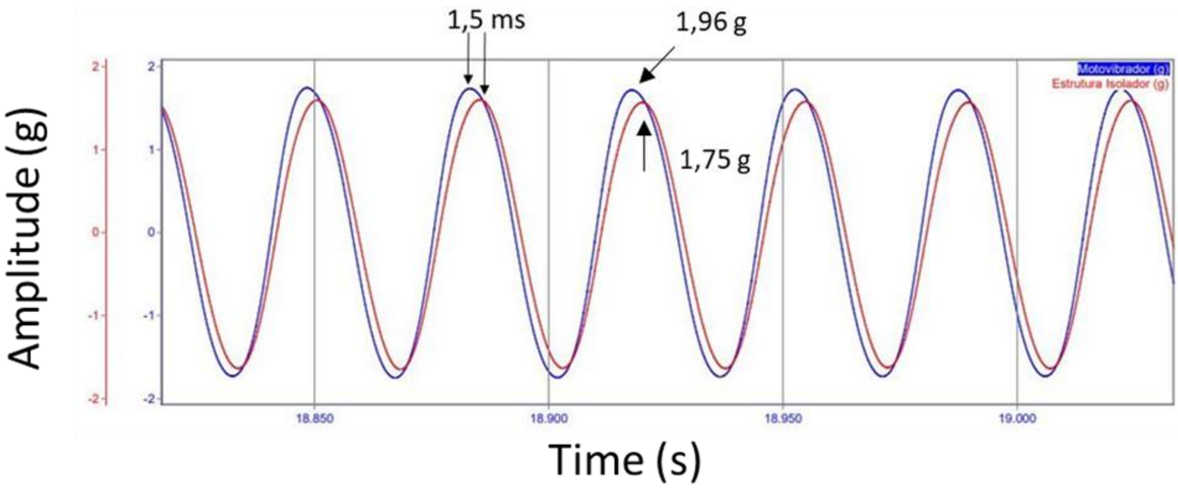

Figure 12: Comparison of the vibration from the vibrator (blue) and insulators' base (red) at 34Hz

The behavior of the LVDT was checked next, where a displacement of 4mm in the first 2,5 seconds and, after this, a displacement of 0,2 mm/s during the rest of the time was noted. These data can be seen in Figure 13.

Finally, the behavior of the contacts when subjected to the 34 Hz vibration was checked.

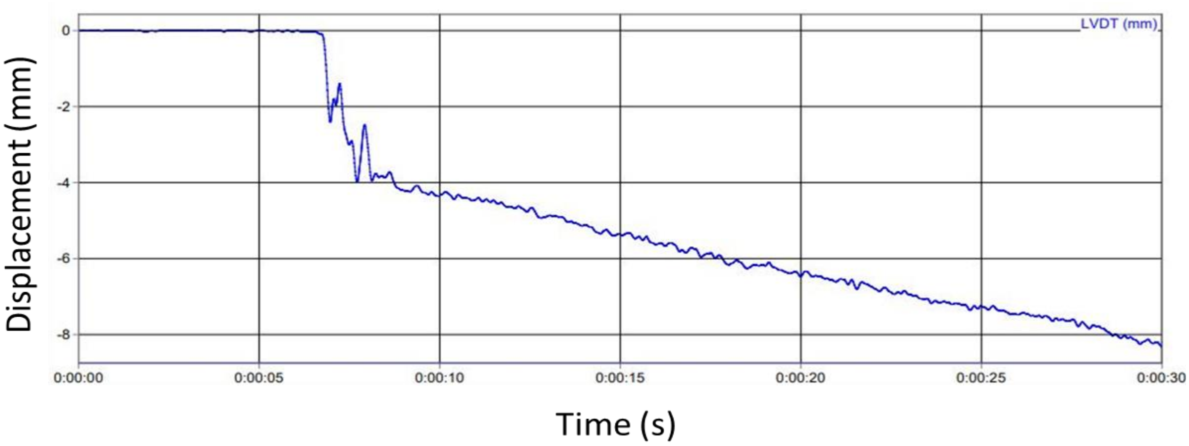

Figure 13: LVDT 34Hz Displacement

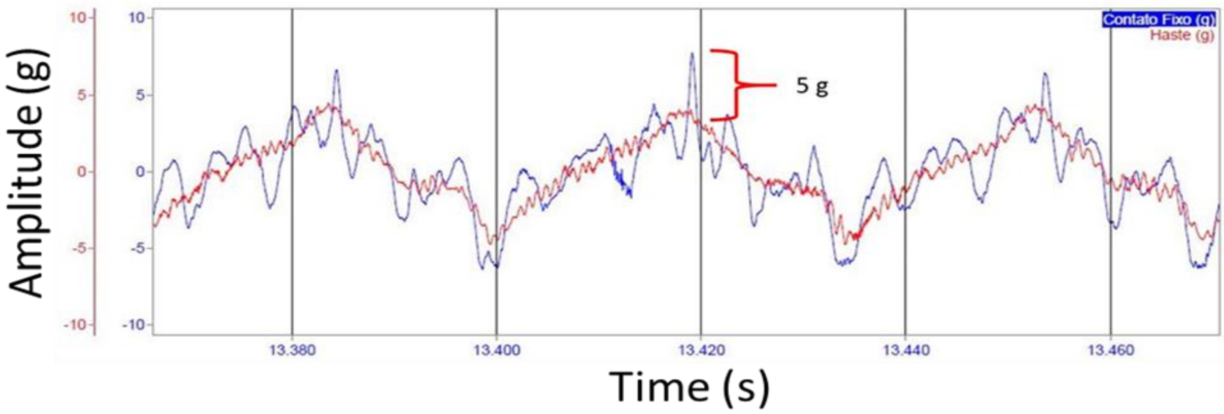

Figure 14: Comparison between 34Hz contacts, mobile contact (red) and fixed contact (blue)

In Figure 14, the behavior of the contact is shown, where a difference of 5 g in the acceleration amplitude of the signals was noted, being this a greater amplitude than for the previous test.

3.3. Frequency 43,5 Hz Data

Finally, data from measuring the frequency 43,5 Hz was checked.

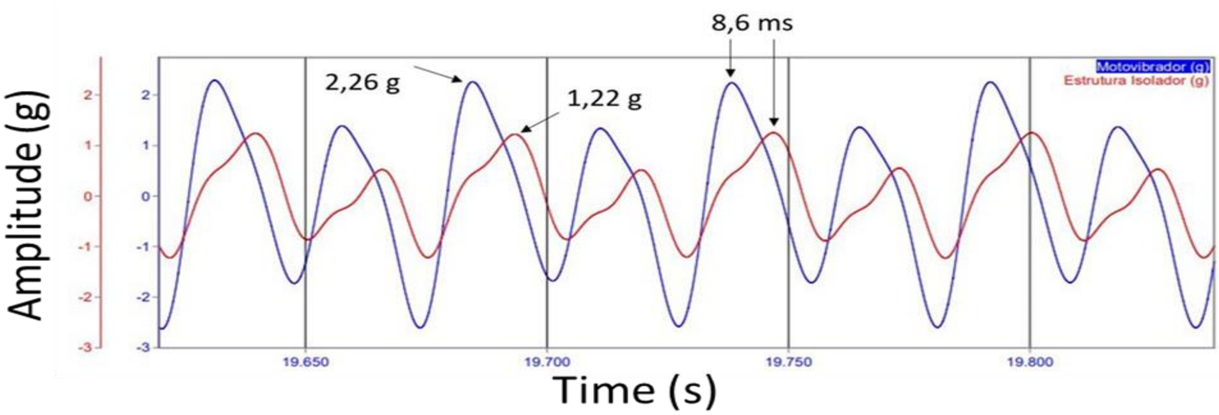

Figure 15: Comparison of the vibration from the vibrator (blue) and insulators' base (red)

In Figure 15, after accelerating the vibration system up to 43,5 Hz, a peak of 2,33 g for the vibration system and 1,22 g for the structure is noted. Also, it is possible to identify a lag of 8,5 ms between peaks. This way, the low use of the energy generated by the vibration system in the structure is evident.

In Figure 16, a significant displacement of 17,04 mm in the first 3,6 seconds of the test is noted, causing the switch to close completely in a few seconds.

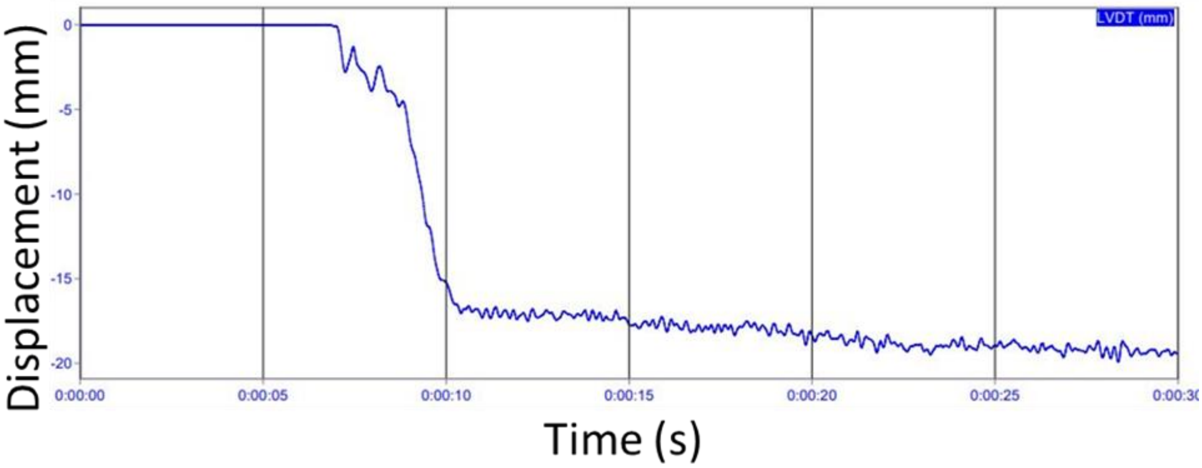

Figure 16: LVDT 43,5 Hz Displacement

Finally, a comparison of the acceleration of the disconnector contacts when subjected to vibration can be seen in Figure 17, where it is possible to see a difference of up to 16 g in a few seconds.

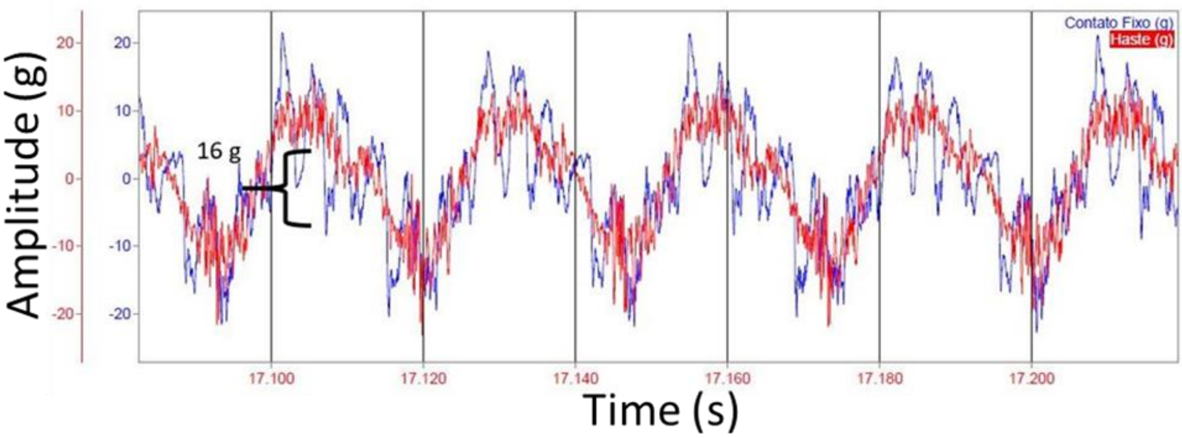

Figure 17: Vibration in fixed contacts (blue) and mobile contacts (red)

4. Discussion

Three topics will be discussed next: the efficiency in the transmission of the vibration energy to the structure, LVDT displacement and the comparison between accelerations in the contacts.

- Efficiency in the transmission of the generated energy

The 24 Hz and 34 Hz frequencies showed good energy transmission of the energy generated by the vibrator to the structure, given that just a little energy was lost.

On the other hand, 43,5 Hz frequency generates a lot of energy, and a great part of this energy is dissipated and does not reach the disconnector switch. This might happen due to some kind of deformation in the structure of the vibrator, or even because of the threaded bars used to fix the vibrator to the structure.

Through the graphic in Figure 5, it is possible to see that there is a wide range of frequencies between 36 Hz and 43,5 Hz, which generate more vibration speed in the moving rod than the 34 Hz frequency and, perhaps, some of these can have a reduced energy loss.

- LVDT Displacement

As shown in Figures 7, 10 and 13, the larger displacement for the 30 seconds of testing is at the 43,5 Hz frequency, followed by the 34 Hz frequency and, at last, the 24 Hz frequency. The same pattern can be seen in Figure 18. It is worth mentioning that there is a delay between the beginning of the displacement of signals and this is due to the beginning of the vibration being activated manually through a button on the frequency inverter.

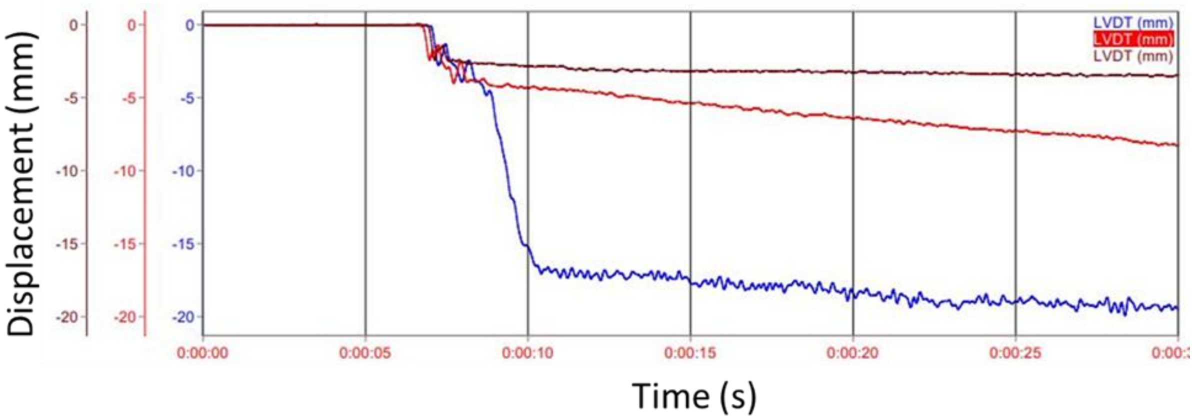

Figure 18: LVDT general displacement – 24Hz (brown), 34Hz (red), 43,5 Hz (blue)

It was possible to check that the 24 Hz frequency is not a functioning frequency to apply vibration to improve the process of closing maneuvers of the tested disconnector switch because at this frequency there was a small displacement and, after this, it did not continue to happen, keeping the disconnector switch open.

The 34 Hz frequency, despite having a slow displacement of the rod in relation to the fixed contact, was moving, which can generate an effective increase in the efficiency of the maneuvers of the tested disconnector switch when increasing the time in which the vibrator is on.

Finally, the 43,5 Hz frequency generated an effective displacement of the rod, which happened in a small space of time. At this frequency, it is possible to greatly increase the effectiveness of the maneuvers of the disconnector switch.

- Comparison of accelerations on contacts

As observed in Figures 8, 11 and 14, there is a great difference in the amplitude of vibrations for the three frequencies tested.

At the 24 Hz frequency, a low difference between acceleration amplitudes in the fixed and mobile contacts was noted, and through LVDT data it is possible to say that, using the same quantity of eccentric masses as in the other tests, this frequency is not enough to close the contacts of the disconnector switch when the maneuver dos not take place properly.

At the 34 Hz frequency, it was possible to observe a difference in amplitudes of up to 5 g and, with LVDT data, it is possible to say that 5 g becomes enough to cause displacement of the mobile contact into the fixed contact, adapting a poorly executed maneuver, however, the necessary time to complete the maneuver would be too long.

At last, 43,5 Hz frequency generated a difference in amplitudes of up to 16g, which is more than necessary to cause the displacement of one contact in relation to the other. The switch closed quickly at this frequency, but vibration amplitudes were high, and simulations regarding fracture and fatigue mechanics might be necessary.

5. Conclusion

Three indicators necessary to improve parameters for a better efficiency in the use of forced harmonic vibration in opening and closing maneuvers of disconnectors were evaluated in this study. Table 1 presents the three frequency ranges used and the result obtained for each variable tested.

Table 1: Comparison of test results

Parameter	Frequency (Hz)		
	24	34	43,5
Energy Transmission		x	
Vibration in contacts		x	
LVDT displacement			x

Through the results presented, it can be concluded that two of the three frequencies tested helped in the proper closing of the fixed and mobile contacts of the high voltage disconnect switch, being 34 Hz and 43.5 Hz.

In the criterion of using the energy transferred to the high voltage switch, it is evident that the greater the energy generated, the greater the lag between the vibration signals from the vibrator to the structure, and this indicates that the vibrator is vibrating in relation to the structure. For this reason, a better fixation can be studied.

When comparing the vibration in the contacts, the frequency of 24 Hz presented the smallest difference between the amplitude of the signals, which indicates the smallest vibration of the fixed contact in relation to the blade of the moving contact. Next, we have the frequency of 34 Hz, which presented a 5 g difference in the amplitude of the signals and 43.5 Hz with a 16 g difference in amplitude.

When comparing the difference in amplitudes with the LVDT signal, it is evident that 5 g of difference in amplitudes is the minimum expected to assist the closing of this disconnector. It is also verified that 16 g of difference exceeds the minimum necessary, which can reduce the fatigue life of several components of the disconnector.

It has been found that by vibrating the fixed contact against the main blade shank, it is possible to reduce the force normal to the surface of the contacts, which reduces friction and facilitates the engagement of the main blade.

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