A Thorough Examination of Circuit Breaker Health

Hydro-Québec TransÉnergie explores alternative diagnostic methods in its high-voltage circuit breaker maintenance program.

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THE PHILOSOPHY BEHIND MAINTAINING CIRCUIT BREAKERS FOCUSES ON PREVENTIVE MAINTENANCE to maximize the longevity of the electrical apparatus. The transmission division of Hydro-Québec TransÉnergie (Québec, Canada) divides activities in this field into three categories: corrective, conditional and systematic. Moreover, maintenance is an integrated part of a continuous improvement process of practices, methods and tools done in collaboration with the manufacturers of circuit breakers and test instruments.

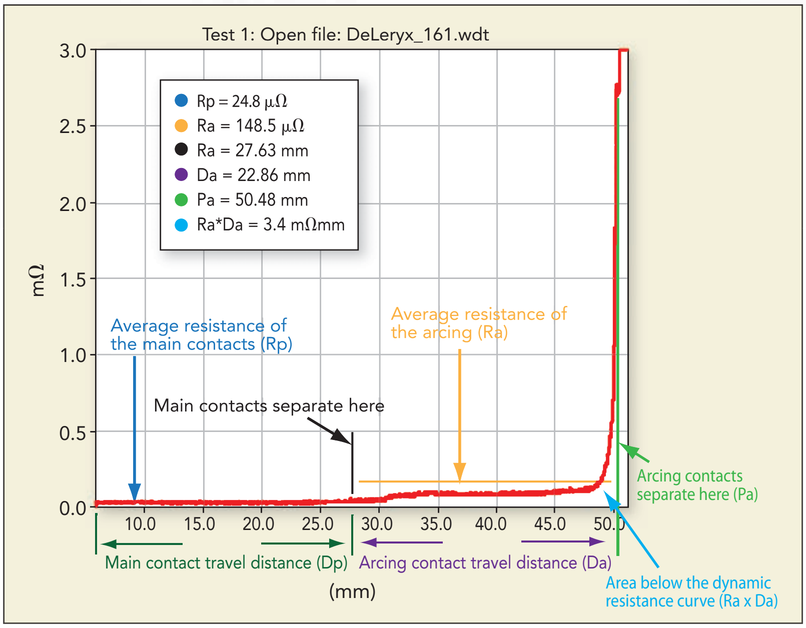

Fig. 1. A typical dynamic-resistance curve.

MAINTENANCE DESCRIPTIONS

Corrective and conditional maintenance are related to tasks performed to repair an apparatus following a fault or a defect. In the first case, the primary function of the apparatus cannot be maintained; while in the other case, it is still possible to operate the equipment. Whether it is corrective or conditional maintenance, the impact of these internventions is significant as they concern the safety of personnel and the operation of the power network.

Systematic maintenance is based on a specific predefined time frame or number of breaker operations, depending on the first occurrence. The content and frequency of these inspections are continuously adapted to the technical aspects, such as the reliability of the technology and the position of the equipment in the substation (lines, power plants, capacitor banks and inductors), as well as problems previously experienced with the same type of equipment.

The preventive inspection of high-voltage circuit breakers includes traditional tests such as alternating-current insulation, static contact-resistance measurement and timing tests with contact travel curves. In addition, one of the interrupting chambers must be inspected, based on the results of the previously mentioned tests. Because of the specific procedures regarding handling and recovery of SF_6 gas, these interventions can become quite complex and demanding. Thus, the idea is to limit the number of intrusive interventions and, in turn, minimize their cost.

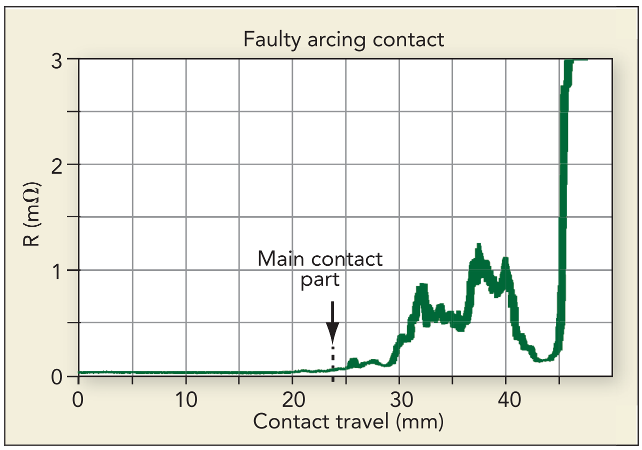

Fig. 2. An abnormal dynamic-resistance curve.

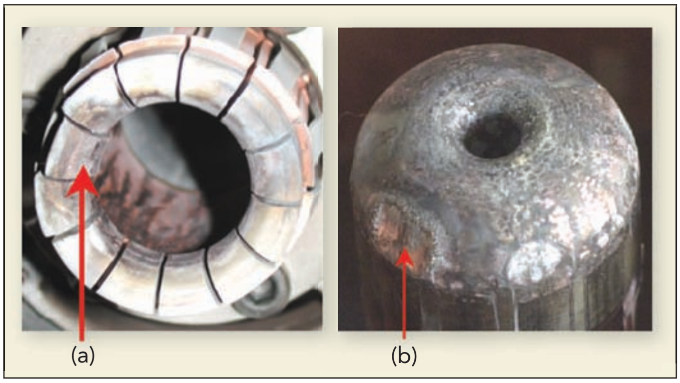

Fig. 3. The arcing contact on the moving part is misaligned (a) and the fixed side is worn (b).

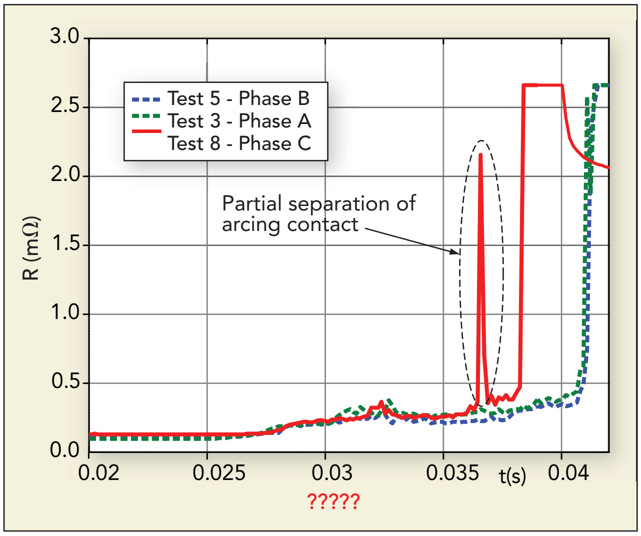

Fig. 4. Partial separation of Phase C's arcing contact.

DYNAMIC CONTACT-RESISTANCE MEASUREMENT

The original approach for dynamic contact resistance was to measure the resistance during a slow open operation of the breaker. Tests were done at low speed, so the partial contact separation was not present, making it easy to measure the resistance with a direct current of 100 A. However, during a field test, a minor incident occurred on the spring operating mechanism due to the slow operation of the breaker. Moreover, extremely high resistance values were measured due to the accretion of SF_6 byproducts on the contacts. Although this method was interesting because of the simplicity of its implementation, the measurement at 100 A could not be universally applied to all types of breakers.

A complementary study was launched to validate the measurement at nominal speed and high current. On one hand, tests on the electrical network confirmed that a continuous current source of 2800 A could burn the SF_6 powders, verifying the actual condition of the breaker contacts. On the other hand, validation tests at nominal opening speed were performed on various types of SF_6 breakers. A direct current of 700 A was determined to be sufficient to avoid the partial contact separation and produce a clean dynamic-resistance curve.

The dynamic-resistance measurement allows a precise evaluation of the wear of both the arcing and main contacts without having to open the breaker. The static-resistance measurement gives information on the status of the permanent contacts, but the wear mainly occurs on the arcing contacts, which are subjected to the heat and energy produced by arcing during each breaker operation. This measurement is applicable to high-voltage circuit breakers (69 kV to 735 kV) insulated with SF_6 and fitted with two sets of parallel contacts (main and arcing). For dead tank breakers, this method is only applicable if necessary precautions are taken to avoid the magnetization of the current transformers. Figure 1 shows a typical dynamic contact-resistance curve.

ARCING CONTACT MISALIGNMENT

A series of tests allowed Hydro-Québec TransÉnergie to establish threshold levels that are easily interpretable by the users of the equipment. For example, the utility was able to detect an anomaly on a 120-kV circuit breaker on a capacitor bank. The results of the dynamic contact-resistance measurement are presented in Fig. 2. An internal inspection of this breaker confirmed the diagnosis determined during the test. In fact, one of the arcing contact fingers on the moving side was misaligned, while the fixed side clearly showed abnormal wear due to excessive arcing (Fig. 3).

TUNGSTEN TIP OF ARCING CONTACT UNSCREWED

In another case, a 120-kV circuit breaker on a capacitor bank cumulated more than 4000 operations. The measurement indicated a partial separation of the arcing contact prior to the other phase (Fig. 4). An internal inspection showed that the tungsten arcing tip had begun to unscrew as illustrated in Fig. 5.

In the two previous cases, an internal diagnosis of the interrupting chambers allowed a necessary and well-timed intervention, which avoided an eventual breaker failure.

VIBRATION ANALYSIS

According to a recent CIGRÉ survey on high-voltage circuit breakers, 44% of major failures and 39% of minor failures are of mechanical origin. These figures reflect the actual situation prevailing at Hydro-Québec TransÉnergie. In fact, new market regulations result in additional operations on specific applications of circuit breakers (power plants, capacitor banks and shunt inductors).

The improvement of mechanical reliability can be achieved by two separate means. For the products in the certification process, mechanical endurance requirements can be upgraded. As for the existing equipment, the strategy relies on having tools with better detection capabilities to find problems before major defects can occur.

The initial strategy consisted of analyzing the market to know what was available. In this case, the products offered did not fulfill Hydro-Québec TransÉnergie's needs. In fact, the sampling frequency, resolution and vibration analysis software were inadequate for diagnosing the mechanical condition of the various types of SF_6 circuit breakers. For these reasons, IREQ, Hydro-Québec's research center, was given the mandate to develop a measuring device prototype. The method and algorithms were validated through real cases simulated in

Fig. 5. Unscrewing of tungsten tip.

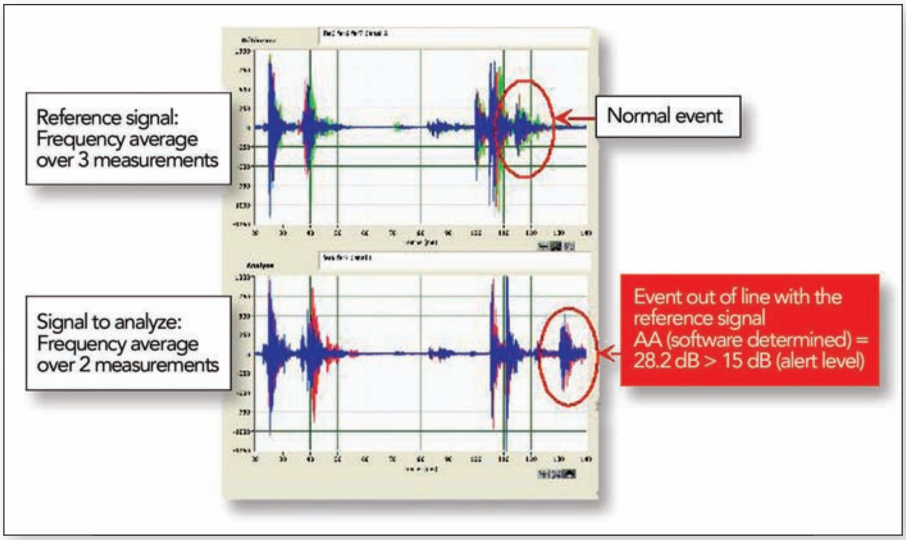

Fig. 6. Need Caption.

a laboratory as well as field-testing. The latter was often followed by internal inspection in order to validate the diagnosis. Once the efficiency of the device was proven, Hydro-Québec TransÉnergie's industrial partner Zensol Automation Inc. (Québec) developed an industrial version of the vibration analyzer. Once again, the validation took place through field-testing.

Vibration analysis allows the detection of mechanical anomalies on the mechanism or interrupting chamber of high-voltage SF_6 circuit breakers. The measuring system includes accelerometers, conditioning modules and a data-recording system, including the corresponding Zensol software. In addition to vibration signals, the system can record any analog signal relevant to the analysis of the circuit breaker's condition, such as contact displacement and position. Two parameters are used to assess the breaker's condition: amplitude deviation measured in decibels and time deviation measured in milliseconds. Universal threshold values were determined based on research works of other authors in that field and were validated through lab and field-testing.

ABNORMAL END OF TRAVEL IMPACT

In the following case, accelerometers were positioned at the top end of each interrupting chamber and inside the

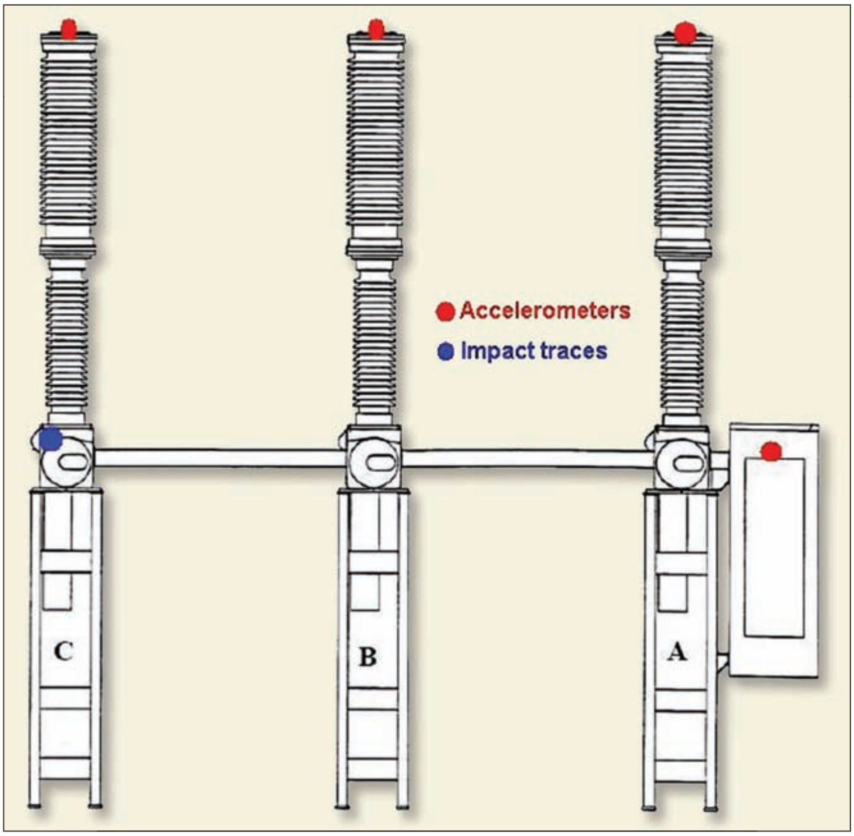

Fig. 7. Location of accelerometers and impact traces.

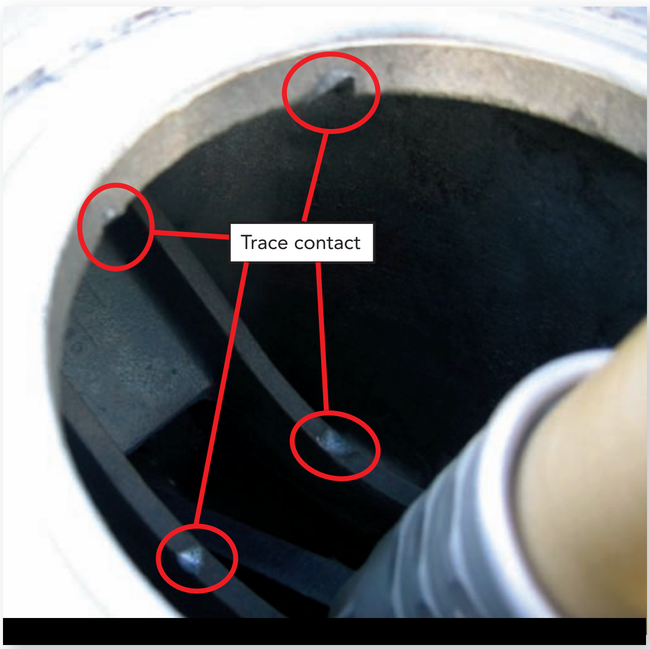

Fig. 8. Traces of impact in the bottom-end crank.

operating mechanism (Fig. 7) of a gang-operated, staggered-pole, 120-kV SF_6 circuit breaker cumulating more than 4000 operations.

The comparison between data recorded two years earlier led Hydro-Québec TransÉnergie to identify the presence of an abnormal end of travel impact on phase C. The internal inspection demonstrated traces of an impact on the crank located at the bottom end of the support insulator (Figs. 7 and 8). Even if the accelerometers were located far from the defect, detection was possible. The circuit breaker was then readjusted to avoid further degradation of the mechanical linkage.

MAINTENANCE TOOL DEVELOPMENT STRATEGY

The need for tools to give the actual condition of the interrupting chamber components emerged with the arrival of SF_6 breakers whose internal inspections are complex because of gas handling and recovery. The search for potential solutions must go through an analysis of the products already offered on the market. When the available products do not fit the utility's needs, the development of new diagnosis tools becomes necessary.

After the development phase, Hydro-Québec TransÉnergie will determine the need to be associated with an industrial partner. The partner is in charge of the evolution of the instrumentation by taking into account the needs of and feedback from different users, thus enhancing the reliability and the precision of the diagnosis. This also facilitates the smooth integration of adding the new methods to the traditional maintenance plan.

Traditional maintenance tests remain helpful when the aging of circuit breakers is progressive. However, in cases where anomalies appear suddenly on a family of breakers, new diagnosis methods such as the dynamic resistance and the vibration analysis can definitely help to precisely assess the condition of the apparatus and to better determine the priority level of a given intervention. In all, it is by clearly defining its needs and by developing tools that fulfill them that Hydro-Québec TransÉnergie can remain at the edge of technology while assuring the longevity of its electrical equipment. TDW

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