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Circuit Breaker Monitoring System of the Rio Verde Substation - Functionality and Performance Analysis

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ABSTRACT

The present electric power scenario in Brazil and abroad has led companies in the industry to operate in a highly competitive context, forcing those companies to constantly strive for better efficiency, higher quality supply and lower costs. Following this general trend, there has been a migration from preventive to predictive maintenance, which is only possible through online monitoring systems.
In these circumstances, circuit breakers, the equipment responsible for electric triggering of transmission lines, transformers, reactors and other equipment in substations are also being monitored.
The circuit breaker monitoring system allows, either locally or remotely, and in real time, providing accurate information to maintenance personnel about circuit breaker status, as well as minimizing failure risks and maintenance costs.
A practical analysis of the system performance is reported in this paper, which explains diagnosis types, their goals and the types of failures they can prevent, as well as how they can help to diagnose the cause of sudden failure in case it occurs. Therefore, future preventive measures can be used. Following this reasoning, monitoring can show a new range of approaches to problems which were unknown before, or were taxonomically treated as the same type of failure.

KEYWORDS

Circuit Breakers, Monitoring, Predictive Maintenance, Diagnostic Systems, Online Systems.

1.0 - INTRODUCTION

For a long time, equipment integrity at the substations and plants depended on preventive maintenance. Currently energy companies and industries coexist with reduced maintenance engineering teams, and it becomes necessary to develop tools to aid in the decision-making process for an accurate intervention.

One of these tools is the implementation of a predictive maintenance program in high voltage equipment based on these equipments' operating condition (1) . In this paradigm, circuit breakers are very important, since they are responsible for the safety of the electrical system if a failure occurs. In addition to that, they are important as maneuvering devices.
The currently adopted maintenance practices are based on fixed time intervals or on the number of performed maneuvers, indicated through the operation counters (2) . Maintenance, formerly based in time, now takes into consideration the equipment status. The emergence of systems that allow the organization, storage, visualization and interpretation of data which are important for maintenance made this paradigm shift possible. These systems allow safe equipment operation and provide the necessary elements for the current maintenance demands based on status.

Table 1 provides a brief comparison between maintenance philosophies based on time and status.

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Table 1 : Comparison between monitoring philosophies.

Time Maintenance	Status maintenance
It requires preliminary equipment maintenance to verify the circuit breaker status.	Main online circuit breaker status indicators.
Possible unnecessary testing.	Accurate intervention. Maintenance acts only where really necessary. It prevents insertion of new failures. Cost reduction and elimination of unnecessary downtime.
Possibility of maintenance only when the equipment is already deteriorated.	The circuit breaker does not cease to be serviced when needed.
Easy maintenance planning.	It assists in planning and maintenance procedures, aggregating value to the performance, reliability and failure analyses.
Time-honored technique.	It provides increased reliability and safety of the electrical system. It allows anticipation or prevention of the reconfiguration of the electric power system.
It does not fully benefit from the asset potential.	With proper maintenance equipment service life has more chances to be longer.

Just as an example, some signals that can be monitored to detect malfunction of circuit breaker components, such as opening and closing times, SF6 gas pressure, pump operation time, were cited in the literature (3). By analyzing these signals and comparing the range of values specified by the manufacturers, one can detect incipient faults in the circuit breaker and classify them as mechanical, located at the main electric circuit or control and auxiliary circuit.
This is the idea behind the diagnostic system based on rules.

2.0 - THE CIRCUIT BREAKER - OPERATION AND FAILURE MODES

2.1 A brief description of the circuit breaker mode of operation

Circuit breakers are electrical switching devices which should be able to conduct, stop and establish currents from the electric power grids, including high fault current (short circuit) (4) .
They consist of interrupting units, also called extinction chambers, which is where the voltaic arc created during the current interruption, and can be of various technologies. They have an operating or driving system which is the subset consisting of components that allow us to store the energy needed for the circuit breaker mechanical operation, as well as the release of energy through appropriate mechanisms, when a command is sent to open and close it; and last, but not least, they are a command unit, made of the circuit breaker command, control and supervision elements.

2.2 Known circuit breaker failure modes

With the purpose of identifying the most common causes of failures in circuit breakers, some research was conducted by CIGRE (5) . At first, it was conducted between the years 1974 and 1977 using a database from observations of 20,000 circuit breakers with a voltage above 63 kV.
The results of this survey showed that 70% of the most frequent failures in circuit breakers are caused by mechanical factors, 19% are connected to control and auxiliary circuits and 11% are due to main circuit electric factors.
The summary results of the second survey conducted by CIGRE in the period from 1988 to 1991 at 18,000 SF6 circuit breakers for voltages above 63 kV are presented in Table 2, published in the IEEE Std.C37.10 IEEE-1995 guide (6) and transcribed here.
It is a procedure to investigate diagnoses and failures in circuit breakers, giving an overview of the components in the circuit breakers which are frequently responsible for failures.

Table 2 : Statistics of circuit breaker failure causes (6)

Operating Mechanisms	**43 – 44%**
Hydraulics, pumps, compressors and related	13.6 to 18.7%
Accumulators	7.2 to 7.6%
Control Elements	9.3- 11.%
Actuators, damping devices	5.1-8.9%
Mechanical transmission	1.4-3.8%
High-voltage components	**21-31%**
Switches	9.4-14%
Auxiliary switches and resistors	0.6-1.3%
Isolation	5.7-20.9%
Control and auxiliary circuits	**20-29%**
Closing and opening circuits	1.5-10%
Auxiliary contacts	2.1-7.4%
Contactors, heaters and related	5.4-7.6%
SF_6 gas density monitors	4.0-10.7%
Other Causes	**5.4-6.8%**

The results obtained in this research allows us to conclude that most circuit breaker failures are associated to the components of the circuit breaker operating mechanism; the second most frequent cause are high-voltage components and the third most frequent cause is connected to control circuits (7) .
The goal of online monitoringn is to prevent issues arising from points listed in Table 2 .

3.0 - BASIC SPECIFICATION OF THE CIRCUIT BREAKER MONITORING SYSTEM ADOPTED AT THE RIO VERDE SUBSTATION.

The Circuit Breaker Monitoring System installed in the Rio Verde Substation is a tool for engineering maintenance that acquires, stores and processes measurements taken from the monitored equipment, generating diagnosis and prognosis of potential problems that could lead to interruptions in electricity supply (8).

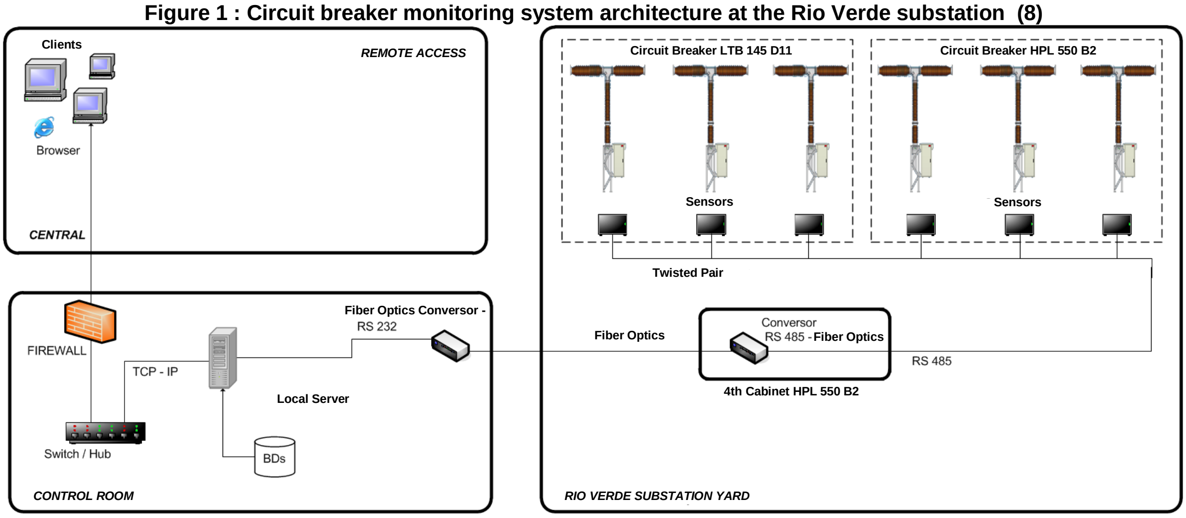
Among the many findings of this monitoring system, we cite those considered most important in this project:

- Rapid diagnosis of the current state of the equipment in order to provide input for decision-making regarding the operation or not of the circuit breaker, thus helping to preserve not only the circuit breaker but also the equipment it is powering.
- The early prognosis of fault conditions before their operation, in order to increase system availability and allow equipment downtime only when needed for corrective action or not include it in the system to prevent damaging it.
- Monitoring equipment operating conditions along its whole life so that equipment is available for operation, in addition to controlling equipment at the end of its service life.
- Quick access to status information from the equipment through the Furnas intranet thus facilitating the access to all information on the equipment.
- Possibility of integration with other corporate monitoring and maintenance management equipment.
- Integration of maintenance management and cost reduction.
- Monitoring of several types of circuit breakers.
- Investment management and insurance premium negotiation.
- Corporate image preservation.

3.1 Monitoring System Architecture

The architecture of the sensor network is shown in Figure 1 :

Figure 1 : Circuit breaker monitoring system architecture at the Rio Verde substation (8)



The main variables collected by the monitoring system sensors are Table 3 :

Table 3 : Key variables obtained by the monitoring system (8)

Continuous Acquisition Variables	Acquisition Variables Triggered by Maneuver
SF6 gas Density and Pressure	Main contact movement
Ambient temperature	Interrupted current
Continuity of opening and closing coils	Operating Times
Position of the auxiliary circuit breaker contacts	Operation number
Number of motor starts	
System self-diagnosis	
AC and DC voltages	
Sensor supervision	

As can be seen in Figure 1, the entire system, to be functional, requires successive stages in the acquisition of the data so that they can be used in monitoring rules.

- Step 1: Field sensing is responsible for acquiring all variables in the circuit breaker monitoring system, during opening and closing operations, spring loading, motor and variables that may be obtained without the operation, for instance, SF_6 gas pressure.
- Step 2: The data obtained are transferred to the software located on the monitoring server where all calculations are made so that this information is displayed to the user. All these data are recorded in SQL Server installed in the monitoring server after this step.
- Step 3: This OLM Explorer SQL Server database is read by the circuit breaker monitoring system, each time a new record is included, thus making all comparisons and calculations needed so the result of monitoring rules is displayed to the users.

After this step, if an alarm is detected, the information will be displayed on the monitoring system website and an e-mail alert will be received by the maintenance team.

4.0 - THE RULE SYSTEM: TURNING INFORMATION INTO DIAGNOSES

The rule system encoded into the monitoring software allows information obtained by the sensors to be transmitted into automatic diagnoses, indicating the kind of problem to the maintenance team, as well as its severity and the maximum time for intervention, if this situation applies.
In Table 4 : Main diagnostic rules used by the monitoring system , the the diagnostic rules and their main function are displayed:

Table 4 : Main diagnostic rules used by the monitoring system (8)

Rule name	Description of Operation / Actuation condition
Current in the Motor	For this rule to become true it is necessary that the motor current, after the closing operation and the spring loading, exceeds the limits, high or very high, low or very low. If it is high or very high the Diagnostic will be actuated that informs that the current is

	off the established limits, just as it happens when the value exceeds the low or very low limits.
Interrupted current	For this rule to apply it is necessary that the erosion rate at the contacts is above 70% or their service life is below the 30% as specified by the circuit breaker manufacturer. To make this possible, the current sum calculation is done at each circuit breaker operation. If this sum exceeds the described limits at the moment the alarm goes off, a trend on how many operations the circuit breaker will reach 100% of contact life will be calculated. When 100% of contact life is reached, the second diagnostic level is informed.
Current in the opening or closing coil.	For this rule to apply it is necessary that the current at the opening or closing coil at the moment of the operation falls outside the specified limits.
Nominal system current during closing.	For this rule to apply it is necessary that the system nominal current is above the limits set in the closing operation.
SF_6 gas density	For this rule to apply it is necessary that there is SF_6 density loss at the circuit breaker chamber. This diagnosis comprises 3 alarm levels. For the trend level, the system performs a calculation with the variables of current density and loss of SF_6 daily average density, then a trend in days to reach the first stage of SF_6 alarm level is achieved. After reaching this stage, if the leak is still present, the system continues performing the same calculation with trends in days to reach the second level.
Opening and closing time difference between phases	For this rule to apply it is necessary that at the opening or closing operation moment the operation time between phases exceeds the specified limits.
1 and 2 Opening Coil Oversight	This rule applies when the opening coil is interrupted.
Closing Coil Oversight.	This rule applies when the closing coil is interrupted.
Circuit breaker control panel temperature	For this rule to apply it is necessary that the circuit breaker control panel temperature exceeds the established limits.
Opening Time Correlated with Opening Speed and DC Voltage	For this rule to apply it is necessary that the time at the opening operation moment is different from the established limits, this variable being inversely proportional to the circuit breaker opening speed.
Opening Time Correlated with DC voltage	For this rule to apply it is necessary that the time at moment of opening operation is different from the established limits, and this variable needs to be inversely proportional to the correlated variable (DC Voltage) of the circuit breaker.
Long Opening time and Short Closing Time	For this rule to apply it is necessary that the Opening time, during its operation, is longer than the established limits, together with the closing time, in its operation.
Long Opening time and Short Closing Time	For this rule to apply it is necessary that the Closing time, during its operation, is longer than the established limits, together with the opening time, in its operation.
Spring Loading Time	For this rule to apply it is necessary that the spring loading time at the moment of the closing operation is longer than the specified limits, and its correlated variable (AC voltage) is inversely proportional to its actuation.
Arc Extinction Time	This rule applies at the opening time, when it is out the specified limits, and this allows to identify when there is a problem with the chamber, or on the main arc contacts.
Auxiliary AC Voltage	This rule applies when the level of AC auxiliary voltage is out of the established limits. It may apply without operation in the circuit breaker, and it is extremely important for other rules, as its correlation is mentioned above.
Opening and Closing Speed	For this rule to apply it is necessary that at the opening or closing operation moment the speed value exceeds the specified limits. This variable is used to create correlation for other rules

The system issues several kinds of diagnoses according to the operating conditions of each one of these rules. The diagnosis can be recognized by the user, releasing the rule operation condition.

5.0 - CONCLUSIONS

Based on the technique proposed here, a procedure can be developed for circuit breaker status diagnosis and follow-up through monitoring several variables relevant to its diagnosis.
The use of the diagnostic rule system associated with signal monitoring makes it possible to have a circuit breaker failure diagnostic system, which can work as an auxiliary tool for the maintenance team in preventing future failures.
The circuit breaker monitoring system based on diagnostic rules installed in the Rio Verde substation has the interesting characteristic of fast interpretation of the obtained data and diagnosis issuance.
The system is installed and operating since January 2010.

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