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EVOLUTION OF THE SIGMA ONLINE MONITORING SYSTEMS FOR TRANSFORMERS AND REACTORS AT ELETROSUL

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ABSTRACT

High voltage assets in substations, such as transformer and reactors, are crucial for the safe operation and continuity of the electric power supply. Consequently online monitoring systems have been used to increase the reliability and availability of those pieces of equipment, and at the same time, to reduce costs. Eletrobras Eletrosul started to implement online monitoring in power transformers in 2001 with the Sigma system. This paper presents the deployment history of the Sigma monitoring system at Eletrosul Eletrobras, as well as its evolution along time, together with the outcomes and benefits brought by improvements in the system.

KEYWORDS

Online monitoring, diagnostics, prognostics, predictive maintenance, sensors.

1.0 - INTRODUCTION

Substation high voltage equipment such as power transformer, shunt reactors, current transformers, capacitive voltage transformers, high voltage circuit breakers and disconnect switches are the production assets of the electric power generation plants, and as such are crucial for the safe operation and continuity of the electric power supply. When operated under appropriate conditions and managed accurately, these assets become a major factor of operational and economic efficiency and competitiveness for the sector's utilities.

In order to ensure greater reliability and availability of the equipment while cutting operating and maintenance costs, as well as increasing maintenance efficiency, the monitoring and diagnostic systems for online monitoring and diagnostic of the asset state have spread over the last decade, providing a tool for the migration from preventive to predictive maintenance and to a maintenance philosophy centered on reliability [1] [2].

Great emphasis has been given to power transformers and shunt reactors, since these are considered the main assets of a substation due to being essential for the generation and transmission of the electric power, and to having high replacement costs and requiring a long time to be manufactured. .

This paper presents a brief history of the deployment and evolution of these systems in Eletrobras Eletrosul and the results obtained.

2.0 - IMPLEMENTATION OF TRANSFORMER ONLINE MONITORING AT ELETROSUL

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In the context above, and as a company which traditionally uses innovative technologies and is a benchmark for the best practices in asset management, Eletrobras Eletrosul started to implement in 2001 the online monitoring of power transformers, seeking to achieve the following general objectives:

- Online diagnostics of the high voltage equipment state
- Reduced risk of failure;
- Service Life extension and control;
- Migration to predictive maintenance:
- Reduction of maintenance costs;
- Increased equipment availability in the system;
- Reduced costs due to equipment availability;
- Optimized asset use;
- Better insurance premium negotiation;
- Preservation of the corporate image;

The deployment started by two 230/138 kV 150 MVA three-phase transformers at the Itajaí substation, with on-load tap changers [3] shown in Figure 1, where the Treetech Sigma system was installed, with a basic architecture like the one shown in Figure 2.

Fig. 1. First monitored transformers at Itajaí substation, 138/13, 8 kV 150 MVA

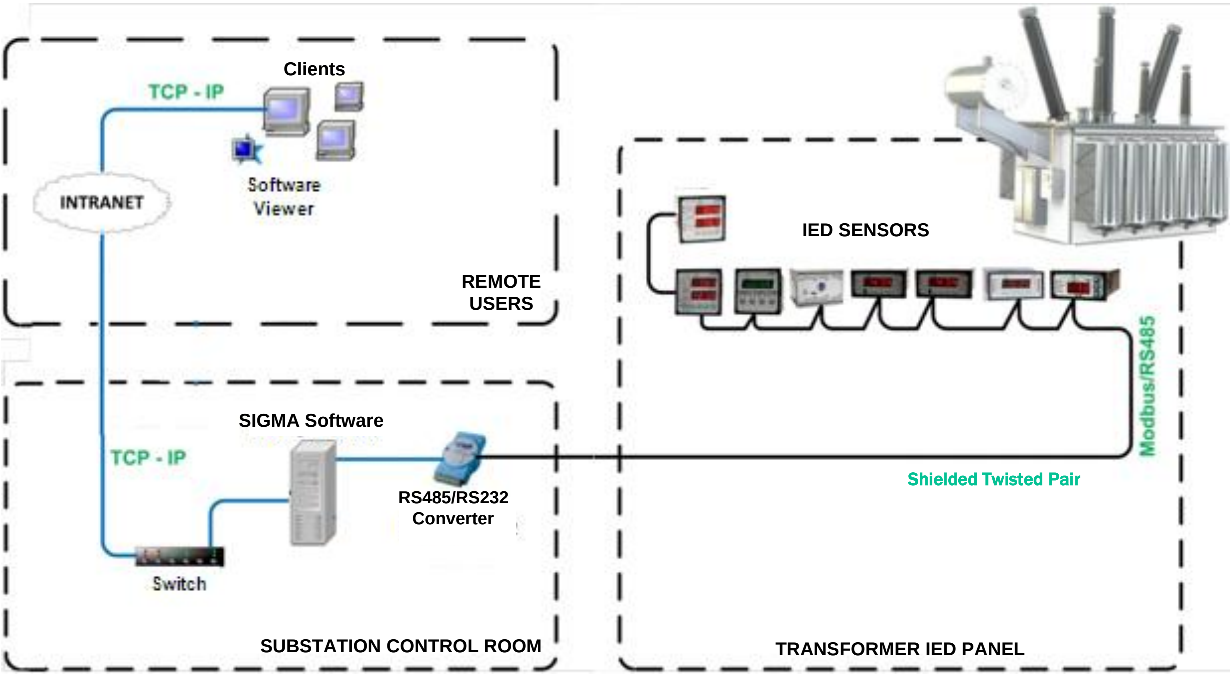

Fig. 2. Original architecture of the online monitoring system deployed in the Itajaí substation

The main features of this solution, shown in figure 2, are:

- Use of a decentralized architecture, with IED sensors, eliminating the need of a centralized element (PLC or other) in the body of the transformer [4] [5];
- IED-type sensors designed and tested specifically for the substation yard environment, ensuring the reliability and durability of the system [4] [5];
- Communication between IED sensors and the RS485 monitoring server, shielded twisted pair physical medium;
- Conversion of the communication medium RS485 to RS232 for connection to the monitoring server;
- Use of an independent monitoring server in the control room of each substation;
- Connection of the monitoring server to the Eletrosul corporate network (intranet) to allow users to have remote access to the monitoring system;
- Installation of a remote viewing software on each remote user's computer connected to the monitoring server.

Monitoried variables, according to Eletrosul's technical specifications, are in Table 1 [3].

Table 1 - Variables monitored in Itajaí substation transformers as specified by Eletrosul

Variable	Sensor
Top oil temperature	Temperature Monitor
Winding temperature (hot spot)	
Ambient temperature	
Oil temperature at the OLTC load switch	
Load percentage	
Oil temperature at the bottom of the tank	Temperature Monitor
Insulation Capacitance	Bushing Monitor
Insulation Tangent Delta	
Gases dissolved in the oil	Gas Monitor
Water content dissolved in the transformer oil	Moisture Monitor
Water content dissolved in the OLTC oil	Moisture Monitor
Membrane rupture / expansion tank bag	Membrane/ bag rupture relay
Line voltages	Digital transducer
Line currents	
Fan/pump voltages	Digital transducer
Fan/pump currents	
OLTC voltages	Digital transducer
OLTC currents	
OLTC tap position	Tap position indicator
Cooling stages on / off	Data Acquisition Module
OLTC operation time	
Alarm contacts: - Buchholz relay, - Pressure relief valve, - Oil level, etc.	

With these variables, the Sigma software performs data processing to obtain useful information for transformer condition diagnosis and prognosis. Engineering functions, made up of mathematical models and algorithms that peform data processing are shown in Table 2 [3].

Table 2 - Engineering Models for transformer condition diagnosis and prognosis.

Engineering Model	Diagnosis and Prognosis

Engineering Model	Diagnosis and Prognosis
Insulation service life	Remaining Insulation service life
	Insulation service life loss trend (% / day)
	Remaining insulation service life (years)
Temperature final gradient forecast	Future hot spot temperature after stabilization
	Time to reach alarm temperature
	Time to reach shutdown temperature
Gases dissolved in oil	Gas in oil evolution trend (mainly H_2)
	Alarms per evolution trend and high or very high gas concentrations
Chromatography / Physicochemical	Gas chromatography offline test reports
	Physicochemical offline test reports
Moisture in oil and on paper	Transformer sealing - expansion tank rubber bag rupture
	Water content in oil (ppm)
	Trend in water content evolution (ppm / day)
	Water content in paper (% dry mass)
	Insulation service life loss acceleration factor through hydrolysis
Bubble formation temperature	Bubble formation temperature
	Free water formation temperature
Cooling efficiency	Top oil calculated temperature
	Difference between measured and calculated temperatures
	Cooling system efficiency
OLTC temperature differential	Instant temperature differential
	Filtered temperature differential
	Differential temperature high alarms
Torque and OLTC motor operation time	Maximum torque of the motor in each commutation region
	OLTC mechanism operation time
	Out-of-starndard alarms per torque values and operation time
OLTC maintenance assistant	Commuter operation number
	Commuted current sum
	OLTC operation time
	Forecast of remaining time before the next OLTC maintenance
	Early OLTC maintenance warnings
Forced ventilation maintenance wizard	Ventilation group operation time, total and after the last maintenance.
	Forecast of the remaining time before ventilation maintenance.
	Early Ventilation maintenance warnings

Later, this same solution has expanded to 27 (twenty seven) other Eletrosul transformers and reactors. Table 3 lists all monitored pieces of equipment.

Table 3 - Sigma monitoring systems installed at Eletrosul

Substation	Transformers	Reactors	Voltage (kV)	Power
Itajaí	3	0	230/138 - 13.8	150MVA
Siderópolis	1	0	230/69 - 13.8	88MVA
Xanxerê	2	0	230/138 - 13.8	150MVA
Campos Novos	6	0	525/230 - 13.8	224MVA
Biguaçu	2	0	230/138 - 13.8	150MVA
Gravataí III	4	0	230/69 - 13.8	55MVA

Nova Santa Rita	3	0	525/230 - 13.8	224MVA
Santo Ângelo	3	3	525/230 - 13.8 550 (reactor)	224MVA 54MVAr
Dourados	1	0	230/138 - 13.8	75MVA

3.0 - EVOLUTION OF ONLINE MONITORING SYSTEMS

Naturally, because at the time of the early implementation (2001), this was a new technology, the Sigma system underwent a process of evolution in which Eletrobras Eletrosul played an important role in interacting with new developments, enhancements and customizations performed in the system.

In this process the system was customized to meet Eletrobras's specific needs, like the inclusion of a proprietary diagnostic algorithm through gas chromatography as well as improvements to facilitate the usability of the system. The following are some system evolution examples:

3.1 Customizing a method for DGA diagnosis for Eletrosul

The analysis of gas chromatography test results takes place at Eletrosul through a proprietary methodology developed as a result of the company's experience with this technique. Due to the fact the monitoring software is open it allows the addition of new monitoring functions by the user, which was done with this Eletrosul proprietary gas-chromatography technique.

3.2 System expansions

Taking advantage of the characteristics of modularity and expandability of the Sigma system, and of the fact that it is an open system, expansions have been included to add other sensors.

IED sensors were initially added to the system to perform online monitoring of bushing capacitance and tangent delta since those sensors were installed on the transformer in a posterior step.

Later, several online sensors were added to the system to detect gas dissolved in oil (primarily H_2); those sensors were already installed in the Eletrosul transformer park. In this case, the fact that the system is open to the development of a specific communication driver for those sensors, which used a factory proprietary communication protocol, was also an advantage. Since the sensors were in other company substations, we used the Eletrosul Intranet to send data from these sensors to the monitoring server in the Itajaí substation control room.

3.3 Sending e-mail alerts

To eliminate the need for an operator to continually oversee the system, an e-mail capability was added to the system so messages are automatically sent to previously registered addresses. This prevents wasting the maintenance engineers’ time during periods in which no problems are diagnosed.

3.4 Upgrading with Web 2.0 technologies

As explained in section 2.0, the system as it was initially deployed in Eletrosul used a viewing software to remotely access the data. This viewing software had to be installed in each user's remote computer.

This solution, while functionally perfect, was inconvenient in some aspects, such as limiting access to the system to previously prepared computers, the waste of computer engineer time to install the viewing software for the users and also to download the necessary updates.

To avoid these inconveniences, and in line with the most modern cloud-computing trends, in which the applications are executed only in remote servers, using as local interface only the internet browser, the Sigma monitoring interface has been updated to use the so called Web 2.0 technologies.

Thus, there is no longer need to install specific software on users' computers; the users now use only their internet browser. Therefore, any upgrades to the system are restricted to the monitoring servers, and do not affect the user computers. The access to the system is possible from any computer in the Eletrosul Intranet, as long as the user has a user ID and a password.

System access security can be preserved through the cryptographed connection protocol HTTPS, in addition to the login and password to access the system.

3.5 Wireless communication with the sensors

In order to reduce the cost and facilitate the installation of monitoring systems, the feasibility of using wireless communications between sensors on the transformer and the substation control room has been verified by a pilot in Santo Ângelo substation, at the time the system was installed in a transformer bank, using the Wi-fi standard. Gas sensors which were already in place were integrated as well as new bushing capacitance and tangent delta monitors. Data are directly transmitted to a router connected to the corporate network and acquired by the Sigma 4 software.

The application performance proved entirely satisfactory, demonstrating the feasibility of this technology with great potential to reduce costs and installation time.

3.6 Adding an Engineering Model

The open and modular architecture of the monitoring system has also allowed the inclusion of a new engineering item for loading simuation. The simulation is possible in two ways:

- Based on current load conditions at ambient temperature, with the user inserting the new hypothetical loading value;
- Based on hypothetical load evolution curves and ambient temperature in 24 hours.

In both modes the user can see the consequences of hypothetical situations in terms of temperatures reached and loss of life related, and can compare the maximum temperature that would be achieved with the temperature of bubble formation due to moisture, also calculated by the monitoring software. In all simulations, the user can modify the cooling command mode (automatic or manual) and the enabling temperatures, as well as the cooling hysteresis.

3.7 Connectivity to other systems

The evolution of the Sigma monitoring systems has provided them with a capability to exchange data with other Eletrosul systems, such as the SAGE supervising system.

This connectivity is possible through different methods, selected according to the need and convenience of the application. Examples of possibilities are SQL databases or, in other standards, OPC, web services, open communication protocols (eg Modbus, DNP 3.0, TCP / IP), among others.

4.0 - RESULTS

The use of automated online monitoring of transformers and reactors has several features that may be beneficial for the maintenance of that kind of equipment, such as reducing risk of catastrophic failure, controlling and extending service life, migrating from preventive to predictive maintenance, with the consequent increase in the availability of the equipment and reduction of the costs due to lack of equipment availablity, among others.

However, the monitoring system is presented as a useful tool not only for maintenance engineering but also for the operation and planning, due to loading simulation and prediction of future temperature as a function of current load, associated with equipment status diagnoses, which provide an indication of the risk to use overloaded equipment, for example.

Another example of the usefulness of the monitoring system could be observed when a 245 kV bushing failed in the Santo Ângelo substation. In this case, the evolution of the bushing defect was extremely fast, leaving no time to remove it from operation before failure, unlike what is normally expected for defects in bushings [6]. However, the presence of the monitoring system with the storage of measurements in databases allowed further analysis of the occurrence, leading to conclusions that would be impossible without the monitoring system - like the fact that the defect evolved very quickly.

Therefore, the monitoring system allowed the technicians to deepen their knowledge about the evolution of this type of defect and to improve the system itself and the procedures when this kind of defect takes place.

5.0 - CONCLUSIONS

This paper has presented the history of installation, expansion, customization and operation of the Sigma monitoring systems in Eletrobras Eletrosul, as well as the evolution of this system over time, including the architectures used to install sensors on the equipment, data output architectures, communication media and user interfaces.

The results obtained were presented as well as the benefits gained with the developments and improvements of the system over time, mostly allowed by Sigma's open, decentralized and modular architecture.

Considering the importance of transformers and reactors in the Eletrosul park for the SIN, the installation of the online monitoring system for that equipment, as well as the possibility of the system evolution and of its uses over time is of great significance to increase the electric power system reliability and the supply continuity, in addition to contributing to cost reductions that help to reduce rates.

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7.0 - AUTHOR BIOGRAPHICAL DATA

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