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STEP UP TRANSFORMER ONLINE MONITORING EXPERIENCE AT TUCURUÍ POWER PLANT

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ABSTRACT

Abstract – The Step Up Transformers at UHE Tucuruí are very important for the National Interconnected System (SIN). Due to that, and due to the severe work conditions, Eletrobrás Eletronorte has always kept a rigorous preventive maintenance program for this kind of equipment. However, transformer failure history in the first powerhouse (older ones) led to the implantation of the online monitoring system, in order to detect the defects early and mitigate the risks even more.

System installation took off in 2006, with sensors and software, by monitoring four transformers which were already operating and installation of a monitoring system for three more, taking advantage of the modularity and expandability features of the decentralized architecture used.

The Architecture and the solutions applied in system implantation, as well as the results obtained, will be described in this paper, some of the goals successfully attained being easier insurance negotiation for some machines and consequently safer personnel, equipment and facility.

KEYWORDS

Online monitoring, diagnosis, prognosis, predictive maintenance, transformer.

1.0 - INTRODUCTION

With the highest installed power among Brazilian plants, 8370MW, Tucuruí hydroelectric power plant has 23 three phase 13.8/550kV step up transformers, of which 12 are 378MVA ones (first powerhouse - transformers which have been operating for up to 18 years) and 11 are 405MVA (second powerhouse - transformers which have been operating for up to 7 years), connected to SF6 insulated busbars cooled by oil-water exchangers.

Those transformers perform a critical role in the transmission of the generated energy; therefore they are essential to operate the National Interconnected System (SIN). Given the importance of those pieces of equipment and their severe work conditions, including high temperatures and normal dielectric demands from the system operation, Eletrobrás Eletronorte has always kept them in a strict preventive maintenance program.

However, past step up transformer failures have shown that this approach was not enough, which led to the implantation of an online monitoring system to reduce failure risk, with the detection of the main types of defects still at the beginning phase, which often is not possible only with preventive maintenance.

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2.0 - TRANSFORMER FAILURE STATISTICS

An international operating transformer power performance research [1] by Cigré including failure data between 1968 and 1978 and involving more than 1000 failures has revealed, for several transformer and types and applications, the main causes of removal from service, either mandatory or planned.

Figure 1 shows those data for transformers without OLTCs in power plants. In that statistics the bushings are the main source of failure in transformers, with one third of the occurrences, with the runner-up, almost tied with first place, being the active part; the tank and oil are the other causes. Those three transformer subsystems, together, answer for virtually 84% of the equipment removed from service.

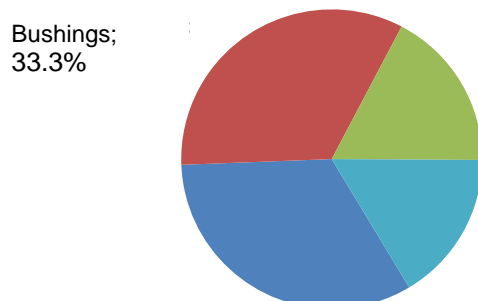


Fig. 1 Statistics of no-OLTC transformer removal from service in plants [1].

Based on those statistics and on the previous experience by Eletrobras Eletronorte the variables to be monitored in the step up transformers were chosen, in addition to the necessary data processing functions, so that the variables measured were turned into useful information for transformer diagnosis and prognosis. The main transformer subsystems were thus covered, therefore reducing failure risk.

3.0 - TRANSFORMER SENSING

The variables measured in the step up transformers at the Tucuruí Power Plant are shown in Table 1, grouped according to the subsystems.

Table 1 - Variables monitored at the step up transformers grouped according to the subsystems

System	Sensor	Variable
Bushings	BM (Bushing Monitor)	Capacitance
		Tangent Delta
		Leakage current
		Phase-to-ground and phase-to-phase Voltages
Active Part	DTM (Temperature Monitor)	Oil Temperature
		Coiling Temperature (hot-spot)
		Ambient temperature
		Load percentage
	Gas monitor	Hydrogen in oil
	Digital Transducer	Line Voltage
		Line Currents
		Active, reactive and apparent power
Tank and Oil	Moisture Monitor	Water in oil Content (ppm)
		Relative water saturation in oil%
		Ambient Temperature Saturation
		Reference temperature saturation
		Water content evolution trend
	MBR - Rupture Relay	Expansion tank bag rupture

System	Sensor	Variable
Cooling System	DTM (Temperature Monitor)	Oil Temperature - exchanger intake
		Oil Temperature - exchanger outlet
		Water Temperature - exchanger intake
		Water Temperature - exchanger outlet
	Digital Transducer	Oil pump voltages
		Oil Pump currents
		Oil Pump power
		Cooling Stages on/off
		Oil Pump Vibration
Other	Data Acquisition Module	Alarm Contacts - Buchholz relay - Pressure Relief Valve, - Oil Level, etc.

For it to entirely fulfill its objectives, the monitoring system must process the aforementioned data, so more useful information are obtained on transformer status, as detailed below.

4.0 - DATA PROCESSING FOR DIAGNOSIS AND PROGNOSIS

In order to process the data obtained from the aforementioned sensors, the installed monitoring system has in its software an Engineering Module, which includes the engineering models shown in Table II.

Table 2 - Engineering Models for Transformer Status Diagnosis and Prognosis

System	Engineering Model	Diagnostics and Prognostics
Bushings	Bushing status	Capacitance evolution trend (pF/day)
		Tangent Delta evolution trend (%/day)
		Remaining time to reach capacitance critic values (days)
		Remaining time to reach tangent delta critic values (days)
Active Part	Insulation aging	Insulation Remaining Service Life (%)
		Insulation Service Life Loss Trend (%/day)
		Insulation Remaining Service Life (years)
Active Part	Moisture in paper	Water content in paper (% dry mass)
		Insulation Hydrolysis Life Loss acceleration factor
		Bubbling Temperature
		Free Water Formation Temperature
	Gases in oil	Hydrogen Evolution Trend (ppm/day)
		Off-line Gas Chromatography Test Results
	Temperature Forecast	Hot Spot Future Temperature after Stabilization
		Remaining Time to Reach Alarm Temperature
		Remaining Time to Reach Shutdown Temperature
	Simulation	Load Step Temperature Evolution Simulation
		Load Step Temperature Evolution Simulation
		Hypothetical Life Loss
Tank and Oil	Physicochemical	Off-line Physicochemical Test Result
		Water content evolution trend (ppm/day)
Cooling System	Cooling Efficiency	Top Oil Calculated Temperature

System	Engineering Model	Diagnostics and Prognostics
		Difference between measured and calculated temperatures
		Cooling System Efficiency
	Cooling Maintenance	Cooling Group Total Operating Time
		Cooling Group Operating Time after Maintenance
		Cooling Group Remaining Time until Maintenance
		Pump Vibration Alarm

Therefore, the raw data from the sensors allow us to obtain useful information for diagnosis and prognosis of the transformer status [2], [3].

5.0 - MONITORING SYSTEM ARCHITECTURE

Figure 2 shows the architecture of the step up transformer monitoring system at the Tucuruí Plant.

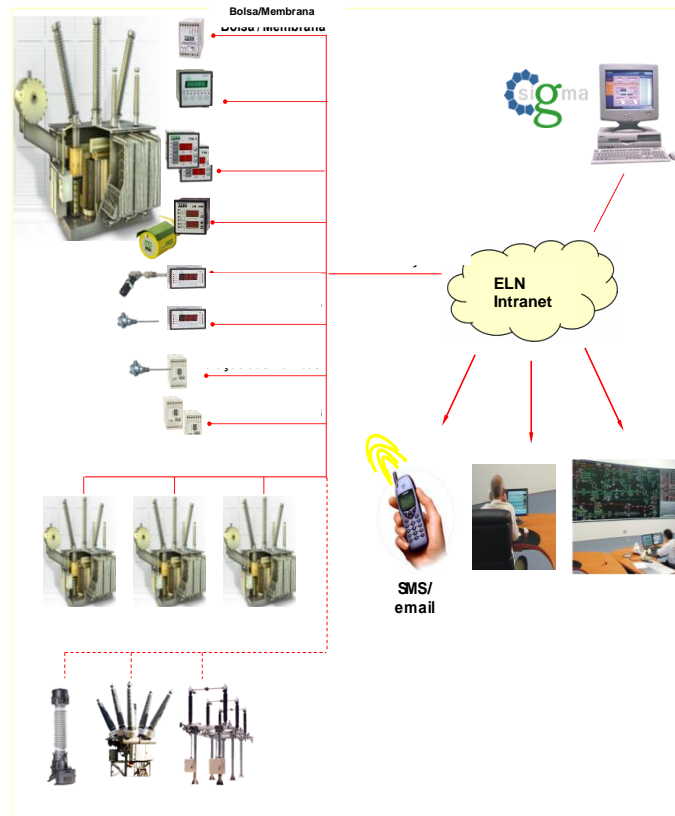


Fig. 2 Step up transformer monitoring system architecture

Variable measurement has already been shown in Table I, and it is done through smart IED sensors (Intelligent Electronic Devices), designed and tested specifically to be used in the substation yard environment which allows them to be installed directly on the transformer body.

Those sensors have communication ports which allow direct connection to a communication network, thus making it possible to transmit the measurements directly to a server in the plant's control room. The structure of the Eletrobrás Eletronorte Intranet is also used for this, making installation easier and reducing costs.

In the server in the control room the Specialist Sigma Monitoring Software is run that processes the data shown in Table II.

Through Eletrobrás Eletronorte Intranet, the users have remote access to the monitoring system, through the HTML page interface, with Web 2.0 technology.

The architecture chosen by Eletrobras Eletronorte is decentralized [4], that is, it does not use a centralizer element on the transformer body, thus avoiding additional costs and eliminating a failure point [5]. That architecture has also brought also some additional benefits to the installation, which were:

- Due to its modularity the system can be easily expanded to several transformers in the plant;
- In the same way it can be expanded to other equipments in the plant such as circuit breakers, disconnect switches, CTs, etc.
- The possibility of system expansion with the addition of new sensors.

6.0 - MONITORING SOFTWARE FUNCTIONALITIES

The main functionalities made available by the monitoring software are:

- Local access at the plant or remote access at any point of the Eletrobras Eletronorte network, through Webpages, without needing to install plugins in the user computers;
- Possibility of remote access through Smartphones, as long as the access was allowed by the system and network system.
- Alerts can be sent by email or SMS if alarms or diagnostics alerts are issued.
- Sensor data storage and engineering model storage in SQL Server Database, keeping a history of the whole transformer life;
- Online data or historic data viewing;
- Check the history through graphs, tables or exportation to XLS file (MS Excel);
- Alarm Announcer Interface with database record of the beginning, recognition and finalization of the alerts and alarms;
- Recording of all of the accesses and operations carried out by the users in the system;
- Access protected by username and password, with access category specific for each user: Viewer, Operator and Manager.

7.0 - SYSTEM INSTALLATION

The monitoring system was installed on the first transformer and started operating in 2006. It has been subsequently expanded to three other pieces of equipment, currently monitoring four step up transformers. Sensor installation is still in progress as well as the system expansion to more step up transformers. This proves the significance of the modularity features and of the expansibility of the decentralized architecture used for this kind of applications.

Figures 3 through 9 below show details of the installation:



Fig. 3 One of the step up transformers, 378 MVA 13.8/550 kV.



Fig. 4 Detail of the installation of the adaptors in the capacitive taps of the 550 kV bushings, for capacitance and tangent delta monitoring.



Fig. 5 Moisture monitor (above) and gas in oil monitor.



Fig. 6 Top oil (left) and ambient temperature sensors.



Fig. 7 Oil intake temperature sensors and heat exchanger water outlet



Fig. 8 Intelligent Sensor Panel (IEDs) on a transformer's body.



Fig. 9 Control Room monitoring Server.

8.0 - RESULTS OBTAINED

Several results were obtained with the installation and operation of the aforementioned monitoring system, and the following goals were attained:

- Reduction in the global value of insurance premium of the Eletrobrás Eletronorte facilities, for the insurance company understands the risk is being mitigated.
- Reduction in the catastrophic failure risk, with the detection of the failures at their inception [6], [7];
- Consequently, plant personnel, the equipments and the facility are safer.
- Equipment service life is increased when accelerated aging conditions are immediately detected.
- Preservation of the corporate image with a reduction of chances that accidents take place;
- Maintenance routine optimization, allowing the gradual migration from preventive to predictive maintenance, based on the equipment status instead of on time;
- Preparation of the equipments for the application of the RCM philosophy (Reliability Centered Maintenance).

Since the installation of those systems is done at the time there are long maintenance stoppages, failures are rarely detected at the time the equipment starts to operate. However, the system has recently shown an alarm of 'oil flow absence' in one of the oil circulation pumps, which led the maintenance team to go check what was happening in loco. The pump was stopping due to overload, which could lead to overheating of the transformer and consequent forced shutdown of the unit. This event serves as an example of the profits obtained with the online monitoring implantation.

With the graph generation tool available in the monitoring software (Fig. 10), it became possible to follow the evolution of defects in real time, allowing the comparative analysis between several operational values, and that made it easier and increased the reliability on failure diagnosis issuing.

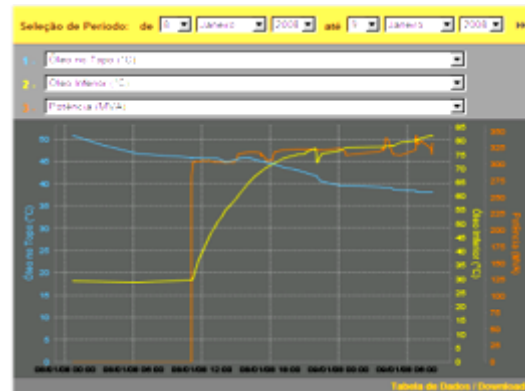


Fig. 10 Monitoring software graph generation tool.

9.0 - CONCLUSION

Considering the importance of power supply by Tucuruí Plant to the SIN, the implementation of an online monitoring system for its step up transformers is a measure of great importance to increase the reliability and availability of the electric system.

With the implantation of the system a very important objective was reached for Eletrobrás Eletronorte, which was to obtain a significant reduction of the insurance premium, since the risk has been mitigated. In addition to that, the installation of monitoring systems gets a positive assessment by insurance companies, which makes it easier to get insurance for the Eletrobrás Eletronorte facilities.

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11.0 - BIOGRAPHIC DATA



José Aliezio A. Severo was born in the city of Jardim – State of Ceará, Brazil, on May 06, 1954, and works as Senior Project and Construction Technician at Eletrobras Eletronorte since July 1989. He works in the electric equipment area, at the Hydroelectric Power Plant Electromechanical Project Management Office. He majored in Electrotechnics from CIU in Ilha Solteira, and is taking the eighth semester of the Computer Engineering course at the Uni CEUB (Centro Universitário de Brasília) - Federal District, Brazil.



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