Step Up Transformer Online Monitoring Experience in Tucuruí Power Plant

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Abstract – **The Step Up Transformers at the Tucuruí Hydroelectric Power Plant 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 these equipments. 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 when they start, and mitigate the risks even more.**

System installation started in 2006, with sensors and software. Four transformers which were already operating began to be monitored and implantation for three more was in progress, 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 were easier insurance negotiation for some equipment and more safety for the personnel, the equipment and the facility.

Keywords **– Online Monitoring, Diagnostics, Prognostics, Predictive Maintenance, Sensors, Software, Transformer, Bushing.**

I. Introduction

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

Those transformers play a critical role in the transmission of the generated energy, and are therefore essential to operate the Brazilian National Power Interconnected System (SIN). Given the importance of those equipments 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 showed that this approach was not enough. This led to the implantation of an online monitoring system to reduce failure risk with the detection of the main types of defects when they are still incipient. Preventive maintenance usually is not enough to guarantee this detection.

II. Transformer Failure Statistics

An international research by Cigré, involving operating transformer power performance [1], including failure data collected between 1968 and 1978 from over 1,000 failures, has revealed the main causes of either mandatory or planned removal from service of several transformer types and applications.

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; the active part placed second, virtually tied in second place with the tank and oil, which are the other causes. Those three subsystems of the transformer assembly caused failures that resulted in virtually 84% of the equipments being removed from service.

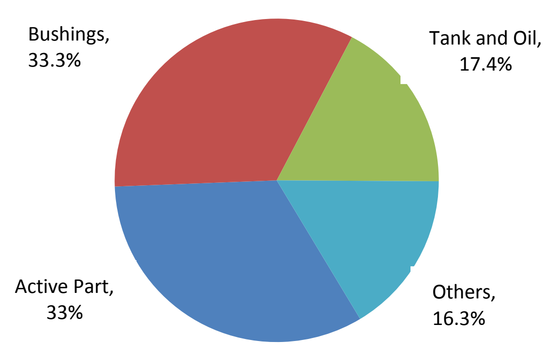

Fig. 1. Statistics of Plant transformer removal from service without OLTC [1].

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

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III. Transformer Sensors

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

TABLE I:
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
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
	Data Acquisition Module	Cooling Stages on/off
		Oil Pump Vibration
Other		Alarm Contacts - Buchholz relay - Pressure Relief Valve, - Oil Level, etc.

To entirely fulfill its objectives, the monitoring system must process the data in the table above, so more useful information are obtained on transformer status, as detailed below.

IV. Data processing for diagnostics and prognostics

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

TABLE II:
ENGINEERING MODELS FOR TRANSFORMER STATUS DIAGNOSTICS AND PROGNOSTICS

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 delta tangent critic values (days)
Active Part	Insulation aging	Insulation Remaining Service Life (%)
		Insulation Service Life Loss Trend (%/day)
		Insulation Remaining Service Life (years)
	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 Assay Results
	Temperature Forecast	Hot Spot Future Temperature after Stabilization
		Remaining Time to Reach Alarm Temperature
		Remaining Time to Reach Shutdown Temperature
	Simulation	Stepped Load Temperature Evolution Simulation
		Stepped Load Temperature Evolution Simulation
		Hypothetical Life Loss
Tank and Oi	Physical-chemical	Off-line Physicochemical Assay Result
		Water content evolution trend (ppm/day)
Cooling System	Cooling Efficiency	Top Oil Calculated Temperature
		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].

V. Monitoring System Architecture

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

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

Those sensors have communication ports which allow direct connection to a communication network, and this makes 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.

The Specialist Sigma Monitoring Software is run in the Server Control Room, and it 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.

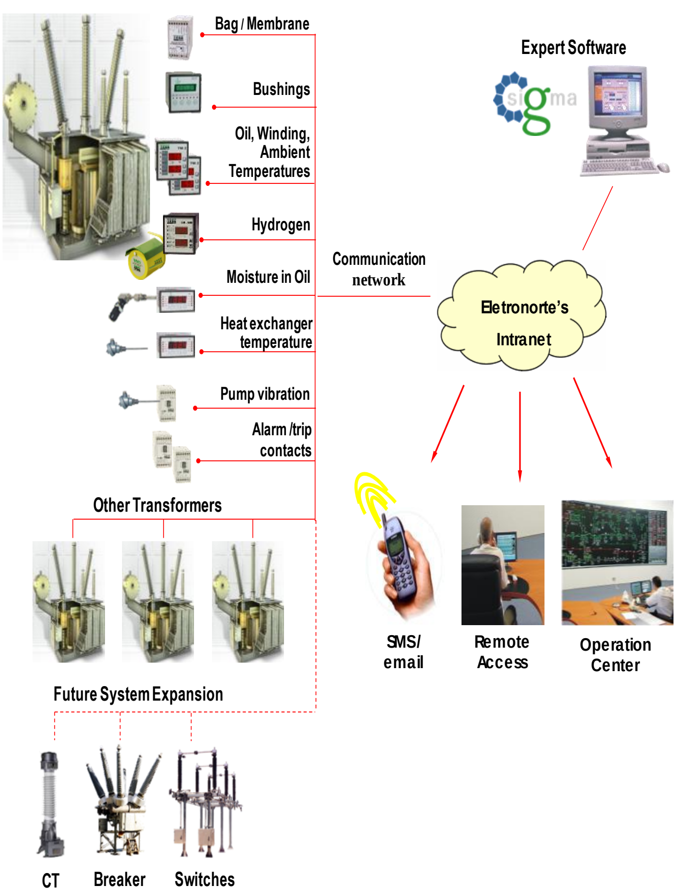

Fig. 2. Step up transformer monitoring system architecture

The architecture chosen by Eletrobras Eletronorte is decentralized [4], that is, it does not use a centralizer element on the transformer body, and with this it avoids additional costs and eliminates a failure point [5]. That architecture has also brought some additional benefits for the installation, listed below:

- Due to the modularity of the system, it can be easily expanded to several transformers in the plant;
- This also allows the system to be expanded to other equipments in the plant, such as circuit breakers, disconnect switches, Tap Changers etc.
- The system can be expanded with the addition of new sensors.

VI. 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, with no need to install plugins in the users' computers;
- Possibility of remote access through Smartphones, as long as the access is allowed by the system and network.
- 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 Databases, keeping a history of the whole transformer life;
- Online data or data history viewing;
- Check the history through graphs, tables or exportation for XLS file (MS Excel);
- Alarm Issuer Interface with database record of the beginning, recognition and finalization of the alerts and alarms;
- Recording of all of the accesses and operations by the users in the system;
- Access protected by username and password, with access category specific for each user: Viewer, Operator and Manager.

VII. System Installation

A monitoring system was installed on the first transformer, and started to operate in 2006. It has been subsequently expanded to three other equipments, currently monitoring four step up transformers.

Sensor installation is still in progress as well as the system expansion to more step up transformers.

The modularity features and expansibility of the decentralized architecture used for this kind of applications are significant.

Figures 3 through 9 below show details of the installation:


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

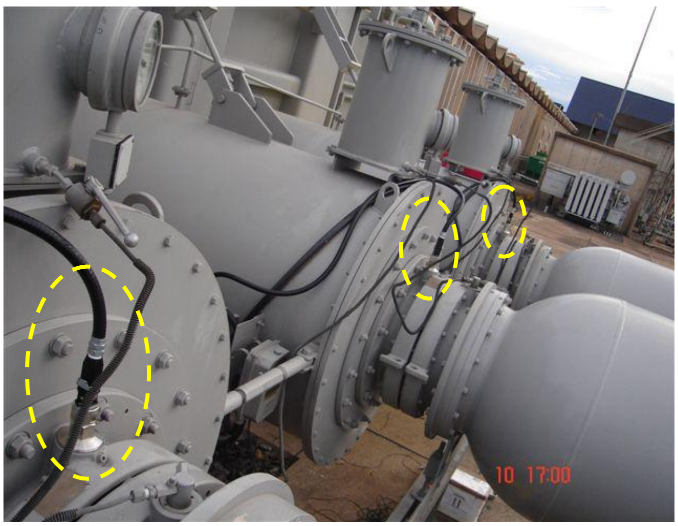
Fig. 4. Detail of the installation of the adaptors in the capacitive taps of the 550 kV bushings, for capacitance and tangent delta monitoring.


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


Fig. 6. Top oil temperature (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.

VIII. Results Obtained

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

- Reduction in the global value of insurance premium of the Eletrobrás Eletronorte facilities, because 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 workers, the equipment and the facility are safer.
- Equipment service life is increased when accelerated aging conditions are immediately detected.
- Preservation of the corporate image, with the reduction of chances of an accident;
- Maintenance routine optimization, allowing the gradual migration from preventive to predictive maintenance based on the equipment status instead of based on time;
- Preparation of the equipment for the application of the RCM philosophy (Reliability Centered Maintenance).

Since the installation of those systems is done whenever there are long interruptions of service for maintenance, failures are rarely detected at the time the equipment starts to operate. However, the system has recently shown an "oil flow absence' alarm in one of the oil circulation pumps. This prompted the maintenance team to go check what was happening in the field. 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 benefits of the online monitoring implantation.

With the graph generation tool available in the monitoring software (Fig. 10), the evolution of defects can be watched in real time, and this allows the comparative analysis between several operational values. This has also made this analysis easier, and increased the reliability on the failure diagnosis issued.

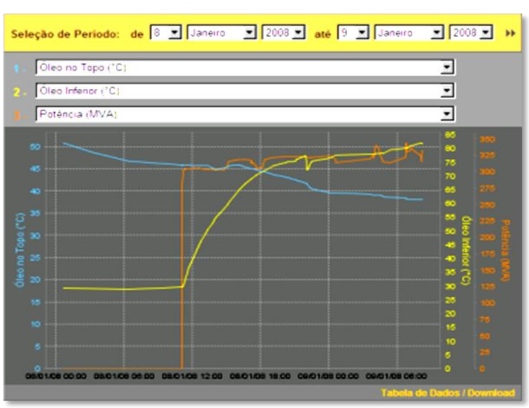

Fig. 10. Monitoring software graph generation tool.

IX. Conclusion

Considering the importance of power supply by Tucuruí Plant to the SIN, the implantation 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, Eletrobrás Eletronorte attained a very important objective: a significant reduction of the insurance premium, because the risk was mitigated. In addition to that, the installation of monitoring systems gets a positive assessment by the insurance companies. With this, it is easier to buy insurance for the Eletrobras Eletronorte facilities.

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XI. Biographies

José Aliezio A. Severe 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 graduated from CIU in Ilha Solteira, with a major in Electrotecnics, and is now taking the eighth semester of the Computer Engineering program at Uni CEUB (Centro Universitário de Brasilia) - Federal District.

Klaxon V. Fantin was born in Belém, State of Pará, Brazil, on January 02 1981, and has been working for Eletrobras Eletronorte since 2007, in association with the operation and maintenance area of the Tucuruí Power Plant. He graduated from the Federal University of Pará, Brazil with a B.S. in Electrical Engineering, and went on to earn his Master's also in Electrical Engineering. He is currently working on his Doctoral degree in Electric Engineering in the same university.

Marcos E. G. Alves (M' 2007) was born in the city of Rio de Janeiro, State of Rio de Janeiro, Brazil, on July 15, 1975, and has been working with Treetech since 1992. He majored in Power Transformer Control and Monitoring, and he currently coordinates the Research, Development and Innovation department. He graduated in 2001 from the Universidade São Judas Tadeu, in São Paulo, with an Electrical Engineering B.S. degree, and in 2005 he concluded his Masters in the Energy and Automation area from the Universidade de São Paulo He is currently taking the course of study to obtain his Doctoral degree in Energy from the same university.