ONLINE MONITORING OF CONVERTER TRANSFORMERS OF SE IBIÚNA HVDC TRANSMISSION SYSTEM

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Summary - *The relevance of Ibiúna Converter Substation for the supply of electricity to São Paulo led Furnas to select the online monitoring of converter transformers, initially by replacing mechanical temperature measurement systems with electronic monitors and subsequently with the complete monitoring of one of the converter transformers. This document provides installation details and in-field experiences concerning the online monitoring, including data transmission of transformer sensors via wireless network using Wi-Fi technology.*

Keywords: Transformers, Converters, HVDC, Online monitoring, Diagnostic, Prognostic, Predictive maintenance

1 INTRODUCTION

Ibiúna is the substation where the converter terminal of Itaipu high-voltage direct current transmission system (HVDC) is located, i.e., Ibiúna substation is the terminal where direct current is turned into alternating current (345kV 60Hz) to supply Greater São Paulo.

This system, transmitting at ±600kVdc half of Itaipu generating capacity (6,300 MW), is comprised of 8 converters, each 2 converters forming a pole and each 2 poles forming a bipole. The substation has 24 converter transformers in operation with installed capacity of 7,200MVA.

Ibiúna converter transformers are single-phase units, each having two primary windings and one secondary winding. Because they are 12-pulse converters, transformer primary windings should be fed by two three-phase systems 30º out of phase between each other. For such, one of the primary windings of single-phase units of each bank is star connected, and the other primary winding is delta connected. The three-line diagram in figure 1 shows this topology for bipole 1 pole 2 containing converters 2 and 4, which is fed at +600kVdc. Pole 1 of the same bipole has identical configuration, except that it is fed at -600kVdc.

Each transformer has two on-load tap-changers (OLTC) that are driven by a common motorized mechanism, given that the operation should be simultaneous. The automatic control system enables the OLTC when valve firing angles exceed the rated operating range. Figure 2 shows an overview of a single-phase converter transformer.

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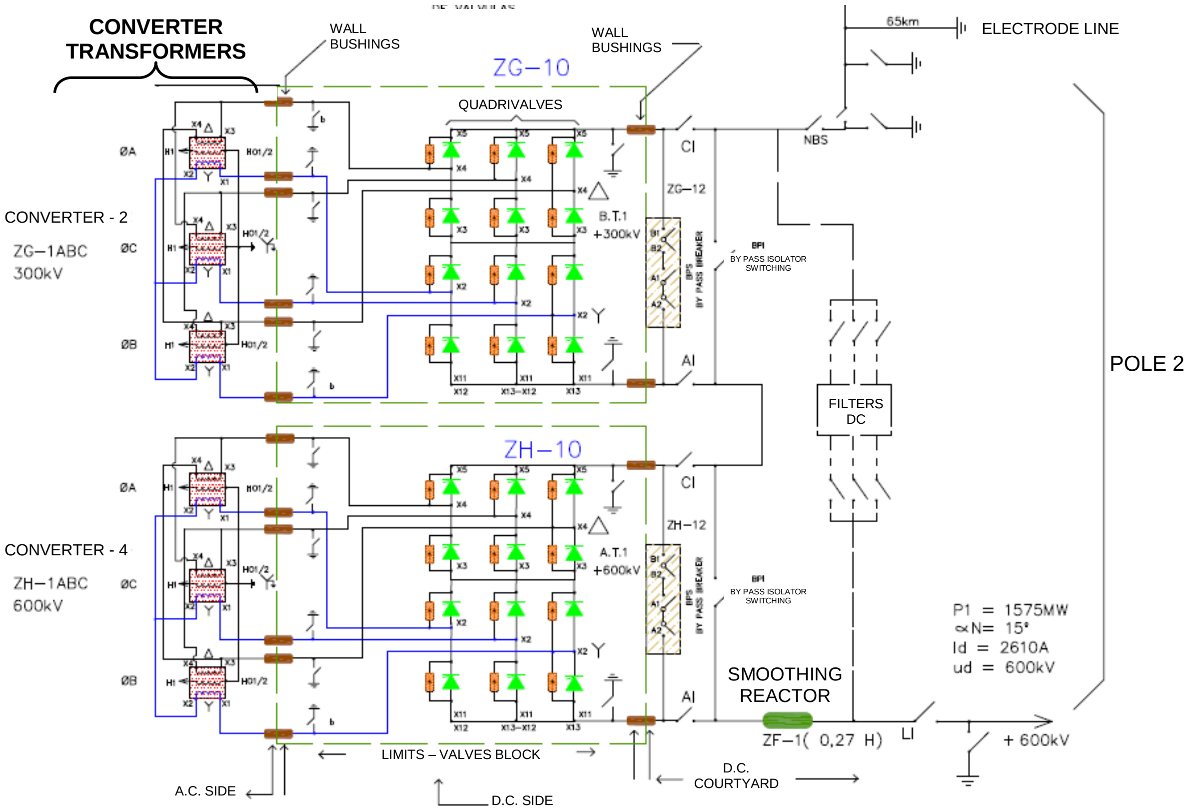


Fig. 1 - Three-line Diagram of Converter Pole

Fig. 2 - Single-phase converter transformer overview

2 CONVERTER TRANSFORMER ONLINE MONITORING

The critical relevance of these transformers for Brazilian electricity system, combined with the unique, harsh working conditions which they are subject to, such as the high content of voltage harmonics, led Furnas to implement online monitoring on these machines performed in two main stages, as described next.

2.1 Temperature Monitoring Upgrade

In the first stage of online monitoring implementation the temperature supervision systems of all 24 converter transformers were upgraded, by replacing all oil thermometers and original, mechanical windings with digital temperature monitors, as figure 3 illustrates.

(a)  (b) 

Fig. 3 - Converter transformer temperature monitoring upgrade (a) Beginning of original mechanical thermometer replacement; (b) Digital temperature monitors installed.

One of the purposes of this stage was to reduce the failure rate of oil temperature measurement system and windings, already obsolete, and remove the need for periodic calibration of these components. Additionally, upgrading the temperature supervision system provided several new functionalities:

- Redundant measurement of oil top temperature, increasing measurement safety and allowing continued operation in case one sensor fails.
- Winding template calculated by mathematical model - enhanced accuracy without the use of heating resistance for simulation;
- Possibility of measuring additional temperatures such as ambient and on-load tap-changer temperatures;
- Self-calibration of measurements;
- Output contacts for alarms, switch-off and cooling commands with timing;
- Current outputs for remote indications of integrated temperatures - removing transducers;
- Cooling command on manual or automatic mode;
- Automatic switchover of forced cooling groups;
- Transformer pre-cooling in case of load current increase;
- Automatic daily drills of cooling groups;
- Mass memory for measurements and events;
- As an option, monitoring of OLTC temperature differential for fault diagnosis.
- Serial communication ports for integration to remote systems.

This latter functionality - serial communication ports - specially opens the possibility of integrating the temperature monitors to an Online Monitoring software, so that the measurements taken by the equipment may be used by mathematical algorithms for transformer status diagnosis. Figure 4 illustrates this application, which indicates that algorithms may be implemented in the monitoring software based on information sent by the Temperature Monitor.

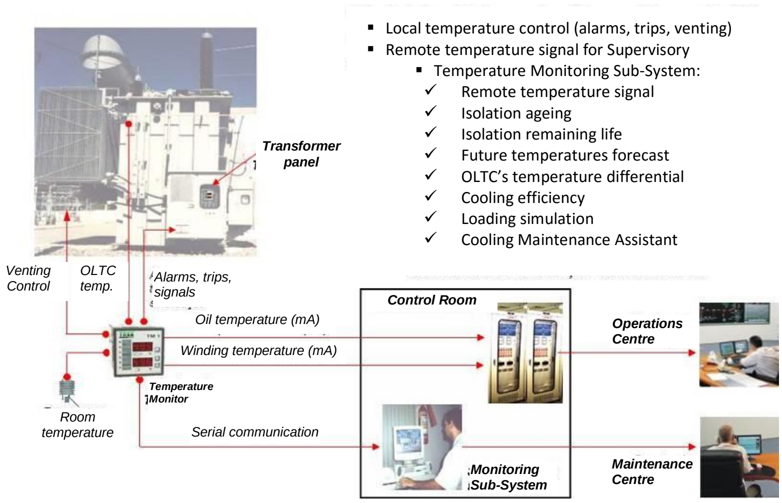
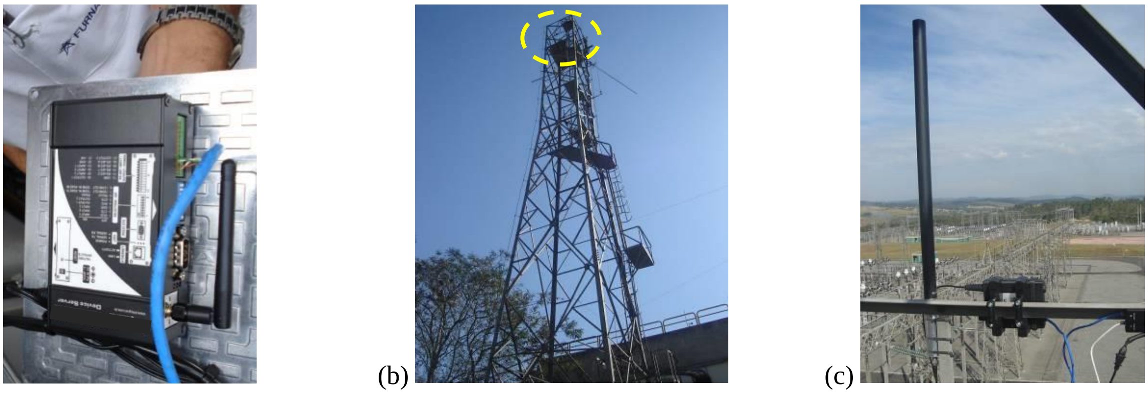


Fig. 4 - Temperature Monitor serial communication port integration to a transformer Online Monitoring software and possible diagnosis algorithms.

To run the Online Monitoring software a server was installed in the substation control room, which is connected to transformer Temperature Monitor serial ports. Initially, the physical media used for this connection were shielded twisted-pair cables. Later, in order to render network installation easier and reduce its costs, Wi-Fi wireless communication was used, which is now in operation with fully satisfactory results despite the high level of electromagnetic interference in this substation. Figure 5 shows the components for wireless communication.



(a) (b) (c)

Fig. 5 - Monitoring System Communication Components. (a) Wi-Fi communication module installed next to temperature monitors and other sensors on transformer body; (b) Tower next to control room where the Access Point was installed for communication with transformer sensors; (c) Access Point detail with antenna and view towards the substation.

To ensure secure access to the Wi-Fi network MAC addresses filtering was implemented in the Access Point, so that only with previously registered MAC are able to be connected. As additional measure, WEP data encryption was used.

2.2 Online Monitoring of Converter 4 Transformers

One of the main features of the monitoring system implemented in SE Ibiúna is its modular design, allowing that new monitoring functions or even new equipment to be easily added. Leveraging on this feature, the second implantation stage of online monitoring for transformers was comprised of adding several sensors to Converter 4, as well as corresponding monitoring software modules. Table I below lists the sensors installed and their corresponding functions, including the existing Temperature Monitor in this transformer.

TABLE I. SENSORS INSTALLED ON CONVERTER 4 TRANSFORMER, THEIR CORRESPONDING MEASUREMENTS AND LOCAL INDEPENDENT FUNCTIONALITIES

Sensor	Measurements Performed	Local Independent Functions
TM1 and TM2 Temperature Monitors	- Oil Temperature; - Temperature of hottest point in Windings - Load current	- Alarm and switch-off by Oil temperature - Alarm and switch-off by Winding temperature - Forced Cooling automatic and manual control - Transformer pre-cooling by load increase - Daily fan drills - On-Load Tap-Changer temperature differential
BM Bushing Monitor	- Bushing capacitance - Bushing delta tangent	- Capacitance upward trend - Delta Tangent upward trend - Time for High/Very High Capacitance Alarms - Time for High/Very High Delta Tangent Alarms
Dissolved Gas-in-Oil Monitor	- Content of dissolved hydrogen in transformer oil (ppm) - Oil temperature at hydrogen measurement point	- Content of hydrogen in oil upward trend - High or Very High hydrogen in oil alarms - High H2 in oil upward trend alarms
DM1/DM2 signal Digitalization Modules	- Measurement of alarm dry contact state - Measurement of transformer oil level	
OLTC Oil Humidity Monitor	- Relative saturation (%) of water in oil - Content of water in oil (ppm) - Oil temperature	- Content of water in oil upward trend - High or Very High water in oil saturation (%) alarms - High or Very High Content of water in oil alarms - High water Content upward trend alarms
Transformer Oil Humidity Monitor	- Relative saturation (%) of water in oil - Content of water in oil (ppm) - Ambient temperature - Oil temperature	- Content of water in oil upward trend - High or Very High water in oil saturation (%) alarms - High or Very High Content of water in oil alarms - High water Content upward trend alarms
Bladder Burst Relay	- Expansion tank bladder burst	- Burst bladder alarm
DTM Temperature Monitor	- Oil Temperature at heat exchanger inlets - Oil Temperature at heat exchanger outlets	
PI Position Indicator	- On-Load Tap-Changer tap position	

Based on the measurements of the sensors above, the monitoring software uses the following Engineering Modules shown in table II for data processing, so as to provide to user diagnostics and prognostics of transformer state.

TABLE II. ENGINEERING MODULES FOR TRANSFORMER STATE DIAGNOSTICS AND PROGNOSTICS

Engineering Modules	Diagnostics and Prognostics Performed
Insulation Aging	• Loss of Insulation Service Life • Loss of service life rate • Remaining service life prediction, in years.
Future Temperature Forecast	• Winding temperature after thermal stability • Forecast of alarm and switch-off events • Calculation of remaining time for alarm and switch-off events.
Cooling Efficiency	• Calculation of expected oil temperature according to load, ambient temperature and operating cooling group • Comparison with actual temperature measured and alarm in case of cooling low performance - measured temperature way above the expected

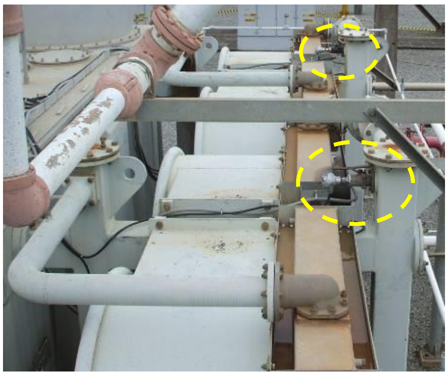
Engineering Modules	Diagnostics and Prognostics Performed
Cooling Group Maintenance	• Cooling group running hours since start up • Cooling group running hours since last maintenance • Cooling average daily running hours • Prediction of remaining time for inspection or maintenance • Advance warning for inspection or maintenance.
Water in Oil and in Paper	• Content of water in Oil • Content of water in Paper • Acceleration of loss of insulation service life by excess of water • Bubble Formation Temperature by excess of water • Free Water Formation Temperature by excess of water in oil
OLTC Temperature Differential	• Tap-changer instantaneous temperature differential • Tap-changer filtrate temperature differential
Chromatography	• Online measurement of dissolved hydrogen in oil • High, very high or upward trend H2 content alarm • Offline gas chromatography analysis database • Calculation of gas increase rates • Reports for gas chromatography analysis according to IEC60599 and Duval
Physical-chemical	• Offline physical-chemical tests in oil database • Automatic reports according to NBR10576

3 FIELD EXPERIENCE WITH ONLINE MONITORING

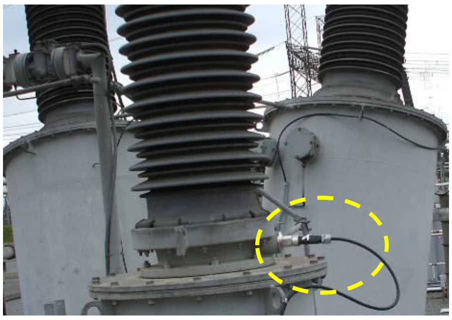
The first installation stage of converter transformer monitoring system, covering the replacement of mechanical thermometers with Temperature Monitors, was performed from 2006 to 2007. The second installation stage, in which remaining sensors were added for complete Converter 4 monitoring, was performed in July/2008.

Figure 6 shows some details of sensor installation and necessary adjustments for such, as transformers were constructed in the 1980's and were not prepared for that. In general, the installation was successful as sensors are operating as expected after start up.

(a) 

(b) 

(c) 

(d) 

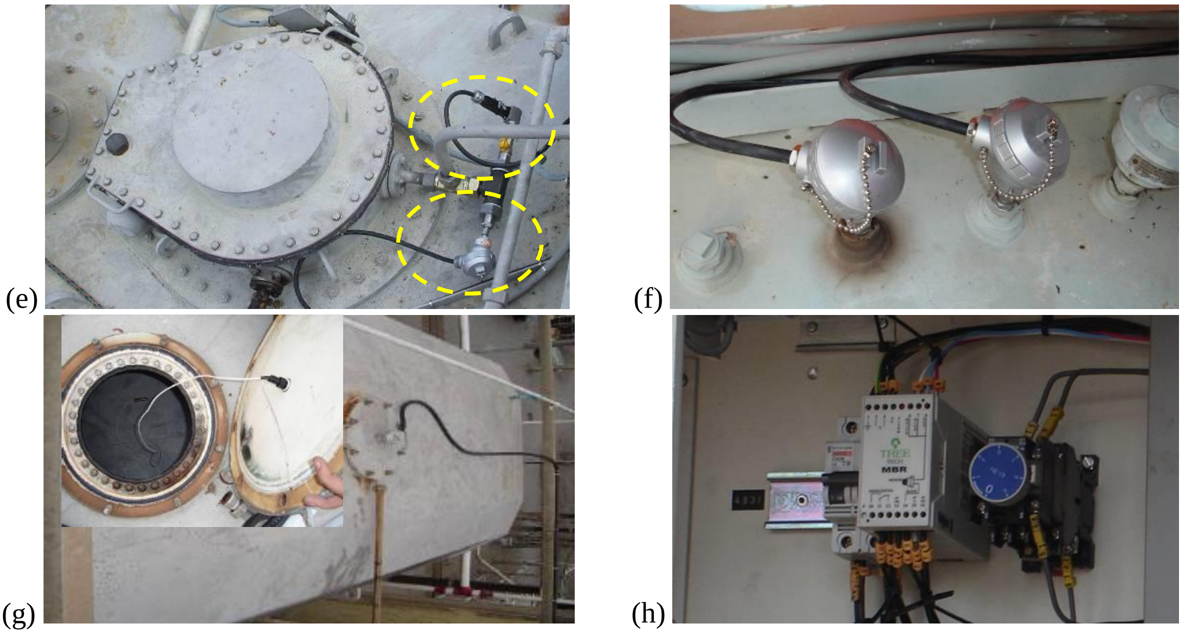


Fig. 6 - In-field installation of Monitoring sensors. (a) Panel with monitoring equipment and ambient temperature sensor; (b) Oil temperature sensor at heat exchanger inlet and outlet; (c) Gas and oil humidity sensors on transformer; (d) Connections to bushing taps; (e) OLTC oil humidity and temperature sensors; (f) Redundant temperature sensors for oil top; (g) Ladder burst sensor; (h) Ladder burst relay.

Following commissioning, the monitoring system started recording the measurements in database, as shown in the example of figure 7, where a chart shows oil and winding temperatures and contents of water in transformer oil and on-load tap-changer oil.

Fig. 7 - Examples of measurements recorded in history database

Because of the large geographical area covered by Furnas, as well as the large number of transformers used, one of the main requirements for a monitoring system is the remote access to information. To allow this access from any point within its facilities, the existing Intranet network in the company was the communication means selected.
For that, the monitoring server located in the control room is connected to the In order with access to data, information, diagnostics and prognostics performed from any computer in the company network.
In addition, with transformers in normal operating conditions, which is expected most of the time, the monitoring system will remain in static condition only eventually issuing a fault diagnosis.
To remove the need for ongoing system tracking, which would consume a great deal of time of the maintenance team, the monitoring system was equipped with an automatic email sending device in case any abnormality is found. For that, the email addresses of people who should be warned must be previously registered in the system.
Figure 8 below shows some examples of typical screens with online measurements and diagnosis of the monitoring system.

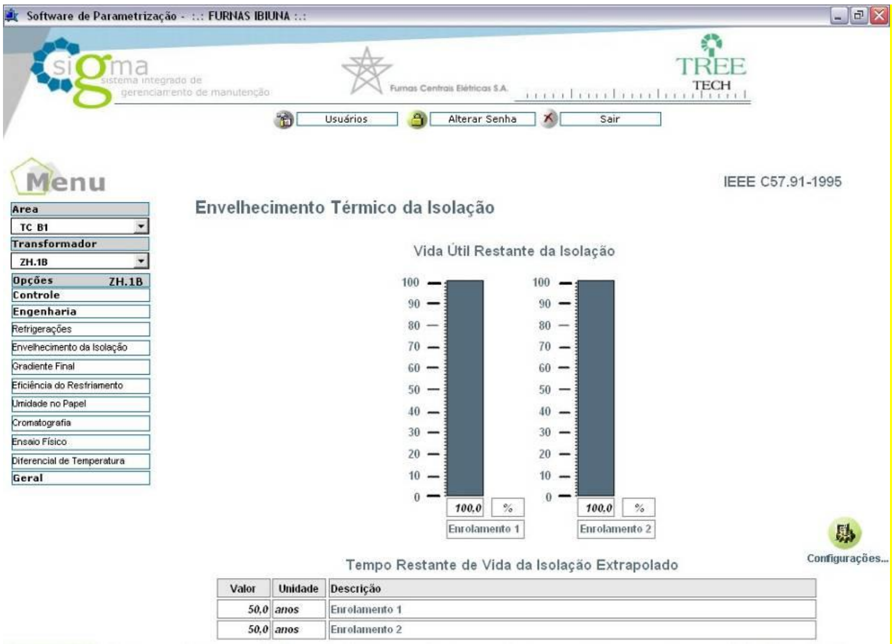


Fig. 8 - Typical monitoring system diagnosis screen

4 CONCLUSIONS

Experiences with the implementation of online monitoring and their practical outcomes achieved concerning HVDC Converter Transformers have been allowing to assess the benefits and effectiveness of the decentralized architecture of sensors, communication means and software solutions used, as well as the ruggedness of the electronic equipment installed in SE Ibiúna, which have been showing satisfactory results.

We may highlights the following benefits provided by the monitoring system installed:

- Elimination of costly and time-consuming annual thermometer calibration procedures;
- Extension of transformer service life by fast detection of conditions that could cause accelerated degrading, such as conservator tank ladder burst;
- Reduced risks of catastrophic failures through, for example, online monitoring of hydrogen in oil;
- Increased equipment availability for the electrical system due to reduced preventive maintenance shutdowns, for example, for bushing tests;
- As a result, reduced maintenance costs and, eventually, insurance costs and others.

Given that the application of HVDC technology for electricity transmission from other hydropower projects in the north of the country is under consideration, the experience with the implementation of online monitoring for SE Ibiúna converter transformers could be highly valuable to enhance reliability and full performance of these new applications.

5 REFERENCES

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