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Integration of On-Line Monitoring to Maintenance Engineering Routines

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ABSTRACT

Since the year 2000, Celeo Redes has been operating on the power transmission industry, and now has 12 Utilities, one of which is under construction, in 11 Brazilian States, totaling more than 3,900 km of 500- and 230-kV transmission lines, and twelve substations with installed capacity of 4,875 MVA.

In the ongoing quest for excellence in maintenance practices and increased reliability, while reducing the transmission system unavailability and maintenance costs, Celeo maintenance engineering seeks to apply state-of-the-art, highly effective tools and technologies. Based on this principle, the implementation of on-line monitoring of the autotransformers and reactors of the group's concessions started in 2011, and now covers virtually all the assets of these families, totaling 38 devices, in addition to some smaller devices – but important for transmission functions, such as grounding transformers.

This paper introduces the corporate system solution adopted to achieve this goal, making use of the corporate Information Technology structure to ensure the proper system maintenance, thus ensuring its continuity, with excellent outcomes, in a similar way to what is already done by default for other corporate systems, such as ERP, SAGE and others.

The paper intends also to introduce a selection of subsystems to be monitored and, consequently, the sensors used, the communication network architecture that enabled integrating substations located in five States of four regions of the country.

Finally, the paper will report on how the corporate monitoring system was integrated into Celeo's maintenance engineering routines, contributing to the achievement of important results in equipment failure risk reduction, reduction of shutdowns for maintenance, reduction of maintenance costs, and, consequently, improvement of the operating results. For this purpose, real-world cases of detection of risk conditions for reactors operating in regions with high ambient temperatures, as well as the mitigation actions in progress.

Therefore, the article will demonstrate how useful the information provided by the monitoring system are, as well as the feasibility of using it to positively influence maintenance routines at transmission utilities.

KEYWORDS

Power transformers, Shunt reactors, Maintenance management, Asset management, On-line monitoring, Status diagnostics, Status prognostics, Smart sensors, Smart electronic devices.

1.0 - INTRODUCTION

Since the year 2000, Celeo Redes has been operating on the power transmission industry, and now has 12 Utilities, one of which is under construction, in 11 Brazilian States, totaling more than 3,900 km of 500- and 230-kV transmission lines, and twelve substations with installed capacity of 4,875 MVA.

In the ongoing quest for excellence in maintenance practices and increased reliability, while reducing the transmission system unavailability and maintenance costs, Celeo maintenance engineering seeks to apply state-of-the-art, highly effective tools and technologies. Based on this principle, the implementation of on-line monitoring of the autotransformers and reactors of the group's concessions started in 2011, and now covers virtually all the assets of these families, totaling 38 devices, in addition to some smaller devices – but important for transmission functions, such as grounding transformers.

The objectives to be achieved in this process include:

- Migration from Preventive Maintenance to Predictive Maintenance
- Increased reliability and reduced risk of faults
- Reduction of maintenance shutdowns and variable parts
- Maintenance management adhering to the predictive maintenance philosophy
- Management system adhering to the industry regulations (ANEEL/ONS)
- Maintenance management system adhering to the power industry practices
- Modular, expandable architecture
- Platform ready for incremental growth of functions (Apps)

These objectives are in line with the evolution of the maintenance techniques and corresponding expectations pointed out by Moubray (1), as shown in figures 1 and 2

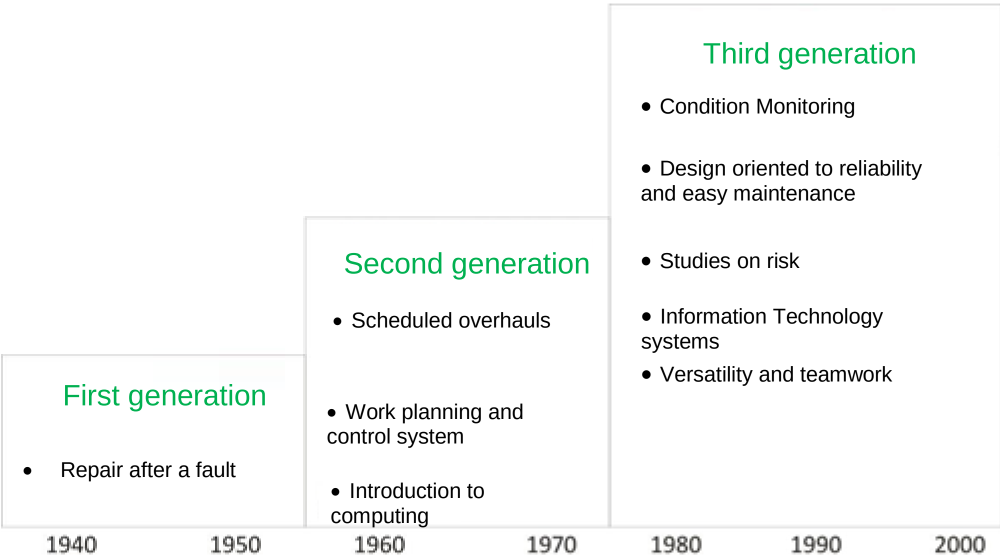

FIGURE 1 - Evolution of the maintenance techniques (1)

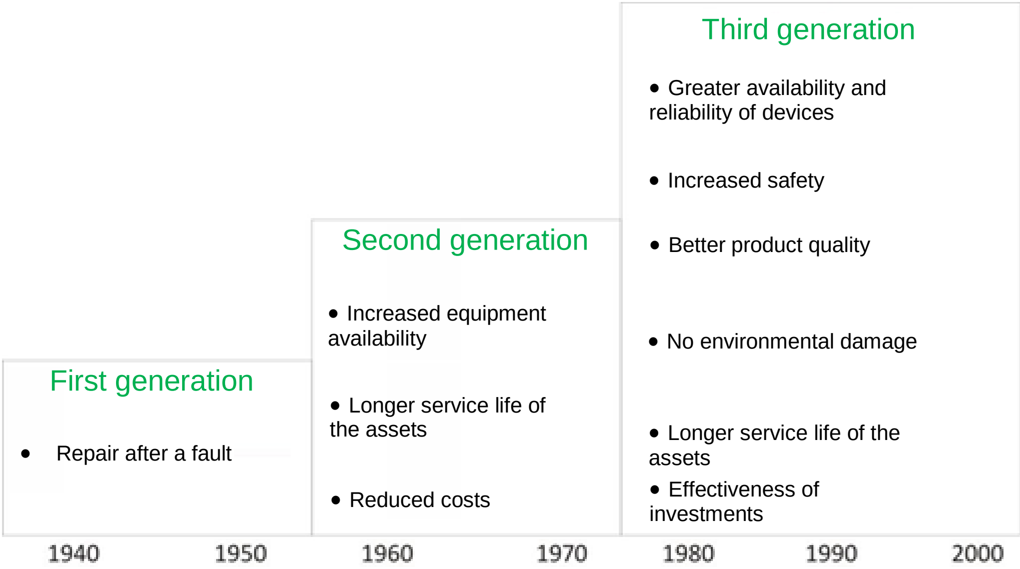

FIGURE 2 - Growth of the maintenance expectations (1)

2.0 - SOLUTION IMPLEMENTATION

The implementation of on-line monitoring and the modernization of maintenance processes at Celeo were carried out in a hierarchical sequence of stages, following the architecture shown in figure 3. The pyramid shown in this figure provides us an insight that the implementation process has sought to build a solid architecture where the proper implementation of a stage lays the foundation to move to the next stage in a consistent manner, thus ensuring the desired final results.

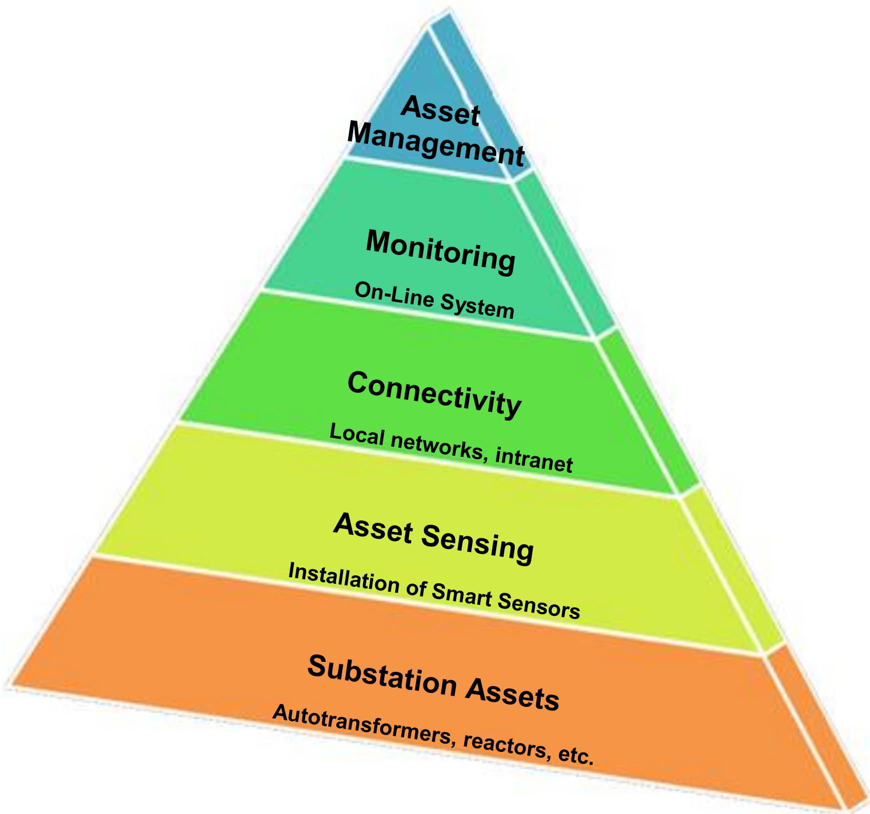

FIGURE 3 - Implementation architecture for on-line monitoring at Celeo Redes

The steps completed to implement the on-line monitoring at Celeo Redes are detailed in the following topics.

2.1 - Stage 1 - Asset Sensing

Asset sensing is considered a fundamental stage for the construction of a functional, reliable on-line monitoring system. For this reason, it was the first step when implementing this system at Celeo.

Figure 4 shows the primary sensing modules available for power transformers, autotransformers and reactors, which were the devices chosen for the initial system implementation, since they are the most valuable ones at Celeo substations.

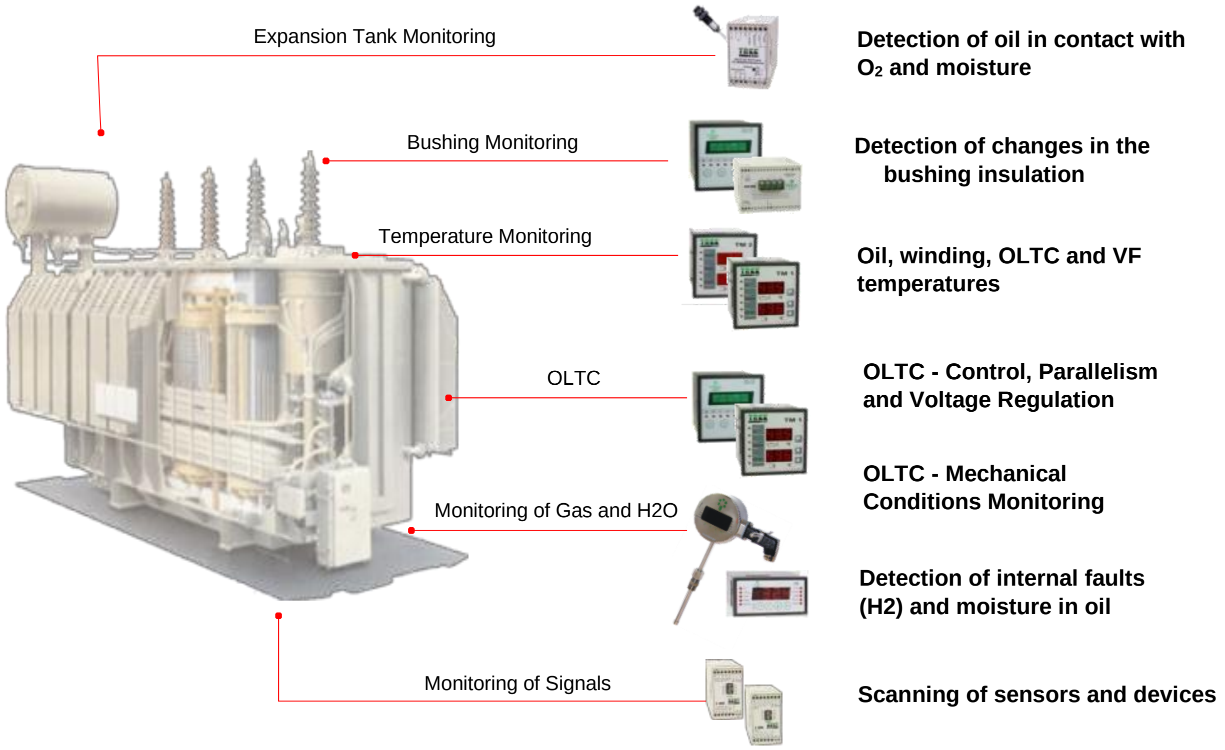

FIGURE 4 - Sensing of power autotransformers and reactors, as applicable

The decentralized and modular architecture (2) used by Celeo for asset sensing allowed, at first, that the sensors deemed priority for the company were selected, thus allowing the monitoring of all assets in these families, totaling 38 devices, in addition to some smaller devices – but very important for the transmission functions, such as grounding transformers.

Table 1 lists the Smart Sensors selected for installation at this deployment stage, in addition to the variables measured and calculated by each of these modules.

As mentioned earlier, the decentralized, modular architecture used will allow, at future stages of system expansion, expanding the sensor base installed in the autotransformers and reactors with other types of sensors, as shown in figure 4.

This architecture will also allow extending the on-line monitoring system to other substation assets, such as circuit breakers, disconnecting switches, etc.

Table 1 - Smart sensors installed at the first On-Line Monitoring implementation stage

Smart sensor	Acquired and processed variables
Temperature Monitor	Oil top temperature
	Winding temperatures (hottest spot)
	Ambient temperature
	Charge currents
	Charging percentages
	Final temperature gradients between winding and oil
	Maximum temperatures reached
	Status of the forced cooling groups
	Status of alarms and trips by oil and winding temperatures
Bushing Monitor	Insulation capacitance
	Delta tangent [FP] of insulation
	Capacitance evolution trend
	Delta Tangent evolution trend
	Time expected to reach critical capacitance values
	Time expected to achieve critical Delta Tangent values
	Bushings leakage currents

2.2 - Stage 2 - Sensors Connectivity

At the Asset Sensing stage, a decentralized, modular architecture was adopted, using Intelligent Electronic Device (IED)-type sensors with native connectivity, i.e., with open communication ports and protocols.

This architecture made integrating the sensors into a local communication network easier, which takes the variables acquired and processed there to the corporate intranet network, already available in the control room of all substations.

As a result, the data from smart sensors was made available for the next stage of the on-line monitoring system implementation, as detailed below.

We stress that the architecture used simply allows expanding the sensing of the assets, since the new smart sensors to be installed can be easily connected to the existing communication network.

2.3 - Stage 3 - Online Monitoring Software

Since the Smart Sensors installed in the autotransformers and reactors are connected to the corporate intranet network, a single on-line monitoring software product was deployed at Celeo Redes for diagnosis and prognosis of the state of all assets, thus constituting a corporate system as shown in figure 5.

Adhering to the philosophy of using a single corporate monitoring system yielded several benefits, the primary ones being:

- Clear allocation of the responsibility for monitoring software maintenance to the corporate IT, which ensures data integrity and availability of the computing environment and the system
- Avoid installing a large number of computers at the various substations
- Reduced deployment and maintenance costs
- Prevent the sprawl of multiple versions and models of on-line monitoring software
- Easy training for users and system administrators
- Consolidation of all asset data into a single database and platform, facilitating reporting and information mapping.

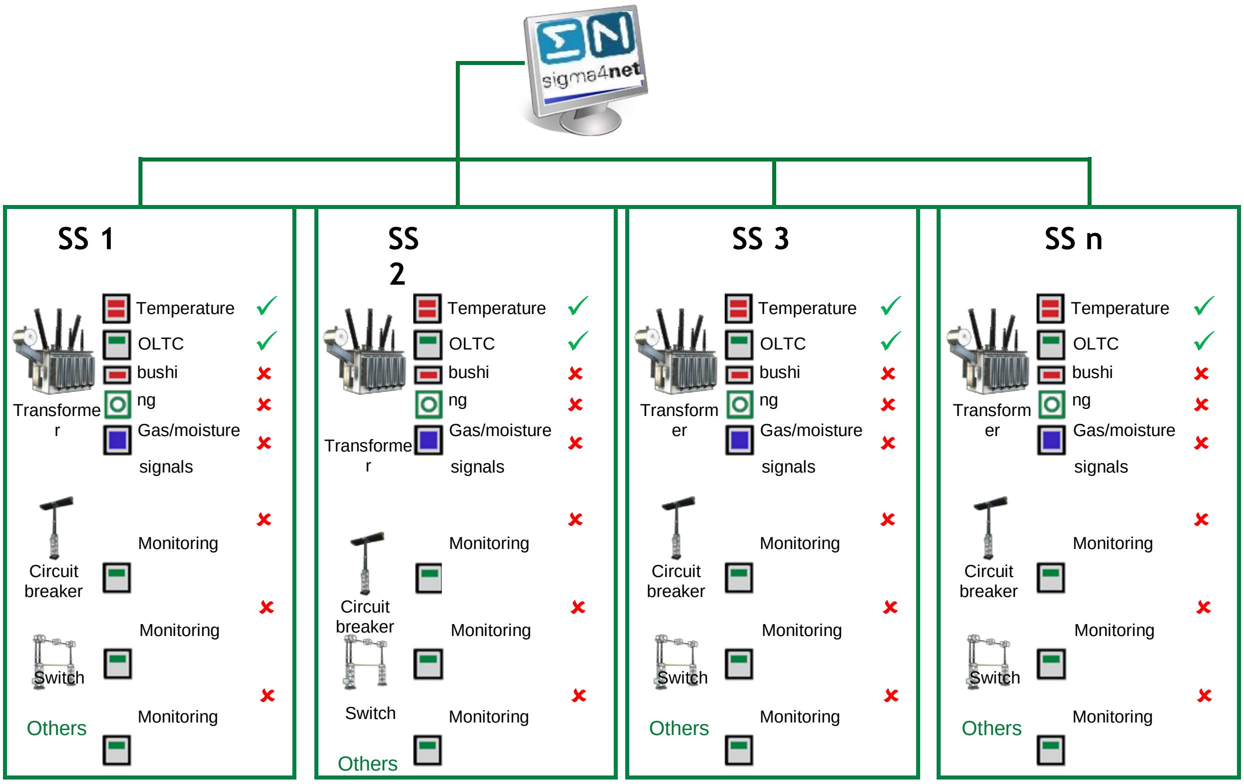

FIGURE 5 - Connecting Smart Sensors at the substations to the Corporate On-Line Monitoring Software

In order to reach the final objectives of the on-line monitoring system with respect to the effective management of Celeo Redes assets, the corporate software deployed includes diagnostic and prognostic algorithms, called Engineering Modules, which can also be expanded as new Smart Sensors are deployed (3) (4). Based on the smart sensors currently deployed in the Celeo autotransformers and reactors, the monitoring system was initially equipped with the Engineering Modules listed in Table 2.

Table 2 - Engineering Modules initially deployed in the corporate On-Line Monitoring system

Engineering Module	**Diagnostic and Prognostic Functions**
Insulation Aging	Insulation aging
	Remaining service life of the insulation
	Service life loss rate
Temperatures forecast	Future temperature forecast
	Remaining time to reach alarm and trip temperatures
Cooling efficiency	Calculated theoretical temperature
	Difference between actual and calculated temperatures
Cooling maintenance assistant	Operation time of cooling groups
	Average daily operating time
	Time remaining until next maintenance
	Early maintenance warnings
Bushings diagnosis	Bushings capacitance
	Bushings delta tangent
	Capacitance and Delta Tangent evolution trends
	Quick evolution of faults in bushings
Charging simulations	Simulation based on the current load and temperature conditions
	Hypothetical charge cycle simulation
Gas-chromatography (off-line)	Gas-in-oil evolution rates
	Ratio between gases
	Diagnostics based on IEC 60599
	Diagnosis based on Duval's triangle in IEC 60599
Physico-chemical (off-line)	Diagnostics based on NBR 10576

3.0 - INTEGRATION INTO MAINTENANCE ENGINEERING ROUTINES

Integrating the corporate on-line monitoring system into Celeo's maintenance engineering routines contributed to the achievement of important results in equipment failure risk reduction, reduction of shutdowns for maintenance, reduction of maintenance costs, and, consequently, improvement of the operating results.

The procedures adopted to implement this integration included the monthly issue of a report on abnormalities in the monitored devices, which is submitted to the company's technical board during a monthly maintenance engineering discussion meeting.

A real-life example of the results obtained from this integration was the detection of risk conditions for shunt reactors operating in regions with high ambient temperatures, allowing risk mitigation measures.

Thus, the implementation of on-line monitoring of autotransformers and reactors at Celeo Redes utilities has achieved the initially proposed objectives, which led the company to move to the next stage shown in Figure 3, namely the implementation of a corporate asset management and maintenance system, described below as the vertical evolution of the solution.

Parallel to this vertical evolution, the organic and natural evolution of the currently implemented solution is in progress as well, consisting of adding new sensors and engineering modules for autotransformers and reactors, and of extending the system to other strategic assets at the substations.

4.0 - VERTICAL EVOLUTION OF THE SOLUTION

The implementation stages for the on-line assets monitoring, mentioned in this article, are currently implemented and consolidated at Celeo Redes, and the expected benefits are already being reaped.

As a result, the next steps in the evolution of the solution are currently in progress, including the implementation of a corporate asset management and maintenance system with native integration to the on-line monitoring system, in order to consolidate the path towards to the final adoption of predictive maintenance, and with technology-based productivity tools, such as mobile applications for field teams.

These system evolution stages will be presented in a timely manner in subsequent papers.

5.0 - CONCLUSION

The paper demonstrated, with a real-world case, the feasibility of integrating on-line asset monitoring systems into maintenance engineering routines, as well as the benefits of such integration.

The heavy reliance of the integration success on selecting a sensing architecture suited to the reality of the power utilities and on establishing a system building process based on logical, sequential stages has been demonstrated as well.

The next solution evolution stages have been indicated as well, being currently at company, and these will greatly enhance the benefits from the technological maintenance upgrade strategically adopted by Celeo Redes.

6.0 – REFERENCES

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7.0 - BIOGRAPHICAL DATA

Marcos E. G. Alves: D. Sc. in Sciences (2013) and M. Sc. in Electrical Engineering (2005) from Universidade de São Paulo, and B. S. in Electrical Engineering from USJT (2001). R&D Director at Radice Consultoria, where he supervises RD&I projects, and Technical Manager at Treetech Sistemas Digitais, where he has been working since 1992, and coordinated the RD&I department. Specialized in control, security, monitoring, diagnosis, and management systems for high voltage assets, such as transformers, reactors, circuit breakers, switches, and TIs. Member of COBEI/ABNT (Brazilian Committee on Electricity, Electronics, Lighting and Telecommunications), where he contributed to the drafting of the Brazilian technical standards; and member of IEEE/PES (Power and Energy Society) since 2007, and of Cigré since 2001, where he has participated in several Working Groups. Born in Rio de Janeiro, 1975.