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EXPERIENCE WITH THE DEPLOYMENT OF A NATIONAL CENTER FOR SMART MANAGEMENT OF ASSETS IN PARAGUAY

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SUMMARY

With the purpose of assuring good supply of Electric Power to its 1.3 million customers spread on a 406,800 km^2 area, ANDE - Administración Nacional de Electricidad, which is the company in charge of the whole generation, transmission and distribution of electric power in Paraguay, implemented a modern national center for smart management of assets. At this center, the performance of important assets located at several substations throughout the country is monitored on-line, which enables to plan more efficient investments and maintenance routines. This article provides details on the achievement of this project.

KEYWORDS: Corporate system, asset management, sensor, IED, power transformer, OLTC, gas in oil, moisture in oil, chromatography, on-line monitoring.

1.0 - INTRODUCTION

ANDE – Administración Nacional de Electricidad, is responsible for the whole generation, transmission and distribution of electric power in Paraguay, servicing near 1.3 million customers in a population of near 7 million inhabitants, within an area of 406,800 km^2. To do that, it operates 5,000km of transmission lines at voltages of 66, 220 and 500 kV and has 66 substations with installed transformation capacity above approximately 6,000 MVA. In terms of generation, it has installed power of near 9,000 MVA available.

By considering the essential role performed by ANDE for electric power supply to Paraguay as a whole, and its economical and social relevance, we can observe an increasingly high degree of requirement for reliability and quality of the power supply combined with the need for low-cost energy rates.

Within this context, the modernization of maintenance procedures is crucial for increase of high-voltage equipment reliability in order to face and overcome the challenges presented. This can be achieved by migration from preventive to predictive maintenance, reducing unnecessary interventions, thus enabling to concentrate the workforce to solve real problems, while preventing equipment failures and power outages.

The big technological leaps occurred in the last years, both in the Information Technology area and in the development of smart expert sensors to be used with high-voltage equipment, is providing a great contribution to make feasible and enable fast deployment of the proposed modernizations, thus achieving positive results almost immediately.

Therefore, ANDE presents in this article its hands-on experience with the use of the state-of-the-art technologies available for deployment of a corporate IT system for management of high-voltage

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assets, starting with the power transformers, but already prepared to the other pieces of equipment at stations, such as circuit breakers, disconnecting switches and others.

2.0 - THE SUBSTATIONS AND TRANSFORMERS MONITORED

The smart asset management center concentrates information of the monitoring systems of several substations throughout Paraguay. The information provided by these systems is the raw material for asset management, including the predictive and preventive management plans.

The project included 33 transformers spread over 13 substations. Some of them, newly purchased by ANDE, have already been delivered with all the required sensors. Other old ones, but considered as critical, have been equipped with smart sensing upon the decision of building the center. In addition, 28 additional transformers should be included in the system within the next months, in order that the current expectation is that the center monitors 61 transformers, although new assets can be integrated at any time.

The composition of these substations is very diversified, including 3-phase and single-phase transformers from several suppliers, and with different power specifications and manufacturing dates. The system architecture of the system chosen is modular and decentralized. Thus, the inclusion of the desired transformers did not present any special hindrance, even when they where equipped with different IEDs or when we chose for adding new sensors to existing systems.

Shown on the table below are the substations integrated to the smart management center, as well as a summary of the profile of transformers and sensors used for monitoring the machines.

Currently

Substations:	**Transformers:**		**Sensors:**	**No**
ES - Acaray	Single-phase:	24	Temperature Monitor TM1	33
ES - Presidente Franco	3-phase:	9	Moisture Monitor MO - Transformer	16
ES - Campo II	Lowest Power:	20 MVA	Moisture Monitor MO - OLTC	18
ES - Capiatá	Highest Power:	81.6 MVA	Gas Monitor GMP	33
ES - General Días	Oldest:	1989	Bushing Monitor BM	11
ES - Guarambaré	Newest:	2014	Torque Monitor IDM	12
ES - Hernandarias			Voltage Regulation AVR	1
ES - Lambaré				
ES - Luque				
ES - Pedro J. Caballero				
ES - Puerto Botánico				
ES - San Antonio				
ES - San Lorenzo				
Soon	**Transformers:**	**28**	**Sensors:**	**105**

Figure 1 below shows the Paraguay map with the disposition of substations included in the project scope.

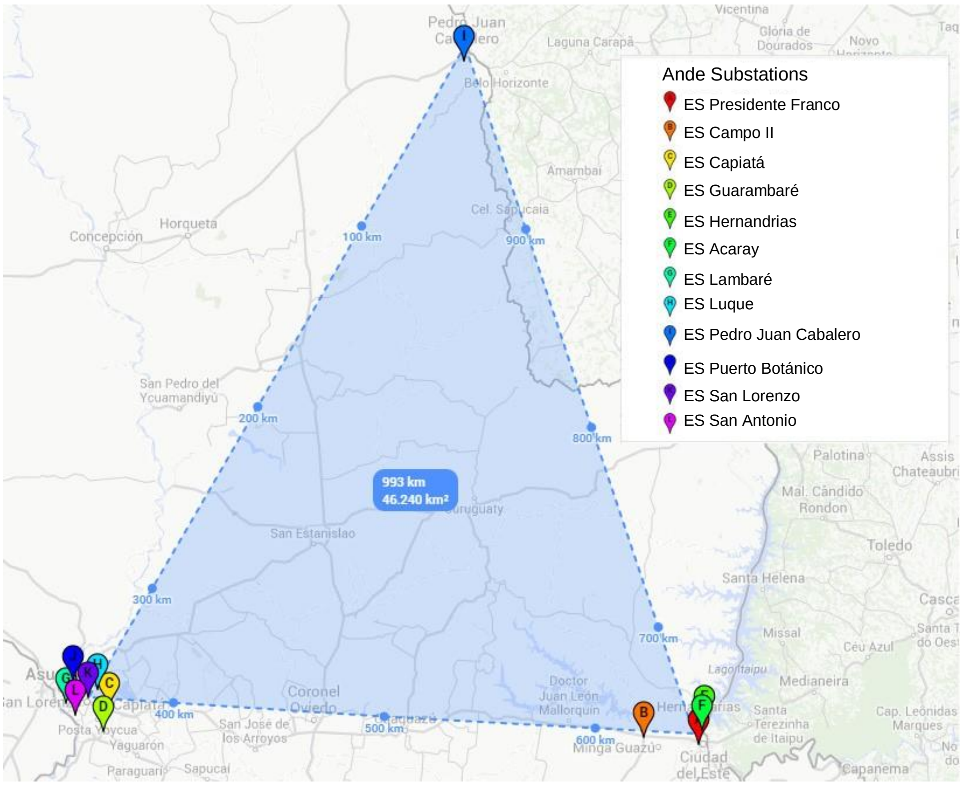

Figure 1 - Location of substations attending this project phase

3.0 - DEFINITIONS OF MAGNITUDES MONITORED AND SENSING

Once defined that the transformers are the initial targets of the smart management center, one of the major and most expensive assets of the substations, the next step was the definition of the magnitudes to be monitored so as to achieve the desired results.

A study conducted by Cigré [1] provides a map of the fault occurrences in the transformers, as shown in figure 2, where it is clear the importance of monitoring not only the active part of the transformer, but also the ancillary equipment, such as bushings and switches (OLTC).

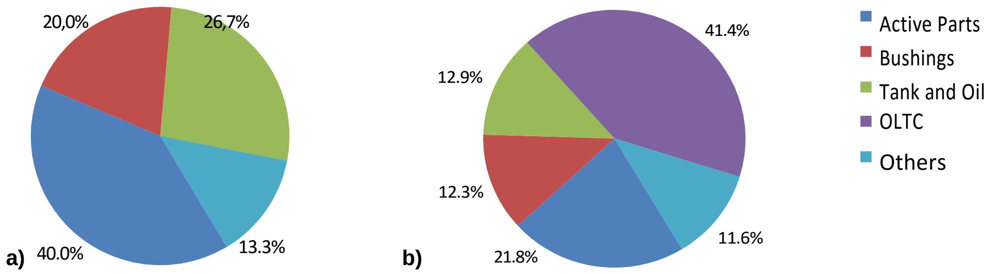

Figure 2 - Statistics of transformer failures, a) Without OLTC b) With OLTC

To follow the active part of the transformer, which includes windings and their insulation, the key elements to be monitored are the loading, oil and winding temperatures, as this enables to prevent that overloads and overheating led to catastrophic failures. In addition, this is an important data to calculate the lifetime expectation of the insulation in the active part of the machine, as its deterioration is a function the temperature it is subject to.

Another important element for good monitoring of the transformer's active part is the concentration of hydrogen in oil, as this can point out failures related to overheating, partial discharges, internal arcs, among others.

Moisture in oil is also another important information to determine the machine operation safety, as this has an important role in the insulation aging and is determinant in the insulation capacity. In addition, the detection of high moisture levels may indicate eventual sealing failures of the transformer's tank, which is other common source of failure in these machines.

Monitoring the condensive bushings is another good practice for smart management of the transformers, as in spite of being relatively inexpensive accessories, the failure of a bushing may damage the transformer which it is installed on, remove it from the electric grid, thus causing losses much higher than its value.

Capacitance and tangent delta indicate th health status of a bushing, and when following its evolution, it is possible to prevent catastrophic failure, as well as plan the maintenance in order to prevent unnecessary disconnections.

Finally, OLTCs must be monitored because they are important elements in a substation, as they help the regulation of the voltage supplied. As they have moving parts and a lot of mechanisms, OLTCs are an abundant source of failures, which are capable of making a transformer unavailable. The difference of temperature between the transformer and OLTC oils, moisture in oil, motor torque profile and motor feed voltage are examples of OLTC elements that, when monitored, help to assure the good operation of this accessory. Due to these reasons, the monitoring of OLTCs was frequently included in this project.

To monitor the elements mentioned, it is necessary to use a special class of sensors, Intelligent Electronic Devices (IED), which are capable of digitizing, processing, storing and transmitting the information acquired at field over digital communication networks. In addition, such sensors must be suitable for operation in environments where the temperatures may range from -40º C to 85º C, and where moisture and dust are always present. The IEDs used for sensing these magnitudes were:

Sensor :	**Basic Functions:**
Temperature Monitor TM1	Measurement and control of oil and winding temperatures in the transformer Measurement of auxiliary temperatures, such as in the OLTC
Moisture Monitor MO	Measurement of moisture in the transformer's or OLTC's oil
Gas Monitor GMP	Measurement of hydrogen dissolved in the transformer's oil Measurement of moisture in the transformer's oil
Bushing Monitor BM	Measurement of fault current, capacitance and tangent delta of bushings
Torque Monitor IDM	Measurement of motor torque, supply voltage, command voltage and operation times of the OLTC. Measurement of current of the anti-condensing system and other auxiliary systems of the OLTC.
Voltage Regulation AVR	Control of OLTCs for voltage regulation Control of parallelism by circulating current

Once achieved the data of the transformer and its accessories, the information is received by the management center, where, in addition to enable observing the evolution of all the magnitudes measured, engineering modules cross-reference the data to determine trends, calculate lifetimes and generate several other important information items for planning the management of transformers.

4.0 - SYSTEM ARCHITECTURE

On-line monitoring systems can be grouped in two types of architecture [3]:

Centralized:	Decentralized:
The PLC concentrates the information received from all the sensors and send it to the monitoring software.	In the decentralized system, sensors are IEDs (Intelligent Electronic Devices), and these send information directly to the monitoring software.
The centralizing element (PLC) is and additional point of failure in th system.	There is no centralizing element, thus eliminating this eventual point of failure.
Sensors must be dedicated to the connection with PLC, resulting in the eventual need for duplicating the sensors and additional costs to the monitoring systems.	The existing IEDs in protection and control systems can be integrated to the monitoring and data gathering systems, thus preventing additional costs with sensors.
A failure in the PLC may cause the loss of all the functions offered by the system.	The failure in an IED causes loss of a part of the functions only – other IEDs remain in service.
The centralizing element (PLC) generates additional costs to the system in terms of its installation, programming and maintenance.	There is no centralizing element, thus eliminating additional costs.
Expansions and maintenance in centralized systems are more difficult.	The decentralized architecture is naturally modular, thus facilitating expansions and maintenance.
The typical operating temperature of a PLC is 55ºC [2]. Its installation close to the transformer's body is not recommended.	The operating temperature ranges from -40 to +85ºC, suitable for installation at the yard with the main equipment.
The PLC installation would be recommended in the control room - large quantities of cables and connections between the device and yard, at a high cost.	IEDs are usually installed close to the asset, at the yard – a single serial communication connects them to the control room.
Typical 500V insulation - improper for the environment in a high-voltage substation [2].	Typical insulation level is 2.5kV – designed for the environment in a high-voltage substation [.
Usually tested for applications in industrial environments [2].	Tested for the adverse conditions at substations, in compliance with international standards: Electromagnetic compatibility, temperature, vibration.
Serial communication ports do not withstand surges, impulses and inductions found in substations, thus requiring the mandatory use of optical fibers in the communication with the control room - high installation cost.	Serial communication ports designed for the environment at a substation, which enable the use of twisted pair cables for communication with the control room – inexpensive installation. Optionally, the use of optical fibers is permitted in the communication.
It usually operates by using industrial communication protocols [2].	Specific communication protocols for installation in power systems (timestamp, clock synchronization, etc.).

The experience of maintenance engineering at several companies with the operation and maintenance of monitoring systems with centralized architecture has shown that they present high incidence of defects, thus generating high workloads for the engineering and field maintenance teams, at a such degree that makes the monitoring system totally inoperative [4].

The same behavior is not observed in systems with decentralized architecture, which provide good reliability and availability [4]. Thus, the on-line monitoring system for transformers adopted by ANDE is the decentralized one, according to the topology shown below in figure 3.

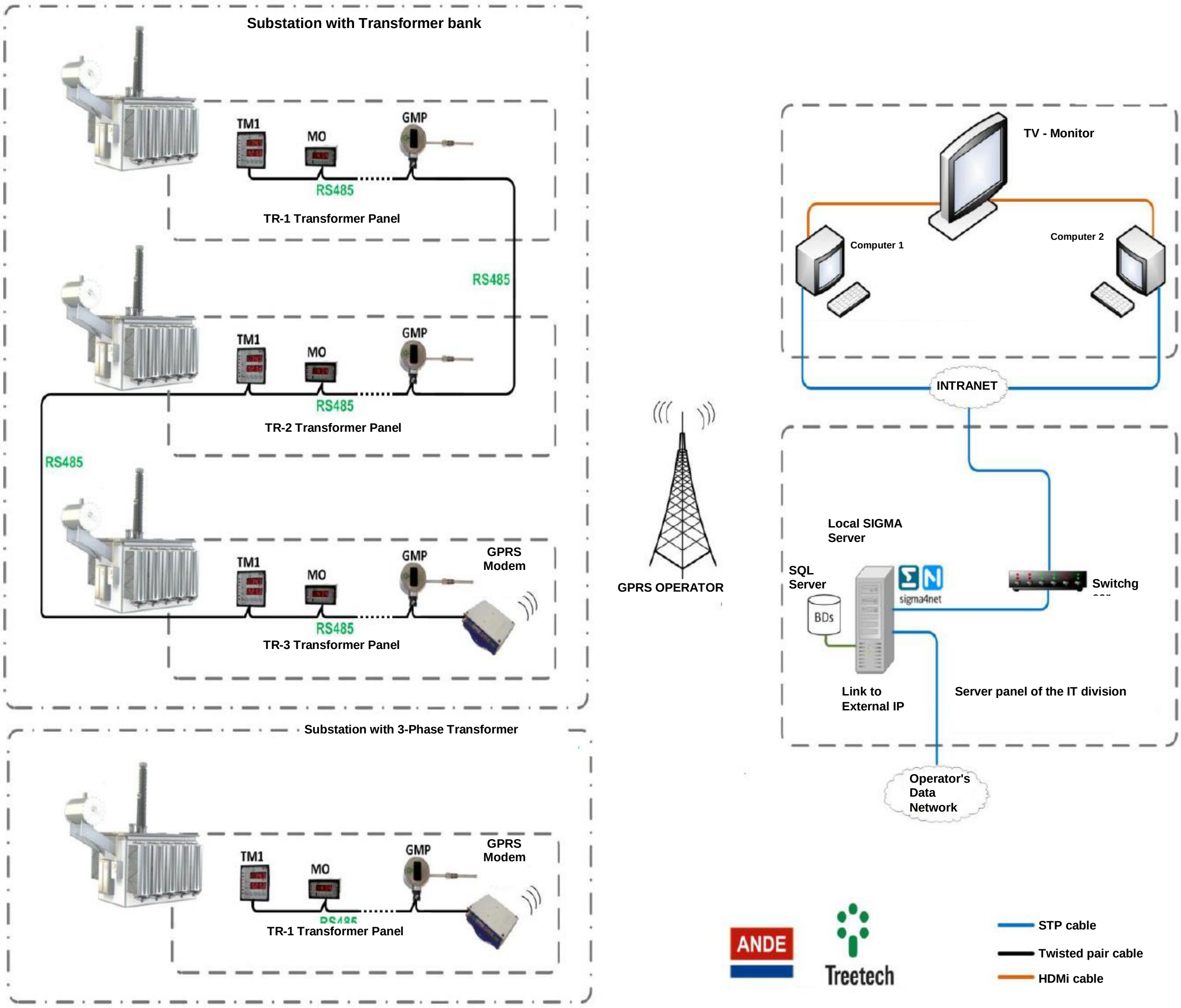

Figure 3 - Topology of the on-line monitoring system at ANDE

RS-485 serial communication cables have been used to install the equipment network, which provide the benefits of low cost and fast installation, thus contributing for cost reduction and financial feasibility of installing the system in lower size transformers.

To establish the communication between the sensor network at each substation and the system server, a cell modem has been installed in each substation with a chip of a private GPRS communication network, integrated to the company intranet.

Finally, connected to the data network of the GPRS operator, the system server stores the measurements collected at field in a field in the database and handles them to discover useful information. The engineers at the center use their computers to access the system over the intranet at ANDE.

This results in a simple and robust system, capable of centralizing data from distant and remote locations, where usually it is not possible to find traditional internet or intranet networks, such as the optical fiber based ones. The architecture of this system has been also evidenced as very inexpensive and scalable, thus enabling the addition of new components without requiring many adaptations or structural expansions.

5.0 - THE SYSTEM

More than a system that simply digitizes measurements, the monitoring system must be capable of converting data into useful information for maintenance, such as diagnostics and forecasts of the equipment status.

To do that, the monitoring system must be equipped with an engineering module that contains algorithms and mathematical models to generate diagnostics and forecasts. Some of the major diagnostic functions that can be performed by the monitoring software are

Engineering Model:	**Diagnostics and Forecasts:**
	Remaining lifetime of the insulation (%)
Insulation lifetime	Insulation lifetime loss trend (%/day) Remaining lifetime of the insulation
	(years Future temperature of the hotspot after stabilization
	Time to reach the alarm temperature
Expected final temperature gradient	Time to reach the disconnection temperature
	Gas in oil evolution trend (mainly H2)
Gases in oil	Alarms by high or very high gas evolution and concentration trends
	Off-line gas chromatography test reports
	Off-line physical-chemical test reports
Chromatography / Physical-chemical	Transformer sealing – burst of the rubber pocket in the expansion tank
	Water content in oil (ppm)
	Water content in oil trend (ppm/day) Water content on paper (% dry mass)
	Insulation lifetime loss by hydrolysis acceleration factor
Moisture on oil and paper	Bubble formation temperature Free water formation temperature
	Calculated temperature on the oil top
	Difference between measured and calculated temperatures
	Cooling system efficiency Instant differential
Bubble formation temperature	temperature Filtered differential temperature
	Alarms by high differential temperatures
	Maximum torque of the motor in each switching region
Cooling efficiency	Operation time of the OLTC mechanism
	Alarms by operation torque and time values out of standards Number of OLTC operations
Differential temperature of the OLTC	Summation of the switched current
	OLTC service time
Operation torque and time of the OLTC motor	Forecast of the remaining time for OLTC maintenance
	Advance warnings for OLTC maintenance
	Operation time of the ventilation groups, total and after the last maintenance
Maintenance wizard of the OLTC	Forecast of the remaining time for ventilation maintenance
	Advance warnings for ventilation maintenance
	Maintenance wizard of mechanical ventilation

Once this information is available, the Engineers at the management center are now able to plan in a more efficient way the maintenance investments and routines for the transformers integrated to the system.

6.0 - NATIONAL ASSET MANAGEMENT CENTER ROOM

The center room, shown in figure 4, provides all the facilities for real time observation of the system, action plans, study of behavior of each individual element and the system as a whole.

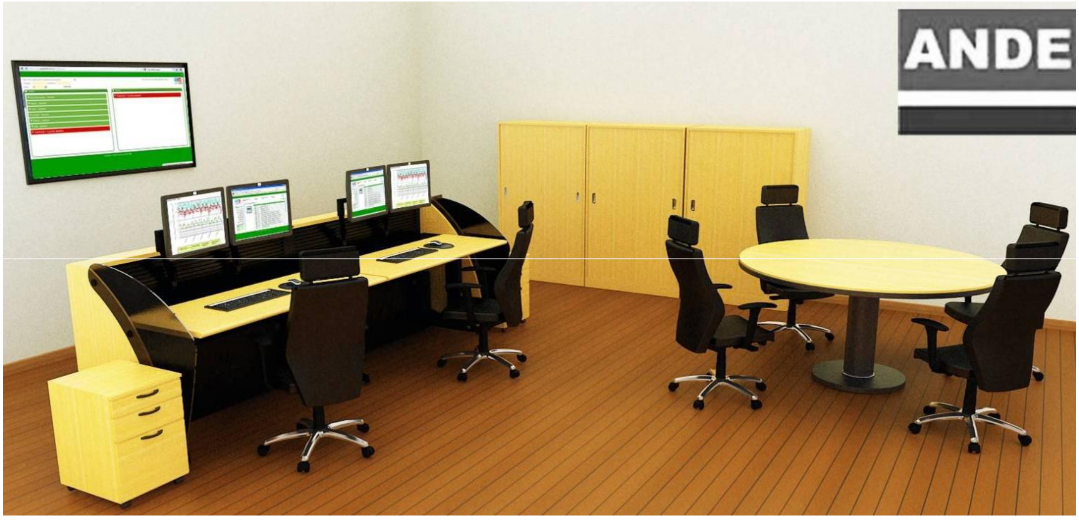

Figure 4 - National asset management center room at ANDE

Maintenance engineers, technicians and managers can meet and define action plans on a small round table installed at the center, while the monitor, installed on one of the walls, displays a view of the general scenario of the assets. The Engineers are provided with two computers connected to ANDE's server over intranet, to follow and search for specific information, whether retrieved from a long data history or measurements collected in real time on the asset conditions at field.

7.0 - CONCLUSION

By always pursuing for excellence in the services provided, ANDE used modern technologies to establish a smart asset management center capable of following on-line the status of tens of transformers spread at substations frequently distant each other.

By providing important information and forecasts, such as the remaining useful lifetime of an asset or the prediction of imminent failures, the asset management team of the company will be able to define investment and maintenance routine plans in a more accurate and localized form.

Such work philosophy provides gains to the electrical power system of Paraguay, in terms of reliability and quality of the power supply, while observing the need for optimization of maintenance costs.

8.0 - BIBLIOGRAPHY

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