DATA MANAGEMENT MODEL FOR THE OPTIMIZED MAINTENANCE OF POWER TRANSFORMERS

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ABSTRACT

The present of the electricity distribution, influenced by a number of technical restrictions and strict regulatory requirements to meet, leads distribution utilities to search new ways of optimizing the maintenance management, developing more effective activities, with lower costs.
For distribution systems, power transformers represent a complex and critical physical asset that requires a careful evaluation of their maintenance practices aiming at more cost-effective tasks.
This paper presents a data management model developed by Edenor, the largest argentine distribution utility, to optimize the maintenance of power transformers.
To do so, key determinations were established to evaluate the condition of the units, obtaining health indices of the fleet to prioritize, if required, the execution of major maintenance actions. Such model is strongly supported by the expert knowledge of specialists on this matter as well as the development of highly qualified manpower.
Through the development of this model, positive results were reached as regard the optimization of the maintenance management, availability and reliability of the transformer fleet and reduction of costs.

INTRODUCTION

Nowadays, electricity distribution is influenced by a number of facts that affects the development of the business: increasing demand of networks, lower redundancy of systems, operating restrictions that limit maintenance outages, incomes tied to the availability of the installations and so on, together with regulatory frameworks that demand strict technical requirements, imposing severe penalties for its non-accomplishment.

The stated situation forces distribution utilities to search new ways of optimizing the maintenance management of their physical assets, aiming at developing their activities more effectively so as to fulfil the requirements imposed in a cost-effective way.

Due to such a context, power transformers represent for distribution utilities a critical physical asset for their strategic role to ensure the operation of the distribution systems and the costs involved, not only in their purchase but also in their maintenance and operation along their lifespan.

In this framework develops its activities Edenor, the largest Argentine electricity distribution company regarding number of customers and energy sold. The company operates a network composed of 73 transformer substations of HV/HV, HV/HV/MV and HV/MV, with a fleet of over 200 HV power transformers, near 15,000 MVA of HV/HV, HV/HV/MV and HV/MV transformation power and voltage levels that range from 132 to 500 kV.

The transformers population presents an average age of 25 years, with limits that go from 1 to 50 years. Their failure index is quite low, with a mean lower than 2% per year (involving major failures that require replacing the unit or the need of major repairs in field).

From the exposed scenery, the use of proactive techniques becomes crucial for a comprehensive maintenance management of a power transformers fleet in any distribution company to consider the present restrictions.

Therefore, a shift in the maintenance strategies followed so far is essential, focusing on the use of all those available resources and management tools that allow minimizing unplanned outages and reducing the frequency of unavailabilities for maintenance, to optimize their performance and reduce operating and maintenance costs.

A PROACTIVE STRATEGY APPROACH

Affording such a situation, imposes strengthening the use of condition based tasks related to the state-of-the-art of maintenance techniques, defining so the most appropriate diagnosis evaluations to keep an adequate and up-dated control of condition and to periodically evaluate the obtained results in order to assure their good performance.

To reach the proposed goal, Edenor bases the maintenance strategies applied in power transformers on a number of key drivers. They include the intensive use of periodic check-list inspections complemented with the development of suitable diagnosis determinations, the systematic monitoring of results and the performing, when necessary, of additional or major maintenance tasks *(Fig. 1).*

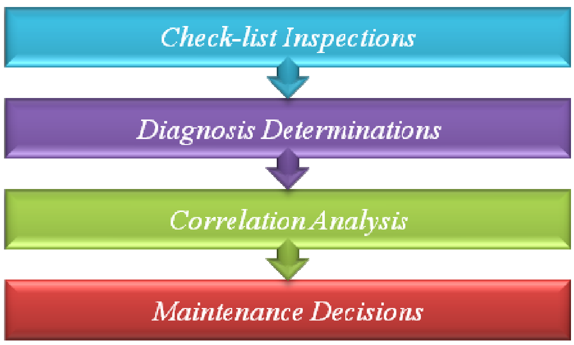

Fig. 1 - Key Drivers of the Data Management Model

Strong emphasis was put on the condition assessment of the oil-paper insulation system, tank and main accessories. Since HV bushings and OLTC failures are responsible for a large number of transformer major damages, special attention was put on the condition of these components. So, key determinations were identified to label their state [1].

The condition of tank, oil leakages and the proper functioning of OLTC and cooling system are evaluated from periodic man-made inspections, which provide many and very valuable primary information.

Since not all the maintenance, is necessarily good maintenance [2], to assign the most suitable maintenance activities, different Work Programs (WPro) were defined [1]. They include the execution of tasks, predictive analysis and measuring with the definition of acceptable threshold.

The obtained results are taken as a basis to assess the paper-oil insulation system condition and decide on the need of major maintenance tasks. When necessary, such determinations are complemented with the execution of additional electrical measures to go further in the condition diagnosis.

CORE CONDITION EVALUATION TOOLS

This model is strongly supported by a number of assessments and monitoring tools. They allow generating and managing the required information and represent a tool-kit, essential for the results of the data management model developed, considered a core factor for the success of the transformers condition assessment, to define further maintenance activities.

Insulating Oil Analysis

The evaluation of the insulating oil is the fastest, easiest and cheapest way of obtaining a general profile of the transformer state. In a short time and with reduced resources, it allows detecting incipient faults or just controlling its condition along its lifespan.

Since a major advantage of its use is that the sample can be easily taken with the unit on-line to make the interpretation afterwards, the state of the insulating oil is widely used "as a witness" to assess the transformer internal condition [3].

Therefore, the oil analysis forms part of the routine maintenance activities executed. In power transformers, more than 1,000 oil samples are taken per year to perform physical-chemical analysis (PCA) and dissolved gas analysis (DGA), considering regular Predictive Maintenance (PdM) activities and control of units under special monitoring [4].

By means of periodic PCA (dielectric strength, water content, dissipation factor, neutralization number, interfacial tension), degradation processes in the oil-paper insulation system are identified and their evolution controlled.

The use of DGA allows detecting electrical, mechanical and thermal faults. Furan analysis performed by high-performance liquid chromatography (HPLC) provides useful additional information about ageing process in paper. When possible, this information is supported with Degree of Polymerization (DP) values [4].

The DGA in field by means of portable equipment *(Fig. 2)* is a valuable tool to obtain the test results on-site in a few minutes. This is useful to control units under critical condition or evaluate emergency situations without having to take the sample to the lab, helping for a faster decision making.

Fig. 2 - Gas-in-oil content analysis in field.

All these determinations are conducted on an annual basis, although such frequency can be modified, depending on the condition and the importance of the units in the HV grid.

Data Management Process

The appropriate management of information in due time and form is critical for the success of any maintenance strategy. Thereby, the maintenance management and the decision making process developed are supported by an IT tool, whose core is a database where all the equipment to be maintained is inventoried [1].

This software provides workflow functions, work orders issuing and tracking and data storage, that help for the planning and programming of the maintenance activities.

Through this decision support system, a number of queries allows obtaining information such as the evolution of electrical measures and critical parameters.

Oil PCA and DGA play a key role in this IT tool. An application shows a register of the oil physical-chemical parameters of the transformers fleet, besides a detailed record of the different dissolved gases in oil. In addition, it is also possible to automatically obtain a DGA transformer diagnosis through different methods *(Fig.3)*.

Since the best use of oil diagnostics is to trend the recent data with all the other test data taken all over the life of the transformer, to show changes that may go undetected in a single test, this tool also provides an easy-to-access detailed record of the entire oil tests and events (oil filtering, regeneration or replace) carried out in the transformer under evaluation along its lifetime.

Fig. 3 - DGA transformer diagnostics.

Water-in-oil content for different operating temperatures and loading conditions can also be obtained and the probable water-in-paper content estimated by different methods.

In a dynamic query linked to the main database, frequencies and priorities for the oil analysis are defined according to the different condition and critical level assigned.

Other outputs are used in the decision making process for the maintenance management, extracting trends and patterns from the data obtained as well as knowledge-based rules, monitoring the evolution of the abnormalities detected to prioritize the corrective actions to be performed and evaluating the obtained results.

Gathering this information, an expert working group can assess the internal health of the units, quantify their criticality and detect weak components, labeling so their condition. By means of this supporting tool the obtained results are evaluated in a systematic way.

Health Indices Development

With a tool of relationship analysis, the dependencies of the evaluated parameters are calculated.

As a result, an algorithm was developed performing a correlation analysis among the obtained results and the transformer condition, to grade the state of every transformer, weighing such parameters to qualify the condition of the units.

This algorithm ponders the condition of every unit considering different variables, grading the condition of the transformers between 0 and 100, to qualify them from the worst to the best condition, to finally obtain Health Indices.

Such algorithm considers oil analysis, state of key components (HV bushings, OLTC) and tank (including oil leakages), weighing each variable in a different way, according to their relative importance, assigned by the expert opinion of maintenance specialists and complemented, when needed, by additional electrical measurements and tests. Therefore, different condition levels are established.

The numeric classification is finally ranked in three critical levels: Low, Medium and High, identifying so the technical risk of the transformer population.

After the diagnosis of the actual condition, eventual maintenance measures according to the results can be performed.

Due to the wide variety of types, models and ages of units in service, from their available backgrounds different patterns of abnormalities and failures are identified, defining so, probable aging models. In transformers of the same design and age, by the relative benchmarking of their indices, typical aging patterns are outlined.

From the obtained information, in a two-dimensional graph with the Health Indices and the Number of Transformers on the two axes, a Risk Index of the whole transformer fleet is represented. This tool helps identifying at first sight the general condition of the fleet (*Fig. 4*).

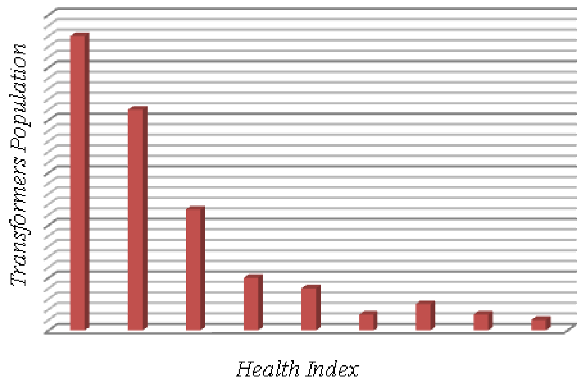

Fig. 4 - Technical Risk Index for a Number of Transformers.

These results allow labeling the condition of the whole fleet to define the need of additional or major maintenance actions to reduce levels of risk.

Matrix of Risk

A risk consists of two different aspects, a probability of an event to occur (e.g. a failure) during a time interval and the consequence of such occurrence. In several publications different models of Matrix of Risk are proposed [5].

Since using a two-dimensional diagram is a better way to present the results of a risk assessment, in the developed model, a Risk Matrix was defined as a normalized product of the technical risk (criticality) and the relative importance (consequences) of the physical asset in the HV grid (*Fig.5*).

From this information, considering the level of criticality of the units and their relative importance in the grid, a "map of risk" of the HV network was developed, identifying levels of criticality of the installations. So, priorities for the transformers maintenance are defined and activities addressed for the different units considering the risk assessment of the HV network as a whole [1].

Tasks to reduce levels of risk include refurbishments, replace of components with background or patterns of failure detected (i.e. HV bushings), technological up-grades (e.g. OLTC), treatment processes (drying-out, oil filtering, degasifying or regeneration) and so on.

Also the relocation of units is performed, placing transformers considered not reliable enough in areas of lower criticality in network. By doing so, units with higher critical levels are replaced and moved to areas of reduced risk levels, minimizing the risk of faults and increasing the reliability and availability of the installations.

Factor		*Criticality*		
		1	2	3
Consequence	1	56	66	14
	2	33	12	3
	3	13	2	5

Fig. 5 - Matrix of Risk of the Transformer Fleet.

Such "dynamic" Matrix of Risk, under periodic revision and up-dating, makes it possible to quickly identify potential areas of high criticality, in order to define major maintenance decisions with a rational allocation of resources.

DEVELOPMENT OF PERSONNEL SKILLS

A central issue for the success of this management model is to count on highly qualified manpower as well as the expert knowledge of specialists in this matter [4]. Therefore, it is essential to have in-house all the required expertise concerning key maintenance activities. From this determination, focus was put on preserving in the company the best practices in the field of power transformers maintenance tasks, considered strategic core skills.

This way, specific knowledge in the field of HV transformers maintenance was concentrated. As a result, a strong emphasis was put on the training of very specialized in-house working teams. By periodically recycling and updating their knowledge and skills, the best maintenance practices are highlighted for their continuous improvement.

The evaluation of the transformer fleet condition, rely on the know-how of an expert working group. This includes a broad experience and up-dated knowledge of the state-of-the-art in transformers design, operating, maintenance and tests, in order to strongly support the evaluation of results and the maintenance decisions to take.

Thus, a best value was added to the maintenance activities, not only in a profitable way but also through seeking additional advantage in terms of quality, performance and service improvement.

OBTAINED RESULTS

The aim of the developed data management model is focused on improving the maintenance management of power transformers concerning the use of human, technical and economical resourced, increasing at the same time, the reliability and availability of such physical assets.

Through this model, outages to perform maintenance tasks could be optimized, unifying technical criterions to be followed, categorizing the abnormalities detected according to severity levels to prioritize the corrective actions to execute and controlling the obtained results.

This model is supported by a strong tendency toward the intensive execution of PdM (on and off-line) activities to assess the condition of the equipment, and the use of risk based maintenance techniques.

The extended use of this management model, has allowed reaching positive results as regards the improvement of the maintenance management, diminishing outages of the equipment and increasing the availability of the installations, making it possible to reduce maintenance costs.

A survey of the evolution of a number of key performance indicators (i.e. number of unwanted events, interruptions, programmed outages, maintenance costs, quality of supply), shows the enhancement achieved by its development concerning the efficiency of the maintenance management as a whole.

CONCLUSIONS

The present electric distribution markets impose reducing programmed maintenance outages in number and duration. Being for distribution utilities a strategic physical asset, special attention must be put on the maintenance of power transformers, to improve their availability and reliability.

To afford this situation, a data management model to optimize the maintenance of power transformers has been developed. Such model considers assigning the most appropriate proactive activities, defining suitable diagnosis determinations to keep an adequate and up-dated control of condition and periodically evaluate the obtained results to assure their good performance.

Its use on a large scale over a whole transformer fleet has provided highly positive results concerning improvement of maintenance activities, related to availability, reliability, costs involved and failure index.

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