CONDITION ASSESSMENT OF POWER TRANSFORMERS: A PRACTICAL METHODOLOGY APPROACH

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ABSTRACT

At present, the development of electricity distribution networks is influenced by a number of technical and regulatory facts that link utility incomes to network availability, affecting so the development of the business.

Utilities operating in this environment regard power transformers as critical assets for their strategic role in the distribution networks and the huge overall investment made during their operational lifespan. In such a context, the use of proactive techniques becomes crucial for the comprehensive maintenance management of the power transformer fleet in any distribution company.

This paper presents a practical methodology developed by Edenor, the largest argentine distribution utility, for the condition assessment of a power transformer fleet. Such methodology, considers the intensive use of selected proactive actions, the development of an algorithm to rank the condition of the transformers and the execution of a Risk Matrix, to define major maintenance decisions.

Its extended use over a whole power transformer fleet has shown to be successful as regards the improvement of the maintenance management and availability of the network, making it possible to reduce maintenance costs, enhancing through its use, the efficiency of the maintenance management.

INTRODUCTION

The development of electricity distribution networks is currently influenced by a number of facts: increasing demand of networks, reduced level of redundancy and operating restrictions limiting maintenance outages. Also regulatory frameworks set strict technical requirements, imposing severe fines for their non-compliance. In addition, utility incomes are linked to network availability. These facts deeply restrain and limit the conditions of the business.

Utilities operating in this environment therefore regard power transformers as critical physical and capital intensive assets. They have a strategic role in the operation of the distribution networks due to the huge overall investment made in their capital, operational and maintenance costs during their operational lifespan.

This is the operating framework of Edenor, the largest electricity distribution company in Argentina in terms of customer numbers (2.8 million) and annual energy sales (21,673 GWh). The company operates a network that extends to 37,007 km and includes 77 HV transformer substations with over 200 HV power transformers, having a total installed transformer capacity of 15,636 MVA. The voltage levels of the HV/HV, HV/HV/MV and HV/MV transformers range from 132 kV to 500 kV.

The average age of the transformer population is 25 years with an annual failure rate of 2% based on major failures that require replacing the unit or the need for major repairs in field.

In this situation, facing the maintenance management of an extensive power transformer fleet makes the company to know the condition of the whole transformer population. This turns out to be a key issue to decide performing major maintenance tasks and prioritize their execution with a rational and cost-effective allocation of human and material resources.

CONDITION OF A TRANSFORMER FLEET

In such a context, managing a systemic analysis of the data collected is a major fact in order to have on-line processed information, for a faster and better decision making process.

To handle this scenery, a practical methodology for the condition assessment of a power transformer fleet has been developed. *Such approach, considers the intensive use of selected proactive actions, the development of health indices and the execution of a Matrix of Risk,* to define the need of taking major maintenance decisions, in a dynamic and continuous condition assessment process (*Fig. 1).*

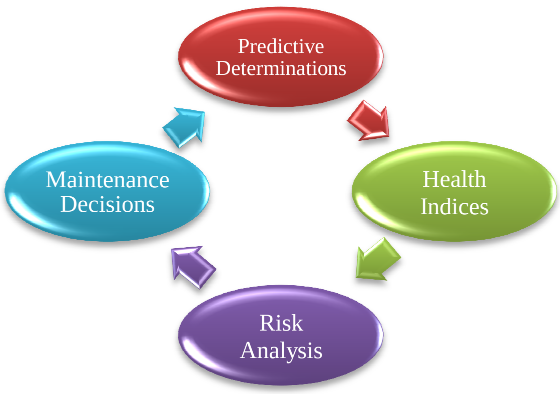


Fig. 1 - Key Drivers of the Condition Assessment Methodology

CHOICE OF CORE EVALUATION TOOLS

A number of tools were defined to be used as a tool-kit in order to optimize the condition assessment of the transformer fleet, which represents a core fact in the development of the methodology designed.

All of them, based on the intensive use of proactive activities, contribute to support a systemic decision making process in order to define further maintenance actions.

Routine Periodic Inspections

The use of periodic check-lists and man-made inspections provide much and very valuable primary information. They helps to identify in field abnormal situations to be reported.

Thoroughly and conscientiously performed, their execution, together with detective tasks searching for hidden faults, make it possible to detect abnormalities such as external damages, breakages, oil leakages, malfunction of auxiliary devices and so on, which are later evaluated in detail to define if additional determinations are needed.

For the successful use of this tool, a strong emphasis was put on the training of very specialized working teams, periodically recycling and updating their knowledge and skills for their continuous improvement.

Insulating Oil Analysis

Evaluation of insulating oil represents the first step to obtain a general profile of the transformer fleet, detecting incipient faults or just monitoring the health condition of the units. It is so, that the state of the insulating oil is widely considered *"as a witness"* to reveal the transformer internal condition along its cycle of life.

Therefore, oil analysis forms part of the routine maintenance activities executed in power transformers. More than 1,000 oil samples are taken annually to perform physical-chemical analysis (PCA) and dissolved gas analysis (DGA), considering regular Predictive Maintenance (PdM) tasks and control of units under special monitoring (*Fig. 2*).

Fig. 2 - Physical-chemical analysis of insulating oil in lab

Periodic PCA (dielectric strength, water content, dissipation factor, neutralization number, interfacial tension) identifies degradation processes in the oil-paper insulation system and their evolution along the time. DGA enables the detection of electrical, mechanical and thermal faults. Furan analysis provides helpful additional information about aging process in the paper insulation; when possible, this information is supported with Degree of Polymerization (DP) values.

These tools allow the early identification of probable abnormalities to be confirmed by additional further verifications.

Electrical Determinations

Electrical tests and trials make it possible to identify incipient abnormalities in on-going development or just to confirm information obtained from other predictive tools.

This way, different maintenance Work Programs (WPro) containing core predictive determinations are defined. They include the execution of tasks, routine electrical measurements and the definition of acceptable threshold. For these WPro, diverse frequencies are assigned, considering the importance and the condition of each unit.

Electrical determinations are also performed, when required, to confirm information about probable on-going abnormalities obtained from PCA and DGA in oil or other predictive determinations.

The periodic and systematic use of these tools enables to define if the units have to be taken out of service for additional or major maintenance actions *(Fig. 3).*

Fig. 3 - Major repair tasks in a 300 MVA transformer on-site.

A Dynamic Data Base System

The bulk management of all this information in due time and form is critical for the success of any maintenance strategy. Thereby, the maintenance management and the decision making process are supported by an IT tool, which core is a database with more than twenty years of stored information where the whole transformer fleet is inventoried and the data collected registered.

Through this tool, a number of queries allows obtaining information such as evolution of measurements, tests and critical parameters.

Oil PCA and DGA play a key role in this IT tool. An application shows a register of the PCA parameters of the transformers fleet and a detailed record of the different dissolved gases in oil. It is also possible to automatically obtain a DGA transformer diagnosis through diverse methods. Water-in-oil content for different operating temperatures and load conditions can also be obtained and the probable level of water-in-paper estimated by different methodologies.

In dynamic queries, frequencies and priorities for the oil analysis are defined according to the different conditions and critical level assigned. Other outputs are also used to extract trends and patterns from the data collected.

Managing such amount of information requires counting on a supporting analysis tool to evaluate it in a comprehensive and systematic way, in order to take faster major maintenance decisions.

A SUITABLE ALGORITHM OF CONDITION

Experience has shown that maintenance activities require an easy to access and use tool, to allow taking maintenance decisions quickly and in a practical way. Although diverse models have been developed and several commercial softwares are available in market, not all of them are friendly enough as regards practical maintenance decisions.

As a result, with the aim of providing support to the maintenance decision making process, a dedicated algorithm was designed by specialists of the company to grade the condition of each transformer of the fleet.

This algorithm, that represents a core factor of the tool, performs a correlation analysis among specific evaluated parameters and the transformer condition. Such development ranks the state of every transformer, weighting those key parameters to qualify them from the best to the worst condition, to finally obtain Health Indices of the whole fleet.

Key Drivers of the EvaluationTool

The core of such algorithm is based on some general criterion and a number of key drivers:

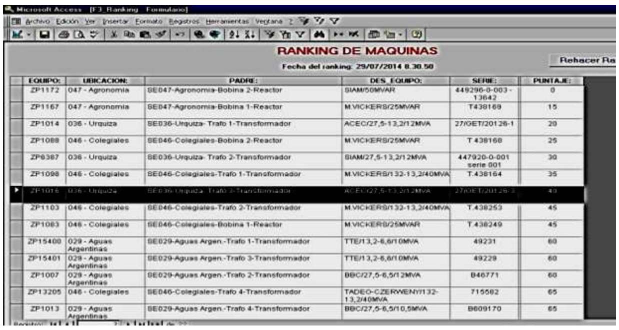
- The condition of all transformers is pondered considering different variables or attributes to be evaluated.
- The classification is numeric; the total grade obtained results from adding all the factors evaluated. Then, a transformer in optimal condition should be qualified as 100.
- As pondering variables, PCA and DGA in oil, condition of key components (HV bushings, OLTC) and oil leakages are evaluated.
- If required, such determinations are supported by additional specific measurements and tests.
- Not all the variables are pondered in the same way. The highest theoretical score allocated to each one in the algorithm, depends on its relative importance assigned in the transformer condition.
- To ponder a variable, different threshold values are used, considering those suggested by international standards and when appropriate, from the experience acquired.
- When applicable, it is considered that the limit threshold values adopted depend on the voltage levels involved (i.e. breakdown voltage, water content).
- The numeric result (addition of factors) can be finally affected by a *k* factor that extends from 0.8 to 1.2 and considers the expert opinion of transformer specialists.
- The numeric qualification reached is finally unfolded in three condition levels: good, regular and critical, to identify the technical risk of the transformer population as a whole.

Information Reported

The development extracts data from the maintenance database where all the information registered of the fleet is uploaded .

To evaluate the scoring of the whole fleet, the algorithm selects the last value obtained of each parameter considered. When the data of any variable is not available, its theoretical highest weighting is taken. It is the case of determinations not executed so far and key components with no backgrounds to be qualified. They are adjusted later performing periodically data uploading tests.

From the available data, the tool processes and generates a report showing the score obtained for each unit (*Fig. 4*). Such report allows different grouping and arrangements related to score order, brand and type of transformer, power rating and location in network and so on.


Microsoft Access [F3_Ranking Formulario]

RANKING DE MAQUINAS

Fecha del ranking: 29/07/2014 8.30.50

EQUIPO:	UBICACION:	PADRE:	DES_EQUIPO:	SERIE:	PUNTAJE:
ZP1172	047 - Agronomia	SE047-Agronomia-Bobina 2-Reactor	SIAM/50MVAR	449296-0-003 - 13642	0
ZP1167	047 - Agronomia	SE047-Agronomia-Bobina 1-Reactor	M.VICKERS/25MVAR	T438169	15
ZP1014	036 - Urquiza	SE036-Urquiza- Trafo 1-Transformador	ACEC/27,5-13,2/12MVA	27/GET/20126-1	20
ZP1088	046 - Colegiales	SE046-Colegiales-Bobina 2-Reactor	M.VICKERS/25MVAR	T 438168	25
ZP6387	036 - Urquiza	SE036-Urquiza- Trafo 2-Transformador	SIAM/27,5-13,2/12MVA	447920-0-001 serie 001	30
ZP1098	046 - Colegiales	SE046-Colegiales-Trafo 1-Transformador	M.VICKERS/132-13,2/40MVA	T.438164	35
ZP1016	036 - Urquiza	SE036-Urquiza- Trafo 3-Transformador	ACEC/27,5-13,2/12MVA	27/GET/20126-3	40
ZP1103	046 - Colegiales	SE046-Colegiales-Trafo 2-Transformador	M.VICKERS/132-13,2/40MVA	T.438253	45
ZP1083	046 - Colegiales	SE046-Colegiales-Bobina 1-Reactor	M.VICKERS/25MVAR	T.438249	45
ZP15400	029 - Aguas Argentinas	SE029-Aguas Argen.-Trafo 1-Transformador	TTE/13,2-6,6/10MVA	49231	60
ZP15401	029 - Aguas Argentinas	SE029-Aguas Argen.-Trafo 3-Transformador	TTE/13,2-6,6/10MVA	49229	60
ZP1007	029 - Aguas Argentinas	SE029-Aguas Argen.-Trafo 2-Transformador	BBC/27,5-6,5/12MVA	B46771	60
ZP13205	046 - Colegiales	SE046-Colegiales-Trafo 4-Transformador	TADEO-CZERWENY/132-13,2/40MVA	715582	65
ZP1013	029 - Aguas Argentinas	SE029-Aguas Argen.-Trafo 4-Transformador	BBC/27,5-6,5/10,5MVA	B609170	65

Fig. 4 - Report showing the scoring of the transformer fleet

It is also possible to differentiate the results for each evaluated parameter to reach the partial scores obtained for every unit. A double click on each parameter shows its last three values registered. So, by selecting individual parameters of each unit, the one that affects the most in the transformer condition, can be easily identified.

BUILDING AN USEFUL MAP OF RISK

From the obtained information, a Risk Matrix of the transformer fleet was built, representing its whole Risk

Index into the network. This tool helps identifying at first sight the general condition of the transformer population.

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, taking into account the probability of failure (criticality) of the units and their importance (consequences) in the HV grid, identifying so different levels of risk of the installations.

From this information, priorities for maintenance are defined and activities addressed for the different units considering the risk assessment of the HV network as a whole. Such activities to reduce levels of risk prioritize firstly, taking actions to “displace” critical units toward areas of lower risk and later on, to make sure that transformers placed in no critical areas not to decline their condition *(Fig. 5)*.

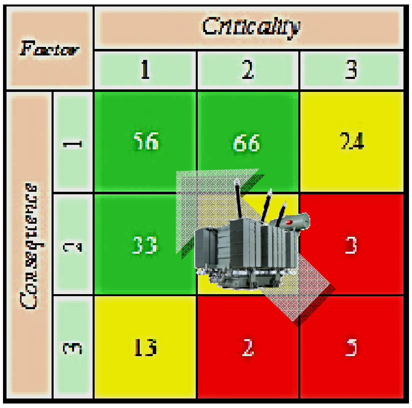


Fig. 5 - Matrix of Risk of the Transformer Fleet.

Tasks performed include refurbishments, replacement of components with background of failure detected (i.e. HV bushings), technological up-grades (i.e. OLTC), treatment processes (drying-out, filtering, degasifying or regeneration of oil), repairs and so on *(Fig. 6)*. Relocation of units is also performed, placing transformers considered not reliable enough in areas of lower importance in network, so as to minimize the impact of failures.

Fig. 6 - Replacing a 230 kV condenser bushing

OBTAINED RESULTS

This tool helps to identify at first sight the general condition of the transformer fleet. The overall results allow labelling the condition of the transformer population in terms of defining the need for additional or major maintenance actions to reduce levels of risk.

As from the broad variety of types and ages of units in service, analyzing the historical background of the information registered, tendencies of every parameter can be established, defining so, probable aging models as well as failure patterns.

It is so, that diverse abnormal on-going processes were recognized. It is the case of units with tight thermal design deriving on thermal affections processes, accelerated ageing development, hydrolysis phenomenon with deterioration of paper in aged units, effects of high water content, performance of key components and others.

These early diagnoses, when confirmed by other additional determinations, make it possible to know the condition of the involved units, to predict probable typical behaviors and evolutions, identifying their reliability and when considered, to take corrective maintenance actions to improve their condition.

A central issue for the success of this management model relies on the expertise of a specialist working group to evaluate the information obtained. This includes a broad experience and up-dated knowledge of the state-of-the-art in transformers design, operating, maintenance practices and tests, in order to strongly support the evaluation of results and the maintenance decisions to take.

The developed methodology, results an on-going procedure subjected to regular adjusts and improvements from the data obtained, experience acquired, and definition of knowledge-based rules, in a dynamic and continuous assessment process.

CONCLUSIONS

Nowadays, electricity distribution utilities deal with the challenge of achieving high levels of availability and reliability of their physical assets. In such a context, power transformers represent critical assets for their strategic role in networks. This situation requires counting on practical assessment tools to label their condition and decide when major maintenance actions are required, performing a comprehensive and systemic evaluation.

To cope with this situation, a practical methodology approach has been designed. This is based on the definition of suitable diagnosis determinations, the use of a dedicated algorithm of condition and the systematic analysis of results.

By the extended use of this data management approach, positive results have been reached, enhancing through this tool in the efficiency of the power transformers maintenance management as a whole.