MAINTENANCE STRATEGIES TO OPTIMIZE THE MANAGEMENT OF POWER TRANSFORMERS

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ABSTRACT

The present scenery of electricity distribution leads distribution utilities to optimize maintenance management, developing their activities both, more effectively and with lower costs.
For distribution systems, power transformers represent a complex and critical physical asset that requires to carefully evaluate their maintenance practices in order to improve the tasks to be done in a cost effective way.
This paper describes the strategies for the maintenance management of HV power transformers developed by Edenor, the largest Argentine electric distribution utility.
Such strategies consider the use of new technological developments, proactive maintenance tasks and an adequate data management process. They are strongly supported by the continuous training of a specialized maintenance workforce.
Through the development of this strategy, positive results were reached as regards optimization of the maintenance management, availability and reliability of such assets 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 the demand of strict technical requirements and the imposition of severe penalties for its non-accomplishment.

The stated situation drives distribution utilities to optimize 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.

In this framework, power transformers represent a critical physical asset for distribution utilities 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 during their lifespan.

Edenor, the largest Argentine electricity distribution company in terms of number of customers and energy sold, operates a network composed by 71 transformer substations of HV/HV, HV/HV/MV and HV/MV, with a fleet of more than 200 HV power transformers, 12,994 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).

A major challenge for Edenor has been to improve the maintenance tasks in power transformers, redefining the former strategies adopted so far, mostly timed-based Preventive Maintenance (PM) with established schedules, turning them into more flexible activities, emphasizing to do so the use of Predictive Maintenance (PdM), to extend the frequency of maintenance outages while keeping at the same time a close control of their condition, in order to optimize their performance and reduce operating and maintenance costs.

MAINTENANCE STRATEGY ADOPTED

To deal with this goal, Edenor has based the maintenance strategies to apply in power transformers in a number of key drivers. They are a balanced combination of using the benefits that the new technologies provide together with the development of proactive maintenance tasks and an adequate data management process (*Fig. 1*).

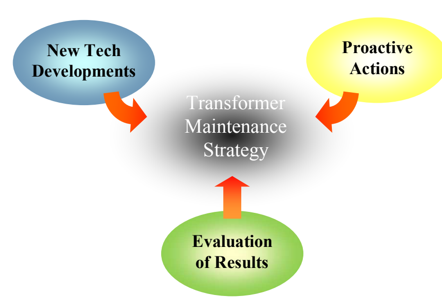

Fig. 1 - Key Drivers of the Transformers Maintenance Strategy

Use of technological innovations

Up to some time ago, technological modifications connected with transformer components and accessories did not have an important development. This situation has drastically changed over the last few years with the availability in the market of a broad variety of low maintenance components.

Since surveys show that bushing and OLTC failures are responsible for a large number of transformer major damages, special attention was placed on the performance of these components, aiming at minimizing possibilities of failures and reducing maintenance tasks. As a result, new transformers are equipped with resin impregnated paper (RIP) bushings technology and vacuum switch OLTCs.

As from some years ago, new transformers include RIP bushings with silicone rubber insulators, which are supposed to be nearly maintenance free and with a longer insulation useful life than the oil impregnated paper (OIP) type. From their use, problems concerning porcelain damages during transport and handling operations as well as risk of explosion are supposed to be avoided. Although today RIP technology is more expensive than the OIP type, it is expected to become cheaper in the short term. The use of RIP bushings made it possible to simplify maintenance activities and provide an increased reliability of the transformer itself.

About 10% of the transformer fleet counts with vacuum switch OLTCs. They are considered maintenance-free switching operation for almost the complete transformer lifetime. From the experience obtained so far after some years in service, they have shown to be a reliable component. At present, their purchase cost closer and closer to the traditional oil switching ones, contributes to their more spread use, what allows to reduce maintenance tasks and outages in a safe way and as a consequence, the transformer life-cycle cost as a whole *(Fig. 2)*.

Fig. 2 - Power transformer with vacuum diverter switch OLTC

The use of oil filtering units represents a good option for elder transformers in service with oil switch OLTCs. These devices clean and dry the switching oil while the transformer is operating, reducing thus oil contamination. This allows satisfying more demanding conditions, improving the reliability of tap-changer and transformer itself. On a first stage, several units have been installed in critical transformers, although it is foreseen to extend its use to the rest of in-oil OLTC in service. By their installation, frequency of maintenance activities for such OLTCs has been extended, reducing so transformer outages.

A key factor to prevent the accelerated ageing of the oil-paper insulation system and to ensure the integrity of the transformer as a whole is the control of the oil condition [3].

Despite not being such a new development, the use of bladder flexible separators in auxiliary tanks *(Fig. 3),* prevents the contact of oil with atmospheric air, avoiding the entry of moisture, minimizing both, contamination of the oil-paper insulation and oil oxidation, with the consequent sludge generation.

Fig. 3 - Auxiliary tank with bladder separator.

The inclusion of on-line monitoring devices in strategic units in network allows a continuous tracking of critical parameters (water in oil content, gas generation) to have an early alert of developing fault conditions and detect changes in tendencies *(Fig. 4)* together with operating values (top oil and hot spot temperatures, cooling system state, OLTC position, alarms and trips).

Fig. 4 - Power transformer oil on-line monitoring.

The use of these technological innovation devices allows mostly to simplify maintenance tasks and to extend their frequency, reducing thus transformers downtime and improving the reliability of the physical assets as a whole.

Development of proactive maintenance actions

To be useful, the use of the available technological developments must be supported and complemented by the execution of suitable proactive maintenance tasks, in order to have a rational allocation of resources.

Therefore, different maintenance Work Programs (WPro) were defined. Every WPro was developed from the existing experience, taking into account the knowledge acquired in field, surveying the existing practices and performing a Failure Mode Effects and Criticality Analysis (FMECA) [1, 2]. They include the execution of tasks, routine measures and the definition of acceptable threshold, used to label the transformer condition and address the necessary actions if additional tasks are required.

A "map of risk" of the HV network was performed to identify the 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].

Taking into account that not all the maintenance, not even PM, is necessarily good maintenance [2], the performing of a number of on and off-line predictive activities, supported by periodic man-made inspections, are taken as a basis to define the need of executing major maintenance tasks, i.e. insulation system drying-out when it is required *(Fig. 5)*, reducing so the execution of unnecessary maintenance, minimizing the risk of faults and increasing the availability of the installations.

Fig. 5 - Power transformer insulation drying-out in field.

Having shown as a valuable tool to early detect thermal anomalies and to identify patterns of failure, Infrared Thermography (IR) is performed over the HV transformers fleet twice a year. For critical units in network differentiated frequencies for IR scans are assigned. Through executing IR inspections, when thermal abnormalities are detected, outages are programmed for the execution of the repairs required according to the critical level assigned.

Since a major advantage of the oil testing is that the sample can easily be taken while the unit is on-line, the state of the insulating oil is widely utilized "as a witness" to assess the transformer condition [3]. Therefore, the oil analysis forms part of the routine maintenance activities executed. Just in power transformers, more than 1000 oil samples are taken per year to perform physical-chemical analysis (PCA) and dissolved gas analysis (DGA), considering regular PdM activities and control of units under special monitoring.

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 and thermal faults. Although these determinations are conducted on an annual basis, such periodicity can be increased (every one, three, six months), depending on the condition and the importance of the transformers in the network. For some critical units, periodical monitoring allows a continuous tracking of the gas evolution as an early alert in case of failure. Furan analysis performed by means of high-performance liquid chromatography (HPLC) provides useful additional information about ageing process in paper.

The analysis of gases in oil content in field by means of portable equipment *(Fig. 6)* is used as a valuable tool to obtain the test results on-site in a few minutes. This is useful to control units under critical condition or evaluation of emergency situations without having to transport the oil sample to the lab, helping for a faster taking of decision.

Fig. 6 - Gas-in-oil content analysis in field.

Proactive maintenance activities also take into account the environmental care. This fact is considered by strictly controlling oil leakages through periodic inspections, which help to identify them, labeling their criticality and assigning priorities for the repairs to execute from the different critical condition defined.

By this approach, aiming at reducing maintenance outages, the emphasis put on the use of proactive maintenance tasks and condition-based activities allows defining if the transformer has to be taken out of service for additional or major maintenance actions or not.

Data Management Process

The appropriate management of information in due time and form is a key factor for the success of any maintenance strategy.

Thereby, the maintenance management and the decision making process developed are supported by a corporate computing system, which 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 (i.e. background, results of measures and tests executed, maintenance records and condition data of the equipment), that helps for the planning and programming of the maintenance activities.

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

An IT application shows a history 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 transformer diagnosis through different methods (IEC 60599, Dornenburg, Rogers, Duval).

Since the best use of oil diagnostics is to trend the recent data with all 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 test and events (oil filtering, regeneration or replace) carried out in the transformer under evaluation along its lifetime.

By an on-going development, still in evaluation and improvement stage, water in oil content for different operating temperatures and loading conditions can be obtained and the probable water in paper content estimated.

Gathering this information, an expert working group can assess the internal health of the units and quantify their criticality, labeling so their condition. In a dynamic query linked with 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.

By means of this supporting tool priorities for the maintenance actions to perform can be defined and the obtained results evaluated in a systematic way.

DEVELOPMENT OF WORKFORCE SKILLS

A key factor for the success of this maintenance strategy is the development of highly qualified manpower.

To perform the maintenance process in the most cost-effective way, part of traditionally in-house maintenance tasks was outsourced. From this determination, focus was put on preserving in the company the know-how of the maintenance activities, strategic core skills that cannot be deprived under any circumstance.

This way, personnel cost could be reduced outsourcing some maintenance activities and 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.

Periodically recycling and updating their knowledge and skills, as well as introducing them in the possibilities and benefits provided by the use of the new technologies in force, to make an expert use of them, the best maintenance practices are highlighted for its continuous improvement.

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.

CONCLUSIONS

In the new electric markets it is essential to reduce 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 face this situation, an improved maintenance strategy has been outlined.

Such strategy is based on the rational use of the new technological developments available, the performing of proactive maintenance tasks and the suitable management of the information obtained, emphasizing besides the development of highly qualified working crews.

By its use on a large scale, highly positive results have been obtained in terms of improvement of maintenance activities, related to availability, reliability, costs involved and failures index.

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