CRITERIA TO PRIORITIZE THE REPLACEMENT OF HV INSTRUMENT TRANSFORMERS IN A DISTRIBUTION UTILITY: A PRACTICAL APPROACH

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ABSTRACT

Nowadays, the electric industry develops its activities in a business environment characterized by competitive markets and regulatory authorities that demand strict technical requirements, imposing severe penalties when unfulfilled. This context drives electric utilities to optimize the management of their physical assets without decreasing their reliability.

In such situation, instrument transformers are important assets playing a critical role in HV power networks. This is so that failures in this equipment, results in unplanned outages affecting the operation of transmission networks and reliability in electricity delivery.

This paper presents a practical approach developed to define priority criteria for the replacement of instrument transformers installed in the HV network of Edenor, the largest argentine electric distribution utility. To do so, focus was placed on defining a methodology to prioritize the replacement of critical units installed. As a result, Reliability Indices of the whole instrument transformers population were developed. So, priorities for the replacement of units are defined considering the risk assessment of the HV network as a whole.

The developed methodology, led to an on-going process subjected to regular adjustments and improvements from the data obtained. By using of this data management approach, positive results have been reached, enhancing the condition assessment of the instrument transformers population and the reliability of the HV network.

INTRODUCTION

At present, 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. All that, together with strict technical requirements and the imposition of severe penalties for its non-accomplishment.

This situation drives distribution utilities to optimize the maintenance management of their physical assets, aiming at developing their activities more effectively, to fulfill the imposed requirements in a cost-effective way.

In such framework, HV instrument transformers (current, voltage or combined transformers), are important assets playing a critical role in HV power networks, providing the input signal required by protection relays, control equipment and energy metering. At the same time, when this equipment fails, an adverse effect occurs in the operation of transmission networks, resulting in unplanned outages and a decrease in the reliability of electricity delivery (*Fig. 1*).

Fig. 1- Failure of a HV 220kV current transformer

International surveys about reliability of HV equipment show that failures in instrument transformers are a major concern for the operation of HV networks [1]. So they represent a weakness in both, HV power substations and as a consequence, in the linked HV transmission grids for the risk of failure that they present, many times with catastrophic consequences, producing fire and damages in nearby healthy equipment (since most of them have external porcelain housing), affecting so, not only the availability of the involved installations but also, the safety of personnel (Fig. 2).

Fig. 2 - Failure with fire on a 132kV combined transformer.

Thus, the ability to evaluate the elapsed life of such units, greatly contributes to reduce corrective maintenance charges and replacement costs, increasing at the same time the reliability and availability of HV electric systems.

Edenor operates a HV network that includes more than 80 HV/HV and HV/MV power substations, with a population of over 1,000 instrument transformers, about 40% of them having more than 30 years in service, and an important number of units more than 40 years old.

Some unpredictable catastrophic faults on these equipments, resulting in fire damaging nearby equipment (*Fig. 3*), imposed taking proactive actions to minimize the chances that these events be repeated, since in many cases, the deterioration processes (evolving from a potential to a functional failure), and the final occurrence of such incidents, cannot be foreseen by means of predictive determinations. This led to the need of facing a massive replacement of units, aiming at increasing the reliability of such equipment, as well as improving the safety of personnel and facilities.

Fig. 3 - Failure on a 132kV current transformer damaging nearby equipment.

BACKGROUND

It is widely understood that the condition of oil - paper insulation systems is affected over time, and bibliography available deals with this topic in depth.

Without considering in detail the complex degradation phenomena that develops in insulation systems, it is broadly known that basically, they are caused by the degradation of solid insulation (thermal ageing and chemical effects) and high water content in the insulation system as a whole.

The highest failure rate in instrument transformers occurs with an age of 25 years or older [1]. Normally, units over 25 years old, develop more combustible gases under normal operating conditions. The ones that most frequently show ageing signs detected as a result of predictive determinations, are those over 30 years [2].

Internationally, it is accepted that instrument transformers over 30 years old, are more vulnerable to failures (many times with catastrophic consequences) due to the degradation of their oil - paper insulation system and loss of tightness, that leads to the accelerated aging of paper, increase of tangent delta (TD) values and generation of combustible gases. This is so, mostly because units of former technologies, used to have a rubber diaphragm, to compensate oil volume variations for temperature changes, which do not completely preserve the units against atmospheric humidity entry, worsening over time and accelerating so, the deterioration process of the insulating system. Therefore, units over 30 years old, normally present a high humidity content in their insulation system, which finally means less reliability. It is noted that such insulation system, once deteriorated, normally cannot be recovered.

The Edenor experience is in general aligned with the international experience; failed units were around 40 years old and, the highest detection of units with high TD values appears on those with over 30 years in service; theoretically around the end of life expectancy of these units.

Ultimately, it can be concluded that units around that age, have had a normal ageing regime, affecting not only their oil - paper insulation system, but also their tightness from the environment. Additionally, their operation under high ambient temperatures and loads along their lifespan, could result concurrent drivers to speed up such ageing development up to their final collapse.

At present, predictive actions performed in field to know the condition of instrument transformers and identify the development of internal on-going fail processes, are based mainly on detective inspections, oil sampling for DGA and water content analysis and TD measuring, all of them with pre-established intervals.

However, many times it is not easy to assess the condition of instrument transformers or predict undoubtedly either, degradation or tendencies to failure in their insulation system, by means of routine determinations. To make matters worse, occasionally the development of abnormal on-going processes could not be detected in time so, early proactive actions are not possible. In addition, many times a failure could occur during the elapsed time between two consecutive condition determination activities. This implies not having the situation completely “under control”, with the risks that this issue presents.

It was concluded so, that it was necessary to count on a methodology that makes it possible to identify the most critical units, in terms of risk levels, in a systematic way, taking into account different factors, in order to plan a massive replacement.

TRANSFORMER FLEET CONDITION

In such a context, managing a systemic analysis of the data collected results a complex fact in order to have on-line processed information, for a faster and better decision making process. To afford this situation, a practical methodology for the condition assessment of the instrument transformers fleet was developed, to execute a replacement plan along the time.

To approach this issue, taking into account specific priority criterion, different options were evaluated and a mix of them was finally adopted.

Methodology

From the exposed situation, the development of a *Risk Index* of the whole HV instrument transformer fleet, based on standard field data and the expertise of maintenance specialists of the company was proposed.

Such indicator relates not only the condition assessment with the risk level of the unit, but also with the reliability of the installation as a whole, and takes into account the following:

- Age in terms of years in service of the units.
- Type of substation where units are installed.
- Equipment with background of failure on units of the same type.
- If performing of assessment diagnosis activities is possible or not.

The evaluation refers also to the voltage levels involved, to consider in the evaluation the impact of failure on major HV networks.

Normalization of Parameters

Since drivers to be considered are of different nature, it is necessary to standardize them. In general, condition factors can be classified as: GOOD (not critical), MODERATED and BAD (very critical). To each possible qualification, a representative numeric value is assigned:

Classification	**Numeric Value Assigned**
GOOD / not Critical	9
MODERATED / Moderated Criticality	6
BAD / Very Critical	1

Table 1 - Normalization of Parameters

Criteria to define the scale used is based on the fact that in-service life expectancy of HV equipment is identified by a bath-tube type curve [3]. Not considering the first part of the curve, where equipment fails for “infant mortality” (ideally should be detected during the commissioning or otherwise, a fail during the first years in service would occur), labeling values assigned are as follow:

9 - Equipment which condition is normal, where probability of failure even existing, is low and constant; as a consequence, the equipment do not require any special attention beyond normal periodic routine verifications;

6 - Apply for equipment that even not under critical condition, requires additional control because an increase of the failure rate is detected.

1 - Used for equipment that must be replaced with priority, since both, its condition/background into its operating context result dangerous. Meanwhile, a close differentiated control must be followed, because of the failure rate could increase dramatically.

Factors of Risk Evaluated

Different drivers representing not only the condition of the units but also the reliability of the installations were considered as described in Methodology.

Table 2 shows how risk factors used are qualified according to their condition.

- Voltage level: the rated voltage for which the equipment was designed and which value is normally applied to the unit under typical conditions.
- Age in service of the unit: refers to the ageing level and also, to the technology of the installed equipment.
- Type of substation: refers to the categorization of the installation, according to its importance in the HV network. Main or primary substations (those with HV bus-bars) are prioritized in the evaluation because of the consequences of a possible failure, higher for both, safety of personnel and impact in the quality of service.
- Background of failures: If the unit belongs to a family with precedent of failures or had shown signs of premature deterioration, such as the case of fast development of high combustible gases content.
- Possible diagnosis determinations: considers the possibility of establishing oil analysis and TD, both, any or none of such determinations.

FACTOR	BAD /VERY CRITICAL (1)	MODERATED (6)	GOOD /NO CRITICAL (9)
Voltage level	220 kV	132 kV	<132 kV
Years in service	Equipment ageing higher than 37 years	Equipment ageing between 15 and 37 years	Equipment ageing lower than 37 years
Type of transformer substation	Main substations with voltage levels up to 220 kV and lowers	Main substations with voltage levels up to 132 kV	Others substations
Failures bachground	Equipment family with background of failures	-	Equipment family without background of failures
Diagnosis methods	No one tests are possible to be executed	Some tests are possible to be executed TD or DGA/water in oil content)	Several tests are possible to be executed (TD, DGA water in oil content)

Table 2 - Risk Factors qualification for different conditions.

Limits for ageing come up from ordering the transformers population according to age and then dividing them into three groups of the same number of specimens. Age values that separate the groups (tertiles) are those considered for the limit qualification: 15 years is the first limit and 37 years the second one. Units over 37 years old belong to the oldest population third.

RELIABILITY INDICATORS DEVELOPED

Since not all the considered drivers have the same importance, it is necessary to standardize the risk factors to obtain an indicator. So the indicator for each unit is calculated as a weighted average, according to *(1)* and *(2):*

$$I = \frac{\sum_{i=1}^{N} P_i * F_i}{N} \quad (1);$$

$$\sum_{i}^{N} P_i = 1 \ (2)$$

Where:

I indicator obtained

P_i *weighting factor for each risk factor (Table 3)*

Fi qualification assigned to each factor,

N total number of considered factors, in this case 5.

Driver	***weighting factor***
Voltage level	*0.1*
Type of transformer substation	*0.1*
Years in service	*0.3*
Failures bachground	*0.25*
Diagnosis methods	*0.25*

Table 3 - Drivers and weighting factors.

As the parameters representing a GOOD (or not critical) condition will be those qualified with 9, the most risky units will be those having a lower qualification.

Putting into practice such approach makes it possible to develop *Risk Indices* on the transformers fleet as a whole, labeling them according to their reliability, into their particular operating context. These are identified as *Reliability Indicators.*

RESULTS OBTAINED

By applying the developed approach to the whole instrument transformer population, it is possible to classify the fleet labeling the units under a *Reliability Indicator*. Ordering from lowest to highest, the less reliable units appear ranked in the first positions, meaning those transformers that present a higher-level of risk.

Applying this methodology shown having around 300 units with reliability equal or lower to 5 (considering 5 as an intermediate reliability level). This helps identifying instrument transformer families presenting a high-risk level (qualification lower than 5).

With this information, different possible strategies can be followed, regarding costs and the resulting impact of the replacements:

a) Replacement of all the units over 37 years old.
b) Replacement of those units with reliability indicator lower than 5 (identified as critical).
c) Replacement of those units both, with reliability indicator lower than 5 (identified as critical) and over 37 years old if installed in main substations.

The last option also follows a forced criterion based on the knowledge of the maintenance specialists, which takes into account the impact of a failure on a main installation.

Considering reliability improvement versus costs involved for either, replacement of units for ageing (option 1) or reliability (or lack of it) (option 2), it is concluded that the second option provides an improvement on the reliability index very close to the replacement strategy based on ageing (15% and 17% of improvement respectively) with an investment cost about 30% lower.

On the other hand, with the replacement criteria prioritizing the oldest units, some considered critical for background of failures would still remain in service, whereas prioritizing the replacement of those low scored, several aged units would not be prioritized to be replaced.

Finally, following the third strategy (mix between the first and the second one), although more expensive (10% higher than the first one), provides benefits related to minimize risks of failure in main substations (reliability improvement of 20%) that although not easy to be quantified, presents a high strategic impact seen from the point of view of reliability of the HV network.

From this evaluation, it can see that the obtained results can be used in more than one way, being the final decision a technical-economical one, considering all these facts.

CONCLUSIONS

Using a tool for the condition assessment of an instrument transformer fleet, considering their reliability based on a global risk level evaluation, allows managing priority criterion in a comprehensive and systemic way. This helps the planning of investment in the short, medium and long-term.

The proposed methodology makes it possible to classify the condition of the transformer population and from this, define priorities for their replacement based not only on considering the ageing of the equipment, but also on a multi-criteria analysis, that considers different key drivers.

This development of this approach resulted in a major five-year-plan, for the replacement of the most critical units of the HV instrument transformers population, aiming at both, improving the age of the fleet and reducing levels of risk.

Such plan, at present in progress, is showing good results related to the renewal of the fleet, reduction of failure events and reliability of the HV network.

REFERENCES

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