Expertise method to diagnose transformer conditions

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Abstract: In this paper we have deduced a new method combining the classic dissolved gases analysis (DGA) techniques for diagnosis of fault transformers.

Based on the interpretation of DGA, a prototype of an expertise system for diagnosis of suspected transformer faults and their maintenance procedures is proposed. The requested estimation is based on historical information provided by the electric company Iberdrola S.A. and its employees.

An expertise method has been developed in order to diagnose transformer conditions, model its aging process, and finally estimate its residual life. In the process of information collecting it is necessary to know transformer data and characteristics, the results of gases analyses as well as the results of the physical-chemical analysis, the records of the machine (carried out revisions, damage repaired, oil degassed and/or filtered, location changes, etc.).

This method is being tested by the utility Iberdrola S.A. to demonstrate its feasibility.

Keywords: Estimation transformers residual life, maintenance, reliability, expertise method.

1 Introduction

In the last years, all over the world there have been incidents in the electric supply. The causes come from different reasons: saturation of the electric system, non-expected peaks of electric consume, etc.

To assure the continuity of service with a determinate level of quality one point to take into account is to take in mind the relationship between maintenance costs and replacement costs.

Moreover, with the deep modifications suffered by the electric power market as a consequence of deregulation laws, it is necessary to reconsider the politic of equipment renovation in electric facilities.

Normally, attempts to approximate the balance among costs, maintenance, reliability, etc. with adaptive control techniques have often been based on the trial and error. The proposed model provides a quantitative connection between reliability and maintenance, the link lost in heuristic approaches. The component ageing process is developed and modelled for the ageing stage.

The methodology used for the achievement of this work has been based on the consideration and combination of statistic classic techniques together with more modern disciplines.

The growing complexity and sophistication of the considered systems makes necessary the development of intelligent instruments that direct the control and design operations. So, it has been considered the use of fuzzy logic and expertise systems to solve these problems.

In this paper, a mathematical model for the evaluation of the state of transformers of electric substations has been developed. This model allows us to decide the most convenient operation to make, substitution or renovation. In the decision the technical reasons as well as the economic ones are evaluated.

Preventive techniques for early detection of faults in power transformers to avoid outages would be valuable. In this way, analysis of the mixture of the faulty gases dissolved in insulation oil of power transformer has received world-wide recognition as an effective method for the detection of incipient faults. However criteria tends to vary from utility to utility. Each approach has limitations and none of them has a firm mathematical description. For this reason, knowledge-based programming is a suitable approach to implement in such a diagnostic problem.

Based on the interpretation of DGA, a prototype of an expertise system for diagnosis of suspected transformer faults and their maintenance procedures is proposed. The significant source of this knowledge base is the gas ratio method. Some limitations of this
approach are overcome by incorporating the diagnostic procedure and the expertise method. Furthermore, a data based adopted from Iberdrola’s gas records of transformers are incorporated in the system to increase the practical performance.

The requested estimation is based on historical information provided by the electric company and its employees with more relevant experience about this subject, and the analysis of the interdependencies of the different possible mishaps, as well as its consequences.

2 Description of the proposed system

Most of all faults of oil-immersed power transformers result from incipient deterioration. Therefore, faults should be identified and avoided at the earliest possible stage by some predictive maintenance technique. DGA is one of the most popular techniques for this problem.

This study is concerned with the following representative combustible gases: hydrogen (H₂), methane (CH₄), ethane (C₂H₆), ethylene (C₂H₄), acetylene (C₂H₂) and carbon monoxide (CO).

Many interpretative methods based on DGA have been reported to diagnose the nature of the incipient deterioration. Many interpretative methods based on DGA to diagnose the nature of incipient deterioration have been reported. Even under normal transformer operational conditions, some of these gases may be formed inside. Thus, it is necessary to build concentration norms for a sufficiently large sampling to assess the statistics.

![Procedure for transformer diagnostic](image)

Fig. 1. Procedure for transformer diagnostic.

As shown in Fig.1 the overall procedure of the routine maintenance for transformers is listed. The core of this procedure is based on the implementation of the DGA technique. The fist step of this diagnostic procedure begins by asking for an oil sample to be tested, the sampling date and the element code. More important relevant information about the transformer’s condition, such as the voltage level, the preservative type, the online-tap-changer (OLTC) state, the operating period, the degassed time and the past remedies is available in the database (supported by historical information provided by the electric company).

Norms (criteria) set up by Iberdrola power transformers’ condition (established from the study of 1390 power transformers) and total dissolved combustible gas (IEEE C57.104, 1978) are used to judge the transformers’ condition. For the normal cases the data are stored as background. For the abnormal cases, the gas ratio method is used to diagnose transformer fault type.

2.1 Diagnosis

The dissolved gas may vary with the nature and severity of different faults. By analysing the energy density of faults, it is possible to distinguish three basic fault processes: corona, arcing discharge (both electrical faults) and overheating (thermal fault).

Many interpretative methods based on DGA have been reported to diagnose the nature of the incipient deterioration.

![Duval’s triangle](image)

Fig. 2 Duval’s triangle

a: high-energy arcing. b: Low-energy arcing. c: Corona dischaeges. d: Hot spots, T<200°C. e: Hot spots, 200<T<400°C. f: Hot spots, T>400°C.

We can use methods as Dornerburg’s [5], Rogers’ [8], Duval’s [2], IEC-IEEE [5], Key Gas Method [4,5], G.E., etc.
gases to judge different faults. Duval’s method, Fig 2, uses the relationships of three gases and a triangular representation to determine the nature of the fault, allowing its application to diagnose a bigger number of cases than the previous methods.

These methods can be automated without complication, use to work well in similar cases and fail mutually in others. Multiple numeric thresholds are used to classify data obtained from the analyses of gases like belonging to diverse intervals. The belonging of information to an interval is used to infer the diagnosis. When a failure is intermittent or of low intensity, some of the values can fall outside but near the respective interval, without the expected diagnosis being obtained. If we use fuzzy logic to define the method, that is to say, the strict intervals of belonging are replaced by fuzzy intervals, the standard method goes on extending its utility automatically although the basis of it stay the same. Fuzzy logic could be applied to all of the classic methods of diagnosis. The graphs of the memberships functions are conditioned by certain requirements: they must adapt to the method in which they are based, each interval border must have a factor of trust of 0.50 and the intuitive relationships among the categories are invariable. In this manner it is possible to extend the method in a logical way, being able to apply it to more cases, but without losing its essence.

Fig 3 Key Gas Method

In the Key Gas Method several significant gases and proportions are assigned to four typical fault types. These gases are called “key gases”. In order to establish the state of a transformer with this method we can estimate the proximity from the sample to each one of these typical cases. These values are not very representative so we have proceeded to standardize the results. We assign to each analyzed sample a proximity factor to these type cases (in the interval [0,1]), which takes the value 1 when the sample is in fact the type standard and the value 0 in the farthest away possible case. If the value of the proximity factor of a sample to a type is bigger or the same than 0.75 we have considered that the "difference" between the current sample and the case type is quite small.

On the other hand, since each rule acts independently, there is no guarantee that each method will yield the same conclusion. Conflicts will arise in many cases. Thus a scheme for solving conflicts must be determined. That will be made with the aid of a fault tree.

In Fig. 4, the fault tree contains information about the relationships between different fault types. In order to solve the conflicts that can arise when different methods of diagnosis of analysis of gases are applied, you can proceed to place in each one of the nodes in the fault tree a label as soon in the Fig. 5. These labels help us to release the diagnostic of the transformer fault.

For the resolution of the conflicts or to proceed to the diagnosis we build a list whose elements are the values of the variables of the labels of the nodes,

\[ E = \{F1, F2, F200, F210, F211, F212, F220, F221, F222, F300, F310, F320, F330\} \]

We update their values as the method is being applied.

Proposed method:

1. Initialize all the label variables of the nodes to 0.
2. Select a diagnostic method.
3. Based on the sample concentrations, apply the individual relationships of the selected method to settle down which is the node corresponding to the state of the transformer.
4. Increase the value of the variable label corresponding to that node in one unit, as well as those of the antecedent labeled nodes in the tree.
5. Repeat the steps 2-4 for each considered diagnostic method.
6. From the final values of the list \( E \) we deduce the problem that affects the observed transformer.

\[
E = \{F_1, F_2, F_200, F_210, F_211, F_212, F_220, F_221, F_222, F_300, F_310, F_320, F_330\} = \{0, 4, 0, 0, 0, 0, 0, 0, 4, 1, 0, 2\}
\]

So, we can conclude that the analyzed transformer has a problem high-temperature thermal fault.

Example 2.

<table>
<thead>
<tr>
<th>METHOD</th>
<th>DIAGNOSIS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rogers</td>
<td>arc with power follow trough (F220)</td>
</tr>
<tr>
<td>Dornerburg</td>
<td>arcing (F220)</td>
</tr>
<tr>
<td>UNE</td>
<td>high-energy arcing (F222)</td>
</tr>
<tr>
<td>Key Gases</td>
<td>corona in oil (F210)</td>
</tr>
<tr>
<td>Duval</td>
<td>low-energy arcing (F221)</td>
</tr>
<tr>
<td>GE</td>
<td>electric fault (F200)</td>
</tr>
</tbody>
</table>

So, in this case

\[
E = \{F_1, F_2, F_200, F_210, F_211, F_212, F_220, F_221, F_222, F_300, F_310, F_320, F_330\} = \{0, 6, 6, 1, 0, 0, 4, 1, 1, 0, 0, 0\}
\]

So, we can conclude that the analyzed transformer has a problem of arcing discharges.

Example 3

<table>
<thead>
<tr>
<th>METHOD</th>
<th>DIAGNOSIS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rogers</td>
<td>unknown</td>
</tr>
<tr>
<td>Dornerburg</td>
<td>unknown</td>
</tr>
<tr>
<td>UNE</td>
<td>unknown</td>
</tr>
<tr>
<td>Key Gases</td>
<td>corona in oil (F210)</td>
</tr>
<tr>
<td>Duval</td>
<td>high-energy arcing (F222).</td>
</tr>
<tr>
<td>GE</td>
<td>electric fault (F200).</td>
</tr>
</tbody>
</table>

So, in this case

\[
E = \{F_1, F_2, F_200, F_210, F_211, F_212, F_220, F_221, F_222, F_300, F_310, F_320, F_330\} = \{0, 3, 3, 1, 0, 0, 1, 0, 1, 0, 0, 0\}
\]

So, we can conclude that the analyzed transformer has a electric problem.

2.3 Expertise method.

More information than just the fault type is needed for further diagnosis. If the results of the proposed
method show abnormal conditions, the diagnostic result is classified into four different degrees of severity: normal, cautious, serious and critical. The expertise method lists the appropriate maintenance scheduling for retesting the oil, and any other proper actions depending on the severity condition.

In this study, most of the diagnostic variables stored in the database are current gas concentration, some are from the user, and others are retrieved from the transformer’s historical database. The knowledge base is the collection of domain expertise, the professional information. It contains facts and knowledge relationships, which uses these facts as the basis for decision making. The production rule used in this system is expressed in conditional forms.

The problem of extracting and coding the knowledge is a fundamental but annoying task; taking a long time to combine the complementary methods with the gas ratio methods. Another fundamental point in the system is the inference. It controls the reasoning strategies and search of the appropriate knowledge. In this system we have incorporated some popular methods of DGA, as well as heuristic rules of maintenance. The results of the diagnosis are classified in different levels of severity: normal, caution, serious or critical. Based on the experience in the maintenance of these transformers, the expertise system proposes an appropriate strategy of maintenance connected with the oil, or any other performance depending on the state again.

An expertise method has been developed in order to diagnose transformer conditions, model its aging process, and finally estimate its residual life. In the process of information collecting it is necessary to know transformer data and characteristics, the results of gases analyses as well as the results of the physical-chemical analysis, the records of the machine (carried out revisions, damage repaired, oil degassed and/or filtered, location changes, etc.). It is also important the information relative to the external circuit that can affect aging and cause important deterioration of the machine (fault dissipation operations, lightning rod’s discharges, short circuit intensities, discharges in the terminals, internal discharges with gases formation and shot Buchholz, etc.). To demonstrate the feasibility of the method, the data supported by Iberdrola have been tested.

The method carries out a punctuation assignment that, in function of the time, will reflect the transformer state. The initial assignment (1200 points) is updated as a function of the evolution and performances carried out on the transformer. Some will add points, (as the periodic revisions, improve of oil quality) others will subtract points (the transformer aging, the important repairs, the discharges on the terminal discharges, internal discharges having an effect on Buchholz relay in the period under consideration or the location change). Thus, its necessary to keep in mind the internal situation, previously deduced in the dissolved gases analysis, the operations of maintenance and repairing, the external circuit incidences influence and the oil operation conditions.

Once the valuation has been established, we have proceeded to fit the given data (time, punctuation) to a function and find the best function in the least square approach. This "best" function is denominated “Aging Curve”.

![Aging Curve](image)

Fig. 6. Aging Curve obtained from the proposal method

On the basis of our experience in the work with transformers, we had a previous idea about its shape. This curve should be almost constant at the beginning of the machine life, should decrease slow but continuously later, except for extraordinary circumstances, until reaching the limit value considered as the end of the useful life. At that moment, it is not convenient or profitable to continue with the operation of the machine.

In the beginning, we considered the possibility of using an exponential type curve, but the exponential function didn’t give us satisfactory results due to its sensitiveness about lack of data.

In the provided data base, there are machines with no data in the first 15 or 20 years from the installation. So we have no idea about the actuations/manipulations suffered by them.

So, the theoretical study of the problem induced us next to another type of function model. The polynomials fit series of points in order to decrease the squares of the deviations sum. The adjust is better when the polynomial degree is the number of valuations minus one. So we depend on the measured points number. We pretend the adjust function to be independent on the number of values, as far as possible.
From numerous analyzed functions the one that provided the most appropriate results, according to the type as well as the quantity of available data, has been the following:

\[ V(t) = 10^{a_1 + b_1 t + c_1 t^2 + d_1 t^3 + e_1 t^4} \]

The obtained curve fits better to the real transformer situation when there are historical controls and data analysis from the transformer installation than when it has lapsed many years since the starting and the first available test.

Example 4. ABB transformer, installed in 1990, registered number Nº 87687 (from Iberdorla’s historical data). The proposed method assigns the following results:

<table>
<thead>
<tr>
<th>No</th>
<th>Date</th>
<th>Valuation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>01/01/1990</td>
<td>1200</td>
</tr>
<tr>
<td>2</td>
<td>14/11/1991</td>
<td>1070.1</td>
</tr>
<tr>
<td>3</td>
<td>30/06/1992</td>
<td>1173.7</td>
</tr>
<tr>
<td>4</td>
<td>27/09/1993</td>
<td>1170.8</td>
</tr>
<tr>
<td>5</td>
<td>21/07/1995</td>
<td>1090.1</td>
</tr>
<tr>
<td>6</td>
<td>02/04/1997</td>
<td>1151.5</td>
</tr>
<tr>
<td>7</td>
<td>06/04/1999</td>
<td>1151.9</td>
</tr>
</tbody>
</table>

In this case we have obtained:

\[ a = 3.07441, \quad b = -9.37497E-03, \quad c = 1.40736E-03, \quad d = -7.04246E-05 \]

From Fig.6, if the vital minimum is established as 300, this transformer will reach this punctuation in 27 years, this is, in the year 2017.

3 Conclusion
In the aim of finding a new method for diagnosis fault transformers, we have combining the classic dissolved gases analysis techniques and afterwards we have developed an expertise method, to model the aging process, and finally estimate its residual life.

We have infered the function which allow us to know the transformer state as well as the residual life, as time function. This method is being tested by the utility Iberdrola S.A. to demonstrate its feasibility.

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References