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Transformer Management System

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Abstract: This paper intends to show what have been done in a Brazilian Utility, named CEEE-Companhia Estadual de Energia Eletrica and a University, named PUCRS-Pontificia Universidade Catolica do Rio Grande do Sul, joined in a research and development (R & D) project to deal with a pilot power transformer management system, including maintenance information system, online monitoring (diagnosis and prognosis) and loss of life assessment.

Key words: management system power transformer, monitoring diagnosis, prognosis, loss of life assessment.

1 Introduction

The R & D project described in this text, starts at the end of the year of 2003, with the following goal: to prepare the most complete possible management system for power transformers.
To achieve this objective, several modules were prepared and installed in a pilot power transformer. These modules are:

- Transformer data bank module, with all information used in utility operational software;
- Transformer maintenance module, composed by maintenance data bank, electrical tests, all information about gas chromatography, 2-furfuraldehyde analysis, physical and chemical analysis. In this module there is a software based in artificial intelligence, to evaluate off line, dissolved gas chromatography;
- Transformer online monitoring module, with monitoring sensors applied directly to evaluate transformer mineral oil, bushings, oil temperature (hotspot), winding thermal image and the on load tap changer, local (near transformer) environmental variables like wind speed, wind direction, ambient temperature. To monitor electrical transformer variables, like current, voltage, apparent, active and reactive power, trough data acquisition systems;
- Transformer loading module, with online loss of life assessment.

In Figure 1 can be seen the first screen of the system presented above, presenting a transformer picture, the name of a substation were it is installed, buttons to select “Data Module”, “Monitoring Module”, “Maintenance Module” and “Loading Module”. These information permits to study the electric system via load flow studies, the evaluate transformer operation using a loading analysis, to check transformer oil verifying chromatographic analysis and so on, just in one man-machine interface.

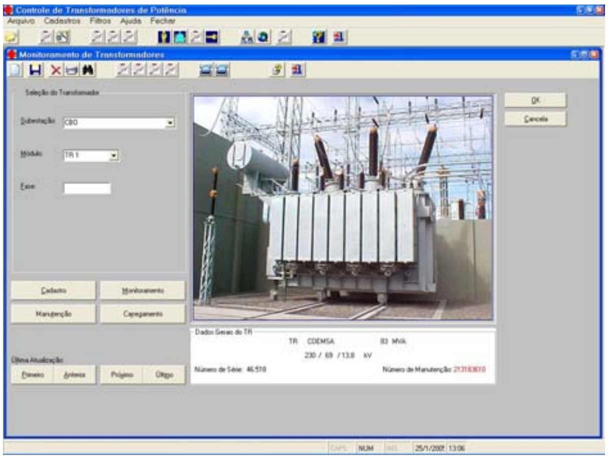

Fig. 1 - First screen of transformer management system.

Behind this screen is the transformer data bank, with all electrical and mechanical information of each transformer in the electrical system of the Utility. This data bank is unique for all Utility and can be accessed for all kind of studies in the Company.
The integrated system is accessed by password, were complete information about transformer is easy found by operating personnel, maintenance personnel, design personnel and planning personnel, simultaneously.
With these system is intended to prepare diagnostics and prognostics of a pilot transformer. The transformer used as pilot, for this R & D Project, presents the following principal characteristics:

- Number of windings: 3
- Rated voltages: 230-69-13,8 kV
- Rated capacity: 50/66,5/83 MVA

- OA/FA/FA Oil-immersed (self cooled/forced-air-cooled, first stage/ forced-air-cooled, second stage).

In the next sections will be described in detail the system modules used to access particular information about the pilot transformer.

2 Data bank module

The data bank structure takes in consideration the particularities of the electrical Utility system extent and the new regulations in Brazil.
A transmission system, in general, is confined in a geographic area with big dimensions. To have operation and maintenance flexibility the geographic system area is divided in small pieces where functions of predictive, preventive and corrective maintenance functions are performed. Due to these aspects, the data bank structure was divided in order to each transformer belongs to its system part, which is in charge for maintenance programming, execution and recorded.
Each transformer has an individual identity, identified as a "maintenance number" that is characterized by a "substation, bay and phase" if it is not a triphasic unit. The maintenance number is a nine-digit number that presents no meaning for most people that will use the information system.
Considering that the transmission system is not static, expansions in the system are common; one specific transformer may be substituted or transferred for another place. For the management and maintenance of these equipments, is of fundamental importance that the information system "moves" from one place to another, carrying all transformers characteristic and historic. The data bank developed to this R & D Project takes in consideration what was stated previously. As example, the pilot transformer used in this project with the maintenance number 213.183.618, is installed in the Campo Bom Substation (SE CBO), transformer bay number 2 (TR2).
The huge number of variables and data to be stored in the power transformer information/management system, was divided as follows:

- Transformer General Information
- Transformer Electrical Information
- Transformer Mechanical Information
- Transformer Thermal Information

The data bank structure was prepared to be easy to manage transformer information, storing, in a safe way all the system data, presenting to all user the required information, as in transformer operation, maintenance, planning and management.

3 Maintenance module

The maintenance module was conceived to store information about the historical data maintenance actions in each system transformer, the preventive maintenance program and a software tool to evaluate the operative condition of each power transformer.
In this module, using the data bank structure, the information of each transformer is stored under the maintenance number.
To easy access to the information and tools in this module, subdivisions were provided as follows:

- Maintenance
    - Historical data
    - Preventive maintenance
    - Predictive maintenance
        - Physical-chemical analysis
        - Gas chromatography
        - 2-furfuraldehyde

3.1 Historical data

In this sub module are stored the actions took in each power transformers, as: transformer and related power system actions records, transformer and transformer components failure records, maintenance records, component changing records and oil, core and windings drying records. The historical database is intended to easy permit to make decisions on power transformer management.

3.2 Preventive maintenance

In this sub module, the preventive maintenance program of power transformers is prepared, including the actions to be taken according to component operating time, operation number of tap changing in OLTC, for example.

3.3 Predictive maintenance

In this sub module, are kept historical data about physical-chemical analysis, gas chromatography analysis and 2-furfuraldehyde analysis, with software tools that permit to identification and

interpretation of results that show a kind of failure class, as incipient failure tendency, high temperature failure tendency and so on, were maintenance requirements are available.
Additionally, to bear actions on predictive maintenance, some other software were prepared, using regular analysis or using artificial intelligence techniques to evaluate the degradation of electrical insulation paper and 2-furfuraldehyde.

As one example of the Maintenance Module will be used the chromatography analysis, were all kind of analysis were prepared to define the best possible decision to the maintenance personnel. Besides the classical methods of Brazilian Standard (NBR), IEC, IEEE, and several other methods found in the technical literature about transformers, a new method was developed mixing information from the other methods that is processed by an artificial intelligence system and balanced by a probabilistic way. The artificial intelligence system selected to deal with the uncertainties of chromatography analyses was a well-known fuzzy logic, as seen in Figure 2.

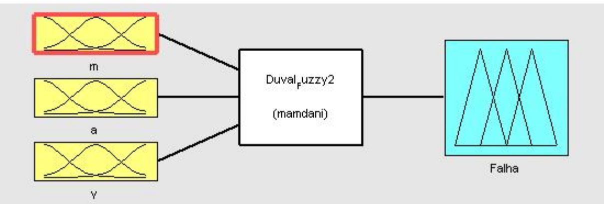

Fig. 2 - Fuzzy logic applied in Duval Method (Input - Inference – Output).

Another easy way to see the application of Fuzzy Logic in Duval Method of chromatography analyses is presented in Figure 3, were fuzzy functions values can be seen. All data necessary to the analyses evaluation is stored in a data bank that follows the transformer wherever it was installed.

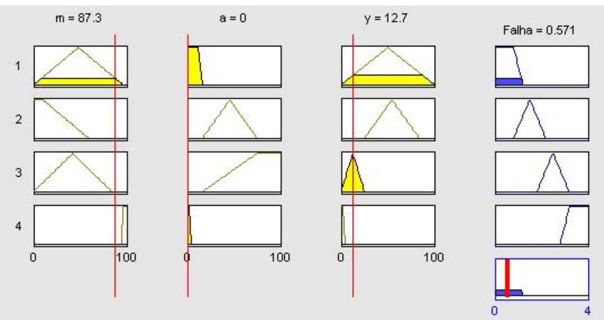

Fig. 3- Fuzzy Logic Inference (Duval Method)

From these analyses a result is proposed with a probabilistic evaluation. Figure 4 shows this approach.

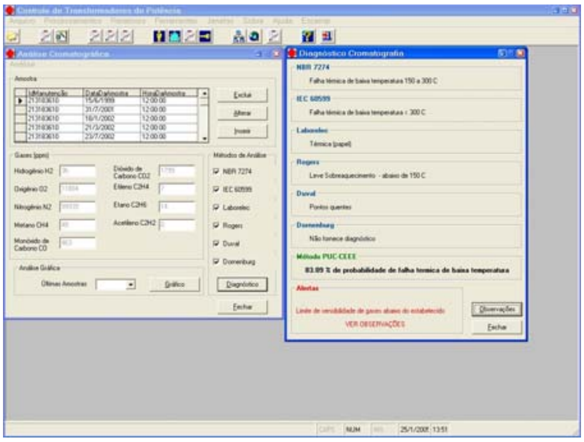

Fig. 4 - Chromatography analyses software.

From selection screen, the user can define what kind of analysis will be performed, if using one or several classical methods or using graphics for trend analyses, as an example.

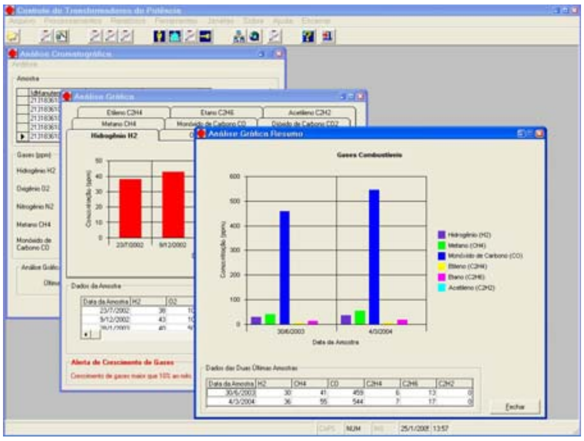

Fig. 5 - Graphical Trend analyzes.

All chromatography samples are stored for each transformer is a companion matter for all of it active life.

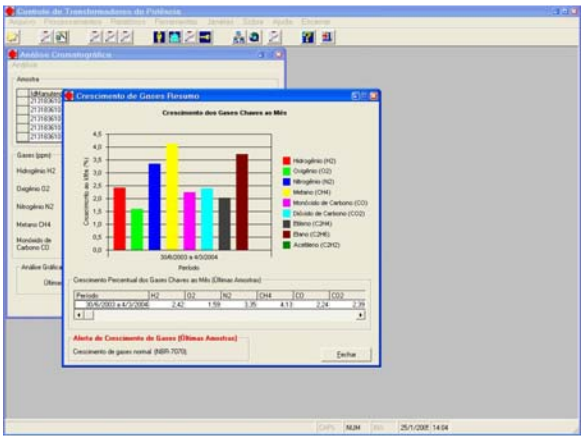

Fig. 6 - Sample graphical analysis.

4 Online monitoring module

In this section will be described the equipment used in the monitoring system of transformer, environmental and electrical variables.

4.1 Transformer

To directly monitoring power transformer mineral oil were applied two different monitoring sensors with to different principles of operation. Both equipments are intelligent electronic devices-IED. The first monitoring sensor described, was directly purchase by the R & D Team. The other one was purchased by CEEE and installed in the same transformer to compare results and different technologies.

The first monitoring sensor is installed in critical transformers for continuous measurement of dissolved hydrogen and water in dielectric insulating fluids. Hydrogen is an indicator of a recent or existing fault. All fault types produce it, to a greater or lesser extent. Monitoring moisture content is also vital to transformer operation as it can quietly build up to the point where serious deterioration to the paper/oil system can arise, leading to major transformer problems.

The second monitoring sensor is installed in critical transformers for continuous measurement of gas-in-oil, with gas response to Hydrogen (H_2), carbon monoxide (CO), acetylene (C_2H_2), ethylene (C_2H_4).

To monitor transformer bushings, was used Intelligent Diagnostic Device for continuously evaluating the condition of bushings. It measures the electrical signal at the bushing by summing the leakage currents measured at each capacitive tap. The analysis requires the monitoring all bushings in a three-phase set. Tap adapters specifically designed for the particular bushing are mounted to the tap, allowing measuring the leakage current. Bushings are evaluated by measuring the current at each tap. The analysis sums the three-phasor values. If the bushings are identical and the system voltages are balanced, the resulting sum vector will be zero. Since bushings are never identical and system voltages are not perfectly balanced, the sum current will be a non-zero value. As a result, the sum current is a vector unique to the bushing set. The system establishes a benchmark sum current during the data collection cycle, which is then compared to the measured nameplate configuration data.

To monitor the oil temperature (hotspot), was used the existing transformer sensors and installed a digital/analog converter to acquire these values in the most convenient way.

To monitor the winding thermal imaging, we used the existing (transformer sensors, PT 100 and Bushing CTs) and installed a digital/analog converter to acquire these values in the most convenient way.[i]

To monitor the on load tap changer, two actions were took:

1) Temperature sensors were installed in the on load tap changer, which were not existing in such equipment;
2) The operational cycle of on load tap changer motor was measured (current, voltage) in order to get its signature.

4.2 Environmental variables

To measure and record environmental local variables, a meteorological station was purchased, were the following parameters were online monitored by special sensors: Temperature with Radiation Shield, Relative Humidity, Maximum Anemometer, Wind Direction Vane, Pyranometer and a Rain Gauge-Tipping Bucket. These instantaneous values will be used to precisely fit the electrical model adopted in R & D Project. As an example can be considered the variability of ambient temperature, a measured real time value, instead of the use of a constant ambient temperature, and usually considered in several transformer load guide models.

4.3 Electrical variables

Some electrical variables were acquired on line for use with transformer life model. These variables are current, voltage, apparent, active and reactive power. These real time values will be used in conjunction with the transformer loss of life model, by the reconstruction of daily load curve (kVA x h).

Considering that the transformer is in use for several years and cannot have all daily load curves during this period in a data bank, some simplifications to evaluate the past loss of life will be assumed.

5 Loading module

The model used to provide diagnosis and prognosis for transformer loss of life assessment, was an adaptation of the Arrhenius reaction rate theory that has the following form[4]:

$$\text{Per unit life} = \mathbf{A} \cdot \mathbf{e}^{\left[\frac{\mathbf{B}}{\theta_H + 273}\right]} \quad (1)$$

where

Θ_H is the winding hottest-spot temperature, °C
A is a constant
B is a constant

Parameters, as top oil temperature, apparent power, etc., are assessed online with calculating in intervals of 15 minutes during transformer normal operation and in one-minute interval during overload conditions. The value of loss of transformer life is used by operation and maintenance personal to define if the transformer must continue in operation or not.
The module that deals with transformer loading is based in the Guide for Loading Oil Immersed transformers from Brazilian Standards (NBR), IEC and IEEE methodology.
The differences with other systems are due to the way that is used to verify the transformer loss of life.

- All the time, transformer loss of life is being counted based in a thirty or forty year transformer life expectancy assumption (see Figure 7) including normal and overload conditions, when data is computed minute by minute;
- When detected an overload future condition, a study module is turned on, and then daily-predefined load curves can be used for transformer loss of life simulation.

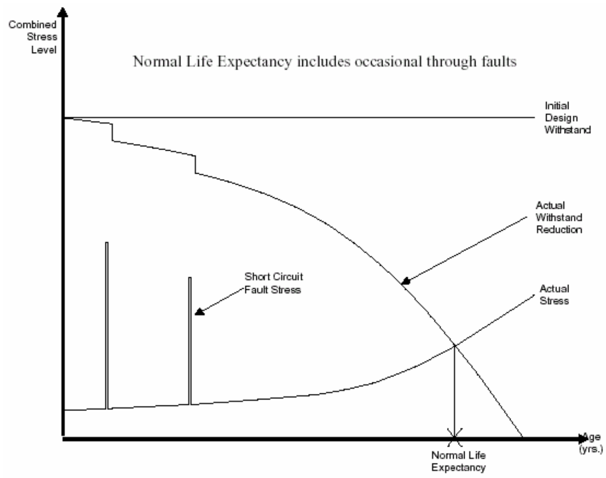

Fig. 7 - Transformer life expectancy [8].

6 Communication systems

As stated before, the Utility communication system was used to access utility Intranet and Internet, using password.
Considering that the acquired equipment use different communication systems, ETHERNET, RS 232, RS 485, 4-20 mA, etc., was necessary to define interfaces between those systems and CEEE intranet, in order to receive the information in the most convenient way.
Figure 8 shows how, communication systems are linked to the several monitoring systems and how the user access the information.

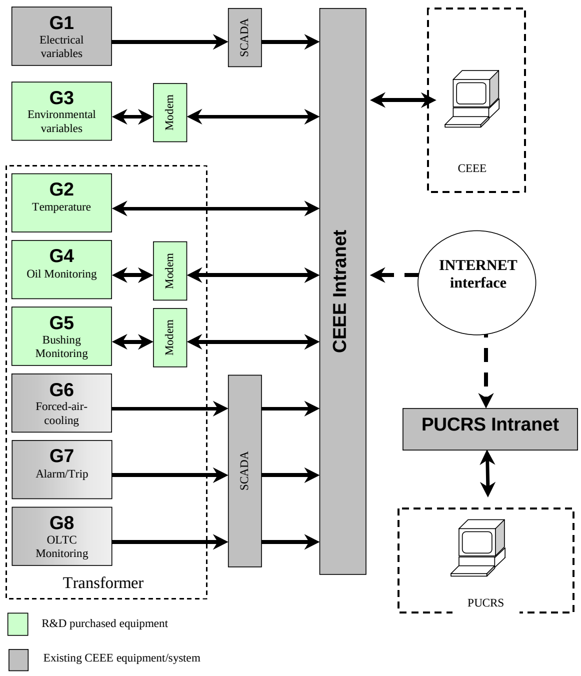

Fig. 8 - Communication systems associated to the pilot transformer.

Due to different communication system (Field bus, RS 232, RS 485, etc.) existing between IED, were adopted different solutions to process the variables acquired to transformer monitoring.

7 Resulting Software

The software structure that result from de analysis described above, is resumed in Figure 9.
This software is operational since the end of 2004.

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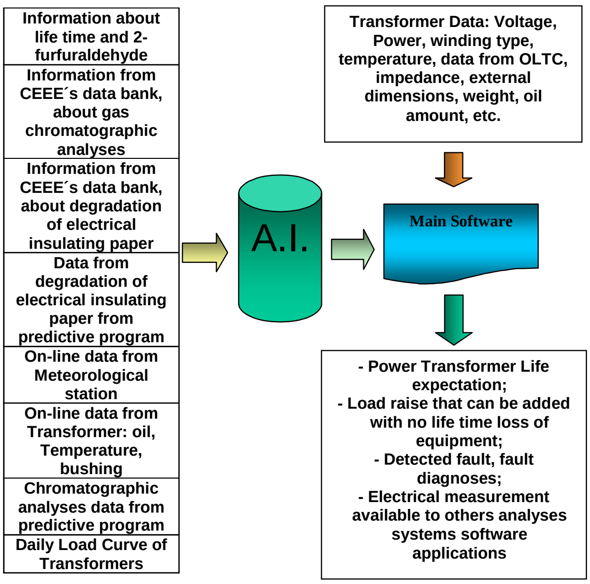

Fig. 9-Proposed software structure.

8 Results

At the moment were this paper is being written, all the equipment related to the R & D Project is installed and the ending tests in the software are finished.

9 Conclusions

Several benefits are being recognized from the start of the R & D Project, unless the results were not visible yet, in terms of equipment installation. Some conclusions from these results are:

- All CEEE data bank were revised and updated using object oriented software;
- Due to the existence of this R&D Project, detailed information about transformer management and monitoring problems and benefits spreads through all the Company;
- As an improvement of the internal process of the technology transference between PUCRS and CEEE, customers will perceive a system with a better Power Quality;
- As improvement of supplied service quality, is intended to execute a better preventive maintenance;
- This R&D Project is innovative and produces benefits to the Brazilian Utilities, considering the improvement of electrical services due to the anticipation of incipient faults in critical Power Transformers and Substations;
- This R&D Project promotes the interaction between academic environment and electric utilities, propitiating the technical and personnel improvement of both parts involved, contributing to technologic and scientific development in Brazil;

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NOTE

The software screens were written in Portuguese because the original program was prepared in this language and that they are easy to be understood.

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