ASSESSMENT OF THE ALLOWABLE SHORT-TERM OVERLOADS IN POWER TRANSFORMERS INCLUDING CONDITION MANAGEMENT

Jorge YASUOKA¹, José A. JARDINI¹, José L. P. BRITTES², Luiz C. MAGRINI¹, Paula S. D. KAYANO¹, Josué de CAMARGO¹

¹Escola Politécnica da Universidade de São Paulo and ²CPFL – Companhia Paulista de Força e Luz – Brazil

jyasuoka@pea.usp.br

INTRODUCTION

The decision about the nominal power of each substation transformer is made based on the peak load value and in the contingency criteria during emergency situations. As emergency criteria, some facilities in Brazil consider that when one transformer is disconnected, the other ones in the same substation need to supply the total load. Others facilities consider that a substation can assume an amount of extra load, up to 30% of its total load from other substations. In both cases, the overload on each transformer must not exceed 20%.

This limit of 20% of overloading has been adopted based on a qualitative study about the typical duration of peak load, aiming to not exceed the oil or hot spot limit temperature. This criteria has resulted in a high amount of installed capacity that should be optimized, postponing the construction of future installations. Within CPFL (Companhia Paulista de Força e Luz, a Brazilian distribution utility), it is considered that it can be allowed an overload more than 150%, depending on the time interval, if a real time system that stores information about transformer heating variables and conditioning maintenance is available. For such, a real time digital system was developed, and its performance is being evaluated in a group of 3 substations and in the Distribution Control Center (DCC).

SYSTEM DESCRIPTION

The integrated system is composed of several local systems, installed in the substations, connected to a managing system at the Distribution Control Center (DCC). Each local system is responsible for load forecasting of substation transformers, calculating a set of possibilities for future use for each one, according to the operational conditions, on the equipment’s history and its accessories characteristics, at the same time assuring the transformer’s reliability whatever loading level.

Until now, two prototypes have been implemented, one at the Campinas Centro Substation, which has three 30/40/50 MVA transformers and twenty 11.95 kV feeders, and another at the Andorinha Substation, which has two 30/40 MVA transformers and ten 11.95 kV feeders. The substation has single bus arrangement, which is the typical CPFL’s substation configuration.

The integrated system’s architecture and the management system are described as follows.

Local System’s Architecture

In each Substation, the Local System consists of two local area communication networks, one with digital meters (IEDs) for the feeders and transformers and another one with RTUs in order to acquire general data of the transformers (temperature, gases, humidity, alarm status, etc.). Two microcomputers are connected to the LAN, one working as SCADA System host and another processing the computational tool for real time supervision and control.

The computational tool consists of four interconnected modules, which are fed by the data acquisition platform. Every 15 minutes a loading forecast is carried out looking to 4 hours ahead (Module 1) supplying information on future possible transformer loading for the other software modules. The Module 2 estimates the top oil and hot spot temperatures considering ambient temperature and previous loading. The module 3 addresses the transformer reliability and defining temperature and current maximum limits for it. Having such information, the system is able to calculate (Module 4) how much time each transformer can be overloaded for periods lasting from 15 minutes to 4 hours (allowable short-term overload).

Follows a more detailed description of each module.
Module 1: Short Term Load Forecaster (STLF). The STLF uses the information in an historical demand database fed by the real time data acquisition system and carries out the load forecasts using a technique based on Artificial Neural Networks (ANNs), for all substation transformers and feeders. The forecast is divided into two parts: 1) Base Forecasting, which is carried out daily at midnight for 24-hour ahead, producing 24 hourly demands. This procedure is used to define the general operational condition of transformers and primary feeders for the coming day; 2) Follow-up Forecasting, which supplies short term forecasts along the day aiming at providing a procedure which monitors occasional loading variations, and accommodates moderate variations along the day. This procedure aims at supplying more accurate conditions of the loading behaviour, every 15 minutes, for five future intervals - ¼ hour, ½ hour, 1 hour, 2 hours and 4 hours ahead. This module has been extensively studied [1]. Figure 2 shows one of such forecast.

Module 2: Transformer Operation Temperature Estimator (TOTE). The TOTE processes the results of Module 1 (load forecasting), producing a thermal analysis of each power transformer in order to allow adequate operating conditions, which does not rely on monitoring devices only. Along the loading curve, expected within 24 hours and the short term forecasting, are calculated the expected temperatures for the top oil and the hottest spot of each transformer (checking if this is capable to bear the load), which form the major step for defining reliability and consequently the admitted loading limits. In order to define the transformer thermal equations to be used, the CPFL has acquired a transformer with 8 internal temperature fiber optic sensors from SIEMENS, including the conventional sensors. These sensors were located in a strategic location like: probable hottest spot point in the high and low voltage winding; the nearby oil duct; and in the bottom oil. Special factory test were conducted in order to record relations between load and temperature like: step change from cool to 70%, 100% and 117% of rated load; loading profile with hourly step varying from 40% to 100% with two step superposed, one of 160% for 30 minutes and another of 170% for 15 minutes. The following equation was used:

$$\theta_{HS} = \theta_{AMB} + \theta_{BO} + \theta_{OD/BO} + \theta_{HS/OD}$$  \hspace{1cm} (1)

where: $\theta$ is temperature; AMB is ambient; HS is hottest spot; BO is bottom oil; OD is oil duct; OD/BO is oil duct temperature above bottom oil.

The parcels are of the type $(1-exp(-t/\tau))\Delta \theta_U$ where $U$ means ultimate values and $r$ is the time constants.

From the test results it was possible to determine ultimate condition for temperature differences and time constants, also the actual application of 170% step when ambient temperature was close to $30^\circ$C.

Details about this study can be found in [2]. It was also concluded that the recommended equations by IEEE Standard PC57.119 Draft [3] Appendix G can be used to determine ultimate temperature differences and time constants. It should be noted that loss of life is calculated and accumulated in this model.

Module 3: Loading Transformer Reliability Analyser (LTRA). The LTRA is responsible for the application of the reliability criteria on the transformers and was implemented using a unique approach. Four independent evaluation criteria were adopted (or Blocks) as related as: Project, Maintenance, Operation and Accessories. The output for each block presents a classification based on Risk (qualitative), one on Alarms and another determining the limiting temperatures. If risks are acceptable, these temperatures are used as a basis for the calculation of how much power can be assigned to the transformer. This module presents the highest complexity among all the modules, either in the quantity of parameters involved, or the representative models of each parameter. The characteristics of each block are:

1) Project: it reflects basically the main technical constructive characteristics, such as technical competence of the manufacturer, measure of the several parts (main tank, conservator, etc.), types of isolation, handling on transportation, stocking and oil fill up, etc.;

2) Maintenance: takes into account the equipment’s historical life, through the reliability influenced variables, such as oil physical-chemical analyses and chromatography, concentration of humidity on the oil and paper, concentration of gases, furfural content, mechanical rigidity and dielectric, etc. Some of the information like total gas and humidity are gathered in real time;

3) Operation: includes the operational conditions of the transformer on the field, such as: frequency and short-circuit level, keraunic level, humidity and ambient temperature in the transformer neighbourhood, etc. It should be noted that the probability of bubble formation indicates a limit on maximum temperature, considered in this module;

4) Accessories: the total equipment reliability takes into account the status of their accessories, such as HV and LV bushings, OLTC, VTs and CTs, etc.

These criteria are analysed individually and, in the end, through a subjective algorithm which leverages grades and weights, a report is released on the general operational condition of the equipment and establishing temperature and/or current limits.
Module 4: Transformer Allowable Power Predictor (TAPP). The TAPP calculates the short term Allowable Power values automatically, that means the power quantity (MVA) which can really be extracted from the transformer during the future loading conditions, without representing a dangerous operational condition in itself. As the Allowable Power is calculated for time window from ¼ to 4 hours ahead, the operator has an important information on the individual situation of each transformer. The previous knowledge about this figure allows the operator to use a much more optimized management strategy, supervising the loading at local and/or systemic levels. It should be noted that this calculation is done using equations of the Module 2 and temperatures or current limits from Module 3. This general procedure also takes into account the transformer’s risk of failure, as a loading function and figures out the probable transformer’s loss of life reduction on this overloading situation. One can also determine the maximum power figure in a certain interval (ex.: 0.25h or 2h) which may take the transformer’s temperature (oil or winding) to its limit. Those figures are available to the operator who will find this overloading convenient or not. With the overloading allowable and the load forecast, the operator can decide how much load can be transferred to other substation or shedded. Figure 3 shows the module TAPP main screen. The measured demand curve, the load forecasted curve at 4 hours ahead, the 24 hour-forecasted curve and of the Allowable Power figures for the following 4 hours can be seeing. The informations are updated every 15 minutes, when these figures are recalculated.

Integrated System’s Architecture

The Integrated System or Transformer Loading Management System (TLMS), will interconnect all substation’s local systems, and will be estimating the future loading conditions of the whole distribution system. The TLMS will gather and makes available at the Control Center all information in real time or the equipment’s history, measured or estimated loads, of each substation transformer and feeder connected to it. This information can be:
- conventional variables such as power, current, voltage, circuit breakers’ status and protections etc. for transformers and feeders, top oil and winding temperatures, and ambient temperature figures in the substations, available every one minute;
- non-conventional variables (in some transformers only) such as air temperature at the entrance of the oil ventilation vents, oil temperature at the refrigeration intake and exhaustation, winding and oil temperatures in the ducts (through the fiber optics), LV bushing base temperature, air relative humidity at the substation, available every one minute;
- forecasted power (MVA) for each transformer and feeder, in short term intervals (from ¼ to 4 hours ahead) and 24 hours ahead, calculated by the STLF module every 15 minutes;
- forecasted top oil and hot spot temperature for each transformer every 15 minutes, in short term intervals (from ¼ to 4 hours ahead), calculated by the TOTE module;
- allowable power figures and the associated risks up to 4 hours ahead, for each transformer, calculated every 15 minutes, based on the transformer reliability;
- warning alarms (and in some cases not releasing the available power) if some reliability variables reach critical levels, such as oil bubble formation temperature, oil power factor etc.

Along with such information, the integrated system will allow the operator to visualize possible configuration topology of the distribution network in a more optimized way, both in expected and non-expected contingency situations. The operator will have, in real time, a set of configuration possibilities for future condition of power transformers being loaded above the nominal power for established intervals and limits, being able to obtain expressive gains both in the operation, planning and system expansion. Using this extra power in the transformer, it is possible to, for example, not dispatching units to maneuver switches on the field, just transferring the block(s) affected by the contingency, switching buses at the substation, avoiding the load shedding (or minimizing it), improving the energy quality and reducing the system’s operational costs.

In the present conception, the system only supplies the operator with the system future loading condition, so that the operator itself decides the best strategy for the network configuration, i.e., the system does not make suggestions for configurations.

The local platform is being extended to a third substation, covering with the two others the biggest part of downtown Campinas City. The characteristics of these 3 substations basically represent the CPFL’s substations, being, by the end of the project, interconnected with the Control Center, validating the tool at the systemic level and giving meaning to the existence of local level tools.

Fig. 3. Main screen of the Local Computing System
In the future, this kind of help may be incorporated to this tool, suggesting configurations, taking into account not only the technical aspect, but also inputing economic variables to this decision, as for example, managing the equipment depreciation.

CONCLUSION

This paper presented a project which aims at developing a digital automated system for use in Distribution System, in order to enable power transformer loading supervision in real time. Besides that, this tool allows a more optimized distribution grid reconfiguration, with expressive gains for the operation planning and system expansion. Two CPFL substations had the prototypes implemented (and a third is being implemented), with very satisfactory results. The automation system may lead to the use of a less conservative limits of transformer loading.

REFERENCES

