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Transformer Dynamic Overload Guide

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SUMMARY

Power transformers are valuable assets that ensure a continuous supply of power on the electrical network. Once a company owns a power transformer, the intention is always to keep the equipment well maintained and fully operational under normal circumstances to avoid fast aging and loss of life or any kind of deterioration that can reduce the time in operation of the asset.

However, it is sometimes necessary to manage the load of a transformer during its operation in order to accomplish a temporary requirement for either a technical or financial reason. Although it might be undesirable, short overloads can represent an alternative to critical situations such as failure in another transformers, load management due to incipient faults, demand increase related to either power line faults, or consumption changes as industrial production requirements.

The cost of a new transformer is directly related to its thermal and electrical characteristics, among them the load capacity and maximum temperature elevation over ambient. Those parameters will influence size, materials, engineering, and other factors that determine the value of the transformer.

Transformers are complex thermohydraulic machines with a lot of interactions happening inside the tank such as mechanical forces caused by electrical effort, fluid flow caused by thermal differences due to electrical current and magnetic flow, and insulation (liquid and solid) deterioration caused by electrical, thermal and mechanical efforts. For this reason, the solid insulation (e.g. paper) is sensitive to overheating, which can be caused by several different aspects. The majority of these overheating causes are unexpected and hard to predict, although on-line monitoring systems can help to identify them early and then act to prevent their evolution.

Sometimes thermal efforts can also occur due to planned overloads. The equilibrium point at which a transformer can be loaded, or even overloaded, and still avoid accelerated aging (or at least have a known and controlled aging) is the reason that this study was developed.

The aim of this paper is to assess the management of a transformer load and/or overload using an optimized approach based on the limiting parameters from the equipment design and the current conditions acquired in real time by an on-line monitoring system such as load, oil temperatures, and ambient temperature.

Based on Capital Expenditure (Capex), transformer owners will always try to minimize the investment cost while also assuring at least the basic requirements on the operational aspect. The initial investment then should be the minimum possible for equipment that will fulfill the plant’s requirement.

To overload a transformer will cause accelerated aging for most of the times during the period of the special request and that means a decrease at the asset value. Consequently, it will also increase, in theory, the Capex along the life period of the transformer, or at least the chances of the transformer’s life being reduced. On the other hand, load management and overloads can be beneficial for the business of transformer owners. To understand how much this accelerated loss of life will impact the life of the transformer is crucial for a financial evaluation regarding the benefits of temporary extra efforts against the depreciation of the equipment.

KEYWORDS

Transformer, overload, aging, insulation, operation

INTRODUCTION

It is very common among transformer's owners the conservative practice of avoiding overloads due to a lack of knowledge about what can happen with the equipment if the increase of load above nominal ratings is taken, even for short periods. This situation could be different if the operator had enough information to decide how to load its transformer knowing the consequences to paper insulation aging and following up the real status during the period of abnormal load.

Another usual belief is that the accumulated aging should always be kept below 1 p.u. to assure a good operative condition to the transformer. Although it is desirable to have the aging under control and the total loss of live equal or below the operating hours, it also doesn't guarantee the equipment is free of failure risks. A more intelligent approach regarding market demand would be to take the decisions based on the risks of operation under certain conditions, the real necessity to operate these assets under specific conditions, and the costs involved regarding acquisition and maintenance of the assets.

With sufficient data and parameters from transformer manufacturing and testing, an Online Monitoring System can guide the operation of one equipment or even an entire fleet to accomplish the usage demand and still have the operational risks under control.

AN INNOVATIVE APPROACH TO LOAD GUIDE

Since transformers started to be used, the management of its load is a point of interest and study. There are currently several papers and articles from different sources that can be found, and this type of study became part or standards [1] [2] as well. The approach of these sources is static and focused on transformer loss of life. It analyzes the effects and consequences of loading an equipment beyond the nameplate ratings, taking into consideration fixed parameters, such as transformer nameplate data and average ambient temperature.

The proposition of this paper is to use all the consolidated study from the standards and apply it to a dynamic situation, in order to help on real-time decision and support any unplanned requirement that might force the transformer to an overload [3]. The dynamic analysis is able to show some possibilities not forecasted on the static approach as the ambient temperature is measured online and can affect the heat exchange between the transformer and the environment. Also, the hot spot temperature curve is continuous and previous conditions are an input to the final temperature and how fast it will be reached.

TRANSFORMER MODELING

Transformer online monitoring systems were developed to predict failures and behaviors as there is no accurate way to understand what happens inside a transformer during the equipment operation – unless some critical point is already reached, and the condition presents an outside manifestation. To avoid undesired stoppages and to reduce the risk of operation, the monitoring systems were presented as a tool that can diagnose the transformer based on its up-to-date condition [4]. To have this feature implemented it is necessary to develop models that interpret the collected data and create an accurate simulation of the equipment – commonly called a Digital Twin. This kind of modeling must consider details and particularities from manufacturing, testing and mode of operation from the different types of transformers and reactors, which implies that the most reasonable manner to have this development successful is basing it on specific knowledge and experience.

Among all models necessary to map the operation of a transformer there is one that serves as a reference for the others and that describes the basic functioning of the equipment – the Thermohydraulic Model. It calculates the temperature on the hottest spot of the transformer, which is on to the top region of the winding, but it also maps all the heat distribution inside the equipment and the heat exchange due to the insulating fluid circulation. This movement, together with other internal phenomena (such as magnetic flux dissipation and electrical current), helps to explain why the top of the winding is the hottest spot of a transformer, unless there is a failure in another spot of the winding that generates overheat – and that is why it is so important to map the overall behavior of a transformer. In a system with fluid circulation and continuous heat exchange the thermal modeling is dynamic and the active cooling stage is fundamental to determine how the heat distribution is presented and how the heat exchange with the environment is set.

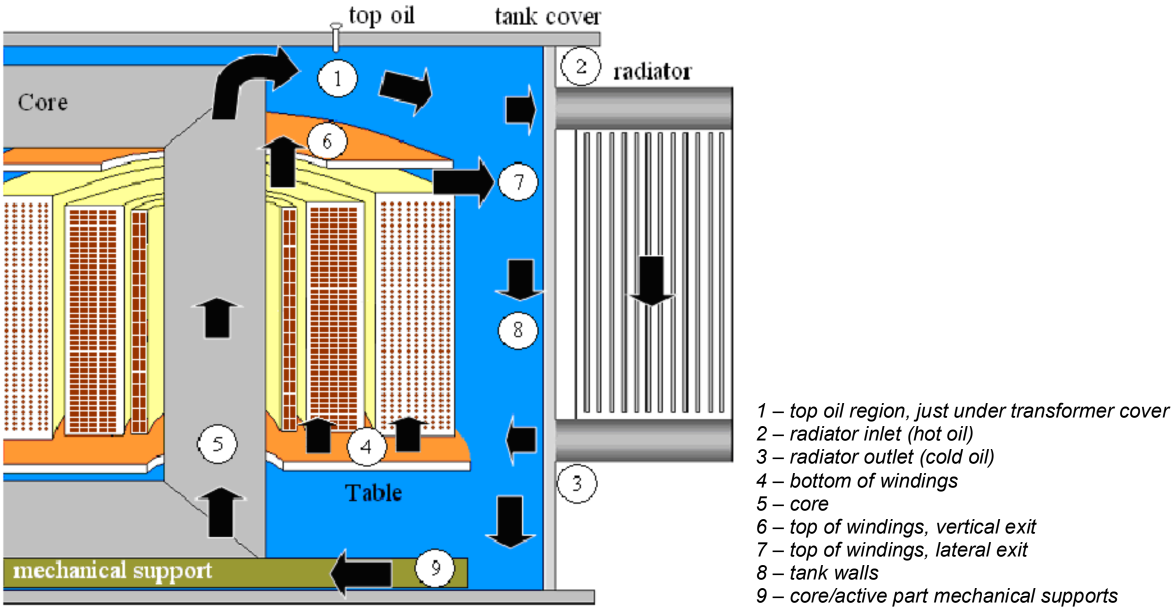

Figure 1: Parts to be considered on a transformer modeling

To reach a more accurate hot spot calculation and, consequently, a better Thermohydraulic modeling, it is crucial to use the bottom oil temperature measurement, i.e. the measurement of oil temperature on or close enough to the cooling system outlet. This is the point where the oil just exchanged heat with the environment and it shows the cooling system efficiency. Also, the bottom oil temperature measurement is used to determine the oil longitudinal gradient, which is the vertical distribution of heat inside the transformer along the oil ducts.

The oil longitudinal gradient (calculated) and the bottom oil temperature (measured) serve as inputs to the Dynamic Overload Guide Model, so the accuracy of the measurements and calculations are of extreme importance to the system. Other measurements used to calculate the maximum load availability are the ambient temperature, transformer load, the top oil temperature and the cooling status. All values must be captured and updated in real-time (online) and the cooling stage status must be captured from the cooling system itself, instead of the cooling system controller, to avoid any miscalculation due to failures on system activation. The ambient temperature is the environment temperature where the cooling system makes the heat exchange process, so for a water-cooled transformer (for example ODWF) the ambient temperature is the water measurement, which must be taken on an inlet spot before the exchange region.

APPLYING ONLINE MONITORING SYSTEMS TO LOAD MANAGEMENT

The question then to transformers owners is how to use online data from monitoring systems to improve the load management of the assets. The Dynamic Overload Guide Model uses the hot spot temperature calculation and provide the emergency loading that the transformer can operate with the maximum cooling capability and with no cooling capability, in case there is any problem with the cooling system. It allows the user to plan overloads even in critical conditions, where the cooling system is not available. The model also shows that the load limit is not always the nominal rating. As the calculation is dynamic, the model indicates in real-time the load limit that is dependent on ambient conditions and the current load of the transformer. If the system indicates one limit load and the user must surpass this limit for any reason, this will directly influence the next interactions.

The model always keeps the limit hot spot temperature as the guide parameter to provide the load limit, because this will keep the aging factor to a maximum of 1 p.u. However, if any other input indicates a lower hot spot temperature limit, this is taken into consideration to update the Dynamic Overload Guide Model outputs. One example is the water bubble formation temperature that can be affected by sudden change on ambient temperature, moisture level at the oil and insulation paper, and many other factors. If the moisture level is available and the system indicates a critical temperature for bubble formation below the hot spot limit that can be reached by transformer overload, the system shall then realize a cross-check and adjust the available load limit to a level where the hot spot temperature doesn’t reach risk levels due to a different factor, in this example case the bubble formation. As the system always indicates the forecasted hot spot temperature with the usage of the indicated load, it is clear that the limitation temperature on some circumstances is due to some other input else than the equipment aging. For the cases there are no external limitation factors the temperature shown is the maximum hot spot elevation temperature or the closest it can be, as a discrete elevation on the load can lead to a hot spot temperature limit surpass.

Using all the features available with this tool the user can give a fast response to load solicitations. This increase on load necessity can happen due to a failure of any parallel equipment, grid solicitation, residential or industrial demand. In any of the cases the decision must be taken fast and the tool presented supplies powerful real-time information for that. On a different approach, the monitoring system also serves to support on maintenance or even replacement planning, as a full analysis of the load requests historic can be checked together with the condition of the transformers during those critical periods. Furthermore, with the usage of several types of sensors the monitoring system will also provide a complete scenario of the transformer condition and trends, what can be used as another input for maintenance planning.

CONCLUSIONS

The content presented on this paper shows how to use transformer online data to evaluate the better option on load management. It goes beyond the standard definitions and apply all knowledge on the topic to a dynamic approach, where the decision is based on the aging evaluation in real-time due to the online acquisition and interpretation of data, as well as the up-to-date load demand from the consumption grid. By providing the availability and also a condition evaluation of the transformer the system allows decisions to be based on true data and avoid the conservative scenario due to lack of knowledge on the equipment status.

An interesting approach that can be developed by the user, or even hired as a consulting service, is the comparison evaluation between the usage level of the transformer and the remuneration received for its overload. This study is most applicable for critical conditions where the load has an unpredictable increase demand and quick decisions must be taken. With enough inputs it is possible to decide if even a short-term accelerated aging is paid off by the financial bonus from attending the sudden demand.

BIBLIOGRAPHY

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[1] IEEE C 57.91 – *"Guide for Loading Mineral-Oil-Immersed Transformers and Step-Voltage Regulators"*, 7 March 2021

[2] IEC 60076-7 – *"Power Transformers - Part 7: Loading Guide for Mineral Oil-Immersed Power Transformers"*, Edition 2.0, January 2018

[3] *"Permissible Loading of Oil-Immersed Transformers and Regulators"*, Facilities Instructions, Standards and Techniques, Volume 1-5, April 1991

[4] *"Power Transformer Condition Monitoring and Diagnosis – IEEE"*, The Institution of Engineering and Technology, 2018