SELF LEARNING EXPERT SYSTEM (SLES) FOR POWER TRANSFORMERS

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ABSTRACT
In a conventional approach the capacity of a power transformer is based on rated power according to the IEC. Therefore continuous load and fixed environmental and operation parameters are used. However, these parameters as well as the load change considerably during the operation of the power transformer. These parameters have significant influence on the temperature behaviour inside the transformer. Our research has shown that the standard IEC-model does not describe the transformers’ thermal behaviour with enough accuracy. Therefore the Dutch DSO Alliander is developing a self-learning expert system (SLES), to define the capacity more accurate. An automatic optimization routine has been added to the SLES to estimate the thermal parameters of each transformer. This system learns from the thermal behaviour in the past and adapts it’s thermal models. With the system Alliander can predict the real capacity of its power transformers at any time and under every condition in a safe and flexible way. As a further step in the development of this SLES, next to the top-oil temperature measurements a couple of new transformers have been provided with fiber optics to get a permanent and direct measurement of the winding temperature. These transformers will serve as test objects to get more information about the thermal behaviour of power transformers in the formation of hot spots. Integrating the SLES power grids will allow guaranteeing a safe operation and efficiently planning grid investments.

INTRODUCTION
The standard methods to determine the capacity of power transformers and other components in the grid are based on static rating. Continuous load and fixed environmental and operational parameters are used for this purpose. However, environmental parameters (solar radiation, wind, ambient temperature, etc) as well as the load change considerably during the operation of the power transformer. The environment and the load, together with the own thermal behaviour of the transformer play a significant role in its temperature variation. Because the loadability of the transformer depends on its maximal allowed temperature, accurate monitoring of these environmental parameters and load profiles is essential. Using the data obtained from this monitoring in combination with an adequate modelling, the real capacity of the transformer can be determined. This so called dynamic rating system allows guaranteeing a safe operation and efficiently planning grid investments.

DYNAMIC LOADING OF POWER TRANSFORMERS:
The benefits
The Dutch DSO Alliander attempts to operate its transformers in a safe and flexible way. To achieve this goal, a method to define the capacity of each single power transformer at any time and under every condition is necessary. Using such a method it is possible to predict the temperature of the transformer winding and in this way the possible arise of hot-spots. Preventing damage of the transformer while exploiting it optimally will be the result. An important aspect were dynamic rating systems offer significant advantages is the investment planning. Figure 1 shows how investment decisions are taken, based on rated capacity and predicted load.

![Investment planning](image-url)

When a bottleneck has been identified, meaning that the load of electrical infrastructure growths beyond the rated capacity (in the figure the crossing between both lines), an investment will be done to solve the problem. The experience learns that it takes about two years from the moment the decision of investing is taken until the moment the components are installed.

Figure 2 shows the variation that can be expected in the capacity of a power transformer and that becomes clear by applying dynamic rating.
Looking at the dynamic capacity of a transformer, basic research reveals that the capacity often can amount to 20% less or 20% more than rated (figure 2). This means that making an investment decision based on rated capacity can lead to two situations. In the first case, supposing that the capacity of the transformer determined by dynamic models reaches up to 20% more than its rated capacity, the investment will be made to early. Because a power transformer is a costly asset it will result in substantial financial losses (depending on interest rates). In the second case, departing from a dynamic capacity that can become 20% lower than the rated, an investment decision based on the static approach will come too late, originating the unacceptable risk of heavily overloading the infrastructure. This can have fatal consequences for the power system, like losing a significant load during a long period.

Besides in the investment planning process, a good dynamic rating system has a significant added value for maintenance planning and daily system operation, specially during contingencies.

**The principle**

Dynamic loading of power transformers is becoming a common practice all over the world. The systems developed to do this are based on international recognized standards. One of this standard is the IEC60076. In this standard a model to describe the thermal behaviour of a power transformer is presented, as well as a description of the boundaries and conditions to be taken in account.

Environmental variables such as ambient temperature and the load of the transformer, local circumstances, together with the own thermal behaviour of the transformer play a significant role in its temperature variation. The temperature rise on the transformer windings is crucial to determine the loadability of the transformer. Here is where hot-spots can arise, harming the isolation and causing aging of the transformer. In extreme situations, it also can result in break down and permanent damage of the transformer. This represents an unacceptable risk, not only because of the damage of the transformer itself but also because of the consequences for the power system, like losing a big amount of load for a long time.

**THE SELF EXPERT LEARNING SYSTEM (SLES)**

The first step Aliander has taken towards a system to accurately describe and predict the thermal behaviour of its power transformers was to provide a couple of transformers with top-oil and ambient temperature measurements. These measurements, in combination with the thermal model described in the IEC-standard serve to simulate the hot-spot temperature of the transformer. In this way it is possible to predict (figure 3) and prevent the exceedance of the hot-spot temperature above the allowed value (140º C), to avoid damage.

However, this study has shown that the standard IEC-model does not describe the transformers’ thermal behaviour with enough accuracy. Many parameters are not enough well known and the influence of all ambient conditions cannot be correctly reproduced using this model. Think for instance about the type of building or box where the transformer is placed. The possibilities are numerous (e.g. compact box, building with or without roof, open field, etc.), also regarding the ventilation of such a building.

Comparing field measurements with the results obtained by simulating the transformer’s temperature, significant differences can be observed (figure 4).

**Figure 2 Investment planning with variation in capacity**

**Figure 3 Dynamic transformer model**

**Figure 4 Measured and simulated top-oil temperature**
calculations based on the IEC model is too low. Relying on the results given by this model to load the transformer could then cause the undesired hot-spots and thus damage of the transformer.

That’s why an automatic optimization routine has been added to the method, in order to use this model to correctly predict the hot-spot temperature. Using professional statistical software, the thermal parameters of each transformer are estimated, such that the simulated top-oil temperature corresponds to the measured. This can be seen on figure 5.

In a further development phase, to refine this self-learning expert system (SLES), a couple of new transformers have been provided with fiber optics to get a permanent and direct measurement of the winding temperature (where the hot-spot can arise) and not only of the top-oil. These transformers will serve as test objects to get more information about the thermal behaviour of power transformers in operation and the formation of hot spots.

**CONCLUSION**

Integrating a self-learning expert system (SLES) for power transformers will result in a more flexible maintenance planning and adequate response during contingencies without taking unnecessary risks. In addition, thanks to a better understanding of the thermal phenomenon and the factors that have influence on it, this form of dynamic rating will contribute to a responsible and optimal investment policy.

**REFERENCES**


Figure 5 Optimization of the transformer thermal model with SLES

Figure 6 shows the results of the simulations of the transformer of figure 4 after this model optimization. Then the difference between the measured and the simulated temperature is very low. The model can now be used to accurately simulate the transformer’s thermal behaviour under every ambient and load condition.

**Figure 6 Top-oil temperature simulation after model optimization with SLES**