Transformer Monitoring for Cost-efficient and Robust Smart Grids

Matthias Rohr[1], Frank Bolinius[2], Rüdiger Busch[3], Xin Guo[1], Till Luhmann[1], Michael Stadler[1]

[1]BTC Business Technology Consulting AG, Escherweg 5, 26121 Oldenburg, Germany,
Matthias.Rohr@BTC-AG.com, phone: +49 441 3612 0, fax: +49 441 3612 3999
[2]EWE NETZ GmbH, Oldenburg, Germany
[3]EWE AG, Oldenburg, Germany

Abstract

Smart Transformer Monitoring is being used in a Pilot installation in Northern Germany in order to increase the efficient use of substation transformers in the context of weather-dependent fluctuating power feed-in from renewables. This action allows to accommodate renewable energy resources while minimising the need of extending the electrical grid by avoiding preliminary aging.

1 Introduction

Due to the on-going installation of renewable energy sources the degree of capacity utilization of distribution grids is constantly rising. Especially in rural regions voltage thresholds and component capacity thresholds are often approached.

A central driver of the smart grid idea is the need to use assets more efficiently [3]. Due to the fluctuating nature of the feed-in generated by renewables, it is cost-inefficient to address the installation of renewables with build-up of grid capacity and grid components, such as transformers and substations. The full capacity would only be used during weather conditions that occur for a relatively short time span per year.

Alternatively, grid operators could request feed-in reductions of renewables every time grid capacity thresholds are approached. However, many countries are enforcing policies that involve financial compensation for producers of green energy and grid construction duties in case of curtailment actions (i.e., feed-in reduction). This encourages grid operators to operate their aging infrastructure at high capacity and to avoid costly curtailment actions.

2 Transformer Safety Monitoring

Transformers have a central role in the power systems. Especially power transformers in primary substations are expensive and their replacement in case of a failure is time-consuming. Their internal temperature increases when transformers are exposed to high and fluctuating loads. Inordinate temperature rise leads to thermal insulation degradation and can result in insulation failures [2]. A global study conducted from 1997 to 2001 identified insulation failures as the leading cause of transformer failures [1].

The following questions arise:

– How to reliably operate transformers in the context of fluctuating loads?
– How to operate transformers at higher utilization rates without accelerating their aging?
– How to plan maintenance operations on transformers in an environment characterized by highly dynamic load patterns due to fluctuating feed-in from renewables?

The key answer to these questions is to replace reactive distribution grid operations by proactive distribution grid operations.

Transformer Safety Monitoring (TSM) developed by EWE NETZ, EWE and BTC, based on transformer load and temperature prediction is an important building-block for this mode of grid distribution operations

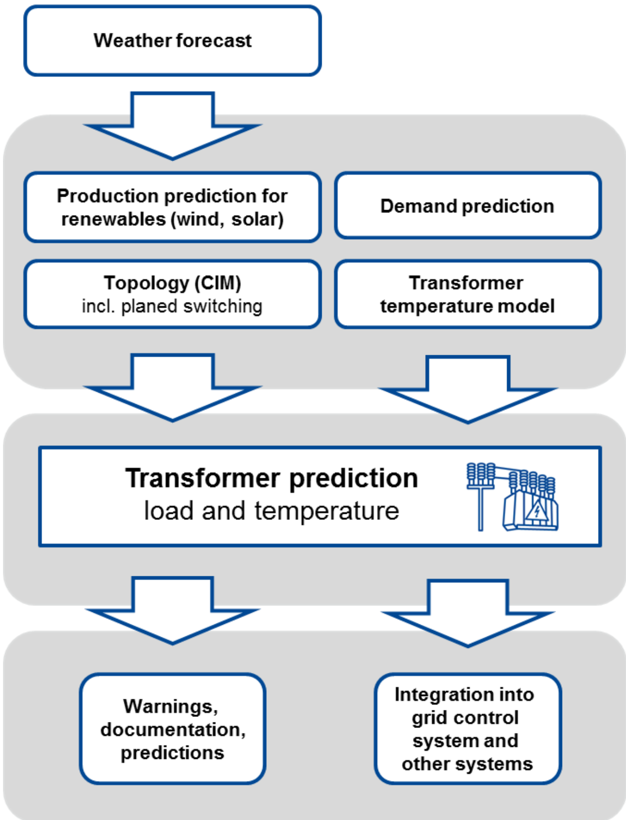

Figure 1 Conceptual architecture

TSM allows to predict loads and temperatures for individual power transformers in the grid 36 hours in advance.
The conceptual architecture of our smart transformer monitoring is displayed in Figure 1. The pilot system, called BTC Transformer Safety Monitoring uses forecasts from external weather services together with neural networks to predict the feed-in from wind-generators. The demand is predicted by a load prediction algorithm assuming standard load profiles for private households. The grid topology is integrated into TSM as IEC CIM model (IEC 61868 and 61970). The static topology model is combined with planned changes in the near future (e.g. because of maintenance and construction).
Together, these predictions provide future electrical and weather parameters for each power transformer. Together with historical measurements and a transformer temperature model these are used to predict the future transformer temperatures. These temperature and load predictions are monitored to detect possible overloads and are provided as input data to other software systems, such as the grid control system. Our Transformer Safety Monitoring supports grid operators by warning them of critical grid states and transformer overloads up to 36 hours before they occur. This creates a time window for early *preemptive* actions and reduces the stress of staff responsible for the grid operation. Furthermore, the additional time reduces the risks of transformer overloads and premature transformers aging.
Additionally, our solution allows grid operators to use the future transformers temperature (i.e., the hottest spot temperature) as operational parameter. This parameter is more accurate and precise for describing the short- and long-term loading capability than the nameplate rating and it already considers relevant influences such as the ambient temperature (e.g., [4]). Consequently, the transformers can be operated more safely not only at higher loads but also with the fluctuating loads of renewables. Therefore, the efficiency improves and some costly and undesired load management activities, such as the feed-in reduction of renewables and the installation of additional transformers, could be avoided.

3 Pilot in North-western Germany

The TSM-concept has been implemented in the grid of EWE NETZ, a distribution grid operator located in northwest Germany next to the North Sea. Due to the high share of renewables in 2011, it was required to carry out 357 grid curtailment operations.
The pilot was installed in 2011 and has been subsequently extended to 60 power transformers (110 kV) in 2012. Before its installation, there was little operational use of predictions for weather, renewable energy, and load predictions on the distribution grid level. Due to the lack of support, grid operators had to *react* in case of congestions in the electric power system instead of being able to proactively manage the grid.
As a result of the pilot installation, it is now possible to switch power lines to adjacent substations in case of predicted overloads.It also became possible to plan maintenance-windows related cut-offs the day ahead of maintenance. Both led to avoidance of curtailments that would otherwise have taken place.
The integration of TSM into the Grid Management System has been judged positively by grid operators, since forecasted transformer loads and temperatures are available at a glimpse without the need of switching applications. Current or predicted shortages can directly be displayed on the management-system's console.
Valuable input for further refining prediction accuracy has been generated during the pilot operation so far.

4 Conclusion and Further Work

We agree with the claim that "true smart grid capabilities will be built on vertical integration of upper-layer applications" [3], TSM being an example for this claim.
TSM is not yet capable of replacing expert assessment of an overall grid situation. Thus, it is to be classified as decision support system. Since taking unsupervised automated actions is not well established in the grid management domain, we do not expect to extend the system to automated actions in the near future.
While tests were generally successful, the rollout to 60 substations revealed problems of prediction accuracy for some of the substations. This is mainly due to feed-in from other sources than wind generators currently not being taken into account. Also, some other conditions influencing predictions adversely and not yet having been factored in could be identified. This knowledge will be used for subsequently improving prediction. As a first step, it is planned to include generation from photovoltaics.
Furthermore, we currently look into the possibility of using the predictions generated by TSM for informing the owners of renewable energy generator systems the day ahead about curtailment actions that will be carried out.
Last but not least, we plan to evaluate how transformer capacity predictions can be used for smart market applications.

5 References

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