DIGITAL TWIN TECHNOLOGY OF SENSFORMER™ ADVANCED

A SIGNIFICANT STEP IN THE DIGITALIZATION OF TRANSFORMERS

Digitalization of transformers will be a decisive step for grid operators in managing the current and future challenges.

First-of-its kind digital twin technology from Siemens Energy offers special advantages compared to conventional solutions.

It enables grid operators to make data-driven decisions, increase the reliability and productivity of transformers and minimize risks using the results of a thermo-hydraulic calculation model.

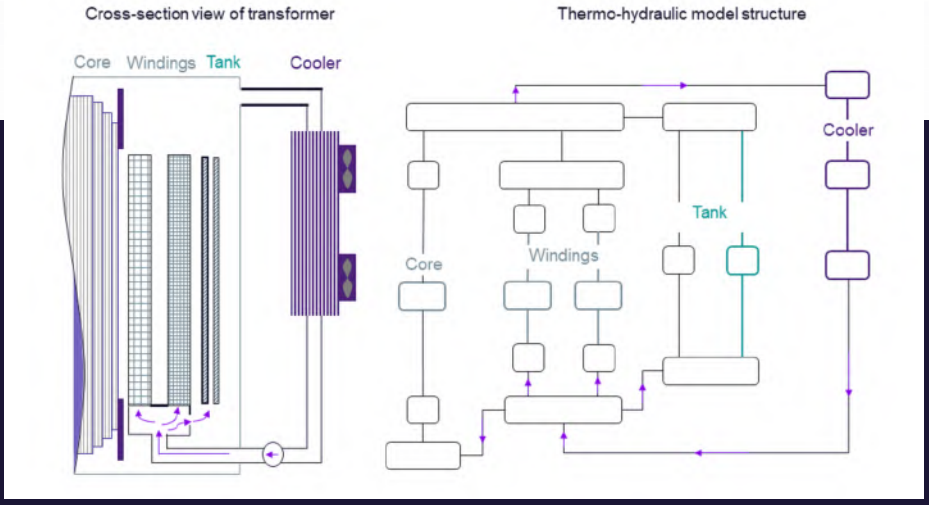
Digitalization helps operators to manage the growing complexity of grids with versatile, intelligent assets, capable of processing large volumes of data and recommending which optimum course of action to take.

Sensformer™ Advanced from Siemens Energy adds a digital layer of operational transparency to power transformers

The world is changing – data has become an inevitable but essential part of everyday life. In 2018, Sensformer™ was introduced as Siemens Energy's first digitally enabled transformer, providing real-time information about the transformer's performance and status. Since then, various other products have joined the Sensproducts™ portfolio (e.g., digitally enabled circuit breakers and gas-insulated switchgears). Challenges, such as the increasing global demand for electricity, which needs to be met with the existing fleet of grid installations, open up opportunities for new solutions. With the aim of increasing transferred energy and optimizing transformer lifetime based on real-time information, Siemens Energy has launched Sensformer™ Advanced with digital twin technology.

The Siemens Energy digital twin technology is also the first of its kind to transfer common technology assets into the new interconnected world, where asset health status as well as dynamic and volatile condition assessment are key and available at any time and any place.

Heat sources of a transformer build a thermo-hydraulic model including the oil flow



Siemens Energy uses a thermo-hydraulic calculation approach which provides an accurate and complete thermal image of a transformer

The digital twin is a virtual replication of each single transformer, established on the basis of its design data. This computational duplication is based on operational data like winding currents, cooling equipment status and ambient temperatures – either in real time to produce an online simulation, or even in advance to simulate potential transformer operation states. The thermo-hydraulic model computes the electrical loss distribution within the transformer's active part. The model takes into account the actual transformer ratio, while considering the tap position. It distinguishes between ohmic and eddy losses with their respective temperature dependency, as a specific feature of the loss calculation. The model is based on real material characteristics like masses and heat capacities of conductive and insulating materials, to allow calculation of the dynamic temperature processes during operation. The hydraulic resistances of certain transformer components such as the core, windings, radiators, etc. are defined as parameters in the model, and the oil flow is determined by the buoyancy forces and optionally additional pump pressures, if pumps are present. Consequently, and contrary to more simplified models, the Siemens Energy digital twin does not use fixed thermal time constants, but can consider the relevant dynamic heat transfer mechanisms in the transformer. Based on this thermo-hydraulic approach, the heat transfer equations can take into account the relevant physical quantities like oil temperature, oil flow, losses, etc. Consideration of the oil flow distribution and heat transfer mechanisms results in a thermal transformer model which covers different cooling modes, as well as the transient behavior between these modes, like xDAF to xNAF or xNAN (note: with x being used for O or K rating). The result is a precise temperature calculation. Moreover, due to the multi-mass approach linked to the oil flow, it is possible to couple the model with other important physical transformer models, for example for a moisture calculation.

Photo: Siemens Energy

Customers can optimize transformer operations based on digital twin calculations

Currently, the digital twin model in Sensformer™ Advanced can be used for three scenarios:

1. for simulating any load and ambient temperature cycle for 24 hours into the future
2. for determining permissible overload with defined boundary conditions
3. for automatically calculating the relative aging of the transformer

This means the customer gains new insights into different transformer conditions. When simulating a load cycle, customers can define values for various operational data for the next 24 hours, which at the same time represent the model inputs (e.g., transformer load, tap position or ambient temperature). The thermo-hydraulic calculation model then simulates the temperature behavior for the transformer top oil temperature, as well as the winding hotspots for the coming 24 hours for the assumed load cycle, starting with the actual thermal transformer condition. Another insight is the continuously determined and visualized maximum permissible transformer's overload capability for the next 30 to 60 minutes. Different boundary conditions such as aging values (loss of life) or temperature limits can be considered in the overload calculation. Finally, automatic calculation of the relative transformer insulation aging is also available. This loss of insulation life is calculated according to the IEC loading guide formulas over the previous 24 hours, the previous 30 days, and since the Sensformer™ Advanced application was commissioned. This provides a real life-time assessment of the transformer and the option of comparing the thermal load of several different transformers.

Customer benefits:

- ***Real-time information available anywhere and anytime***
- ***Notification app to minimize risks and improve environmental protection***
- ***Analytics-based and data-driven decision-making***
  - ***Improved operational reliability and productivity***
  - ***Condition-based maintenance***
- ***Data download for reporting***
- ***High-level certified security and cyber security standard***

Design-specific modelling based on customer-specific design

Each transformer has its individual digital twin model. Depending on the design of the transformer (oil natural vs. oil directed, number of windings, coolers, fans etc.), a particular model structure is created which is parameterized with specific design information. The required model parameters such as oil volume, heat capacities, insulation thicknesses, ohmic resistances and hydraulic resistances, are determined from the real data of the transformer. Dimensions, materials, thermal data, fan and pump characteristics and many more play a significant role. The thermo-hydraulic calculation is therefore tailored to each transformer design, and it can consequently predict the overload capacity, aging and service requirements with a high level of accuracy.

The main difference between conventional models and Siemens Energy digital twin technology is the use of a multi-mass approach

The main difference between simplified standard thermal models and the Siemens Energy digital twin is the multi-mass approach. Simple models often consider only the thermal behavior of a single winding for a specific tap position and specific cooling mode. It is only possible to simulate for this winding its hotspot temperature for load and ambient changes. However, this is clearly less accurate and not sufficient in terms of real thermal stress within a transformer, as the position of the highest temperature can vary from one winding to another when a transformer is operated at a different tap position. In contrast, the Siemens Energy digital twin covers all windings and the possible cooling modes of the transformer. Depending on the tap position, the loss distribution occurring in the windings is calculated and consequently the hotspot in the transformer can be continuously calculated. The Siemens Energy digital twin is based on a multi-mass model, which also includes the oil flow. In the near future, further other essential physical relationships will be considered, like moisture calculation and insulation degradation. Only these models will really constitute a complete digital twin of a transformer which will allow a very deep insight into the transformer.

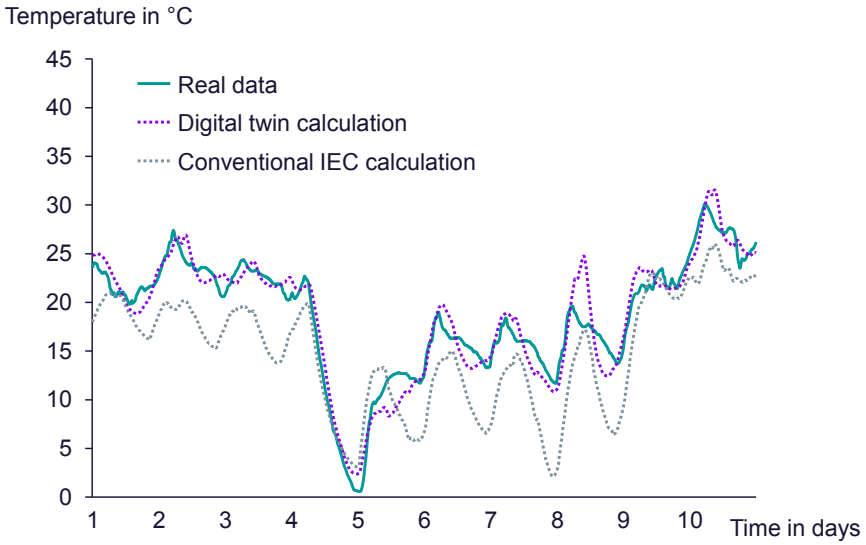
The temperature behavior is an essential part of the digital twin technology, where the comparison of measured and calculated values during operation gives an insight into the quality of the calculation model. The diagram on the next page shows such a comparison for an oil natural cooled medium power transformer over a certain period of time. The most accurate correlation between the measured and calculated top oil temperature of the transformer is found in the case of the digital twin, whereas the conventional IEC standard model results in higher deviations and consequently less accurate estimated conditions.

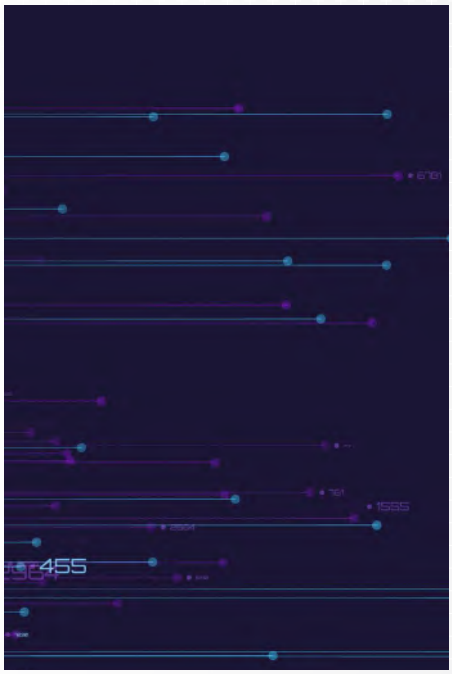
Photo: Siemens Energy

Customers have 24/7 access to Sensformer™ Advanced applications and can use the information provided to cut OPEX

Using the digital twin technology, the Sensformer™ Advanced provides a digitalized solution for different scenarios. The Sensformer™ Advanced web application provides grid operators with 24/7 access and increases transparency in the performance of the transformers. Early warnings and push notifications on mobile devices can further help to alert operators when situations are getting critical (e.g. oil loss, excessive temperatures, etc.). The information provided by Sensformer™ Advanced applications can be used to cut maintenance costs by reducing man-hours at the facility thanks to condition-based maintenance and the prevention of unscheduled outages. Moreover, active load prediction and the aging trending and projection supports the lifetime planning of transformers, which is beneficial for long-term grid modernization. Comprehensive visualization tools support further decision-making in the evaluation of equipment conditions.

Comparison of different calculation methods for transformer top oil temperature





Investing in digitalized equipment is an essential step forward

The worldwide increase in electricity demand as well as the need for sustainable measures to stabilize grids due to an increase in renewable power generation call for digital solutions. Sensformer™ Advanced, based on the Siemens Energy digital twin technology, provides the customer with real-time information on the status of the transformer, which is available anywhere and anytime. A notification app minimizes risks and the information provided allows overload operation, OPEX reduction and enhanced transformer lifetime planning.

The Siemens Energy digital twin is the first of its kind. Further digital twins will follow in the near future, complementing the dynamic condition assessment of a transformer, for example assessing transformer condition when events leading to failures. Exploiting the overall power of digital twins from different sources will complete the transformer operation in future, and will provide a permanent, real-time and independent assessment of asset condition. The holistic twin will be the all-embracing digital re-build of an asset driving the asset reliability and therefore the decarbonization to a new level.

Investing in digitalized equipment is an essential step towards transparent, flexible and reliable grid operation. Better be born connected!