Focus on Operational Reliability and Sustainability:

Cast-Resin Transformers Meet the Highest Standards

by **Heinz Raithel**

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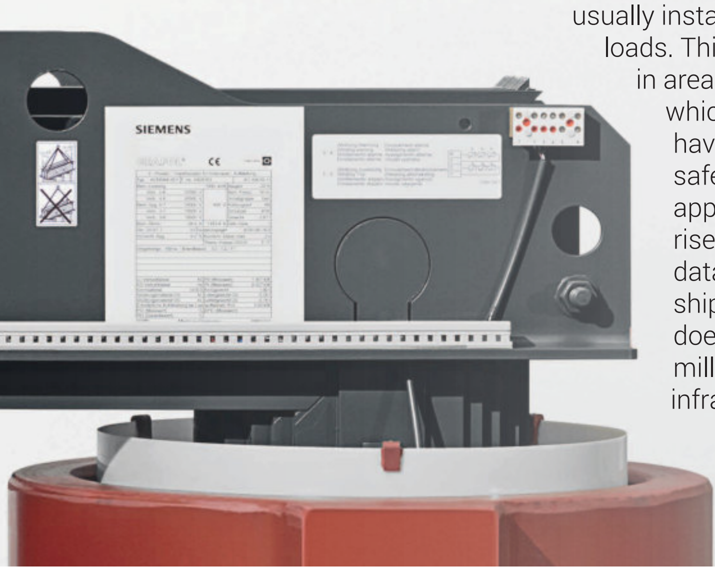
Photo: Siemens

One of the main focuses of the ongoing technological development of cast-resin transformers (category: dry-type transformers) is the exceptional operational reliability and fault tolerance of these highly available components, while also increasing their sustainability and economic viability. Digitalization is currently creating new possibilities for optimizing availability and service life.

Like other transformer types, cast-resin transformers are mainly used where electricity needs to be transformed from the medium-voltage level down to low voltage, or to another incoming mains voltage. Unlike traditional models, they operate with high-voltage windings fully encapsulated in cast-resin insulation instead of transformer oil or other liquid insulating materials, which makes a tank with insulating and cooling liquid unnecessary.



Thanks to this apparently simple idea, the technology has been successful ever since its market launch in 1966. **The percentage of cast-resin transformers compared with traditional, oil-immersed transformers continues to grow worldwide – with good reason, as they offer characteristic benefits.**

In order to avoid the long low-voltage cable routes that increase transmission losses and to boost the overall efficiency, transformers are usually installed near the electrical loads. This almost always means in areas frequented by people, which is why transformers have to operate extremely safely and reliably. This applies as much to high-rise buildings, hospitals, data centers, metro stations, ships, and oil rigs as it does to paper mills, rolling mills, airports, and other infrastructure with high power requirements. In addition, transformers often operate in close proximity to passersby and residents, only separated from their immediate surroundings by the wall of a secondary unit substation or transfer substation or by a metal housing. That's why safety is everyone's top priority.

In light of the above benefits, cast-resin transformers are the preferred option wherever distribution transformers have to be installed in close proximity to people, because they ensure users a high level of safety in operation. At the same time, they have excellent electrical, mechanical, and thermal characteristics. Transformers with these features require minimal maintenance and ensure a generally high level of safety in terms of their behavior in fire. Given appropriately high-quality standards in development, design, and production, cast-resin transformers are reliable in operation, environmentally compatible, flame-retardant, self-extinguishing, and non-toxic.

Given appropriately high-quality standards in development, design, and production, cast-resin transformers are reliable in operation, environmentally compatible, flame-retardant, self-extinguishing, and produce no toxic gases.

Their characteristic strengths make cast-resin transformers ideal for applications like onshore and offshore wind power generation. In these cases, cast-resin transformers are used to step up the voltage supplied by the nacelle-mounted generator to the correct level for feeding into the medium-voltage network. Transformers for wind turbine generators are usually designed for operating voltages on the medium-voltage level up to 40.5 kV.

Transformers installed in wind turbine generators are subject to much greater mechanical, electrical, and thermal stresses than transformers installed in standard secondary unit substations. Due to the limited space, accessibility is also frequently restricted, which means high demands on design, product quality, and safety. These can be met with mechanically reinforced versions that are easily able to tolerate the strong nacelle vibration. All metal parts must also be painted with a special coating to protect them from the aggressive, salt-laden marine atmosphere.

The high operational reliability of this technology makes it possible to install cast-resin transformers in close proximity to the consumer: for example, at airports, metro stations, in buildings, etc.

The highest quality standards for their development, design, and production satisfy extreme requirements for operational reliability and availability.

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The relevant standards are monitored by international testing institutes such as KEMA/DNV-GL in the Netherlands, FGH Engineering & Test GmbH in Mannheim (CESI, Germany), and IABG (Industrieanlagen-Betriebsgesellschaft mbH) in Munich, Germany. As part of an extensive program of numerous complex tests, the cast-resin transformers are evaluated for vibration resistance, lightning impulse withstand capability, and short-circuit strength. To verify their suitability for installation in the nacelle of a wind turbine generator, for example, Siemens transformers are exposed to acceleration of up to twice the gravitational acceleration in all three coordinates in order to assess their mechanical resistance to operationally induced vibration and transportation stress.

In addition to the important aspect of safety, cast-resin transformers also often have a smaller footprint than comparable liquid-immersed or gas-insulated transformers and are extremely flexible in terms of the position of their high-voltage and low-voltage terminals. No fire-extinguishing equipment or oil troughs are required, which means additional space savings.

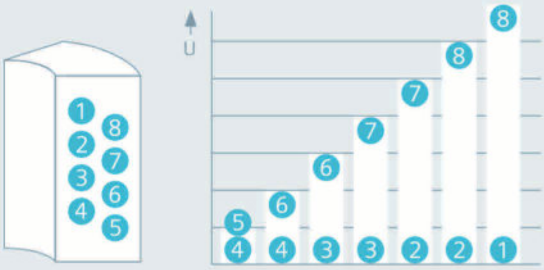
Designs with reduced no-load and short-circuit losses increase the transformer's efficiency, which in turn reduces its operating costs. This is how appropriately designed cast-resin transformers also meet official efficiency requirements, like the specifications of the United States Department of Energy or the requirements for implementing the European Ecodesign Directive 2009/125/EC. Epoxy resin-insulated transformers are also practically maintenance-free – a key criterion for remote offshore wind farms.

Cast-resin transformers must be classified according to verified environmental, climate, and fire classes. Geafol transformers satisfy the strict requirements of environmental class E2/E3, climate class C2/C3, and fire class F1 according to the international standard IEC 60076-11 and are also available in versions that qualify for higher classifications. The MTBF (mean time between failures) statistics for these devices from Siemens are equally impressive: They have a mathematical availability of over 98 percent, even after 30 years of operation.

In wind turbine generators in particular, transformers are subject to extreme stresses; however, thanks to mechanically reinforced versions, cast-resin transformers can easily tolerate the strong vibration in the nacelle.

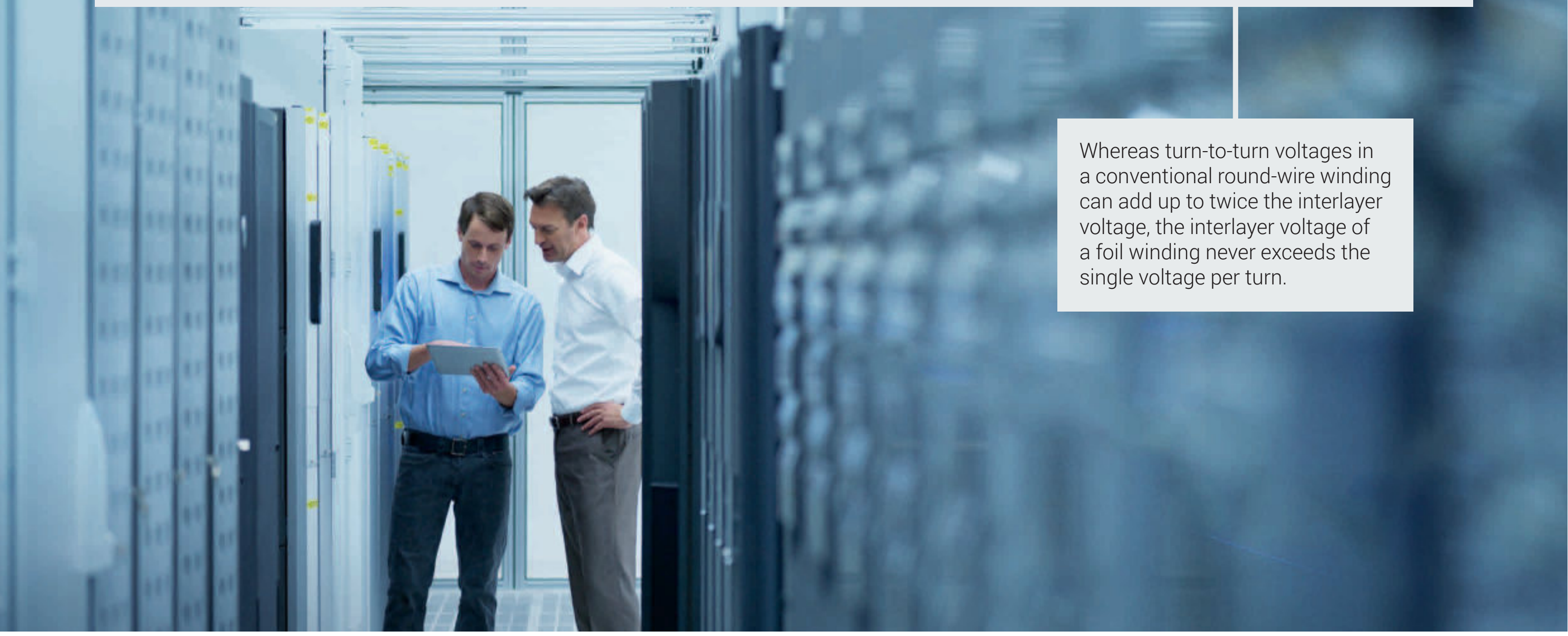
This type of absolutely reliable solution in a limited space is also required, for example, when supplying electricity to critical and industrial infrastructures and data centers. **It is therefore essential that extremely high requirements for operational reliability and availability be met, based on the highest quality standards in development, design, and production.** In large part, this requires a great deal of expertise and experience, from the selection of materials and their precise processing to the structural implementation of high dielectric and mechanical strength.

It's often a matter of details, which is perfectly illustrated by Geafol cast-resin transformers from Siemens, more than 150,000 of which have been installed worldwide to date. They've been on the market in their basic form since 1966 and have been continuously refined ever since. Over the past five decades alone, the weight of our transformers has been reduced by more than one-third, with no reduction in output range or adverse effects on operational safety and reliability. However, development isn't limited to just weight reduction: Important changes have also been made to the transformers' active components. Modern cast-resin transformers have long ceased to be dependent on copper windings, although these transformer types continue to be in demand and are also offered by Siemens. Over the years, however, the use of aluminum foils and strips insulated with high-grade plastic film has prevailed. Similar to the way capacitors are manufactured, this technology has moved to the forefront because the foil winding combines a simple technique with high electrical safety. The insulation is exposed to much lower electrical stress than in other types of winding.



Round-wire winding
The interturn voltages can add up to twice the interlayer voltage.

Foil winding
The interlayer voltage is equal to the interturn voltage.



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To guarantee long-term compliance with strict international safety standards, cast-resin transformers – although largely maintenance-free by design – also need to be checked at regular intervals to ensure that they're in good working order.

Whereas turn-to-turn voltages in a conventional round-wire winding can add up to twice the interlayer voltage, the interlayer voltage of a foil winding never exceeds the single voltage per turn. This is because all layers uniquely consist of a single winding, ensuring excellent power-frequency voltage strength and impulse voltage strength. But why aluminum? Aluminum's coefficients of expansion are very similar to those of the special Siemens formulas for casting resin and result in only minimal mechanical stress, especially in the context of load change-induced temperature fluctuations. Efficiency calculations based on a comprehensive evaluation of conductivity, material price, specific weight, and loss balance have also shown that the aluminum conductor invariably offers advantages.

Modern Geafol cast-resin transformers are manufactured using strip winding machines that enable a number of high-voltage and low-voltage phase windings to be produced in one shift. Once the primary- and secondary-side windings have been completed, the coils are sealed with special resin mixtures. The quality of the encapsulation of the high-voltage coils plus the electrical advantages of the foil winding are crucial factors in ensuring freedom from partial discharges up to twice the rated voltage. The cast epoxy resin used to encapsulate the high-voltage coils is applied under vacuum and at high temperature, which prevents harmful gas inclusions. Special high-performance vacuum pumps generate the vacuum required for this process in the casting chamber.

The transformer core is comprised of grain-oriented, cold-rolled electric sheet steel whose thickness and layering are a function of requirements related to no-load losses and noise level.

As in the case of rolling mills and high-tech factories, the market increasingly needs transformers with higher ratings for larger offshore wind turbine generators. The reason is that cast-resin transformers are highly reliable in operation and are also extremely efficient, which results – beside the lower maintenance costs – in a reduction of the operating costs. With transformers, higher power ratings generally mean higher currents and therefore greater heat loss. The solution to this problem is special cooling ducts – and not just for the low-voltage winding but also for the fully encapsulated high-voltage winding. To achieve extremely high MVA ratings, additional cooling ducts must therefore be incorporated both on the high-voltage side and in the core.

Transformers are the key operating elements at hubs in the distribution system. In terms of winding technology, transformers have to be designed to reliably handle overvoltages caused by switching operations without additional, external protective devices. Extensive trials using a combination of Siemens Geafol cast-resin transformers and vacuum switches have proven that the medium-voltage windings can easily handle switching overvoltages.

Photo: Siemens

A great deal of effort is invested in producing cast-resin transformers that not only conform to familiar international standards according to UL, CSA, or TÜV but that can also be aligned with GOST, SABS, or ANSI/IEEE on request. Specifications according to UL1562, ANSI/IEEE C57.12.01, and CSA C22.2 must be taken into account for the North American market in particular. For companies active in European and European-influenced markets like Asia and the Middle East, the most important standards for the transformers used in these areas are IEC 60076-11 and DIN EN 60076-11.

To guarantee long-term compliance with these high standards, cast-resin transformers – although largely maintenance-free by design – also have to be checked at regular intervals to ensure that they are in good working order and, if necessary, cleaned or repaired. Models like the Geafol transformer that comprise multiple components offer advantages in this context because individual parts can be replaced relatively easily, quickly, and inexpensively for maintenance and repairs.

Geafol transformers are equipped with temperature sensors to protect them from thermal overloading. The most cost-effective monitoring solution is the PTC thermistor detector in the low-voltage windings combined with a trip relay. In the case of converter transformers, the core temperature is also monitored.

If two PTC thermistor detector systems are used to monitor temperature, one is wired to give an alarm and the other to switch off the transformer. The nominal operating temperatures of both systems differ by 20 K. A third system can, for example, take over the task of controlling the fans. The temperature sensors function as PTC resistors.

If the response temperature of a sensor is reached, the resistance rises sharply and the trip relay switches over immediately. If the winding cools down by about 6 K below the operating temperature, the relay coil in the trip relay is fully energized and the contact switches back. The highest permissible ambient temperature for the trip relay is limited to about 60°C, making it suitable for installation in medium- or low-voltage distribution cabinets.

As an alternative to conventional PTC thermistor detectors, Pt100 temperature sensors can be used to continuously measure temperature. Additional sensor types for recording other operational safety- and service-related parameters with appropriate analysis devices will be available in the near future.

As the amount of operational data obtained from the transformer increases, it stands to reason that this data should be used for tasks like making predictions about the plant's future output or developing schedules for preventive maintenance. Real-time performance data can also be processed in the cloud, and this creates numerous possibilities for integrating transformers into networked IIoT (Industrial Internet of Things) environments. This idea is especially interesting in the case of transformers with higher ratings. Specific benefits include more efficient maintenance models and longer service intervals as well as evaluation and analysis options that extend over longer periods of time, thereby enabling reliable run-time predictions and, as a result, longer operating cycles.

In view of these factors, Siemens has been gradually equipping its transformer portfolio with digital intelligence since 2018. The fact that transformers – along with low- and medium-voltage switchgears – are located at the hub of the power grid with access to all information on the energy flow, which makes them ideal sensors for detecting grid status. As "Sensformers," formerly simple transformers have now become information hubs. The data allows conclusions to be drawn about the status of the units and the power grid, enabling more flexible, optimized operation of the entire grid. Existing transformers are being equipped with an IoT gateway for this purpose. Every operator is given access to a cloud-based platform application that visualizes the data collected and enables conclusions about the status of the transformer and its output on the different voltage levels. If operators know the exact status of their transformers, they can address their current challenges: for example, integrating the growing proportion of renewable energies and distributed power generation into the power grid while still operating the grid as cost-effectively as possible.

The transformer becomes a sort of information interface, in that it records the latest measured values and operating parameters in real time and transfers them to the cloud.

Conclusion

The percentage of cast-resin transformers compared with traditional, liquid-immersed transformers continues to grow worldwide – with good reason, because their high operational reliability and long service life have been allowing operators to install this technology in close proximity to the consumer for over 50 years. Ongoing technological developments have focused on their exceptional operational reliability and fault tolerance while also increasing their sustainability and economic viability. Relatively new application areas in particular – like onshore and offshore wind turbine generators and data centers – require absolutely reliable solutions. The same applies to the supply of electricity to critical and industrial infrastructures. Once again, digitalization opens up new possibilities for further optimizing the availability and service life of cast-resin transformers.

Photo: Siemens

The weight of the Geafol transformer has been reduced by one-third over the past five decades with no reduction in output range or adverse effects on operational safety and reliability