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GEAFOL[®] cast-resin transformers in protective housings with an air-water cooling system

Technical report by Gerd Maur

Answers for energy.



GEAFOL-AFWF in operation since 1996 on the luxury cruise ship "Grand Princess"

Reliable performance under all operating conditions

An intelligent combination of proven technologies

GEAFOL cast-resin transformers are flexible, environmentally friendly, largely maintenance-free, and universally suited for virtually all applications and installation locations. Thanks especially to their advantages in terms of reliability, fire safety, and eco-friendliness, they have been in operation around the world since 1965 in everything from power generation applications to use by end consumers. They are available in the power range from 50 to approximately 50,000 kVA and for operating voltages up to 45 kV.

For demanding ambient conditions, Siemens offers the complete unit "Transformer in IP44 protective housing with cooling method ADWF" as an alternative, which has advantages over the classic design with natural or forced-air cooling (AN or AF) in the form of "Transformer IP00" or "Transformer with protective housing, for example, IP23." With the optimized design of this unit, Siemens combines proven GEAFOL technology with straightforward coolant supply, shockproof transformer installation, and immunity to ambient conditions.

Cooling requirements for special applications

GEAFOL transformers achieve efficiencies of over 99 percent. Nevertheless, heat loss does occur in operation, and it must be eliminated with suitable cooling. Depending on the place of installation, this sometimes requires enhanced technical and structural precautionary measures. A typical distribution transformer in the medium power range of around 3,500 kVA needs a circulating cooling air volume of approximately 6,000 m³ per hour. With higher power ratings or increased requirements, such as the operation of variable-speed drives, they need a correspondingly higher cooling capacity. The inflow and outflow of these air volumes can lead to a significant additional structural cost for air ducts, as well as additional measures for noise reduction if forced ventilation using fans is required.

Special attention must also be paid to the temperature of the cooling air. If the values defined in IEC 60076-1 for yearly average temperature, mean daytime temperature in the hottest month, and maximum temperature are



20-MVA-GEAFOL transformer ADWF 33.00/11.50 kV for what is currently the world's largest FPSO for gas production and liquefaction off the west coast of Australia

exceeded, then either the transformer dimensions must be increased or its power output must be reduced. In many cases, a protective housing with a higher protection class may be desirable for the protection of personnel or in harsher ambient conditions (including heavily dust-polluted or corrosive cooling air) in order to avoid construction costs for a transformer cell.

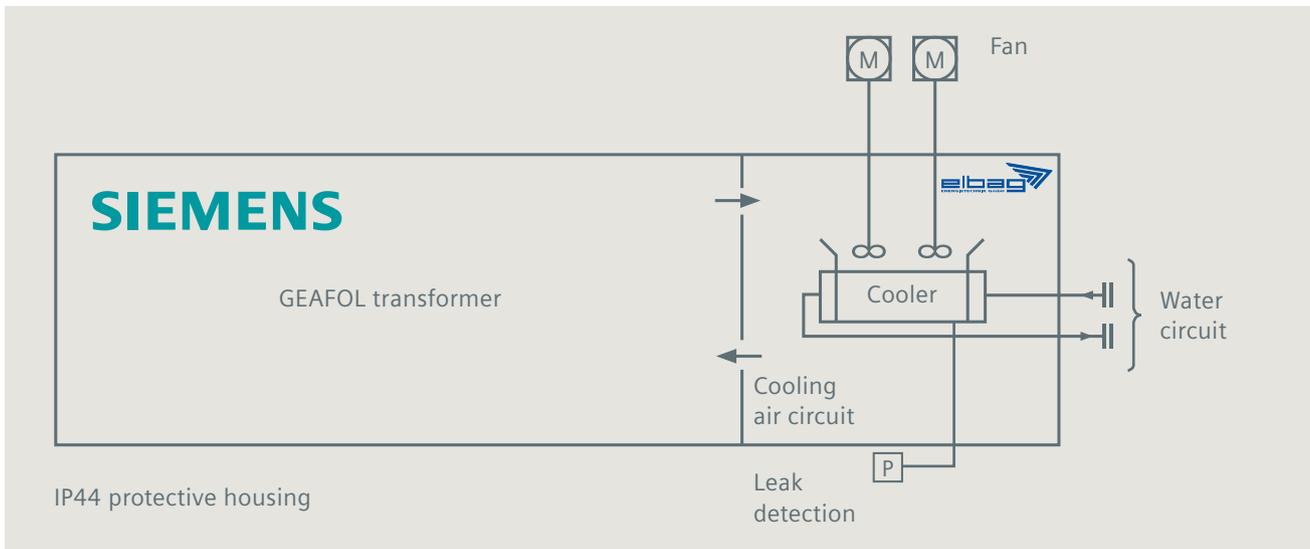
The solution: the former GEAFOF AFWF-IP44 and the new GEAFOF ADWF-IP44

Siemens offers an optimized alternative for these special requirements – the GEAFOF AFWF-IP44 or GEAFOF ADWF-IP44. These differ from “classic” GEAFOF cast-resin transformers with respect to the method of cooling. **AFWF** stands for **air forced – water forced** cooling, and **ADWF** for **air forced directed – water forced** cooling.

Protection class IP44, as specified in DIN EN 60529, signifies protection against ingress of solid foreign particles ≥ 1.0 mm diameter and splashing water. A reliably sealed housing is indispensable for optimized forced ventilation.

The first transformers of this design with power ratings of 9,150 kVA were manufactured for the 5-star cruise ship “Grand Princess” at the Siemens transformer plant Kirchheim (Teck) back in 1996. Since then, hundreds have been built in the power range from 2 to 20 MVA.

The largest transformers of this type built to date, with a power rating of 20 MVA and AFWF cooling, weigh in at about 36 metric tons each and are deployed on a ship-like liquid gas production platform (FSPO).



Schematic diagram of the functioning of a GEAFOL cast-resin transformer in protective housing with air-water cooling system

GEAFOL ADWF – simply functional

Compact performance

The actual GEAFOL transformer is largely of conventional design and manufacture, although it is smaller and lighter because of its forced cooling. The construction of the transformer is based on a stable, all-round base frame that also reinforces the surrounding protective housing. This consists of two air-filled chambers. The first chamber encircles the transformer; the second is flange-mounted to the front as an air duct and incorporates an air-water heat exchanger as well as the required fans. For larger units with higher power losses, identical air ducts can be provided in a mirror-image arrangement on the opposite-end face or on the longitudinal sides of the housing. Both air chambers are connected top and bottom by adequately sized air-inlet and air-outlet apertures.

Closed circuits

The cooling air heated by the transformer in operation rises and is extracted by fans, compressed through the cooler in the air duct and then, after recooling to the optimal temperature, is fed back down to the transformer windings. Air guidance systems ensure the best possible

distribution of cooling air to all windings and phases of the transformer. The cooling water required in the heat exchanger to absorb the heat losses can be discharged relatively easily through a pipeline system and re-cooled at a suitable location on the installation site.

These two closed cooling circuits allow unrestricted continuous operation of the transformer, keeping it within its permissible operating temperatures, which is a crucial factor for its lifetime. Generally, less than 10 percent of the heat loss is radiated via the surfaces of the housing; over 90 percent is dissipated into the water circuit. Ingress of polluted or corrosive ambient air to the inside of the housing is almost entirely prevented.

If the air or water circulation fails, the transformer can continue to be operated at about 20 percent of its rated power for a limited period of time, because the housing can dissipate the heat that is still being generated by the transformer through radiation. The fans and coolers can be dismantled and reinstalled easily from the outside for maintenance purposes.



3,000-kVA GEAFOLE double-tier converter transformer ADFW 6.60/2x2.20 kV for an oil-drilling platform in the North Sea

Reliably monitored

For safety reasons, the coolers are designed as double pipes and also have a leak-detection system. This transmits a signal to the switchgear on the high-voltage/low-voltage side in the event of a leak in the inner pipe system and protects the transformer from water ingress while the transformer is live through the timely disconnection of all power sources.

In addition, the temperature of the GEAFOLE is monitored with Pt100 or PTC sensors; the external cooling water circulation is normally monitored within the system. To prevent condensation within the sealed housing when the transformer is powered down, thermostat and hygostat-controlled space heaters are fitted and switch on or off automatically. Fan control and system monitoring units are fitted in an add-on control box and can be connected from there to an overriding control unit on the system itself.

Increased lifecycle by changing from cooling method AFWF (air forced – water forced) to ADFW (air forced directed – water forced)

Siemens is breaking new ground in the area of cast-resin transformers through its use of the ADFW*) cooling method. Directed cooling “D” per IEC 60076-2 results in a reduction in hot-spot temperatures of about 5 K, similar to oil-immersed power transformers with, for example, cooling method ODWF. This would actually enable GEAFOLE transformers to be designed with a 5 K higher mean winding temperature, but Siemens prefers to instead provide a greater safety margin. The higher thermal utilization capacity of the insulating material is kept in reserve, which theoretically means cutting the rate of aging by nearly half and approximately doubles the thermal lifetime. This results in a further reduction of the already excellent failure rate (< 0.1 percent) and an increase in the MTBF (mean time between failures, > 1,100 years) of GEAFOLE cast-resin transformers.

*) Inclusion of the ADFW cooling method in IEC 60076 is currently at the planning stage.



5,000-kVA GEAFOLE double-tier converter transformer ADWF 13.80/2x0.72 kV for an oil drilling platform in the North Sea (before and after installation in the protective housing)

GEAFOL ADWF-IP44: The advantages increase with the power

Systematic cost advantages

The system comparison on the following page shows the cost- and space-saving potential of the GEAFOLE ADWF-IP44 design compared with the conventional AN construction. The savings are essentially due to the fact that water cooling is significantly more efficient than air cooling. The cooling air requirement also rises steeply with increasing power, so that finding a technical solution for air supply and discharge becomes more and more complicated. This effect is further intensified if noise abatement measures are required because of the volume of the moving air masses.

A GEAFOLE ADWF-IP44 only needs about eight m³/h of cooling water instead of the 6,000 m³/h of cooling air mentioned above (for the GEAFOLE AN-IP23 version), given an identical power rating of 3,500 kVA. Compared with the considerably more complex large-diameter air ducts, cooling water can be transported much more easily through a compact network of water pipes.

Smaller, lighter, more powerful

In addition, the AN design rating of the transformer is reduced by up to 50 percent by forced-air cooling, which is reflected in the construction costs of the transformer thanks to the resulting weight reduction and smaller dimensions. Naturally, the costs for the housing including cooler, leak detection, fan, air conduction system, and switching cabinet must be factored into this comparison. In addition, there are the unavoidable costs for the external cooling system. With respect to the actual transformer, however, the GEAFOLE ADWF-IP44 generally offers a cost advantage over the AN-IP23 upwards of about 3,500–4,000 kVA in capacity, which increases with the rated power. The table on the next page shows an approximate comparison for three selected typical examples:

**3-phase GEAFOL distribution transformer 1,600 kVA – 11.00 ± 2x2.5%/0.42 kV – 60 Hz
6% u_z – Dyn11 – 95 K winding temperature rise – onshore installation – standard accessories**

Rated power	1,600 kVA	
Cooling method	AN	ADWF
Housing protection class	IP23	IP44
Housing mounting	free-standing	common base frame
Total losses P ₀ + Pk ₁₂₀	15 kW	18.5 kW
Coolant requirement/hour	3,000 m ³ air	4 m ³ water/400 m ³ air
Total weight	4,000 kg	3,750 kg
Housing external dimensions LxWxH	2,100x1,500x2,300 mm	2,300x1,500x2,100 mm
Costs	100%	135%

**3-phase GEAFOL double-tier converter transformer 3,500 kVA – 11.00 ± 2x2.5%/2x0.72 kV – 60 Hz
8% u_z – Dd0 Dy11 – 95 K winding temperature rise – marine version – standard accessories**

Rated power	3,500 kVA	
Cooling method	AN	ADWF
Housing protection class	IP23	IP44
Housing mounting	free-standing	common base frame
Total losses P ₀ + Pk ₁₂₀	28 kW	35 kW
Coolant requirement/hour	6,000 m ³ air	8 m ³ water/600 m ³ air
Total weight	7,500 kg	6,000 kg
Housing external dimensions LxWxH	2,700x1,600x3,000 mm	2,600x1,600x2,700 mm
Costs	100%	100%

**3-phase GEAFOL distribution transformer 10,000 kVA – 22.00 kV ± 2x2.5%/6.30 kV – 60 Hz
8% u_z – Dyn11 – 95 K winding temperature rise – marine version – standard accessories**

Rated power	10,000 kVA	
Cooling method	AN	ADWF
Housing protection class	IP23	IP44
Housing mounting	free-standing	common base frame
Total losses P ₀ + Pk ₁₂₀	55 kW	65 kW
Coolant requirement/hour	11,000 m ³ air	15 m ³ water/1,000 m ³ air
Total weight	18,500 kg	16,000 kg
Housing external dimensions LxWxH	3,500x2,200x3,900 mm	3,500x2,200x3,500 mm
Costs	100%	85%

Comparison of different designs' power ratings AN-IP23 compared with ADWF-IP44 (all values are approximate)

In service on the high seas: GEAFOL ADWF



26 GEAFOL 3,500 and 4,000 kVA converter and distribution transformers each for five deep-sea drilling vessels



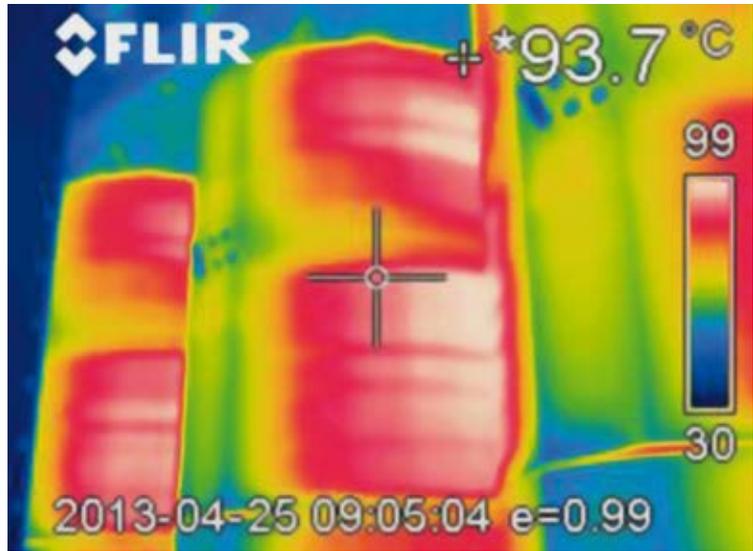
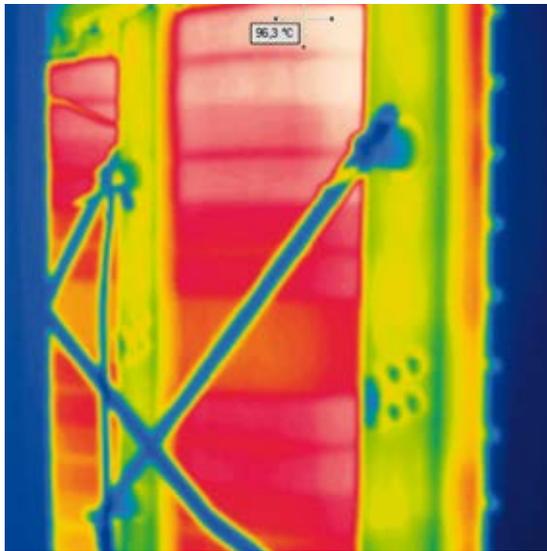
The largest and most fuel-economical container ships in the world today: 2 x 4,400 kVA ADWF transformers for the Triple E class



2,400 kVA GEAFOL four-winding converter transformer ADFW for a drilling platform in the North Sea



The largest FPSO in the world for natural gas production and liquefaction under construction – with 11 GEAFOL ADFW transformers of 6,300 to 20,000 kVA



Position of the hotspot temperatures in the windings of comparable transformers with AN cooling (left) and ADWF cooling (right) – the result is a higher power reserve

Typical application areas for GEAFOLE ADWF-IP44

The GEAFOLE: Strength in versatility

GEAFOLE transformers in an air/water-cooled housing are especially valuable in the case of complicated installations and extreme ambient conditions. Essentially, this means installation sites where it is difficult to eliminate heat by means of cooling air: for example, in a heavily contaminated or chemically corrosive atmosphere, in transformer rooms inconveniently designed for cooling systems, or in cases where a higher protection class is required for reasons of personnel safety. That's why the GEAFOLE ADWF-IP44 is especially suitable for installation inside oil drilling platforms, below the waterline in vessels of all kinds, in chemical plants, in very hot enclosed spaces, and in underground applications (including mining, tunneling, and drainage systems).

GEAFOLE made to order

As with the conventional GEAFOLE, Siemens also offers a large number of customer-specific detailed solutions in the GEAFOLE ADWF-IP44 version in close cooperation with the housing manufacturer:

- **Material properties of the coolers:**
Adaptation to the chemical composition of the cooling water, including anti-freeze additives where relevant, stainless steel coolers, and seawater-resistant coolers
- **Cooler operating pressure:**
In addition to the standard 0.6 MPa (6 bar) operating pressure, heat exchangers are also available for higher water pressures (for example, 1.2 MPa operating pressure/1.8 MPa test pressure)
- **Technical data of the fans:**
Number of phases, rated voltage, and rated frequency according to customer's requirements, other special versions as needed
- **Housing protection class:**
IP54 as alternative to standard version IP44
- **Pressure relief vents** for the housing in the event of faults
- **Access to the transformer:**
Via bolted panels or doors, lockable on request or with safety interlock system
- **Thermographic monitoring of the power terminals on the transformer:**
Thermographic windows in the housing walls



The main components – fans and air-water heat exchangers (with leak detector)

- **Layout of coolers, fans, switch cabinet, and power cable entries** according to individual specifications
 - **Type of electrical power terminals:**
Cables or busbars through antimagnetic cable entry plates, MCT frames, or free openings for sealing after installation, cable terminal boxes or plug-in connections
 - **Premagnetization device:**
For reducing the starting current inrush in low-power on-board systems
 - **Corrosion protection and color:**
In addition to the standard colors RAL7032 (pebble gray) and RAL7035 (light gray), special color shades can also be arranged; powder coating available for corrosivity categories up to C5M long as per DIN EN ISO 12944-6
 - **Additional monitoring of the cooling air and cooling water temperature** (upstream and downstream of the fan)
 - **Warning and information signs** by arrangement (including language)
 - **Marine certifications:**
For example, ABS, CCS, DNV, GL, LR, RINA and others (also for coolers)
 - **Factory tests:**
Internal routine tests in accordance with IEC 60076-1; in the marine version, acceptance testing including heating measurement. Additional tests or acceptances by arrangement.
- Other special requirements can be arranged individually.

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