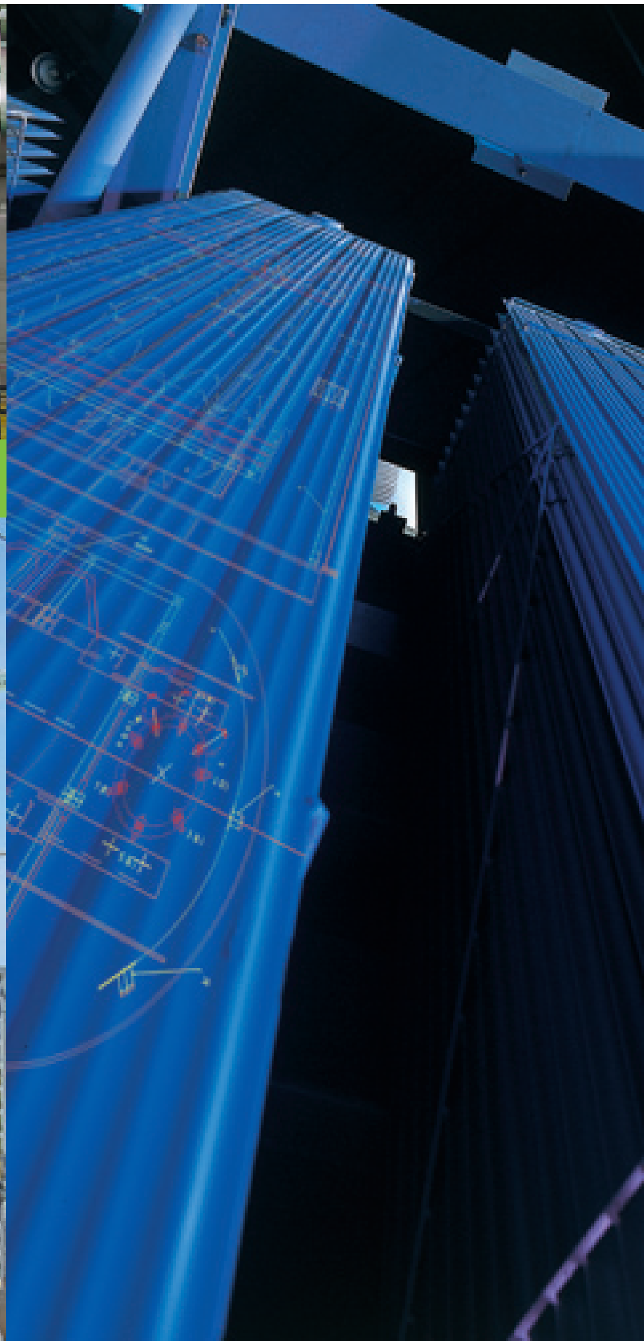
Smart solutions.
Strong relationships.

Power Transformers



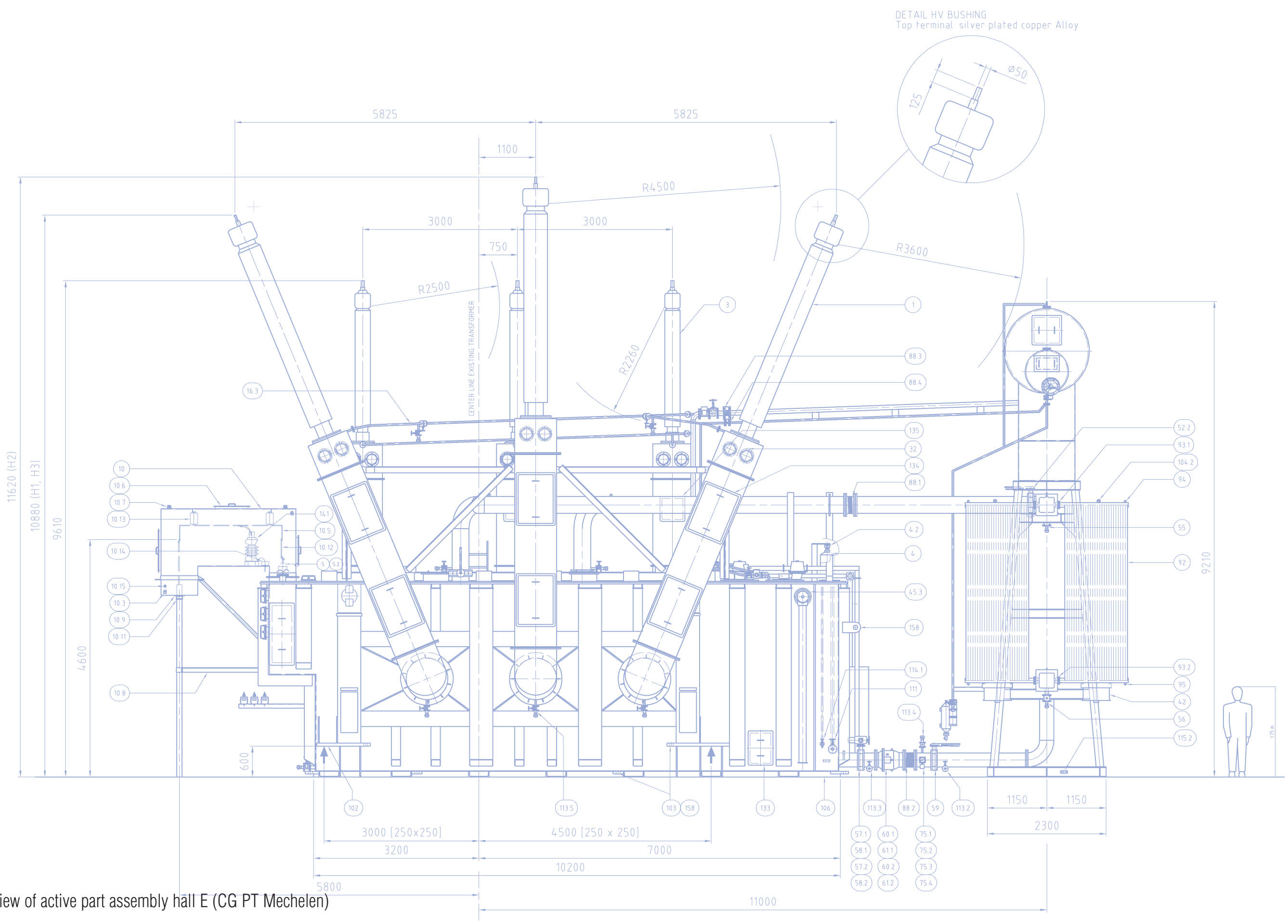
Your partner in energy solutions

Contents

< A 750 MVA 380/230/13.8 kV autotransformer during heat-run test in test bay

CG Power Systems (formerly Pauwels) ranks as one of the world's top manufacturers of power transformers. As a certified full-line supplier, the company has manufacturing plants on three continents and a world-wide network of sales offices and specialized agents serving customers in over 135 countries. More than 500,000 CG Power Systems transformers are currently in use throughout the world.
From its base in Mechelen, Belgium, CG Power Systems acts as the company's headquarters, defining the group's corporate strategy.

CG's full range of power transformers consists of:
- > Medium & large power transformers
- > Mobile transformers
- > Phase shifting transformers
- > Generator step-up transformers
- > Auto-transformers
- > HVDC transformers
- > Trackside transformers
- > Shunt reactors
- > Booster transformers



< View of active part assembly hall E (CG PT Mechelen)

Our designers are familiar with all international and national standards such as ANSI, IEC since we supply our transformers throughout the world.

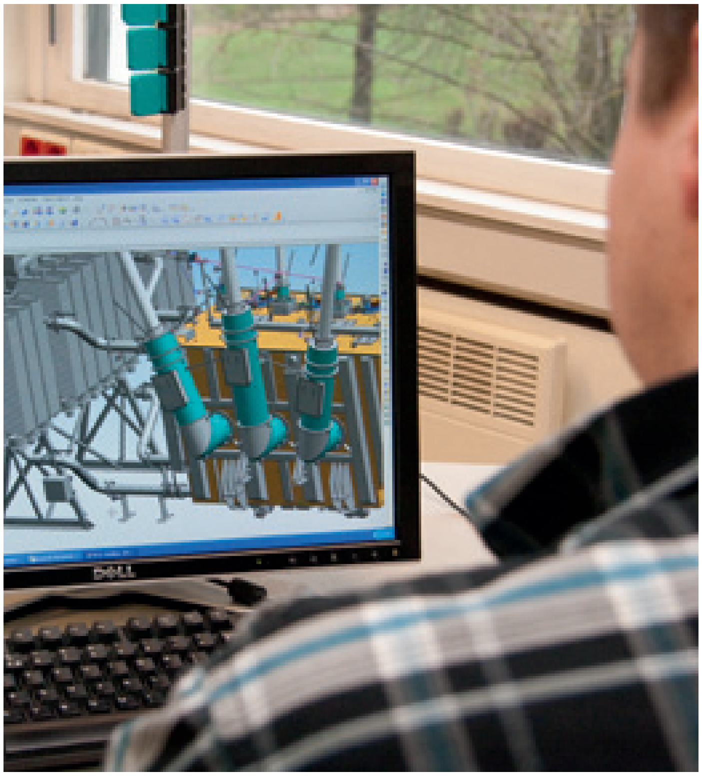
Every transformer is individually designed to its specific requirements and applications.

The following specially-developed computer programs are used to further ensure the reliability of the product:
> optimization of design in relation to labor and material costs, loss evaluation and sound level,
> distribution of voltage stresses during lightning impulse and switching surge conditions,
> behavior during short-circuit conditions,
> analysis of those areas where high electrical stresses can occur, and,
> calculations of stray losses and thermal effects.

Should seismic withstand be required, CG Power Systems can provide either a static or a dynamic design analysis to prove that the transformer can withstand the specified conditions.

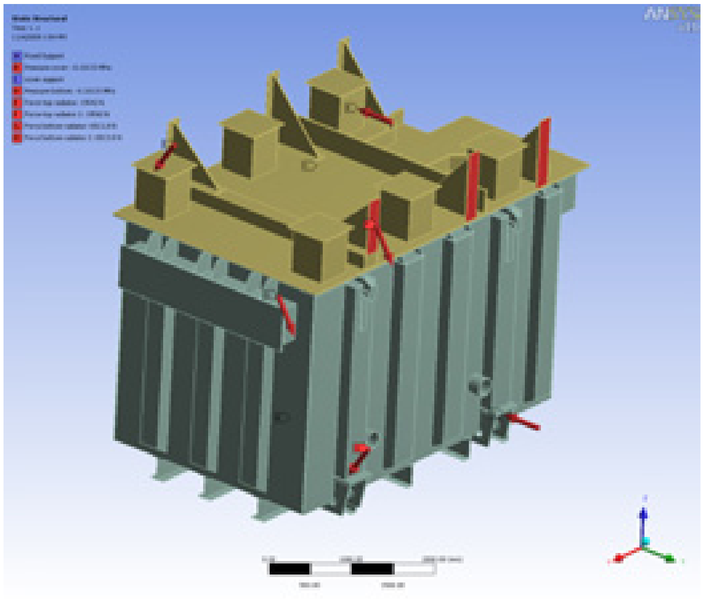
Design Team

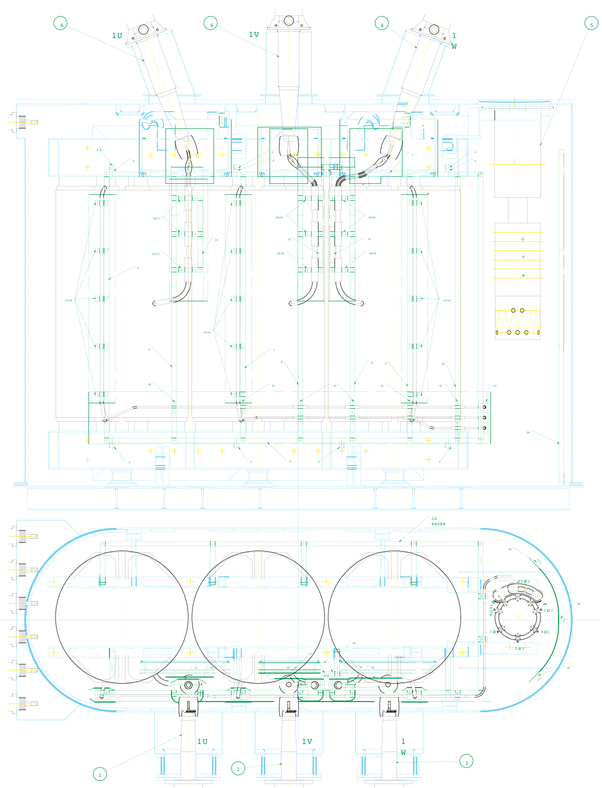
Before being issued to the plant, new designs are reviewed by a team consisting of representatives from Engineering, Quality Assurance, Manufacturing, Testing, and Research and Development. Each design remains the responsibility of the individual project engineer, who carefully follows and checks progress throughout the manufacturing process.



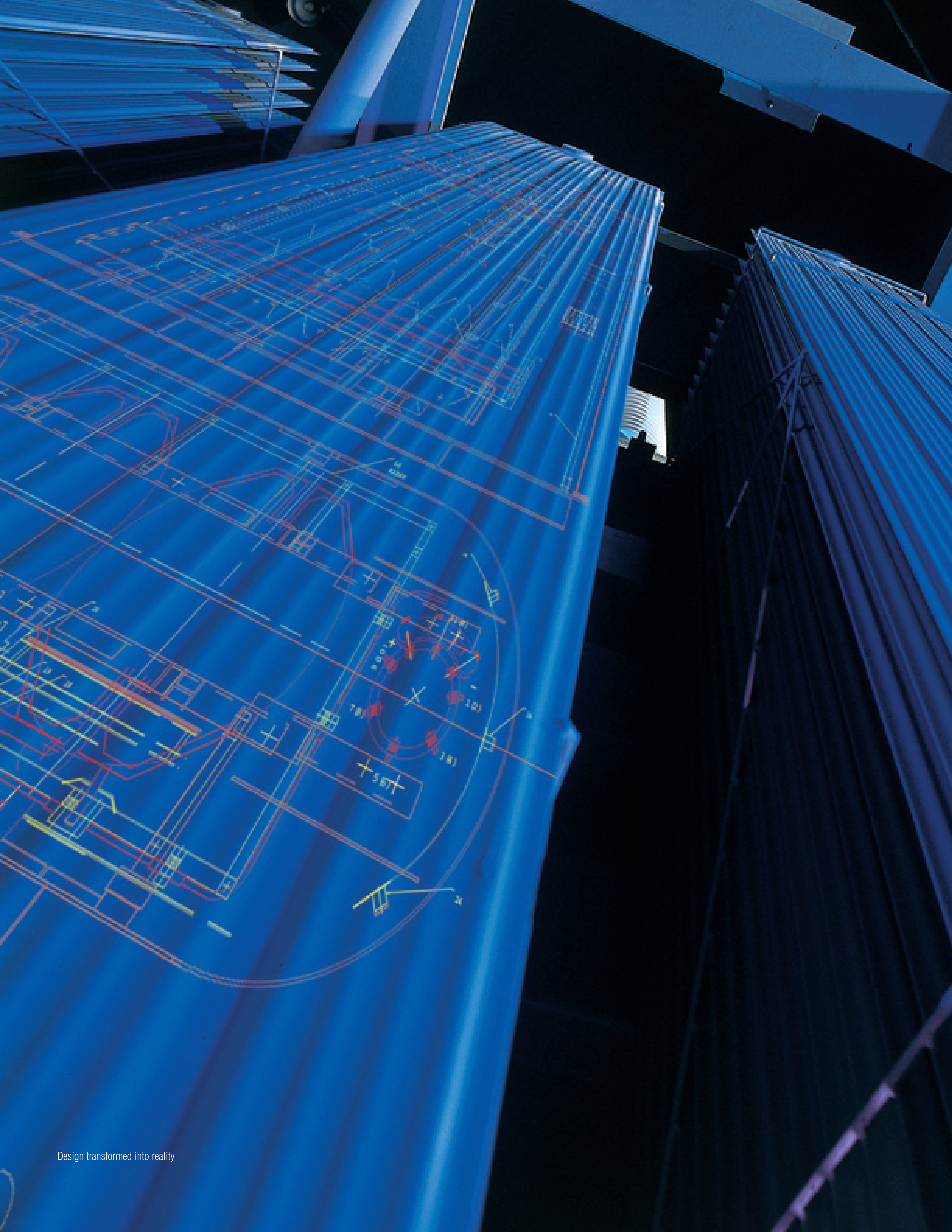
^ Mechanical designers use 3D design software

v The mechanical design is checked by a finite element calculation software





^ Design of the leads



Design transformed into reality

CG Power Systems' goal is to build products which perform safely and reliably, meeting the requirements specified by its customers and providing excellent life cycle value. The establishment of measurement standards and inspection procedures is only one step towards this goal. The major step is the complete commitment of all employees towards the entire concept of quality.

All CG Power Systems plants are ISO 9001 certified. Certification was achieved through recognized institutes such as AIB Vincotte, Kema and the Canadian General Standards Board.

ISO 9001 includes the greatest number and scope of quality system elements available in the 9000 series, including elements such as delivery and service. The ISO standards describe elements of quality systems which are designed to ensure that products and services meet all requirements before they are delivered to the customer. In order to achieve registration, facilities have to document every process they follow, and successfully undergo an audit by an independent third party.

Qualified employees inspect, check and sign the progressive control record book system at their particular stage of manufacture. The quality inspectors audit the system by checking various aspects of the work to ensure that the system is working correctly. They direct any corrective action which may be required. In addition, inspectors perform incoming and final inspections to ensure that materials meet the required quality level.

The progressive control record system ensures that a complete, permanent record is kept of each stage of the manufacturing process. The method of using qualified employees to perform inspections in their own area requires that they are well-trained in the procedures and purpose of the work they carry out. All employees continue to receive in-depth training in all aspects of their jobs.

^ Oil quality is checked in the CG chemical lab

Each transformer is SFRA fingerprinted in the test bay >

CG Power Systems transformers are of the "Core Form" design. All cores are stacked, using high-quality grain-oriented silicon steel laminations, purchased slit-to-width and coated with carlite to increase the interlamination resistance and to reduce eddy current losses. Where loss evaluations justify its use, laser or mechanically scribed or plasma treated silicon steel will be used.

All cores utilize the step lap principle in the corner joints to reduce losses, magnetizing current and sound level. The cores are fully-mitered on all joints in order to improve the flux distribution.

Ultra modern computerized core shears supply fully-mitered, high-efficiency cores. These machines are able to shear the maximum width of core steel currently available.

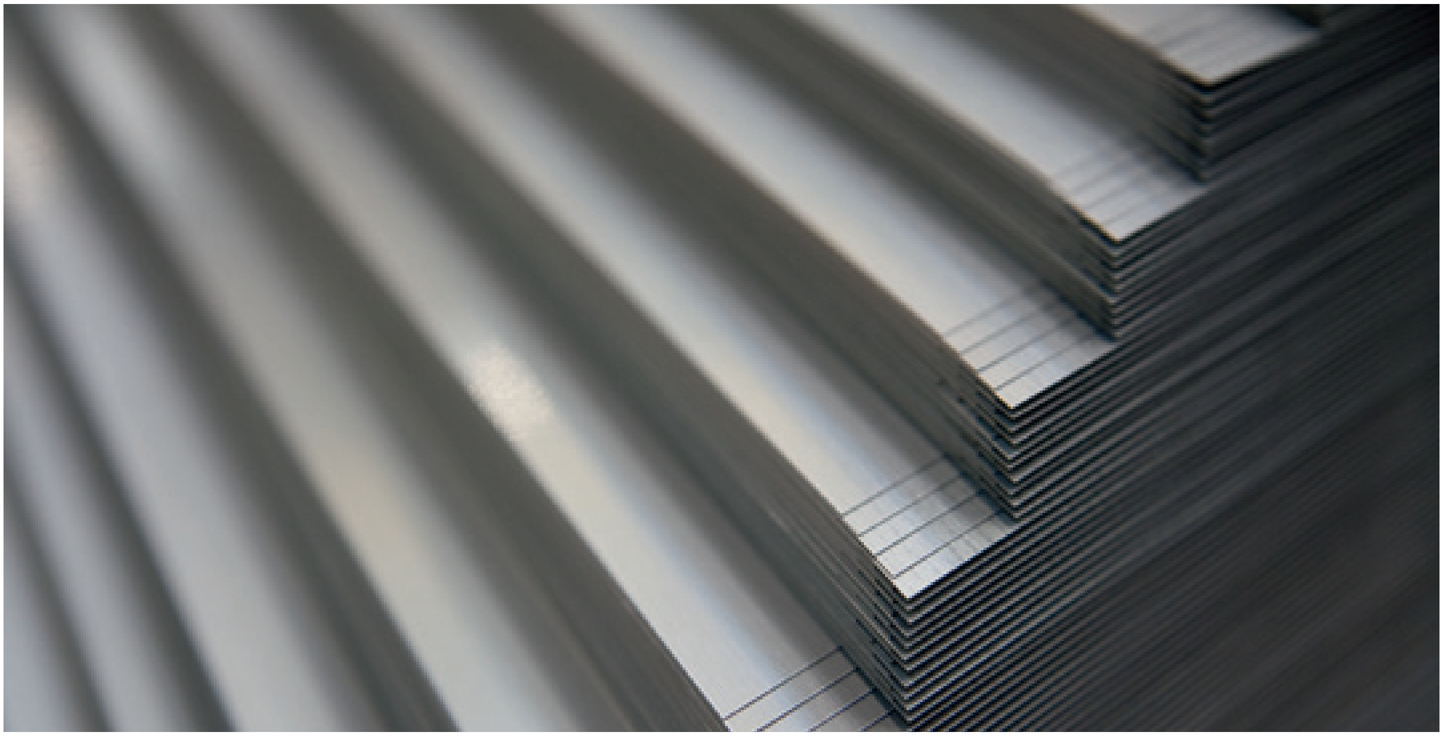
The laminations are stacked in steps, resulting in a circular core shape which gives the windings optimum radial support, especially during short-circuit conditions.

The exposed edges of all finished cores are bonded with low viscosity, high-strength epoxy resin on the legs and bottom yoke to help lower the sound level. The temperature rise of the core is designed to be low and is controlled, if necessary, by careful placement of vertical oil ducts within the core packets.

The core is clamped using structural steel clamps which provide high strength under both static (lifting and clamping) and dynamic (short-circuit) mechanical loads. The clamps are very lightweight for their strength and provide a smooth surface facing the winding ends, eliminating regions of high local electrical stress.

^ The core is erected after stacking

v To minimize magnetic resistance, the step-lap principle is used for core stacking



Making a regulating winding with twin copper conductor

Windings are of circular design, with concentric coil placement. This arrangement provides the highest short-circuit strength while providing good cooling of conductor surfaces. Both copper and aluminum conductor can be supplied depending upon customer requirements. Generally, only copper conductor is used in medium and large MVA designs.

Conductors are either paper- or Nomex® covered magnet wire or continuously transposed cable. High tensile-strength conductor is supplied if required to meet anticipated short-circuit forces. Conductor cross sections are chosen to be as large as possible to minimize short-circuit stress, while ensuring that eddy losses in the conductors are kept under control.

Continuously transposed cable can be supplied with epoxy bonding, greatly increasing its short-circuit strength. Modern winding machines utilize fully adjustable steel mandrels to ensure tight tolerances and more efficient winding operations. The winding machines are equipped with hydraulic braking devices which ensure that the proper tension is maintained on the winding.

Winding types are selected by the design engineer, depending upon the specific application. Strip, barrel, layer, helical, disc, shielded and interleaved disc types are all available to the designer, depending on the voltage and current requirements of the design. Control of electrical stress is achieved by placement of custom-designed stress rings on the ends of high voltage windings and anywhere else they are required. Dovetailed key spacers are employed to give the windings extra strength.

Oil flow through the windings is directed in a zigzag pattern to ensure cooling of all conductor surfaces and to limit the hot spot temperature. Careful attention is paid to ensure an even distribution of oil to all sections of all windings.

On request, fiber optic temperature sensors can be inserted in the winding to measure actual hotspot temperatures during testing and in service.

Following completion of the windings, all coils are dried in a hot air oven and hydraulically pressed to size to obtain the design height and to guarantee full short-circuit resistance. This allows an accurate determination to be made of their final size and provides a dimensionally-stable assembly. The windings are then ready to be mated with the core, leadwork and other internal accessories.


Fiber optic sensors measure the actual hotspot temperature


Finished windings waiting to be assembled

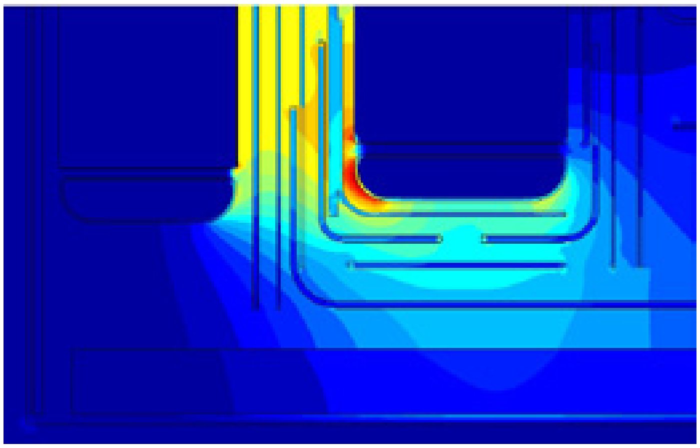
All major insulation is manufactured from the highest quality transformer board or Nomex® insulation material, fully oil impregnable to eliminate internal partial discharges from voids. Winding keyspacers are manufactured from precompressed transformer board to provide high mechanical and short-circuit strength.

Care is taken in the manufacturing of the insulation components to ensure that all critical surfaces have an adequate supply of oil during impregnation and service in order to limit partial discharges.

Insulation can be standard paper, upgraded paper or Nomex®. Hybrid is an optimized mixture of Nomex® and paper >

Special pre-moulded insulation parts are used with respect to the electrical field to optimize the design >

∨ Insulation is checked during design with finite elements calculations



Core and coil assembly

First, the individual windings are assembled one over the other to form the entire phase assembly.

The radial gaps between the windings are subdivided by means of solid transformer board barriers.

Stress rings and angle rings are placed on top and bottom of the windings to achieve a contoured end insulation design for optimal control of the oil gaps and creepage stresses.

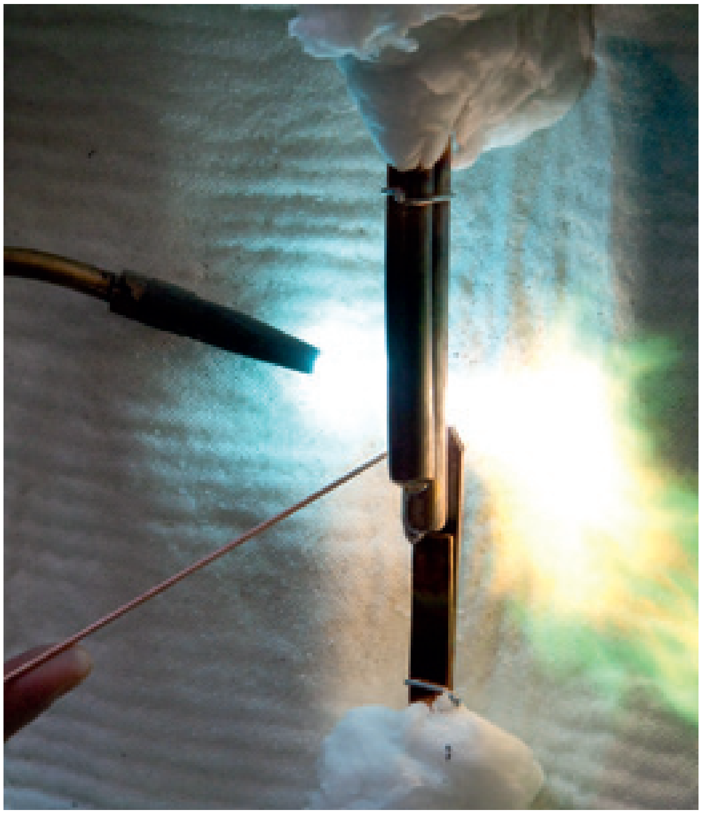
The complete phase assemblies are then carefully lowered over the separate core legs and solidly packed towards the core to assure optimal short circuit capability.

The top core yoke is then repacked and the complete core and coil assembly is clamped.

The lead exits (if applicable) and the lead supports and beams are installed. All winding connections and tap lead connections to the tap changer(s) are made before drying the complete core and coil assembly in the vapor phase oven.

Coil assembly of a 60MVA 230/27.5/27.5 kV trackside transformer >

Brazing under hydrogen for clean connections >



∨ Brazing of a 40 MVA 230 kV winding lead

Tanks

Our tank design is fully computerized. The computer determines the optimum size and the number and location of required tank supports. Occasionally the corners of the tank will be rounded off to further reduce the transformer weight without sacrificing quality and reliability. The objective is to reduce the tank size and weight as much as possible, which facilitates easier handling, transportation, assembly and installation on site.

All tanks are designed to withstand full vacuum and are manufactured from high-quality steel plate.

Facilities for lifting, jacking and pulling are provided on each transformer tank. Handholes and manholes are placed for easy access to interior components such as deenergized tap switches and bushing connections. Tank bases are either flat or have structural members which allow skidding of the transformer in two directions, as required by the specification. The transformer can be designed with a welded or a bolted cover or as a bell type tank.
All metal parts are grit-blast cleaned to remove weld splatter, mill scale and oxides, providing an excellent surface for the adherence of the primer and paint. The inside of the tank is painted with a white oil-resistant paint to create good visibility during internal inspection.

All metal parts are extensively tested on oil tightness via penetrant and pressure test at the tank manufacturer and with an extra 24 hours leakage test after complete assembly.

Tank of a 60 MVA 230 kV trackside transformer >

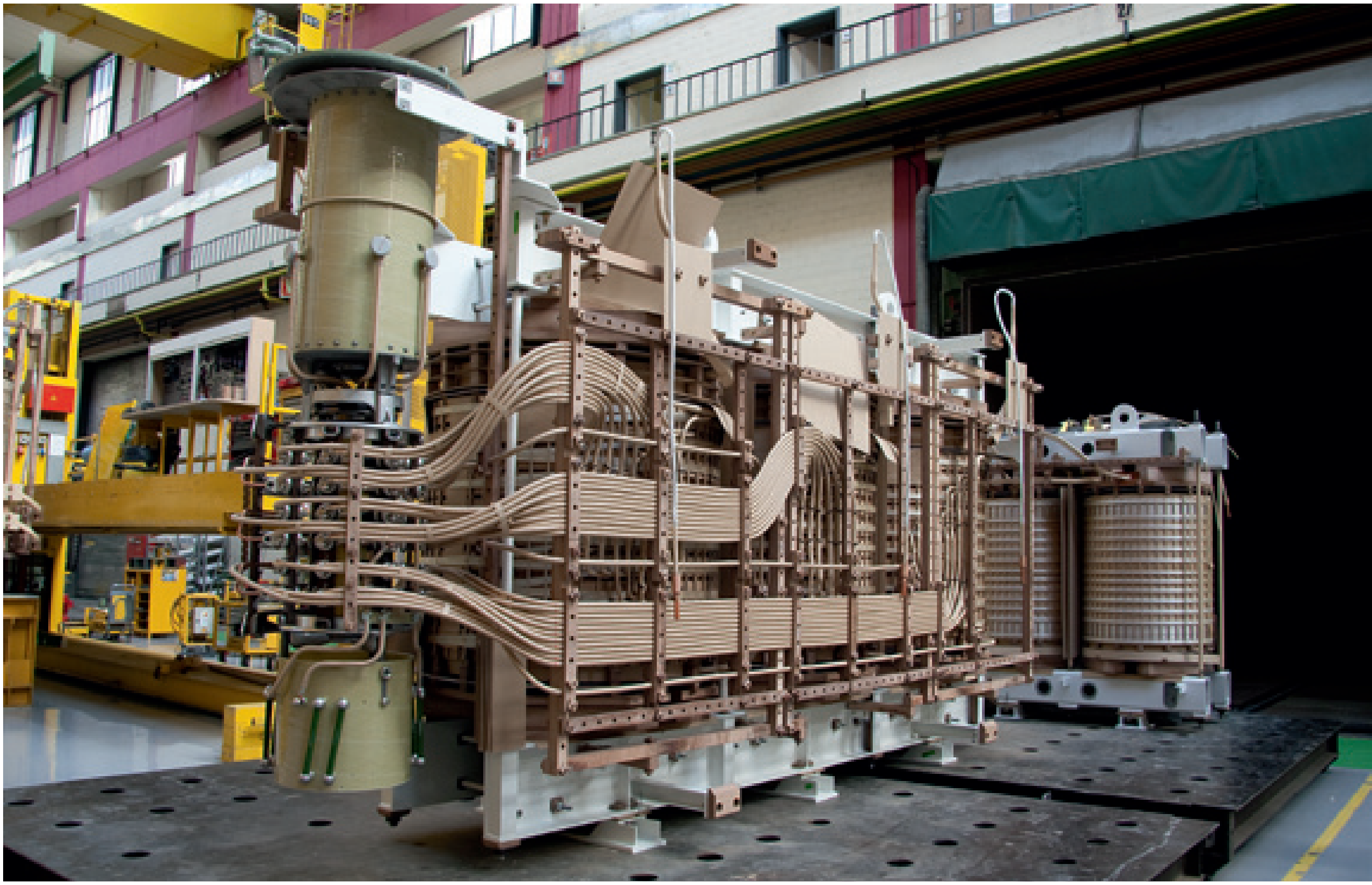
Each tank is airspray-finished before transport >

Processing of core and coil assembly

The completed core and coil assembly is thoroughly dried to pre-determined power factor readings by the vapor phase drying process , providing the fastest, most efficient and most effective drying of the transformer insulation available. The vapor phase process uses the standard kerosene cycle method. In this system, kerosene is vaporized and drawn by vacuum into a heated autoclave where the transformer has been placed. Condensation of the vapor on the core and coil assembly rapidly causes the temperature to rise and allows moisture to be drawn out of the insulation by the vacuum. High temperature and pressure are used to accelerate the drying process.

When the power factor measurements and the removal rate of moisture have reached the required levels, the flow of kerosene vapor is stopped and a high vacuum is used to boil off the remaining moisture and kerosene. Because so much water is removed in this process, the insulation physically shrinks in size. Following removal from the autoclave, the transformer is repacked as required and then undergoes its final hydraulic clamping to ensure maximum short-circuit strength in the finished product

∨ Two active parts ready for drying in the vapor phase oven



Oil preservation system

Unless otherwise specified, CG Power Systems will use a conservator oil preservation system as a standard. Many publications have stated the technical advantages of this system over both sealed tank and automatic positive pressure oil preservation systems, these being:
1. high dielectric integrity,
2. positive static pressure on unit at all times,
3. reduced maintenance,
4. possibility to use a buchholz relay & to collect gasses

The conservator oil preservation system uses an expansion tank to and from which the transformer oil may flow freely as it expands or contracts due to oil temperature changes. This system always provides a head of oil above the main tank and keeps it completely filled. An oil level gauge is mounted on the conservator and indicates the change in liquid level.

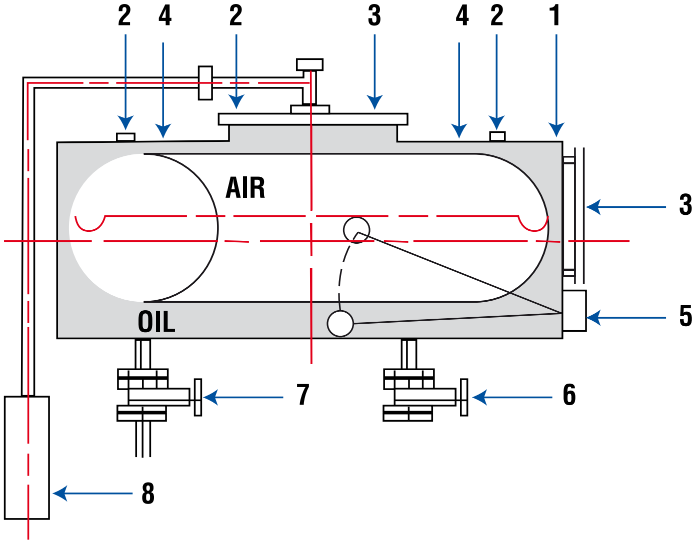
Due to the heating of the oil in the transformer, oil expands and flows freely towards the conservator. The oil expansion of the On-Load Tap Changer diverter is completely separate from the transformer oil. A separate compartment is mounted to the main conservator. Both conservator compartments are equipped with an oil level gauge with a minimum alarm contact, pipes for oil draining, air inlet from the breather and connection to the transformer or OLTC. The oil level gauge is tilted downwards for the ease of reading when standing at the base of the transformer. The breather is filled with silica gel (Caldigel Orange) that removes all moisture and dust particles from the air that is inhaled by the conservator. To reduce maintenance and to save the environment, the standard silica gel breather can be replaced by an automatic breather with repetitive heating cycle on request.

Atmoseal

The main conservator can be fitted with a nitrile membrane to avoid all contact of ambient air with the transformer oil. This eliminates the possibility of moisture entering the transformer oil and oxidation of the oil in the conservator. On request, a leakage detector can be mounted on the conservator to signal a rupture of the membrane. A nitrile membrane in the load tap changer compartment is not possible due to the gasses produced at each tap change operation. For the same reason, a buchholz relay cannot be fitted on the load tap changer compartment; a special protective relay is designed for this purpose with an oil-surge sensitive damper system that cannot be tested with gas pressure (RS2001 by MR) or a spring operated pressure relay (Beta by ABB).

^ The conservator with oil level indicator for main tank oil at 30° angle

v Drawing of the conservator



1. Expandable nitrile membrane
2. Air vents
3. Removable flanges
4. Suspension hooks
5. Magnetic oil level gauge with 1 low level contact
6. Oil drain valve
7. Valve in the connecting pipe to the tank
8. Silicagel breather

Tap changing

CG Power Systems transformers can be equipped with either a de-energised tap changer or a load tap changer or with both.

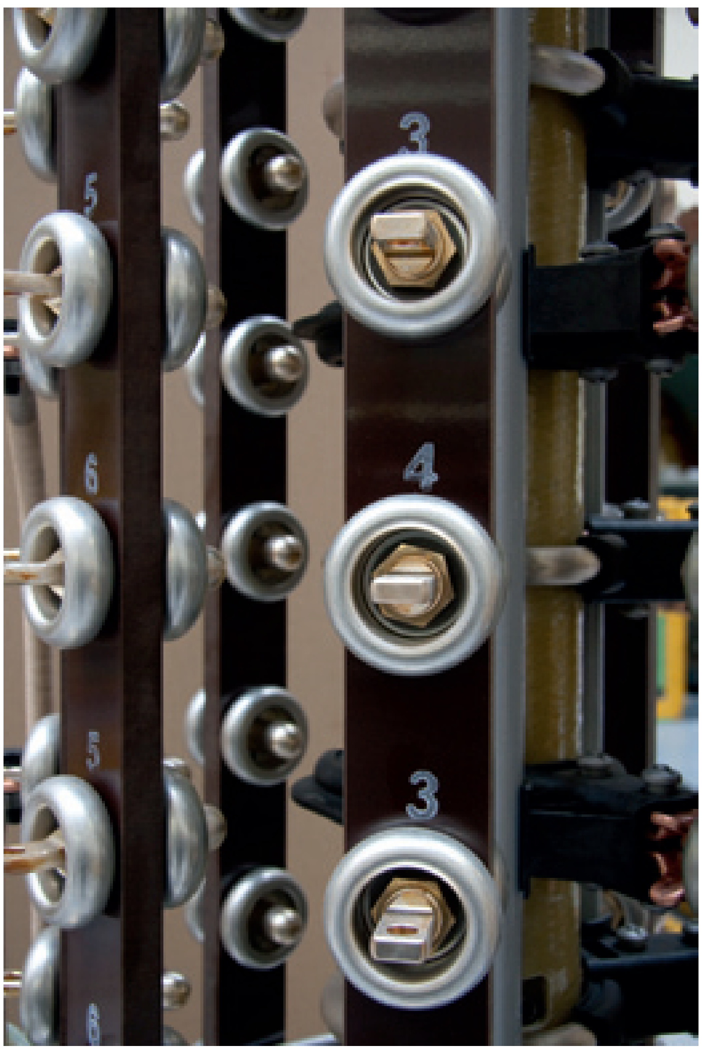
Should load tap changing be required, CG Power Systems can provide a resistive bridging type or reactor type LTC. Both types offer up to 500,000 operations between contact replacement and substantially reduce maintenance intervals.

The LTC can be installed in the transformer tank with the diverter switch in its own oil compartment, so that no contamination of the transformer oil occurs due to arcing during switching, or can be mounted on the main tank.

To prevent voltage surges on the tap changer during switching MOV surge suppressors can be installed.

^

∨ Detail of the selector of an in-tank load tap changer



∨ A 400 MVA phase shifter before tanking. View of the six load tap changers

CG Power transformers are commonly cooled with detachable panel radiators, providing a reliable and low maintenance cooling solution. To boost the efficiency of the radiators fans can be used (ONAF cooling). If design recommends or specifications require, the cooling efficiency can further be increased by pumping the oil through the windings (ODAF cooling).

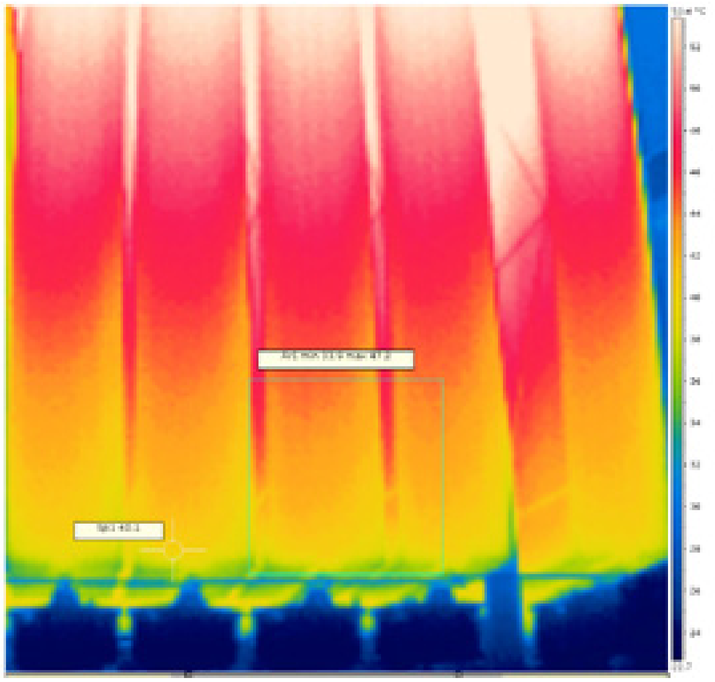
CG Power transformers has also a large experience with other type of coolers, like compact oil-air cooler or oil-water coolers and these solutions can be provided on customers demand.

Cooling control

Cooling control is highly dependable on the transformer and the cooling design. All components for the cooling control are selected for their high quality and time lasting properties. For pumped units, oil flow sensors are used for signaling cooling malfunctions and, when necessary, for automatically switching to the backup pump system. Time relays are used to sequentially start pumps and fans to lower the starting current. All necessary signaling contacts are provided as a standard. All cooling control equipment is neatly housed in an IP54 control box (IP55 possible for small control boxes).

The cooling bank af a 750MVA transformer >

∨ Thermal image of the cooling bank of a 750MVA autotransformer at ONAN cooling stage

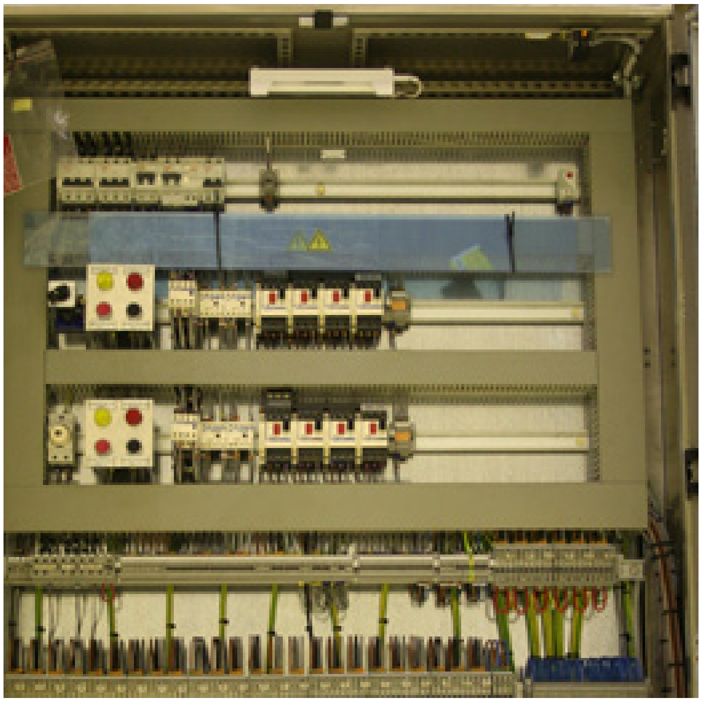


Transformer auxiliaries

The transformer control cabinet groups all signals of the auxiliaries mounted on the transformer together with the cooling control equipment.
Every CG Power Systems transformer with conservator oil preservation system is equipped with a gas collection relay (Buchholz relay). In the unlikely event of an internal fault, combustible gases will be generated in the oil, which try to escape at the highest point of the transformer. The Buchholz relay is mounted between the main tank and the conservator and collects the escaping gases. If a sufficient amount of gas has been collected, a float will operate a contact to give an alarm signal. In case of a severe fault, e.g. a short circuit, the Buchholz relay acts as an oil-surge relay. A large volume of gas or oil will be generated and immediately activates the contact of a second float which trips the transformer breaker. The oil-surge function of the Buchholz relay eliminates the need for a separate sudden pressure relay. The Buchholz relay is mounted at a position above the highest turret so that the Buchholz floats are a back-up for the oil level alarm. In case there is no oil in the conservator, the oil level gauge will activate an alarm but the Buchholz relay will trip the transformer when the oil level decreases further below the Buchholz level.

An auto-reclosing pressure relief valve can be fitted on the transformer tank & on the LTC on request to reduce the risc of a tank rupture in case of large internal faults. For the protection of personnel, this pressure relief device can be fitted with a directive shield and an oil drainage pipe to ground level.

The transformer lifetime expectancy is highly dependable on the absolute temperature of the winding hot-spot that is influenced by the oil temperature & the load. All transformers are standard equipped with an oil temperature indicator and minimum one winding temperature indicator containing cooling control, alarm and trip contacts. To achieve a long transformer lifetime, the standard setting of the alarm and trip contacts is very conservative but may be set different on request.



^ View inside the control cabinet of a 120 MVA ONAN/ONAF transformer

Monitoring & Electronics

CG avoids the use of electronics for the cooling control and only uses reliable components that guarantee a flawless operation for the whole lifetime of the transformer. For transformer monitoring however very sophisticated systems are used.
Monitoring systems allways consist of the following 4 functions:

- measurement sensors; mainly Pt100 temperature sensors for top-oil, bottom oil, LTC oil and ambient temperature, CT transducers for load currents & cooling current, dissolved gas and moisture sensor, tap-position transducer. Also a separate Partial Discharge monitor or a dedicated tap-changer monitor can be installed on request.
- a microprocessor based controller unit that collects all data and stores data
- calculation models that process the data and give advanced information about the transformer's condition & required maintenance such as winding hot-spot temperature calculation, loss-of-life calculation, LTC contact wear, calculation of the bubbeling point and associated overloading limits.
- communication from the monitor to a computer or SCADA system, or to a LAN using a communication protocol like TCP/IP, Modbus, DNP3, Profibus or others. CG uses a fiber optic communication between monitoring system on the transformer and the substation computer to ensure electrical isolation at all times.

An optional Automatic Voltage Relay can be supplied with the transformer as a loose component or build-in a stand-alone control box to integrate in the substation control-room.
Fiber-optic sensors can be inserted in the windings to read hot-spot temperatures during operation with tha associated relays or only for heat-run testing.

Prior to shipment, all transformers manufactured by CG Power Systems are tested in accordance with the latest applicable standards according to customer specifications. All industry standard and optional tests with the exception of short-circuit tests, can be performed in-house by trained personnel using accurate and modern test equipment.

Impulse Testing

A state-of-the-art digital impulse recording system, the Haefely HIAS system, provides the most accurate analysis of impulse results available today. Electronic recording of the impulse current and voltage waveforms allows quick mathematical comparisons to be made, including the difference between the two waveforms under scrutiny. Accurate printed and plotted final results are quickly available. If required, photographic transparencies from the impulse oscilloscope can be supplied.

The construction of the test area incorporates a complete copper mesh ground mat system, with extensive grounding points provided. This eliminates high impedance grounds and provides exceptionally clean test records. The impulse generator is rated at 200 kV per stage for a total of 2.8 MV, with 210 kJ total stored energy. For precise triggering, this generator is equipped with a pressurized polytrigatron gap in each stage. For chopped wave tests, a Haefely multiple chopping gap is used. Our plants are fully capable of performing lightning impulse, switching impulse and front-of-wave tests as required.

Induced Testing

For induced testing, a variable voltage alternator, rated 1500/1000 kVA, 3/1-phase, 170/240 Hz, is used. Voltage control is by solid state automatic voltage regulator, and solid state speed control of the 1000 kW DC driving motor. During the induced test, partial discharge measurements both in pC and µV are taken and equipment is available to locate internal partial discharges by the triangulation method.

Loss Measurement

Power is provided to the loss measuring system by a 5/10 MVA regulating transformer feeding three single-phase 10 MVA variable ratio transformers and a 110 MVAR capacitor bank. Losses are measured by an automated system using CTs for current and gas capacitors for voltage. This system has a fully automated digital readout and printer.

Testing environment for a 150 MVA 235/34.5 kV ODAF generator transformer with special tank construction according to German Rail standards >

AC Testing

A test supply with an output voltage infinitely adjustable from 3-350 kV is available for high voltage AC testing. To measure the applied voltage level, a digital peak-responding RMS calibrated voltmeter capable of measuring up to 1600 kV is used.

Short-circuit testing

CG Power Systems' high profile on the international transformer market is amply backed up by many years of short-circuit testing at the independent test laboratories of KEMA in The Netherlands and IREQ in Canada.

The following transformers have successfully been subjected to Short-Circuit Tests:

CIRCUIT TESTS OF CG POWER SYSTEMS POWER TRANSFORMERS				
MVA	**HV/LV**	**Impedance**	**Lab**	**Year**
25	69,8/15,7	11	Kema	1990
10	37,5/10,4	9,85	Kema	1992
30/36	115/13,8	11,47	Kema	1992
23	66/11,5	13,02	Kema	1994
90 *	150/2x27,5	13,46	Kema	1995
10 *	55/27,5	1,28	Kema	1995
120/120/40	220/63/10,5	13,24	Kema	1996
185 *	$\frac{400}{\sqrt{3}}$ $\frac{165}{\sqrt{3}}$ 34	22,9	Kema	1998
58	34,5/11	8,2	Kema	1998
19	33/11,5	6,14	Kema	1998
100/120	220/31,5	12,0	Kema	2001
40	220/(63/31,5)	12,0	Kema	2001
11,2	22,86/13,2	5.165	HydroQuebec	2001
90/120	220/63/10,5	12,35	Kema	2004
81 *	400/27,5+27,5	14,95	Kema	2004
30/40	60/10,5/5,5	11,88	Kema	2005
30	132/16,05/10	11	Kema	2008
25	45/16,05/10	11	Kema	2008
100	225/64	12	Kema	2009
60 *	230/27,5	16,8	Kema	2009

* Single Phase

< Elia transformer Brume 110 MVA; 400/76/36 kV in test bay for dielectric testing

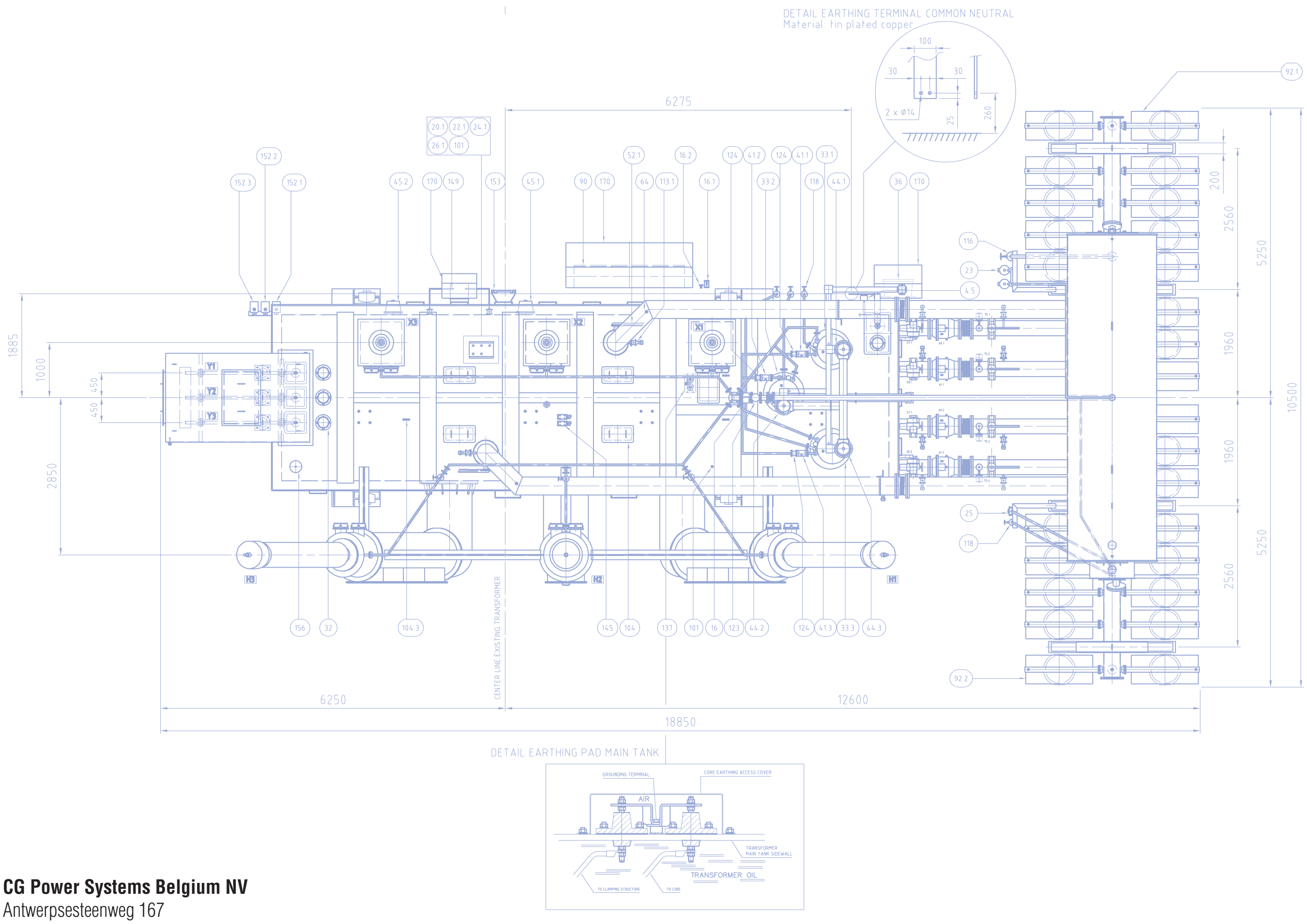
Depending on transportation considerations, CG Power Systems transformers may be shipped either with or without bushings, radiators, fans, conservator and oil.

CG Power Systems' experience in delivering power transformers to over 135 countries throughout the world guarantees fast and reliable transportation.

Installation of the transformer can either be done by the customer or by an experienced CG Power Systems Field Service Crew.

Special transport of a generator step-up transformer for the German utility RWE - 332 MVA water cooled; 115/21 kV >

Shipping of a complete mobile substation



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