Ensuring efficient flow of bulk energy

HVDC converter transformers

siemens.com/transformers
HVDC converter transformers – the backbone of reliable power supply

Safe and reliable power supply is what societies rely on. Especially in the most vital parts of the world the huge energy demand meets the challenge that accompanying energy sources are distributed and located far away from the load centers. This situation is further escalated by the increasing amount of highly volatile infeed of alternative energy sources (such as wind and solar power) into the AC transmission networks. What is needed to secure a solid, efficient, and highly reliable network are HVDC transmission systems. By converting AC into DC, the power losses over long distance transmission are greatly reduced. Taking into account the advantages of HVDC such as reduced energy transmission losses and smaller footprint as well as reduced right-of-way costs, an investment into HVDC equipment pays off easily.

Regardless of the energy sources, be they wind, water, or conventional, non-renewable resources – the applications for HVDC transmission systems are manifold. In addition, HVDC systems can serve as a means for interconnection of two different grids, when AC lines are not applicable, e.g. diverging network frequency or connection through the sea.

The HVDC converter transformers play a vital role within the HVDC systems; hence there are high requirements on their reliability and availability.

Siemens Transformers have more than 100 years of experience in manufacturing transformers – and were the first manufacturer worldwide to master the 800-kV level in 2008 for a Chinese customer. Since this big step towards a new age of HVDC transmission, we have also built a prototype for 1,100-kV UHV DC transmission and a 1,200-kV UHV AC transformer. The evolution in the field of bulk energy transmission using HVDC took place over roughly ten years, and we continue to passionately drive this process towards the future.

The application of increasing voltage levels together with the continuous application of innovative solutions is mastered by Siemens Power Transformers.
Your reliable high-quality partner with expertise

Designing and building an HVDC transformer is comparable to manufacturing Swiss clockwork: a precision job. HVDC transformers are subject to operating conditions that set them apart from conventional power transformers. The special requirements at a glance:

- Combined voltage stress, with a superposition of AC and DC voltage
- High content of harmonics during operation
- DC pre-magnetization of the core

Our high-quality standards are known and acknowledged internationally. All Siemens transformer manufacturing plants worldwide work with consistently certified quality management systems, such as DIN ISO 9001:2008, among others. Above all, our high standard of quality is based on more than a century of experience in this field, as well as continuous research and development work.

Knowing that HVDC transformers are the masterpiece in transformer manufacturing, we rely on very well educated employees that are specifically trained for this kind of work – no matter whether they work in the design department, project management, or production shop. All employees live our values of high-quality manufacturing along with “Safety first” personnel safety standards along the value chain.

It is self-evident that we only use the material with the highest quality available. Our design and manufacturing processes set standards in transformer production. As we are manufacturing the whole range of transformers at Siemens Transformers, we reflect outstanding processes from HVDC to AC transformer production. Thus, we apply the same high-quality standards required for manufacturing HVDC transformers also for AC transformers.

We make sure our transformers are installed properly to secure high quality at all times.
Siemens transformers are manufactured in factories around the world, of which four locations manufacture HVDC transformers. It is crucial for those hi-tech products to secure the high quality, independent of a single manufacturing location – be it in Germany, China, India, or Brazil.

Our factory network ensures that our customers worldwide profit from the special skills and solutions of all locations. No matter where our customer or their (future) HVDC project is located, our experts are always close by to assist, consult, and provide service when needed. Having four HVDC facilities spread on a global scale, distances for transport can be kept to a minimum, while the lead center in Nuremberg ensures that German quality is maintained at all times. Our lead and production plant concept makes sure that the same extensive know-how and the same technology and quality are available to our customers around the world, regardless of their location. As an additional benefit, the customer always knows there is a backup plant to secure the progress of a project at all times.

Also, our dedicated sub-suppliers have been chosen and qualified according to the same stringent quality standards that the Siemens Transformer group follows. Harmonized design, globally standardized design guidelines, and sophisticated IT tools ensure that our customers always receive the best possible product. A modular structure makes it possible to implement customers’ specific requirements.

Finally, our German lead plant has two independent test fields able to test HVDC converter transformers at its premises, which adds to the production capacity.
HVDC PLUS: world-class top innovation enables new applications of well proven HVDC transmission

The innovative design of HVDC PLUS provides technical as well as economic benefits. Via implementation of a new concept of modular multilevel voltage-sourced converters, HVDC PLUS is the preferred solution when HVDC transmission needs to be combined with network-supporting functions (STATCOM) such as voltage phase-angle control or black-start capability, or where power has to be transmitted in offshore conditions. It is ideal for connection of remote offshore platforms and wind farms to the main power grid as well as for power supply to megacities. HVDC PLUS improves the performance of the transmission grid with regard to system security. Dedicated functions make HVDC PLUS ready for future power system developments and HVDC grids. The next step towards cost-efficient integration of offshore wind introduces an innovation in HVDC converter transformers:

A solution combining a diode rectifier together with the converter transformer itself has been developed. This solution is part of the new Siemens DC grid access solution, enabling the connection of offshore wind to onshore networks at drastically reduced investment cost. This solution helps to greatly reduce the size of the required offshore converter platforms and is another highlight in Siemens HVDC converter transformer technology.

Testing, research and development in our own chemical and physical test laboratory

At our lead plant we have our own testing and development laboratory accredited according to ISO 17025. It is a vital part in safeguarding our high quality by material testing and searching for new ways to introduce innovation into the manufacture of HVDC converter transformers. Being the innovation leader in modern HVDC transmission, it is our aim to always deliver cutting-edge solutions that our customers can rely on. Thus, it is crucial for us not to rely on external parties to test materials and drive research. The main tasks of this lab are:

- General, basic scientific research
- Materials research and testing
- Dielectric testing for quality assurance
- Component testing

The high harmonic content of the operating current resulting from the converter cause additional losses in the windings and other structural parts. Proper selection of all parts as well as their design and shielding require in-depth expertise combined with laboratory testing resources which are supported by our test lab.

Further, innovation has been driven in order to adapt biological degradable insulation liquids, such as esters, for HVDC converter transformers. The advantages beside the improved green footprint are the reduced fire hazard due to the higher flash and fire point of esters. A commercial use can be seen for HVDC systems up to a system voltage of ±500 kV.

Innovation in HVDC transformer technology

Testing, research and development in our own chemical and physical test laboratory

At our lead plant we have our own testing and development laboratory accredited according to ISO 17025. It is a vital part in safeguarding our high quality by material testing and searching for new ways to introduce innovation into the manufacture of HVDC converter transformers. Being the innovation leader in modern HVDC transmission, it is our aim to always deliver cutting-edge solutions that our customers can rely on. Thus, it is crucial for us not to rely on external parties to test materials and drive research. The main tasks of this lab are:

- General, basic scientific research
- Materials research and testing
- Dielectric testing for quality assurance
- Component testing

The high harmonic content of the operating current resulting from the converter cause additional losses in the windings and other structural parts. Proper selection of all parts as well as their design and shielding require in-depth expertise combined with laboratory testing resources which are supported by our test lab.

Further, innovation has been driven in order to adapt biological degradable insulation liquids, such as esters, for HVDC converter transformers. The advantages beside the improved green footprint are the reduced fire hazard due to the higher flash and fire point of esters. A commercial use can be seen for HVDC systems up to a system voltage of ±500 kV.
Special demands require special solutions

The core

Usually HVDC transformers are single-phase two- or three-wound units with valve windings for the star and delta connection separated or combined in one tank. This depends on the rated power, the system voltage and transportation limits. Appropriately sized return limbs ensure good decoupling for a combined arrangement of windings. Special attention must be paid to DC pre-magnetization of the core due to small asymmetries during operation and vagabond DC currents from the AC voltage network. Those effects have to be compensated by appropriate design and manufacturing efforts, like additional core cooling ducts and avoiding flux pinching in the core sheet.

The tank

The tank design of HVDC transformers looks different than that of large power transformers:

• The valve-side bushings mostly project into the valve hall.
• Characteristic is the installation of the compact forced air cooling system on the transformer tank to grant fast exchange of the transformer for a spare unit.
• For HVDC transformers with delta and star valve winding in one tank, the valve bushings must be arranged so that their ends conform to the geometry of the converter.
• Application of heavy bushings horizontally or at an angle together with big tank openings for the big turrets pose high mechanical requirements on the tank regarding stiffness and oil tightness.

The windings

There are a variety of parameters for an HVDC transformer concerning transport limitations, rated power, transformation ratio, short-circuit voltage, tolerances, and guaranteed losses that require significant expertise in the design of windings. In concentric winding arrangements, mostly the valve windings are arranged directly on the core. In this case the line winding (normally with tapped winding) is mounted radially outside this core configuration. For higher DC voltages, the valve windings have to be arranged as outer windings. The valve windings with high test voltages and a large portion of current harmonics cause particular demands on the design and the quality of winding manufacture. Together with its pressboard barriers, each limb set, including a valve, a high-voltage line, and a tapped winding, form a compact unit, which is able to cope with the voltage stress, loss dissipation, and short-circuit withstand capability. In contrast to AC winding blocks there is a need for more solid insulation material to control the DC field stress. The winding geometry is partly predetermined by the impedance voltage (uk), requiring a certain height of the winding. Deviations would have great impact on the performance and efficiency of the HVDC converter, and therefore on the whole HVDC system.

The cooling

Since HVDC systems often run close to their capacity, a highly sophisticated cooling system for HVDC converter transformers is the most economical solution.

A special development to reduce both acoustic noise and auxiliary losses of the cooling system is Transviso®.

It applies more efficient DC motors which are speed-controlled, cutting down both noise level and low losses.

In the operation mode maximum cooling, it extends the transformers lifetime by reduced aging (more even and lower oil temperature). Finally it is preferred to use directed oil flow (OD), granting that the cool oil is led by a predetermined, optimum path through the core and windings, reducing both size of the active part and the cooling system.

AC (left) and DC (right) field distribution within a winding geometry. 50% increase in performance at the same transport size.
Development trends

Development trends in HVDC technology require two major issues to be addressed: ever-increasing power rating combined with growing transmission distances. These result in increased MVA rating as well as increased DC voltages for the converter transformers. Siemens HVDC transformers continuously address this development, proven by the increase of MVA rating by the factor 1.5 between the world’s first 800-kV transformer delivered in 2009 and the second generation 800-kV transformer delivered in 2013 which have the same transport dimensions. This trend is continued by the world’s first 1,100-kV HVDC transformers which will be delivered in 2017, increasing the transmission capacity by 30% compared to 800-kV HVDC systems.

Why Siemens HVDC transformers make a difference

• Outstanding external failure rate in operation, according to CIGRE working group A2.37
• Only the oil-free bushings protrude into the valve hall, thus eliminating any fire hazard caused by the transformer
• Transviso cooling control: flexible solution, allowing reduction in both noise and power consumption, reduction of the overall transformer temperature possible -> longer lifetime
• Bushings and tap changers are sourced from within the Siemens company network: independence from external sub-suppliers
• In-house design and manufacturing of state-of-the-art, high-quality lead exits and barrier systems in an internal insulation shop

The bushings

In HVDC transformers it is preferred to use oil-free RIP bushings with silicone insulators, as they greatly reduce fire hazard and weight, and are better suited for service within the valve hall, avoiding oil to spilling in the valve hall case of oil-leakage. Thus, oil-free RIP bushings are better suited for HVDC service and increase the overall reliability of the converter transformer.

Further, they provide better protection against humidity, dust, and debris.

The final testing

To verify the performance ability of our transformers in operation, every single unit has to pass various tests before leaving the factory. Special tests undertaken with HVDC converter transformers are:

• DC separate source voltage withstand test
• AC separate source voltage withstand test including PD measurement for an extended duration of 60 min.
• Polarity reversal test
• Switching and lightning impulse levels for the valve windings are predetermined by insulation coordination of the DC line, causing higher stresses
• Load loss evaluation taking harmonics into account

Part of a tank, conservator, plus oil-free RIP bushings with silicone insulator surface.

The last step of each transformer’s production: final testing.

Cooling of an HVDC transformer.
Replacement that pays off easily

The evolution in HVDC transformer technology has been progressing immensely in the last few years. This is why today’s products perform extremely economical economically: new materials and new technologies save a large amount of losses in modern HVDC transformers combined with tremendously increased reliability. Cutting-edge technology of new replacement units can therefore cut the costs of operation so much that an investment in a replacement pays off very easily within a short time frame.

Siemens Transformers is your consultant when it comes to the decision whether to invest in a repair or opt for a replacement solution. We have developed tools that compare continued operation with existing units over operation with Replacement units, taking into account reliability, losses, and smart cooling, in order to support our customers in the decision process.

To assist even more, also in financial regards, we work in close cooperation with our own financial partner, Siemens Financial Services (SFS). Being part of Siemens, they know the energy industry by heart and are able to develop dedicated concepts for replacement solutions that general banks and financing partners would never think of.
This is only an excerpt of our references. In total Siemens Transformers has manufactured more than 450 HVDC transformers worldwide over the years.

**Hami (China)**

HVDC transformers for the 800-kV level: reliable high-tech delivered from several plants of Siemens transformers for the energy transmission of 8,000 MW over a distance of more than 2,000 km from north-west China to central China.

**Gui-Guang 1 (China)**

The HVDC long-distance transmission system of Gui-Guang transmits 3,000 MW of power from the Anshun substation in Guizhou Province near the load center of Guangzhou. The converter transformers are of the single-phase two-winding type. After the first project in 2002 the second project in 2005 was also awarded to Siemens.

**Neptune (USA)**

The purpose of the 105-km 500-kV DC undersea and underground cable link is to transmit 660 MW of power from the Sayreville substation in New Jersey to Duffy Avenue substation on Long Island. Siemens supplied eight HVDC transformers, 245 MVA each, plus three units rated at 80–115 MVA.

**Bass link (Australia)**

The 295-km-long Bass link crosses the Bass Strait, delivers hydroelectric power from Tasmania to the Australian state of Victoria, and also allows the import of base load from Victoria to Tasmania. Siemens provided eight HVDC transformers rated 196 MVA each for the 500-MW connection.
References

**INELFE (Spain)**

INELFE is the world’s first VSC HVDC with 2x 1,000 MW. The installation connects Perpignan in France with Santa Llogaia in Spain, and can transmit rated power of 1,000 MW per link with minimal transmission losses. Siemens Transformers delivered 14 transformers for the 400-kV level.

![INELFE Transformer](image)

**Western Link (UK)**

Fourteen HVDC transformers and four reactors for a 2,200 MW grid connection between Scotland and England, the world’s first submarine interconnector with 600-kV DC voltage level, and a length of 420 km. The three-winding transformers have a rating of 444 MVA each.

![Western Link Transformers](image)

**Sylwin 1 (Germany)**

Four transformers and two reactors for an 864 MW HVDC offshore grid connection of a wind farm located in the German North sea. The transformers for the HVDC PLUS (voltage-sourced converter technology) have a rating of 630 MW each.

![Sylwin 1 Transformers](image)

**COMETA (Spain)**

The COMETA HVDC project connects the Spanish peninsula with the Balearic island of Mallorca in order to meet the increasing demand of electric power on the island. The submarine link crosses the Mediterranean Sea at a max. depth of 1,500 meters and has a length of approx. 250 km. Siemens Transformers delivered 14 transformers.

![COMETA Transformers](image)