Brazed Ceramic-Metal Composites as Key Components for the Energy Turnaround

Renewable energies call for a more flexible energy distribution. This requires the transmission of high powers by means of alternating current technology over longer distances.

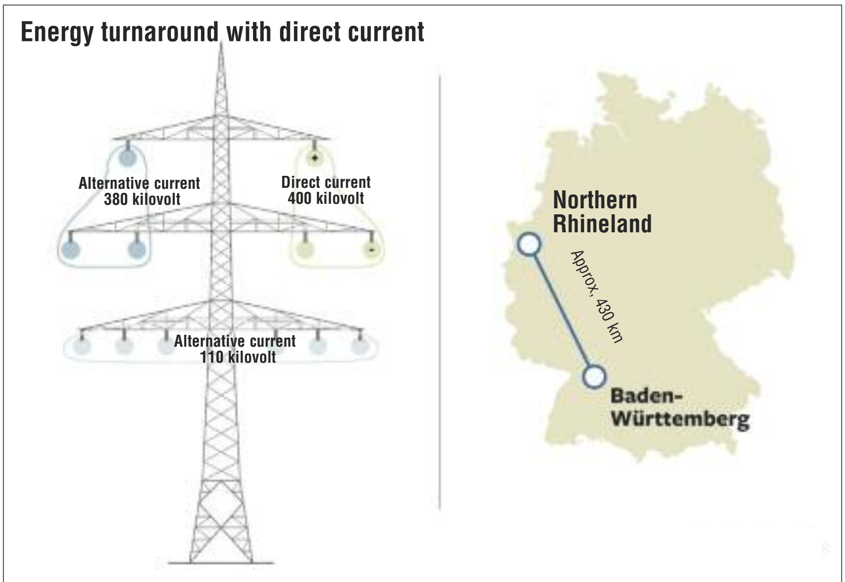

Fig. 1
"Welt am Sonntag: Im Gleichstrom, marsch!" [1] dated 13 May 2012 (source: www.amprion.com)

The switch-off of nuclear power plants at the end of their remaining operating time as part of Germany's agreed energy turnaround requires restructuring of the current energy mix such that the base load ranges so far largely covered by nuclear power plants can be supplied by renewable energies. This calls for a more flexible energy distribution entailing new challenges like, for example, the transport of electricity from the wind-favoured coast to the energy-intensive south of Germany. This requires the transmission of high electric power by means of alternating current technology within Germany over longer distances of 400–700 km. Associated with alternating current technology, however, are transmission losses of up to 9 % as a result, for example, of the reactive power loss (50 Hz).

Keywords
High-voltage direct current transmission, energy turnaround, thyristors, diodes

To reduce energy losses in vast countries like China, Russia and the USA, electric energy is transmitted over distances of more than 600–800 km by means of high-voltage direct current transmission to the grids. This grid technology was developed in Germany in the 1940s, but was not used for power transmission in Germany as the distances here are quite short compared to those in the above-mentioned countries, even though the associated power loss at 2–6 % is much lower than that of alternating current technology and despite the fact that a reverse load is possible. Reasons for this are the high investment costs for the transformer substations (valve halls), in which the generated alternating current is transformed into direct current. At least two of these valve halls are needed, one for power input and one for power output. In addition, direct current power lines are needed, as it so far has not been possible to use direct current and alternating current lines on one pylon owing to mutual induction yet.

New approaches in transmission technology, however, now enable transmission of a 400 kV – direct current line with around 2700 A on the same pylon as alternating current lines. With this approach, no transformer substations are eliminated, but almost no new line routes are necessary. According to the grid operator, it is expected that 90 % of the already existing line routes can be used.

According to the operator *Amprion*, completely new approaches would result in the extension of the HVDC grid in Germany with the advantages of lower losses and higher flexibility thanks to the possible load reversal.

Thyristors and diodes

One key component of these grids is the thyristor, which depending on its diameter

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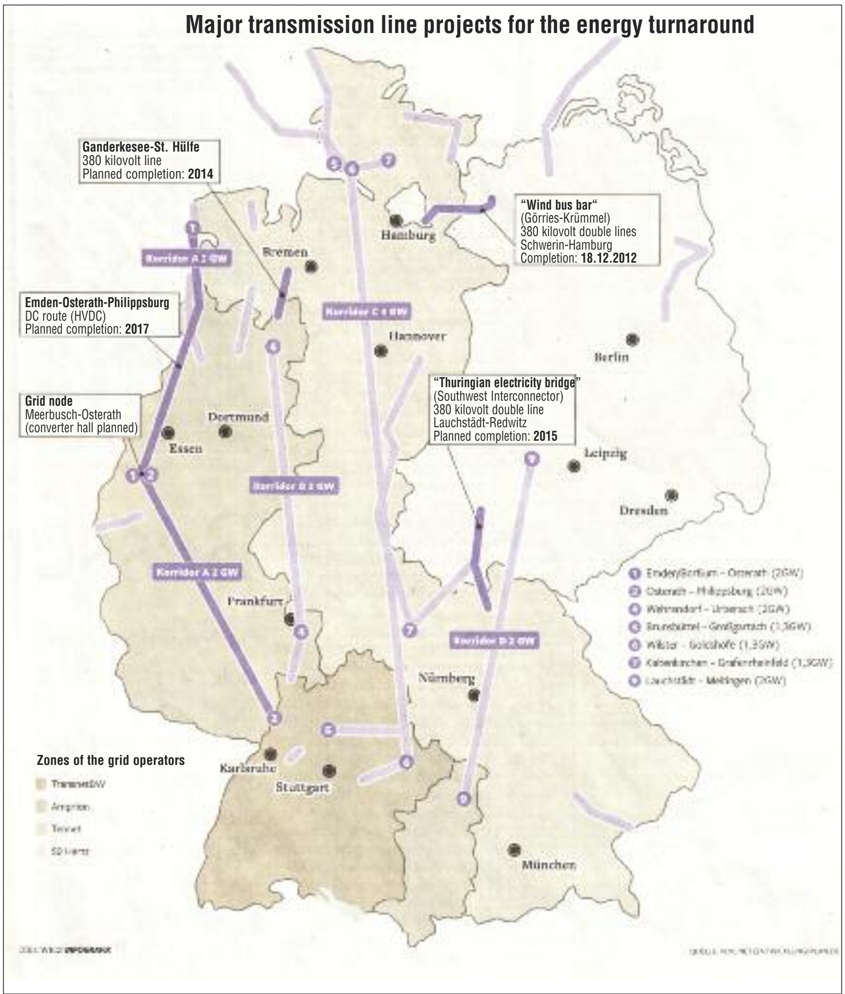

Fig. 2
"Welt am Sonntag: Endlich klappt was bei der Energiewende" [2], dated 16. Dec. 2012
(Source: VDN, grid development plan)

can transmit up to 10 GW per component. Control is based on a low current that blocks the thyristor or switches to forward current. Accordingly, with low control currents, large currents and thus energies can be controlled.

The components of the direct current transmission technology – including bipolar systems – can be divided into controllable components (thyristors) and non-controllable components (diodes). Thyristors are available in a wide range of sizes which are usually specified in inches of the copper contact diameter. Thyristors are used in the range 1"–3" (industrial applications) to a diameter of 6" (high-performance electronics for, for example, high-voltage direct current transmission. Typical applications in industry are welding diodes for automotive engineering (not controllable), "fast starters" or frequency inverters for wind power systems. For the high-performance electronics for high-voltage direct current transmission, various thyristors are used, which depending on the type (IGCT – Integrated Gate Commutated Thyristor, LTT – Light Triggered Thyristor [Fig. 4], GTO – Gate Turn Off Thyristor) have different characteristics, which are mostly related to shortening of the thyristor blocking time ("snubber").

Basically all casings for high-performance thyristors are designed as ceramic-metal composites, the alumina ceramic ensuring electrical insulation between the two electrodes of the current path. Voltages of up to 8500 V are applied. In addition the ceramic has to protect the semi-conductor against oxidation with a vacuum-tight joint over the lifecycle (≈40 years). The influence of arcing and leakage current, caused by dirt on the surface of the ceramic, is prevented on the outside by convolutions to lengthen the leakage path and a layer of glaze which largely prevents any dust transported in the air sticking to the ceramic. The thyristor casing consists of the casing and the top. The top consists of oxygen-free copper (OF-CU), which ensures maximum current conductivity. Requirements are typically up to 10 000 A. The casing consists of the contact, the ceramic casing, the gate connections and the casing flange. The latter assembly is joined in a brazing process under forming gas (H_2/N_2) to a ceramic-metal composite. As a precondition for brazeability, the ceramic casing (Fig. 5) is printed on both connecting ends with a MoMn paste, which is burned in prior to the brazing process also in forming gas at around 1400 °C.

So that the Ag/Cu solder later wets the solder joint and sufficient joint strength is achieved, the previously metallized surface is either chemically or galvanically nickel-plated. The brazing process itself is performed at around 800 °C also under forming gas. A vacuum-tight, high-strength joint is obtained. 100 % vacuum tightness

Fig. 3
Different models of thyristors and diodes

Fig. 4
Light triggered thyristor (LTT)

is assured in a He-leakage test up to 10^{-9} mbar·l/s.
Following the entire process, a flatness of better than 5 µm for the contacts on the semi-conductor end must be guaranteed so that the semi-conductor element installed later by the customer has contact over the full area. Finally, the two components are nickel-plated to prevent oxidation of the copper in air. The customer positions the internal components and welds casing and top at the casing flange/top interface to a thyristor assembly. These are now connected in series until the necessary voltage of the high-voltage direct current transmission connection is reached.
High-voltage direct current transmission is currently used where power has to be conducted or distributed over long distances. Tyherefore countries like China, Russia or America are markets for this technology. The map shown in Fig. 6 of the planned high-voltage direct current transmission routes in China gives an idea of the potential still available in this market. The transmission powers of the individual projects go up to 6,4 GW. Technological development is aiming at more than 10 GW for the future.
As a result of technology transfer to China, an inner-Chinese industry has become established to serve this market segment. In recent years, therefore, an increased migration of the technology especially in the relatively low power ranges with diameters up to 4“ has been observed. Up until 2010 *LAPP Insulators Alumina GmbH* served around 45 % of the HVDC transmission market, but the trend is now dipping downwards.
IGBTs (Insulated Gate Bipolar Transistor) are also bipolar high-performance com-

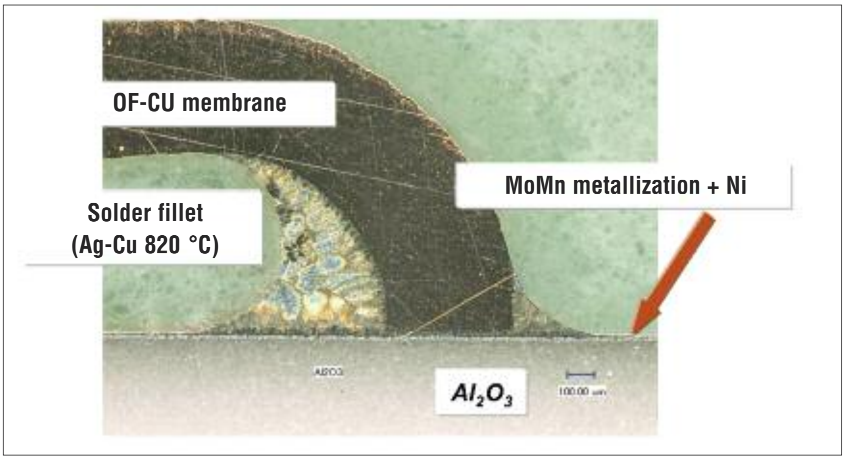

Fig. 5
Polished section of a ceramic casing

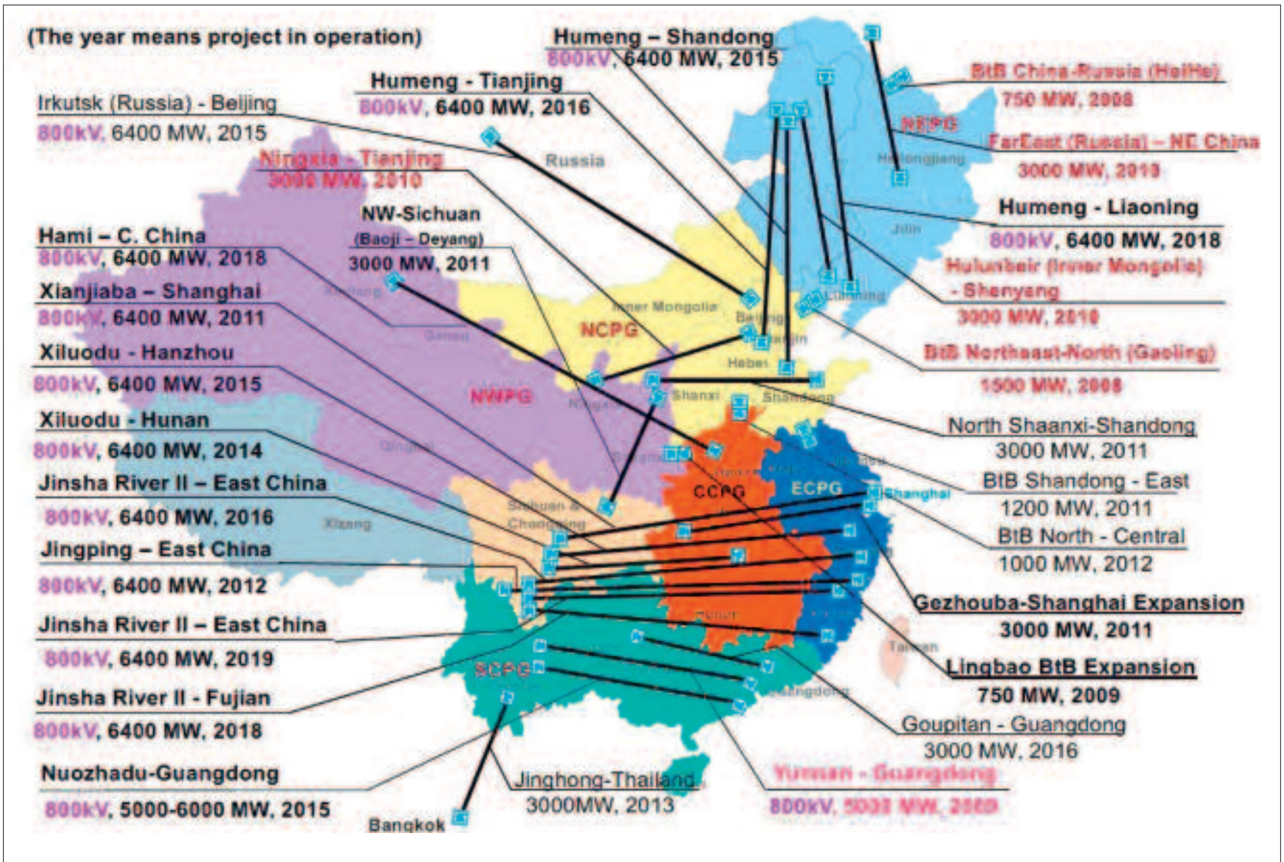

Fig. 6
Project map of China showing high-voltage direct current transmission routes [3]

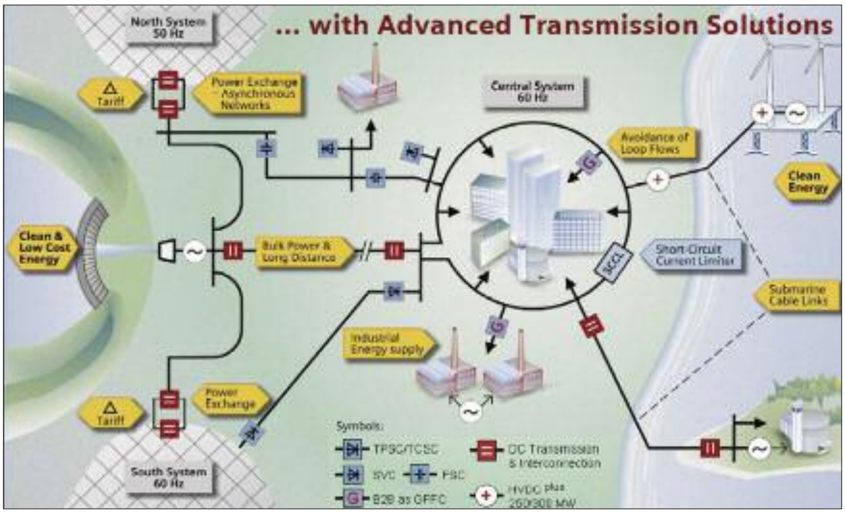

Fig. 7
Smart grid [4]

Fig. 8
Typical products: laser beam generator tubes/feed-through with CF flange/special design with clamping thread on the side

ponents, which, in addition to the offering of the usual advantages of bipolar transistors, also guarantee almost powerless activation. This gives them high flexibility, but with max. 2000 MW transmission power, they cannot operate in the power class of thyristors.

Smart Grids

The already mentioned flexibility compared to thyristor technology such as

- infinitely variable provision of reactive power,
- black start capability
- low losses (1–3 %)

becomes more apparent especially with the interconnection to "smart grids". The term "smart grid" refers to the communicative networking and control of power generators, storage, electrical consumers and grid equipment in energy transmission and distribution grids for electricity supply. As shown in Fig. 7, different power generators such as wind power, hydropower or, for instance, small to medium combined heat and power plants can be interconnected to form a "smart grid". For the inclusion of these lower powers in the range up to 2000 MW, IGBT are ideally used. The IGBT technology is currently being further developed in the direction of higher power classes to 4000 MW, which will put further pressure on the thyristor market.

The best-known project in this sector is "Desertec", with the operators wanting to use the "Asia Super Grid" for the transmission and distribution of renewable energy via high-voltage direct current transmission. Owing to the collapse of the solar market and Siemens' exit from the Desertec programme, the realization of this project has been shifted into the distant future.

The urgently necessary grid development in Germany with regard to energy distribution and flexibilization make high-voltage direct current transmission increasingly interesting even for quite short distances of less than 800 km within Germany and can be realized with technology "Made in Germany".

LAPP Insulators Alumina GmbH has adapted to these changes on the market and for some time now has pursued the goal of implementing its core technologies such as ceramic-metal solder joints to approach new products and markets in measurement, vacuum and laser technology. Based on sales, the "New Products" division has been thriving with double-figure growth rates. 60 % of the turnover is generated with products that are no older than three years.

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[1] Welt am Sonntag, 13.5.2012: Im Gleichstrom, marsch! Source: www.amprion.com ("Forwards with direct current!" from the German Sunday newspaper "Welt am Sonntag" dated 13.5.2012)

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