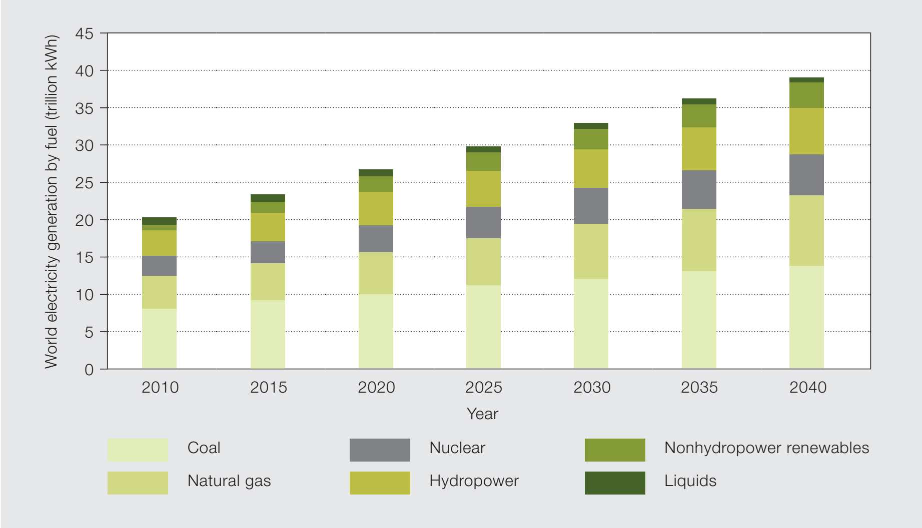
Corridors of power

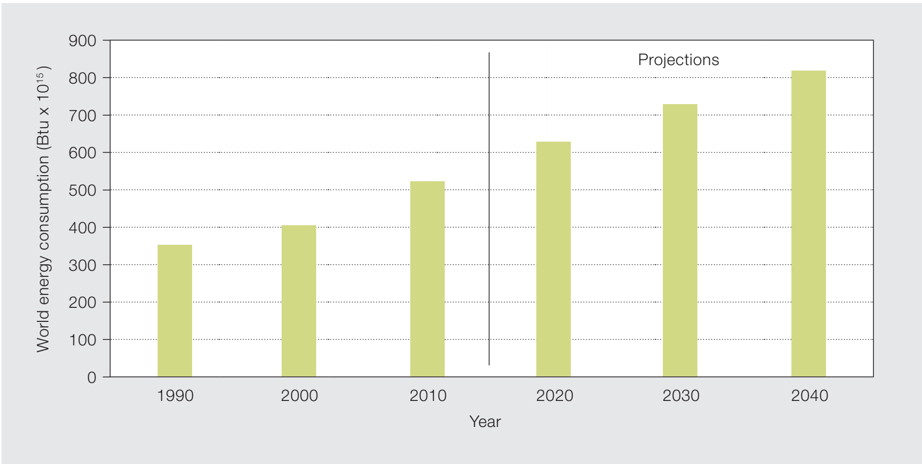
Next-generation UHVDC will send more power through existing transmission corridors

RAUL MONTANO, BJORN JACOBSON, DONG WU, LILIANA AREVALO – With a forecasted average annual growth rate of 9 percent [1], the world's voracious hunger for clean, reliable electrical power is set to continue for many years to come. Power utilities struggle to keep up with this surging demand. Indeed, in order to cope, they would need to increase their power generation base by an average of 11 percent each and every year for the foreseeable future [1]. A further complication arises in that much power generation capacity is situated at some distance from those places where it is consumed – a trend exacerbated by increasing urbanization and industrialization. To ensure future supply, power transportation corridors will have to increase their voltage- and current-carrying capabilities. Despite the maturity of ultrahigh-voltage direct current (UHVDC) technology, these new ratings represent major technological steps that will have to be taken in a very short time.

1 World energy forecast from EIA [1]



1a World electricity generation by fuel (2007-2035) in trillion kilowatt-hours



1b World market energy consumption (1990-2035) in quadrillion (10^{15}) Btu

World energy consumption and the power generation to match it are set to continue to rise for the foreseeable future [1] → 1. Unfortunately, the bulk of the energy resources needed to satisfy rising demand are not located near the load centers. For example, in China, large resources of untapped hydroelectric power – up to 500 GW – are available in the west of the country, in Sichuan, Xizang and Yunnan provinces. In addition, additional significant coal-fired generation capacity is planned in the Xinjiang area. The distance of these generation sources from the heavily industrialized regions along the coast in eastern China (Beijing, Shanghai) and southern (Guangzhou) China is between 1,000 and 3,000 km.

All over the world, diverse factors make the construction of new transmission lines ever more complex: public resistance, narrow transmission corridors, limited availability of rights of way, requirements to minimize routes through forests and other sensitive ecosystems, and the general protection of flora, fauna and people. If a transmission corridor is long, the chance of exposure to one or more of these factors is increased.

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Often, the best solution is to increase the power-carrying capacity of existing routes.

China, for example, is investigating the possibility of using a voltage rating of 1,100 kV for power transmissions of 10 to 13 GW per line for distances over 2,000 km in order to achieve as much power throughput per line as possible. For shorter distances, the utility in China has been considering an increase of the rated current of 800 kV DC systems. Despite the maturity of HVDC technology, these new ratings – of voltage or current – represent major technological steps that will have to be taken in a very short time.

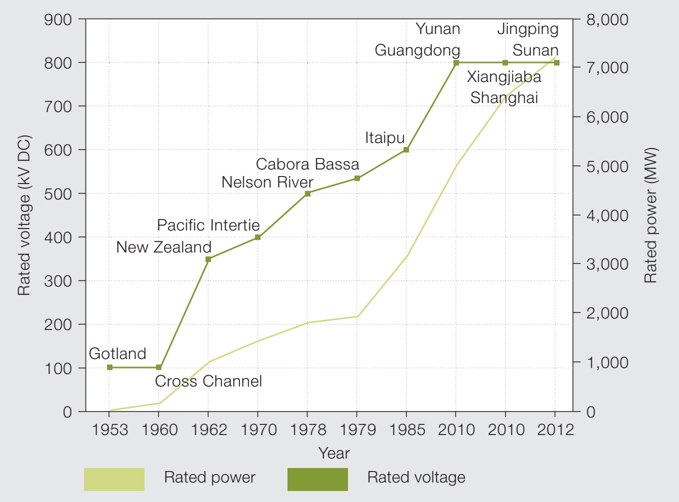
Technical-economical solution

In recent years, 800 kV DC transmission systems, capable of transmitting more than 7 GW over 1,400 km, have been in operation → 2. However, when the transmitted power is increased above 10 GW, 800 kV systems become much less economic because it is not possible to transmit these power levels over a single UHVDC transmission line – two lines are needed.

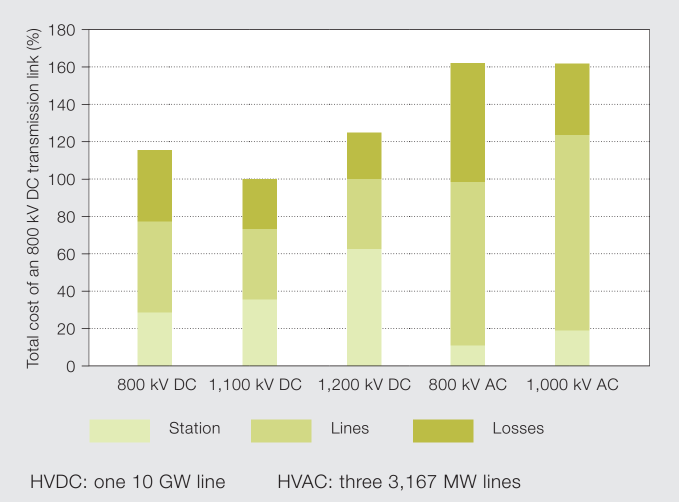
Title picture

Rising demand and the difficulty of building new HVDC transmission lines means new technology has to be developed to allow existing lines to carry more electrical power from distant generators to centers of consumption. Shown is the valve hall in the Xiangjiaba-Shanghai Fengxian UHVDC station.

2 HVDC systems evolution



3 Cost comparison of various options in percentage of the total cost of an 800 kV DC transmission link



There is no question that using higher voltages reduces losses and allows target energy costs to be achieved → 3. However, for power lines to be able to cope with the higher-voltage demands that will soon be put upon them, new system components, especially thyristor valves, will have to be developed.

Challenges

ABB has worked for many years in high-voltage power transmission and this experience is exploited in the development of products that meet the challenges faced when transporting power over very long distances at very high voltages. Several aspects become critical when designing UHVDC systems: availability and reliability, electromechanical design and equipment transport, and the type of DC yard.

Availability and reliability

UHVDC systems designed to transmit power levels above 10 GW need to cope with higher requirements on availability and reliability. After all, one single-pole trip will disconnect energy equivalent to half of the installed capacity of a very large hydroelectric power plant – eg, the 12 GW Itaipu plant in Brazil. This will also impose a high strength requirement on the AC systems at both ends of the UHVDC transmission. Also, thorough investigations are necessary to ensure that single, small events that occur in regions into which multiple UHVDC systems feed do not escalate into something more dramatic. This all means that reliability is a very important issue and represents a major design parameter.

Electromechanical design and equipment transport

Outdoor high-voltage insulators face many challenges, among which is the risk of flashover – atmospheric pollution, for example, can lead to excessive contamination of the insulator and thus to flashover if creepage length and general design is not adequate. Insulators designed for higher voltages have to be longer – necessitating a diameter increase to provide the required mechanical stability and this, in turn, decreases flashover performance. The battle to reconcile insulation, mechanical and electrical requirements can quickly spiral into a runaway situation if great care is not taken in the design phase [2].

The equipment subjected to the new, higher voltages will be larger, which brings further challenges. For example, converter transformers are assembled, tested and shipped to site. Shipment might be no longer possible with larger-sized transformers, so on-site manufacturing and the reliability issues this entails have been assessed.

Reliability throughout the entire range of products and components destined for use in these new, higher-voltage environments is of critical importance – electrode size, corona shielding, terminal forces, etc. all need to be properly designed and tested to guarantee a cost-effective solution with the reliability that the new generation of UHVDC systems requires → 4.

Indoor vs. outdoor DC yard

Today, both outdoor and indoor DC yards have been adopted by different 800 kV UHVDC projects. However, operational experience at this voltage level is still limited [2]. One reason for selecting an indoor solution is to minimize the footprint of the converter station → 5. For equipment inside this weather-protected building, the creepage distance needed and the mechanical strength required can be reduced. Switching impulse voltage will be the dimensioning parameter. Therefore, smooth electrodes with a larger diameter can be adopted to reduce the required air clearance [2].

The cost of the building makes the indoor approach more expensive than the outdoor. In addition, depending on the requirements on the ambient conditions inside the hall, auxiliary equipment, such as a humidity controller, may be required [2]. However, part of the building costs will be returned by the reduced cost of the apparatus itself and the costs saved by reducing outages will usually more than cover the rest. A reduced risk of failure is the major benefit of the indoor solution.

All over the world, diverse factors conspire to make the construction of new transmission lines ever more complex.

4 High-voltage test laboratory

5 Indoor DC yard

ABB technology development

In 2010, ABB started research into and development of the key components for the next generation of UHVDC transmission systems, ie, those exposed to the new rated voltage (1,100 kV DC). By means of advanced electromagnetic simulations, transient studies and high-voltage testing, ABB has developed prototypes for the converter valve, valve hall design, converter transformer, bypass switch, radio interference capacitor, surge arrester, transformer bushing and wall bushing. Also, conceptual designs for station layout and indoor DC yards have been completed.

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New UHVDC applications

The Chinese economy has exhibited an average annual growth rate of around 12 percent over the last 30 years. Improvement in affluence and economic growth is closely associated with increased energy requirements. To cope with the increasing electricity demands, and to keep the costs reasonable, China has pioneered the implementation of new high-voltage systems in both the AC and DC realms. It was the first country to commission and fully operate 800 kV DC transmission systems and more than 21,000 GW of transmission capacity is now installed at this rated voltage. Further economic growth is expected in the coming years – and with it further demand for high-voltage transmission systems.

After 2020, a further seven hydroelectric power projects, with a total rating of 110 GW, are planned in Xizang. The power from these will be transmitted to the eastern and southern provinces of China. To enable the bulk transmission from these and from other projects, even further development of UHVDC systems will be required – either at 1,100 kV DC or at existing voltage ratings with higher current-carrying capabilities. Presently, there is no immediate market interest for the new UHVDC transmission systems outside of China. However, this may change with the emergence of future hydroelectric and solar generation sources in Africa, India, the United States and South America that are far removed from the centers of consumption and that are needed to satisfy the world's apparently insatiable hunger for power.

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[1] EIA, International Energy Statistics database, available March 2014, http://www.eia.gov/forecasts/ieo/more_highlights.cfm

[2] D. Wu, et al., “Selection between indoor or outdoor DC yards,” article submitted to CIGRE 2014.