High-voltage DC transmission lines

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One of the challenges of renewable energy resources is that energy collection usually takes place far away from where humans need to consume the energy. For example, building a concentrated solar power (CSP) farm in North Africa to provide energy to Germany and other European nations, as has been recently contemplated [1], would require electricity transmission over thousands of miles. The energy loses and expense of long transmission reduces the economic attractiveness of such ideas.

The usual way that electricity is delivered to your house or business starts with a power plant within a few hundred miles of you. The energy of the power plant is converted to AC electricity at voltages of several kV. This voltage is stepped up to a much higher value for long-distance transmission to a distribution station much closer to your home. The transmission voltage may be as high as 1000 kV. The distribution station then steps down the voltage at various stages before it enters your home at the modest and safer values of 120 V.

It is desirable to keep the loss of energy due to long-distance transmission to a minimum. It is for that reason that the voltage is stepped up to such a high value in the transmission stage. The power delivered is the current multiplied by the voltage: $P_{gen} = IV$. However, the power lost is the current squared multiplied by the power line resistance: $P_{loss} = I^2 R_{line}$. To minimize power lost, one should minimize the current in the transmission line as much as possible. Given that P_{gen} is an input to the transmission system and is a fixed value, the only way to reduce the current is to increase the voltage. This is accomplished easily by voltage step-up transformers in alternating current circuits. With $I = P_{gen}/V$, one can then rewrite power loss in transmission as $P_{loss} = P_{gen}^2 R_{line}/V^2$, which more clearly shows how important it is to increase the voltage to as high a value as possible.

The voltage cannot be increased to arbitrary high values because additional loses due to corona discharges [2] start to become more important than normal line resistance losses. Corona discharges are due to the high electric field ionizing the material around the conductor, enabling discharge of energy to the surrounding medium. This loss effect, which can be reduced only at very high cost for high fields, is why a maximum of about 1000-2000 kV is designed for long-distance transmission lines.

Despite being at very high voltages and low current, the long-distance transmission lines across the United States still lose about 6 to 7 percent of energy. The line resistance scales with distance, and so lines twice as long as the typical long-distance transmission line would have nearly double the transmission loses. Furthermore, transmission with alternating current lines is costly because three conducting wires are needed for each circuit in the standard three-phase transmission approach. And finally, the size of the conducting wire is determined by requirements of handling peak voltage, whereas the power transmitted is proportional to the root-mean-square voltage of the alternating current, which is about 30% less.

This is where high-voltage DC transmission lines come in. They have several advantages when considering transmission over very long distances. For one, the conducting wire size is gauged to the maximum voltage, which is also the relevant voltage for power transmission. DC circuits only require two wires rather than ACs need of three wires. These two factors alone reduce the cost by more than a third for each mile of DC transmission line. Other advantages of DC transmission lines include the ability to connect between asynchronous AC regions (that is, out of phase grid connections), the ability to interface between two difference AC frequency grids (for example, 50 Hz vs. 60 Hz), and high power grid stability.

There is a rather significant disadvantage of DC transmission over AC transmission, which is the reason why the majority of transmission systems are AC. The "terminal costs" of DC transmission is significantly higher. Converting from power generator electricity to a DC transmission is costly. Voltage conversions are still important for the DC transmission, but AC circuits transformers are the only real way to go. Converting then from AC to DC is costly. Therefore, only when the distance is very long (thousands of miles) or the technical need is very great (asynchronous system stability issues) is high-voltage DC transmission cost effective and desirable.

The need for long-distance transmission of energy from renewable sources is one major reason for the increased attention to building large high-voltage DC transmission grids around the world.

Additional resources: Siemans corporation has developed web pages describing other aspects and projects of high-voltage DC transmission networks [3]. Technical descriptions and additional listing of projects can also be found in a summary review [4] written by employees of ABB and the World Bank.

References

[1] *MENA tipped for CSP Boom*, Renewable Energy World, 2011.

[2] *Corona Discharge*, Youtube video, 25 Oct 2007.

[3] Siemens Corp., *High Voltage DC Transmission Systems (HVDC)*, http://www.energy.siemens.com/hq/en/power-transmission/hvdc/ (accessed June 2011).

[4] R. Rudervall, J.P. Charpentier, R. Sharma, *High Voltage Direct Current (HVDC) Transmission Systems Technology Review Paper*, 2000.