EFFICIENT ELECTRICAL ENERGY TRANSMISSION AND DISTRIBUTION

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

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Growing populations and industrializing countries create huge needs for electrical energy. Unfortunately, electricity is not always used in the same place that it is produced, meaning long-distance transmission lines and distribution systems are necessary. But transmitting electricity over distance and via networks involves energy loss.

So, with growing demand comes the need to minimize this loss to achieve two main goals: reduce resource consumption while delivering more power to users. Reducing consumption can be done in at least two ways: deliver electrical energy more efficiently and change consumer habits.

Transmission and distribution of electrical energy require cables and power transformers, which create three types of energy loss:

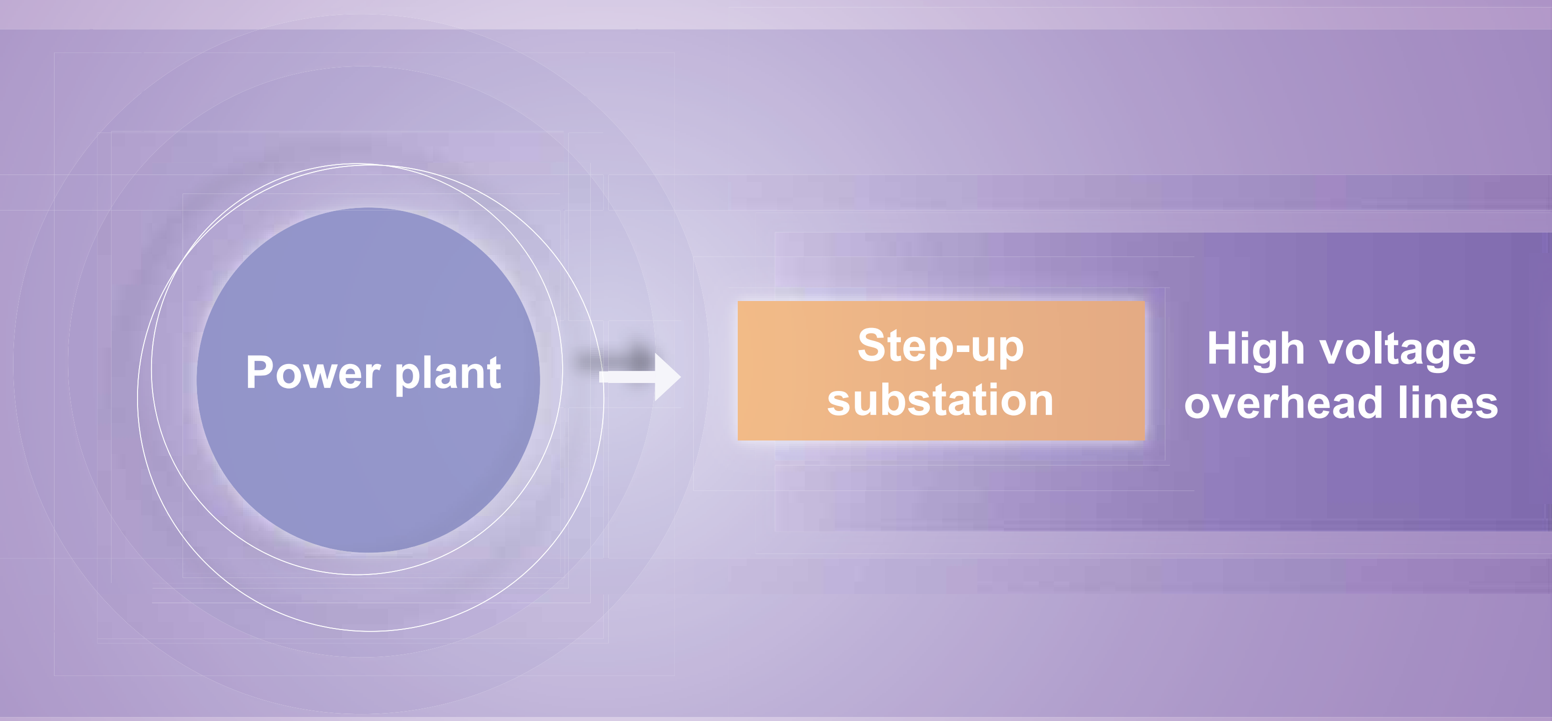
- the Joule effect, where energy is lost as heat in the conductor (a copper wire, for example);
- magnetic losses, where energy dissipates into a magnetic field;
- the dielectric effect, where energy is absorbed in the insulating material.

The Joule effect in transmission cables accounts for losses of about 2.5 % while the losses in transformers range between 1 % and 2 % (depending on the type and ratings of the transformer). So, saving just 1 % on the electrical energy produced by a power plant of 1 000 megawatts means transmitting 10 MW more to consumers, which is far from negligible: with the same energy we can supply 1 000 - 2 000 more homes.

Changing consumer habits involves awareness-raising programmes, often undertaken by governments or activist groups. Simple things, such as turning off lights in unoccupied rooms, or switching off the television at night (not just putting it into standby mode), or setting tasks such as laundry for non-peak hours are but a few examples among the myriad of possibilities.

On the energy production side, building more efficient transmission and distribution systems is another way to go about it. High efficiency transformers, superconducting transformers and high temperature superconductors are new technologies which promise much in terms of electrical energy efficiency and at the same time, new techniques are being studied. These include direct current and ultra high voltage transmission in both alternating current and direct current modes.

OUTLINE OF AN ELECTRICAL TRANSMISSION/DISTRIBUTION SYSTEM



Note: Only the main elements are on the schematic diagram since controlgear and switchgear do not create significant losses.

Step-down substation → Medium/Low voltage transformer → Users

ELECTRICAL LOSSES AND OVERALL EFFICIENCY

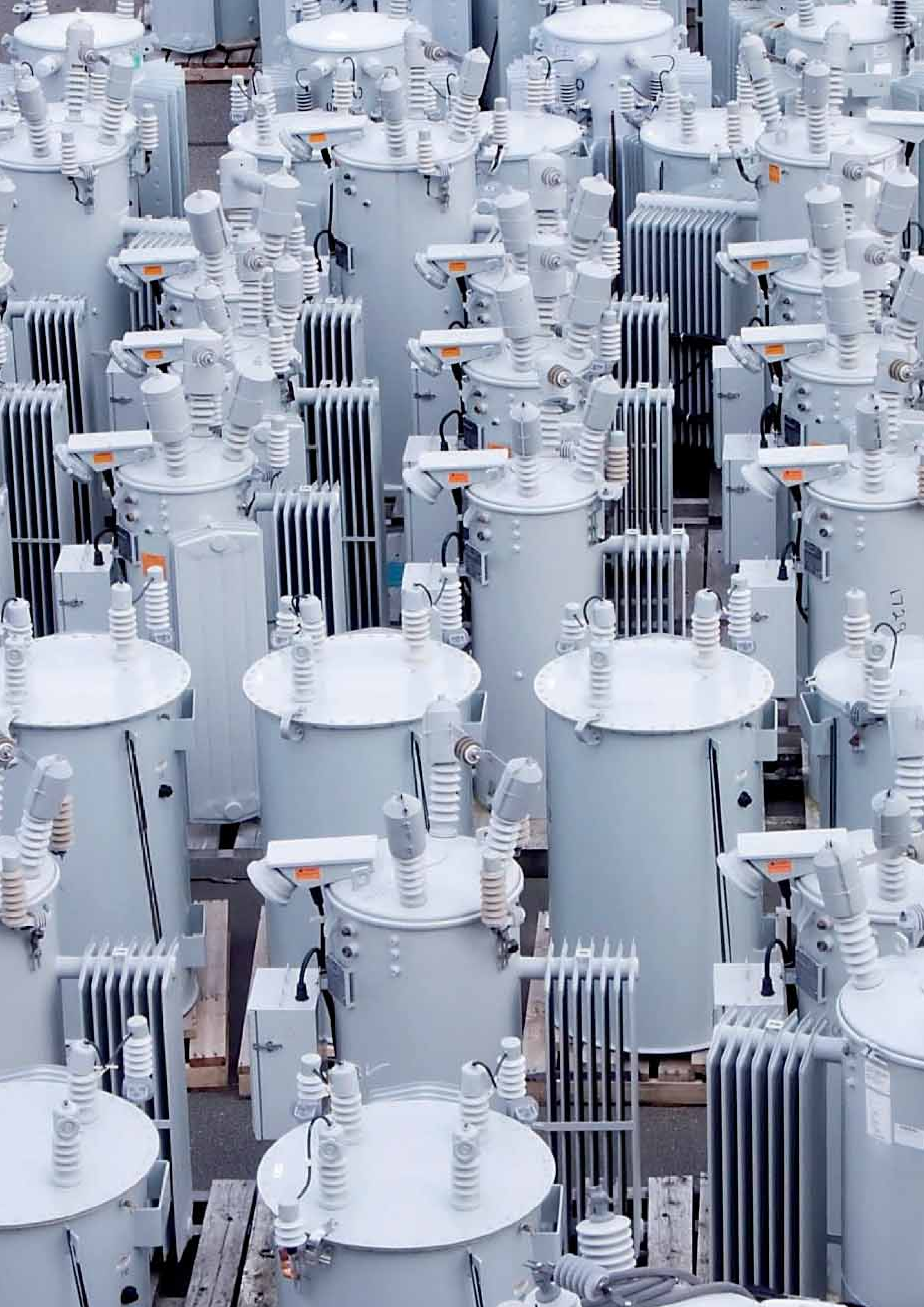
A power plant produces electrical energy in medium (20 000 V) or low (1 000 V) voltage which is then elevated to high voltage (up to 400 kV) by a step-up substation. Electrical power is then transmitted across long distances by high-tension power lines, and the higher the voltage, the more power can be transmitted. A step-down substation converts the high voltage back down to medium voltage and electrical power can then be transported by medium voltage lines to feed medium and low voltage transformers using overhead lines or underground cables. Most of the users are fed in low voltage, but bigger ones, such as factories, commercial buildings, hospitals and so forth, can be directly fed in medium voltage.

The length of cables between a power plant and a step-up substation is short since they are usually installed in the same place, so the energy losses there are quite low. The situation is not the same between the step-down substation and users where kilometres of medium and low voltage cables must be erected or buried to reach them.

Energy losses essentially come about in transformers and cables. The efficiency of large power transformers in step-up and step-down substations is quite high and may reach 99 %, but this depends mostly on the real power delivered, compared with the maximum power it could in principle deliver. A transformer operating at power close to the assigned value has the best efficiency. Medium and low voltage transformers are of different types and their efficiency may range between 90 % and 98 %, again depending on the power delivered.

For cables it's the contrary. Those carrying high current sustain more heating and therefore endure more energy loss because of the Joule effect, which is an increase in heat resulting from current flowing through a conductor. Essentially, electrical current passing through a conductor raises its temperature and this heat bleeds away as lost energy. This raises design considerations for overhead lines for long distance transmission cables and underground ones which deliver energy from the step-down substation to the user.

Electricity supply companies generally try to limit energy losses in overhead lines to about 2.5 %. So, between the power plant and the step-down substation the total losses range between 3 % and 5 %. Between the step-down substation and users the losses can be about the same or even greater. Therefore the overall losses between the power plant and users can easily be between 8 % and 15 %, which suggests that there is still some room to improve efficiency in the transmission/distribution system and hence reduce CO_2 emissions.



RELEVANT IEC TECHNICAL COMMITTEES

IEC Technical Committees work in a variety of associated fields, with the list including:

- TC 7 Overhead electrical conductors
- TC 8 System aspects for electrical energy supply
- TC 10 Fluids for electrotechnical applications
- TC 11 Overhead lines
- TC 13 Electrical energy measurement, tariff and load-control
- TC 14 Power transformers
- TC 17 Switchgear and controlgear
- TC 20 Electric cables
- SC 22F Power electronics for electrical transmission and distribution systems
- TC 42 High-voltage testing techniques
- TC 55 Winding wires
- TC 68 Magnetic alloys and steels
- TC 90 Superconductivity
- TC 112 Evaluation and qualification of electrical insulating materials and systems

In addition, TC 113, *Nanotechnology standardization for electrical and electronic products and systems*, involves the IEC in a very promising area that could see important breakthroughs across a broad range of technological fields, including insulation and conductivity.

IEC STANDARDS AVAILABLE

Although the following list is not exhaustive, it does give a good idea of the broad range of subjects the IEC addresses when dealing with efficiency for electricity transmission and distribution:

- **IEC 60076** series for liquid immersed or dry power transformers covering ratings, test methods, measuring methods for losses, loading guides, and so forth.
- **IEC 61378** series on converter transformers.
- **IEC 61803**, Determination of power losses in HV direct current converter stations.
- **IEC 60183**, Guide to the selection of high-voltage cables.
- **IEC 60287** series for calculating the current rating and losses for electric cables.
- **IEC 60885** series on electrical test methods for electric cables.
- **IEC 61788** series on superconductivity.
- **IEC 60028**, International standard of resistance for copper
- **IEC 61039**, General classification of insulating liquids
- **IEC 61181**, Mineral oil-filled electrical equipment - Application of dissolved gas analysis (DGA) to factory tests on electrical equipment
- **IEC 61620**, Insulating liquids - Determination of the dielectric dissipation factor by measurement of the conductance and capacitance - Test method
- **IEC 60826**, Design criteria of overhead transmission lines
- **IEC 62052** series on general requirements, tests and test conditions for electricity metering equipment (AC)

- **IEC 62056** series on electricity metering - data exchange for meter reading, tariff and load control
- **IEC 62271** series on high-voltage switchgear and controlgear
- **IEC 60060** series on high-voltage test techniques
- **IEC 60317** series on specifications for particular types of winding wires
- **IEC 60404** series on magnetic materials
- **IEC 60505**, Evaluation and qualification of electrical insulation systems
- **IEC 60243** series on test methods for electrical strength of insulating materials

TECHNOLOGIES WITH POTENTIAL

High efficiency transformers, superconducting transformers and high temperature superconductors are technologies that promise much in terms of electrical energy efficiency.

High efficiency transformers

According to the Leonardo ENERGY website, which is the global community for sustainable energy professionals: “The worldwide electricity savings’ potential of switching to high efficiency transformers is estimated to be 200 TWh. This savings potential is not only technically advantageous, but also brings economic and environmental benefits. Taking the full life cycle cost into account, selecting high efficiency transformers is often an economically sound investment decision despite their higher purchase price.”

High efficiency transformers have been around for decades. But because their prices are greater than for ordinary transformers, buyers should estimate the energy savings which can be made during the life cycle of a transformer and then choose the most appropriate one. These transformers differ from ordinary ones in that they use high quality magnetic material and selected insulating substances and are designed in such a way that they can be cooled down better.

Regulators may also require using certain kinds of transformers within the context of the Kyoto Protocol.

Superconductivity

Most conductors have some degree of resistance which prevents electricity from flowing effortlessly. Superconductors are materials that have no resistance to the flow of electricity and mostly this occurs at extremely cold temperatures. The first occurrence, in 1911, was in a material which became superconducting at 4 degrees Kelvin (-269° Celsius / -452° Fahrenheit). By the 1950s with the discovery of new materials this had risen to 17.5° K and in the 1980s to 92° K, which is warmer than

Photo courtesy of Sumitomo Electric

liquid nitrogen – a commonly available coolant. Today, superconductivity is happening at 138° K, but that's still -135° C (or -211° F). Despite the apparent coldness, this is known as high temperature superconducting, or HTS, and it holds a lot of potential for being energy efficient in the future.

Superconducting transformers

When a transformer is under a loaded condition, Joule heating of the copper coil adds considerably to the amount of lost energy. Although today's utility power transformers lose less than 1 % of their total rating in wasted energy, any energy saved within this 1 % represents tremendous potential savings over the expected lifetime of the transformer as they can be in service for decades.

We are all used to seeing copper and aluminium electrical wires and cables, which conduct electricity at ambient temperatures but lose energy due to the Joule effect. With superconductors, losses due to the Joule effect become essentially zero, thereby creating the potential for dramatic reduction in overall losses. Even with the added cost of making them cold enough for superconducting, transformers in the 10 MW and higher range are projected to be substantially more efficient and less expensive than their conventional counterparts.

High temperature superconducting cables

Superconducting cables offer the advantage of lower loss, lighter weight, and more compact dimensions, as compared to conventional cables. In addition to better energy efficiency of the utility grid, this can lead to easier and faster installation of the cable system, fewer linking parts, and reduced use of land. The high performance of superconducting materials leads to reduced materials use and lighter and more compact cable technology. In this way, energy and cost are saved in the whole chain of manufacturing, transport, installation, use and end-of-life disposal.

In the shorter term, these HTS cables offer energy efficiency, cheaper installation, and lower system cost. The long-term perspectives include low-loss backbone structures that transmit electric power over long distances. The driving factors for such backbone structures are:

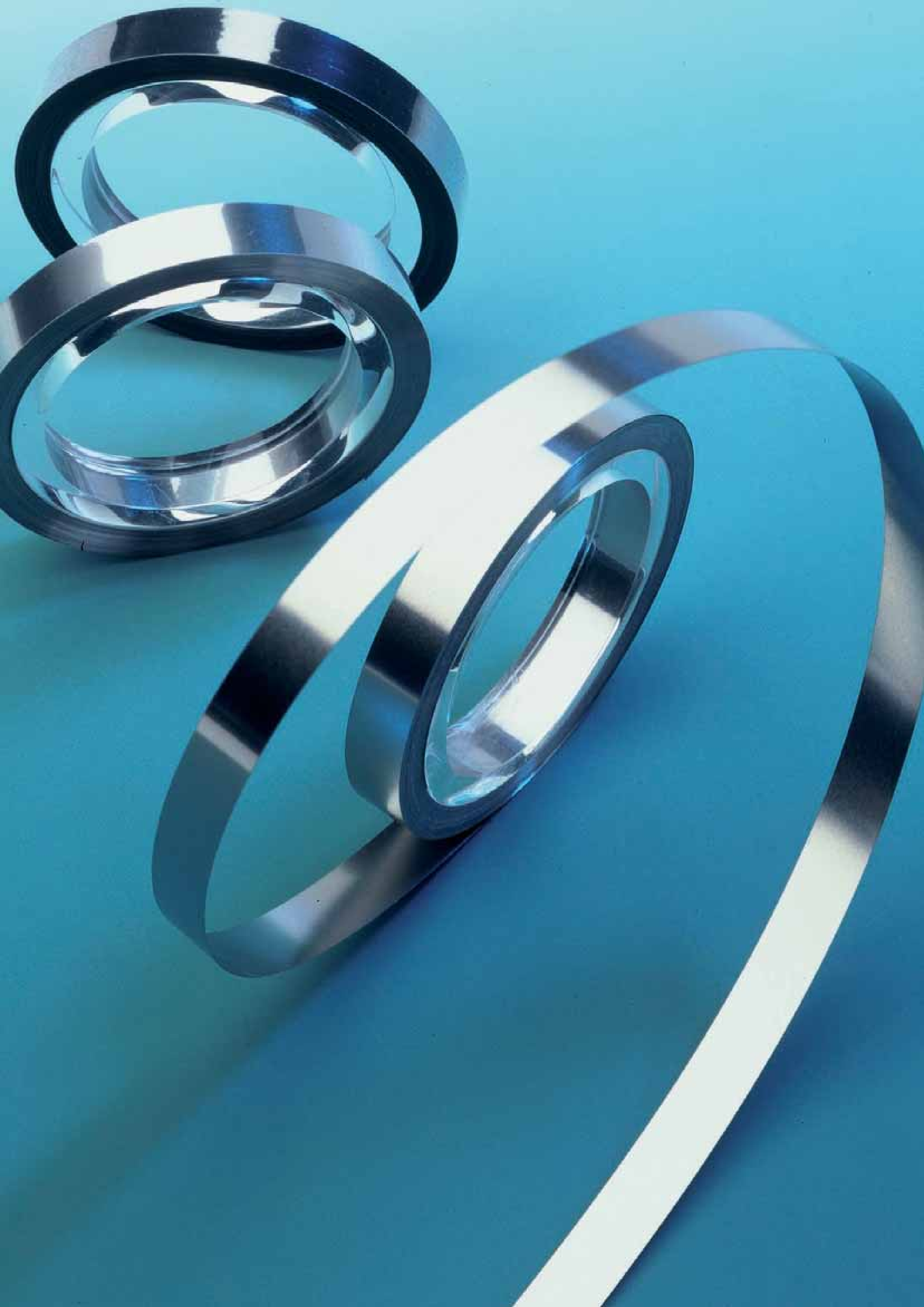
- uninhibited exchange of electricity in interconnected networks;
- solar energy potential in North Africa;
- green energy (hydroelectric and wind) in northern Europe.

HTS cable backbones, which do not yet exist, would be designed as DC systems with power ratings in multiples of gigawatts. They can be created as "virtual backbones" joining and reinforcing existing networks, or as actual lines traversing continents.

HTS backbones will be an alternative or complement to gas and oil pipelines, oil tankers and overland transport of hydrogen or other energy types. The determining factors for them, apart from cost, are political stability within the connected regions, ownership and tariff structures.

The IEC committees where these technologies are being considered are TC 14, *Power transformers*, TC 20, *Electric cables*, and TC 90, *Superconductivity*.

Other transmission techniques are also being studied, such as direct current and ultra high voltage in both alternating current and direct current modes.



CONCLUSION

The IEC has been developing standards that deal with electrical efficiency since its creation in 1906. As an example, at a meeting held in Paris in 1932, IEC Advisory Committee No. 2 (as the TCs were then known), which at that time covered the entire field of electrical machinery, decided to set up a permanent subcommittee to consider the issue of “efficiency and losses”. Technical Committee 2, Rotating machinery, and TC 14, Power transformers, today continue that work by delivering the highest quality International Standards involving the best means of producing and providing electrical energy efficiently.

Overall, IEC work addresses a vast array of technologies. Standardizing the transmission and distribution of electricity is one of the fields where the IEC can really make a difference to the future of the world in its quest for greater energy efficiency.

THE IEC

The IEC, headquartered in Geneva, Switzerland, is the world's leading organization that prepares and publishes International Standards for all electrical, electronic and related technologies – collectively known as "electrotechnology". IEC standards cover a vast range of technologies from power generation, transmission and distribution to home appliances and office equipment, semiconductors, fibre optics, batteries, flat panel displays and solar energy, to mention just a few. Wherever you find electricity and electronics, you find the IEC supporting safety and performance, the environment, electrical energy efficiency and renewable energies. The IEC also administers international conformity assessment schemes in the areas of electrical equipment testing and certification (IECEE), quality of electronic components, materials and processes (IECQ) and certification of electrical equipment operated in explosive atmospheres (IECEx).

The IEC has served the world's electrical industry since 1906, developing International Standards to promote quality, safety, performance, reproducibility and environmental compatibility of materials, products and systems.

The IEC family, which now comprises more than 140 countries, includes all the world's major trading nations. This membership collectively represents about 85 % of the world's population and 95 % of the world's electrical generating capacity.

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