The future of long distance high power electric transmission: superconducting D.C. lines.

Production facilities of electric power from renewable energies are to be situated in suitably chosen areas of substantial size. These new power plants, of which a considerable number will need to be built in the next decades, have to be located where the conditions (solar radiation, geothermal, wind) are available and this will be generally far away from cities and densely populated areas.

The generated energy will have to be transported over long distances, up to several thousand of kilometres, in analogy with the long pipelines spanning over entire continents for the distribution of gas and oil that are used today.

A worldwide deployment of these new forms of electricity cannot occur without renewed investments in the transmission infrastructures. In order to extend the transport distance beyond the standard three-phase Alternating Current lines (AC), which are presently limited to a few hundred kilometres, the present technology is based on the use of ultra high voltages, up to 1 million Volt Direct Current (DC) rather than AC, with an appropriate conversion of the electric supply.

In conventional transmission lines, the exploitation of higher voltages is an inevitable necessity. The main reason of this advantage is that the electricity transmission capacity of a line (i.e. the fractional power loss) is roughly proportional to the square of the voltage. For instance a 765-kV line can carry as much electricity as five 345-kV lines, thus correspondingly increasing the distance over which a given electricity can be transported with acceptable electricity losses. Higher-voltage transmission is a proven technology with a number of economic, environmental and efficiency benefits over the lower-voltage lines that are generally used today.

Many thousand kilometres of 800-kV transmission lines with individual distances of up to 3000 km are currently operational or under development in the world. China, Brazil, India and other countries are planning to build tens of 800-kV DC lines over the next decade. The chosen value for the voltage represents a fundamental limit, since the phenomena of spontaneous corona discharge is a major problem for much higher voltages.

The electrical transmission towers are tall, massive as well as unsightly. In the more populated transport areas, especially in developed countries, substantial costs have to be added for the acquisition of the right of way. Environmental objections may be severe and difficult - or even impossible - to overcome. The alternative of high-power, high-

voltage buried cables has the disadvantage of considerably higher costs, about one order of magnitude above the ones of overhead lines. But the most important factor is that for long distances the ohmic losses in conventional 3000-km electricity transport systems are about 10 percent of the transmitted energy, amounting in practice to many Gigawatts dissipated as ohmic power.
Calculations have shown, for instance, that the surface occupied by the above-ground distribution system of the planned solar energy facility based in North Africa to the European Continent and other distant African regions (DESERTEC) would occupy a surface larger than the solar collecting surface of the entire power collecting system.
An interesting development, which is the purpose of the present Workshop, is the substitution of standard HVDC lines with DC superconducting lines. Superconductors, because of the absence of ohmic resistance, have the property of exactly zero electric losses. The dominant losses are then only the static thermal losses through the cryostat. This is not a new idea: the absolutely perfect conductivity (zero resistivity) was discovered by Kamerlingh-Onnes in 1911. Incidentally, in 1915 he had proposed a first persistent current loop to be built between Paris and London.
It was in 1967 that Richard Garwin and Juri Matisoo of the IBM Research Division showed how one could ensure transmission of massive amounts of electric power over very long distances with the help of liquid He at 4.2 K, in conditions which only superconductivity could permit. Their paper has laid the foundations of the present day options for electric power over very long distances.

Before the mid-eighties, practical applications and future expectations of technical superconductors were almost entirely based either on pure Niobium, or its alloys, NbTi and Nb3Sn. These materials excel for their performance at temperatures around the one of liquid Helium (4.2 K), but fail to be used at temperatures that would allow cheaper and/or more convenient cooling techniques. In spite of that, NbTi and Nb3Sn, in form of wires, have nowadays become a commodity in the superconductivity market, as they are widely used in a few practical applications that currently constitute a world market value exceeding 3 B$/year in 2005.

In 1986, the biggest breakthrough in the Superconductivity world since 1911 appeared with the discovery of Cuprate High Temperature Superconductors (HTS), by Nobel Laureates Bednorz and Müller. Because of their critical temperature, well above that of the cheap and readily available liquid nitrogen coolant, these new materials have changed forever the impact that superconductivity will have in the future. The discovery of Cuprate HTS has not halted the research on new superconductors, and in January 2001, the community has been again astonished about the sudden announcement of Akimitsu et al., reporting superconductivity at 40 K in a very simple, and already well known binary compound, MgB2, or Magnesium Diboride. This surprisingly simple compound is quite unique for its properties, as it lies in between traditional Nb-alloy superconductors and the HTS from different viewpoints. This material can be readily manufactured into wires, and is based on precursors that are very abundant in nature and cheaper than any other competing superconductor.

Despite its recent discovery, MgB2 has already shown its full potential as a superconductor that can represent a logical step of evolution in the upcoming years for most of the applications which are now counting on Nb-alloy superconductors and while waiting for the Cuprate HTS to reach their targets.

The present Brainstorming Workshop has been organized by the Earth, Energy and Environment (E3) Section of the Institute for Advanced Sustainability Studies (IASS) in Potsdam. It will concentrate on the survey of the present status of the long-distance energy transport through superconducting electric lines, aimed at analyzing in a critical way the most advanced R&D activities worldwide and defining the appropriate "niches" in which IASS may develop innovative projects and future opportunities. The participation of the best known experts from Academia, Research Institutions and Industry, will provide an excellent opportunity to define very precisely the possibilities and the limits for the IASS activities in this specific area of research. The Workshop will be a platform for the world's leading researchers working on superconductivity to present and discuss their most recent results on the emergent industrial experience in the construction of superconducting cables for electric power transport.

Following this extensive analysis, the establishment of a collaboration between IASS and a number of external Research Institutions and partners from Industry is envisaged, with a view to produce comparative and definitive assessments on the subject in the form of a detailed and comprehensive Research Report. This Research Report will be widely advertised to the scientific community and the media, later eventually leading to concrete proposals for further actions, which may be then progressively taken over by a wider number of Research Institutions and Industry.

In conclusion: Unlike Oil and Natural Gas, Renewable Energy sources imply the use of electric energy over thermal energy generation. On the other hand optimal source locations are very selective, requiring the availability of large, dedicated areas, far from the more densely populated regions. Zero ohmic resistance offered by Superconductivity may become therefore an absolutely unavoidable future asset for a wide number of different applications and, in particular, for superconducting lines at distances and powers unavailable by any other method.

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