ELECTRIC POWER TRANSMISSION

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Summary

Overhead lines rated at 145-345 kV AC are and will remain in the foreseeable future the core of most electric power industry projects, particularly in developing countries. Because such lines account for a major part of investment and materiel earmarked for electric power grids they will be the focus of further advancement of research and development in the power transmission area, with emphasis on compaction and supercompaction of overhead lines, reduction of transmission losses, minimization of environmental impact and the like.

Over a century of power transmission evolution, research, engineering, construction, and operation of alternating current (AC) overhead power transmission lines of ever growing rated voltages and development of substation apparatus for such lines made it possible to raise the transmission voltage from 10 kV to 1200 kV and the power transmission capacity from 180 kW to 5 GW, i. e. by four orders of magnitude. At present commercial AC transmission lines and networks of medium, high, extra-high

and ultra-high voltage are capable of meeting almost all challenges of the electric power industry, power transmission over long and super-long distances, and interconnection of power systems.

Alternating current cable lines rated at 10 kV to 245 kV are used for supplying municipal, industrial and other distribution networks, while those rated from 245 kV up to 550 kV act as bulk transmission links bringing electric power to major metropolitan and urban centers. EHV AC cables, rated as high as 800 kV, are applied for transmission of electric power to short distances, for instance, at the outputs of large hydro-electric, nuclear and thermal power plants, water crossings, overhead/underground interfaces and the like.

Electric power transmission at ultra high voltage (UHV), i. e. at line voltages of 1000 kV AC and above, can be practical for unique projects only, when an HVAC line has to carry power blocks in excess of 4 GW from a remote cluster of hydro- or thermal power generation stations. Ultrahigh voltage can be also necessary for interconnection of very large power pools.

High voltage direct current (HVDC) power transmission technology can be effectively used in the following areas: 1000 to 2000-2500 km long- and superlong-distance overhead lines of a 4 to 6 GW total transfer capacity (2 to 3 GW per circuit), with or without power tapping at intermediate points; long-distance submarine lines of a 1 to 1.5 GW transfer capacity per cable; hybrid overhead/submarine transmission lines, with a major share of underwater cables; and back-to-backs and/or overhead, submarine, and hybrid lines for asynchronous interconnection of power systems which operate at different rated frequencies (50 and 60 Hz) or use different frequency control requirements.

Interest in cryogenic power transmission stems stems from superconductivity, i. e. property of some pure metals and metallic alloys of having negligible resistance to the flow of an electric current at very low temperatures. Cryogenic power cables are cooled by liquid gases with the operating temperatures below 120 K. A cryogenic power transmission line includes three main components: a cryogenic cable, a refrigeration system, and current leads at its ends. Depending on the operating temperature and material used for conductors, such lines may be subdivided into hyperconducting and superconducting ones. In the 1980s, practical interest in hyperconducting versions was mainly associated with a combination of high-purity aluminum conductors and liquid nitrogen as a coolant, although even this combination did not offer significant economic advantages as compared to conventional cables. First commercial cryogenic power transmission lines were commissioned early in the 21st century. They were made possible by discovery in 1986 of high temperature superconductors made of ceramic materials that exhibit superconducting properties at temperatures about 80 K and therefore requiring less expensive cooling systems than those needed for low temperature superconductors (<10 K).

Environmental considerations involved in planning and operation of EHV and UHV overhead lines and substations cover the following environmental impacts: electromagnetic interference, which impairs wanted electromagnetic signals and thus normal functioning of such facilities as radios, TVs and communication lines; induced currents and voltages near AC overhead lines and ion currents from DC overhead line conductors, which under certain conditions can become human health hazards; forest conservancy issues in the selection of overhead line routes, and others.

1. Introduction

Overhead transmission lines rated at 145-345 kV AC will remain in the foreseeable future the core of most electric power industry projects. Numerous EHV and UHV AC overhead lines will be required to feed major switchyards and to interconnect large power systems for synchronous parallel operation.

Sulfur hexafluoride (SF_6) insulated equipment will be widely used at substations of AC lines; use will be of both all-SF_6 indoor switchgear in urban areas and for particularly compact facilities and of hybrid installations, with a widely varying share of SF_6-insulated equipment - from circuit breakers alone to those with bushings and arresters only situated outdoors.

HVDC facilities, including overhead and submarine lines and back-to-backs, will find a wider application both in traditional and new areas. Additional investment in power transmission lines of all kinds will be necessary to minimize their environmental impact. Technological progress of electric power transmission, first to short and medium distances and further to long and extra-long ones, is intrinsically related to the demand for electrical energy and to the state of the art of electrical engineering, particularly to research, development and manufacture of high voltage apparatus, cables, insulation etc.

As shown by analysis of electric power industry statistics published by the United Nations Organization and many countries of the world, a megawatt of installed power at an electric power plant calls for construction of an average of 0.5 to 2 kilometers of electric lines, which are mostly of the overhead distribution class, rated at 11 to 60 kV, the investment in electric networks accounting for at least 30 to 40 % of the total investment in power systems.

Overhead networks rated at 20 to 550 kV AC, which make up over 90% of all overhead and underground (submarine) alternating and direct current transmission lines at present, will remain the core of power systems of the world for many decades. A bulk of investment in a new overhead power transmission line is distributed among its towers, conductors and right-of-way, or the land occupied by the line. The total investment in an overhead transmission line and the shares of the three major components depend substantially on the line's rated voltage.

A high cost of transmission lines necessitates close attention, still at the planning stage, to minimizing expenditures on steel and reinforced concrete for towers, aluminum for conductors and to cutting the width of the right-of-way. Power cables with extruded solid dielectric insulation that became widely used in recent decades feature a simple design and ease of operation and keep replacing their costlier predecessors in 10-245 kV distribution grids and in 245-550 kV feeder networks. The most sensitive and important power cables, including those used for submarine, long-distance HVDC, and bulk transmission lines, are designed and manufactured with oil-impregnated paper and polypropylene film insulation. Wide application was found by long-distance HVDC transmission lines laid under water for crossing seas, lakes, bays and large rivers. Much effort is given to increasing the current capacity of power cables, which is governed by the maximum permissible temperature of the cable insulation. Principal approaches to solving the problem are to increase the cross-section area of the copper conductors, up to 3000 mm^2, to lower dielectric losses in the insulation of AC cables, and to improve the internal and external cooling of the cable.

Substation equipment for such lines was developed and implemented using two different approaches, viz. the philosophy of outdoor switchgear in Russia and that of hybrid SF_6–insulated switchgear in Japan. Both sets of major substation apparatus, however, call for further operational development and, very much like the case was with 735–800 kV equipment earlier, for various improvements. Still, principal engineering challenges were successfully met as regards UHV lines and substations, including profound limitation of overvoltages, single-phase reclosing, and environmental impact.

The findings of comprehensive research and development efforts that were carried out on UHV test lines in USA, Italy and Russia and on a commercial prototype 1150 kV transmission line in Russia confirmed early scientific forecasts and design approaches. Most probably, during the first decade of the twenty first century 1100–1200 kV AC power transmission lines will find further practical application in major power industry projects, for instance in Japan, as well as in large countries like China, provided the UHV AC transmission line and the receiving power system are made totally compatible.

Overhead HVDC transmission lines can be bipolar, with two pole conductors per tower, or quadrupolar, or double-circuit, each tower carrying four poles. Their cost is generally 15 to 20% lower than that of overhead HVAC lines having the same number of circuits and identical transmission capacity. HVDC submarine cables can be manufactured in 50 km lengths and coupled together, making it possible to lay transmission lines under water across straits and along sea coasts to unlimited distances. HVDC converter substations and back-to-backs comprise an outdoor part, with mostly HVAC facilities, and an indoor part housing thyristor converter bridges.

Elimination of the electrical resistance under direct current conditions and relatively low 50/60 Hz losses in self fields result in far lower transmission losses with superconducting cables than with conventional cables. They also offer advantages in terms of their environmental friendliness. In contrast to the overhead power transmission lines they have no effect on the landscape, require only small cable trenches, involve no radial heat flow, and produce no external magnetic or electric fields. Due to their special properties superconducting 3-phase alternating current cables are suitable for power transmission over short and medium distances (around 50 km) in heavily populated areas (high power density, relatively narrow cable routes, environmentally acceptable) and for long distances (matching of load and cable impedance). Discovery of high-temperature superconductivity offers good prospects for practical application of cryogenic cables due to increased operating temperatures (77 K and higher) and possibility of application of liquid nitrogen, being simultaneously a cooling and an insulating liquid.

Heavy electric fields near 400 kV–1200 kV AC overhead lines and at their substations can be a source of electric discomfort. Electric field-induced currents and voltages are a real hazard at a contact between a person and a large rubber-tired vehicle, such as a trailer, harvester and the like, parked close to an HVAC overhead line rated at 550 kV and above. In order to avoid health hazards and fatal accidents, such vehicles must be grounded or have tires made of conductive rubber. Radio and television interference and audible noise that stem from the local corona on overhead line conductors can be mitigated through careful selection of bundle conductor designs

HVDC overhead lines rated at ±(400–800) kV feature a concentration of positive ions which can be 100 to 1000 times as high as the normal level. Because continuous breathing of such ions is a health hazard, the ion concentration must be lowered through optimization of pole conductors and increase of the minimum clearance between the poles and the ground.

Forest conservancy issues must be considered when planning routes and designs of overhead lines in forested areas, with the view to minimize cutting for the right-of-way. Mitigation of the environmental impact of power transmission facilities calls for extra investment in their construction and operation.

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Biographical Sketches

Nikolay N. Tikhodeev was born in Russia in 1927. He received the Electrical Engineer, the Candidate of Technical Sciences and the Doctor of Technical Sciences degrees in 1952, 1955, and 1966, respectively, from the Leningrad Polytechnic Institute; at present he lectures there as Professor. In 1979 he was elected a Corresponding Member of the USSR (now Russian) Academy of Sciences where he became an Academician (Full Member) in 1992. Within CIGRE he is a member of SC33 "Overvoltages and Insulation Coordination" and now a Distinguished CIGRE Member. He became an IEEE Senior Member in 1990. In 1980 he was awarded the National Prize for his contribution to development of 750 kV AC power transmission lines and in 1997, the Russian Academy of Sciences Yablochkov Prize for a series of papers published in 1991-1997. Since 1955 Prof. Tikhodeev has been with High Voltage Technology Department of HVDC Power Transmission Research Institute in St. Petersburg. He directed the Department from 1958 to 1996; since 1997 he is Scientific Director of the Department. He does research in many fields of high voltage engineering, including theory of bundle conductors with large numbers of subconductors; large-scale studies of air gaps and line insulation in the megavolt range of voltages and overvoltages; development of statistical methods of calculation and coordination of insulation; experimental and theoretical studies of various facilities for reducing environmental effects of overhead lines, etc., but the area of his major interest is EHV and UHV AC and DC power transmission. Prof. Tikhodeev was directly involved in research efforts relating to development and implementation of 525, 750 and 1200 kV AC power transmission lines, as well as to planning of 1500 kV DC transmission in the USSR. He authored eight books and some 240 technical papers. Professor N. N. Tikhodeev is the author of Articles 1-6 and 8 of the *Electric Power Transmission* Topic of EOLSS.

Lidia I. Chubraeva was born in Russia. She received the Electromechanical Engineer, the Candidate of Technical Sciences and the Doctor of Technical Sciences degrees in 1970, 1980, and 1992, respectively, from the Leningrad Institute of Aircraft Instrumentation (now Academy of Aerospace Equipment); at present she lectures there as Professor.

From 1970 to 1996 she was with the All-Russian Research Institute of Electrical Machinery. Since 1996 she has been Deputy Director of the Division for Basic Research in Electric Power Engineering of the Russian Academy of Sciences (RAS). At the same time she holds position of Manager of Department for Non-Conventional Electrical Machines and Devices at the Academy of Aerospace Equipment.

In 1997 she was elected a Corresponding Member of RAS, and in 1998, a Full Member of the Academy of Electromechanical Sciences of the Russian Federation.

Research and development activities of Prof. Chubraeva are related to advanced fields of electrical machine engineering, including non-conventional machines based on application of superconductive materials, such as high-purity metals, rare earth magnets and the like, at cryogenic temperatures.

Professor L. I. Chubraeva is the author of Article 7 ‘*Cryogenic Power Transmission*’ and cryogenic power transmission sections of Article 1 of the *Electric Power Transmission* Topic of EOLSS.