COMPONENTS AND SUBSTATIONS FOR ELECTRICAL TRANSMISSION AND DISTRIBUTION SYSTEMS

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Summary

Substations play an important role in power transmission systems. They transform the electric power parameters: from low generated voltages into higher transmission voltages and to voltages suitable to final energy users.

For this purpose power transformers form a major component of power substation elements. Another important element is the system of apparatus for energy switching on and off – switchgear and interrupters for power system integration or if necessary for isolation. The last situation becomes necessary in the case of different faults in power transmission systems – short circuits (mostly to the earth), transmission line damages due to hurricanes or other similar causes. In the case of power system faults switchgear operate on the action of relay systems. Nowadays relay systems are very much sophisticated and mostly digital.

In many cases it is necessary to provide the reactive power exchange. For this purpose batteries of capacitors or thyristor regulation system are used. They are also included

into substation equipment systems. In the fault situations the electric apparatus and systems become dangerous to humans. To decrease the danger the electric installation grounding is used. It must be obvious for all types of electrical installations in which open parts of the elements at dangerous voltages may be exposed.

1. Capacitors and their Applications

Capacitors are widely used in electrical energy systems and appliances. Batteries of capacitors with series and shunt connections contribute to reactive power in a.c. systems. In a.c. the current through the capacitor leads the voltage nearly by 90°. The capacitor having very small active losses contributes to reactive power that is often required to counter reactive power due to inductive devices. Thus capacitors are used to improve the power factor of the energy users by means of full or partial compensation of their their inductive reactive power thereby decreasing power losses in generators, transformers, lines and stabilize the voltage at the users' end.

In order to increase the stability of the parallel operation of a.c. systems and to improve their regimes large capacitor batteries are used in series to compensate for the effect of inductive reactance in the system. In the recent decades much attention is paid to thyristor regulated capacitor batteries which offer some advantages for power systems – optimum efficiency, reduction in short circuit currents, and flexibility of operation. The installations for series compensation are also used in electrified railways, in metal industry where the supply systems operates at strongly varying loads, and for starting of large rating a.c. motors. In a power system capacitor batteries are also used for shunt compensation of the reactive power in order to improve the operating modes of the power system by providing the proper voltages in the power system elements.

The capacitor property - reactance $\mathrm{x_c} = 1/2\pi fC$ in inverse proportion to frequency f is widely exploited to create filters to remove higher harmonics and shape waveforms to sinusoidal form as far as possible (invertors, furnaces etc.). Capacitors are used as filters in d.c. installations in which the useful part is the constant component of voltage and fitters are used to decrease the voltage ripples. In this case the filters don't permit the high harmonics penetrate into other installation elements and to the supply system. In the reactive filters the inductive and capacitive properties are exploited.

Power capacitors are made of metal foil, condenser paper of small thickness, different unipolar films impregnated with oil or synthetic liquids (chlorinated diphenyls, phenylxylylethane, dioctylphthalate, etc.). The chlorinated diphenyls are now prohibited because they are toxic for humans and for surrounding nature.

High voltage power capacitors are usually made for 6-20 kV and for specific energy of the order of 8-10 kVAr/dm^3 and reactive power up to 400 kVAr. The largest capacitor batteries are usually placed in a large tank filled with insulating gas SF_6 (Japan) and have capacity up to 1 mF and rated voltage ± 250 kV.

The main technical parameters of the power capacitor are its reactive power and reliability (the life expectancy not less than 25 years).

2. Cables in Electrical Energy Systems

The first modern (according to to-day’s views) a 10 kV cable line was built in 1890 (Ferranti, London) and was in successful operation for 40 years. This line opened the era of underground energy transportation system. Now nobody can imagine city energy supply without underground cable systems. In the Ferranti cable system everybody can see all the features of the modern cables.

In the 1930s the first oil filled 35 and 110 kV cables appeared. Over the 110 year of cable design evolution many types of cables were developed. They attained very high reliability parameters. In the modern times energy supply large cities is based on 110 and 220 kV lines. But it seems that in the nearest future they will not satisfy the requirements. For example, Chicago power needs exceed 10 GW. It was expected that the middle energy densities of 5-10 MW/km^2 can be reached and even 100 MW/km^2 in the most energy demanding regions. For such energy densities it is economical to use the 220 kV cables and even 345 kV (New York City).

The 110-500 kW cables are widely used for underground outlets from large hydraulic, nuclear and thermal power stations (usually from transformers to the distribution substations).

High voltage cables are made of paper-oil insulations. When the oil law pressure (Figure …a) 35-110 kV cables are used they are placed directly to the open rows, the 220-750 kV high pressure cables – to the steel tube (Figure …b) filled with oil (oil filled cable) or gas (gas filled cable). Working voltages and thermal regime are the main factors which determine the cable construction. The most important cable places are the cable inlets and cable connections.

The power capability of the cables of higher voltage classes is limited by the highest possible temperature insulation. Therefore the power losses in the insulation play an important role – if for the 110 kV cables losses in the insulation are of the order of some percents, for the 500 kV cables they compare with the copper losses and it means that the cable power capability depends on both the cable current and on the phase voltage U_{ph} and physical insulation properties ($tg\delta$). Increasing the cable copper cross section is not so effective as in the overhang air-lines because it leads also to increase of the insulation volume and losses in it.

In order to increase the cable power capacity there are some effective measures. At first it is possible to increase the cable copper cross-sections. Nowadays oil filled cables with low and high pressure for 400 and 500 kV respectively with copper cross-section up to 2500 mm^2 and power capability up to 1 GW are in use. The second way – is to use insulation with low losses factor $\varepsilon tg\delta$. To decrease this loss insulation with $tg\delta$ = 0.15% and $\varepsilon \approx 3.3\varepsilon_0$ (instead of $tg\delta$ = 0.3% at $t_n \approx 80°C$ and $\varepsilon \approx 3.7\varepsilon_0$ for usual cable paper) is used. At the same time the electrical strength of the paper is also increased. Such a paper is used for 500 kV cables. This paper was developed with special synthetic liquids for impregnation. Combined insulation with higher properties was also developed. This insulation represents two layer cellulose paper with one layer polypropylene film ($tg\delta = 0.08\%$, $\varepsilon \approx 2.7\varepsilon_0$) with 10-15% more electric strength.

The critical length of 220-500 kV cables is about 30÷40 km and in order to transport electric energy for longer distances it is necessary to introduce transversal compensation for the line reactive power. For this the shunt-regulated reactors are used on the end of the lines.

The main limitation for expansion of cable lines is connected with their higher prices in comparison with overhead lines of the same capacity. During the last decades significant reduction in the cost of cables has been achieved by introducing of unlimited extruded polyethylene insulation.

The demand for 110-500 kV cables is rapidly growing especially for city lines. As if to consider the energy transmission for long distances – the cables are unsuitable.

For the distributed city lines and industrial purposes the most widely used will be cables for 0.4-35 kV with polyethylene insulation.

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Biographical Sketches

Boris E. Kirichenko was born in St.-Petersburg in 1950. He graduated from State Marine Academy, St.-Petersburg in 1972. He joined RAS in 1995. Now he serves as scientific secretary of the Division for Basic Researches in Electric Power Engineering and is the laboratory chief "Unconventional Energy Sources and Ecology" in the same division.

Nikolay N. Tikhodeev, was born in Russia in 1927, 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.