Introductory Chapter: New Challenges in High-Voltage Engineering

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1. Introduction

Since the advent of electricity industry, a feasible way to overcome power losses and voltage drop in transmission lines has been to increase line voltage level of the transmission network. A higher voltage leads to a higher efficiency and less loss as well as more transmission capacity of the line and extends the value of transmitted power over longer distances. High-voltage engineering is the science of planning, operating, and testing high-voltage electrical devices and designing the insulation coordination in order to ensure the reliable operation of the power network. Therefore, high-voltage engineering provides the access to electrical energy for consumers far away from power generation units. This branch of science develops and optimizes operating characteristics of internal and external insulators.

The appearance of semiconductor valves and attractive aspects of direct current network have been led to the development of high-voltage DC transmission lines (HVDC). Some advantages of HVDC transmission systems are their high dynamic stability, ability to be connected to large DC renewable sources and DC micro-grids, etc. Thus, developing large load centers and restricting high-voltage installation places makes it possible to extend HVDC underground cable lines. This attracts the attention of high-voltage engineers to improve the characteristics of cable insulators and other DC equipment's insulation.

As the concerns about global warming, greenhouse gas emission, and recycling the artificial wastes have been growing recently, different industries are forced to produce recyclable devices with lower environmental consequences. High-voltage researchers have extensively investigated nanopolymer cable insulators and environment-friendly materials to replace existing insulation materials. Cross-linked polyethylene (XLPE) is a well-known high and ultrahigh voltage cable insulation with interesting features such as excellent electrical and mechanical characteristics, high reliability, and low cost. However, because of recycling difficulties and environmental pollution, high-voltage scientists are trying to replace XLPE by nanopolymers like polypropylene/inorganic nanocomposites. The nanocomposites have better thermal and electrical characteristics than XLPE. Of course, nanopolymer manufacturing technologies are progressing, and there are many challenges in this way with regard to interactions between temperature, electric field, space charge, and DC volume resistivity under multifield coupling. It is necessary to review polypropylene and polypropylene/inorganic nanocomposites, as well as the opportunities and challenges for using them in HVDC cable insulation.

Another development in high-voltage engineering for environmental compatibility is realized through replacing insulation gas SF_6 by environmentally friendly gas CF_3I in gas-insulated stations (GISs) and high-voltage circuit breakers. SF_6 is an inert and electronegative gas with an excellent insulation strength. When a high-voltage circuit breaker opens short current from the source, the contacts are separated, while SF_6 fills contact gaps; the gas experiences severe arc discharge for extinguishing the electrical arc. After extinguishing, because of an extremely high temperature, a plasma channel is formed. The powerful gas attracts plasma energy to avoid circuit breaker destruction. However, for avoiding global warming due to greenhouse gases, CF_3I is used, as an environmentally friendly gas. CF_3I is a colorless and volatile gas, and because of high boiling point of pure CF_3I liquid, it cannot be used as a dielectric substance. Therefore, CF_3I mixed with CO_2 or N_2 offers a dielectric strength by 75–80% higher than that of SF_6. Thus, extended researches have been performed to replace SF_6 by CF_3I (mixed with CO_2 or N_2) with different ratios, considering operating characteristics.

Because the conductors of a high-voltage cable line are packed in a confined space, the resultant voltage gradient causes an intense electric field, which in turn leads to high capacitance. Therefore, the cable current flow contains significant capacitance component rather than inductive component; this results in higher voltage at downstream node. Due to equivalent capacitance and inductance, natural frequency of a high voltage cable can be excited by harmonic content of a transient impulse that leads to destructive overvoltage known as "resonance" phenomenon. Actually, when natural frequency of equivalent capacitance and inductance is equal to one of harmonic components of transient switching impulse waveform, the resonance occurs. Depending on equivalent circuit in the branch where resonance occurs, resonances are categorized into three groups, i.e., series, parallel, and compound. The series resonance leads to voltage drop across the resonating branch. A very large impedance appears across the parallel branch that can create destructive overvoltage by a flowing small leakage current. Therefore, designers must consider the resonance in the planning of the insulation coordination of the networks.

One of the main challenges in designing and operating high and ultrahigh voltage transmission lines is the occurrence of short circuit that makes bulk transmitting lines out of service and can destabilize the overall network. The overvoltage caused by lightning or switching is one of the main reasons for short-circuit occurrence along transmission lines. Therefore, planning engineers perform appropriate insulation coordination for line insulators against this kind of overvoltages with considering voltage level and line characteristics. Nevertheless,

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pollution aggregation on the insulator surface decreases the electric withstand. The pollution can be formed by combined dust, humidity, and salt in industrial or coastal areas where maintenance intervals may be very long. Therefore, planning engineers must know environmental circumstances in addition to electrical characteristics of transmission lines. Of course, this problem can be solved by increasing insulation strength, using more compatible insulators and washing the line insulators periodically.

Artificial tests of manufactured products are necessary in industrial applications as well as scientific studies. High-voltage devices need testing in manufacturing process, before sale, laboratory, and quality control stages, after installation for ensuring safe transportation/ installation and predetermined maintenances. High-voltage testing is performed under loading or artificial impulses such as switching or lightning waveforms. The loading tests are performed in order to detect capacitance discharge of dielectric or partial discharge and insulation resistance. The impulse tests are performed to determine insulation strength of an external insulator that is not considered sufficient. The external insulator is designed for outdoor usages at different distances from the ground or on top of another isolator as in porcelain cover of bushings, buses, and sectionalizing insulators. Therefore, testing voltage is applied to a device more than one time, and then, complete flashover probability is calculated. The insulation strength has a stochastic nature, so it can be evaluated by statistical approaches. Characteristics of testing waveforms must be determined in a way that actual conditions can be realized.

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