Measurement and modeling of surface charge accumulation on insulators in HVDC gas insulated line (GIL)

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ABSTRACT

Gas insulated lines are a means of buck electric power transmission at high or extra high voltage. They have been used for linking GIS to overhead lines or to power transformers in AC power systems for over four decades.

However, nowadays, the design of a HVDC GIL with the same reliability as HVAC remains a challenge. It is mainly due to the charge accumulation on the insulator surface under DC field, as a result of a substantial distortion of the initial field and an unexpected decrease of flashover voltage.

The paper introduces a surface charge measurement system based on a 220 kV GIL unit. The surface potential distribution on the insulator is obtained. A model is also provided to help to understand the surface charge accumulation process. The results in this paper may be useful for the design and optimization of HVDC GIL.

KEYWORDS

Gas insulated line; GIL; surface charge accumulation; insulator; HVDC

INTRODUCTION

The development of electrical transmission systems all over the world will involve the installation of HVDC systems to bridge the growing geographical distance between energy generation and consumption. Further, the connection of the renewables such as offshore wind farms to the grid has to be done with DC technology as long as AC sea cables are not possible [1]. Alternative to overhead lines, gas insulated line (GIL) is an optimum technology for bulk electric power transmission at high or extra high voltage. It can be installed underground or in tunnels with low environmental impact and thus the public acceptance is expected to be higher than for overhead lines, which makes this technology interesting for the future [2].

Operating experience with GIS and GIL under AC voltage has existed since the 1960s. By now, these systems are state of the art in all voltage levels from 72.5 kV up to 1200 kV [3]. However, the design and operation of a HVDC GIL with the same reliability as the HVAC GIL remains a challenge. Unlike the quasi-static displacement field under AC voltage which is determined by the permittivity of the insulating materials and the given electrode arrangement, the stationary resistive field under DC voltage is dominated by the volume and surface conductivity of the insulating materials [4]. The surface charges will accumulate particularly at the interfaces between different materials and thus influence the dielectric stress of the insulation system significantly. Especially in situations of polarity reversal, the flashover voltage can be reduced considerably in the presence of accumulated charges. The mechanism of surface charge accumulation has not yet been fully understood. Therefore, the surface charge phenomenon on the insulators in GIL has to be revisited for future HVDC applications.

For this purpose, a surface charge measurement system is established using the electrostatic probe method based on a 220 kV GIL unit. The surface charge distributions on a cone-type insulator made of Al_2O_3-filled epoxy resin are obtained in air and SF_6 under different voltage amplitudes and polarity reversal conditions. Some phenomena are studied and the possible sources of surface charges are discussed.

Meanwhile, a simulation model is used to calculate the surface charge accumulation on the gas-solid interface of HVDC gas insulated system. The model takes into account both the dielectric properties of the insulator material and physical processes in the insulation gas, including the charge carriers' generation, drifting, recombination and diffusion.

With this paper, the authors would like to contribute a better understanding of surface charge accumulation phenomenon and its mechanism in HVDC GIL. The results in this paper may be useful for the design and optimization of HVDC gas insulated system.

EXPERIMENTAL

Experiment setup

The surface potential is measured on a cone-type insulator with the outer diameter D_1=440 mm and thickness d_1=40 mm. The insulator is made of Al_2O_3-filled epoxy resin and is installed into a 220 kV GIL test unit. The layout of the setup is diagrammed in Fig.1.

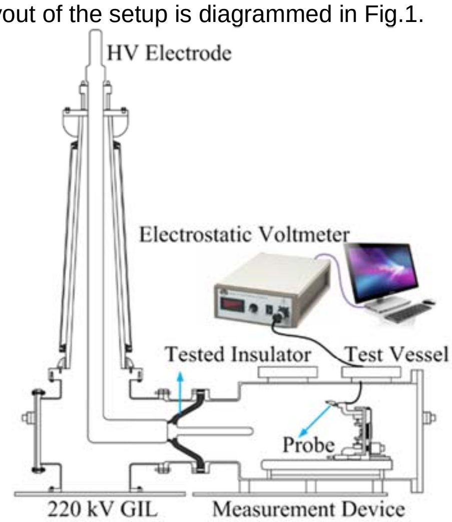

Fig. 1: Layout of the experiment setup.

An electrostatic voltmeter applying the Kelvin probe principle with a range of 0 to ±3 kV is used to measure the surface potential on the insulator. In order to scan the entire surface of the insulator, a lab-made robotic arm