DEIS-GRADUATE FELLOWSHIP

2012 New Project Proposal

Competency: DIELECTRIC PROPERTIES

Research on Electrical Performance of Icicle and Its Impact on Ice Flashover Due to Morphology Difference

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Project Team:

Coming from Tsinghua University, China

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Objective:

Composite insulators have been widely used in power transmission lines because of light weight, anti-pollution flashover, especially in UHV transmission lines. However, icing always happen to composite insulator since its small shed spacing, and is more inclined to ice flashover accident. The objective of this project is to study the electrical performance of icicle and its impact on flashover process due to electric field distortion and salt migration in composite insulators. This project aims to achieve the following goals **in one year**:

- Extend our understanding on the whole life cycle of icicle growth under energized conditions and the interaction between dynamic icicle growth and electrical field distribution.
- Investigate how the electrical performance of icicle was affected by freezing duration, pollution level and hydrophobicity. Study the impact of icicle morphology, including bridged and non-bridged, on the ice flashover process during melting process under energized condition.
- Based on ice flashover mechanism concerning surface discharge on hydrophobicity surface, a new type of composite insulator with anti-pollution and anti-icing performance will be proposed to achieve the goal of ice flashover voltage improvement.

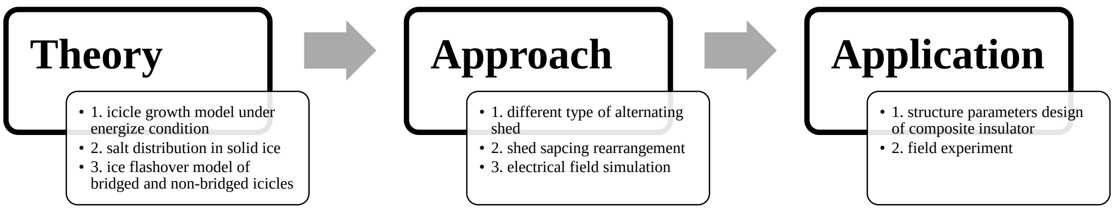


Fig.1 Technique road map

Relevance to DEIS:

During icicle growth process, salt in cooling water migrated, leading to salt distribution difference and melting water conductivity variation. This process is affected by the combined effects of electrical field, freezing time, applied water conductivity, pollution level and hydrophobicity. It is important to investigate the electrical performance of icicle and its surface discharge, thus providing reasonable guideline to insulator design in icing districts. My paper closed related to this part of work, titled "Mechanism of Salt Migration in Icicles during Phase Transition and Its Impact on Ice Flashover" has been accepted by IEEE TDEI, and will be published in IEEE Transaction on Dielectrics and Electrical

Insulation, Vol.19, Issue 5, pp1700-1707, October 2012. We are planning to achieve practical results and publish papers to Transaction on DEI.

State of the Art:

- Significance of investigation on ice flashover mechanism

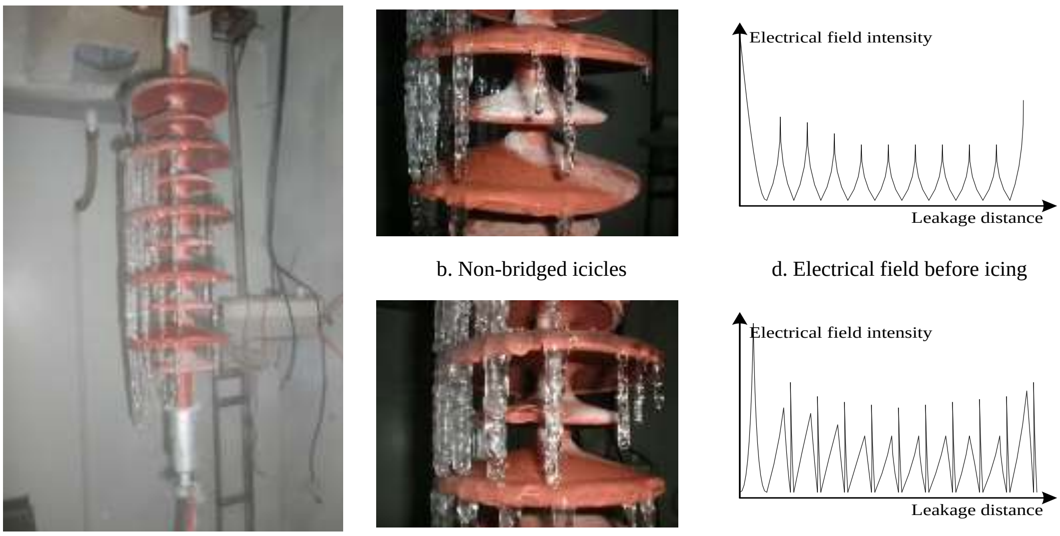
With the development of industry in China, the demand of electric power is rising rapidly and UHV transmission lines have been the main component of power system. Since light weight, excellent anti-pollution and low maintenance cost, composite insulators have been widely used. However, icing always happen to composite insulator since its small shed spacing, which is more inclined to form non-bridged and bridged icicles, leading to ice flashover. In 2008, severe icing attacked southern cities in China, and bad performance of composite insulators in icing area lead to power outage for a long period of time. However composite insulators must be used in China for the sake of heavy pollution, a new kind of composite insulator structure should be designed to improve its performance in icing area.

Most icing problems are mainly caused by glaze. Appearance of icicles leads to the electric field distortion and water film could make it worse. Ice flashover is always happened in light icing area, where insulators are not totally wrapped by ice but accompanied with heavy pollution. That is different from foreign research work. This phenomenon can be hardly interpreted by the flashover models now used, thus salt migration in icicles and its melting process, cannot be ignored and need to be taken into consideration. Investigations on ice flashover mechanism can not only deepen our understanding on ice flashover accidents, but also provide guideline to outdoor insulator design.

- Works has been done and problems needs to be solved

1. Interaction between electrical field intensity and icicle growth

Glaze is recognized to be the most dangerous icing disaster to Power Grid. Icicle growth model under non-energized condition was proposed by Maeno. But it is different when applied to energized conditions. Electrical field distribution of composite insulators is unevenly. During icicle growth period, electrical field and icicles interact, leading to bridged and non-bridged icicles, as show in Fig.2. According to our previous research, these two kind of icing show great difference in their electrical performance, especially the flashover channels.



b. Non-bridged icicles

d. Electrical field before icing

a. Composite insulator during icing

c. Bridged icicles

e. Electrical field after icing

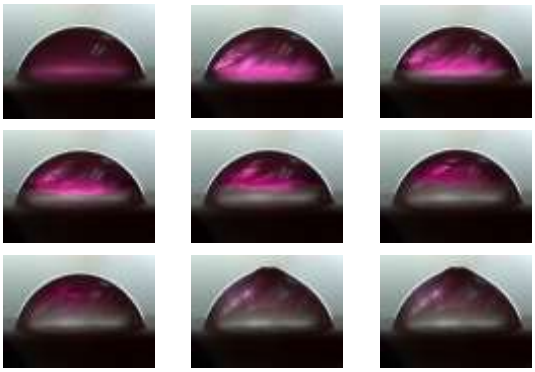
Fig.2 Icing morphology under energized condition and electrical field distribution schematic diagram

Potential impact and research results

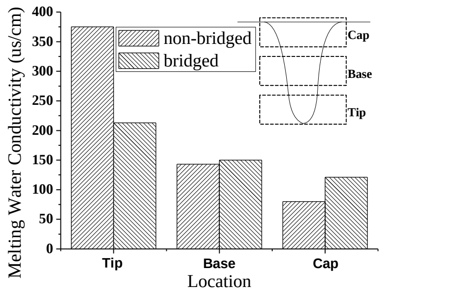
Most of research work is paid more attention to electrical field simulation under different icicle length in steady state. But the interaction of them were not concerned, especially how the corona discharge at the icicle tip interact with icicle growth. This part of work analyzes the interaction between icicle growth and electrical field distribution theoretically and experimentally, and makes a dynamic simulation. Finally characterizing method of icing condition should be acquired in order to explore the minimum ice flashover voltage in subsequent experiments.

2. Flashover due to icing morphology and salt migration

Melting process and salt migration of icicle was paid little attention, and close related work were only focused on the relationship between leakage current and melting conditions. Salt in water will be excluded by means of squeezing effect during condensation process, forming brine cell. M. Farzaneh found that high conductivity of water film, caused by rejection of impurities from the solid part toward the liquid portion of water, led to voltage drops essentially across air gaps. In order to gain explicit observation of salt migration in cooling water, KMnO4 solution with purple color was used in my experiment. From Fig.3, salt migrated to the top of the droplet during freezing process. After a while, most salt gathered in liquid water layer and then totally froze.



a. migration process in cooling water



b. Melting water conductivity at different freezing velocity

Fig.3 KMnO4 migration process in cooling water and salt distribution in icicles

According to appearance characteristics of icicles, K. Hokari proposed rod icicle (compact ice) and pipe-like icicle (incompact ice) models and implied that resistance of pipe-like icicle was lower than rod ones and more incline to flashover. M. Farzaneh studied arc root and channel characteristics on a simplified physical model to simulate ice-covered insulators and developed a multi-arc model for predicting critical flashover voltage. According to our previous research, there were two different discharge phenomena acted on icicle caused by the combined effect of icicle morphology and applied voltage, as shown in Fig. 4.

(a) Morphology of icicle after surface discharge

(b) Morphology of icicle after partial discharge inside

Fig. 4 Two different discharge phenomena acted on icicle during flashover

Potential impact and research results

Condensation of cooling water happened to insulators started from the bottom surface to the top, which is the critical to salt migration. Moreover, hydrophobicity of silicone rubber will change the shape of water droplet, and contamination will be wrapped up due to hydrophobic transfer, thus leading to different salt distribution in ice. Although a lot of work has been done, most researchers have paid only attention to icicle type and external characteristic of ice-covered insulators. However, there were two process ignored. The first one is dynamic melting process. Flashover circuit is not simply a series connection of arc and residue ice layer, but there exists dripping dew during melting period which determines how the arc elongate and develop. On the other hand, melting water conductivity is affected by salt migration during icing period, thus resistance of residue ice layer cannot be assumed a constant and another dynamic flashover process should be modeled. Based on this part of work, characteristic parameters, such as icicle length, can be obtained and provide guidelines for subsequent structure design of composite insulator.

3. Composite insulator structure design

Characteristic of outdoor insulation is determined by material and structure. Under the combined action of environment and electrical force, hydrophobicity can be weakened or even lost, and structure plays the important role at this moment to improve its electrical performance. Composite insulator shed with equal-diameter has been gradually replaced by one-big-one-small structures and leakage distance provided by small sheds can effectively improve pollution flashover voltage, as well as good performance on the prevention of heavy rain flashover. But in icing area, composite insulators now applied in Power Grids can be easily bridged or non-bridged by icicles, leading to electrical field distortion or even ice flashover.

Potential impact and research results

There is still no unified standard of composite insulator structure used in icing area concerning its hydrophobicity, contamination and icing. Based on the research works above, a new kind of composite insulator structure should be well proposed with excellent anti-icing and anti-pollution performance.

This research work is mainly focused on the structure of composite insulators and its anti-icing performance. Three processes, including icicle growth, salt migration and flashover, should be deeply investigated to provide dynamic icicle growth and flashover model, searching for characterization method to evaluate icing condition. Finally, based on the work above, guideline for composite insulator structure design in icing area can be provided.

Equipments

- Experimental setups
  - Low temperature cooling fluid circulation pump (DLSB-5L/25, Yuhua Instrument Co., Ltd) is required to simulate condensation process.
  - DC source (YB1730A-5A, Lvyang Electronic Co., Ltd) and AC source (TDGC2-1, Tianzheng Group Co., Ltd) were used to generate DC and AC current respectively.
  - Microscope (E2000, Yigongfang Technology Co., Ltd) is used to observe micro-structure of ice during phase transition.
- Analysis equipments in this study
  - An HSC (Motion scope M3, 3200fps) is used in our lab to record the flashover path.
  - A high-speed AD card (high-speed digitizer type NI 5112) is used to acquire leakage current and phase to ground voltage waveforms.

All the experiment equipments needed are available.