The Tony Davies High Voltage Laboratory

Investigation of Partial Discharge in Solid Dielectric under DC Voltage

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Motivation

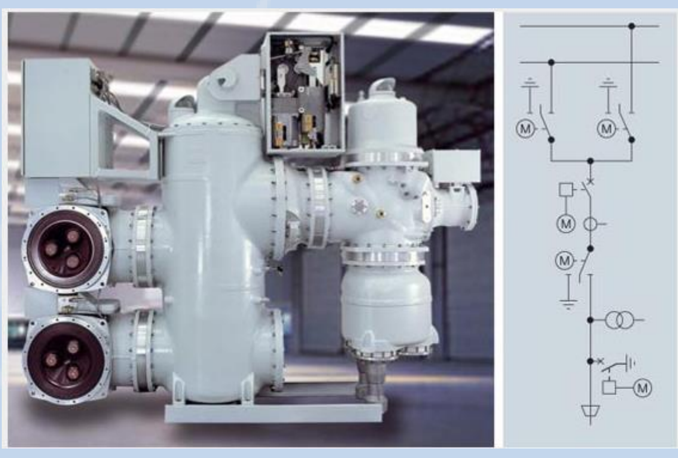
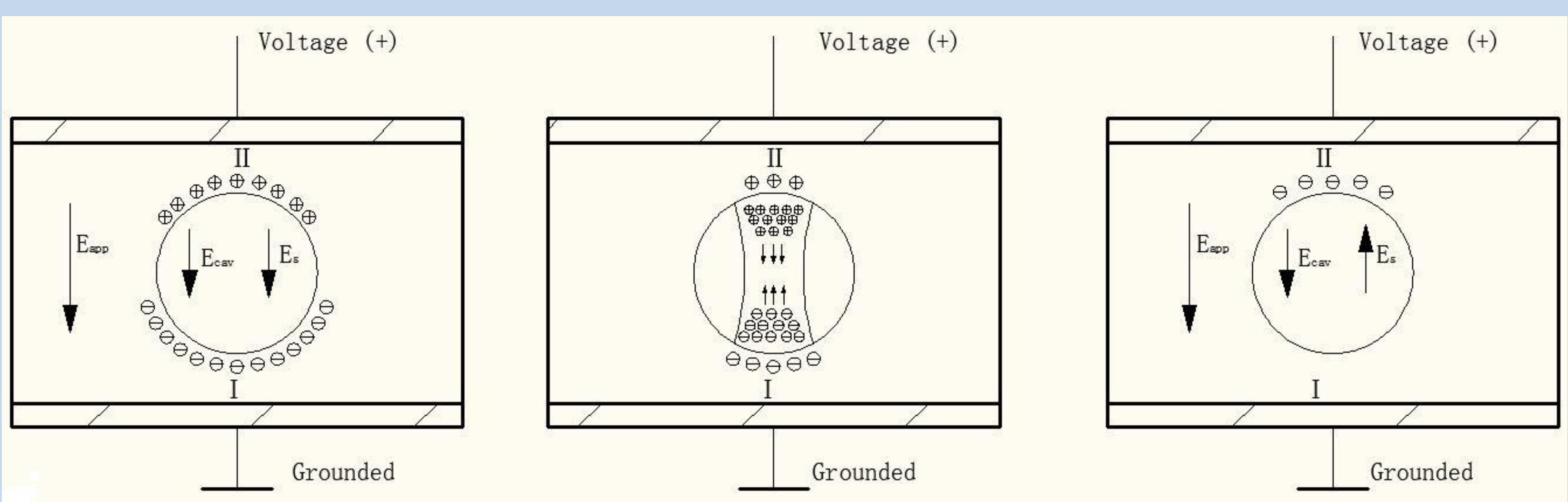


Figure 1: Type 8DN8 gas-insulated switchgear

A partial discharge, or PD, is defined as an electrical discharge that is localized within only a part of the insulation between two separated conductors. Recent research on PD mainly focuses on the study of PD characteristics under AC voltage. Compared with DC, PD under AC is more serious and can be easily detected in terms of PD number. As the results of these concentrated research, the understanding of PD under AC condition has been significantly improved and features extracted from PD measurements have been used to diagnose the insulation condition of many power apparatus.

Recently, rapid development in HVDC transmission and power grids connection, and widely applied DC cable and gas-insulated switchgear because of their benefit in long distance usage lead to an increasing concern about PD under DC. However, available study for the condition is little and related research is therefore necessary and essential for understanding the lifetime and reliability of apparatus.

PD Difference Between AC & DC



a) b) c)

Figure 2: Process Illustration: a) Before PD; b) During PD; c) After PD

AC process

Once dielectric material is applied with voltage, charge carriers are introduced into material and accumulated on the surface of cavity, enhancing the electric field inside the cavity.

$$E_{cav} = f \cdot E_{app} + E_s$$

E_{cav} is the electric field inside the cavity, f is the geometry coefficient, E_{app} is the applied field, and E_s is the field caused by the surface charge.

PD occurs when E_{cav} is higher than the inception field E_{cav}, and a discharge tunnel appears inside the cavity. The cavity turns from non-conductive to conductive, and accumulated charges neutralize and migrate towards to the other electrode through this channel. E_{cav} keeps dropping during PD and discharge current appears inside. PD stops once E_{cav} is lower than the extinction value, E_{ext},. Amount of charges on the surface decreases greatly. Generally speaking, the ability of negative charges injection into insulator is stronger than positive ones, more carriers are negative. Consequently, area Ⅱ is occupied by negative carriers once electrode is anode, and the trend is enhanced by PD in the same cycle.

After PD, resulted from the remaining negative carriers, the relationship can be rewritten as

$$E_{cav} = f \cdot E_{app} - E_s$$

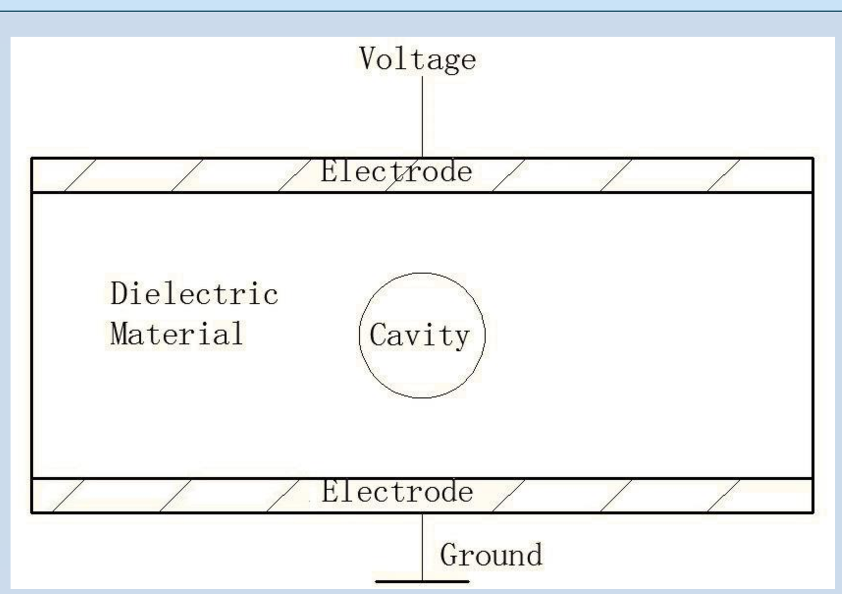
Physical process at area Ⅰ is the same to what has been discussed. However, as negative carriers are distributed in area Ⅱ, introduced carriers will firstly interact with existing carriers and injected amount is reduced. Once polarity reverses, the charge distribution situation will force a new PD happening quickly. Physical process is the same to that in the first half cycle. Time interval between two PDs is few milliseconds.

DC Process

DC voltage is considered as a voltage with constant magnitude and polarity. It takes time to reach the magnitude with a given ramp. Process of DC is similar to that under AC condition. Voltage value is stable and negative charge distribution will be saturated after long time in area Ⅱ, as the electric field caused by the trapped charges reduces the applied field greatly and limits carriers migration towards the electrode.

Compared with the situation under AC condition, PD under DC voltage has a longer time lag and the time interval between two consecutive PDs is much longer. Consequently, there is much less PD over the same period of time and the influence of the previous PD temperature change on the next one is reduced. Generally, the time interval between two PDs is around hundred seconds or even longer.

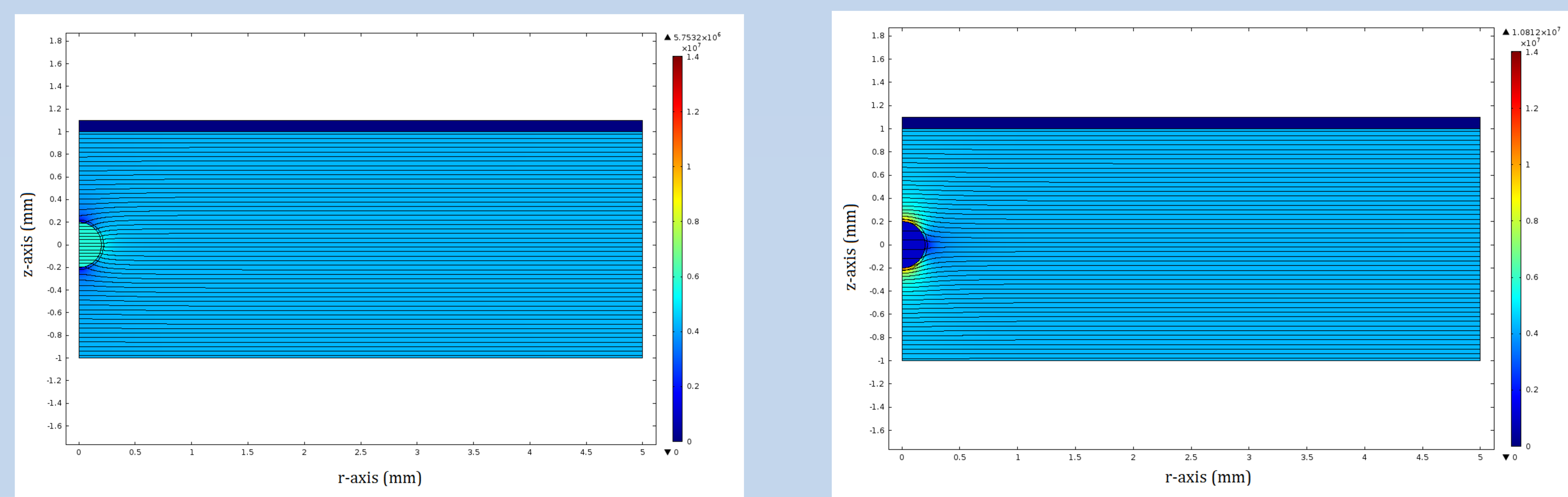
Simulation Model



Voltage is applied on the Voltage terminal, and the bottom electrode is grounded. Electrodes can be selected as copper or aluminum. Cavity filled with air is set at different place inside the material with various size for investigating the potential influencing parameters. Dielectric material, or sample material, depends on the application of project. LDPE or XLPE is used when this project is applied to power cable, and epoxy resin is selected for GIS, the gas-insulated switchgear.

Simulation Result and Discussion

Electric Field



a) Before PD b) After PD

Figure 3: Electric Field Change caused by PD

Temperature

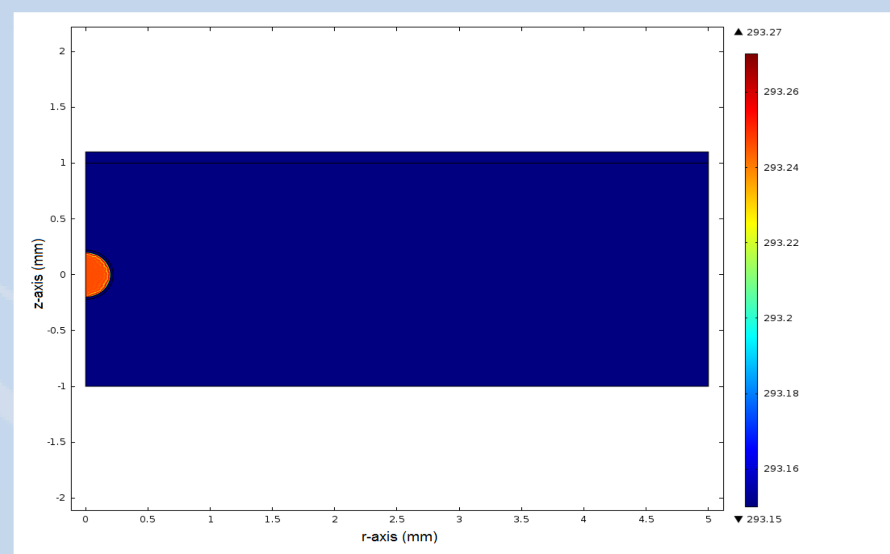


Figure 4: Temperature Situation

PD Simulation Results

Table 1: Simulation Condition

Parameter	Value	Description
U_{app}	14 [kV]	The amplitude of the applied voltage
t_{inc}	32 [s]	The increasing time of the applied voltage
r_{cav}	0.2 [mm]	The radius of the cavity
h_{cav}	0[mm]	The distance between the cavity center and the middle

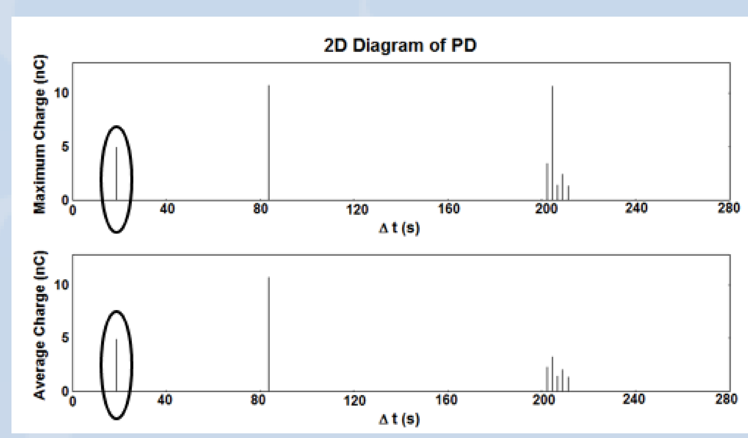


Figure 5: PD time interval situation under DC

Maximum: The peak charge value appears during PD

Average: Charge value during a process of PD on average

•PD happens after long time is serious with large PD number in a discharge process.

•Once research the PD process, study time should be long. The shown simulation is applied for over 1200s.

•If we just consider the situation at constant voltage, trend of PD distribution will be more uniform, with a constant time interval. PD in circle area happens in the voltage increase process.

•If charge is saturated in area Ⅱ, no PD will be detected again. Therefore, it is predicted that DC PD is much less serious as AC PD will exist for long, until breakdown appears.

Affected Factors

DC PD can be affected by many factors, such as shape, size and position of cavity, the applied electric field and material parameters. It is found that applied field is a dominant factor.

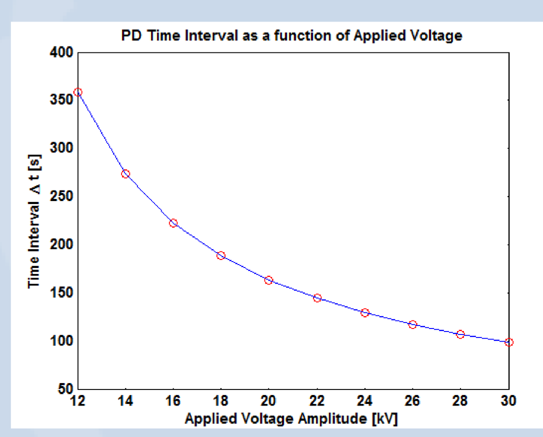


Figure 6: PD situation with different applied voltage

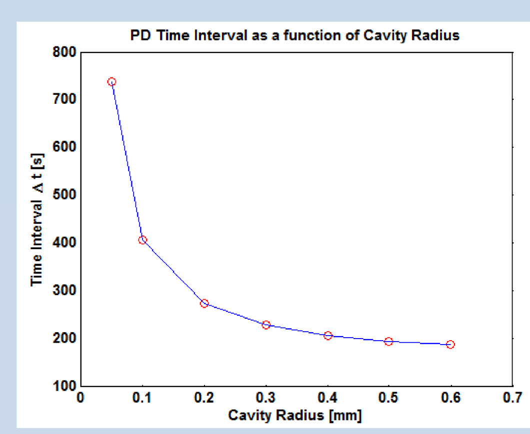


Figure 7: PD situation with different cavity radius

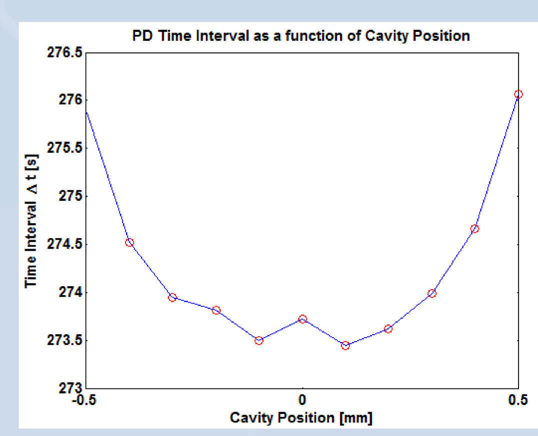


Figure 8: PD situation with cavity at different location

- Increase in the applied voltage reduces the time interval. Therefore, PD happens more frequently. This trend enhances the aging process and limits the insulator reliability;
- Increase in cavity radius limits the time interval. Reason is mainly the change in applied field and inception field inside the cavity, and inception voltage is a key factor;
- When the cavity locates in the middle region the time interval between two consecutive PDs is smaller. As expected, the trend is almost symmetrical. However, the time interval is of little difference for different cavity location. It means that cavity location has little influence on the PD under DC condition.

Future Work

In the work PD under DC condition has been simulated using the existing model. The time interval between two consecutive PDs and its relationship with the applied voltage, cavity size and the cavity location have been obtained.

For future work, the model refining is essential. The present model is quite simple and some potential factors are not considered, such as charge barrier and influence of space charge. Space charge is important under DC condition and its presence will no doubt affect PD behaviours.

Polarity reversal is a possible operation mode in HVDC system. Its impact on PD needs to be studied as well. Insulation in HVDC apparatus may also experience lightning strikes or transient voltage surge, PD study under such environments will be of importance to the reliable operation of HVDC systems.