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PARAMETERS THAT INFLUENCE THE PARTIAL DISCHARGES OCCURRENCE IN CAVITY DEFECT WITHIN ELECTRICAL CABLE INSULATION

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Abstract

The electrical cable reliability is largely linked to the state of its insulation, which can be threatened by the partial discharges (PDs) activity. This phenomenon is localized in defects created within insulation during the manufacture process and the cable installation. The cavity defect is among the most known defects within the insulating material filled with different gases and having various forms. Under electrical stress, the PDs occur and lead with time to a cable failure. The PDs simulation in cavity defect within cable insulation has became an important tool for a complementary understanding of the experimental task. The plasma model has been considered in last decade as an alternative to describe physically and chemically the PDs mechanism versus the other models such as the capacitance, conductance model. Using plasma model our work aims to simulate the PDs in cavity defect within cable insulation by showing the parameters influence such as the type of gas contained in the cavity, the voltage magnitude and frequency imposed on the insulation on their occurrence through its occurrence mechanisms. This helps to assess the PDs severity on the insulation system to carry out its diagnosis and therefore to have an effective reliability of cable.

Keywords: electrical cable insulation, cavity defect, partial discharge, plasma model, parameters influencing PDs.

List of Symbols/Acronyms

D_e	The electron diffusivity
D_ε	The energy diffusivity
E	The electric field.
f_0	The applied voltage frequency
f	The electron energy distribution function
m_e	The electron mass (SI unit: kg)
n_e	The electron density.
n_ε	The mean electron energy.
n_k	The ions density.
N_n	The total neutral number density (1/m^3)
R_e	The electron source
q	The elementary charge
T_e	The electron temperature
V	The electric potential
Z_k	The number of elementary charges on the ion
$\tau_{statave}$	The average statistical time lag,
μ_e	The electron mobility
μ_ε	The energy mobility
Γ_e	The electron flux.
$\Delta\varepsilon_j$	The energy loss from reaction j (V)
ε	The energy (V),
σ_k	The collision cross section (m^2)
ε_r	The relative permittivity of insulation martial
ε_0	The permittivity of free space
ρ_s	The surface charge density
$\boldsymbol{\gamma_P}$	The secondary emission coefficient.
ε_P	The secondary electrons mean energy

1. INTRODUCTION

The reliability of an electrical cable is closely linked to the state of its electrical insulation, which can be threatened by the activity of the partial discharges (PDs). This phenomenon is localized at the level of defects created in the insulation during the process of its manufacture or the installation of the accessories of the cable. These defects take several forms such as gas-filled cavities created within the insulating material with different geometries. Under electrical stress, this leads to the appearance of partial discharges which participate in its aging and consequently the failure of the cable insulation [1, 2, 3].

To diagnose the state of the insulation of an electrical cable, it is necessary to detect the existence or not of the activity of the partial discharge in this insulation. There are several experimental methods which have been put into service to do this task. But these methods cannot give a view on the physical and chemical mechanisms of PDs behavior in the cavity defect. For this reason that we always come back to modeling and simulation for a complementary understanding of the activity of PDs.

The Modeling and simulation of partial discharge activity in the cavity defect in the cable insulation has became an important tool for further understanding of the experimental task. This is justified by returning to the various research works carried out during the last two decades which confirm firstly that the PDs modeling has been used as a complement to diagnostic systems for the insulation of electrical assets through artificial defects created experimentally to generate PDs based on off-line and on-line testing. However, interpreting the measurement results on defects of cables in service is much more complicated [4]. Then, the modeling task predicts PD measurable characteristics such as PD inception initial voltage, apparent charge and PDs statistical characteristics. In addition, the physical processes of PD are studied in order to establish mathematical models that reflect objectively the laws determining the physical phenomena of the appearance of PD. This makes it possible to explain the appearance and evolution of defects and determine their effect on the condition of the insulation. Therefore, the PD modeling is a good alternative to understand PD by determining the parameters affecting its behavior [5, 6].

Finally, the simulation using the three-capacity model has contributed against the experimental task to obtain easily certain microscopic physical processes which are difficult or even impossible to have by this latter, for example the propagation of the streamer in a cavity. Moreover, it allows any factor to be adjusted freely so that critical parameters and physical processes influencing PD behavior can be identified. it was also able to elaborate the relationships between the cavity parameters, the solid dielectric characteristics, the state of aging and the test conditions with the PD events. Significant advances by simulating PD in the cavity through several physical processes of PD, including free electron supply, discharge development, and surface charge decay, are embodied. Regarding the combination of physical processes and the use of free parameters, experimental results under various test conditions can be reproduced by simulation. As a result, a better understanding of the mechanism of PD has been obtained and the factors that participate in the PD behavior have been clarified. On the other hand, as it is not accessible to the cavity, there was no experimental observation on the decay of the surface charge. A few years later, the advent of the measurement method based on the Pockels effect provides a tool to study it experimentally, but the relevant investigations are insufficient [7].

Several models have been used to simulate the behavior of PDs using the three capacitance model in which the discharge process was considered as charging-discharging of capacitors. Thereafter, the conductance model which shows the increase in conductivity during discharge governed by the current continuity equation to calculate discharge parameters. On other hand, others have presented the discharge by the deployment of charges in the cavity using Poisson’s equation. Of course, these models could represent the transient phenomenon of a discharge, but they don’t reflect its physical processes. Recently, a plasma model was used to simulate PD activity, in which the impact ionization, drift, diffusion, recombination, and other processes were quantitatively described by fluid equations. In our turn, using the plasma model in comsol software, we will show the effect of different parameters on the behavior of PDs such as the type of gas contained in the cavity defect, the applied voltage amplitude and power frequency imposed on insulation system of an electrical cable. This is to see its risk on the state of the insulation of electrical cable [8].

2. PARTIAL DISCHARGE ACTIVITY IN CAVITY DEFECT WITHIN CABLE INSULATION

The partial discharges develop from one part of the cavity surface through the gas contained in it, to the other end of cavity surface. Thus the PDs bridge only the cavity without crossing the solid dielectric. Thereby the cavity defect represents a weak area in insulation due its lower breakdown strength. This intensifies the electric field to generate a discharge activity in cavity defect. This cavity defect can be formed through process control errors during the production of solid dielectric, such solid dielectric (PE, XLPE, EPR) are used so much in insulation system of electrical cable [3, 9].

2.1 The cavity effect on the cable insulation

The exposure of the cavity walls to PDs activity results in surface erosion of the cavity due to physical and chemical mechanisms generated at the level of the dielectric material and therefore progressive degradation and destruction of the surrounding insulation which occurs in different ways.

- Bombardment of surrounding insulation with ions and electrons;
- Chemical reactions in surrounding insulation surface;
- Burst of chains in organic insulation caused by ultraviolet radiation.
- Significant variations in gaseous composition and pressure in cavity.
- increase on the temperature in insulation defect [10, 11, 12].

2.2. The parameters influencing the behavior of PDs

There are several parameters that influence the behavior of PDs, among them we can mention.

2.2.1. The content and composition of the gas filling the cavity

All the studies that have been made on the behavior of PDs in the cavity defect considering that this latter is air-filled voids rather than gas-filled voids without giving any idea on the chemical mechanism which intervenes in the PDs process. Which does not reflect the reality of this event because of the characteristics of the gas and the surface of the cavity influencing the behavior of PDs through the ionization parameters of the gas that vary according to its composition, to the charge drift or the rate of recombination and to the emission at the surface of cavity [13, 14].

2.2.2. The electrical voltage amplitude

The amplitude of the high voltage is an important factor in partial discharge activity .When applied voltage is increased, the electric field is enhanced and the electron generation rate is increased and the effects of the surface charge decay through conduction along the cavity wall on PDs are significant. As a result, the PDs activity is dependent on the voltage amplitude [15, 16].

2.2.3. Applied voltage frequency

There has been consensus on the recognition of discharge mechanism parameters that influence how the supply voltage frequency affects PDs activity in insulation materials. In fact, the intention of variation of frequency value is to evaluate the quality of insulation of such equipment at other frequency than power frequency. So the advantage of this manipulation is that the characteristic parameters in cavity defect within the insulation, such as electric field, and surface charge accumulation process, change with the varying frequency, leading to the changing of PDs behavior. This is for more information about the insulation system condition. In addition, the frequency-dependence of PD behavior could be useful for the classification of different PDs defects and evaluation of the progressive aging degree. On the other hand, the study of the effect of different frequencies on PD behavior becomes a necessity because of harmonic frequencies in the electrical grids. For example, solar power stations get tied to the grid through inverters with electronic components are considered a principal source of harmonics and other frequencies [17, 18, 19, 20].

To see the effect of the voltage frequency on PDs activity, we go back to defining the statistical time lag which is the time difference between the inception field achievement and the PDs occurrence. The average statistical time lag, τstatave can be seen dependent on the frequency of the applied voltage. It can be expressed by the following relation [21].

$$\tau_{statave} = 0.3296 f_0^{-1.221} \quad (1)$$

The relation above shows that the average statistical time lag decreases with the frequency. When the frequency is higher, the time is shorter. Thus, the amount of charge due to previous PD which still left when the next PD is likely to occur is higher. This causes the electron generation rate to be higher, reducing the statistical time lag. Thereby, a PD appears after the inception field achievement [21].

3. METHOD AND SIMULATION TOOL

The simulation of PDs activity by using the model of plasma could be considered as a powerful tool to clarify a discharge in a cavity bounded by material insulation by exploiting the breakdown in dielectric barrier discharge. In the meaning of physical processes, a discharge in cavity defect is almost filamentary dielectric barrier discharge in which the electron avalanche turns into a positive or negative streamer. Using fluid equations coupled with Poisson's equation, a gas discharge process is simulated very well by describing the impact ionization, charge drift, diffusion and recombination. As a result, we can obtain a microscopic physical processes consisting in streamer development and the surface charge density distribution and macroscopic parameters such as the inception field and the residual field. Consequently, the exploitation of the plasma model in our case is implemented in Comsol Multiphysics 5.5 [8, 10, 22, 23].

3.1. The simulated cable

We consider an electrical medium voltage cable section shown in the figure 1. The cable is composed of insulation with a 9.5 mm thickness and a relative permittivity equal to 2.3. The cavity is cylindrical of radius 1.5 mm filled with a gas having the relative permittivity 1, far away from the HT conductor of 4.6mm.

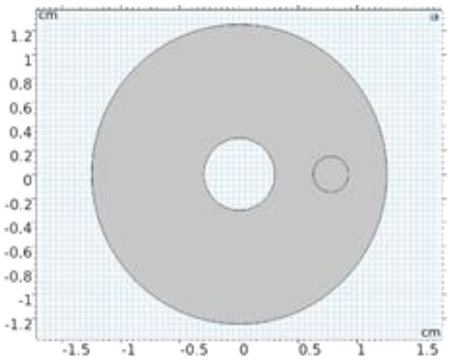

Fig.1 .The cable simulated in 2D

This cable is supplied with different voltages ranging from 21KV to 30 KV which represent the real operating condition of such equipment in the medium voltage level as mentioned in [4]. So, all the geometrical characteristics of the cable are extracted from the experimental and simulated work of Illias in order to compare and validate our results with its [24].

The figure bellow illustrates the simulated model mesh that is a critical step in the simulation in the case of the plasma model. We used the triangular mesh by refining the domain of the plasma as well as the limits of the plasma in order to have very accurate solution. The complete mesh consists of 4340 domain elements and 194 boundary elements.

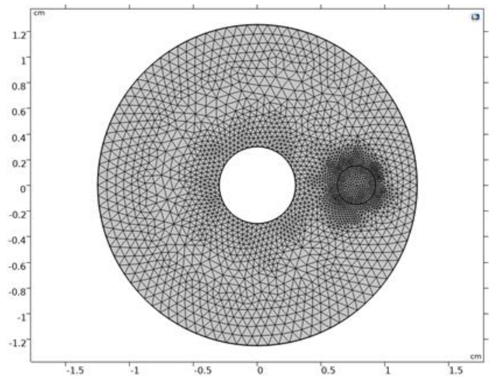

Fig.2. Mesh of the cable simulated

3.2. Governing equations

The electron density and mean electron energy are calculated by solving a pair of drift diffusion equations [25, 26].

$$\frac{\partial n_e}{\partial t} + \nabla.[-n_e(\mu_e . E) - D_e.\nabla n_e] = R_e \quad (2)$$

$$\frac{\partial n_\varepsilon}{\partial t} + \nabla.[-n_\varepsilon(\mu_\varepsilon . E) - D_\varepsilon.\nabla n_\varepsilon] + E.\Gamma_e = R_\varepsilon \quad (3)$$

Where $D_e = \mu_e T_e$, $\mu_\varepsilon = (\frac{5}{3})\mu_e$, $D_\varepsilon = \mu_\varepsilon T_e$

The electron source is expressed as follow:

$$R_e = \sum_{j=1}^{M} x_j k_j N_n n_e \quad (4)$$

And the energy loss R_ε due to inelastic collisions is obtained as follow.

$$R_\varepsilon = \sum_{j=1}^{P} x_j k_j N_n n_e \Delta\varepsilon_j \quad (5)$$

Where x_j is the mole fraction of the target species for reaction j, k_j is the rate coefficient for reaction j (SI unit: m^3/s). The rate coefficients can be calculated in this way:

$$k_k = \gamma \int_0^\infty \varepsilon\, \sigma_k(\varepsilon) f(\varepsilon) d\varepsilon \quad (6)$$

Where $\gamma = (\frac{2q}{m_e})^{1/2}$ (SI unit: $C^{1/2}/kg^{1/2}$)

For non electron and heavy species transport properties are obtained by Maxwell-Stefan equation presented as follow:

$$\rho \frac{\partial w_k}{\partial t} + \rho(u.\nabla) w_k = \nabla. j_k + R_k \quad (7)$$

j_k is the diffusive flux, R_k is the rate reaction for species k ($kg/(m^3 \cdot s)$), u is the mass averaged fluid velocity (m/s), ρ denotes the gas density (kg/m^3), w_k is the mass fraction [26, 27, 28, 29].

The Poisson's equation describes plasma region expressed as.

$$-\nabla \varepsilon_0 \varepsilon_r \nabla V = \rho \quad (8)$$

The space charge density is computed using the formula.[25,26]

$$\rho = q\left(\sum_k^N Z_k n_k - n_e\right) \quad (9)$$

3.3. Boundary conditions

The electron flux resulted from the secondary emission effects and will be picked up by the wall are presented by following boundary condition [25]:

$$n.\Gamma_e = \left(\frac{1}{2} v_{e,th} n_e\right) - \sum_P \gamma_P(\Gamma_P . n) \quad (10)$$

In regards to boundary condition of the electron energy flux is presented as follow:

$$n.\Gamma_\varepsilon = \left(\frac{5}{6} v_{e,th} n_\varepsilon\right) - \sum_P \varepsilon_P \gamma_P(\Gamma_P . n) \quad (11)$$

The ions are lost to the wall due to surface reactions and expressed by following boundary condition:

$$n. j_k = M_w R_k + M_w c_k Z \mu_k (E.n)[Z_k \mu_k (E.n) > 0] \quad (12)$$

The surface charge accumulation at the wall due to fluxes between the electrons and ions where the plasma forms is expressed as:

$$n.(D_1 - D_2) = \rho_s \quad (13)$$

Where n is the unit normal, D1 and D2 are the electric displacement fields. Therefore the surface charge density can be obtained by solving the Ordinary Differential Equations (ODE):

$$\frac{d\rho_s}{dt} = n.J_i + n.J_e \quad (14)$$

$n.J_i$ and $n.J_e$ are respectively the normal components of the total ion and electron current density at the wall [25, 29].

3.4. Chemical Plasma

The purpose of the chemical plasma is to consider the volume ionization and surface emission in order to clarify the chemical aspect of discharge process which is not implemented before in the literature in the case of modeling and simulation of partial discharges in the cavity defect. In this chemical plasma, we use the both gases argon and nitrogen to see the influence of gas type contained in cavity defect on the cable insulation. The table below shows the different collisions and reactions in the partial discharges process [25, 26, 30].

Table 1. Collisions And Reactions Modeled In Cavity Volume [25, 26].

Gas	reaction	Formula	Type	Δε(eV)
Argon	1	e+Ar=>e+Ar	Elastic	0
	2	e+Ar=>e+Ars	Excitation	11.5
	3	e+Ars=>e+Ar	Superelastic	-11.5
	4	e+Ar=>2e+Ar+	Ionization	15.8
	5	e+Ars=>2e+Ar+	Ionization	4.24
	6	Ars+Ars=>e+Ar+Ar+	Penning ionization	-
	7	Ars+Ar=>Ar+Ar	Metastable quenching	-
Nitrogen	1	e+N=>2e+N+	Ionization	15.5

Table 2. Surface Reactions In Walls Cavity [25, 26].

Gas	reaction	Formula	Sticking Coefficient
Argon	1	Ars=>Ar	I
	2	Ar+=>Ar	I
Nitrogen	1	N+=>N	I

4. RESULTS AND DISCUSSIONS

We submitted our cable to a (21KV) sinusoidal alternating voltage of frequency 50Hz. In the following figure here is the variation of this voltage in function of time.

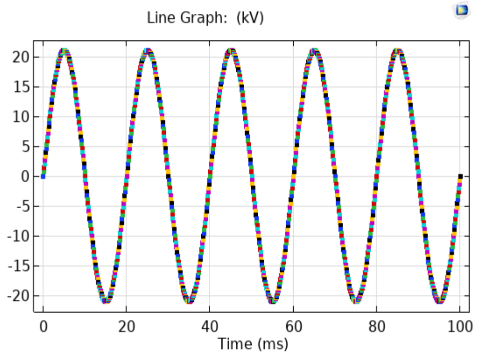

Fig. 3. the variation of applied voltage in function of time

4.1. Influence of the gas contained in the cavity defect within the insulation

In the heterogeneous case, where an insulating part is simulated with the presence of a defect as cavity filled with gases (argon, nitrogen) to see the influence of the gas contained in the cavity on the appearance of partial discharges.

4.1.1. Case of cavity filled with argon gas

Firstly, in the case of a cavity filled with a simple component of air which is argon. The figure illustrates the electric field variation along the thickness of the insulation of a cable before and after the appearance of a partial discharge with the help of plasma model. It shows that the presence of a defect affects the electric field variation a in zone where it is located.

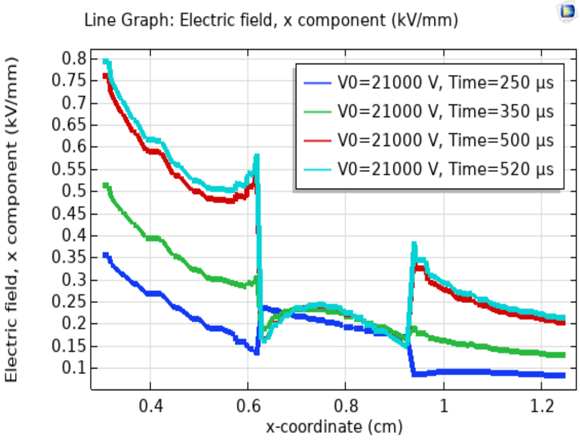

Fig.4. Variations of the electric field in cavity filled with gas of argon along the insulation thickness before and after PDs

At time $t = 250\mu s$ and just before the occurrence of PD, we observe that the electric field in cavity volume is non-uniform at this moment compared to previous works that considered the distribution electric field to be uniform within the void, i.e. flat surface insulation for this reason the calculation has been effected in the center which is confirmed by the literature through the ILLIASS work cited in [24]. We also observe that the electric field will amplify at the cavity following the streamer mechanism because we considered a virgin cavity in our simulation i.e. the initial surface charge is 0 μC/cm^2. From the curve 4, we can thus obtain the inception electric field in the cavity, E_{in}= 0.2 kV /mm .which corresponds to an inception voltage 0.8 KV. We find that this value is higher than that of Paschen of argon gas 0.137 KV, and consequently, it coincides with the value required to start the streamer discharge which is usually higher than the voltage corresponding to the Paschen curve as it is confirmed in the reference [31]. This further confirms our model which simulates the PD in a virgin cavity following the streamer mechanism. From the instant $t = 350\mu s$ appeared in curve 4, the electric field inside the volume of the cavity will gradually decrease due to the appearance of the partial discharge caused by the increasing of the surface charge density on the high voltage and ground void surfaces. A correspondence of the surface charge to the decrease of electric field in cavity volume and to its increase at level of cavity wall is indicated in the figure 5.

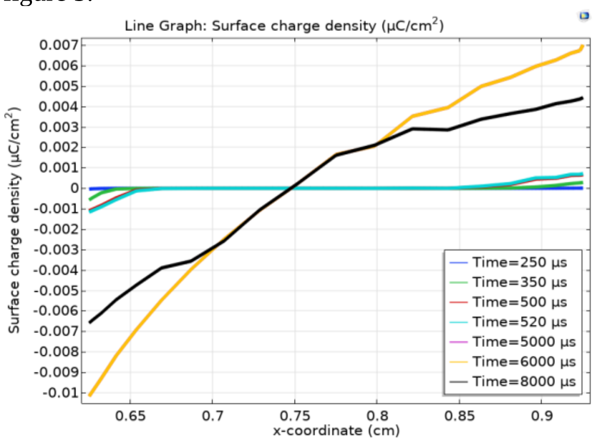

Fig. 5. Variations of surface charge density along the cavity wall in the case of a cavity filled with argon gas

We observe that the negative surface charge begins to appear at the instant $250\mu s$ to have a value -4.10^{-5} µc/cm^2 until reaching the value -0.01 μC / cm^2 at the instant 5$00\mu$s ,then it will have the value -0.0066 µc/cm^2 at the instant 8$000\ \mu$s for the applied voltage (12KV).On the other hand, the positive surface charge reaches only the value +10^{-5} μC / cm^2 at the instant $250\mu s$, then it will gradually increase to reach the maximum value +0.007 μC / cm^2 at the instant 5$000\mu$s . This difference is due to the rapid increase in electron density compared to ion density *Ar +* because of the drift velocity of electron is higher than the ion *Ar+* of 100 (cm/s). These obtained results for the both cases confirm the non-bipolarity and the non-symmetry of the surface charge distribution justified by the earlier numerical studies and experimental work investigating PD in cylindrical voids in [8, 22, 24 ,32]. In addition, in our case, this later may be due to the non-uniformity of the electric field.

4.1.2. Case of cavity filled with nitrogen gas

Then, when the cavity defect contains the nitrogen gas, we see in figure 6 that the electric field intensifies more and more during the different instants without distortion even after the instant 5000 µs in which the applied voltage reaches its maximum 21 (kV), this means that there is no partial discharge to appear due to any presence of surface charge on the cavity wall. This is introduced by non-achievement of the breakdown voltage of paschen of nitrogen gas.

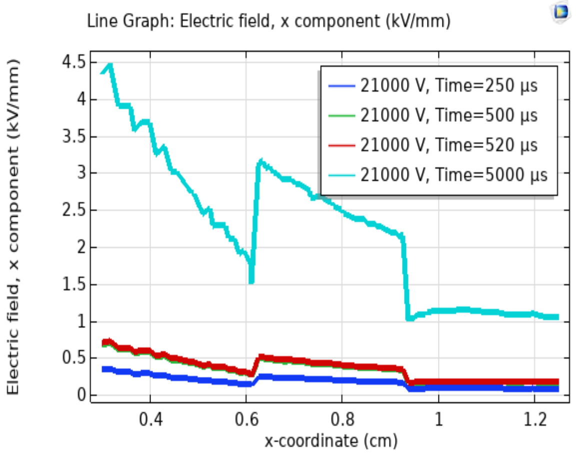

Fig. 6. Variations of the electric field in the cavity filled with gas of nitrogen along the insulation thickness before the PDs.

If the voltage is increased. We observe that the electric field gradually increases to reach a critical value of 3.35 kV/mm that corresponds to applied voltage 28KV at the instant 4000µs as show the figure 7. When we compare the obtained value of the electric field with that obtained (2.8kV/mm) in the work carried out by ILLIAS using the conductance model on the same sample of the cable, we find a good agreement between the two results with a slight difference which may be due to the non-consideration of the chemical mechanism of the discharge by the conductance model used in [24]. The induced degradation by the PD in the cavity defect is due to the chemical mechanisms during the PD event. It was found in [14] that the cavity surface was not degraded if the electric field is less than 2.28 kV/mm. This confirms and validates our result very well.

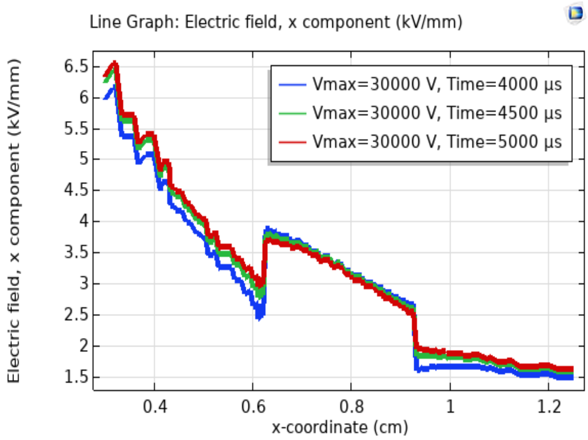

Fig.7. Variations of the electric field in the cavity filled with gas of nitrogen along the insulation thickness before and after the PDs.

From the instant 4500 µs at which the applied voltage reaches 29.6KV, the electric field will be deformed and reduced due to the appearance of partial discharges justified by the accumulation of surface charge at the cavity wall as shown in the figure 8.

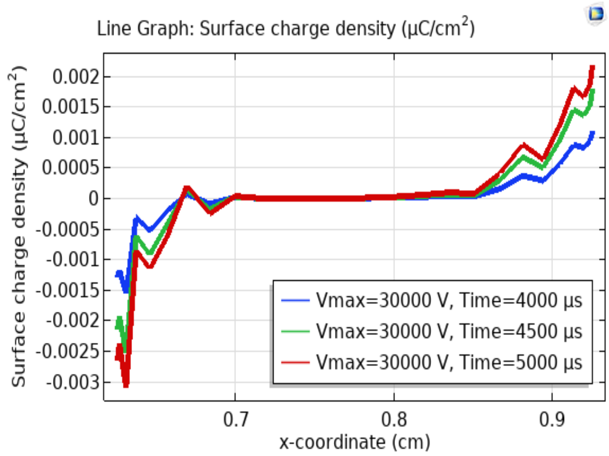

Fig .8. Variations of surface charge density through cavity defect filled with nitrogen gas.

We observe that the negative surface charge reaches the value -0.0031 µc/cm^2 at time 5000µs, moreover the positive surface charge can have a maximum value +0.002 µc/cm^2 at the same time .Which is less important compared to the argon-filled cavity case discussed previously. When comparing the partial discharge occurring in the cavity filled with argon gas with that appeared in the cavity filled with nitrogen gas. It is noted that the PD in the cavity filled with nitrogen gas requires a higher voltage to be broken down to maintain this discharge. In fact, the partial discharge occurrence depends on the breakdown voltage of contained gas, especially as the gas is easy to breakdown more that the gravity of the partial discharge is important and consequently the aging accelerates increasingly. Therefore, the type of gas contained or composition of the gas trapped in the defect of the cavity influences the life of the insulation by participating in the appearance of partial discharges in this later and which reflects clearly the influence of the chemical aspect in the partial discharge mechanism. In addition, our result reflects the dielectric degradation by ionization impact across the gas-insulator interface which must be robust and anti-oxidant against any type of gas formed probably in the cavity defect by modifying the characteristics of the insulating material surface as confirmed by the literature cited in [13, 14].

4.2. Influence of voltage amplitude on the occurrence of PDs in the cavity defect within the insulation

We will consider in this case that the cavity defect is filled with nitrogen because the latter can represent the air by the rate of 78٪ which is confirmed in [14]. Then we will impose our cable to an increase in voltage amplitude from 24KV to 38KV at time 5000 µs to see its influence on the appearance of PDs in the cavity defect. We have the following figure that gives the electric field variation.

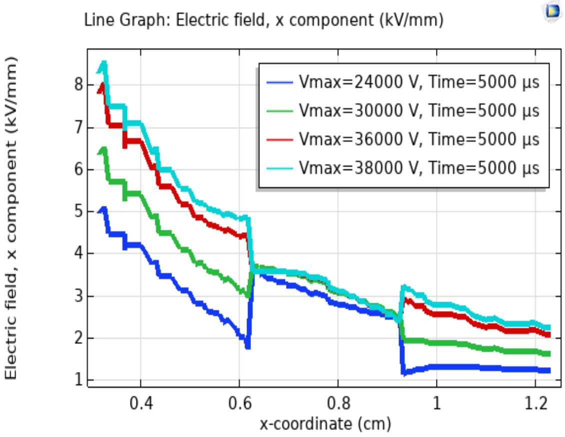

Fig. 9. Variations of the electric field in the cavity filled with nitrogen gas along the insulation thickness in function of amplitude

Depending on figure 9, we notice that the electric field increases more and more until it reaches a value of 3.30KV/mm at the instant 5000 µs under the voltage 30kV that which practically reflects the over-voltage temporary increase during the operation of the power supply system resulted from variations in load or equipment switching justified by the work cited in [2]. Then, at the voltage 36 KV, the electric field will be distorted and reduced in the cavity volume and on the other hand an intensification of the field at the upper and lower sides of cavity is indicated, this is justified by the surface charge density shown in figure 10.

Under the voltage 24 KV, the surface charge value is almost 0 (nC / cm^2) in this case we do not register a partial discharge. While the negative surface charge begins to appear at the applied voltage 30 KV to have the value -0.003nC /cm^2. Then it will reach the value -0.008nC /cm^2 under the voltage 38 KV. Moreover the positive surface charge increases from 0.002 nC/cm^2 to the value 0.006 nC/cm^2. This is always confirmed by the no-polarity of surface charge distribution. It can be concluded that as the voltage amplitude increases, the electric field, the surface charge density and consequently the partial discharge multiplies more and more leading to breakdown with time. All these results are validated by the works cited in [2, 33].

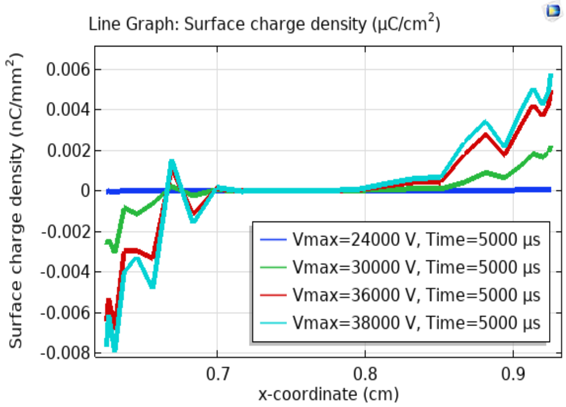

Fig.10. Variations of surface charge density along the cavity wall in function of voltage amplitude

4.3. Influence of Voltage Frequency on Occurrence of PDs in Cavity defect within Insulation

In this case we will vary the frequency of the applied voltage to see its effect on the appearance of PDs in the cavity defect filled with nitrogen within the cable insulation.

4.3.1. Partial discharge behavior in the case of frequency less than 50Hz

According to the curve 11, we observe that the electric field, under the applied voltage 30 KV at the instant 5000 µs, increases progressively with the increase in the frequency value, it reaches 3 KV/mm at the frequency 30 Hz. In addition , the electric field begins to deform and reduce at the frequency of 50 Hz, which means that the partial discharge is triggered and this can be justified by the accumulation of the surface charge.

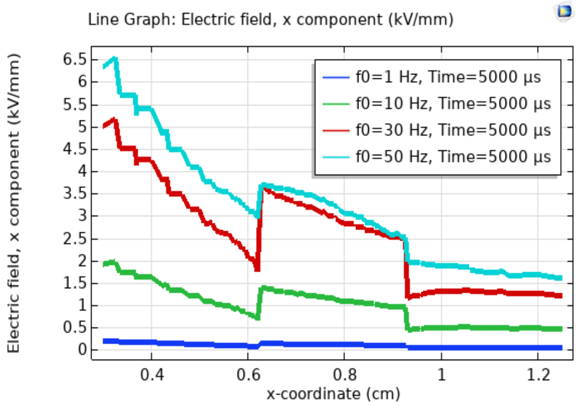

Fig. 11. Variations of electric field in cavity defect filled with nitrogen gas along the thickness in function of frequency less than 50Hz .

Indeed as shown in the figure 12, the surface charge begins to appear at the frequency 30 Hz to have the value -2.0575.10^{-5} µC /cm2. Consequently the partial discharge activity multiplies with the frequency increase until maximum surface charge at the frequency 50 Hz. This has been validated by subsequent research in [14, 18, 19, 34] which shows that the breakdown processes as well as its value are different and also having various breakdown voltage values along the interval 1 hz up to 50 hz .

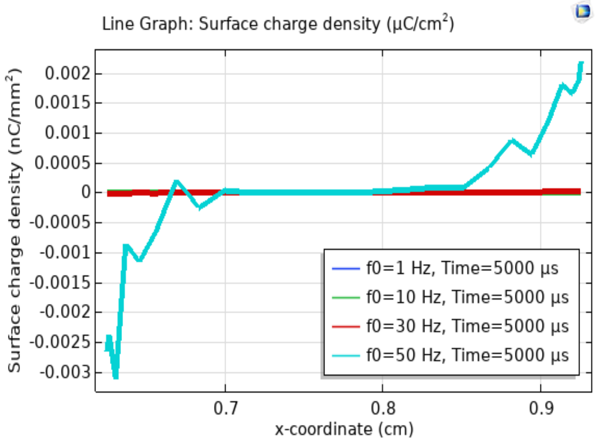

Fig.12. surface charge variations in cavity filled with gas of nitrogen along the thickness in function of frequency less than 50 Hz

Regarding the absence of appearance of DPs at small frequencies like the example of our case (1Hz). This may be due to a long statistical time τstat which does not allow ions and electrons to accumulate even after that the applied voltage reaches its maximum. As a result, the space charges produced by the electronic avalanches decay rapidly through different physical mechanisms like recombination, conduction along the cavity. Therefore, at low frequency (1 Hz) of applied voltage, these charges are more probable to pass away because they have sufficient time to cross over the cavity or recombine with the free electrons. At this time, the free electrons availability to trigger a partial discharge continuously reduces along drift paths. Also, the longer period of low frequency of applied voltage allows some charges to be found inside cavity defect that don't cause any change to the electric field in cavity defect. On the other hand, this long periodic time permits the free electrons to vanish and become trapped in the cavity defect. So, at low frequencies, the periodic time increases more than material trapping time constant resulting in a greater charge decay at the cavity surface [35, 36].

Otherwise, the activity of the partial discharge at low frequencies, in particular at the 50 hz frequency, can be justified by the fact that the frequency increases, the periodic time of voltage decreases by approaching the τstat which permits a period shorter for space charges to be disintegrated by conduction or recombination mechanism or supposed to be constant on cavity surface. Therefore, the lowest statistical time at the power frequency favors an increasing electron generation rate than that noted under the applied voltage at very low frequency (1Hz). This facilitates the rate of degradation of the insulation and hence its aging and breakdown over time that is confirmed in [14, 20, 35, 37].

4.3.2. Behavior of the partial discharge in the case of frequency more than 50hz

We observe in the figure 13 that from the frequency of 65Hz, the electric field value will be reduced in the middle of cavity as well as at the level of the lower and upper sides of the cavity.

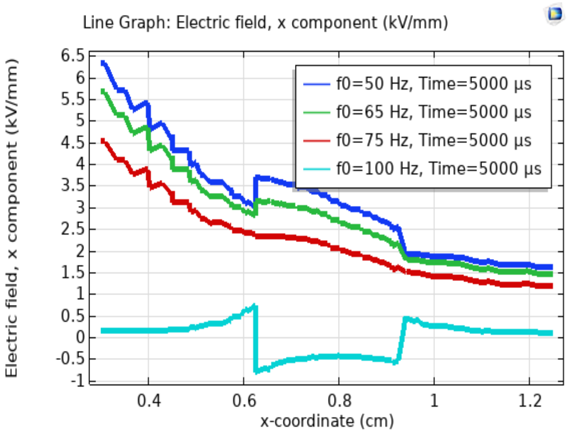

Fig.13. variations of the electric field through insulation thickness containing the cavity defect as a function of frequency over 50 Hz

We observe in the figure 14 that the surface charge will be reduced from the 65Hz frequency, which implies that the activity of the partial discharge begins to decrease. This is justified by the work cited in [20,34,38**]** which shows that the amplitude of the PDs event decreases at frequencies above 50 Hz.

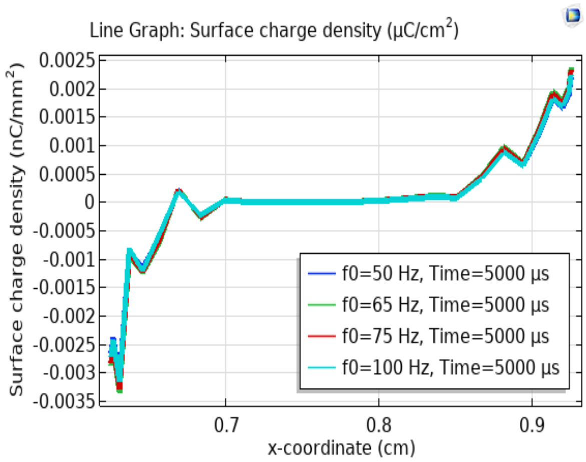

Fig. 14. Surface charge variations along the thickness of the insulation containing the cavity defect as a function of frequency over 50 Hz

At frequency over 50 Hz, the periodic time is coming closer to τstat that the PDs number decreases due to probable reduced starting of a discharge activity. In addition, the charge decreases with increased frequency due to charge accumulation on cavity wall leading to weak streamer process. Therefore, the partial discharges behavior is closely related to frequency less than 50 Hz and is negligible for frequency over 50 Hz which is validated in [35,36]. In addition, it is found on the one hand that the frequency variation between 30 Hz and 65 Hz practically reflects the effect of the temporary fluctuation due to the variation of the load on the power frequency and on the other hand the effect of the proliferation of invertor-based grid-tied renewable energy sources on it. These two causes influence on the occurrence of PDs leading to aging process and consequently to the electrical cable failure.

5. CONCLUSION

The task of modeling and simulating of the partial discharge activity in the cavity defect within insulation system contributes to a good diagnosis of the state of the electrical cable through a good understanding of the partial discharge activity mechanism in order to quantify it and to predict the operating time of the cable. There are so many parameters and factors that intervene and influence the PDs behavior. By using the plasma model, firstly, due to the gases contained in the defects formed by destructive factors or errors done in the manufacturing process, we could show the influence of the type of gas contained in the cavity defect on the appearance of partial discharge by a comparison in the two cases where there is argon gas and that of nitrogen assumed as example of such gases formed. Indeed, the appearance of the partial discharge depends on the breakdown voltage of the contained gas, especially since the gas is easy to breakdown that the gravity of the partial discharge is important and therefore the aging accelerates more. Consequently, the type of gas contained in the defect of the cavity influences the lifetime of the insulation through participating in the appearance of partial discharges and this reflects clearly the influence of the chemical aspect in the mechanism of the partial discharge event and consequently on the deterioration of the surrounding insulation by ionization impact through the gas-insulator interface which must be robust and anti-oxidant against any type of gas probably formed in the cavity defect .This directs the manufacturers to choose the best insulator or develop more its characteristics which resist the oxidation effect and thus guarantees the reliability of the electrical cable.

Then, we implemented the effect of voltage amplitude on the occurrence of PDs, as the voltage increases more that the amount of PDs increases through the increase of surface charge density. This helps to conclude on the effect of the sudden increase in voltage of the electrical network due to variations in load or equipment switching on the aging of the insulation caused by the successive PDs appearance and consequently its failure. Finally, the dependence of the PDs occurrence on the voltage frequency is affirmed through comparison of the PDs behavior in the frequency variation from 1 Hz to 100 Hz that is practically due to inverters with electronic components and to the temporary fluctuation produced by the variation of the load leading to aging process and finally to the electrical cable failure.

Despite all the satisfactory results obtained, there are recommandations to be made in future research. On the one hand, it is appropriate to implement all the gases composing the air in the cavity defect to conclude in addition on the chemical influence produced by the PDs event and consequently to see its gravity on the insulation of the electrical cable. Moreover, it is necessary to couple the plasma model with the different aging models to predict its lifetime. On the other hand, the PDs simulation in cavity defect in 3D using the plasma model should be done to conclude further on the parameters affecting the PDs activity in the cavity defect in the insulation of the electrical cable.

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