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Mechanism of the free charge carrier generation in the dielectric breakdown

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Mechanism of the free charge carrier generation in the dielectric breakdown

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Abstract. Many studies have been conducted to investigate the effect of environmental, mechanical and electrical stresses on insulator. However, studies on physical process of discharge phenomenon, leading to the breakdown of the insulator surface are lacking and difficult to comprehend. Therefore, this paper analysed charge carrier generation mechanism that can cause free charge carrier generation, leading toward surface discharge development. Besides, this paper developed a model of surface discharge based on the charge generation mechanism on the outdoor insulator. Nernst's Planck theory was used in order to model the behaviour of the charge carriers while Poisson's equation was used to determine the distribution of electric field on insulator surface. In the modelling of surface discharge on the outdoor insulator, electric field dependent molecular ionization was used as the charge generation mechanism. A mathematical model of the surface discharge was solved using method of line technique (MOL). The result from the mathematical model showed that the behaviour of net space charge density was correlated with the electric field distribution.

1. Introduction

Insulation is the most important part in the high voltage application to resist some mechanical, thermal, electrical and environmental stresses that act permanently or temporarily on insulators [1]. Thus, a precaution must be taken to reduce the factors of insulation failures caused by stresses. A good insulator must be able to avoid the flow of current to the undesired path.

Outdoor insulators in polluted environments are often exposed to pollution. This condition does not affect the performance of the insulators until the surface of the insulators become moisturized because of dew, rain or fog [2]. Due to the surface discharge activities, a conducting path arising from the drying out process will be formed on the surface of the insulator and it will allow the flow of leakage current from the high voltage electrode to the ground electrode [3]. Although the leakage current flow is quite small, the long term of leakage current flow due to the discharge may lead to the insulator breakdown. Thus, studies on physical discharge activities on insulator are essential to decrease system failure.

In order to understand the propagation of surface discharge on insulators, the mechanism for the charge carrier generation and transportation must be known. There are several types of mechanisms for the charge carrier generation and transportation that can lead to the breakdown of the insulators; impact ionization [4], field emission [5], secondary electron emission [6], ionic dissociation [7] and molecular ionization [8]. Besides, recombination of free charge carriers like electrons, positive ions, and negative ions with each other and the surrounding media also contributes in the charge carrier generation of the insulation. In addition to the recombination of the free charge, electrons are also combined with neutral molecules to form negative ion in the process of electron attachment [5].

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The charge transport continuity equation which accounts for Nernst Planck theory is used to understand the charge carrier behavior on the insulator [9] and this equation is coupled with Poisson's equation for the field distribution equation. Therefore, studies on the mechanisms that can lead to the breakdown of the insulators are very important to prevent some failures in the high voltage system. Thus, this paper was to study the charge carrier generation mechanism that could cause the surface discharge activities. In order to investigate the behavior of the charge carrier, a model of surface discharge was developed.

2. Governing Equation

The charge transport continuity equation which accounts for Nernst Planck theory is used to model the behavior of the charge carriers like positive ions, negative ions and electrons in the insulator system. The Nernst-Planck theory has been used to model the ion transport in many physical and biological system such as protein channel of biological membranes [10], neuron cell membranes [11], and electrolytic solutions [12]. Generally, the charge transport continuity equation can be written as [5]:

$$\frac{\partial N_i}{\partial t} + \nabla . J_i = f(\vec{E}, \mu_i) \tag{1}$$

where the suffix $i = p, n, e$ indicates the species of the charge; positive ion, negative ion and electron in the dielectric system respectively. J_i $[mol\, m^{-2}\, s^{-1}]$ is a total current density for species i at distance x $[m]$ between the electrode, N_i $[mol\, m^{-3}]$ is the density of each charge carrier, and $f(\vec{E}, \mu_i)$ describes the charge generation and recombination and it is depending on the electric field $(\overrightarrow{E})$ and ion mobility (μ_i). The total current density for each charge carrier in equation (1) can be given as follows [13]:

$$J_i = -D_i \frac{\partial N_i}{\partial x} - z_i \mu_i N_i \vec{E} + N_i v \tag{2}$$

where D_i $[m^2\, s^{-1}]$, z_i and N_i $[mol\, m^{-3}]$ are the diffusion coefficient, the valence and the concentration for the species i respectively, v $[m\, s^{-1}]$ is the charge velocity, and $\frac{\partial N_i}{\partial x}$ is the concentration gradient. The first term on the right hand side of equation (2) represents Fick's law equation, the second term accounts for the migration of the species in an electric field and the last term represents the convection movement of the solution induced, density gradients or bulk movement of fluid [14]. The charge transport mechanism continuity equations are coupled with Poisson's equation to determine the electric field distribution. The equation of Poisson's equation can be expressed as follows:

$$\nabla . \left(-\varepsilon_0 \varepsilon_r \vec{E}\right) = \left(N_p - N_n - N_e\right) q N_A \tag{3}$$

where $\vec{E}$ $[V\, m^{-1}]$ is the electric field vector, ε_0 $[F\, m^{-1}]$ is permittivity of free space charge, ε_r is relative permittivity of material, $N_p, N_n, and\ N_e$ are the density of each charge carrier determined from the charge transport mechanism continuity equations (1), q $[C]$ is the elementary charge and N_A $[mol^{-1}]$ is the Avogadro's number.

3. Charge Generation

There are some mechanisms for the free charge carrier growth in insulator when it is exposed to the high electrical fields such as impact ionization, field emission, electric field dependent ionic dissociation and electric field dependent molecular ionization. Under normal condition, insulators have few free charge carriers and in normal condition. However, insulator will transform into conductors if there is a high electrical stress that may increase the free charge. Eventually, these free charge carriers will lead to the insulation breakdown. Therefore, identifying the mechanisms of the growth of free charge carriers in the insulator under high electrical stresses are important.

3.1 Impact ionization

In terms of impact ionization, electrons move away from the cathode because of the influence of the electric field. Through impact ionization, as the electron travel, they gain enough energy to liberate new electrons and positive ions. Positive ions due to the ionization drift towards cathode and then the bombardment of positive ions leads to the emission of electrons. A theory on impact ionization in insulator often comes from gas discharge theory. A new method in describing the evaluation of impact ionization coefficient α in insulators had been used by Solomo et. al., in their study of impact ionization for Silicon Dioxide SiO_2 [4]. The results showed the impact ionization and recombination as the dominant process in the breakdown events for Silicon Dioxide SiO_2. The model for ion impact ionization charge generation can be expressed as follows:

$$\alpha(\overrightarrow{E}) = A_t \exp\left(\frac{-B_t}{|\vec{E}|}\right) \tag{4}$$

where A_t is the pre-exponential coefficient with units in $[m^{-1}]$ and B_t is the exponential term in $[\frac{V}{m}]$.

Nonetheless, in the case like dense medium such as water, the value of ionization coefficients for gas cannot be used by other dielectric elements [15], causing difficulties in modelling the impact ionization for different dielectric elements such as liquid and solid. However, there are some studies in the dielectric liquids that use impact ionization as the charge generation. Haidar et. al. conducted a study on Cyclohexane and Propane liquids [16] and the results showed that the regular pulse regime of this two dielectric liquids are correspond to the electron multiplication. Obodovski et. al. showed the electron multiplication through impact ionization which is observed in xenon liquid by the occurring space charge [17].

During the early studies, breakdown in dielectric liquids concentrated on the bubble mechanism in the liquid. However, study by Atrazhev et. al. [15], showed that high mobility liquid breakdown can be defined by the electron ionization breakdown mechanism. They also concluded that the electron ionization mechanism defines upper limit of electrical strength under very short voltage pulses approximately several nanosecond (ns) compared to gas bubble formation that is similar or more than microsecond ($\geq \mu s$). In another study, Kumara et. al. investigated the surface charge effect on the impulse flashover of outdoor polymeric insulators and found, that the effective ionization coefficient depends on the electrical field strength [18].

3.2 Field emission

The field emission of electrons occurs at cathode electrodes. The field emission theory is referred as Fowler-Nordheim theory, [19] field emission of electron from metal to free space. The Fowler-Nordheim equation indicates that emission should be apparent at fields of about 10^7 V/cm or more [20]. Both Fowler and Nordheim relates the field current and the voltage gradient as shown in the equation (5). According to the physical process, the electron must have sufficient energy to escape above the top of the barrier. Therefore, the tunnelling of the electron increases exponentially with the electrical field. The basic equation of Fowler-Nordheim theory of field emission can be expressed as [19]:

$$J(\vec{E}) = \frac{e^3|\vec{E}|^2}{8\pi h\emptyset} \exp\left(-\frac{8\pi\sqrt{2m}\emptyset^{\frac{3}{2}}}{3he|\vec{E}|}\right) \tag{5}$$

where J, is the current density, e is the electron charge, $|\vec{E}|$is electric field, h is Planck's constant and $\emptyset$ is metal's work function. As described by Fowler and Nordheim [21], this field emission theory is suitable for electron emission from the metal to the free space. Thus, some modifications have been done for describing the field emission from metal to other medium like liquid [5]. A theory of electron emission from electrode into the liquid or free space is known as boundary effect theory. The source of charge generation can be accounted by setting boundary conditions and initial conditions for the charge continuity equation [5].

From the equation of Fowler-Nordheim theory, an increase in the electrical field will lead to an increase in the Fowler-Nordheim tunneling current [22]. This theory is supported by Chen who found that the mobility of charge carriers is a function of the electrical field [22]. However, Kao stated that the field emission equation of Fowler and Nordheim must have been modified to correlate with the experimental current-voltage characteristics of liquid [23]. This is because it is hard for electron to gain sufficient energy to ionize a molecule and the mean free path of an electron in a dielectric liquid in order of 10 A. Meanwhile, Nakano et. al., investigated the mechanism of surface discharge in vacuum by the charge activities on solid insulators. According to this study, explosive electron emission (EEE) on cathode is the mechanism that causes the impulse surface flashover due to extreme field emission [24].

EEE can occurs for several times due to the erosion and regeneration of the electron. However, the field emission of electrons only occurs at the negative electrode and this mechanism is only suitable for the negative streamer growth. Therefore, according to O'Sullivan, this mechanism is unimportant for the streamer development along the dielectric surface [5].

3.3 Electric field dependent ionic dissociation

Other mechanism of dielectric breakdown is electric field dependent ionic dissociation. According to Onsager theory, electric field dependent ionic dissociation is defined as the formation of ions by dissociation of neutral molecules in the presence of electric field. This theory is confirmed by the deviations from Ohm's law for solutions of weak electrolytic of liquid such as water and solid such as glass [7]. From this theory, it shows that ionic dissociation depends on the strong electric field. In addition, this theory concerns about the rates of dissociation and recombination of the ions. According to this theory, dissociation rates are dependent on the electric field because dissociation increases by the factor of $F(|\vec{E}|)$ while the recombination rates are independent to the electric field because the derivation of recombination is equivalent to the Langevin equation. The electric field dependence of dissociation constant can be expressed as:

$$K_D(\vec{E}) = K_D^0 F(\vec{E}) \tag{6}$$

where K_D^0 is the dissociation constant when electric field is zero, and $F(E)$ is constant's electric field. $F(\vec{E})$ can be expressed as:

$$F(\vec{E}) = f(b) = \frac{I_1 4(b)}{2b} \text{ where } b = \sqrt{\frac{q^3\vec{E}}{16\pi\varepsilon k^2 T^2}} \tag{7}$$

where I_1 is the modified Bessel function, q is the electron charge, E is the magnitude of electric field, ε is the permittivity of dielectric liquid, k is Boltzmann's constant and T is the temperature. The relative concentrations of neutral ion-pairs and free ions in thermal equilibrium and no applied electric field can be expressed as:

$$cK_D^0 = n_{\pm 0}^2 K_R \tag{8}$$

Because the value of n_{+0} is equal to n_{-0}, the zero field free ion concentration can be expressed as:

$$n_{\pm 0} = \frac{\sigma}{q(\mu_+ + \mu_-)} \tag{9}$$

where σ is the conductivity of dielectric liquid. Therefore, charge generation rate based on Onsager's theory can be expressed as follows:

$$K_D(\vec{E}) = \left[\frac{\sigma}{q(\mu_+ + \mu_-)}\right]^2 K_R F(\vec{E}) \tag{10}$$

There are many studies that involve electric field dependent ionic dissociation as a charge generation mechanism. Castellanos et. al. generalized the Thomson model to include field enhanced dissociation in the bulk and field dependent unipolar charge injection [25]. Gafvert et. al., presented a physical drift-diffusion model that uses electric field dependent ionic dissociation to predict the behavior of the electric field in oil-pressboard structures [26]. In this study, the predicted behavior of the electric field is in agreement with Kerr's measurements compared to the RC-model that is strongly deviated from the measured fields. However, according to O'Sullivan et. al, the model for electric field dependent ionic dissociation does not produce the same results as the results of electrical breakdown in transformer oil [27]. This is because the electric field levels necessary for dissociation to occur can only be found in the region close to the tip of needle electrode. In addition, the low mobility of dissociated ions only leads to the formation of current density at the needle tip. Thus, a very limited thermal enhancement occurring in the dielectric liquid.

3.4 Electric field dependent molecular ionization

Another mechanism that might also be contributing to the breakdown of the dielectrics in the presence of high electric field is a molecular ionization process. Electric field dependent molecular ionization is a direct ionization mechanism that extracts electrons from neutral molecule which then generates free electrons and positive ions. Thus, Zener theory [8] of tunneling electron in solid that is correlated with molecular ionization mechanism in the presence of high electric field is used in the modelling of dielectric breakdown. The ionization rate γ of Zener theory is given as:

$$\gamma\left|\vec{E}\right| = \frac{ea|\vec{E}|}{h}\exp\left(-\frac{\pi^2 m^* a\Delta^2}{eh^2|\vec{E}|}\right) \quad (11)$$

where e is the electronic charge, a is the molecular separation, $\left|\vec{E}\right|$ is the magnitude of electric field, h is the Planck's constant, m^* is the effective electron mass, Δ is the molecular ionization potential. In order to give a charge density rate source term for inclusion in the positive ion and electron, electric field dependent molecular ionization rate must be multiplied by the ionisable charge density, N_0 [5]. Hence, the ionization rate can be expressed as:

$$G_i\left|\vec{E}\right| = \frac{e^2 N_0 a|\vec{E}|}{h}\exp\left(-\frac{\pi^2 m^* a\Delta^2}{eh^2|\vec{E}|}\right) \quad (12)$$

Charge generation mechanism by molecular ionization in the presence of high electric field has been analyzed by few researchers. Some researchers use this theory in the modelling of streamer in dielectric liquid such as in transformer oil [5][28][29]. However, this mechanism is not suitable to measure negative sharp points as stated by Becerra et. al. in the study of charge carrier generation in Cyclohexane [30]. According to this study, although this equation is suitable for the current-voltage (IV) characteristics in positive point, it is fails to predict the currents for the negative points.

3.5 Comparison of the charge generation mechanism

By studying different types of charge carrier generation, the modelling of surface discharge on the insulator surface is developed. Not all type of the charge generation mechanism has the same effect for the real cases. The summary of the charge carrier generation is shown in Table 1.

Table1: The comparison of charge generation mechanism

Charge generation	Basic equation	Theory	Description
Impact Ionization	$\alpha(\overrightarrow{E}) = A_t \exp\left(\frac{-B_t}{\lvert\vec{E}\rvert}\right)$ [4]	Gas discharge theory of breakdown. The process of bombardment of positive ions that leads to the electron emission	Not suitable for the charge generation in dense medium.
Field Emission	$J(\vec{E}) = \frac{e^3\lvert\vec{E}\rvert^2}{8\pi h\emptyset}\exp\left(-\frac{8\pi\sqrt{2m}\emptyset^{\frac{3}{2}}}{3he\lvert\vec{E}\rvert}\right)$ [19] (Boundary effect generation)	The emission of electron from the metal surface ooccurred with the high electric field greater than 5 x 10^8 V/m.	Only occurred at the negatively electrode and suitable for negative streamer growth.
Electric Field Dependent Ionic Dissociation	$K_D(\vec{E}) = \left[\frac{\sigma}{q(\mu_+ + \mu_-)}\right]^2 K_R F(\vec{E})$ [7]	Formation of positive and negative ions by dissociation of neutral molecules in the presence of high electric field.	The low mobility of dissociated ions only leads to the formation of current density at the high voltage electrode.

Electric Field Dependent Molecular Ionization	$G_i\lvert\vec{E}\rvert = \frac{e^2 N_0 a \lvert\vec{E}\rvert}{h} \exp\left(-\frac{\pi^2 m^* a \Delta^2}{e h^2 \lvert\vec{E}\rvert}\right)$ [8]	Zener theory extracting the electron from neutral molecule and generating free electron and positive ions.	The fast mobility of electron leads to the electric field wave propagation from the high voltage electrode to the ground electrode.

The ionization coefficients for gasses cannot be used by another dense insulator like liquid and solid [15]. Hence, impact ionization is not suitable for the modelling of surface discharge on the outdoor insulator that involves the flow of electrolyte. Meanwhile, field emission of electrons always occurs on the negative electrode in which the development of negative streamer propagation can take place [5]. Thus, the field emission of electrons is not suitable for the modelling of surface discharge along the surface of outdoor insulator.

Electric field dependent ionic dissociation is also one of the charge carrier generation mechanisms that has been discussed earlier. From a study by Sullivan et. al., electric field dependent ionic dissociation mechanism occurs on the region near the high voltage electrode [27]. Therefore, this mechanism is not applicable to model the surface discharge formation that occurs along the surface of the outdoor insulator that involves the flowing of the electrolyte from the high voltage electrode to ground electrode. However, the electric field dependent molecular ionization mechanism has been used by some researchers in the modelling of positive streamer in the liquid insulator [5][28][29]. In their study, at good correlation between simulation result and experimental result for the streamer formation in the liquid insulator has been observed. Thus, the results showed the distribution of charge carrier and electric field along the insulator.

3.6 Recombination

The concentrations of free charge carriers can exist during the formation of surface discharge on the insulator surface and is generated by the generation mechanism discussed previously. The combination of free charge carriers like electrons, positive ions, and negative ions with each other and the surrounding media may lead toward of electron/positive ion recombination, positive/negative ion recombination and electron attachment. For the charge recombination, Langevin’s relation for recombination coefficient has been used [5] [31]. In Langevin’s relation the recombination coefficient is based on the diffusion equation of charge carriers in the electric field [32] and the Langevin’ theory which can be expressed as follows:

$$K_{rpn} = \frac{q(\mu_p+\mu_n)}{\varepsilon\varepsilon_0} \tag{13}$$

$$K_{rpe} = \frac{q(\mu_p+\mu_e)}{\varepsilon\varepsilon_0} \tag{14}$$

where, $\mu_p, \mu_n, and\ \mu_e$ are the mobility of positive ion, negative ion and electron respectively, $K_{rpn}\ and\ K_{rpe}$ are recombination coefficient of positive/negative ion and positive ion/ electron recombination, $q, \varepsilon_0\ and\ \varepsilon$ are elementary charge, relative permittivity and permittivity of free space charge respectively. However, in the dense media like gases and non-polar liquid that have higher electron mobility, the value of recombination coefficient is deviated from the diffusion controlled rate constant [33]. In the dielectric liquid studies, some authors have used Langevin’s recombination coefficient for ion-ion recombination to model ion-electron recombination [5][28]. This method has been effectively compensating the electron-ion recombination by reducing the electron mobility.

3.7 Electron attachment

In addition to the recombination theory, electrons are also combined with neutral molecules to form negative ion. This process of electron attachment, τ_a is modelled by an attachment time constant that describes the lifetime of energetic electron in a dielectric. The electron attachment time constant is calculated simply by the electron attenuation length, electron mobility and electric field strength and can be described as follows:

$$\tau_a = \frac{\lambda_a}{\mu_e|\vec{E}|} \tag{15}$$

where, τ_a is the electron attachment time constant, λ_a is the electron attenuation length, μ_e is the electron mobility and $|\vec{E}|$is the magnitude of electric field. Becerra et. al., showed that field-dependent attachment should be considered in the estimation of electric current in the liquid phase [30]. Meanwhile, according to the studies on the streamer growth in dielectric liquid [5][28] , few authors stated that the impact of electron attachment during the streamer growth in dielectric liquids is reasonably small due to the attachment processes which have a longer time scale. Therefore, the electron attachment gives small impact on the charge carrier generated.

4. Toy Model of Surface Discharge on the Outdoor Insulator Surface

Outdoor insulators in polluted areas are often exposed to pollution. This condition does not affect the performance of the insulator until the surface of the insulator becomes moisturized because of dew, rain or fog [34]. Due to the surface discharge activities, a conducting path due to the drying out process will be formed on the surface of the insulator and it will allow the flow of leakage current from the high voltage electrode to the ground electrode [35]. Although the leakage current flow is quite small, the long term of leakage current flow due to the discharge may lead to the insulator breakdown. Thus, studies on the physical discharge activities on the insulator are quite important to decrease the system failure.

In summary, electric field dependent molecular ionization is chosen in the modelling of surface discharge on the outdoor insulator. This is due to the surface discharge activities which occur along the insulator surface when there is a flow of wet contaminant and leads to the flow of leakage current. In order to solve this problem, a toy model of surface discharge is developed by taking into account the simplification of all the parameters involved. The purpose of the toy model development is to investigate whether this model is suitable for the exact problem. For the development of surface discharge model, charge transport continuity equation accounted for the Nernst Planck theory is used to investigate the charge behaviour and Poisson's equation is used to determine the electric field distribution. For the equation of the current density in equation (2), only diffusion and migration terms are considered. This is because in the surface discharge development high electric field is given and the charge carrier is diffused from high concentration to the low concentration in the electrolyte. Thus, the diffusion and migration terms are taken as a dominant role and the convection term is neglected because no bulk movement of fluid is involved [14]. Thus, the migration-diffusion equation for the charge carrier (positive ion, negative ion and electron) generation includes electric field dependent molecular ionization, recombination, electron attachment and charge transport which can be expressed as follows:

Positive ion:

$$\frac{\partial N_p}{\partial t} + \nabla.\left(-D\nabla N_i + N_i\mu_i\vec{E}\right) = \frac{qN_0 a|\vec{E}|}{h}\exp\left(\frac{-\pi^2 m^* a\Delta^2}{qh^2|\vec{E}|}\right) - N_pN_nK_{rpn} - N_pN_eK_{rpe} \tag{16}$$

Negative ion:

$$\frac{\partial N_n}{\partial t} + \nabla.\left(-D\nabla N_i - N_i\mu_i\vec{E}\right) = \frac{N_e}{\tau_a} - N_pN_nK_{rpn} \tag{17}$$

Electron:

$$\frac{\partial N_e}{\partial t} + \nabla.\left(-D\nabla N_i - N_i\mu_i\vec{E}\right) = \frac{qN_0 a|\vec{E}|}{h}\exp\left(\frac{-\pi^2 m^* a\Delta^2}{qh^2|\vec{E}|}\right) - N_pN_eK_{rpe} - \frac{N_e}{\tau_a} \tag{18}$$

where F, R, and T are Faraday's constant ($\frac{C}{mol}$), relative gas constant ($\frac{J}{mol.K}$), and temperature (K) respectively. The charge generation term in equation (1) can be seen only in equation (16) and equation (18) because by electric field dependent molecular ionization as discussed previously, only positive ion and electron are extracted from the neutral molecule. Meanwhile, the generation term for negative ion in equation (17) is the electron attachment. The Poisson's equation can be expressed as follows:

$$\nabla.\left(-\varepsilon_0\varepsilon_r\vec{E}\right) = \left(N_p - N_n - N_e\right)qN_A \tag{19}$$

The boundary conditions that were applied for this model can be expressed as follows:

- Charge Transport Continuity Equations: The boundary equation at the high voltage electrode and ground electrode is set to zero normal flux as follows:

$$\hat{n}(\nabla N_i) = 0 \tag{20}$$

- Poisson's Equation: The high voltage electrode was set to a supply voltage V_0 at boundary of $x = 0$. This boundary was supplied with DC voltage. Meanwhile, for the ground voltage at $x = d$, it was set to zero normal electric field component.

$$x = 0; \quad \hat{n}(V) = V_0 \tag{21}$$

$$x = d; \quad \hat{n}(V_i) = 0 \tag{22}$$

In order to solve the mathematical modelling, method of line technique (MOL) is used and can be solved using the finite difference method. Thus, this finite difference method was solved using ODE15s in MATLAB software.

From the simulation of the mathematical model, the net space charge density is shown in Figure 1. Meanwhile, the electric field distribution due to the charge generation is shown in Figure 2. In the simple model, the scaling of the charge was about 10^{-2} and the scaling of the distance was order 1. The resulting charge generation from the molecular ionization and attachment, tended to move to the opposite direction of their charge. The slow mobility of the charge was essentially remaining stationary. Thus, this condition led to the formation of the net space charge density.

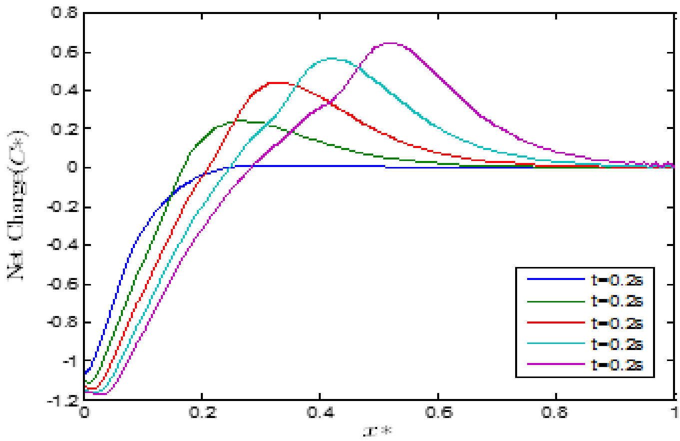

Figure 1: Net Space Charge Density

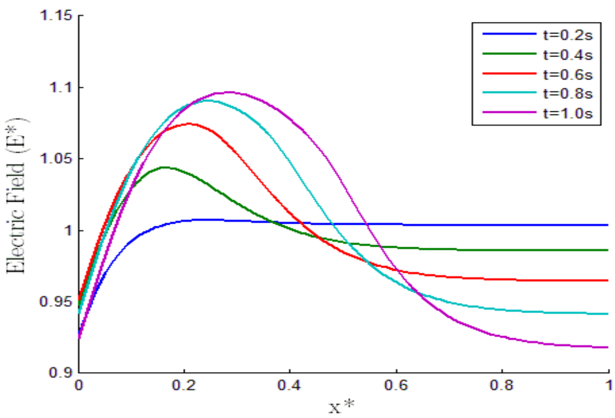

Figure 2: Electric Field Distribution

Figure 1 and Figure 2 shows, the relationship between the charge density and the electric field distribution. Similar to equation (19), the charge density influenced the electric field distribution [5]. The position of the region of net space charge density indicated the location of the peak of the electric field distribution and ionization during the surface discharge on the outdoor insulator. In summary, this simple model can be used to predict the behavior of the charge density during surface discharge.

5. Conclusion

Studies on the physical process of charge generation mechanism is important to prevent the system failure in the high voltage application. This paper provides fundamental study of the charge carrier generation mechanism that can cause surface discharge and then lead to the breakdown of the insulator. There are several types of charge generation mechanism and each mechanism is depending upon the parameters of the insulator, surrounding media and the electric field applied. Similar to previous studies, the total net space charge in the insulator influences the amount of electric field distribution on the insulator. Based on the simple model presented in this paper, the results show that the total net space charge density is influencing the electric field distribution of this model. In the next study, this model will be used to investigate the charge behavior using exact parameter values.

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