Effect of Dew and Raindrops on Electric Field around EHV Transmission Lines

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Effect of Dew and Raindrops on Electric Field around EHV Transmission Lines

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Abstract

This paper analyses the change of electric field in the proximity of 500 kV extra high voltage (EHV) transmission lines, in the presence of raindrops and dew. The computations were carried out using MatLab software by solving the electrostatic equations. The analysis depicts that the spatial distribution of the electric field strength varies with water drop content along the lateral distance along the transmission line. The peak electric field reduces with the water drop content, whereas the electric field remains the same at around 36 m from the transmission line. Then onwards the field strength increases with the water drop content. At long distances the field strength is not affected by the water drops. Such variation is highly important to analyse the adverse effects on the insulators used in HV applications. The results are of high significance to a country such as Indonesia where the precipitation levels are generally high in most parts of the country.

Keywords: *Dew-droplets, electric field, transmission lines, EHV (Extra High Voltage)*

1. Introduction

The climate of Indonesia is almost entirely tropical. The uniformly warm waters that make up 81% of Indonesia's area ensure that temperatures on the land remain fairly constant, with the coastal plains averaging 28 °C, on the land and mountain areas averaging 26 °C, whereas the higher mountain regions averaging 23 °C. Temperature varies little from season to season, and Indonesia experiences relatively little change in the length of daylight hours from one season to another season. The main variable of Indonesia's climate is not temperature or air pressure but rainfall. The area's relative humidity ranges between 70% and 90%.

Furthermore, Indonesia has experienced extreme variations in rainfall associated with the rainy season. In general, there is a dry season (June to October), influenced by the air masses of the Australian continent, and the rainy season (November to March) caused by Asian and Pacific air masses. As a consequence, when a rainy season came, most of the route of extra high voltage transmission lines fell into the path of fogginess of dew and raindrops accompanied by rainstorms.

If the air surrounding the conductors of an extra-high voltage transmission lines (EHV) is filled by water droplets (raindrops), pure air permittivity will be converted into composite permittivities (i.e. composite mediums of air and water droplets). At the same time the media of the dielectric constant change, so that the voltage gradient level and the exposure of the electric field on the ground surface will change too. The change of the E-field phenomenon corresponds to $E=D/\varepsilon$, where E is electric field (V/m), D is flux density (C/m^2), and ε is permittivity of the medium.

According to the International Radiation Protection Association (IRPA) guidelines [1], the exposure limits are 10 kV/m during the entire working day and 30 kV/m during the short-time working day for occupational exposures, meanwhile 5 kV/m on a continuous basis and 10 kV/m during a few hours per day for public exposures.

The research of electric field at which the insulator surface has been polluted showed that the electric field close to the water droplet tends to be higher as the diameter of the droplet increases, and becomes lower as the relative permittivity of the pollution layer increases [2]. In practice, the presence of water droplets over the insulator surface creates locations of high

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electric field intensity, a region where the electrical breakdown can initiate [3]. The presence of water droplets at insulator surface will increase the electrical field intensity which creates elecrical breakdown or flashover and combination of moisture and contamination causes flashover at operating voltage; hence, affecting reliability of power delivery [4]. Another research that has been conducted showed that the occurrence of water droplets on outdoor insulators due to rain, fog, dew etc. leads to localized field enhancement causing partial discharges and dry arcs which ultimately result in complete flashover [5]. The presence of water droplets over the insulator surface enhances the electric field intensity and leads to electrical breakdown. Water droplets/films lead to the breakdown of the insulator even under the absence of actual contaminants. The effect of water droplets / films in causing an electrical breakdown on practical insulator at various levels of hydrophobicity [6].

The effect of water droplets on the surface of the insulating material (i.e. silicon rubber and porcelain) against the electric field has been researched. The result showed that E-field intensity depended on the distance between the water droplets and the electrodes and also on the relative distance between two water droplets and for multiple droplets the field patterns varied with respect to the change in number, relative position, contact angle of droplets and the location of the water droplet is more significant compared with the number of water droplets [7]. Meanwhile, these water droplets cause the electric field enhancements at the triple points (interfacial point of three dielectric mediums i.e. solid, liquid and air) which may lead to external partial discharge or even flashover [8].

The purpose of this research is to know the fluctuation of the voltage gradient at the ground surface that was affected by the presence of the raindrops and dew in the space between each phase conductor of the extra high voltage transmission lines and the ground surface. The research subject was a 500 kV, EHV Transmission lines that are located at Gabusan Village in Sewon Sub-District, in Bantul Regency, in Yogyakarta Special Territory, Indonesia.

By calculation, this paper analyzed the influences of the ‘fog-dew’ and raindrops on the electric field through modelling approach of the conductors’ configuration design of the transmission lines, the electrostatic equation model, to determine the Maxwell Potential Coefficient Matrix (MPCM) and finally the magnitude of voltage gradient and the exposure of the electric field can be visualized.

2. Research Method

2.1. General View of the Extra High Voltage Transmission Lines

The extra high voltage (EHV) transmission lines have 500 kV operational voltage at the frequency of 50 Herzt, 3-phase, vertical configuration, two-ground wires, and 6-phase conductors with double circuit. For the purpose of analysis, the method of computation indicated in the following is valid for the most general case, and for any kind of line configuration, including multiple circuits. Each conductor of the transmission line, including wires at the ground potential, must be considered. In the case of regular bundles, it is sufficient to consider their equivalent single conductor having diameter d_{Eq} [9] given by:

$$d_{Eq} = D \sqrt[n]{\frac{n \cdot d}{D}} \tag{1}$$

where D is the bundle diameter; i.e. the diameter of the circle on which the subconductors lie, n is the number of subconductors, and d is the diameter of the subconductors. The charge Q on the conductors is determined through the voltage and the Maxwell potential coefficients P, the equation is known as electrostatic equation in the form of matrix [9].

$$[Q] = (P)^{-1} \cdot [V] \tag{2}$$

Both voltages and charges can be represented by complex quantities [9] and the above matrix relationship is intended for both the real and the imaginary part

$$[Q] = [Q_r] + j\,[Q_i] = [P]^{-1} \cdot \{\,[V_r] + j\,[V_i]\,\} \tag{3}$$

where

$$[Q_r] = [P]^{-1} \cdot [V_r]\ dan\ [Q_i] = [P]^{-1} \cdot [V_i] \quad (4)$$

The elements of the matrix [P] are given by [9]

$$P_{xx} = \frac{1}{2\pi \cdot \varepsilon} \ln\left(\frac{4H_x}{d_x}\right) \text{ dan } P_{xy} = \frac{1}{2\pi \cdot \varepsilon} \ln\left(\frac{L'_{xy}}{L_{xy}}\right) \quad (5)$$

where H_x is the height of the conductor x above ground, d_x is the conductor diameter, L_{xy} is the distance between conductor x and conductor y, and L'_{xy} is the distance between conductor x and the image of conductor y. The voltage gradient at ground level [9] due to each conductor line charge is:

$$G_x = \frac{Q_{rx} + j\,Q_{ix}}{2\pi\varepsilon} \cdot \frac{2\,H_x}{(H_x)^2 + (L_x)^2} \quad (6)$$

where Q_{rx} and Q_{ix} are the real and the imaginary parts of the charge on the conductor x, L_x is the horizontal distance between conductor and the point on the ground at which the gradient is computed. Therefore, the total gradient of a transmission line [9], 3-phase is given by:

$$G = \sum G_X \quad (7)$$

The llustration of the voltage gradient Gx that corresponds to equation (7) is as follow [9]:

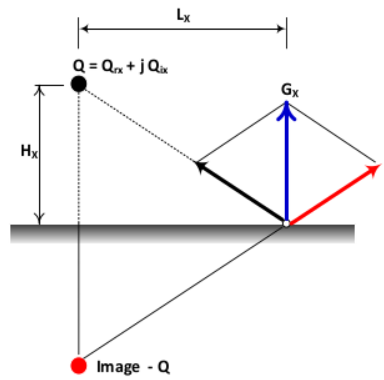

Figure 1. Voltage gradient at ground caused by a single conductor line charge

Several models and analysis in this research are needed. There are five stages that consist of :

a. Model of the air space of a 500 kV, EHV transmisson lines
b. Model of the Composite Dielectric Constant
c. Model of Maxwell Potential Coefficient Matrix
d. Model of Electrostatic Equation
e. Calculation of Electrical Field of a 500 kV, EHV Transmission lines

2.2. Model of the air space of a 500 kV, EHV transmisson lines

The model of the transmission line was the air space with 300 meters in length, 200 meters in width, and 60 meters in height. The air space will be filled by water when it rains and filled by pure air when it does not rain. Because the rain is the water droplets, the medium shape of a dielectric material is the composite medium between dielectric material of the water droplets and the pure air. The formulation of this composite medium is given by the permittivity ε_c [10]:

$$\varepsilon_c = \frac{\left(\varepsilon_1 \times \frac{a}{a_1}\right)}{1+\left(\frac{\varepsilon_1}{\varepsilon_2} \times \frac{a_2}{a_1}\right)} \tag{8}$$

The following is the sequence of modelings of extra high voltage transmission lines when the air space is filled by water droplets:

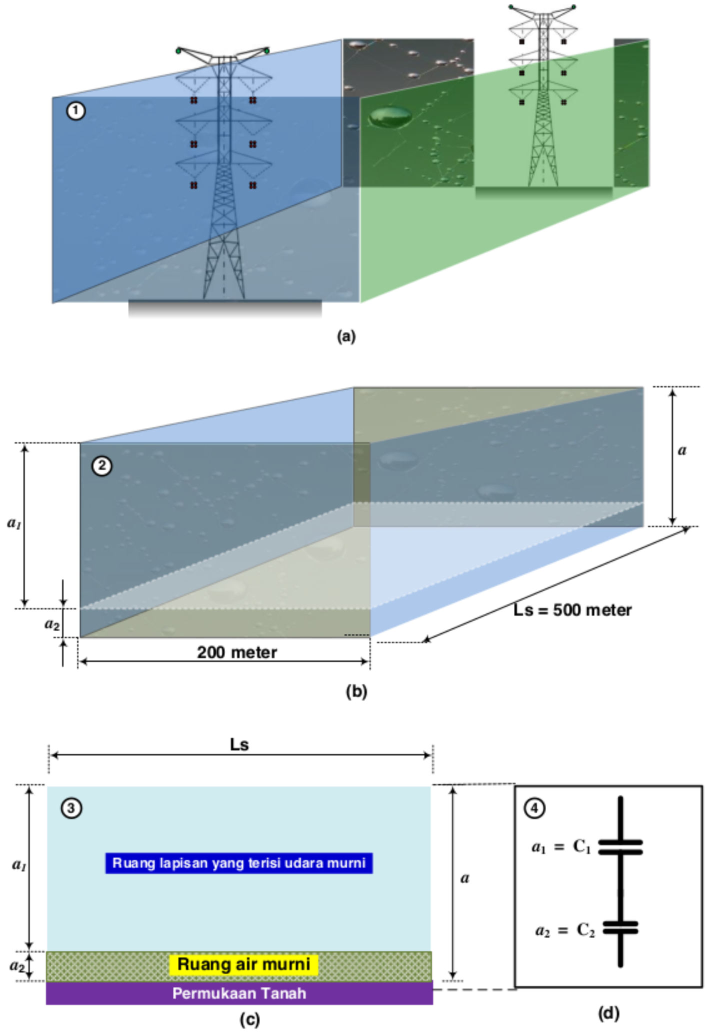

Figure 2. Modeling of the space between phase-conductor and ground surface when dew and raindrops are present

2.3 Model of the Composite Dielectric Constant

Figures 2c and 2d are a model of the composite delectrics between the pure air and dew and raindrops that have been composited and have value of composite permittivity as shown by the equation (8). From the computer study the value of composite permittivity between water droplets and the pure air that entered the air space as shown in Figure 2a and the curve of the composite permittivity is shown by Figure 3 [11].

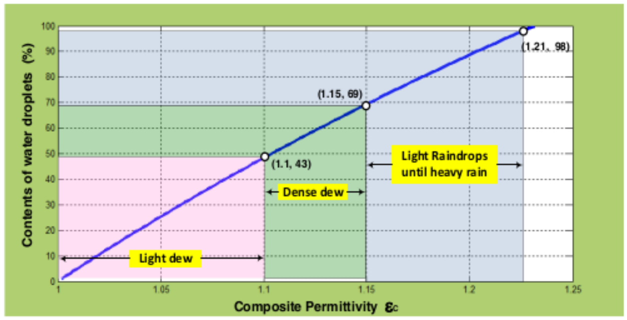

Figure 3. Composite permittivity between air and dew/raindrops

2.4 Model of Maxwell Potential Coefficient Matrix (MPCM)

The Maxwell Potential Coefficient Matrix (MPCM) is shaped by equation (5) through design data of the transmission lines that apply the concept of electric dipole to the conductors of transmission lines that have the tower structure of vertical configuration. The following is the form of the MPCM that is based on the configuration of an extra high voltage transmission lines which are evaluated [11].

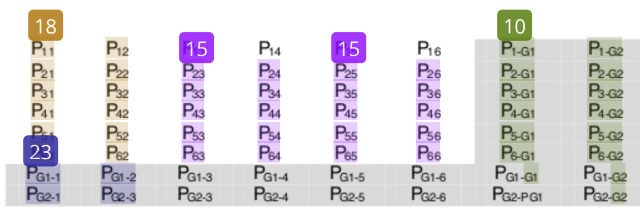

Figure 4. The Maxwell Potential Coefficient Matrix (MPCM)

2.5 Model of Electrostatic Equation

The electrostatic equation of the EHV tansmission lines 500 kV, vertical configuration, double circuit (R, S, T and U, V, W), and two ground wires (G_1 and G_2) are the simultaneous linear equations (SLE) that have 8 equations with 8 variables Q (electric charge) that were not known. The variables of Q_1 until Q_6 are charges in phase-conductors. Furthermore, the Q7 and Q_8 are charges in the ground wire respectively. The SLE can be written as follows:

$$
\begin{aligned}
V_1 &= P_{11}Q_1 + P_{12}Q_2 + P_{13}Q_3 + P_{14}Q_4 + P_{15}Q_5 + P_{16}Q_6 + P_{1,G1}Q_{G1} + P_{1,G2}Q_{G2} \\
V_2 &= P_{21}Q_1 + P_{22}Q_2 + P_{23}Q_3 + P_{24}Q_4 + P_{25}Q_5 + P_{26}Q_6 + P_{2,G1}Q_{G1} + P_{2,G2}Q_{G2} \\
V_3 &= P_{31}Q_1 + P_{32}Q_2 + P_{33}Q_3 + P_{34}Q_4 + P_{35}Q_5 + P_{36}Q_6 + P_{3,G1}Q_{G1} + P_{3,G2}Q_{G2} \\
V_4 &= P_{41}Q_1 + P_{42}Q_2 + P_{43}Q_3 + P_{44}Q_4 + P_{45}Q_5 + P_{46}Q_6 + P_{4,G1}Q_{G1} + P_{4,G2}Q_{G2} \\
V_5 &= P_{51}Q_1 + P_{52}Q_2 + P_{53}Q_3 + P_{54}Q_4 + P_{55}Q_5 + P_{56}Q_6 + P_{5,G1}Q_{G1} + P_{5,G2}Q_{G2} \\
V_6 &= P_{61}Q_1 + P_{62}Q_2 + P_{63}Q_3 + P_{64}Q_4 + P_{65}Q_5 + P_{66}Q_6 + P_{6,G1}Q_{G1} + P_{6,G2}Q_{G2} \\
V_{G1} &= P_{G1,1}Q_1 + P_{G12}Q_2 + P_{G13}Q_3 + P_{G14}Q_4 + P_{G15}Q_5 + P_{G16}Q_6 + P_{G1G1}Q_{G1} + P_{G1,G2}Q_{G2} \\
V_{G2} &= P_{G2,1}Q_1 + P_{G22}Q_2 + P_{G23}Q_3 + P_{G24}Q_4 + P_{G25}Q_5 + P_{G26}Q_6 + P_{G2G1}Q_{G1} + P_{G2G2}Q_{G2}
\end{aligned} \tag{9}
$$

2.6 Simulation of Electrical Field of a 500 kV, EHV Transmission lines

The simulation was conducted using equation (6) at which value of charge (Q) was determined by inversing [P] in the equation (9). The exposure of the electric field was ploted through variables Lx, Hx, and the charge Q in equation (6).This simulation was conducted by computer which used Matlab. The following is the flow chart of the simulation [11]:

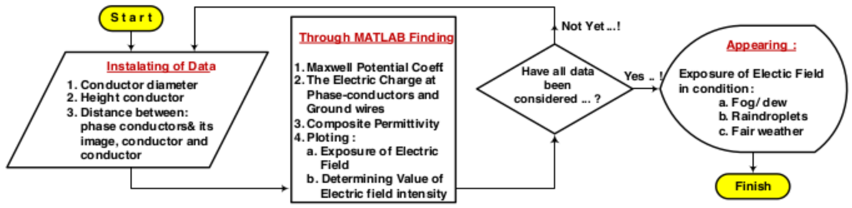

Figure 5. Flow chart of computer for the calculation of electric field

3. Results and Discussion

3.1 The Electric Field of a 500 kV EHV Transmission Line

The exposure of the electric field is presented in the condition: fair weather with contents of water droplets 25%, 50%, 70%, and 100% (in heavy rain condition). The exposure of electrical field is divided into four corridors: A, B, C, and D corridors. These corridors are located at lateral distance which is the same as at its axis: 0 m, 36 m, 62 m, and 150 m respectively as shown in Figure 6.

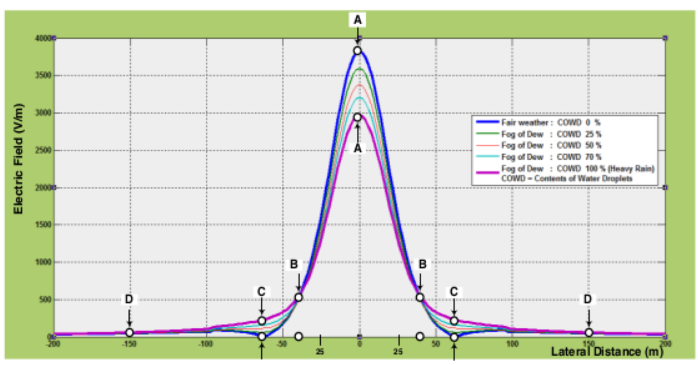

Figure 6. The exposure of lateral electric field with distance of 200 m

The result of the research conducted by Mpanga et al showed that the lateral distance was taken as far as 40 meters on the corridor edge with a range of electric fields fluctuating from 10 kV / m (minimum) to 32.38 kV /m (maximum) [12]. In this research, the growth of axis was taken as far as 200 meters to the edge of the corridor, each divided into the corridors A, B, C, and D, i.e. as far as: 0 m, 36 m, 62 m, and 150 m at the axis.

Mpanga et al did not take into account the air condition around transmission lines which have construction of a horizontal configuration [12], not a vertical configuration, as in the case under investigation. The consequence is that the position of the height of the conductor will certainly be different. Mpanga et al only expose the electric field distribution in a longitudinal profile and mix the exposure of the voltage gradient to the conductor surface and the lateral electric field distribution profile on the surface of the soil [12].This study showed that the electric field exposure curve had a good agreement.

The electric field generated by the extra high-voltage transmission line is part of a quasi-electrostatic electric field. The result of the research conducted by Caibo et al [13] about the influence of contamination on electric field distribution in direct current (DC) voltage dividers showed that the intensity of the electric field along the surface path which has been subjected to electric field magnitudes for electrostatic field types is slightly larger than the type of quasi-electrostatic field (almost insignificant) [13]. This fact indicates that when the air around the phase conductor is contaminated with moisture and water droplets (in humid contamination conditions) it turns out that each corridor has a small electric field fluctuation difference as shown Table 1, except in corridor C where the fluctuation interval is slightly larger than corridors A, B, and D. However, if a cluster of fog of the dew or rain droplets enter the volume space of the EHV transmission lines, the electric field intensity of transmission lines at the level extra high voltage (EHV) can increase and decrease.

3.2 The Electric Field at the Corridors A, B, C, and D

At corridor C located 62 meters from the coordinate (0.0) as shown in Figure 6, the magnitude of the electric field is 5.59 Volt/m. On the other hand, the electric field in the corridor A (0 meter from the coordinate 0.0) the magnitude of the electric field will be 3,821.31 Volt/m at condition of fair weather. Furthermore, when the air is fog of dew with contents of the water 25 %, 50 %, 70 %, and 100 % (heavy rain), the electric field at corridor 'A' will be 3,594.44 Volt/m, 3,374.98 Volt/m, 3,205.77 Volt/m, and 2,964.81 Volt/m respectively. Tabel 1 below showed the change of the electric field at corridors: A, B, C, and D.

Tabel 1. The influence of the dew and raindroplets against the elecric field Intensity

Corridor	Corridor Location (meter)	The intensity of Electric Field (Volt/meter)				
		Fair Weather CW = 0 %	Fog of Dew CW = 25 %	CW = 50 %	CW = 70 %	Rain droplets CW = 100 %
A	0	3,821.31	3,594.44	3,374.98	3,205.77	2,964.81
B	36	718.36	674.79	651.22	648.30	670.78
C	62	5.59	57.71	115.82	162.38	232.25
D	150	45.15	44.14	45.75	48.78	55.60

Note: CW = Contents of Water

3.3 The Change of the Electric Field at Corridors A and B

Corridor A is a location of the exposure of electric field at the coordinate (0, 0), the electric field of which has maximum value. At this corridor the electric field decreases linearly as shown in Figure 7 when the weather under fog of the dew at which contents of the water droplets in the air are from 0% to 25%, 50%, 70%, and 100% (rain droplets condition).

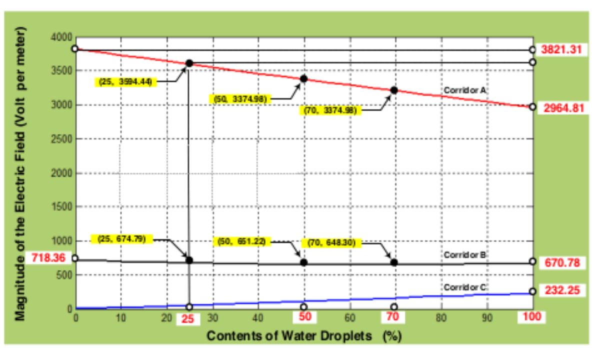

Figure 7. The change of the electric field at corridor A, B and C

Corridor B is a location of the exposure of electric field at the coordinate (36.0) which is the magnitude of the electric field with the value of: 718.36, 674.79, 651.22, 648.30, and rises again to 670.78 V/m. The change of the electric field is shown by Figure 7 as a parabolic curve. The change of the electric field corresponds to contents of the water in air i.e. 0%, 25%, 50%, 70%, and 100% at the coordinate (36.0).

3.4 The Change of the Electric Field at Corridors C and D

Corridor C is a location of the exposure of electric field at the coordinate (62.0) which is the maghnitude of the electric field with the value of: 5.59, 57.71, 115.82, 162.38, and rises again to 232.25 V/m. The change of the electric field is shown by Figure 8 as a linear curve and makes the rate of electric field change that corresponds to contents of the water in air space i.e 0%, 25%, 50%, 70%, and 100% at the coordinate (62.0).

Corridor D is a location of the exposure of electric field at the coordinate (150.0) which is the maghnitude of the electric field with the value of: 45.15, 44.14, 45.75, 48.78, and then rises to 55.60 V/m. The effect of the droplets (raindrops) and dew agaisnt the exposure of the electric field at corridor D is shown by Figure 8 as a little part of a parabolic curve that corresponds to contents of the water in air i.e.: 0%, 25%, 50%, 70%, and 100% respectively.

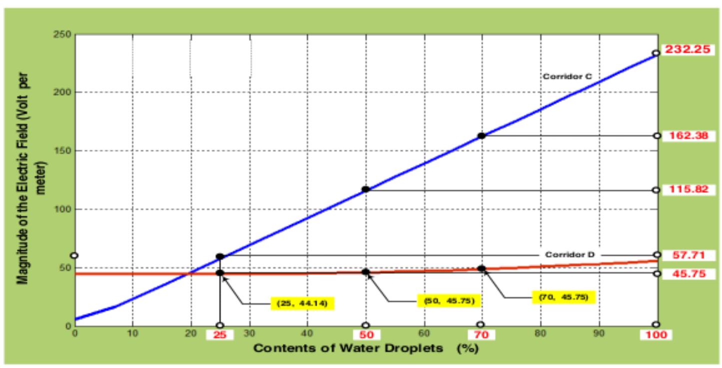

Figure 8. The change of the electric field at corridor C and Corridor D

4. Conclusion

Based on the analysis and description above it can be concluded that the exposure and intensity of the electric field in several places under the extra high voltage (UHV) transmission lines changed when dew and raindrop were present in the air space under the UHV transmission lines. There were four locations where the changing of the intensity of the electric field occurred due to the dew and raindrops i.e. corridors A, B, C, and D with coordinate (0.0); (36.0); (62.0) and (150.0) respectively. The effect of the water droplets either the water of dew or the raindrops at corridors A, B, C, and D can increase and decrease the intensity of the electric field. The corridor A, located at the coordinat (0, 0), the electric field will decrease along with the increase of the contents of the water. Otherwise, at corridor C, the intensity of the electric field will increase along with the increase of the contents of the water. At corridor B, the electric field decreased to 648.30 Volt/meter that corresponds to the contents of the water in air 70% while at corridor D, the electric field decreased to 44.14 Volt/meter with condition that the contents of the water in air are 25%.

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