2000 Conference on Electrical Insulation and Dielectric Phenomena

Regression Technique for Prediction of Salt Contamination Severity on High Voltage Insulators

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Abstract

In the east-coast of Peninsular Malaysia high voltage insulators of power plants and factories suffered from rapid salt contamination accumulation because of heavy wind coming from the South China Sea. One attempt has been done at one of these plants which is located about 500 meters from the seashore to determine the severity of this kind of contamination and subsequently to determine a suitable mitigation method to overcome this problem. This work describes a mathematical model, which could help to determine the contamination level. It has been proven that the contamination severity predictive model is possible by using regression technique and it is a useful method for determining Equivalent Salt Deposit Density (ESDD).

Introduction

Many researchers have studied the effect of meteorological conditions on outdoor insulation with respect to flashover on high voltage insulators or with ESDD [1, 2]. They have taken one or two, at the most, of the atmospheric parameters in their considerations to develop some mathematical relationships to correlate the effect of these parameters against flashover voltage or ESDD. Kimoto et al. [1] found that ESDD on insulators depends on the (wind speed)^3 and also the distance from the seashore. The contaminants that can not be easily removed by wind velocity less than 10m/sec can produce a high leakage current at high humidity which can leads to flashover [3]. Some researches have proved that rainfall is an effective factor for cleansing the insulator surfaces [4, 5]. On the other hand, reported in [6] that in the presence of rain the flashover occurs at lower contamination severity. than in clean fog. Heavy rain can washes off the salt and reducing leakage current [6]. The wind from the sea produces pollution and the pollution cycle depends on the wind direction [8]. A higher temperature is responsible for a lower relative humidity, which leads to lower flashover voltages [4, 9]. The air pressure does affect the flashover voltages of polluted insulators and the critical flashover voltage decreases as the air pressure decreases [10, 11]. J. S. Barrett et al. have developed a new statistical tools and performed some tests on the suspension insulators of transmission line and substation post insulators on the some parameters which can affect the reliability of power system to determine their probability of failure under design stresses [12]. In this paper, most of the meteorological parameters such as temperature, humidity, rainfall, pressure, wind speed and wind direction have been considered to study the ESDD accumulation pattern on the high voltage insulator surfaces. A mathematical model for relating ESDD with the above mentioned meteorological conditions has been developed using a multiple linear regression technique.

Data Collection

The relevant meteorological parameters such as ambient temperature, relative humidity, quantity of rainfall, pressure, wind speed and wind direction were measured at Paka Power Station corresponding to 120 number of observations. From Fig. 1, it is clear that the inverse relationship exists between ESDD and temperature. Fig. 2 reveals that there is no clear effect of the humidity on ESDD. Whereas pressure adds a clear positive effect on ESDD, see Fig. 3. Contrary to our assumption that the rainfall gives an inverse effect towards ESDD and it also provides a naturally washing for the insulators, it has been recorded that this independent variable does not add any clear effect on ESDD value, see Fig. 4. There is a great significance of wind speed variable to ESDD. Fig. 5 shows that the increase in wind speed provides a clear increase in ESDD. It was found that wind direction variation does influence ESDD pattern. The increase in wind direction angle results a clear decrease in ESDD.

The inter-dependency and influence of the above parameters on ESDD was studied by mean of a multiple regression analysis. In the regression analysis, the ESDD was the dependent variable while the other parameters were the driving variables (independent). In the model the six independent variables which were used in the equation as follows; temperature (X_1), humidity (X_2), pressure (X_3), rainfall (X_4), wind speed (X_5) and wind direction (X_6). So, the predictor model in raw-score form is:

$$Y = B_o + B_1 X_1 + B_2 X_2 + ...+ B_j X_j \text{ ....} (1.1)$$

and compute values for the B's in a way that satisfies the least squares criterion. The value obtain for B_o represents the predicted value of Y when X_1, X_2, ...X_6 remain constant. Similarly, the value of B_2 gives us the predicted rate of response in Y to the change in X_2 if X_1, X_3, ...X_6 remain constant, etc.

Unstandardized Regression Coefficient

The ESDD in this case can be pinpointed at the intersection of six scores. Accordingly, we decide to base our relationship investigation on a random sample of 120 tests. The variables in our investigation, with the units of measurements are:

1- Temperature, independent variable (X_1) in C^o
2- Humidity, independent variable (X_2) in %
3- Pressure, independent variable (X_3) in mbar
4- Rainfall, independent variable (X_4) in mm
5- Wind speed, independent variable (X_5) in m/s
6- Wind direction, independent variable (X_6) in degree
7- ESDD, dependent variable (Y) in mg/cm^2

The multiple linear regression equation can be written base on the dependent and independent variables considering that all independent variables have positive response with the dependent variable Y as:

$$ESDD = B_o + B_1X_1 + B_2X_2 + B_3X_3 \text{........} B_6X_6 \text{ .....} (1.2)$$

Using the least squares criterion to select the values for the B's, we obtain the result:

$$ESDD= -2.332 - 4.412E\text{-}03X_1 - 3.752E\text{-}04X_2 + 2.426E\text{-}03X_3 - 5.044E\text{-}05X_4 + 7.439E\text{-}03X_5 - 1.586E\text{-}04X_6 \text{ ......} (1.3)$$

From this equation we can predict the rates of response of ESDD to change in the independent variables. A typical sample of temperature: for each 1^o variation in temperature with no change in other variables, a predicted reduction of 4.412E-03 in ESDD since B_1 = temperature coefficient. The same way follows to predict the response in ESDD for every independent variable, taking into consideration the coefficient sign. It is noted that since B_o = -2.332, the predicted ESDD at a point of all independent coefficient variables = 0, is – 2.332. Therefore, it can be established the confidence interval for the estimated B. For example, if the estimated B for wind speed is 7.439E-03 and the standard error of this B is 0.001, the 95% confidence interval would be:

$$7.439E\text{-}03 - 1.96 (0.001) < B < 7.439E\text{-}03 + 1.96 (0.001) \text{ ......} (1.4)$$

the B estimates follow the *t* distribution with (N-2) degree of freedom. Therefore, the 95% confidence interval for B given the sample size of 120, estimated B for wind speed = 7.439E-03, and the standard error of B = 0.001, is given by:

$$7.439E\text{-}03 - 1.98 (0.001) < B < 7.439E\text{-}03 + 1.98 (0.001) \text{ ......} (1.5)$$

The value (1.98) is obtained from the table of Student's *t* distribution with the degree of freedom equals to 120.

Standardized ESDD Model

The multiple regression analysis is computed using a standardized model:

$$Z_Y = B_1Z_1 + B_2Z_2 + \text{.........} + B_6Z_6 \text{ ....} (1.6)$$

In which $B_{1,\ 2,\ 3...}$ are called standardized partial regression coefficients, and Z_Y and $Z_{1,\ 2,\ 3\ ...}$ are the criterion variable and the predictor variables, respectively, expressed in standardized form. From the regression analysis of the data the standardized model is;

$$ESDD= -0.197Z_1 - 0.064Z_2 + 0.235Z_3 - 0.028Z_4 + 0.513Z_5 - 0.231Z_6 \text{ ......} (1.7)$$

T-Test

In many investigations we are interested in discovering and evaluating the differences between effects, rather than the effects themselves. The *t* is a statistic generally applicable to a normally distributed random variable where the mean is known and the population variance is estimated from a sample [13]. In our model the statistic

t is distributed as a student's t with (N-1) degree of freedom. The test is carried out by comparing the observed value with the appropriate tabulated critical t value. The usual test is for $B_1=0$ in which case t reduces to the ratio of B_1 with confidence coefficient $(1-\alpha)$ is given for the model;

$B_1 \pm t$ {N-7, $\alpha/2$}[SE (B_1)] .... (1.8)

where t (N-7,α) is the $(1-\alpha)$ percentile of at distribution with (N-7) degree of freedom. For our model, the printed t values test the null hypothesis $H_0(Bi=0)$ against an alternative H_1 $(B_1\neq 0)$. From the t distribution table it is seen that only the variables B_0 (constant), pressure (X_3), wind speed (X_5) and wind direction (X_6), have regression coefficient that approach being significantly different from zero with confidence 95%, since the critical value for the variables from the t distribution table is t=1.98. And the computed values of t for the variables are:

for B_0=-2.624, for X_1=-1.411, for X_2=-0.488, for X_3=2.924, for X_4=-0.401, for X_5=7.986, for X_6=-3.204

In case variables (X_1, X_2 and X_4), we cannot reject the H_0 for these variables, which means that these variables have no significant effect on ESDD value.

Tests of Significance

The procedure for test of significance is to calculate the probability of finding a deviation as extreme as or more extremes than the observed deviation on the assumption that the Null Hypothesis is discredited. Usually the value of the probability P=0.05 gives sufficient assurance and the results is usually referred to as significant and when P=0.01 as highly significant [14]. We have chosen the P=0.05 for our model. From the result we can see that only pressure, wind speed and wind direction have values of significance less than the probability value. Therefore, we will consider these variables as having significant effects on changing ESDD. On the other hand, the variables such as temperature, humidity and rainfall have less significance; thus, we can remove them from our model.

Conclusions

Regression technique is a useful method to develop a new ESDD mathematical model which could allow us to predict the contamination severity. Also the model

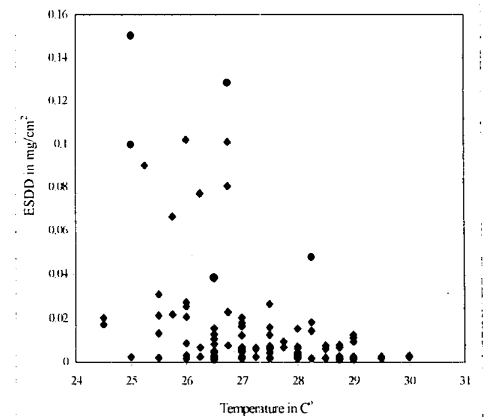

Figure 1: ESDD vs. temperature/daily sample

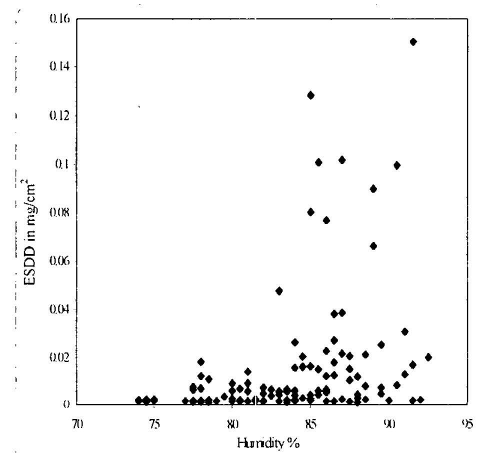

Figure 2: ESDD vs. humidity/daily sample

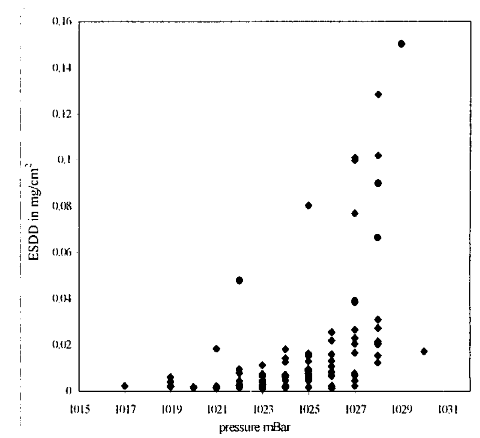

Figure 3: ESDD vs. pressure/daily sample

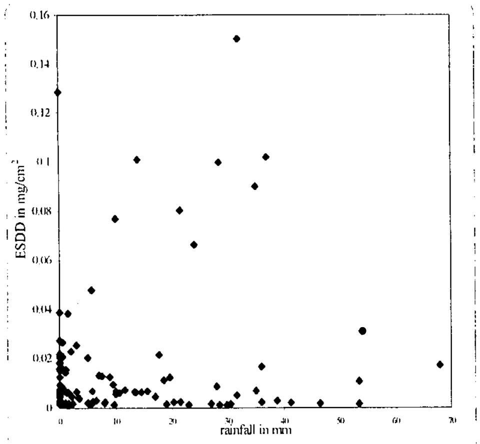

Figure 4: ESDD vs. rainfall/daily sample

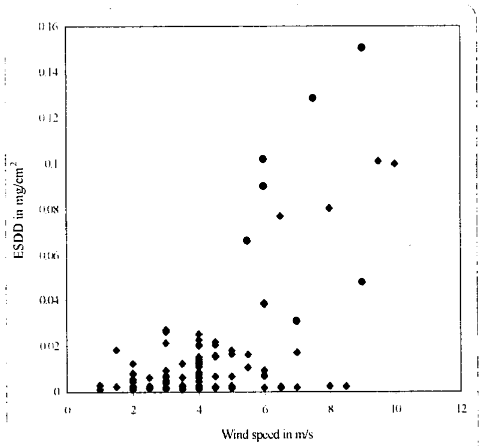

Figure 5: ESDD vs. wind speed/daily sample

provides an ideal way for determining the frequency of maintenance of the contaminated insulators. Through this model we have found that the wind speed has the largest effect on ESDD followed by air pressure and wind direction and the predictor variables such as temperature, humidity, rainfall and wind direction have negative regression coefficients sign which means that ESDD increases when all these variables decrease.

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