A Novel Approach to Predict Leakage Current in Insulators from Wind Velocity

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ABSTRACT

A relationship between the leakage current and wind velocity, which is the first of its kind, has been proposed in this paper. This relationship has been derived based on Dimensional Analysis technique. The proposed relationship has been applied for prediction of leakage current in the 275 kV insulators of YTL (Yeoh Tiong Lay) Power Station, which situated at the coast of South China Sea, Terrengannu, Malaysia. The calculated results were compared with the measured leakage current data. There was an excellent concordance between the experimental results and those calculated from the mathematical model.

Keywords: Leakage current, Wind velocity, Dimensional analysis, Insulator.

1. INTRODUCTION

The insulators of power lines, switchyards and other power installations sited near seacoast get contaminated with wind borne salt and dust particles and formed contamination layer. Such a layer is composed of largely inert and often conductive compounds as carbon, metal oxides and salts. This layer may form conductive path, usually in the presence of fog or dews or light rain. This conductive layer allows the flow of leakage current through the insulator surface under system voltage. It results in the ohmic heating on the insulator surface and drying of the contaminated layer by rapid evaporation of the moisture at the location oh high current density. This phase of development is known as the dry band formation [1]. The dry band has a high resistance, across which the entire energized voltage of the insulator existed. This causing a localized breakdown or arc bridging over the dry band and leading to a widening of the dry band due to moisture evaporation and finally arc extinction. These intermittent arc bridging and arc extinction produce leakage current pulses with sharp peaks [2]. If the insulation resistance of the insulator decreases abruptly due to excess contamination on its surface, then leakage current becomes large. When the rate of current change is extremely high, full flashover occurs on the insulator surface. During the flashover on the insulator surface the leakage current increases tremendously. This is due to the non-uniformity of the distribution of the contamination on the insulator surface [3-4].

In order to prevent wetting and hence formation of conducting film in the presence of contaminants that give rise to uncontrolled leakage currents resulting in flashover, polymers are presently used as alternative materials instead of glass and porcelain for outdoor insulators [5]. Though polymers help in attaining high flashover voltage these are expensive compared to commonly used porcelain and glass insulators.

The porcelain and glass insulators of YTL (Yeoh Tiong Lay) Power Station at Terrengannu, Malaysia are facing contamination problems due to wind velocity at the seacoast. The location of YTL Power Station is shown in Fig. 1.

For getting better performance, the insulators of that power station should be washed at appropriate times. The decision for washing is taken by YTL Power Station engineers through measurement of leakage current of selected insulators. It appears from a review of the literature [6-9] that although a number of measurement techniques on leakage current and other parameters are available, no mathematical relationship between leakage current and wind velocity has yet been proposed. This paper presented the development of a mathematical model considering the effect of wind velocity on the variation of leakage currents in the contaminated insulators using Dimensional Analysis technique [10]. The results calculated from the proposed model are compared with the available measured leakage current data made available from YTL Power Station.

List of Symbols

- $I$ Leakage current in the insulator;
- $w$ Wind velocity;
- $N$ Static arc constant;
- $w$ Weight of the insulator;
- $et$ Exposure time;
- $L$ Length of fundamental SI units;
- $M$ Mass of fundamental SI units;
- $T$ Time of fundamental SI units;
- $A$ Current of fundamental SI units;
- $n$ Arc constant;
- $k_1$ Exponent of the variable $I$;
- $k_2$ Exponent of the variable $w$;
- $k_3$ Exponent of the variable $N$;
- $k_4$ Exponent of the variable $w$;

Manuscript received on July 15, 2005 ; revised on November 4, 2005.

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2. EXPERIMENTAL PROCEDURE

The insulators in YTL (Yeoh Tiong Lay) Power Station are located at a height of about 50 meters from the sea level. For measuring leakage current, the artificial electrode is fixed near the first shed of the 275 kV line post test insulator and tightened by a screw. This arrangement is shown in Fig. 2 (a). A cable is connected between the electrode and the leakage current measuring instrument, which is shown in Fig. 2(b).

The Leakage Current Monitor (LCM) measures the leakage current and the highest leakage current is printed and remains on display until a next higher value occurs or the instrument is reset. The leakage current of the contaminated insulator is found to be 0.01.

The insulators in YTL (Yeoh Tiong Lay) Power Station were measured using velocity meter. All instruments used in the experiment are calibrated with the standard instruments before commencing the leakage current measurement. The percentage of error of comparison results between the standard and LCM instrument is found to be 0.01.

3. DEVELOPMENT OF RELATIONSHIP

The leakage current of the contaminated insulator is dependent on wind velocity, exposure time, insulator weight and static arc constant. The mathematical relations among them can be written as,

\[ I = I(wv, N, w, et) \] (1)

The dimensional matrix of the above variables with exponents can be written [9] as

<table>
<thead>
<tr>
<th>( k_1 )</th>
<th>( k_2 )</th>
<th>( k_3 )</th>
<th>( k_4 )</th>
<th>( k_5 )</th>
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<tbody>
<tr>
<td>I</td>
<td>wv</td>
<td>N</td>
<td>w</td>
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<tr>
<td>L</td>
<td>0</td>
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<td>M</td>
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<td>T</td>
<td>0</td>
<td>-1</td>
<td>-3</td>
<td>0</td>
</tr>
<tr>
<td>A</td>
<td>1</td>
<td>0</td>
<td>n-1</td>
<td>0</td>
</tr>
</tbody>
</table>

Here, the rank of the above matrix is 4 and the dimensionless product of the whole set is 1. The algebric equations from the above dimensional matrix can be written as:

\[ k_2 + k_3 = 0 \] (2)
\[ k_3 + k_4 = 0 \] (3)
\[ -k_2 - 3k_3 + k_5 = 0 \] (4)
\[ (n-1)k_5 + k_1 = 0 \] (5)

By assigning [9] the value of \( k_1 = 1 \), the solutions may be arranged in the matrix form as given below:

\[
\pi = \begin{bmatrix} I \\ wv \\ N \\ w \\ et \end{bmatrix} = \begin{bmatrix} 1 \\ \frac{1}{2(n-1)} \\ \frac{1}{2(n-1)} \\ \frac{1}{2(n-1)} \\ \frac{1}{n-1} \end{bmatrix}
\]

The expression of \( k_5, k_4, k_3 \) and \( k_2 \) in terms of \( k_1 \) can be derived from equation (2), (3), (4) and (5) as

\[
k_5 = -\frac{1}{n-1}k_1, \quad k_4 = \frac{1}{2(n-1)}k_1
\]
\[
k_3 = -\frac{1}{2(n-1)}k_1, \quad k_2 = \frac{1}{2(n-1)}k_1
\] (6)

4. RESULTS AND DISCUSSION

Numerical values of the leakage currents for the YTL Power Station for Blocks 10 and 20 insulators have been calculated from the equation (9). During the simulation, the values of dimensional constants \( (D_e) \) and exponent \( (b) \) are considered [11] as 2.4 and 2.2 for the insulators of Block 10 while 4.8 and 4.4 for the Block 20 respectively. The calculated and measured leakage currents of an insulator at Block 10 versus wind velocity are plotted in Fig. 3 for comparison. In this Figure the experimental and numerical values of leakage currents are close to each other. Similarly the measured and calculated values of leakage currents for Block 20 are plotted in Fig. 4. In the Fig. 4, the experimental and numerical values of
leakage currents are close to each other up to wind velocity 3.75 m/sec. After this wind velocity, there is a discrepancy between the experimental and numerical values of leakage currents. This may be due to non-uniform contamination layer on the insulator surface of the respective block. The non-uniform contamination layer on the insulator surface is due to anomalous direction of the wind velocity. Currently, the insulators at YTL Power Station are washed every week due to non-uniform salt contamination.

It has been found in the YTL Power Station that whenever measured leakage current is above 13 mA, the insulators undergo flashover. In this range, the obtained analytical values of leakage currents also do not differ widely so that a wrong conclusion about flashover occurrence based on the proposed analytical model is unlikely.

For calculating leakage current, the effect of weight of the insulator is considered instead of its exposed area just for the development of the relationship between them. Also in the experiment, the leakage current is recorded only with the variation of wind velocity of the fixed number of insulators.

For designing high voltage equipment like insulators, the closed form formula is required where related terms or factors are involved. In this research, the important term is considered as wind velocity. The insulators could be designed for that region by considering the effect of contamination layer, which deposited with the help of wind velocity.

5. CONCLUSIONS

In this study, a mathematical relationship between the leakage currents and wind velocity has been proposed using the Dimensional Analysis technique. The proposed relationship provides results in close agree-
ment with the measured values of leakage currents. This will be helpful for the utility engineers to take decision for washing the insulators time to time just by knowing the wind velocity. Also insulators can be designed properly by using the relationship to predict leakage currents likely to occur at various wind velocities.

References