

Research Article

Modelling the Effects of Leakage Current Resistance in Transmission Line

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Abstract: Determining the mechanisms and influences of leakage current resistance that results power loss in transmission line is an outstanding quest. Perfect insulations are pre-requisite for electrical systems to achieve maximum efficiency. The level of insulator contamination determines the loss enhancement in power transmission systems mediated by leakage current. This phenomenon in turn changes the physical characteristics of the insulation through the enhancement of resistance. In this study, we propose a new model using MATLAB to examine the effect of leakage current resistance on the short and medium transmission lines of five buses. Three levels of leakage resistance (high, medium and low) are incorporated into the model through delta-star/star-delta conversion and two-port network concept. The input impedances for the load flow equations are updated. Results show that the leakage current resistance mediated via the deposition of the pollution on the transmission line plays a major role in the power loss. The amount of power losses and the cost factor in the presence of leakage can be estimated with this model our simplified model to examine the effects of leakage current in power transmission lines may be useful for loss minimization and remedy.

Keywords: Insulator, leakage current, modelling, transmission line

INTRODUCTION

Leakage current is defined as any current that flows from the hot conductor to the ground over the outside surface of an insulator. In the absence of a grounding connection, this current flow from the conductive part or the surface of non-conductive parts to ground if a conductive path is available and it often become fatal when touched by humans. Detecting, monitoring, quantifying and determining this leakage current are essential for maintaining safety and ensuring cost efficiency (Amin *et al.*, 2009). High power transmission line can be protected via the detection of leakage current resistance and assessment of the conduction quality during operation. The working efficiency of the transmission system depends on the leakage strength. The value of total resistance between point of insulation failure and the ground is a significant factor in ensuring safety.

The insulator in transmission line plays a key role in the power system. Generally, the insulation in any transmission system deteriorates over a particular time span because of temperature, moisture and other factors. Based on the nature of the material used, insulators can be categorized as porcelain, glass and polymer insulators. These insulators in transmission lines under operation are frequently exposed to pollution effects that accumulate on their surfaces. Consequently, under wet conditions, the generated

leakage currents originate non-uniform heating on the surface of the insulator and this in turn causes dry-band arcing and possible flashover. Insulation flashover leads to service outages, which affect reliability and results economic losses for both the user and the supply company. The transmission systems are expensive and damages in their insulation often causes high economic losses and life-threatening effects. Therefore, an in depth examination of leakage current is significant for all electrical devices and insulators (Jiang *et al.*, 2011; Fierro-Chavez *et al.*, 1996; Piah and Darus, 2004). Overcoming these leakage effects and minimizing the losses involved are the challenging tasks.

The leakage current both for devices and for insulators is drawn from the main supply. it never contributes to any useful power in the load and instead leads to wastage. Nevertheless, it remains important in the design, selection and installation of the transmission line. The performance of the insulator is drastically affected by the increase in leakage current. In this situation, the current cannot pass inside the insulator and a path of relatively low resistance exists over the surface, as shown in Fig. 1 (Amin *et al.*, 2009).

The leakage current is found to directly proportional to the surface pollution deposit. In fact, thick layers of pollutants are capable of trapping more rain water in wet conditions. Much water on the surface reduces the surface resistance and thereby enhances the leakage current. The insulators used in coastal and

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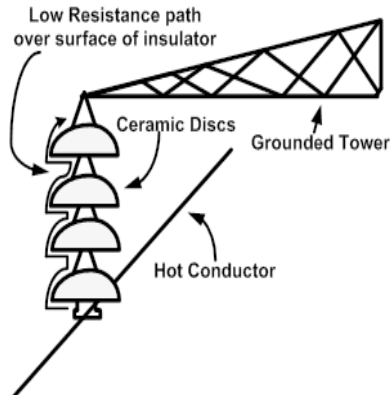


Fig. 1: Low resistance path on the insulator surface

industrial environments receive severe pollution deposits. In service, the surface resistance of the insulator under wet conditions the presence of contaminations considerably decreases (Piah and Darus, 2004). Essentially, the insulator with a surface resistance lower than 400 kΩ must be replaced or washed off to avoid the leakage current losses (Fierro-Chavez *et al.*, 1996). The power loss is obviously low in the absence of any precipitation (Wei *et al.*, 2012). Despite some efforts, no standard method has been established thus far to determine the amount of leakage currents or compute the effective leakage current losses in terms power and economy.

We developed an improved transmission line model to determine the effect of surface insulator resistance on the load flow program for the system. The values of active and reactive power components, voltages and angles for buses are calculated. The effects of leakage current on the real power losses, especially with the increase in fuel cost, are evaluated. The medium and short transmission lines (five buses) are used with high, medium and low levels of leakage resistance. Delta-star/star-delta conversion and two-port network concept are utilized to update the input impedances for the load flow equations. The effects of these losses because of leakage over a long period of the time are analysed. This model may be useful in identifying the insulator severity level in load flow studies and determine loss in transmission line.

METHODOLOGY

Modeling: Transmission lines are specialized cables or conducting structures designed to carry electricity or the electrical signal of radio frequency. They are used for electric-power transmission (bulk transfer of electrical energy) from generating power plants to the electrical substations. The interconnected transmission lines are called transmission networks. As one of the most important and integrated parts of electric power systems, transmission lines require absolute stabilization, precise control and regular monitoring. As previously mentioned, the pollution

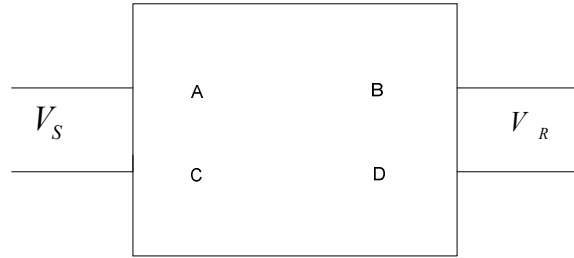


Fig. 2: Two-port representation of transmission line

deposits on the insulators in transmission lines give rise to the leakage current. The Majority of previous works on the load flow in power systems neglected the role of leakage currents compared with that of the actual current flow in the transmission line (Wadhwa, 2005). However, in our view, the influences of leakage currents must be considered in the load flowthrough representation of all towers as a resistance. The purposes are to make an accurate estimate of loss and identify the corresponding solution needed. A complete evaluation of this leakage current related loss in transmission line may assist the power provider to save on power costs and ensure the smooth running of power station at this juncture when the fuel cost is exponentially increasing. Generally, leakage current appears in every transmission line as low, medium and high levels. We focus on the short and medium transmission line model.

Short transmission line model: Resistance, inductance and capacitance are the integrated components of any transmission line. For short transmission lines (lower than 80 km), the capacitance (c) can be neglected and the equivalent circuit includes only the Resistance (R) and the inductance (X_L) (Saadat, 2002). We use a series connected model with a Voltage source (V_S), current source (I_S) and Voltage load (V_R) to characterize the short and medium transmission line as depicted in Fig. 2. The line containing the impedance is divided into many sections during the incorporation of the effects of leakage current resistance in the transmission line between buses. All sections are represented following π -section and two-port network concept.

The current voltage relationship in the two-port network is written as:

$$V_S = AV_R + BI_R \quad (1)$$

$$I_S = CV_R + DI_R \quad (2)$$

$$\begin{bmatrix} V_S \\ I_S \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix} \quad (3)$$

$$\begin{bmatrix} A = 1 \\ B = Z \\ C = 0 \\ D = A \end{bmatrix} \quad (4)$$

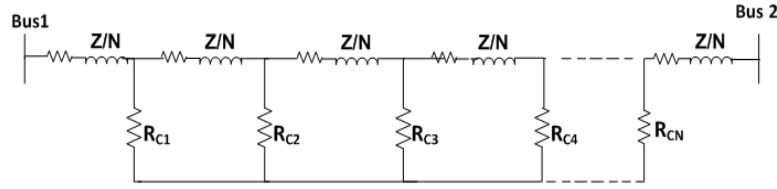


Fig. 3: Short transmission line with leakage current effects

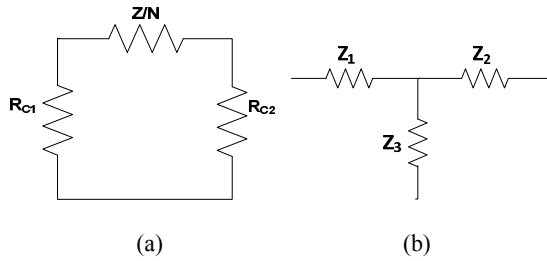


Fig. 4: Delta (a) star (b) conversion in short transmission line

The number of towers N existing in the transmission line is defined by:

$$N = T_d / d_t \quad (5)$$

where,

T_d = The total distance between two buses

d_t = The distance between two towers

Figure 3 shows that a new network model can be designed by introduction of leakage current resistance in the transmission line.

This new model contains the delta-star/star-delta conversion as displayed in Fig. 4, which is used to simplify the two-port network.

The expressions for the impedances (Z_1 , Z_2 and Z_3) in the simplified two-port network model are obtained as:

$$Z_1 = \frac{\left(\frac{Z}{N}\right) * R_{C1}}{\left(\frac{Z}{N}\right) + R_{C1} + R_{C2}} \quad (6)$$

$$Z_2 = \frac{\left(\frac{Z}{N}\right) * R_{C2}}{\left(\frac{Z}{N}\right) + R_{C1} + R_{C2}} \quad (7)$$

$$Z_3 = \frac{R_{C1} * R_{C2}}{\left(\frac{Z}{N}\right) + R_{C1} + R_{C2}} \quad (8)$$

where,

Z = The impedance line

R_{C1} and R_{C2} = Leakage current resistances

Medium transmission line model: Transmission lines of length longer than 80 km and shorter than 250 km are classified as medium transmission lines. They can

be modelled as nominal π and T forms. In this study, π -representation is used, where the total admittance as a result of the line capacitance is equally divided into two halves and each half is connected at both transmitter and receiver ends (Saadat, 2002). The impedance equation yields:

$$Y = (G + jw_c) l \quad (9)$$

where, C is the line to neutral capacitance per km, Y is the total shunt admittance, l is the line length and w_c is the signal frequency. Under normal condition, the shunt conductance per unit length represents the leakage current over the insulator. The leakage current as a result of the corona is negligible and the value of G is assumed to be zero. Using Fig. 5, the transmitter end voltage and current for the nominal π -section are obtained.

The constants A , B , C and D for the nominal π model take the form:

$$A = \left(1 + Z \frac{Y}{2}\right), B = Z \quad (10)$$

$$C = Y \left(1 + \frac{ZY}{4}\right), D = \left(1 + \frac{ZY}{2}\right) \quad (11)$$

Generally, the constants A , B , C and D are complex. the π model is a symmetrical two-port network model, so $A = D$ is obtained. The determinant of the transmission matrix represented by Eq. (3) is reduced to:

$$AD - BC = 1 \quad (12)$$

In solving Eq. (3), the quantities in the receiver end in terms of the transmitter one can be expressed as:

$$\begin{bmatrix} V_R \\ I_R \end{bmatrix} = \begin{bmatrix} D & -B \\ -C & A \end{bmatrix} \begin{bmatrix} V_s \\ I_s \end{bmatrix} \quad (13)$$

Now, the new model for medium transmission line in the presence of leakage current resistance (Fig. 6) is achieved.

The values of the transmission matrix for all sections (A , B , C and D) can be computed in the presence of leakage effects. The number of sections

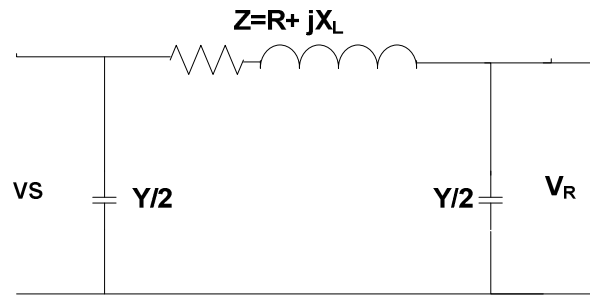


Fig. 5: Nominal π -model for medium length line

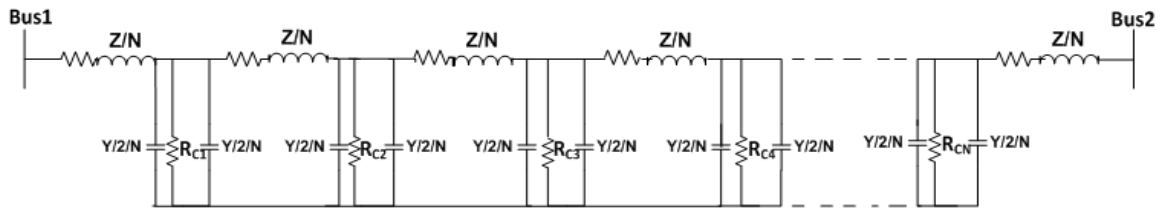


Fig. 6: Medium transmission line modelled with leakage current resistance

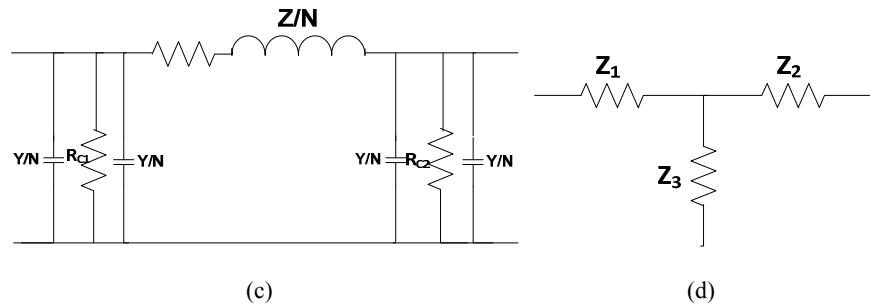


Fig. 7: Delta (c) star (d) conversion in medium transmission line

critically depends on the line. Finally, the expression for transmission matrix is represented as:

$$\begin{bmatrix} A_1 & B_1 \\ C_1 & D_1 \end{bmatrix} * \begin{bmatrix} A_2 & B_2 \\ C_2 & D_2 \end{bmatrix} * \begin{bmatrix} A_3 & B_3 \\ C_3 & D_3 \end{bmatrix} \dots \begin{bmatrix} A_N & B_N \\ C_N & D_N \end{bmatrix} = \begin{bmatrix} A_T & B_T \\ C_T & D_T \end{bmatrix} \quad (14)$$

The model network as displayed in Fig. 7 encloses the delta-star/star-delta conversion which simplifies the two-port network concept.

The impedance equations in this simplified picture are given by:

$$Z_{in1} = \frac{\left(\frac{1}{2 * \frac{Y}{N}}\right) * R_{C1}}{\left(\frac{1}{2 * \frac{Y}{N}}\right) + R_{C1}} \quad (15)$$

$$Z_{in2} = \frac{\left(\frac{1}{2 * \frac{Y}{N}}\right) * R_{C2}}{\left(\frac{1}{2 * \frac{Y}{N}}\right) + R_{C2}} \quad (16)$$

$$Z_1 = \frac{\left(\frac{Z}{N}\right) * Z_{in1}}{\left(\frac{Z}{N}\right) + Z_{in1} + Z_{in2}} \quad (17)$$

$$Z_2 = \frac{\left(\frac{Z}{N}\right) * Z_{in2}}{\left(\frac{Z}{N}\right) + Z_{in1} + Z_{in2}} \quad (18)$$

$$Z_3 = \frac{Z_{in1} * Z_{in2}}{\left(\frac{Z}{N}\right) + Z_{in1} + Z_{in2}} \quad (19)$$

The input impedance in the load flow equation is updated to include the leakage current resistance.

RESULTS AND DISCUSSION

Table 1 displays the impedance and admittance between two buses in the 5-bus system without the effect of leakage current resistance (Stevenson, 1982). Table 2 lists the corresponding values in the presence of leakage current resistance effects (400 k Ω) in all transmission lines.

Figure 8 and 9 shows the variation of impedance and admittance for short transmission line between

Table 1: Data for 5-bus system

Impedance without leakage current effect				
Line bus to bus	Length km	R per unit	X per unit	Y/2
1-2	64.4	0.0420	0.168	0
1-3	48.3	0.0314	0.126	0
2-5	48.3	0.0314	0.126	0
3-4	96.5	0.0630	0.252	0+j0.0305058
5-4	128.7	0.0840	0.336	0+j0.0410078
3-5	80.5	0.0530	0.210	0+j0.0255048

Table 2: Data for 5-bus system

Impedance with leakage current effect				
Line bus to bus	Length km	R per unit	X per unit	Y/2
1-2	64.4	0.0417	0.1685	0.0368
1-3	48.3	0.0312	0.1269	0.0288
2-5	48.3	0.0312	0.1269	0.0288
3-4	96.5	0.0619	0.2532	0.0513+j0.0304
5-4	128.7	0.0814	0.3382	0.0682+j0.0409
3-5	80.5	0.0520	0.2112	0.0429+j0.0254

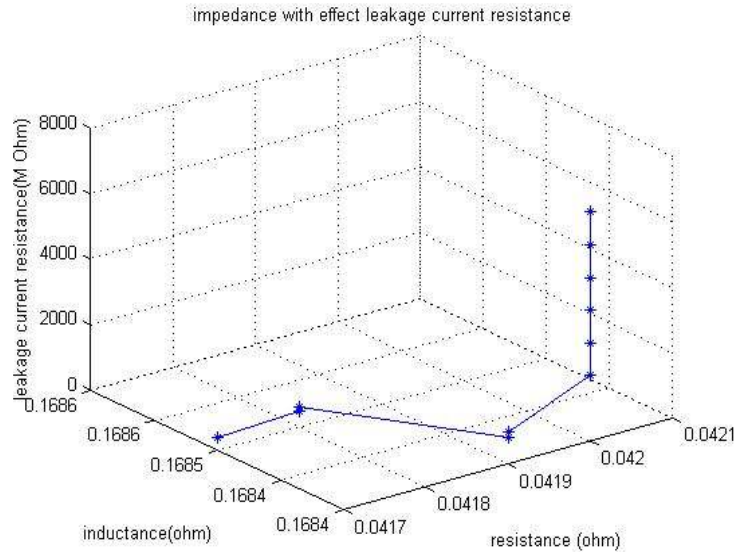


Fig. 8: Impedance for short transmission line between buses 1-2

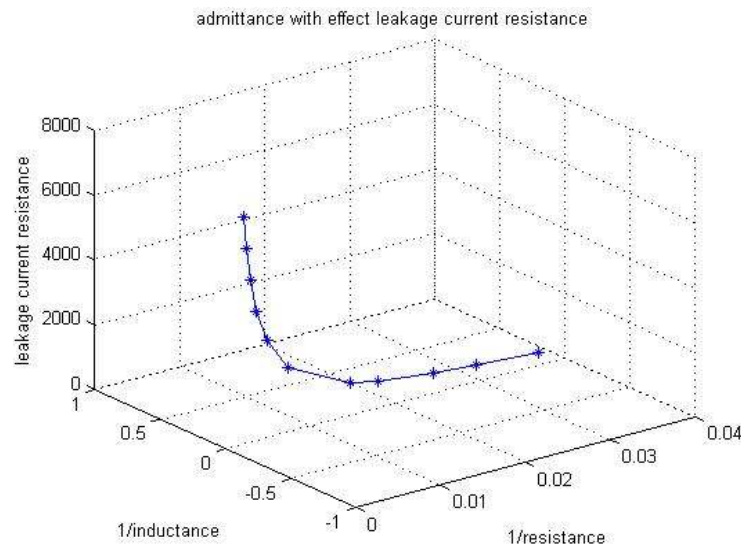


Fig. 9: Admittance for short transmission line between buses 1-2

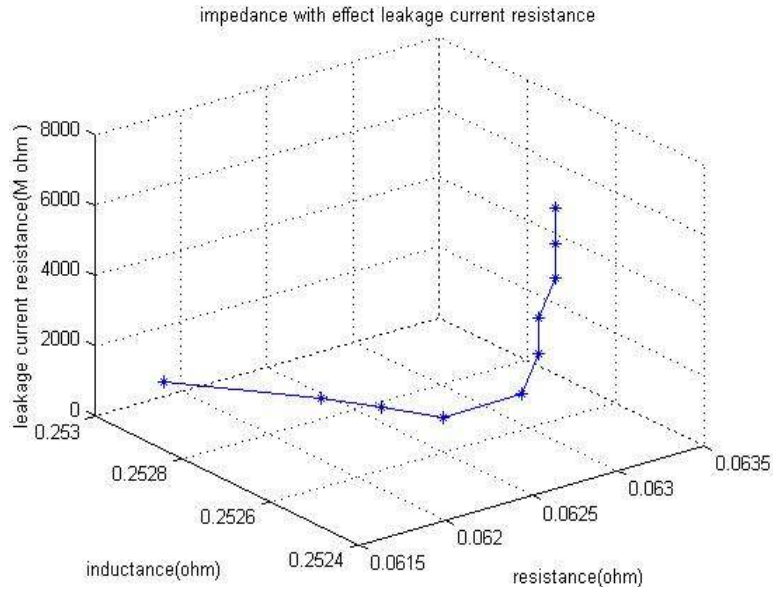


Fig. 10: Impedance for medium transmission line between buses 3-4

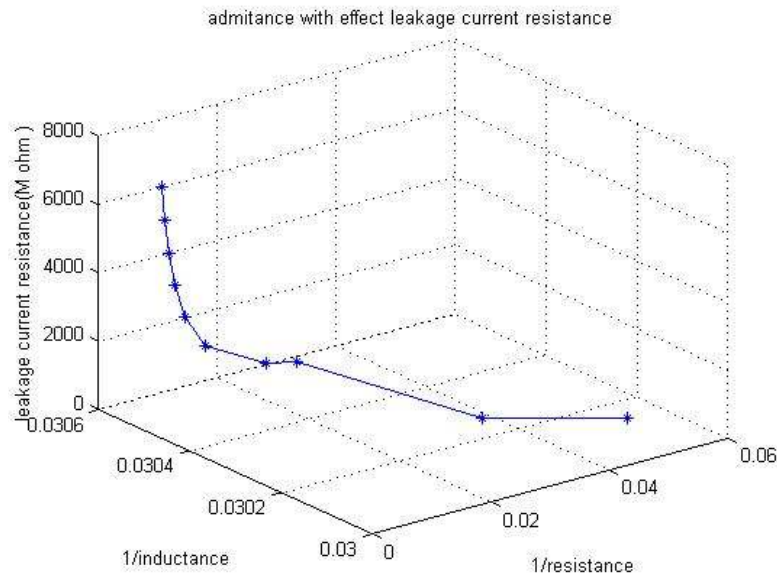


Fig. 11: Admittance for medium transmission line between buses 3-4

buses 1-2 in the presence of the effect of leakage current resistance. The leakage current resistance value is varied between 0.4-7 M Ω .

Figure 8 and 9 clearly exhibit that for increased value leakage current resistance both the impedance and admittance is increased. However, by lowering value the leakage current resistance the impedance is found to be decreased and admittance is increased. Only the real part (resistance) of the admittance is shown with the effect leakage current resistance.

Figure 10 and 11 reveal that for higher effect of leakage current resistance, the impedance is lower and the admittance is higher. However, as the value leakage current resistance is reduced the impedance is found to

decrease and admittance is increased. The real part and imaginary part of the admittance are shown with the effect leakage current resistance.

CONCLUSION

The design of the newly developed model for short and medium transmission line are presented to establish the relationship between effect of leakage current and load flow in the system. Each tower in the transmission line is represented as a resistance to accurately estimate of loss. The leakage resistance is incorporated into the model through delta-star/star-delta conversion and two-port network concept to update the load flow equations.

Three levels of leakage current such as high, medium and low resistances are used. MATLAB programming is used to model the transmission lines with 5-buses. It is asserted that the leakage current resistance significantly contributes towards the power loss. The impedances and admittances between different buses are found to vary strongly with the leakage current resistance. Our comprehensive model, including the effects of leakage current in power transmission lines may serve to achieve an insight in loss minimization, control and safety.

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