Deicing of Medium Voltage Power Transmission Lines by Joule Heating Method

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***Abstract*— In this paper, the principle of Joule heating method for overhead transmission lines deicing is proposed.**

This method is simply applicable to power transmission lines, and is able to melt accumulated ice in a short period. In the mountain regions of Iran e.g. areas in the Gharb Regional Electric Power Co. in Kurdistan province in the cold seasons of year, ice accumulation on transmission lines causes many problems.

At first, the required electrical current and the time needed for melting the accumulated ice as a function of wind speed, air temperature and ice thickness were determined by using a finite - difference heat transfer model that considers all of the heat flux terms associated with this problem, then the use of the proposed method for a 63 kV line in this area (Saghez-Baneh) as a case study is described.

I. Introduction

Ice covered overhead transmission lines could cause many difficulties such as galloping, heavy loading, phase-to-phase short circuit, falling the towers,…[1]-[3].

Different techniques have been proposed for dealing with this problem [4]-[6]. One of the proposed methods is using the Joule losses [5]. In this method the heat generated from passing the current trough the line melts the accumulated ice.

In this paper short circuit by using the reduced voltage is introduced as an effective and applicable method for de-icing of sub-transmission lines of Gharb Regional Co. and the algorithm of application of this method is proposed.

Firstly by using a finite-difference model [7], the required time for de-icing operation for different climatological conditions and different amount of current has been calculated. Then the procedure for production of this current has been proposed for a 63kV overhead line in Gharb Regional Co. in Kurdistan province of IRAN.

II. Finite -Difference Heat Transfer Model

At first, consider steady state radial heat conduction. At this case the current flowing through the line, produces a heat flux, which is equal to the cooling fluxes of the system. Under this condition, there is no temperature change versus time. This means that the temperature of different points of the wire-ice system is constant.

The region of ice-wire system is divided into M cylindrical subregions; each of thickness Δr, given by:

$$\Delta r = \frac{r_i}{M} \tag{1}$$

where r_i is the radius of wire-ice system. Each circle is indexed with a number. The center of system is No.1 and the surface is No.M+1. (As illustrated in Fig.1)

The problem involves M+1 node temperatures, denoted by:

$$T(r) = T[(m-1)\Delta r] \equiv T_m \qquad m = 1,2,\ldots, M+1 \tag{2}$$

For the interior surfaces we have:

$$\begin{pmatrix}\text{Rate of heat entering}\\ \text{by conduction}\end{pmatrix} + \begin{pmatrix}\text{rate of energy generation}\\ \text{by Joule losses}\end{pmatrix} = 0 \tag{3}$$

For the surface No.m which has the temperature T_m:

$$\begin{pmatrix}\text{Rate of heat}\\ \text{entering}\\ \text{by conduction}\end{pmatrix} = A_{m-1,m}K_m \frac{T_{m-1}-T_m}{\Delta r} + A_{m+1,m}K_m \frac{T_{m+1}-T_m}{\Delta r} \tag{4}$$

where K_m is the thermal conductivity of the surface No.m, $A_{m-1,m}, A_{m+1,m}$ are the areas of the cross section between surfaces No.m-1 , No.m and No.m, No.m+1 respectively.

$$\begin{pmatrix}\text{Rate of energy}\\ \text{generation}\\ \text{by Joule losses}\end{pmatrix} = A_m \Delta r g_m = 2\pi L(m-1)(\Delta r)^2 g_m \tag{5}$$

where g_m is the generated energy per unit volume and L is the length of the wire.

For the center of the system the energy balance will be:

$$4(T_2 - T_1) + \frac{(\Delta r)^2 g_1}{K_1} = 0 \tag{6}$$

For the surface of ice we could write:

$$\begin{pmatrix}\text{Rate of heat}\\ \text{entering}\\ \text{by conduction}\end{pmatrix} + \begin{pmatrix}\text{rate of heat}\\ \text{entering}\\ \text{by convection}\end{pmatrix} + \begin{pmatrix}\text{rate of heat}\\ \text{entering}\\ \text{by radiation}\end{pmatrix} = 0 \tag{7}$$

where:

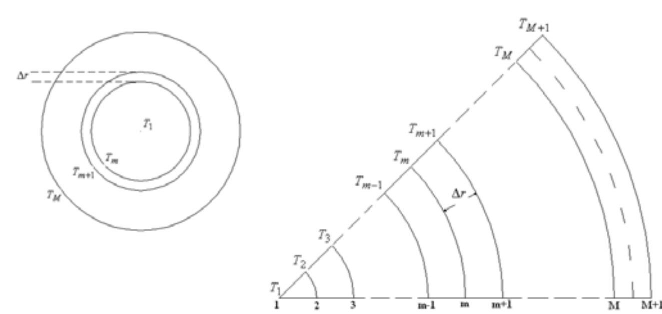

Fig. 1. Nomenclature for finite-difference energy balance formulation

$$\begin{pmatrix}\text{Rate of heat}\\ \text{entering}\\ \text{by conduction}\end{pmatrix} = 2\pi L[(M-.5)\Delta r]K_{M+1}\frac{(T_M - T_{M+1})}{\Delta r} \quad (8)$$

$$\begin{pmatrix}\text{The rate of heat entering}\\ \text{by convection}\end{pmatrix} = 2\pi LM\Delta r h_\infty (T_\infty - T_{M+1}) \quad (9)$$

$$\begin{pmatrix}\text{The rate of heat entering}\\ \text{by radiation}\end{pmatrix} = \varepsilon\sigma 2\pi LM\Delta r\left(T_\infty^4 - T_{M+1}^4\right) \quad (10)$$

where T_∞, h_∞ are the ambient temperature and its heat transfer coefficient, respectively. ε is the emissivity of ice and σ is Stefan-Boltzmann constant.

Now, these equations provide M+1 algebraic equations for the determination of M+1 unknown temperatures. It is worthy to state that these equations are only for the steady state and are valid only when the temperature of ice sections is below $0^\circ C$.

In Fig. 2 the temperature distribution through the Lynx wire and ice is plotted under the following conditions:

The thickness of ice=12.4mm, $T_\infty = -10^\circ C$, wind speed $= 5m/s$ and the current through the wire is 100 Amperes.

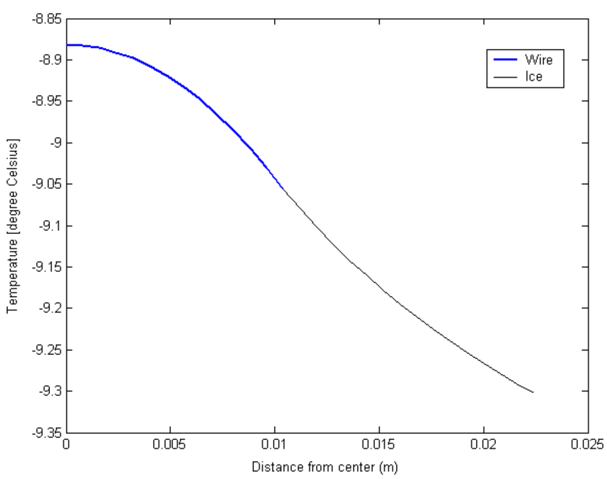

Fig. 2. Temperature distribution through the system in steady state (ice thickness=12.4mm, ambient temperature=-10 degree Celsius, wind speed=5m/s, wire current=100A)

It should be noted that in the conductors in the form of multi-layer stranded, most of the heat conduction is done through the small gaps between the contacts of strands. For this reason efficient thermal conductivity should be used. Morgan calculated the value of $1.5W/(mK)$ for the ACSR conductors [8].

Now consider the conditions where the flowing current through the wire is increased suddenly. The steady state equations are no longer valid, because the part of generated energy is caused the system internal energy and consequently the temperature to increase. This condition is divided into two stages:

A) Until the first part of ice reaches $0^\circ C$.

For the interior surfaces we could write:

$$\begin{pmatrix}\text{rate of heat}\\ \text{entering}\\ \text{by conduction}\end{pmatrix} = 2\pi LK_m\left[(m-1-.5)T_m^i - 2(m-1)T_m^i + (m-1+.5)T_m^i\right] \quad (11)$$

where T_m^i is the temperature of m-th surface at time step i and:

$$\begin{pmatrix}\text{rate of increase of}\\ \text{internal energy}\end{pmatrix} = \rho_m C_m 2\pi L(m-1)(\Delta r)^2 \frac{T_m^{i+1} - T_m^i}{\Delta t} \quad (12)$$

where ρ_m is the density of m-th surface and C_m is its specific heat.

Now energy balance will be:

$$\begin{pmatrix}\text{Rate of heat entering}\\ \text{by conduction}\end{pmatrix} + \begin{pmatrix}\text{rate of energy}\\ \text{generation}\end{pmatrix} = \begin{pmatrix}\text{rate of increase of}\\ \text{internal energy}\end{pmatrix} \quad (13)$$

For the outer surface the energy balance will be:

$$\begin{pmatrix}\text{Rate of heat}\\ \text{entering}\\ \text{by conduction}\end{pmatrix} + \begin{pmatrix}\text{rate of heat}\\ \text{entering}\\ \text{by radiation}\end{pmatrix} + \begin{pmatrix}\text{rate of heat}\\ \text{entering}\\ \text{by convection}\end{pmatrix} = \begin{pmatrix}\text{rate of}\\ \text{increase of}\\ \text{internal energy}\end{pmatrix} \quad (14)$$

where :

$$\begin{pmatrix}\text{Rate of heat entering}\\ \text{by conduction}\end{pmatrix} = 2\pi L[(M-.5)\Delta r]K_{M+1}\frac{T_M^i - T_{M+1}^i}{\Delta r} \quad (15)$$

$$\begin{pmatrix}\text{rate of heat entering}\\ \text{by radiation}\end{pmatrix} = -\varepsilon\sigma\left[\left(T_{M+1}^i\right)^4 - T_\infty^4\right]2\pi LM\Delta r \quad (16)$$

$$\begin{pmatrix}\text{rate of heat entering}\\ \text{by convection}\end{pmatrix} = 2\pi LM\Delta r h_\infty\left(T_{M+1}^i - T_\infty\right) \quad (17)$$

$$\begin{pmatrix}\text{rate of}\\ \text{increase of}\\ \text{internal energy}\end{pmatrix} = \rho_{M+1}C_{M+1}2\pi L[(M-.25)\Delta r](\Delta r/2)\frac{T_{M+1}^{i+1} - T_{M+1}^i}{\Delta t} \quad (18)$$

Now, we have M+1 equations and by knowing the present temperature of each surface (at time step i), the temperature of different surfaces at time step i+1 could be found. These equations are valid only until the fist part of ice reaches $0^\circ C$. After that stage B should be used:

B) At this stage Latent heat of fusion for water should be added to equations.

This means that a part of energy is used to melt each part of ice.

At the practical situations it is no need to melt all of the accumulated ice. After melting some of accumulated ice, the remaining will be cracked and shed from the wire.

All of these factors were added to the de-icing simulation program.

In the Fig. 3 the required time for de-icing of 12.4mm accumulated ice when the wind speed is 5m/s is sketched for different current flowing in the Lynx wire and different ambient temperatures.

III. De-icing Method

One of the proposed methods for de-icing is the production of required currents by special connection of transformers [5]. This method is applicable to each substation that might have a free transformer and a free low voltage busbar. Other method is also available for substations that feed from two incoming lines [6].

The methods based on special connection of transformers due to need for changing the configuration of transformers and need for using each phase independently, are not feasible for Kurdistan province substations. These substations are feed radially with only one incoming line and the methods in [5] could not be used also.

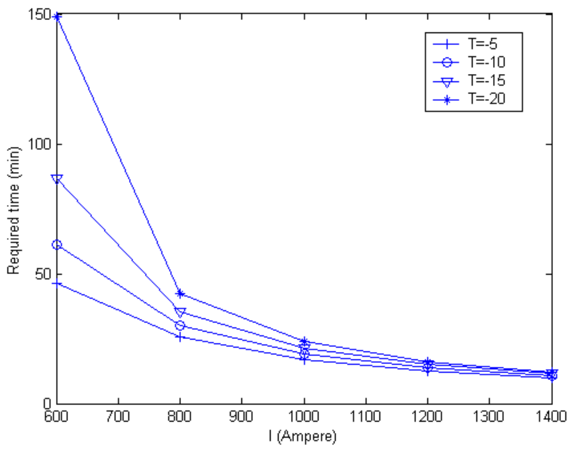

Fig. 3. Required time for de-icing (ice thickness=12.4mm, wind speed=5m/s)

A. The proposed method

In the proposed method, after disconnecting the end of line that should be deiced from its loads, a 3-phase short circuit is applied in that location, and by passing a high current that flows through the overhead line (in a short period) the accumulated ice will be melted because of Joule losses.

Two main restrictions in this method are: 1) the current rating of facilities 2) source capacity [9].

By considering the above restrictions, the proposed method uses the reduced voltage, In this method, instead of feeding the line by rated voltage, a voltage with a value of about 20 to 40 percent of its rated voltage should be applied and a short circuit at the end of the line should be made.

1) The algorithm of the method

1. Collecting the data for power system included the data for overhead lines, transformers, loads, feeders, capacitors, reactors, protections,….
2. Selecting suitable current and required time for deicing by considering the characteristics of power system and local climatological data of that region (in this stage, based upon the climatological data such as the thickness of accumulated ice, wind speed, ambient temperature, relative humidity, altitude, … and by using the proposed calculation in the previous section, tables had provided for different part of Kurdistan province [10] that suitable current and the required time for de-icing could be selected from them.)
3. Disconnecting both ends of line from the system.
4. Applying the required changes on loads, transformers, protections,…(this changes could be calculated from the load flow of the system).
5. Feeding the line with the reduced voltage by connecting the line to the lower level voltage (for example for the 63kV line, 20kV voltage should be used)
6. Applying the short circuit to the end of line via the earth system of the substation or a separate earth system that provided for de-icing operation.
7. Checking the current flowing through the line and continuing the operation to the determined time.
8. Returning the applied changes to the normal conditions.

2) Applying the proposed method to Saghez-Baneh 63kV line

Saghez-Baneh 63kV overhead line is one of the lines in the Gharb Regional Co. area, which has many difficulties because of ice accumulation. The characteristics of this line is shown in Table I. Fig. 4 shows the location of this line in the network.

TABLE I
ELECTRICAL CHARACTRISTICS OF SAGHEZ-BANEH 63KV OVERHEAD LINE

<table>
<tr><td colspan="2">Line length: 49.8 km</td><td colspan="2">Number of Circuits:1</td></tr>
<tr><td colspan="2">SEL Capacity: 11 MW</td><td colspan="2">Thermal Capacity :53MW</td></tr>
<tr><td colspan="2">Charge capacity:0.57MVAR</td><td colspan="2">Conductor type: Lynx</td></tr>
<tr><td colspan="2"></td><td colspan="2">Guard wire type: 7N08</td></tr>
<tr><td colspan="4">Electrical Characteristics per unit and based on 1000MVA</td></tr>
<tr><td>$R_1=0.2122$</td><td colspan="2">$X_1=0.4926$</td><td>$B_1=0.0057$</td></tr>
<tr><td>$R_0=0.569$</td><td colspan="2">$X_0=1.6132$</td><td>$B_0=0.003$</td></tr>
<tr><td>$I=126\ A$</td><td colspan="2">$MW=15$</td><td>$MVAR=2$</td></tr>
</table>

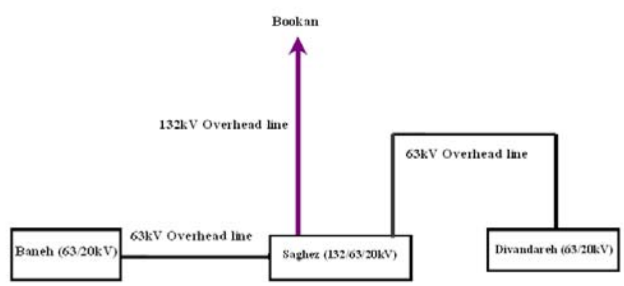

Fig. 4. Saghez-Baneh 63 kV overhead line in the local network

Short circuit levels of these substations are: Saghez: 249 MVA, Baneh: 107 MVA and Divandareh: 260 MVA.

For the executing of the de-icing operation on Saghez-Baneh, this line is fed by one of the reserved 20kV feeders in the Saghez substation and at the end of the line (at Baneh substation) short circuit is done by closing the earth switch. Schematic diagram of the method is shown in Fig.5.

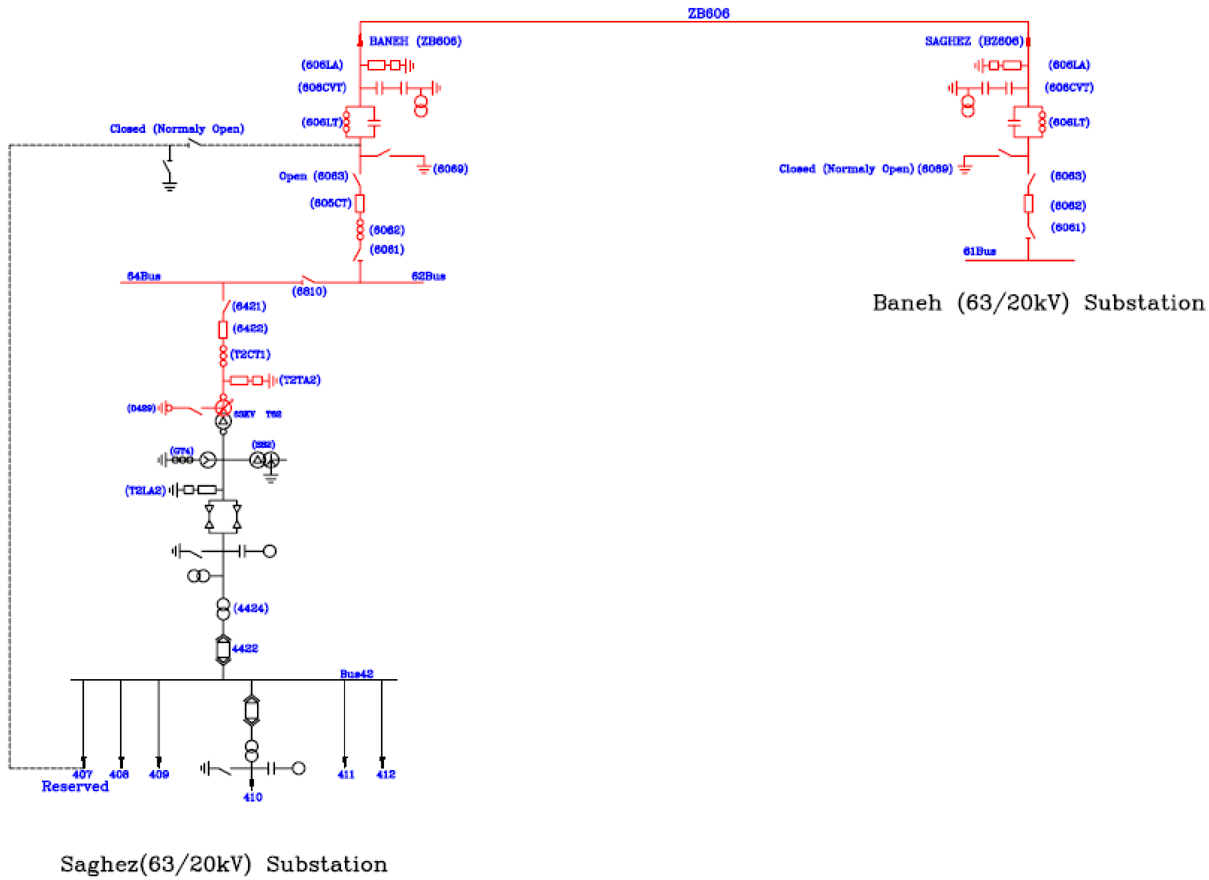

Fig. 4. Schematic diagram of de-icing operation for Saghez-Baneh 63kV overhead line.

Using this method and putting the tap of 63/20kV transformers in Saghez substation on 381.67=5.01% could regulate the voltage of Saghez 20kV busbar in the appropriate limit.

By using this method the produced current in Saghez-Baneh will be 780A (rms) or 1109A(peak).

In this method by using the breaker No.4072 on the reserved 20kV feeder of Saghez substation(No.407), a connection for feeding the 63kV line of Saghez-Baneh will be provided by an additional switch.

In Baneh substation, the connection of line to the earth will be done by using the earth switch (6069).

Because the applied short circuit is 3-phase, the E/F relay could not detect it, but the O/C relay setting of breaker No.407 should be set on 1.2*1000A.

IV. Conclusion

In this paper by using a finite-difference heat transfer model, the required time for melting the accumulated ice on overhead transmission lines for different values of line current and climatological conditions was calculated. And the basis for Joule heating de-icing of overhead transmission lines by the use of short circuit with reduced voltage was described. This method could be easily applied to ice covered overhead transmission and sub-transmission lines.

V. Acknowledgement

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