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Assesment of the Decrement in Tensile Strength of an Overhead Transmission Line's Conductor in Korean Power System

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Abstract

The tensile strength of an overhead transmission line's conductor in response to an aging is being assessed in this paper. It is our view that, the decrement in the conductor's tensile strength is a key index that can be used to determine a conductor's end of life and a current limits. This paper describes a probabilistic method of assessing this index for main transmission lines which are responsible for the north bound power flow in the Seoul metropolitan area. Such an assessment can be a useful guide for economic system operation.

Key Words : Tensile Strength, Conductor of Overhead Transmission Line, Aging

1. Introduction

The power flow through electricity transmission line is decided by considering multiple components including the mechanical character decrement capacity limitation according to the violation of stability or any trouble on a power system, decrement in tensile strength, and aging. The considered environmental problem is forming of high temperature and electromagnetic field on the surface of ground. The tensile strength decrement, among them, due to high temperature generated from transmission line, becomes a critical parameter to decide the life of transmission lines.

Considering the facts such as where the total life of lines is calculated as about 36 years under high temperature, the worst weather condition without wind, and continuity of current flow, about 10[%] decrement of tensile strength is brought in comparison with initial state of the lines.

The conventional method to calculate the allowable electrical current over an OH(over head) transmission lines has been done under the assumption of continuity of the current flowing during its life under the worst situation.

If we can know the quantity of tensile decrement of the line under the conventional installing condition and operation, we may operate the line system economically without violating the mechanical limited condition, though the capacity of current flow at the present situation is

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increased until the life of the lines is expired[1, 2].

2. Main subject

2.1 Heat balance equation

The heat balance equation may be used to obtain the temperature of the lines when the virtual data corresponding to exterior condition and electrical current flowing in the lines is known. Inversely, when the maximum temperature allowable to the line is known, it may also be used to obtain the maximum current in the range not beyond that temperature. In the process to calculate the decrement of tensile strength among these parameters, the value to be required is the temperature variation of the lines. That is, the heat balance equation can be used to obtain the previous temperature of electrical lines by inputting the previous current value and the previous virtual data. The heat balance equation expresses the statical equilibrium state that is attained at the equilibrium of heat emitted from outside and the heat generated from the OH transmission lines. This is expressed as in equation (1)

$$q_j + q_s + q_m + q_i = q_c + q_r + q_w \tag{1}$$

where q_j is the Joule's heat due the current of electric power, q_s is the solar heat, q_c is the cooling by convection, and q_r is the cooling by radiation. Magnetic heat q_m, corona heat q_i and cooling by evaporation q_w are neglected when only OH lines are considered.

Though the solar heat (q_s) has no relation with the temperature of the lines, the temperature of the line depends on Joule's heat (q_j), cooling by convection (q_c), and cooling by radiation (q_r) as the main parameters of the function. The power flow on the lines gives influence to the Joule's heat only.

2.1.1 Joule heating

The relation between the heat generated by the power flowing on the lines and the resistance of the line may be expressed as in equation (2), where the resistance of line becomes a function of the temperature of the line, Tc , and their relation can be expressed as in equation (3)

$$q_j = I^2 R(T_c) \tag{2}$$

$$R(T_c) = \left\{ \frac{R(T_{High}) - R(T_{Low})}{T_{High} - T_{Low}} \right\} \times (T_c - T_{Low}) + R(T_{Low}) \tag{3}$$

To know the resistance of an electric line, the resistance of the line with respect to two kinds of temperature related with the subjected line must be known. As per IEEE standards, the resistance of a line with respect to the temperature of the line within 175[℃] may be generally calculated exactly by a linear interpolation using the resistance at 25 [℃] and at 75[℃]

2.1.2 Solar heating

The heat generated on an OH line, by receiving the solar energy directly, is calculated as in the following equations.

$$q_s = \alpha Q_s \sin(\theta) A' \tag{4}$$

$$\theta = \cos^{-1}\{\cos(H_c)\cos(Z_c - Z_l)\} \tag{5}$$

where, α is the solar absorptivity of absorption by the electric line, Q_s is the heat flux, A is the area per unit length of conductor exposed to the sunlight, H_c is the altitude of the sun, and Z is the azimuth angle of the sun.

2.1.3 Convective cooling

The cooling by convection is largely classified into the convection by force (q_{c1}, q_{c2}), and the one by nature (q_{c3}) according to the magnitude of the wind speed. The region by this wind speed is again classified into high speed region q_{c1} and low speed region q_{c2}. The region having the greatest value among these three cooling by convection governs the cooling by convection, and that value is defined as cooling by convection.

$$q_{c1}=\left\{1.01+0.371\left(\frac{D\rho_f V_w}{\mu_f}\right)^{0.52}\right\}k_f(T_c-T_a) \qquad (6)$$

$$q_{c2}=0.1695\left(\frac{D\rho_f V_w}{\mu_f}\right)^{0.6}k_f(T_c-T_a) \qquad (7)$$

$$q_{c3}=0.283\,\rho_f^{0.5}D^{0.75}(T_c-T_a)^{1.25} \qquad (8)$$

where, D is the diameter of electric line, V_w is the wind speed, T_a is the temperature of circumference of the line, ρ_f is the air density, μ_f is the absolute viscosity of the air, and k is the heat transfer rate of the air. The cooling by forced convection is differed from the cooling by natural convection, that is, the region of no wind is varied in the extent of cooling according to the angle formed between the line and the wind direction. This is expressed as in equation (9) by using ϕ (the angle formed between the line and wind direction). Equation (9) is used by multiplying equation (6) and (7) concerning the forced convection

$$K_{\angle}=1.194-\cos(\phi)+0.194\cos(2\phi)+0.368\sin(2\phi) \qquad (9)$$

2.1.4 Radiative cooling

The cooling by radiation is risen by the difference between the temperature of the line and the ambient temperature, regardless of the wind. Accordingly, the following equation (10) is deduced by the two parameters the temperature of the line and the atmospheric temperature.

$$q_r=0.138D\varepsilon\left\{\left(\frac{T_c+273}{100}\right)^4-\left(\frac{T_a+273}{100}\right)^4\right\} \qquad (10)$$

where ε is the emissivity of an OH line. The real values of parameters to be used into the heat balance equation are mentioned in detail in IEEE standard 738[3].

2.2 Temperature of Over head transmission line

The tensile strength of an over head(OH) transmission line is decreased gradually due the aging by the repeated heating and cooling during a long time. To know the quantity of decrement of tensile strength, the variation of temperature on the line must be known. The best accuracy method to know the quantity is to measure the temperature of the line directly and to accumulate the value of the temperature that has been measured from the initial installation of the line. However, since there is no existing domestic previous data measured directly, the temperature of the line under operation in reality, the temperature history must be calculated numerically by using the past current data and the past weather data.

To do it, we use the heat balance equation, and the result value that we would obtain from the heat balance equation is the temperature of the line. All the values except it are the variables for inputting.

While there exist input variables fixed, including the shape of the line and the position of installation, the variables varied with time include the current, the altitude of the sun, the wind speed and the wind direction.

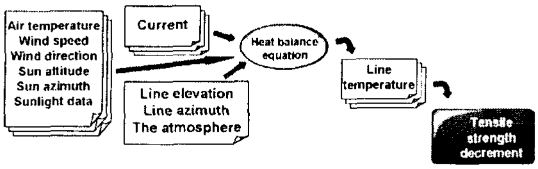

Fig. 1. Calculation for the quantity of reduced tension

Therefore, if we can know the information of the weather data according to each time and the electricity flow of the line, except the basic information with respect to the transmission line subjected to the decrement of tensile strength, we can calculate the history and the probability distribution of the past line temperature. However, when the heat balance equation is arranged with respect to the temperature of line, it is not a simplified polynomial equation and that makes it difficult to obtain the solution by means of using a numerical formula. Therefore, the numerical analysis technique must be applied. The method to get the temperature of the line is largely classified into two categories[1,2,4]. One is the sequential technique that may obtain the present temperature of the line from the initial one by applying the past current data and the weather data every hour. The other is MCS(Monte-Carlo Simulation) technique using probability density function(PDF) instead of using the past history itself. The components of the weather are arbitrarily abstracted by the MCS technique under the premise of the assumption that the components of weather are independent from each other.

Though the components of the weather have no relationship to each other, yearly, they have inter relation in a season or a day and a night.

Usually the temperature and power flow in the daytime are higher than in night time, and the wind speed and the temperature in the Summer are higher than in the Spring and Autumn. The most fundamental method able to consider such characters is sequentially imitating the weather data according to the order of time as did to the data of current. Although it takes long time since the quantity of data is huge but it is regarded as the most accurate method. When the probability density function is obtained by using the past data, MSC technique has relatively the simplification in comparison with the sequential technique. However, due to some unreality of the assumption that inter data are independent from each other, the result by the sequential technique can be relatively regarded to have more accuracy[4].

2.3 Calculation formula of tensile strength decrement

Vincent T Morgan has discussed numerous conventional techniques to calculate the tensile strength decrement by using the temperature of an OH transmission lines[5]. The technique used in this paper, among them, is expressed in equation (11) that Vincent T Morgan had proposed[6]. The decrement of tensile strength was expressed as the rate of a hundred percent of tensile decrement with respect to the initial tensile when it was installed.

$$W = W_a\left[1-\exp\left\{\begin{array}{c}-\exp(A+m\ln t\\+BT_c+C\ln(\frac{R}{80}))\end{array}\right\}\right] \tag{11}$$

$$R = 100\left\{1-\left(\frac{D_w}{D_0}\right)^2\right\} \tag{12}$$

where, t is the temperature of the line; T_c is continuation time; D_w: is the diameter of the line, D_0 means the diameter of the drawn rod before the line is made. All constant except these are given according to the material of the line as in table 1.

When the historical temperature of the OH transmission line is applied directly, long time is required to calculate because the continuation time of the temperature is shortened into an hour unit as the temperature of the line is varied every hour. So it is unreasonable to apply equation (11) in direct.

Table 1. Coefficients of equation (11)

Constant	Aluminum	Al alloy	copper
A	-8.3	-14.5	-7.4
B	0.035	0.060	0.0255
C	9	18	11
m	0.285	0.79	0.40
Wa[%]	56	60	41

Instead, if the PDF of each line is used, the time occupied over temperature of each line among entire operational time can be known. After all, when the decrement of tensile strength on the line is calculated in the method accumulating continuity by using equation (13) according to the magnitude of the line temperature, the calculation becomes more simple and it is expressed as:

$$\sum W=\left(\frac{t_1}{\overline{t_1}}+\frac{t_2}{\overline{t_2}}+\cdots+\frac{t_n}{\overline{t_n}}\right)^m \qquad (13)$$

where, $\overline{t_n}$ is the temperature of the line path, such that the continuation time until the decrement rate is reached up to 1[%] at T_n, and t_n means the real continuation time of T_n .

2.4 Case study

To estimate the tensile strength decrement of an domestic OH transmission, the weather data were used with the data obtained from 1992 to 2005, (fourteen years). Each data was written by an hour unit, and as an exception, the previous weather data of the year 1999 was written by three hour unit.

The weather data required in this paper among diverse data is of temperature, wind speed, wind direction, and current. Though the insolation has been written by measuring, only 22 observatory stations of total 78 weather observatory stations have measured it. Therefore, this paper have not used the data of the insolation directly but rather used to calculate, with the data of sunlight, the solar altitude corresponding to date and time, indirectly.

Since the sunlight data is displayed as the rate of the duration of sunshine by 0.1 unit by the base of every hour, it can be applied into equation (4) that may calculate the solar heat among the heat balance equation as a weighing value. Again the weather data of the interval existing null data were assumed as same as the value of previous interval.

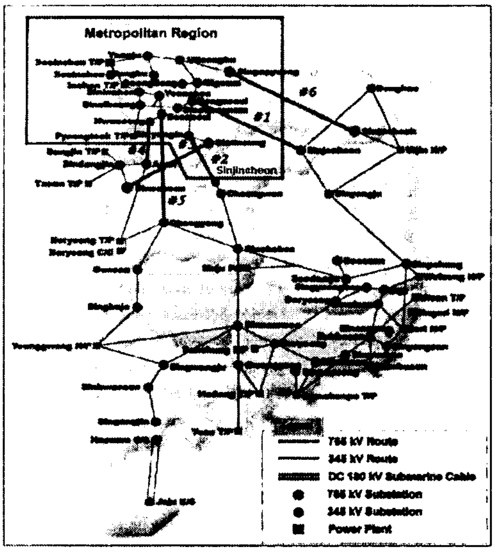

Fig. 2. The main transmission lines

To choose the main line to calculate the decrement of tensile strength among the transmission lines of domestic power system, the capital region was separated from the region of non capital region as in figure 2. The majority connection line - more than 345[kV] grade -

between the capital region and non capital region consists of a total of 6 routes. Figure 2 shows each route, and the bus between both terminals of each route.

Among six routes of main northern line paths, bus of New Ansung and bus of New Suhsan, and the route between bus of New Gapyung and bus of New Taebaek are all the transmission lines of 765[kV] grade. The rest four routes are 345[kV] grade line system, but the kind of all the lines is equal, that is ACSR 480[㎟], currently under operation.

The name of the buses connected to the 6 main routes, the weather position of the lines, SLR, and the azimuth angle are shown in table 2.

Table 2. Parameters of the main transmission lines

Name of lines	Bus		Azimuth angle [degree]	Weather position [%]
	from	to		
Asan	Hwasung	Asan	150	50
Seochung	West Seoul	Chungyang	10	30
New Youngin	New Youngin	New Jinchun	150	65
New Ansung	New Ansung	New Susan	60	30
New Jechun	East Seoul	New Jechun	120	45
New Taebaek	New Gapyung	New Taebaek	120	55

As the azimuth angle is expressed as degree unit in clockwise with the reference as zero degree defined with the direction from north to south, it is the value calculated by considering the position of both buses at both terminals of the line path.

The weather position is expressed as a hundred percent and the meaning of weather position value is to display the rate occupying over total length of the line path distance till being out of the weather observatory station related to the data of the bus from the bus.

To help in understanding, when we analyze the meaning of the 30[%] weather position of Seochung T/L, it means that the 30[%] among total line distance of Seochung T/L is influenced by the weather condition of Suwon observatory station that belongs to West Seoul bus, and that the rest 70[%] is governed by the weather condition of Boryung weather observatory that belongs to the bus of Chungyang.

The weather data of the bus at both terminals of the 6 main lines were obtained from the data of the nearest weather observatory station. When the bus position and the altitude on the sea level are arranged, table 3 shows these values.

Table 3. Parameters for buses at both ends of the main transmission lines

Bus	Weather station	North latitude	East longitude	Elevation above sea level [m]
Hwasung	Suwon	37° 16'	126° 59'	33.6
Asan	Cheonan	36° 47'	127° 07'	24.9
West Seoul	Suwon	37° 16'	126° 59'	33.6
Chungyang	Boryung	36° 19'	126° 34'	15.3
New Youngin	Suwon	37° 16'	126° 59'	33.6
New Jinchun	Cheongju	36° 38'	127° 27'	57.4
New Ansung	Icheon	37° 16'	127° 29'	77.8
New Susan	Susan	36° 46'	126° 30'	25.9
East Seoul	Seoul	37° 34'	126° 58'	86.0
New Jechun	Jechun	37° 09'	128° 12'	263.2
New Gapyung	Chuncheon	37° 54'	127° 44'	76.8
New Taebaek	Taebaek	37° 10'	128° 59'	713.4

The three buses Hwasung, West Seoul, and New Youngin all use the data from the Suwon weather observatory station. The data of north latitude, and east longitude of the buses are used to calculate the altitude of the sun and the azimuth angle every hour. The altitude on the sea level is used to calculate the height of the lines for the purpose of using into compensation coefficient of the solar heat.

To display as the height of one line with two altitudes of two buses above the sea level at the two terminals, a hundred percent rate is used the same way as that of the weather position.

To calculate the decrement of tensile strength over the six main transmission lines from the installation time to December 31st 2005, the weather data until the current time from the time when the transmission lines were installed, are required.

However, since the past result with the previous data of 1992, could not be obtained, it was assumed that the weather data from 1992 to 2005 has been repeated.

We have assumed 0.7 as the absorptivity of a line getting older than 50[%] of the entire life. An exception to this is that the absorptivity and emissivity of all the lines were assumed as 0.5 the same value as the domestic standard.

Since the weather data and the current data on the lines are subordinated to each other and even the weather data are dependable, as mentioned in chapter 2.3, we chose the sequential technique to get the data. The current value of the 6 main transmission lines could be obtained from the data measured by one hour unit at each power station, and the average value of the two power flow values obtained from the power station at both the terminals of a transmission line was assumed as the current of each line. Due to matter of the space, only the PDF of the past historical current of Asan T/L among the 6 north main lines of current is shown in figure 3.

Looking into the PDF in figure 3 it can be seen that the Asan T/L of 345[kV] grade has the allowable current as 917[A], but in reality the current using this line has high PDF at the area near 300~320[A]

Though it is assumed that each line system is operated not exceed 450[A], that is, 50[%] of SLR level for ready to the assumptive contingency by the remaining lines, in reality, we can find out that the quantity of power flow flowing through this line system is far low in comparison with its capacity.

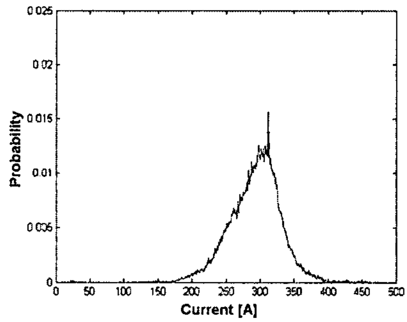

Fig. 3. PDF of power flowin Asan T/L

Again, the six transmission lines dealing with the case study play the most important role of the undertaking of the electricity flowing up toward north, where is the capital region. However, since the voltage stability of capital region is very vulnerable, it cannot be operated under the limitation of transmission to secure the stable supply of electric power and the surplus volume of the transmission line can be regarded as an excess.

We could calculate the PDF of the line temperature by means of the sequential technique using the history of data from the weather observatory stations and power flow data of the 6 main lines. The consequent results of Asan T/L is shown in figure 4.

The temperature PDFs of the 6 routes of the transmission lines flowing up toward north have all a similar shape of probability distribution as an alphabet “M”.

Since the current flowing on the line is very small when compared with the limit value, the probability distribution of the line temperature shows a similar shape to the probability distribution of the surrounding temperature showing M's shape.

When the decrement of tensile strength during a total period of usage is accumulated according to the order of line temperature by using the probability distribution of temperature on the 6 transmission lines, its result is shown in figure 5. When the results are organized, these values can be related as in table 4.

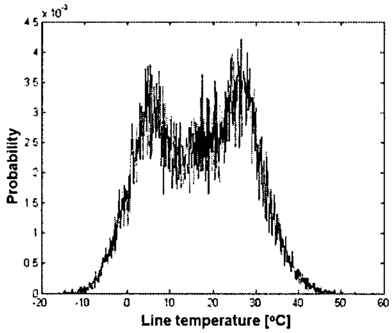

Fig. 4. PDF of conductor temperature in Asan T/L

Table 4. The reduced tension and the corrected value of limit temperature

Name of line	Installation time	Decrement of tensile [%]	Allowable temperature[℃]
Asan T/L	1993. 12	0.7219	93.30
Seochung T/L	1983. 01	0.7952	98.29
New Youngin T/L	1977. 06	0.8350	102.77
New Ansung T/L	2001. 06	0.4943	91.09
New Jechun T/L	1985. 07	0.7454	96.86
New Baebak T/L	2000. 07	0.4691	91.35

When the results of tensile decrement are seen, the decrement rate of New Youngin T/L 345[kV] grade, which is the oldest in terms of the installation time, appears as the highest, whereas Asan T/L 345[kV] grade and New Jechun T/L 345[kV] shows similar decrement rate. Nevertheless, there exists difference in installation time. Since the power flow volume on the line of Asan T/L was greater than that of New Jechun T/L, and the tensile decrement happened severely within a short term, though the Asan T/L is shortened in the usage term, the tensile decrement appeared similar to New Jechun T/L. While the New Ansung T/L and New Taebaek have been installed the latest, the tensile decrement is the lowest.

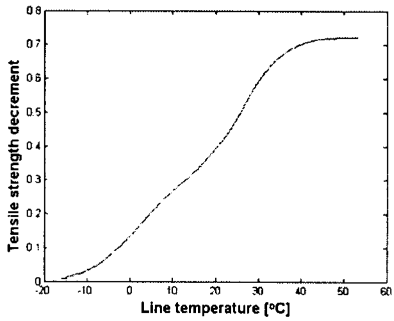

Fig. 5. Quantity of the reduced tension in Asan T/L

When it suggests that the life of an OH transmission line is thirty six years, we can know the tensile decrement percent allowable during residual life term in the base of tensile decrement of 10[%]. The continuation allowance temperature during the residual life term through it can also be calculated as the allowable temperature on the right of table 5.

If we can know the decrement of tensile strength until now, it can be used to calculate how the operation at any temperature shall be reached to 10[%] decrement of tensile strength during the residual term of life. For instance, since the decrement of tensile in Asan T/L is 0.7219[%] for 12 years, if it is operated with approximate 93.30 [℃] as continual allowable temperature, the residual term of 24 years makes the decrement of tensile strength into 10[%]. However, no electric line has been operated under continual allowable temperature. So, since it has been run under far below the continual allowable temperature, the decrement of tensile never exceeds the 10[%] even though it is used for 36 years.

Since the allowable temperature renewing according to the life has higher than the conventional allowable temperature of 90[℃], this proposes the base for more economically usage rising the allowable power flow of an OH transmission line.

3. Conclusion

This paper has introduced the techniques that able to calculate the decrement of tensile strength due to harden aging of an OH transmission line, and it has calculated the real tensile decrement with respect to 6 main lines beyond 345[kV] grade that undertake the power flow toward north where the capital region locates, among the domestic power system. The allowable power flow of the transmission line using the current is defined as the power flow on the line able to be reached up to the continual allowable temperature under the worst weather condition. However, since the real weather condition surrounding the lines is not reached up to the worst situation, and the power flow volume is small in comparison with the allowable value, the decrement of tensile strength is slightened when compare with 10[%] decrement displaying the line life. Accordingly, if higher allowable temperature of the line is used during a life term through the quantity of decrement of tensile until now or if the life of the line is expanded while the allowable temperature at the current keeps on, more economical operation of the power system would have been possible.

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