Paper

Examination of CIGRE Method of Assessing Transmission Line Conductor's Temperature

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The temperature of a transmission line conductor is one of the important factors used to determine its current carrying capacity. There are several standards and methods by IEC, IEEE, CIGRE and JCS on the calculation of conductor temperature. Apart from heat dissipation by convection where some differences exist, almost the same formulae are used in these standards and methods in calculating the other terms of the heat equation that is used in determining the conductor temperature.

In this paper, a comparison of how the heat dissipation by convection is assessed using these standards and methods is reported. In order to compare the conductor temperature obtained by calculation and that measured experimentally, laboratory experiment of temperature measurement of ACSR conductors was carried out under several currents, surface and wind conditions. In the calculation, CIGRE method is used because it is virtually adopted worldwide. Under low wind velocity, however, the difference between calculated and measured conductor temperatures is quite significant. A new equation is proposed in order to narrow the differences between the measured and calculated temperatures under low wind velocity conditions. By applying the probabilistic technique or approach, the proposed equation and the CIGRE method were then employed to assess conductor temperature using actual climatic and current data. This is to provide a wider basis for comparison.

Keywords : Conductor temperature, Heat dissipation by convection, Wind tunnel, ACSR conductor.

1. Introduction

The thermal limits of a transmission line is known to have a very significant influence on both the line's capacity and operation. The sag in the line, the loss of tensile strength and deterioration of joint of the conductor, just to mention a few, are all thermal limits. This makes the conductor temperature and its determination a major concern to power transmission and distribution engineers as well as other researchers in the power industry.

There are some standards and methods to calculate the temperature of transmission line conductors [1-4]. Notwithstanding the fact that all these standards and methods fundamentally employ the same heat equation, there are some differences between the results obtained by using these standards and methods. All the terms in the heat equation are almost the same in all these standards and methods apart from the heat convection. And because heat convection plays a very significant role in the cooling process, the differences in assessing this term translates into significant differences in the obtained results.

Recently, it has been confirmed that the use of CIGRE methods would be appropriate in Japan [5] and IEEE is also revising its method to make it closer to the CIGRE method [6].

It is also reported that measured temperature of TACSR 410mm^2 agrees well with calculated value using CIGRE method for wind velocities of 0.5m/s and above [7]. However, for wind velocities 0.5m/s and below, it was observed that the measured conductor temperature disagrees with those calculated with the CIGRE method [8].

In this paper, a comparison of all these formulae as described in the existing standards and methods is made by using these standards and methods to assess heat convection under the same conditions. In addition, measurements of temperatures for ACSR transmission line conductors that were obtained from experiments conducted in a laboratory using a wind tunnel are reported. The wind tunnel was used to artificially produce wind at velocities ranging from 0-4m/s. Experimental results are compared with calculated results using CIGRE method. And to narrow the differences at low wind velocities, a new equation is proposed. By applying the probabilistic approach, this new equation and the CIGRE method are used to assess the conductor temperature using climatic and current data so as to provide a wider basis for comparison.

2. Heat convection

2.1 Assessment of heat convection

The formula for heat convection, *Pc* in W/m, as given in each of these standards and methods is shown below with the used terms in these equations also as defined below with their units in brackets.

D[m]: outer diameter of conductor, v[m/s]: wind velocity, t_a[℃]: ambient temperature, t_c[℃]: conductor temperature, ρ [kg/m^3]: air density, μ_f[kg/s·m]: absolute viscosity of air, K_f[W/m·℃]: thermal conductivity, λ [W/m·K]: thermal conductivity of the air film in contact with the conductor, Nu: Nusselt number, Re: Reynolds number, λ_f[W/m·K]: coefficient of thermal conductivity of air, δ [°]: angle between conductor and wind direction.

(1) JCS [1]:

$$P_C = \frac{0.572}{\left(273 + \frac{t_c + t_a}{2}\right)^{0.123}} \pi (Dv)^{0.5} (t_c - t_a)$$

Under zero wind velocity or in still air

$$P_C' = 0.035 \pi D^{0.75} (t_c - t_a)^{1.25}$$

(2) IEEE [2]:

The larger value of P_1 and P_2 is used as Pc.

$$P_1 = \left[1.01 + 0.0372 \left(\frac{D \rho_f v}{\mu_f} \right)^{0.52} \right] K_f (t_c - t_a)$$

$$P_2 = 0.0119 \left(\frac{D \rho_f v}{\mu_f} \right)^{0.6} K_f (t_c - t_a)$$

Under natural cooling, Pc is as given as below.

$$P_0 = 0.0205 \rho_f^{0.5} D^{0.75} (t_c - t_a)^{1.25}$$

(3) IEC [3]:

$$P_C = \lambda Nu (t_c - t_a) \pi$$

$$Nu = 0.65 \mathrm{Re}^{0.2} + 0.23 \mathrm{Re}^{0.61}$$

$$\mathrm{Re} = 1.644 Dv \left(273 + \frac{t_c + t_a}{2}\right)^{-1.78} \times 10^9$$

(4) CIGRE [4]:

Heat dissipation by convection, Pc, is as given below.

$$P_C = \lambda_f Nu (t_c - t_a) \pi$$

Calculating Nusselt number:

In the case of forced cooling with wind velocity greater than or equal to 0.5m/s, the Nusselt number is determined from the equations listed below.

$$Nu_{\delta=90} = B_1 (\mathrm{Re})^n \quad \text{for } \delta = 90°$$

$$Nu = Nu_{\delta=90} \left[A_1 + B_2 (\sin\delta)^{m_1} \right] \quad \text{for } \delta \neq 90°$$

In the above equation, A_1, B_1 and B_2 are constants. For wind velocities below 0.5m/s, it is difficult to determine δ, and thus the maximum of the following expressions is used.

$$Nu = Nu_{\delta=90} \left[A_1 + B_2 (\sin 45°)^{m_1} \right]$$

$$Nu = 0.55 Nu_{\delta=90}$$

$$Nu = A_2 (Gr \cdot \mathrm{Pr})^{m_2}$$

In these equations, A_2 and m_2 are constants with Gr and Pr as Grashof and Prandtl numbers respectively.

2.2 Comparison of calculated heat convection

Heat dissipation by convection was calculated using the five equations described above in order to compare these standards and methods. The following conditions were used. Conductor diameter: 18.2mm, ambient temperature: 16.3°C, temperature rise: 73.7°C, absolute viscosity of air: $2.04392 \cdot 10^{-5}$kg/ms, air density: 1.0309kg/m^3, coefficient of thermal conductivity of air: 0.02585W/m·K.

The results are shown in Fig.1. These standards and methods compare very well for wind velocities below 0.5m/s. For other wind velocities however, values obtained using JCS's method are lower compared with those obtained by the other three methods.

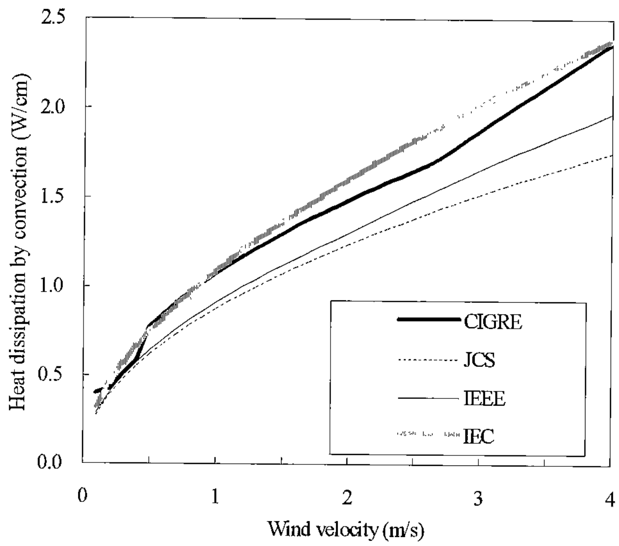

Fig.1: Comparison of heat dissipation by convection

3. Wind tunnel experiment

In order to examine the validity of the CIGRE method, laboratory experiments were carried out. Because it was difficult to measure separately the heat dissipation by convection, the measured and calculated conductor temperatures were compared instead. Since the formula of the other three terms in the heat equation namely heat dissipation by radiation, Joule and solar heating are almost the same in these standards/regulations, the heat dissipation by convection affects the conductor temperature directly.

3.1 Specimens and experimental procedure

Bare ACSR transmission line conductors of sizes 160, 410, 610 and 810mm^2 were used in these laboratory experiments. The length of the conductor, which was determined by considering the limited space of the laboratory and the results of the preliminary experiments, was 4m in each specimen. For each specimen, three surface conditions namely non-treated, sandblast and black-painted surfaces were adopted and used. The non-treated surface specimen is a newly manufactured conductor with surface conditions unchanged. The sandblast, which is treated with very fine sand to give it a surface color of gray and lusterless, simulated a lightly contaminated conductor surface. The black-painted specimen simulated a heavily contaminated conductor surface and was obtained by spraying a black paint onto the surface of the new specimen.

By connecting both ends of the specimen, a ring-shape sample as shown in Fig.2 was made. The specimen was positioned such that the section of the specimen to be monitored lied horizontally within the aperture of the wind tunnel as shown in Fig.2. A thermocouple was however, connected outside this region in order to compare readings. It was confirmed in the preliminary experiments that with this arrangement, heat generation due to contact resistance at the connecting part did not affect temperature of the conductor at the aperture of the wind tunnel.

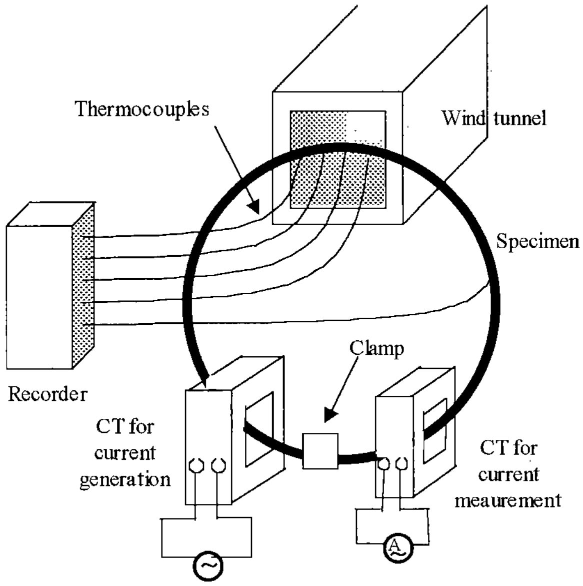

Fig.2: Experimental setup

The size of the aperture of the wind tunnel was 80 x 80cm, and the distance between the two apertures was 1m. Wind velocity in the range of 0.3 – 4m/s was generated in the wind tunnel. Wind velocity was measured with a hot-wire anemometer whose accuracy is ±5%±0.05m/s for wind velocities below 1m/s. The wind velocity at the plane of the aperture was almost uniform and the deviation was less than 5% even for a velocity of 0.3m/s. It is considered that little disturbance of wind occurred since the wind tunnel is installed in an isolated room.

Twenty-two thermocouples were used to measure the specimen's temperature. Eighteen thermocouples were connected to the surface of each specimen at every 10cm with half of them facing the windward side and the other half facing the leeward side. Two each were connected to the upper and lower sides of the specimen lying within the center of the aperture of the wind tunnel. A measurable ac current was supplied to the specimen through a current transformer that was connected to a 7.5kVA, 200/0~400V single-phase transformer. The time variation of the conductor temperature was monitored continuously with a hybrid recorder. Experiments were carried out at various currents and wind velocities. It took about two hours to reach thermal equilibrium with the actual time depending on the prevailing conditions. Continuous monitoring of the current showed no variation in the conductor current in the course of carrying out the experiment.

The results of the experiment were compared with these standards and methods by normalizing the results in terms of Reynolds and Nusselt numbers and using the normalized work of other researchers [9,10] as the basis of comparison. The IEEE's method is not included in this comparison because the method is undergoing revision to include corrections to make it closer to the CIGRE method [6].

This is shown in Fig.3. The nomenclatures "cigre", "iec" and JCS refer to our normalized experimental results using CIGRE, IEC and the JCS methods respectively. Similarly, the nomenclature "others" is the normalized data for other researchers with "lobf" as the line of best fit for the normalized data of other researchers.

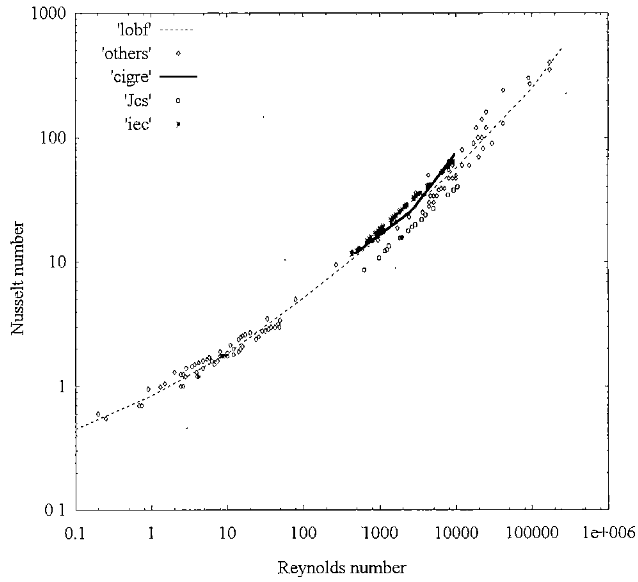

Fig.3: Nusselt number against Reynolds number

3.2 Calculation of conductor temperature

The well-known heat equation was employed in the analyses in accordance with the CIGRE method [4].

$$P_j + P_s = P_c + P_r \, . \tag{1}$$

P_J, P_s, P_c and P_r are the Joule heating, solar heating, convective cooling and radiative cooling respectively, and are determined from the following equations:

$$P_j = I_{dc}^{\ 2} R_{dc}[1 + \alpha(t_c - 20)] \, . \tag{2}$$

$$P_s = \alpha_s SD \, . \tag{3}$$

$$P_c = \lambda_f Nu(t_c - t_a)\pi \, . \tag{4}$$

$$P_r = \pi D \varepsilon \sigma_B [(t_c + 273)^4 - (t_a + 273)^4] \, . \tag{5}$$

The parameters used in these equations are defined as below with their units indicated in the brackets. I_{dc} [A]: direct current which results in the same power input as the alternating current at the same average temperature, R_{dc} [Ω /m]: dc resistance of the conductor at 20°C, D [m]: conductor's outer diameter, σ_B [W/m^{2}K]: Stefan-Boltzmann's constant, ε [-]:emissivity of the conductor surface, λ_f [W/mK]: thermal conductivity of air, t_c[°C]: conductor temperature, t_a[°C]: ambient temperature, α [1/°C]: temperature coefficient of resistance, α_s [-]: solar absorptivity of conductor surface, S [W/m^2]: global solar radiation and Nu [-]: Nusselt number.

By solving (1) numerically, the conductor temperature can be obtained. Using (2) takes care of the magnetic heating, P_m [4]. The corona heating, P_i and evaporative cooling, P_w were ignored for reasons stated in [4]. For wind velocities between 0 and 0.5m/s, Nusselt number in (4) varies as described in section 2.1. In subsection 5 of 2.1, A_1=0.42, B_1=0.68 and m=1.08 when the angle of attack is between 0° and 24° and take the values of 0.42, 0.58 and 0.90 respectively when the angle of attack lies between 24° and 90° [4].

3.3 Measurement of emissivity

In calculating the conductor temperature, the emissivity of each of these specimens is required. However, it was difficult to measure the emissivity of a sample cut from the conductor specimen because an ACSR conductor surface is not flat. In the measurement of emissivity, aluminum boards of 2.5×2.5×0.5cm were used. Sandblasted or black-painted aluminum board was made in the same manner described above. Table 1 summarizes the results obtained using a Fourier infrared spectrophotometer for the calculation. Some typical emissivity values, given in standards [1,2], are shown in Table 1. The obtained emissivity for sandblast and black-painted aluminum were almost the same as the value adopted in the standards. That of non-treated aluminum is much smaller compared with the IEEE value.

Table 1: Emissivity of specimens.

Specimen	Measured	Ref.#1	Ref.#2
Non- treated	0.04	N/A	0.23
Sandblasted	0.41	N/A	0.50
Black-painted	0.94	0.9	0.91

3.4 Measured and calculated conductor temperature

No significant difference in temperature was observed along the conductor length facing the aperture of the wind tunnel. Figure 4 shows measured conductor temperature, which is the average of temperatures at eight locations, two each of windward, leeward, upper and lower sides at the center of the aperture, of a 160mm^2 sandblast specimen as a function of wind velocity and current. Conductor temperature calculated using CIGRE method is also shown in the figure. In the calculation, ambient temperature and emissivity of 16.3℃and 0.41respectively were used. Solar heating was ignored, assumed to be zero, since the experiment was carried indoors.

For wind velocities of 0.5m/s and above, the measured conductor temperature agreed well with that calculated using CIGRE method. However, a significant difference was observed between the measured and calculated conductor temperatures for wind velocities less than 0.5m/s. The same tendency was observed for the other specimens.

In the experiment with the natural wind, with the wind tunnel turned off, air circulation might have occurred near the conductor due to temperature difference between the conductor and the air surrounding the conductor, which might cause a slight reduction in conductor temperature. However, it is difficult to explain the large discrepancy between measured and calculated temperatures.

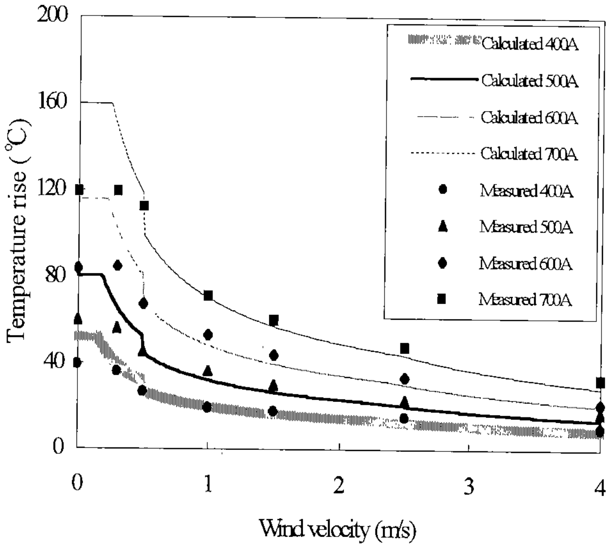

Fig.4: Calculated and measured temperature rise—CIGRE

Figure 5 shows the effect of emissivity of the conductor surface on its temperature, the calculated temperature for 160mm^2 specimen under natural wind. The conductor temperature is not so sensitive to emissivity. Thus, it is considered that the discrepancy between measured and calculated conductor temperature for wind velocities below 0.5m/s is essential.

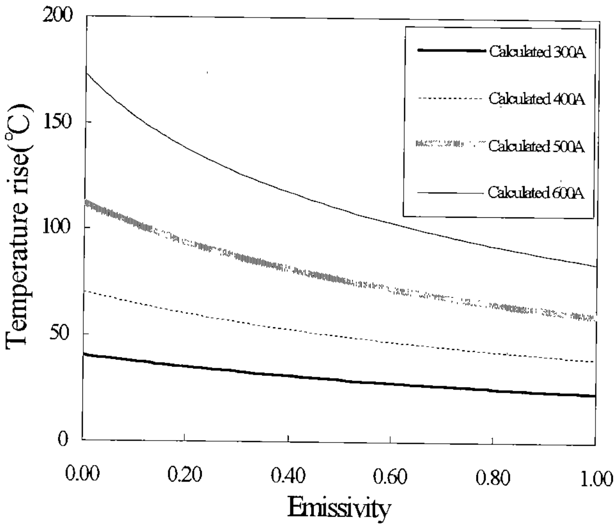

Fig.5: Effect of emissivity on conductor temperature

3.5 Proposition of an experimental equation

The existing equation of heat dissipation by convection formulated by CIGRE does not seem suitable for wind velocities below 0.5m/s. For this reason, the following equation is proposed based on our experimental results. v denotes wind velocity.

(1) For v≧0.5m/s: Existing method described by CIGRE.
(2) For 0.3m/s≦v < 0.5m/s: The existing CIGRE method

for v≧0.5m/s is extrapolated.

(3) For 0≦v < 0.3m/s: Heat dissipation is assumed to be independent of v. The value at v=0.3m/s is used.

The calculated conductor temperature using the proposed experimental equation and the measured conductor temperature are shown in Fig.6.

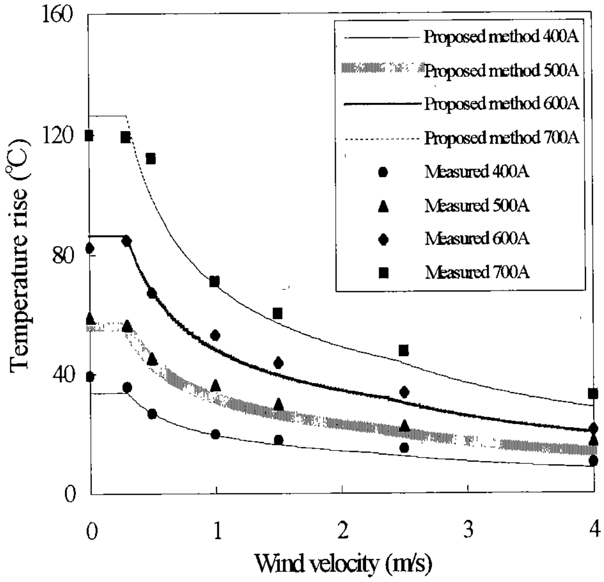

Fig.6: Calculated and measured temperature rise--proposed

From our experimental results, the calculated conductor temperature agrees very well with the measured values in the range of 0≦v≦4m/s.

4. Conductor temperature calculation with actual data

The conductor temperature of a transmission line is calculated with a probabilistic method using climatic and current data. The static method [11,12], which is one of the probabilistic methods and uses the probability distributions of the factors being used for the study, was used.

4.1 Climatic and current data

Ambient temperature, wind velocity, wind direction and global solar radiation have significant influence on conductor temperature. Consequently, data on these factors were used in the study. These are hourly-recorded data, from April 1997 to March 1998, and were obtained from the Nagoya Weather Observatory Station. As an illustration, a typical distribution of wind velocity is shown in Fig.7. And the ranges of the data on these climatic factors are:

(1) Ambient temperature: –3 °C ~ 35 °C,
(2) Wind velocity: 0~13 m/s,
(3) Wind direction: 0~90° and
(4) Global solar radiation: 0~3.6 W/m^2.

For the current data, an hourly-recorded data of electric power in MW recorded by Chubu Electric Power Company for a specified ACSR 410mm^2 transmission line for the mentioned period was used. The current was calculated from the data, and its distribution is shown in Fig.8.

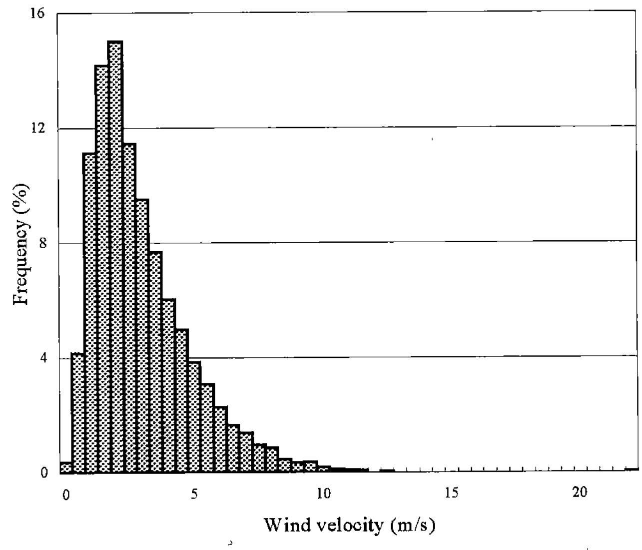

Fig.7: Wind velocity distribution

A 410mm^2 ACSR conductor was used in the study since that is the conductor strung on the transmission line on which the current data was recorded.

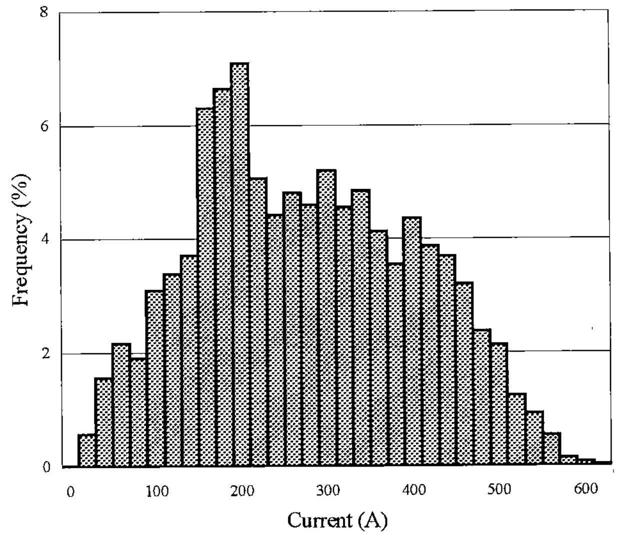

Fig.8: Current distribution.

4.2 Calculation results

Using climatic and current data, the conductor temperatures were calculated by numerically solving (1). The proposed equation made in section 3.6 was used for the calculation of heat dissipation by convection with the aim of comparing the results with that obtained from the CIGRE method. To determine the angle between wind direction and the conductor, it was assumed that the conductor is installed in east-west direction or plane. The distributions for the conductor temperature calculated using the proposed method in this study and the CIGRE method are as shown in Fig.9. However, the conductor temperature distribution for each of these methods temperature is almost the same as shown in Fig.9. This is attributed to the fact that the frequency of wind velocity below 0.5m/s is as low as 0.5% in the recorded data shown in Fig.6. It therefore became necessary to investigate a case of having a high frequency of wind velocity being less than 0.5m/s in order to compare these two methods. Ideally, it was intended to use climatic data from Maizuru and Kofu, where the frequency of wind velocity below 0.5m/s are 20% and 16.6% respectively [13].

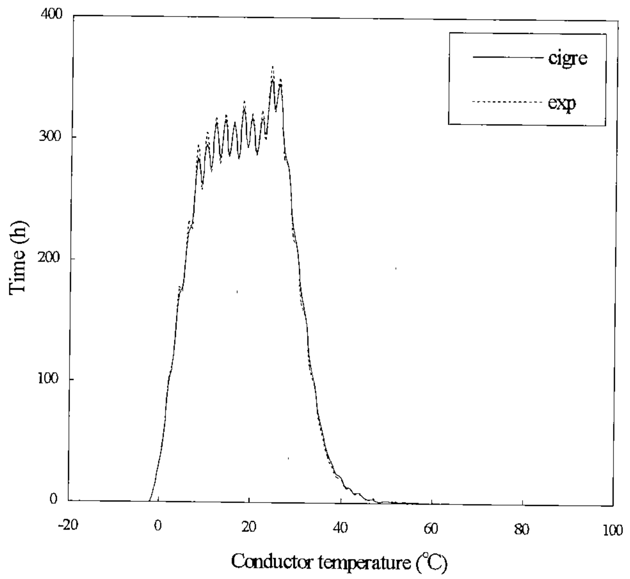

Fig.9: Distribution of calculated conductor temperature

Unfortunately however, these data could not be obtained. It was therefore decided to use an extreme case where the conductor is not exposed to wind and thus the wind velocity was 0m/s. This can be likened to conductors and busbars that are constructed in underground facilities and for that reason are not exposed to windy conditions. And because underground facilities like these are not exposed to global solar radiation, this climatic factor was excluded in the said investigation. All other data on the factors being used for the study was unchanged and the distributions for the calculated temperatures for the two methods are as shown in Fig.10.

From these two studies, using the actual data and the extreme case, it can be observed that the difference between these two methods becomes significant as the percentage of the wind velocity below 0.5 m/s increases. And since the percentage of wind velocity below 0.5 m/s for both Maizuru and Kofu lie between these two cases, it is expected that the difference between these two methods can be significant in terms of temperature.

The significance of the conductor temperature on power transmission lines lies in the fact that higher temperatures are capable of causing a reduction in tensile strength of the conductor and also reducing the conductor to ground clearance of the line, just to mention a few. These temperature distributions can be translated into sag, and for that matter the conductor to ground clearance, and reduction in tensile strength as in [14] and [15] respectively. From both the reduction in tensile strength and conductor to ground clearance points of view, there is no significant difference between the CIGRE and the proposed method.

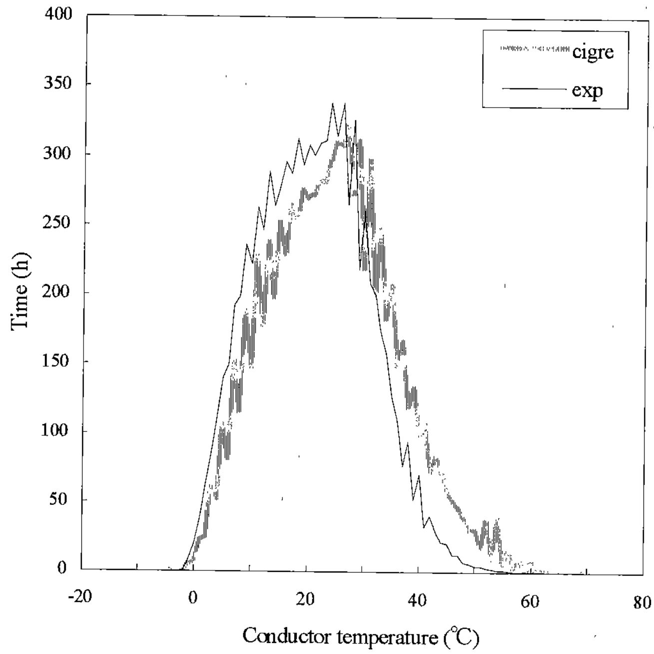

Fig.10: Distribution of calculated conductor temperature

5. Conclusion

Measurement of a bare conductor temperature was carried out in an experiment using artificial wind generated from a wind tunnel. The measured conductor temperature was very much in agreement with that calculated using CIGRE method for wind velocities of 0.5m/s and above. Below this wind velocity, the measured temperature was much lower than that calculated using the CIGRE method.

Based on the experimental results, a method was proposed to narrow these differences. The proposed method compared very well with the existing CIGRE method when these two methods were used to carrying out thermal analyses on a conductor with actual recorded data. The difference between the two methods is not significant for the said study. And even in the extreme case, notwithstanding the difference in temperature distributions, the two methods compared favorably on the basis of the assessed reduction in the tensile strength of the conductor and the conductor to ground clearance. The use of the CIGRE method is thus considered suitable in spite of the inconsistency in handling calculations for wind velocities less than 0.5m/s.

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References

[1] JCS Standard, "Current Capacity of Bare Aluminum Transmission Line Conductor", 374-A, 1993, in Japanese.

[2] IEEE Standard, "IEEE Standard for Calculating the Current-Temperature Relationship of Bare Overhead Conductor", IEEE Standard 738-1993.

[3] IEC, "Overhead Electrical Conductors Calculation Methods for Stranded Bare Conductors", IEC-1597, 1995.

[4] CIGRE WG22.12, "The Thermal Behavior of Overhead Conductors", Electra, No.144, pp.107-125, 1992.

[5] *Transmission & Distribution World*, Intertec Publishing Corporation, U.S.A, March 2000 Edition.

[6] T. O Seppa, "Application of IEEE Standard 738-1993 for Static Ratings", Presentation at 1996 Summer Power Meeting, Symposium on Thermal Rating, Denver, U.S.A, 1996.

[7] N.Iwama, I.Murasawa and K.Naito, "Experiment about Heat Dissipation from Conductor in Wind Tunnel", Annual Conference of Power and Energy Society IEEJ, No.491, 1997, in Japanese.

[8] A.Mannami et al., "Measurement of Power Conductor Temperature under Forced Cooling Using Wind Tunnel", Annual Meeting of IEEJ, No.1630, 1998, in Japanese.

[9] C. W Rice, "Free and Forced Convection of Heat in Gases and Liquids", AIEE Transactions, pp.653-706, 1923.

[10] K. Adomah, Y. Mizuno, K. Naito, "Heat Convection from Power Conductors", IEEJ National Conference in Kyoto, Paper No. 1704, March 1997.

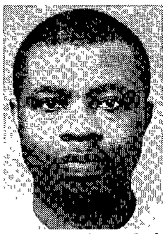
[11] G. Karady, D. Dallaire, D. Mukhedkar, "Statistical Method for Transmission Line Insulation Design for Polluted Areas", IEEE PES WM A76, pp.220-224, 1976.

[12] K. Naito, Y. Mizuno, W. Naganawa, "A Study on the Probabilistic Assessment of Contamination Flashover of High Voltage Insulator", IEEE Transactions on Power Delivery, Vol.10, No.3, pp.1378-1384, 1995.

[13] IEEJ, "Current Capacity of Overhead Transmission line Conductor", Technical Report No.660, p.38, 1997, in Japanese.

[14] K. Adomah, Y. Mizuno, K. Naito, "Probabilistic Assessment of the Sag in an Overhead Transmission Line", Transactions of IEEJ, Vol.120-B, No.10, pp1298-1303, October 2000.

[15] Y. Mizuno, H. Nakamura, K. Adomah, K. Naito, "Assessment of Thermal Deterioration of Transmission Line Conductor by the Probabilistic Method", IEEE Transactions on Power Delivery, Vol.13, No.1, pp.266-271, January 1998.



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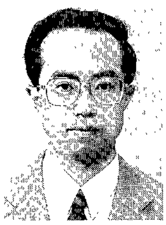

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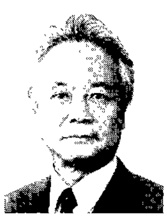

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