PROBABILISTIC APPROACH TO FIX THE OVERHEAD LINE POWER TRANFER LIMITS, WITH EFFECTIVE WIND COOLING

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Degree of Master of Science

by
D.M.J. ROSHAN KUMARA

Supervised by: Eng. W.D.A.S. Wijayapala
Eng. D.G. Rienzie Fernando

Department of Electrical Engineering
University of Moratuwa
Sri Lanka

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Abstract

Open distribution line access and economic uncertainties are the reasons why many utilities are operating their lines at much higher loads than they were initially designed for. Because of this, the effects of higher operating temperatures on the safety and reliability of overheads lines were studied in this dissertation.

It is observed that overloading of conductor usually occur during peak hours in according to the average daily load pattern of Sri Lanka. During this time conductor temperature reaches to its maximum. However, conductor temperature may not increase due to the cooling effect on availability of wind. The over temperature causes reduction of the tensile strength of the conductor.

The work has been identified in significant areas where improved analytical methods are relevant. Several such methods have been created and their impact is discussed in this report.

As such, present conductor ratings are studied in accordance to IEC standard [7] and IEEE standard [5, 6]. Wind data at four different sites have been collected and are used for the analysis. Current variations of three different sites are taken for the study.

The probability of over temperature could be determined by applying Rayleigh distribution and cumulative frequency distribution respectively when the wind speed is below 1mls and the current rating is more than 202A. At the second stage, sag at maximum temperature has been calculated for each span. Finally,. Economical optimizations of losses are analyzed.

In the first part, allowable loss of strength of Aluminium is analyzed through a probabilistic approach. Accordingly, it is observed that strength of Aluminium is not

ever reduced below 90% of its original strength during the conductor lifetime of 50 years. This reduction of strength is negligible. Therefore, effective wind speed can be taken as 1m/s.

In the second part, sag variations were analyzed for each span which is presently used in CEB against maximum allowable temperature (90°C) in the absence of wind speed. It is observed that ground clearance is not violated when it is operated at maximum allowable temperature (90°C).

Finally, under this method costs and benefits are evaluated with increase of losses against investment incurred in strengthening of the , CEB network. Net present value is analyzed considering present value of expenses (increase of losses of existing system) and present value of savings (investment incurred in strengthening of the CEB network). Net present value is positive for load patterns of Omara, Ratmalwala and Kudagammana. Therefore those projects are financially viable.

DECLARATION

The work submitted in this dissertation is the result of my own investigation, except where otherwise stated.

It has not already been accepted for any degree, and is also not being concurrently submitted for any other degree.

UOM Verified Signature

D.M.J. Roshan Kumara
Date: 28th January 2010

We endorse the declaration by the candidate.

UOM Verified Signature

Eng. W.D.A.S. Wijayapala
Senior Lecturer
University of Moratuwa

UOM Verified Signature

Eng. D.G. Rienzie Fernando
Managing Director
Amithi Power Consultants (Pvt) Ltd

D. G. RIENZIE FERNANDO
B.Sc. Eng (Hons) C. Eng. MIE (SL)
Managing Director
Amithi Power Consultants (Pvt) Ltd

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Abbreviations

ACSR	Aluminium Conductor Steel Reinforced
Avg.	Average
CCC	Current Carrying Capacity
cdf	cumulative density function
CEB	Ceylon Electricity Board
CIGRE	International Council on Large Electrical Systems
EDT	Everyday Tension
EDS	Everyday Stress
IEC	International Electrotechnical Commission
IEEE	The Institute of Electrical and Electronic Engineers
HGSS	Hambantota Grid Sub Station
LKR.	Sri Lankan Rupees
Max.	Maximum
Min.	Minimum
pdf	probability density function
PVF	Present Value Factor
UTS	Ultimate Tensile Strength

Chapter 01

Introduction

1.1 Background

Recently, electrical utilities show more interest in utilization of distribution network to their maximum capacity. Therefore an utility has to open many accesses which cause heavier and heavier loads on distribution lines. But, economic uncertainties have made most distribution lines and utilities very reluctant to expend capital resources for network reinforcements and construction of new lines. In turn, this has resulted in a greater need to operate distribution lines at high currents and at high temperatures than initially designed for. Thus the assessment of the impact of these desired increase in power transfer capability on reliability and safety are of increased and vital importance.

Wind speed and wind direction are two important weather parameters which affect the cooling of the overhead conductors. Rating practices and assumptions are varying from utility to utility. The most of common practice to calculate line rating at highest ambient temperature, full solar radiation and effective wind speed of 0.61m/s. Nevertheless the IEEE/CIGRE survey shows that over the past decade, number of utilities has incrementally increased their line ratings by relaxing some of the rating assumptions. Some utilities now assume that an effective wind speed of 0.91m/s. or even higher.

This dissertation focuses on the improvement of power transfer limits on existing distribution lines with effective wind cooling.

1.2 Objective

To carry out an investigation for improvement of power transfer limits (overloading capability) on existing distribution lines with effective wind cooling.

1.3 Scope of work

The scope of this work are given below.

- Investigate conductor rating and collect wind data of several specific areas.
- Find the possibilities to fix a wind speed to up rate the conductor rating.
- Find the possibility to adopt a new rating on probabilistic possibility on conductor facing over temperature.
- To study ground clearance violations when operating on higher temperatures.
- Possibilities to adopt the new rating considering related losses.

1.4 Determination of maximum permissible conductor temperature

As per the IEC Standard 1597-1995[7] and IEEE Standard 738-2006[6], maximum temperature limit is selected,

- In order to minimize loss of tensile strength of conductor
- To keep appropriate clearance
- Economical optimization of line loss, or a combination of above.

Chapter 02

Problem Statement

Open distribution line access and economic uncertainties are the reasons why many utilities are operating their line at much higher loads than they were initially designed for. Because of this, the effects of higher operating temperature on the safety and reliabilities of overhead lines were studied.

Current carrying capacity of conductors mainly depend on intensity of solar radiation, solar absorption coefficient, emissivity coefficient, ambient temperature, conductor diameter, electrical resistance, wind speed and wind direction.

Wind speed and wind direction are two important weather parameters which affect the cooling of the overhead conductor. Rating practices and assumptions vary from utility to utility. The most common practice is to calculate line rating at highest ambient temperature, full solar radiation and effective wind speed of 0.61m/s.

It is noted that ACSR Racoon conductor's CCC become 202A at the temperature of 80°C and at still air conditions, and 221A at the wind speed 1 m/s and zero wind angle. However, in the absence of wind speed conductor temperature reaches to 87°C. By analyzing wind data of several areas, it is observed that most of time wind speed is more than 1 m/s. As such, probability of over temperature could be determined by applying Rayleigh distribution when wind speed is below 1m/s.

Further, it is noted that line is becoming overloaded during peak hours. Probability of overloading could be determined by applying cumulative frequency when it is more than 202A.

Over temperature of conductor can occur due to wind speeds below 1 m/s and conductor loading more than 202A. This dissertation focuses on the probabilistic approach for the improvement of power transfer capability of existing Racoon distribution lines up to 220A with effective wind cooling and to study the behavior of the conductor on overloading and possible over temperatures that the conductor may undergo. Further the advantages and disadvantages that might be experienced by the supply authority on economic viability have been studied.

ACSR Racoon conductor is the most commonly used conductor in the existing distribution system of CEB. Therefore this conductor was chosen for the calculation in the study.

Chapter 03

Maximum Admissible Loss of Tensile Strength

The passage of electric current through a conductor causes a rise in temperature which can have annealing effect on Aluminium causing a loss of strength. The amount of strength that is lost depends on the temperature and duration, and the effect is cumulative. i.e 10 hrs each year of 10 years has similar effect to heating the conductor continuously for 100 hrs at the same temperature [7]. It is a normal practice to limit operating temperatures to 80°C and emergency load temperature to 125°C for ACSR conductors.

By analyzing load pattern of CEB network and wind speed data of Sri Lanka, it is noted that when wind speed become below 1 m/s and current becomes more than 202A, it causes over temperature of conductor. Since these two events are independent, probability of over temperature of conductor can be calculated by multiplication of above probability of occurrence of the above two events.

This chapter describes the mathematical formulation to evaluate the current carrying capacity of a bare conductor. There are many methods for calculation of line loading. Most commonly used method uses the conductor temperature to solve the heat balance equation to evaluate the current carrying capacity.

3.1 Units and identification of letter symbols

Symbol	Description	SI Units
A'	Projected area of conductor per unit length	m^2/m
C	Solar azimuth constant	degree
D	Conductor diameter	mm
H_c	Altitude of sun	degree
H_e	Elevation of conductor above sea level	m
I	Conductor current	A
K_{angle}	Wind direction factor	-

Table 3.1 Units and identification of letter symbols

Symbol	Description	SI Units
K_{solar}	Solar altitude correction factor	-
k_f	Thermal conductivity of air at temperature T_{film}	W/m °C
Lat	Degrees of latitude	degrees
N	Day of the year	-
$q_{cn}, q_{c1}, q_{c2}, q_c$	Convected heat loss per unit length	W/m
q_r	Radiated heat loss rate per unit length	W/m
q_s	Heat gain rate from sun	W/m
Q_s	Total solar and sky radiated heat flux rate	W/m^2
Q_{se}	Total solar and sky radiated heat flux rate elevation corrected	W/m^2
$R(T_c)$	AC resistance of conductor at temperature, T_c	Ω/m
T_a	Ambient temperature	°C
T_c	Conductor temperature	°C
T_{film}	$(T_c + T_a)/2$	°C
T_{low}	Minimum conductor temperature for which ac resistance is specified	°C
T_{high}	Maximum conductor temperature for which ac resistance is specified	°C
V_w	Speed of air stream at conductor	m/s
Z_c	Azimuth of sun	degrees
Z_l	Azimuth of line	degrees
α	Solar absorptivity (0.23 to 0.91)	-
δ	Solar declination (0 to 90)	degrees
ε	Emissivity (0.23 to 0.91)	-
φ	Angle between wind and axis of conductor	degrees
β	Angle between wind and perpendicular to conductor axis	degrees
p_f	Density of air	kg/m^3
θ	Effective angle of incidence of the sun's rays	degrees
μ_f	Dynamic viscosity of air	Pa s
ω	Hours from local sun noon times 15	degrees
χ	Solar azimuth variable	-

Table 3.1 Units and identification of letter symbols (continued)

3.2 Current carrying capacity of ACSR Racoon conductors

The CCC of a conductor is the maximum steady state current inducing a given temperature rise in the conductor, for given ambient conditions.

3.2.1 Steady-state heat balance equation

The steady-state temperature rise of a conductor is reached whenever the heat gained by the conductor from various sources is equal to the heat losses. This is expressed by equation given below [6].

$$q_c + q_r = q_s + I^2 R(T_c) \tag{3.1}$$

q_c is the convection heat loss

q_r is the heat loss by radiation of the conductor

q_s is the solar heat gain by the conductor surface

$I^2 R(T_c)$ is the heat generated by Joule effect

Note that magnetic heat gain, corona heat gain, evaporative heat losses are not taken into account in equation (3.1).

3.2.2 Forced convection heat loss

$$q_{c1} = \left[1.01 + 0.0372\left(\frac{D\rho_f V_w}{\mu_f}\right)^{0.52}\right] k_f K_{angle}(T_c - T_a) \tag{3.2}$$

$$q_{c2} = \left[0.0119\left(\frac{D\rho_f V_w}{\mu_f}\right)^{0.6}\right] k_f K_{angle}(T_c - T_a) \tag{3.3}$$

Equation (3.2) applies at low winds but is inaccurate at high wind speeds. Equation (3.3) applies at high wind speeds, being incorrect at low wind speeds. At any wind speed, the larger of the two calculated convection heat losses is used [6].

The convective heat loss rate is multiplied by the wind direction factor, K_{angle} where φ, is the wind direction and the conductor axis:

$$K_{angle} = 1.194 - \cos\varphi + 0.194\cos 2\varphi + 0.368\sin 2\varphi \tag{3.4}$$

Alternatively, the wind direction factor may be expressed as a function of the angle, β, between the wind direction and a perpendicular to the conductor axis. This angle is complement of α, and the wind direction factor becomes:

$$K_{angle} = 1.194 - \cos\beta - 0.194\cos 2\beta + 0.368\sin 2\beta \qquad (3.5)$$

This is the form of the wind direction factor as originally suggested in Davis [13] and is used in the computer program listed in Annex A.

3.2.3 Natural Convection

With zero wind speed, natural convection occurs, where the rate heat loss is as shown in below [6].

$$q_{cn} = 0.0205 p_f{}^{0.5} D^{0.75} (T_c - T_a)^{1.25} \qquad (3.6)$$

It has been argued that at low wind speeds, the convection cooling rate should be calculated by using a vector sum of the wind speeds or "natural" wind speed. However, it is recommended that only the larger of the forced and natural convection heat loss be used at low speeds instead of their vector sum as this is conservative. The computer program listed in Annex A takes this approach.

For both forced and natural convection, air density (p_f), air viscosity (μ_f), and coefficient of thermal conductivity of air (k_f) are taken from Table 3.2 or calculated with the equations of 3.2 at T_{film} where:

$$T_{film} = \frac{Tc + Ta}{2} \qquad (3.7)$$

3.2.4 Radiated heat loss rate

Radiated heat loss rate is expressed by equation given below [6].

$$q_r = 0.0178\, \mathrm{D}\, \varepsilon \left[\left(\frac{\mathrm{Tc}+273}{100} \right)^4 - \left(\frac{\mathrm{Ta}+273}{100} \right)^4 \right] \qquad (3.8)$$

3.2.5 Rate of solar heat gain (see Table 3.4, Table 3.5, Table 3.6)

Rate of solar heat gain is expressed by equation given below [6].

$$q_s = \alpha Q_{se} \sin\theta \ A' \tag{3.9}$$

Where

$$\theta = \arccos[\cos(H_c)\cos(Z_c - Z_1)] \tag{3.10}$$

3.2.6 Conductor electrical resistance

The electrical resistance of bare stranded conductor varies with frequency, average current density, and temperature. For 50 Hz ac, at temperature of 40°C to 80 °C gives calculated values of electrical resistance for ACSR Racoon conductor.

These calculated values include the frequency-dependent "skin effect" for all types of stranded conductor, but for other than single layer ACSR, do not include a correction for current density dependent magnetic core effects, which is significant for ACSR conductor having odd numbers of layers of Aluminium strands.

In this standard, electrical resistance is calculated solely as a function of conductor temperature: however, the resistance values entered may be function of frequency and current density. For an example, the values of conductor resistance at high temperature, T_{high}, and low temperature, T_{low}, are available for ACSR Racoon conductor. The conductor resistance at any other temperature, T_c, is found by liner interpolation according to equation given below [6].

$$R_{(Tc)} = \left[\frac{R_{(T_{high})} - R_{(T_{low})}}{T_{high} - T_{low}}\right](T_c - T_{low}) + R_{(T_{low})} \tag{3.11}$$

This method of resistance calculation allows the user to calculate the high and low temperature resistance values by whatever means is appropriate.

3.3 Equations for air properties, solar angles, and solar heat flux

In the following section, least square polynomial regressions were performed on tabular data for thermal conductivity (3.2.3), total heat flux (3.2.6), and solar heat correction for elevation (3.2.7) to fit an equation on the following form [6]:

$$Y = A + BX + CX^2 + DX^3 + EX^4 + FX^5 + GX^6$$

Algebraic equations are given for viscosity (3.2.1), density (3.2.2), solar altitude (3.2.4), azimuth (3.2.5).
Tables of typical values are provided for convenience.

3.3.1 Dynamic viscosity of air

The dynamic viscosity of air is determined by the algebraic equation given below [6].

$$\mu_f = \frac{1.458 * 10^{-6}(T_{film}+273)^{1.5}}{T_{film}+383.4} \tag{3.12}$$

3.3.2 Air density (Table 3.2)

The air density is determined by the algebraic equation given below [6].

$$p_f = \frac{1.293-1.525\times10^{-4}H_e+6.379\times10^{-9}H_e^2}{1+0.00367T_{film}} \tag{3.13}$$

3.3.3 Thermal conductivity of air (Table 3.2)

The thermal conductivity of air is determined by the algebraic equation given below [6].

$$k_f = 2.424 \times 10^{-2} + 7.477 \times 10^{-5}T_{film} - 4.407 \times 10^{-9}T_{film}^2 \tag{3.14}$$

Temp. T_{film}	Dynamic viscosity μ_f	Air density p_f (kg/m^3)				Thermal conductivity of air k_f
°C	(Pa·s)	0m	1000m	2000m	4000m	W/m°C
0	0.0000172	1.293	1.147	1.014	0.785	0.0242
5	0.0000174	1.270	1.126	0.995	0.771	0.0246
10	0.0000176	1.247	1.106	0.978	0.757	0.0250
15	0.0000179	1.226	1.087	0.961	0.744	0.0254
20	0.0000181	1.205	1.068	0.944	0.731	0.0257
25	0.0000184	1.184	1.051	0.928	0.719	0.0261
30	0.0000186	1.165	1.033	0.913	0.707	0.0265
35	0.0000188	1.146	1.016	0.898	0.696	0.0269
40	0.0000191	1.127	1.000	0.884	0.685	0.0272
45	0.0000193	1.110	0.984	0.870	0.674	0.0276
50	0.0000195	1.093	0.969	0.856	0.663	0.0280
55	0.0000198	1.076	0.954	0.843	0.653	0.0283
60	0.0000200	1.060	0.940	0.831	0.643	0.0287
65	0.0000202	1.044	0.926	0.818	0.634	0.0291
70	0.0000204	1.029	0.912	0.806	0.625	0.0295
75	0.0000207	1.014	0.899	0.795	0.616	0.0298
80	0.0000209	1.000	0.887	0.783	0.607	0.0302
85	0.0000211	0.986	0.874	0.773	0.598	0.0306
90	0.0000213	0.972	0.862	0.762	0.590	0.0309
95	0.0000215	0.959	0.850	0.752	0.582	0.0313
100	0.0000217	0.946	0.839	0.741	0.574	0.0317

Table 3.2 Viscosity, density and thermal conductivity of air

3.3.4 Altitude of the sun (Table 3.4)

The solar altitude of the sun, H_c, in degree (or radians) is given by Equation (3.15) where inverse trigonometric function arguments are in degrees (or radians) [6].

$$H_c = \text{arc sin}\,[\cos(\text{Lat})\cos(\delta)\cos(\omega)+\sin(\text{Lat})\,\sin(\delta)] \qquad (3.15)$$

The hour angle, ω, is the number of hours from noon times 15°C (for example 11 a.m. -15°C, 11 a.m., 2 p.m. is +30°C).

The solar declination, δ, is shown in Equation (3.16) [6].

$$\delta = 23.4583 \sin\left[\frac{284+N}{365} 360\right] \qquad (3.16)$$

Where, the argument of the sin is in degrees.

The equation is valid for all latitudes whether positive (northern hemisphere) or negative (hemisphere).

3.3.5 Azimuth of the sun (Table 3.5)

The solar azimuth, Z_c, (in degree) is shown in following equation [6].

$$Z_c = C + arc\tan(x) \qquad (3.17)$$

Where

$$x = \frac{\sin(\omega)}{\sin(Lat)\cos(\omega) - \cos(Lat)\tan(\delta)} \qquad (3.18)$$

The solar azimuth constant, C, (in degree), is a function of the "hour angle", ω, and the solar azimuth variable, x, as shown in the table 3.2[6].

Hour Angle," ω (degrees)	C if x> 0 (degrees)	C if x<0 (degrees)
-180 < ω < 0	0	180
0 < ω < 180	180	360

Table 3.3 Solar azimuth constant, C (in degree), is a function of the "hour angle", ω, and solar azimuth variable, X

	Local sun time						
Latitude	**10:00 a.m.**		**Noon**		**2:00 p.m.**		
(Degrees North)	**H_c**	**Z_c**	**H_c**	**Z_c**	**H_c**	**Z_c**	**N**
-80	32	33	33	180	32	327	350
-70	40	37	43	180	40	323	350
-60	48	43	53	180	48	317	350
-50	55	52	63	180	55	308	350
-40	60	66	73	180	60	294	350
-30	62	83	83	180	62	277	350
-20	62	96	90	180	62	264	20
-10	61	97	88	180	61	263	50
0	60	91	90	180	60	269	80
10	61	85	89	180	61	275	110
20	62	85	90	180	62	275	140
30	62	97	83	180	62	263	170
40	60	114	73	180	60	245	170
50	55	128	63	180	55	232	170
60	48	137	53	180	48	223	170
70	40	143	43	180	40	217	170
80	32	147	33	180	32	213	170

Table 3.4 Solar altitude, H_c, and azimuth, Zc, at various latitudes for an annual peak solar heat input

3.3.6 Total heat flux received by a surface at sea level (Table 3.5 and Table 3.6)

The total heat flux density at sea level is dependent on both the solar altitude and atmospheric clarity.

The heat flux received by a surface at sea level as shown in table 5 may be represented by the following regression equation [6].

Y= total heat flux, Q_s (w/m^2)

X= solar altitude, H_c (degree)

$$Q_s = A + BH_c + CH_c^2 + CH_c^3 + CH_c^4 + CH_c^5 + CH_c^6 \tag{3.19}$$

Clear atmosphere	
A	-42.2391
B	63.8044
C	-1.9220
D	$3.46921\text{x}10^{-2}$
E	$-3.61118\text{x}10^{-4}$
F	$1.94318\text{x}10^{-6}$
G	$-4.07608\text{x}10^{-9}$
Industrial atmosphere	
A	53.1821
B	14.2110
C	$6.6138\text{x}10^{-1}$
D	$-3.1658\text{x}10^{-2}$
E	$5.4654\text{x}10^{-6}$
F	$-4.3446\text{x}10^{-6}$
G	$1.3236\text{x}10^{-8}$

Table 3.5 Coefficient for equation (3.19)

Degrees solar altitude	**Clear atmosphere**	**Industrial atmosphere**
H_c(deg)	**Q_s(W/m^2)**	**Q_s(W/m^2)**
5	234	136
10	433	240
15	583	328
20	693	422
25	770	502
30	829	571
35	877	619
40	913	662
45	941	694
50	969	727
60	1000	771
70	1020	809
80	1030	833
90	1040	849

Table 3.6 Total heat flux received by a surface at sea level normal to the sun's rays

3.3.7 Total heat flux elevation correction factor (Table 3.6)

$$Q_{se} = K_{solar} Q_s$$

Where

$$K_{solar} = A + BH_e + CH_e^2$$

$A = 1$

$B = 1.148\times10^{-1}$

$C = -1.108\times10^{-8}$

Elevation above sea level H_e(m)	Multipliers for values in Table 3.5
0	1.00
1000	1.10
2000	1.19
4000	1.28

Table 3.7 Solar heat multiplying factors, K_{solar} for high altitudes

3.4 Sample calculations

3.4.1 Steady state thermal rating

The calculation of steady-state thermal rating given a maximum allowable conductor temperature, weather conditions, and conductor characteristics may be performed by the computer program in Annex A [5]. However, since the process does not require iterative calculations, it can be done by hand. Doing so demonstrations the use of the formulas and yields some insight into the calculation process.

Note that in the following, the number of significant digits does not indicate the accuracy of the formula.

3.4.2 Problem statement

Find the steady-state thermal rating (CCC) for ACSR Racoon cond following conditions.

a) Wind speed (V_w) is 1m/s perpendicular to the

b) Emissivity(ε) is 0.6

c) Solar absorptivity (α) is 0.5

d) Ambient air temperature is 30°C

e) Maximum allowable conductor temperature is 80°C

f) Conductor outside diameter(D) is 12.27mm

g) Conductor ac resistance $[R(T_c)]$ is:

R (40°C) 0.4310 (kΩ/m)

R (80°C) 0.5192 (kΩ/m)

h) The line runs in an East-West direction so azimuth of line, Z_l 90°

i) Latitude is 10° North

j) The atmosphere is clear

k) Solar altitude (H_c) for 12:00 Noon on

l) Average conductor elevation 100m

3.4.3 Convection heat loss (q_c)

The natural convection heat loss is calculated by means of equations (3.6). See

Where

D = 12.27 mm

$T_c = 80°C$

$T_a = 30°C$

$$T_{film} = \frac{80 + 30}{2} = 55°C$$

p_f = 1.076kg/m^3 (Table 3.2)

$$q_{cn} = 0.0205 \times (1.076)^{0.5} \times 12.27^{0.75} \times (80 - 30)^{1.25}$$

$$q_{cn} = 18.54 \text{ W/m}$$

Since the wind speed is greater than zero, the forced convection heat loss for perpendicular wind is calculated according to equation (3.2) and (3.3), corrected for wind direction and compared to the natural and forced heat convection is used to calculate the thermal rating.

Where

D = 12.27 mm

V_w = 1m/s

T_c = 80 °C

$T_a = 30$ °C

$$T_{film} = \frac{80 + 30}{2} = 55 \text{ °C}$$

$\mu_f = 1.98 \times 10^{-5}$ Pa s (Table 3.2)

$p_f = 1.076$ kg/m^3 (Table 3.2)

$k_f = 0.0283$ W/(m °C) (Table 3.2)

From equation (3.2)

$$q_{c1} = \left[1.01 + 0.0372\left(\frac{12.27 \times 1.076 \times 1}{1.98 \times 10^{-5}}\right)^{0.52}\right] 0.0283 \times \quad 0.388 \times (80 - 30)$$

$$= 22.36 \text{ W/m}$$

From equation (3.3)

$$q_{c2} = \left[0.0119\left(\tfrac{12.27 \times 1.076 \times 1}{1.98 \times 10^{-5}}\right)^{0.6}\right] \times 0.0283 \quad \times 0.388 \times (80 - 30)$$

$$= 20.40 \text{ W/m}$$

As instructed in 3.1.2, select the larger of the two calculated convection heat losses.

$q_c = 22.36$ W/m

Since the wind speed is along the axis of the conductor, the wind direction multiplier, K_{angle} is 0.388, and the forced convection heat loss. Therefore, the forced convection heat loss will be used in the calculating of thermal rating.

3.4.4 Radiated heat loss (q_r)

The radiated heat loss is calculated with equation (3.8).

Where,

D = 12.27mm

$\varepsilon = 0.6$

$T_c = 80$°C

$T_a = 30$°C

$$q_r = 0.0178 \times 12.27 \times 0.6 \times \left[\left(\frac{80 + 273}{100}\right)^4 - \left(\frac{30 + 273}{100}\right)^4\right]$$

$$q_r = 9.30 \text{ W/m}$$

3.4.5 Solar heat gain(q_s)

The conductor is at 10°C North latitude: Approximate values of H_c and Z_c can be obtained from Table 3.3 and 3.4. From Table 3.3, the solar altitude, H_c and the solar azimuth, Z_c can be determined as follows:

H_c at 12:00 noon = 89°

Z_c at 12:00 noon = 180°

From table 3.5 for H_c = 89° with clear atmosphere:

$Q_s = 1039\ W/m^2$ (By interpolation)

$Z_1 = 90°$ or $270°$

$\theta = \arccos[\cos(89°)\cos(180°-90°)] = 90°$

Where

$\alpha = 0.5$

$A' = D/1000 = 12.27/1000 = 0.01227m$

$K_{solar} = 1.0$

$q_s = 0.5 \times 1039 \times \sin(90°) \times 0.01227$

$q_s = 6.37\ W/m$

3.4.6 Steady state thermal rating

Using Equation (3.1), the thermal rating can be found where:

$q_c = 22.36\ W/m$

$q_r = 9.30\ W/m$

$q_s = 6.37\ W/m$

$R\ (80°C) = 5.192 \times 10^{-4}\ \Omega/m$

$$I = \sqrt{\frac{22.36 + 9.30 - 6.37}{5.192 \times 10^{-4}}}$$

$I = 221\ A$

The program listed in Annex A can also be used to calculate the steady-state thermal rating.

3.5 Input data

Careful selection of input data for current-temperature relationship is as important as the method of calculation itself, and requires considerable engineering judgment in the selection of values for each of the variables. These variables are discussed separate heading, with suggestions given on how to select values to suit particular circumstances. Some suggestions are give as to what factors should be considered when it is necessary to make decisions.

3.5.1 Wind and ambient temperature

Weather conditions have a considerable effect on the thermal loading of bare overhead conductors. The weather provides cooling principally by means of convective heat loss (q_c) to surrounding air. The degree of cooling depends on the air temperature and the wind velocity component perpendicular to the conductor.

The effect of wind direction relative to the conductor is concluded in this standard as equation (3.4 and 3.5). For a given wind speed, winds blowing parallel result in a 60% lower convective heat loss than winds blowing perpendicular to the conductor.

Height of conductors above ground is significant in terms of wind shielding. 33kV lines (where the ground clearance is greater) may be expected to be less shielded by trees and terrain than low-voltage lines.

Wind speed (m/s)	Wind direction relative to conductor axis (degrees)
0.6	90
0.8	45
1.3	22.5
2.2	0

Table 3.8 Equivalent combination of wind speed and direction for equal convective cooling

3.5.2 Air density, viscosity and conductivity

The density, viscosity and conductivity of air are used in the calculation losses and can be obtained from Table 3.2.

3.5.3 Emissivity and absorptivity

Emissivity and absorptivity increase from about 0.2 to 0.9 with age. The exact rate of increase depends on the level of atmospheric pollution and the line's operating voltage. Values of 0.5 for solar absorptivity (α) and 0.6 for Emissivity (ε), has been used for ACSR (Racoon) Conductor.

3.5.4 Solar heat gain

A simple method for the calculation of solar heat gain is provided by equation (3.9) and (3.10). The most conservative results are obtained by assuming an angle of incidence of 90°, which will give the lowest value of current carrying capacity and will be appropriate for many purposes.

Solar heat input to bare overhead conductor can cause a conductor temperature rise above air temperature of up to 15°C in still air. However, more typically, periods of maximum solar heat input are associated with significant wind activity and the actual temperature rise measured for bare conductors in overhead transmission lines seldom exceeds 5°C to 10°C.

Chapter 04

Probabilistic Approach to Allow for Maximum Admissible Loss of Tensile Strength

4.1 Probability of over temperature

The probability of over temperature could be determined by applying Rayleigh distribution and cumulative frequency respectively when wind speed is below 1m/s and conductor current rating is more than 202A.

4.1.1 Rayleigh probability distribution

The probability theory and statistics, the Rayleigh distribution is a continuous probability distribution.

Rayleigh probability density function (pdf) is [16]

$$\int (x:\sigma) = \frac{x}{\sigma^2}\exp\left(\frac{-x^2}{2\sigma^2}\right)$$

for $x \in [0, \propto), \sigma > 0$

Cumulative distribution function (cdf) is [16]

$$1 - \exp\left(\frac{-x^2}{2\sigma^2}\right)$$

4.1.2 Cumulative frequency

The cumulative frequency is the frequency where the value of a variable Y is less than a reference value X. The cumulative frequency F_c (Y<X) is found from F_c (Y<X) M_X/N, where M_X is the number of data Y with a value less than the reference value X, and N is the total number of data. Considering X as a variable, F_c (Y<X) can be called the cumulative frequency function or cumulative frequency distribution of Y. The previous expression may be briefly written as $F_c = M/N$. As the minimum value of M is zero and the maximum is N, the value of F_c ranges between 0 and 1 or 100%

The cumulative frequency can also be called the frequency of non-exceedance. The frequency of exceedance F_e is found from $1 - F_c$[17].

4.2 Calculation of probability of wind speed by applying Rayleigh distribution

Wind data at 10 m above ground level of few sites has been collected from Energy Purchase branch, CEB and those data have been used for the probabilistic analysis.

Actual frequency of wind speed for a period of one year (2001) at Narakkalliya is indicated in figure 4.1.

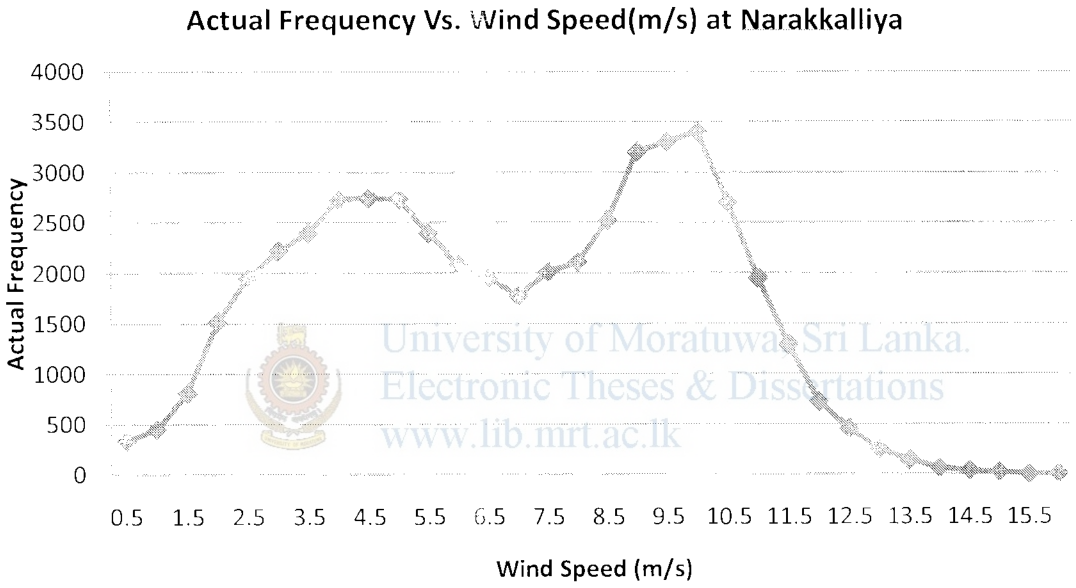

Figure 4.1 Actual frequency vs. wind speed (m/s) at Narakkalliya.

By applying Rayleigh distribution for above wind speed data is indicated in figure 4.2.

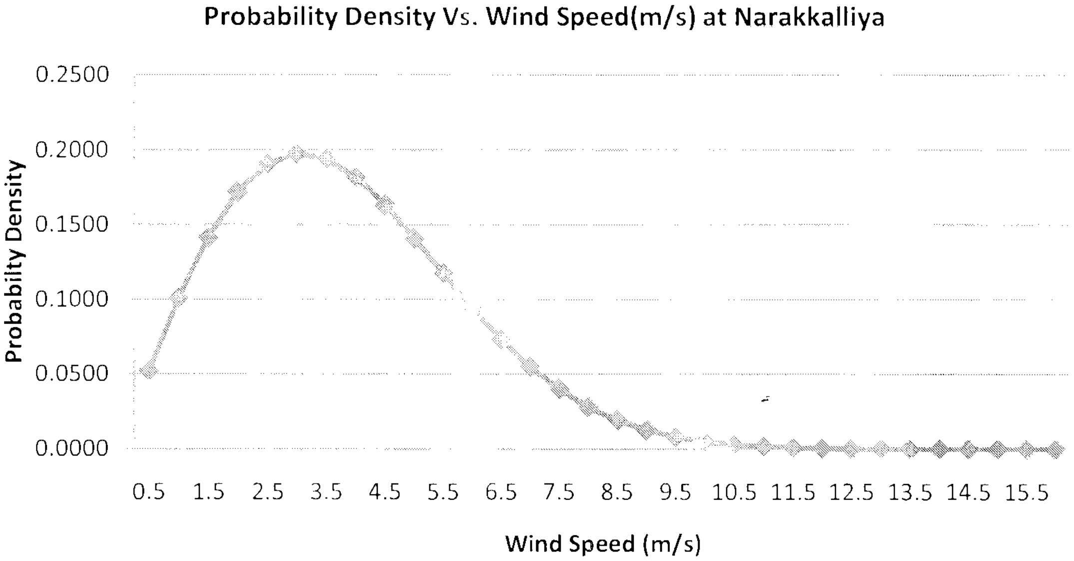

Figure 4.2 Probability density vs. wind speed (m/s) at Narakkalliya

Cumulative distribution for wind speed data is indicated in figure 4.3 by applying Rayleigh distribution.

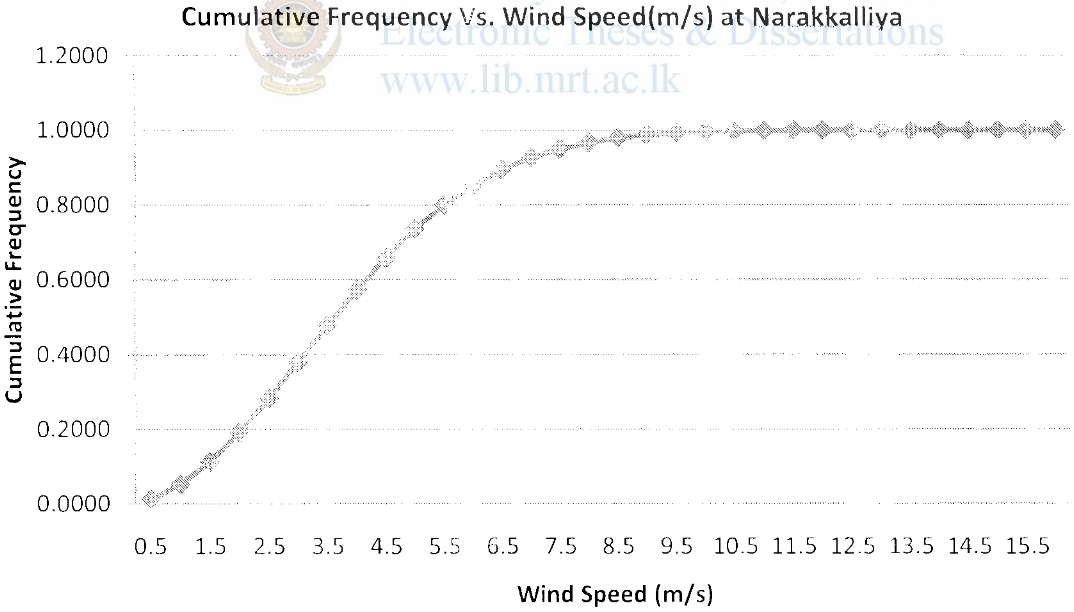

Figure 4.3 Cumulative frequency vs. wind speed (m/s) at Narakkalliya

Figure 4.3 shows that the cumulative frequency of wind speed below 1m/s is 0.0518 at Narakkaliya. Above calculations were repeated for a few sites of Sri Lanka and summary of probability is given in Table 4.1.

Site	Variance of normal (σ)	Rayleigh probability (P_u< 1 m/s)
Narakkalliya	3.07	0.0518
Sevanagala	2.81	0.0612
Kajuwatta	2.00	0.1178
Mirijjawila	3.22	0.0471

Table 4.1 Rayleigh probability distribution for wind speed below 1m/s

It is noted that the highest probability of wind speed below 1m/s is 0.1178 at Kajuwatta in Hambantota District.

4.3 Calculation of probability of over current

Average current distribution for 24 hrs of three sites in Hambantota District is indicted in figure 4.4 and those are taken as current distribution pattern of CEB. Average current was multiplied by factor in order to reach maximum value as 220A.

Site	Voltage level (V)	Min. Avg. current (A)	Max. Avg. current (A)	Multiplication factor	Min. Avg. current (A)	Min. Avg. current(A)
Omara	230	8	131	1.67	13	219
Ratmalwala	230	11	124	1.77	19	219
Kudagammana	230	48	277	0.79	38	219

Table 4.2 Voltage level, Avg. current and multiplication factor

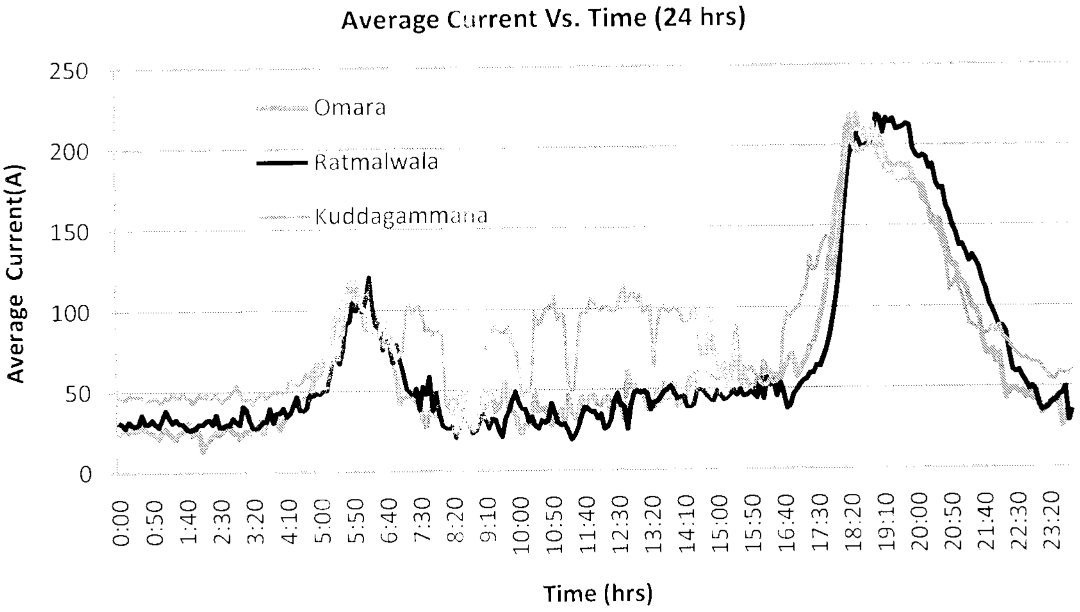

Figure 4.4 Average current vs. time (24 hrs)

Actual frequency vs. average current distribution for above three sites is indicated in figure 4.5

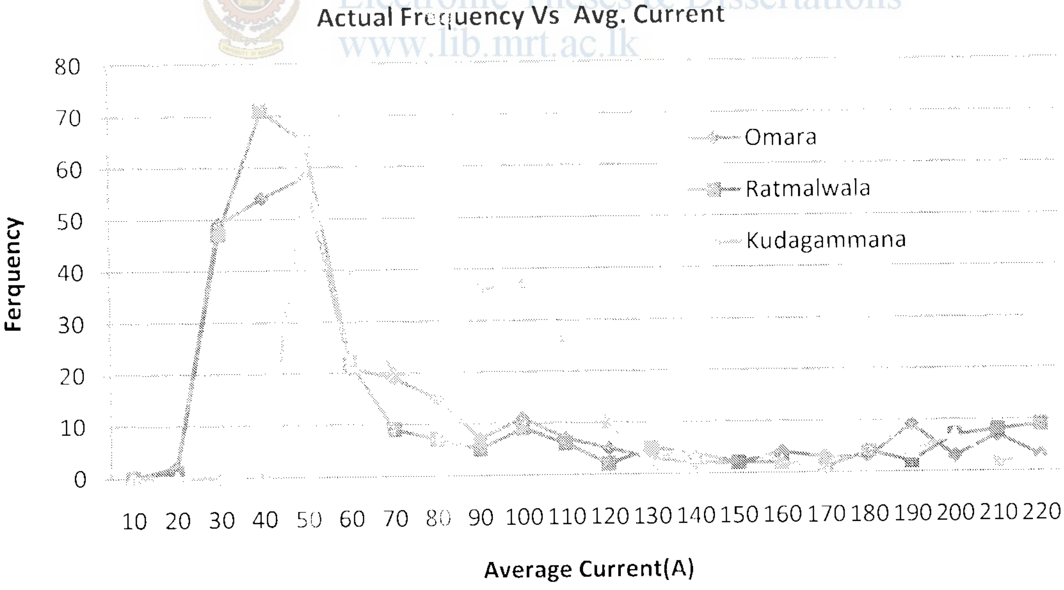

Figure 4.5 Actual frequency vs. average current

Probability density for above current variation data is indicated in figure 4.6.by applying Rayleigh distribution.

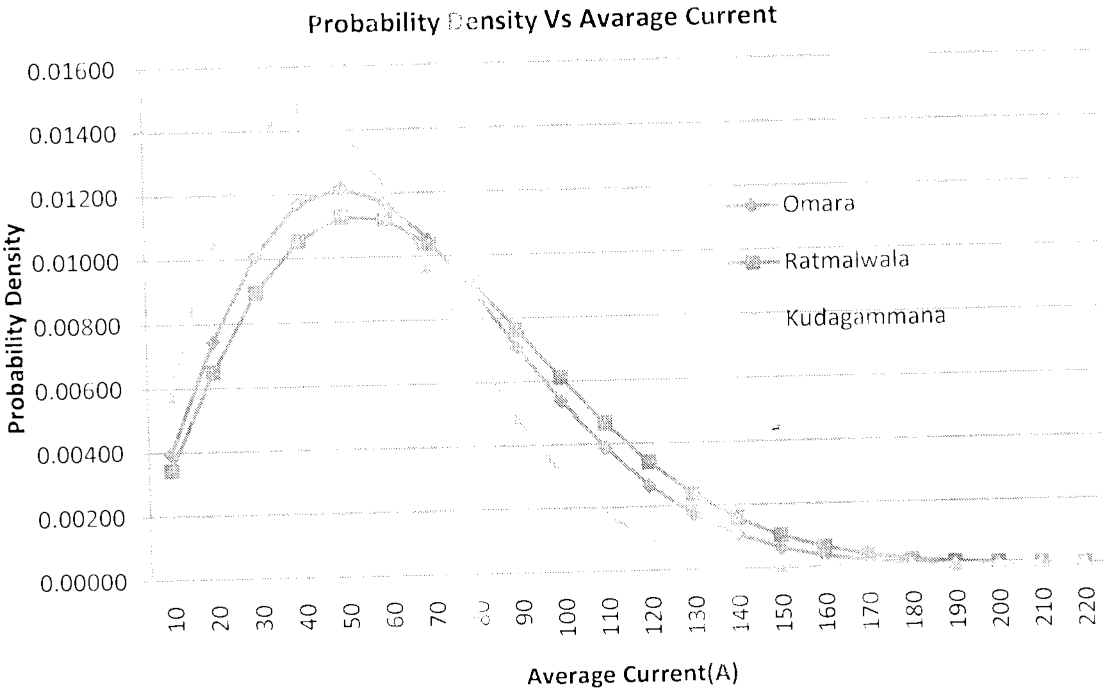

Figure 4.6 Probability density vs. average current

Cumulative distribution for above current variation data is indicated in figure 4.7 by applying Rayleigh distribution.

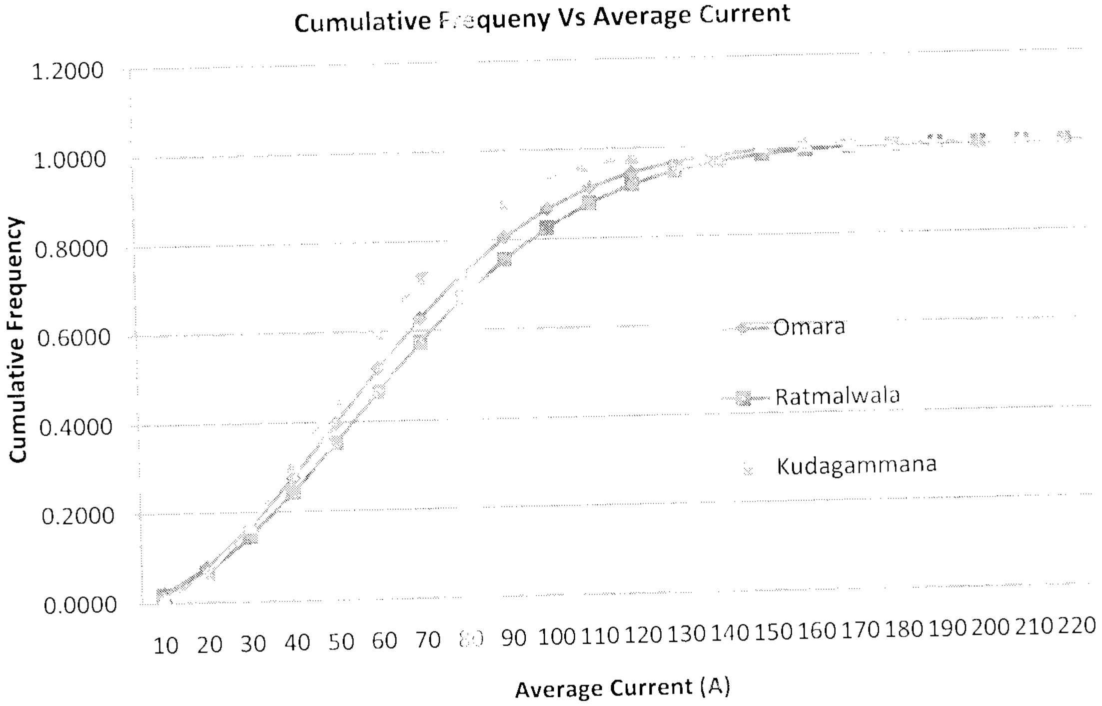

Figure 4.7 Cumulative frequency vs. average current

Site	Variance of normal (σ)	Rayleigh probability (I >202A)	Cumulative frequency (I >202A)
Omara	49.79	0.00031	0.0348
Ratmalwala	53.97	0.00094	0.0590
Kudagammana	40.94	0.00001	0.0139

Table 4.3 Probability distribution for load more than 202A

It is noted that Rayleigh probability is lower than cumulative frequency. Therefore cumulative frequency is taken as reasonable value of probability of above 202A for more accuracy. However, the highest value of probability occurs at Ratmalwala as 0.0590.

4.4 Probability of over temperature up to 87 °C

Over temperature of ACSR (Racoon) conductor may become due to the combination of,

- Wind speed should be below 1 m/s and
- CCC should be more than 202A
- Since wind speed and CCC are independent events, probability of over temperature (P_Z) can be calculated by multiplication of the two probabilities.
- P_Z (P_u< 1 m/s) x (I >202A)

  0.1178 x 0.0590

  6.95 x 10^{-3}
- Time period of over temperature per year

  6.95 x 10^{-3}x24x365hrs

  61 hrs
- Time period of over temperature for life time (50 year)

  = 61x50 hrs

  = 3050 hrs.
- Time period of over temperature per year with safety margin

  = 61hrs x 2.5

  152 hrs
- Time period of over temperature for life time (50 year) with safety margin

  3050 hrs x 2.5

  7625 hrs.

The percentage reduction in tensile strength of Aluminum type A1 at different temperature and durations is shown in figure 4.8. These figures are based on data assembled from various sources and test results [7].

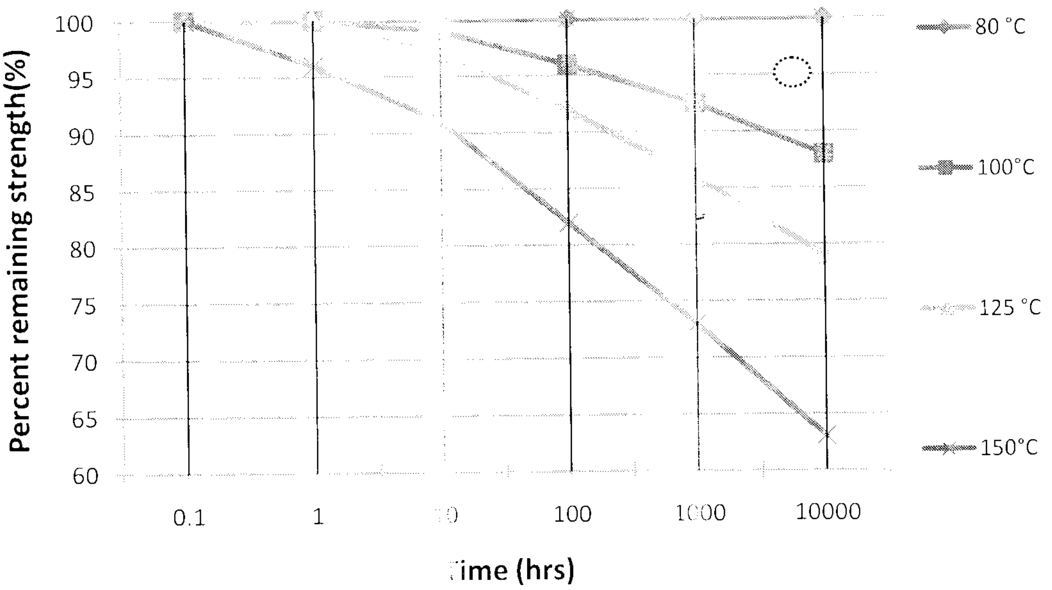

Figure 4.8 Loss of strength of Aluminium type A1 as a function of temperature

According to the above figure, it is observed that loss of strength of Aluminium is not ever reduced below 95% in the life time and it is not reduced below 90% with 2.5 safety margin.

4.5 Method of line tension calculation

Stranding Diameter	4.09	mm
no of strand steel	1	
no of strand Aluminium	6	
Minimum UTS of Al wire	165	N/mm^2
Percent remaining strength of Aluminium	1	
Minimum UTS at 1% extension of steel	1100	N/mm^2
π	3.14	

UTS of Racoon Conductor $= 165 \times \pi \times (4.09/2)^2 \times 6 + 1100 \times \pi \times (4.09/2)^2$

UTS of Racoon Conductor = 27470 N (taken as 2705 daN)

The following table indicates the UTS of Racoon conductor against percentage of remaining strength of Aluminium. Further, it has been calculated that conductor tension for temperatures from 15 °C to 65 °C and its relevant percentage of available UTS. Hence, it is observed that loss of strength of Aluminium up to 90 % can be allowed.

Percentage of remaining strength of Aluminium		**100 %**	**95 %**	**90%**
Available UTS of Racoon Conductor		27470 N	26819 N	26169 N
Conductor temperature (°C)	Conductor tension (N)	% UTS	% UTS	% UTS
15	4992	18	19	19
20	4364	16	16	17
30	3226	12	12	12
40	2344	9	9	9
50	1775	6	7	7
60	1432	5	5	5
65	1304	5	5	5

Table 4.4 Conductor tension for various temperatures as a percentage of available UTS

Chapter 05

Appropriate Ground Clearance

5.1 Introduction

Maximum allowable conductor temperature is typically selected so as to limit either loss of strength of the conductor due to annealing of Aluminium or to maintain adequate ground clearance.

5.2 Sag and tension.

Conductor sag on a flat terrain is maximum at mid-span. Further, this sag will increase with temperature and be a maximum at maximum operating temperature.

5.2.1 Equivalent span

The equivalent span is calculated in order to use sag and tension charts. The tension is uniform between two section poles and supported on intermediate poles. The equivalent span that results from this uniform tension is calculated with the formula below.

$$S_e = \sqrt{\frac{S_1^3 + S_2^3 + S_3^3 + \ etc}{S_1 + S_2 + S_3 + etc}} \tag{5.1}$$

Where:

S_1, S_2, S_3, etc are the individual span lengths between section poles.

Having determined the sags and tension on the equivalent span at various temperatures, the sags on the actual span can be determined from the formula:

$$\text{Sag on any span} = \frac{\text{Sag on equivalent Span} \times (\text{Actual Span Length})^2}{(\text{equivalent span length})^2} \tag{5.2}$$

While fixing the spacing, it should be as uniform as possible subject to maintain of minimum ground clearance. The maximum sag for different pole heights can be obtained from the sag table.

5.2.2 Selection of tension

Conductor sag and tension vary in accordance with the following parameters.

- The maximum sag will occurs at defined maximum operating temperature 90 °C with no wind.
- The maximum tension will occur at the defined conductor wind loading of 0.575 kN/m^2 and minimum temperature of 15°C [4].
- Constant conductor tension occurs at the defined normal everyday temperature of 30°C. This tension is termed as everyday tension (EDT) and the corresponding stress is everyday stress (EDS).
- Average tension of the conductors shall be limited to 17% of the UTS of the conductor [4].
- Maximum allowable stress with wind and low temperature shall be limited to 40% UTS [4].

5.2.3 Sag and tension formula

The sag and tension relationship is given by:

$$S = \frac{T_0 \times \left|\cosh\left(\frac{wl}{2T_0} - 1\right)\right|}{w} \qquad (5.3)$$

Or approximate formula

$$S = \frac{wl^2}{8T} \qquad (5.4)$$

Where:

S is sag (m)

T_0 is initial tension at lowest point (N)

w is conductor weight (N/m)

l is span or horizontal distance between two supports

T is conductor tension

After a conductor has been fixed into a position, the consequent variation in sag (S) due to wind pressure and temperature variations can be calculated from:

$$T_1^2 \times [T_1 - (T_e - xAE(\theta_1 - \theta_2) - AEF_2^2 l^2/24T_e^2)] = [(AEF_1^2 l^2)]/24 \qquad (5.5)$$

$$T_f^2 \times [T_f - (T_e - xAE(\theta_3 - \theta_2) - AEF_2^2 l^2/24T_e^2)] = [(AEF_3^2 l^2)]/24 \qquad (5.6)$$

Where:

T_1	conductor tension in initial condition (daN)
T_e	conductor tension in everyday condition (daN)
T_f	conductor tension in final condition (daN)
x	coefficient of thermal expansion
A	conductor area (mm^2)
E	Young's modules (daN/mm^2)
Θ_1	conductor temperature in initial condition (°C)
O_2	conductor temperature in everyday condition (°C)
Θ_3	conductor temperature in final condition (°C)
F_1	resultant wind and weight force in initial condition (daN/m)
F_2	resultant wind and weight force in everyday condition (daN/m)
F_3	resultant wind and weight force in final condition (daN/m)

5.2.4 Design criteria

- Conductor tension
  - At everyday temperature the conductor tension shall be 17% of UTS.
  - At these tensions at EDT the tensions applicable at the lowest temperature and maximum wind calculated and checked with the maximum pole top loading
- The ground clearance is checked with the specified minimum clearance
- Soil type of foundations has been taken as good soil for the above calculations

5.3 Sample calculations

Consider the following pole spacing chart:

Pole no.	Span	Cumulative span
1	30	
2	40	70
3	50	120
4	60	180
5	30	210
6	40	250
7	40	290

Table .1 Pole spacing chart

Equivalent span:

Using Equation (5.1), the equivalent sag can be calculated as:

$$S_e = \sqrt{\frac{2 \times 30^3 + 3 \times 40^3 + 50^3 + 60^3}{2 \times 30 + 3 \times 40 + 50 + 60}}$$

$$S_e = 45 \text{ m}$$

Calculate everyday tension (T_e):

Now assume the EDT at 30 °C as % of UTS.

Take UTS 27050 N

EDT (T_e) 27050 x 0.17

= 4598.5 N

Gravitational force	9.80665 m/s^2
Young's modulus	7946 daN/mm^2
Thermal expansion coefficient	0.00001908 /°C
Cross section area	91.99 mm^2
Weight of conductor	0.3129 kg/m
Diameter of conductor	12.7 mm
Temperature at initial condition, C	15 °C
Everyday temperature, C_e	30 °C

Temperature at final condition, C_f = 90°C

Wind pressure = 57.5 daN/m^2

Weight of conductor = weight of conductor x Gravitational force /10

= 0.3129 kg/m x 9.80665 m/s^2

= 0.30685 daN/m

Wind force at initial condition = Wind pressure x diameter of conductor (m)

= 57.5 daN/m^2 x 0.0127m

= 0.73025 daN/m

Wind force at everyday condition = 0 (daN/m)

Wind force at final condition = 0 (daN/m)

Resultant wind and weight force at T_1 condition

= ((Weight of conductor^2 + Wind force at initial condition^2))$^{1/2}$

F_1 = ((0.3068[illegible]^2 + 0.73025 ^{2})) ^{½}

= 0.79209[illegible]2 daN/m

Resultant wind and weight force at T_e = Weight of conductor

F_2 = 0.30685 daN/m

Resultant wind and weight force at T_f = Weight of conductor

F_3 = 0.30685 daN/m

Using equation (5.5), the initial sag at T_1 can be calculated. This is a third order polynomial in terms of T_1. The roots of this polynomial can be calculated by solving this equation by iterative methods. The Excel program listed in Annex B can be used to calculate the T_1.

T_1 = 716.865507399581 daN

Using equation (5.6), the final sag at T_f can be calculated. This is also a third order polynomial in terms of T_f. The roots of this polynomial can be calculated by solving this equation by iterative methods. The Excel program listed in Annex B can be used to calculate the T_f.

T_f = 106.582234917787 daN

Using equation (5.3). the sag at each condition can be calculated as:

$$\text{Equivalent sag at } \mathrm{T_1}\,(\mathrm{m}) = \frac{\mathrm{T_1} \times \left|\cosh\left(\frac{\mathrm{wl}}{2\mathrm{T_1}} - 1\right)\right|}{\mathrm{w}}$$

$$\text{Equivalent sag at } \mathrm{T_1}\ (\mathrm{m}) = \frac{716.8655 \times \left|\cosh\left(\frac{0.792099\mathrm{x}45}{2\mathrm{x}\ 716.8655} - 1\right)\right|}{0.792099}$$

$$\text{Equivalent sag at } \mathrm{T_1} = 0.291\ \mathrm{m}$$

$$\text{Equivalent sag at } \mathrm{T_e}(\mathrm{m}) = \frac{\mathrm{T_e} \times \left|\cosh\left(\frac{\mathrm{wl}}{2\mathrm{T_e}} - 1\right)\right|}{\mathrm{w}}$$

$$\text{Equivalent sag at } \mathrm{T_e}(\mathrm{m}) = \frac{459.85 \times \left|\cosh\left(\frac{0.30685\mathrm{x}45}{2\mathrm{x}\ 459.85} - 1\right)\right|}{0.30685}$$

$$\text{Equivalent sag at } \mathrm{T_e} = 0.176\ \mathrm{m}$$

$$\text{Equivalent sag at } \mathrm{T_f}\ (\mathrm{m}) = \frac{T_f \times \left[\cosh\left(\frac{wl}{2T_f} - 1\right)\right]}{w}$$

$$\text{Equivalent sag at } \mathrm{T_f}\ (\mathrm{m}) = \frac{106.58223 \times \left|\cosh\left(\frac{0.30685x45}{2x106.58223} - 1\right)\right|}{0.30685}$$

$$\text{Equivalent sag at } \mathrm{T_f} = 0.763\ \mathrm{m}$$

Sag on any span

Using equation (5.2). the equivalent sag on any span can be calculated as:

$$\text{Initial sag at } \mathrm{T_1} = 0.291 \times \frac{(30)^2}{(45)^2}$$

$$\text{Initial sag at } \mathrm{T_1} = 0.1293\ \mathrm{m}$$

$$\text{Everyday sag at } \mathrm{T_e} = 0.176 \times \frac{(30)^2}{(45)^2}$$

$$\text{Everyday sag at } \mathrm{T_e} = 0.0782\ \mathrm{m}$$

$$\text{Final sag at } \mathrm{T_f} = 0.758 \times \frac{(30)^2}{(45)^2}$$

$$\text{Final sag at } \mathrm{T_f} = 0.3369\ \mathrm{m}$$

Vertical sag at initial condition (m)

$$\text{Vertical sag at } T_1 = \frac{\text{Initial sag at } T_1 \text{ x weight of conductor(daN/m)}}{\text{resultant wind and weight force at } T_1 \text{ conditon(daN/m)}}$$

$$\text{Vertical sag at } T_1 = \frac{0.1293 \text{ x} 0.30685\text{(daN/m)}}{0.792099\text{(daN/m)}}$$

$$\text{Vertical sag at } T_1 = 0.0501 \text{ m}$$

Vertical sag at everyday condition (m)

$$\text{Vertical sag at } T_e = \frac{\text{Initial sag at } T_e \text{ x weight of conductor(daN/m)}}{\text{Resultant wind and weight force at ED conditon(daN/m)}}$$

$$\text{Vertical sag at } T_e = \frac{0.0782 \text{ x} 0.30685\text{(daN/m)}}{0.30685\text{(daN/m)}}$$

$$\text{Vertical sag at } T_e = 0.0782 \text{ m}$$

Vertical sag at final condition (m)

$$\text{Vertical sag at } T_f = \frac{\text{Initial sag at } T_f \text{ x weight of conductor(daN/m)}}{\text{resultant wind and weight force at } T_1 \text{ conditon(daN/m)}}$$

$$\text{Vertical sag at } T_f = \frac{0.3369 \text{ x } 0.3369 \text{ (daN/m)}}{0.3369\text{(daN/m)}}$$

$$\text{Vertical sag at } T_f = 0.3369 \text{ m}$$

As per design criteria, the maximum tension occurs at 15°C and given maximum air pressure conditions shall be limited to 40% UTS.

$$T_1 \text{ as percentage of UTS} = \frac{716.8655}{2705}$$

$$T_1 \text{ as percentage of UTS} = 27\% < 40\%$$

Average tension of the conductors shall be limited to 17% of the UTS of the conductor.

$$T_e \text{ as percentage of UTS} = \frac{459.85}{2705}$$

$$T_e \text{ as percentage of UTS} = 17\% = 17\%$$

$$T_f \text{ as percentage of UTS} = \frac{106.5822}{2705}$$

$$T_f \text{ as percentage of UTS} = 4\%$$

5.4 Clearance from the Ground

Overhead line conductors shall be so located that their ground clearance [4] in any direction from any position after sag under the influence of load current shall not be less than the distance as follows.

Maximum allowable Sag = Pole Height - Buried Length - Clearance

Voltage	Type of ground clearance	Clearance (m)	Max. allowable sag (m)
650V to 11kV	Across the road or street	6.1	10 m pole - 2.2 11 m pole - 3.1
	In any other places	5.2	
	Place inaccessible to vehicular traffic	4.6	
11kV to 33kV	Across the road or street	6.4	10 m pole – 1.9 11 m pole 2.8
	In any other places	6.1	
	Place inaccessible to vehicular traffic	4.9	

Table 5.2 Maximum allowable sag for each pole

5.5 Maximum sag for ACSR Racoon conductor

Using above formula, sag and tension were calculated in each equivalent span and summary is given below.

Equivalent span (m)	Conductor temperature	Conductor sag (m) for span			
		30m	40m	50m	60m
45	[illegible]0 °C	0.34	0.60	0.93	1.35
		60m	70m	80m	90m
90	[illegible]0 °C	0.76	1.03	1.35	1.71

Table 5.3 Conductor sag for each span vs. conductor temperature

It can be observed that the maximum sag 1.71 m is less than maximum allowable sag 1.9 m for 10 m pole. Therefore, the ground clearance is not violated when operating on higher temperature of 90°C. Also sag may increase on wind speed below 1m/s and maximum loading more than 202A. Probable occurrence of this is given in chapter 04 as 3050 hrs for a conductor life time.

Chapter 06

Economical Optimization of Losses

Costs and benefits shall be evaluated with increase of losses against investments incurred in reconstructing of the CEB network. It is noted that investment can be postponed at least 4 years when annual growth rate is considered as 2.5%. This simulation is done by using SynerGEE software which is presently used for distribution planning of CEB.

6.1 Energy losses due to increase of CCC

If it is required to replace Racoon conductor, next available conductor of CEB is Lynx conductor. Therefore, loss comparison has been calculated by simulating Racoon and Lynx conductors for Hambantota F3 Gonnoruwa line.

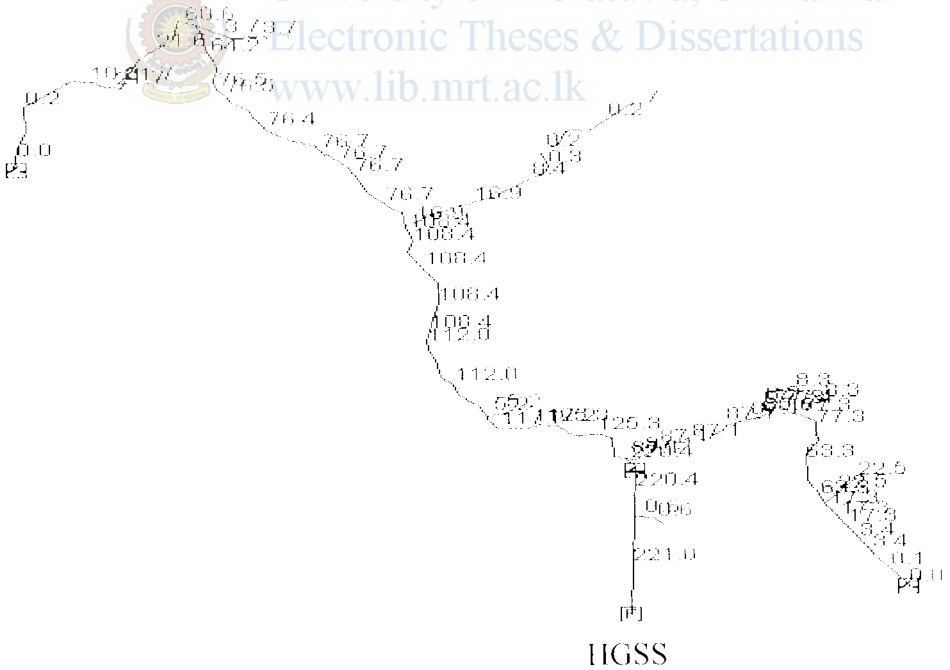

Figure 6.1 Hambantota F3 Gonnoruwa line

Hambantota F3 Gonnoruwa line	**Dist**	**1st Year**			**2nd Year**			**3rd Year**			**4th Year**		
		Racoon	**Lynx**	**difference**	**Racoon**	**Lynx**	**difference**	**Racoon**	**Lynx**	**difference**	**Racoon**	**Lynx**	**difference**
Section Name	**kM**	**kW**	**kW**	**kW**	**kW**	**kW**	**kW**	**kW**	**kW**	**kW**	**kW**	**kW**	**kW**
7296244739	3.1	171	70	101	179	74	105	188	77	111	198	81	117
707948922	0.9	89	36	53	93	38	55	98	40	58	103	42	61
7511616332	0.3	16	7	9	17	7	10	16	7	9	19	8	11
Total	4.3	276	113	**163**	289	119	**170**	302	124	**178**	320	131	**189**

Table 6.1- Loss difference vs. each distance at Hambantota Gonnoruwa line

6.2 Present value of losses

Following data are used to calculation of present value of energy losses

Over current time per day	= 0.84 hrs (taken from load pattern of Omara)
Unit cost	= 14.00 LKR/kWh [3]
Annual tariff increment	10 %
Discount rate	15 %

Year	Additional loss (kW)	Total loss per year (kWh)	Unit cost (LKR)	Total cost (LKR)	PVF	PV of expenses (LKR)
1	163	49976	14.00	699.661	0.870	608.401
2	170	52122	15.40	802,679	0.756	606.940
3	178	54575	16.94	924.497	0.658	607.872
4	189	57947	18.63	1,079,792	0.572	617.374
						2,440,588

Table 6.2 Present values of expenses (losses)

6.3 Estimated cost of reconstruction

Next proven method for increasing the line capacity is reconstructing. Racoon conductor can be replaced by Lynx conductor. Hence, it is required to estimate cost of reconstructing. Reconstructing cost has been calculated as follows using CEB standard rate [2].

• Lynx line cost for construction per km	LKR. 3,140,000
• Removal cost for existing lines per km	LKR. 75,000
• Scrap cost per km (Assumed as 10%)	LKR. 222,400
• Total actual cost of reconstructing per km	LKR. 2,992,600
• Reconstructing line length	4.3 km
• Total cost for 4.3 km	LKR. 12,868,180

6.3.1 Present value of savings

Due to the economic uncertainties, estimated cost can be taken from loan with interest rate 15% and loan period is 4 years. Then, total present value of interest has been calculated as follows.

Project cost	13,824,500	LKR
Loan	13,824,500	LKR
Loan period	4	Years
Interest rate	15	%

Year	1	2	3	4
Opening balance	12,868,180	9,651,135	6,434,090	3,217,045
Interest	1,688,949	1,206,392	723,835	241,278
Loan repayment	3,217,045	3,217,045	3,217,045	3,217,045
Closing balance	9,651,135	6,434,090	3,217,045	0
PVF	0.870	0.756	0.658	0.572

Table 6.3 Present value of savings

6.4 Economic viability of the project

Case 1: Using existing line

	Year 1	Year 2	Year 3	Year 4
Extra cost of losses	699,661	802,679	924,497	1,079,792
PV of cost	608,401	606,940	607,872	617,374
Total cost (C)	**LKR. 2,440,588**			

Table 6.4 Present value of extra cost of losses

Case 2: Constructing new line

	Year 1	Year 2	Year 3	Year 4	Salvage value
Capital cost	3.217.045	3.217.045	3.217.045	3.217.045	11.838.726
Interest	1.688.949	1.206.392	723.835	241.278	
Total cost	4.905.994	4.423.437	3.940.880	3.458.323	11.838.726
PV of total cost	4.268.214	3.344.118	2.593.099	1.978.161	6.771.751
Total cost (B) = (Year 1+Year 2+Year 3+Year 4- Salvage value) = LKR. 5,411,841					

Table 6.5 Present value of constructing a new line

Load pattern	Present value of expenses (C) LKR. (Case 1)	Present value of savings (B) LKR. (Case 2)	Net present value (B-C) LKR.
Omara	2,440.588	5.411.841	2.971.253
Ratmalwala	4,125.756	5.411.841	1.286.085
Kudagammana	958.802	5.411.841	4.453.039

Table 6.6 Net present value of each project

In this case study, present value of expenses means energy losses due to over current of existing line (Case 1). Present value of savings means cost incurred in constructing a new line (Case 2).

It is observed that present value of savings larger than Present value of expenses for all load patterns. Therefore, constructing a new line is more expensive for load patterns of Omara, Kudagammana and Ratmalwala. In other words, implementation of above three projects is financially viable.

Chapter 07

Conclusions

The objective of this project is to fix the overhead line power transfer limits, with effective wind cooling through the probabilistic approach. The analysis consists of the maximum temperature limit of ACSR Racoon conductor that is selected in order to minimize loss of strength, sag, line loss, or a combination of the above.

In the first part, allowable loss of strength of Aluminium was analyzed through the probabilistic approach. Loss of strength of ACSR Racoon conductor can occur due to wind speed below 1m/s and CCC more than 202A. During the study, it is observed that strength of Aluminium is not reduced below 90% of its strength during the lifetime of 50 years. This reduction of strength is negligible. Therefore, effective wind speed can be taken as 1 m/s.

In the second part, sag variations were analyzed in each span which was presently used in CEB against maximum allowable temperature (90°C) in the absence of wind speed. It is observed that ground clearance is not violated when operating at higher temperatures.

Finally, Costs and benefits were evaluated with increase of losses by this method against investment incurred in strengthening of the CEB network. It is noted that investment can be postponed at least 4 years when annual growth rate is considered as 2.5%.

Net present value was analyzed from present value of expenses (due to loss increase of existing system) and present value of saving (postponement of investment incurred in strengthening of the CEB network). Net present value is positive for load pattern of Omara, Kudagammana and Ratmalwala. Therefore project is financially viable. Sometimes in unavoidable circumstances, CEB is forced to delay the augmentations.

The reasons may be as follows.

1. Difficulties in raising funds for the augmentations
2. Delays in planning and designing
3. Expected major changes that might take place in near future, hence the planning of augmentation is delayed

Whatever the reason, this study gives a guide to the extent of possible overload of the lines without violation of technical limiting parameters and the cost benefits/losses in such operations.

Finally, the results show that in some cases, postponing of investment, incurred in strengthening of network instead of replacing conductors, to the extents in time and current limits as studied, is economically viable and beneficial to CEB.

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[17] http://en.wikipedia.org/wiki/Cumulative_frequency

[18] Overhead Aluminium Bare Conductors, ACL Cables PLC, December 2008.

Annex A

The following computer program is used to calculate thermal rating of bare overhead conductors.

Annex A of IEEE standard 738- 1993

Listing of the "RATEIEEE" program for steady-state and transient calculations of temperature and thermal rating for bare overhead conductors.

Annex B

Third order equation for calculating T_1

V15 = T_1 (daN)
J15 = T_e (daN)
`$B$5` = Young's modulus (daN/mm2)
`$B$6` = thermal expansion
`$B$7` = coefficient (/deg c)
K15 = temperature at initial condition, C_1 (deg c)
L15 = everyday temperature, C_e (deg c)
T15 = resultant wind and weight force at T_1 condition (daN/m)
H15 = equivalent span
S15 = resultant wind and weight force at T_1 condition (daN/m)

Solver(T_1)=`POWER(V15.3)- J15-$B$5*$B$6*$B$7*(K15-L15)-`
`$B$7*$B$5*POWER(T15,2)*POWER(H15,2)/ 24*POWER(J15,2) )*POWER(V15,2)-`
`$B$7*$B$5*POWER(S15,2)*POWER(H15,2)/24`

Third order equation for calculating T_f

X15 = T_f (daN)
M15 = temperature at final condition, C_f (deg c)
L15 = everyday temperature, C_e (deg c)
U15 = resultant wind and weight force at final condition (daN/m)
H15 = equivalent span

Solver(T_f)=`POWER(X15.3)-(J15-$B$5*$B$6*$B$7*(M15-L15)-`
`$B$7*$B$5*POWER(T15,2)*POWER(H15,2)/(24*POWER(J15,2)))*POWER(X15,2)-`
`$B$7*$B$5*POWER(U15,2)*POWER(H15,2)/24`

$B$3 = Gravitational force (m/s/s)

Equivalent sag at T_1 (m)

= (V15*10/ (S15*10))*(COSH (S15*10*H15/ (2*V15*$B$3))-1)

Equivalent sag at Te (m)

= (J15*10/ (T15*10))*(COSH (T15*10*H15/ (2*J15*$B$3))-1)

Equivalent sag at T_F (m)

= (X15*10/ (U15*10))*(COSH (U15*10*H15/ (2*X15*$B$3))-1)

$Z$15 equivalent sag at T_1 (m)
C16 Span (m)
($H$15 equivalent span
Initial sag (m) = $Z$15*POWER (C16, 2)/POWER ($H$15, 2)

$AA$15 equivalent sag at Te (m)
Everyday sag (m) = $AA$15*POWER (C16, 2)/POWER ($H$15, 2)

$AB$15 equivalent sag at Te (m)
Final sag (m) = $AB$15*POWER (C16, 2)/POWER ($H$15, 2)

AC16 Initial sag (m)
$N$15 weight of conductor (daN/m)
$S$15 resultant wind and weight force at T1 condition (daN/m)
Vertical sag at initial condition (m) = AC16*$N$15/$S$15

AD16	everyday sag (m)
$T$15	Resultant wind and weight force at everyday condition (daN/m)

Vertical sag at everyday condition (m)   AD16*$N$15/$T$15

AE16	final sag (m)
$U$15	resultant wind and weight force at final condition (daN/m)

Vertical sag at final condition (m)   AE16*$N$15/$U$15

Annex C

Definition for Economics Evaluation

C.1 Interest Rate and Discount Rate

Interest Rate

The percentage increase in the value of money over a period of one year. In addition to the time value of money, interest rate includes the effect of inflation and escalation.

Discount Rate

The time value of money, as perceived by an investor. Usually expressed in percentage per year.

Salvage Value

Assume that salvage value is remaining life time value as follows.

Salvage value Capital cost x 46/50

Where 50 is life time and 46 is remaining life.

Present Value

Discount Rate r %

Year	Value	PV Factor	Present Value
0	V_0	$\frac{1}{(1+r)^0}$	$\frac{V_0}{(1+r)^0}$
1	V_1	$\frac{1}{(1+r)^1}$	$\frac{V_1}{(1+r)^1}$
2	V_2	$\frac{1}{(1+r)^2}$	$\frac{V_2}{(1+r)^2}$
3	V_3	$\frac{1}{(1+r)^3}$	$\frac{V_3}{(1+r)^3}$
....	....	....	....
9	V_9	$\frac{1}{(1+r)^9}$	$\frac{V_9}{(1+r)^9}$
10	V_{10}	$\frac{1}{(1+r)^{10}}$	$\frac{V_{10}}{(1+r)^{10}}$

Cost – Benefit Analysis.

Year	Cost	Benefit	Present Value	
			Cost	Benefit
0	C_0	B_0	$\bar{C}_0$	$\bar{B}_0$
1	C_1	B_1	$\bar{C}_1$	$\bar{B}_1$
2	C_2	B_2	$\bar{C}_2$	$\bar{B}_2$
3	C_3	B_3	$\bar{C}_3$	$\bar{B}_3$
…….	………	………	………	………
n-1	C_{n-1}	B_{n-1}	$\bar{C}_{n-1}$	$\bar{B}_{n-1}$
n	C_n	C_n	$\bar{C}_n$	$\bar{B}_n$

$$\bar{C} = \sum_{i=1}^{n} \bar{C}_i = \sum_{i=1}^{n} \frac{C_i}{(1+r^i)} \qquad (C1)$$

$$\bar{B} = \sum_{i=1}^{n} \bar{B}_i = \sum_{i=1}^{n} \frac{B_i}{(1+r^i)} \qquad (C2)$$

$$\text{Net Present Value(NPV)} = \bar{B} - \bar{C} \qquad (C3)$$

Project Accepted If NPV >0