REAL TIME DYNAMIC THERMAL RATING METHOD TO UPRATE THE AMPACITY OF OVERHEAD TRANSMISSION LINES IN SRI LANKA

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Degree of Master of Science

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DECLARATION

I declare that this dissertation does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any University or institution to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

…………………………. Date: ………………………………

S.Rishanthi

I endorse the declaration by the candidate:

Signature of the supervisor:

…………………………….. Date: ………………………………

Dr.Asanka Rodrigo

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ABSTRACT

Real time dynamic thermal rating (RTTR) is a smart-grid technology, which allows to utilize the overhead line conductors by increasing the current carrying capacity of the line based on real time weather data. Traditionally, Static thermal rating (STR) calculates current rating based on ‘Worst case weather conditions”, which is used in Ceylon Electricity Board (CEB) as well as most of the utilities around the world. These assumptions may reduce the actual line capacity whenever real weather conditions are less stressful.

The optimal current carrying capacity(CCC) of a line is primary determined by the critical span along the line route. Therebefore the sag of the line has been analysed in detailed to identify the critical span with help of PLSCADD Software. Then, the real time weather data have been applied and RTTR values for interested transmission lines has been calculated.

In this research, current rating using real time weather cases have been calculated for selected transmission lines in Sri Lanka and compared the results with static thermal rating methods. A software based RTTR model was also developed in VBA platform in order to calculate the real time CCC. This software interface can be used to analyse entire transmission network of Sri Lanka to calculate weather based current ratings.

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CCC	-	Current Carrying Capacity
RTTR	-	Real-time thermal rating
STR	-	Static Thermal Rating
ACSR	-	Aluminium Conductor Steel Reinforced
CEB	-	Ceylon Electricity Board
HTLS	-	High Temperature Low Sag
UTM	-	Universal Transverse Mercator
GL	-	Ground Level
VBA	-	Visual Basic for Application
GP	-	Ground Points
BP	-	Bend Points

CHAPTER 1. INTRODUCTION

1.1 Background

Demand for electricity is increasing rapidly with technological growth and increase in the quality of life. As a result of the increased power flow, some transmission lines are close to its maximum ampacity limits and become overloaded while introducing bottle necks into the system. When conductor is overloaded it will violate the maximum allowable conductor temperature. An excessive conductor temperature may give rise to an excessive elongation of the conductor with consequent dangerous reduction of the electrical clearances to ground. In addition, it could also produce annealing and high temperature creep on the conductor and decrease of the capability of compression joints [1]. All these effects caused by an excessive current may put public safety at risk.

The system operators are striving to increase transmission capacity of existing overhead lines to overcome bottlenecks in the network while maintaining the system security at an acceptable level. The capacity enhancement of transmission line can be done in multiple ways [2]. The most obvious and widely adopted way is to construct new transmission lines. However, constructing new transmission lines are delaying because of funds, political issues, social and environmental issues. Similarly, reconductoring the existing transmission lines using HTLS conductor is another good solution to increase current carrying capacity of a line. Still, there are some practical difficulties in reconductoring process like obtaining line interruption for a longer period which makes some other part of network heavily stressed.

Existing transmission lines have static or fixed thermal ratings that limit the amount of power that can be transferred. This current carrying capacity is restricted by maximum allowable conductor temperature, which determines the maximum sag of the line, and creep. During planning and design stages, the current currying capacity of overhead conductors have been historically calculated using worst case weather conditions [3]. This method is called as static thermal rating (STR) method [1].

Static thermal rating method is calculated for worst case weather conditions such as highest ambient temperature, highest solar intensity, lowest wind speed, etc. [3]. But in reality, weather parameters are widely varying depending on time, place and season. It has long been realized that this rating method is conservative and results in under-utilization of conductors. Real time dynamic thermal rating (RTTR) method is calculated for actual weather data [1]. The same STR values are used for the entire country irrespective of actual weather. Static thermal rating method is underestimating actual current carrying capacity of a conductor while real time dynamic thermal rating method allows full utilization of a line. The real time dynamic thermal method enables the transmission system operators to utilize existing power lines more effectively and more safely either during steady state condition or system emergency.

Calculating CCC using RTTR method is beneficial in system operation and power flow management. However, calculating RTTR for an entire line is difficult since the weather could be different in one place than another [4]. The several sections in the same line can be facing different weather patterns. Hence, changes in weather conditions significantly and have different effects on the CCC and sagging level of spans. If sagging increases, it may violate the electrical clearance and may cause harm on living species and valuable assets under the line. On the other hand, underrating a conductor wastes a large portion of unused CCC. To deal with the spatial nature of capacities, a typical approach is to study selected line sections with their local weather conditions. Deterministic capacity for each section is calculated and the minimum is then chosen as the rating for the entire line [4]. This prediction of CCC will helpful for system operators to take a decision especially in an emergency situation without violating any electrical clearances.

For the new wind farms interconnections, the transmission lines with equal capacity need to be installed. Since higher wind speed will increase both wind power generation and current carrying capacity by convection cooling, RTTR method can offer most economical solutions for use of transmission line capacity by using low rating conductor (smaller diameter) [5]. If there are generation clusters where in regions connected by lines which have lower capacity than dispatchable combined generation, RTTR method can be used.

Generally, RTTR method provides more utilization of any existing transmission overhead lines to the system operators. Besides, it enables the secured operating conditions in terms of contingency and supports better economic dispatch up to some extent. Moreover, Same application warns the system operators when transmission line rating may be less than the historically assumed Static values.

In this research, calculating CCC of overhead transmission lines and the full-scale utilization of existing transmission lines in Sri Lankan system via RTTR method is analysed and discussed in details.

1.2 Objective

Detailed analysis to uprate the ampacity of overhead transmission lines in Sri Lanka effectively and safely, by using Real-Time Dynamic Thermal Rating method.

1.3 Benefits of RTTR method

- Lower rates for customers

  Enables better economic dispatch by operating low cost power plants to reduce the marginal generation cost.

- Reduced capital costs

  By reducing reconductoring and reconstruction, by using existing transmission lines more effectively, the capital cost can be reduced.

- Increasing transmission line reliability

  RTTR method provide more information on transmission line's unused capacity.

- Increased efficiency of generation resources

  By reducing transmission congestion constraints, the more economic generators could be taken into dispatch.

CHAPTER 2. LITERATURE REVIEW

Current carrying capacity (CCC) of a conductor is depends on

- Conductor material properties
- Conductor diameter
- Conductor surface condition
- Weather conditions
- Conductor temperature

For a given conductor the first two properties are same and in a shorter period, the surface condition of a conductor shall not change rapidly. Weather conditions and conductor temperature are varying with time. Maximum permissible conductor temperature shall be given by the manufacturer or utility. This maximum permissible operating temperature is lower than the temperature which results in the greatest permissible sag (allowing for creep) or that which results in the maximum allowable permanent loss of tensile strength due to annealing. Following are the weather parameters which influence in the CCC of a given conductor [1].

- Ambient temperature
- Solar intensity
- Wind speed
- Wind angle

There are two types of thermal rating methods available when calculating current carrying capacity of a conductor

- Static Thermal Rating
- Real-time Dynamic Thermal Rating

2.1 Static Thermal Rating

Static thermal rating current has been calculated when weather conditions, conductor temperature are assumed constant for all time. This current rating has been calculated for “Worst case weather” conditions (Lowest wind speed, highest ambient temperature, highest solar intensity, etc.). Same worst-case weather condition is used for all transmission lines irrespective of the actual weather.

2.2 Real-Time Dynamic Thermal Rating

Real-time dynamic thermal rating is a smart grid technology which allows conductors to operate at an enhanced rating. RTTR is calculating using real time weather data rather than fixed weather data values. They vary as a function of time, depending on the in ambient conditions. This method allows to use unused CCC of a conductor.

2.3 Current carrying capacity of a conductor

The current carrying capacity is calculated using IEEE 738 (2012) and IEC 61597. Both standards are based on the thermal balance between the gained heat and lost heat in the conductor due to the load and environmental conditions.

2.4 Heat balance equation

$$Q_c + Q_r = Q_s + I^2 . R\ (T_{avg})$$

Where,

$$R(T_{avg}) = \left[\frac{R(T_{high}) - R(T_{low})}{T_{high} - T_{low}}\right] . \left(T_{avg} - T_{low}\right) + R(T_{low})$$

From this heat balance equation the CCC can be found using below equation.

$$I = \sqrt{\frac{Q_c + Q_r - Q_s}{R\ (T_{avg})}}$$

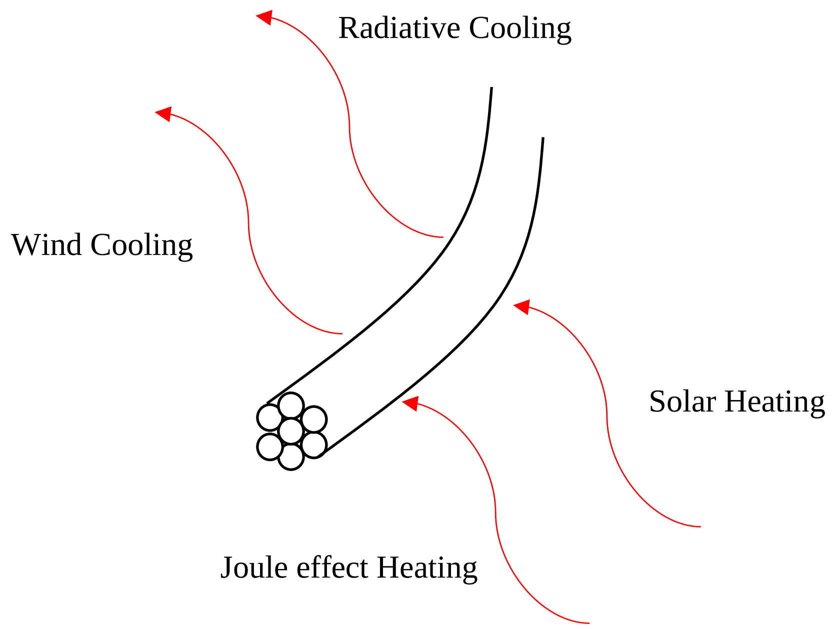


Figure 2.1 – Illustration of conductor cooling and heating methods

2.4.1 Convective heat loss (Q_c)

Convective heat loss has divided into two types. They are natural convection and forced convection. Natural convection occurs during still air condition. Cool air surrounding hot conductor is heated and is replaced by cool surrounding air. Forced convection occurs when blowing air moving past the conductor carries the heated air away. Forced cooling has high cooling capacity than natural cooling.

2.4.1.1 Forced Convection heat loss

There are two equations to calculate forced convection heat loss. Equation to calculate Q_{c1} is for low wind speeds but underestimates forced convection at high wind speeds. Equation to calculate Q_{c2} is for high wind speeds but underestimates forced convection heat loss at low wind speeds. At any wind speed, larger value of the two is the forced convection heat loss rate.

$$Q_{c1} = K_{angle}[1.01 + 1.35. N_{Re}^{0.52}]. k_f. (T_s - T_a)$$

$$Q_{c2} = K_{angle}. 0.754. N_{Re}^{0.6}. k_f. (T_s - T_a)$$

Where,

$K_{angle} = 1.194 - cos\,\emptyset + 0.194. cos\,2\emptyset + 0.368. sin\,2\emptyset$

$N_{Re} = \frac{D_0.\rho_f.V_w}{\mu_f}$

2.4.1.2 Natural convection

Natural convection heat loss happens with zero wind speed. The heat loss rate equation for the natural convection is shown below.

$$Q_{cn} = 3.645.\rho_f^{0.5}.D_0^{0.75}.(T_s - T_a)^{1.25}$$

2.4.2 Radiated heat loss (Q_r)

Energy transmitted by the radiation to the surroundings is called radiated heat loss. This happens when the conductor is heated above the ambient temperature. The heat loss rate is depends on the difference between the conductor temperature and ambient temperature, surface condition of the conductor and emissivity. The equation for radiated heat loss rate is shown below.

$$Q_r = 17.8.D_0.\epsilon.\left(\left[\frac{T_s + 273}{100}\right]^4 - \left[\frac{T_a + 273}{100}\right]^4\right)$$

2.4.3 Solar heat gain (Q_c)

Heat energy from the sun is provides heat energy to the conductor. The solar heat gain is depends on sun's position on the sky, solar constant, orientation of the conductor, conductor's surface condition, etc. The below equation from IEEE 738 (2012) is used to calculate solar heat gain of a conductor.

$$Q_s = \alpha\,.\,Q_{se}.\sin\hat{O}\,.\,A'$$

Where,

Q_c	-	Convective heat loss
Q_r	-	Radiated heat loss
Q_s	-	Total solar and sky radiated heat gain
$R\ (T_{avg})$	-	AC resistance of conductor at temperature, Tavg
K_{angle}	-	Wind direction factor
N_{Re}	-	Dimensionless Reynolds number
Ø	-	Angle between wind and axis of conductor
D_0	-	Outside diameter of conductor
ρ_f	-	Density of air
V_w	-	Speed of air stream at conductor
μ_f	-	Absolute (dynamic) viscosity of air
k_f	-	Thermal conductivity of air at temperature T_{film}
T_s	-	Conductor surface temperature
T_a	-	Ambient air temperature
Ô	-	Effective angle of incidence of the sun's rays
A'	-	Projected area of conductor
Q_{se}	-	Total solar and sky radiated heat intensity

2.5 Wind Span

The wind span of a tower is half the sum of the adjacent span lengths [2].

2.6 Weight span

The weight span is the distance between the lowest points of adjacent sag curves on either side of the tower. In hilly terrains, weight span can be negative [2].

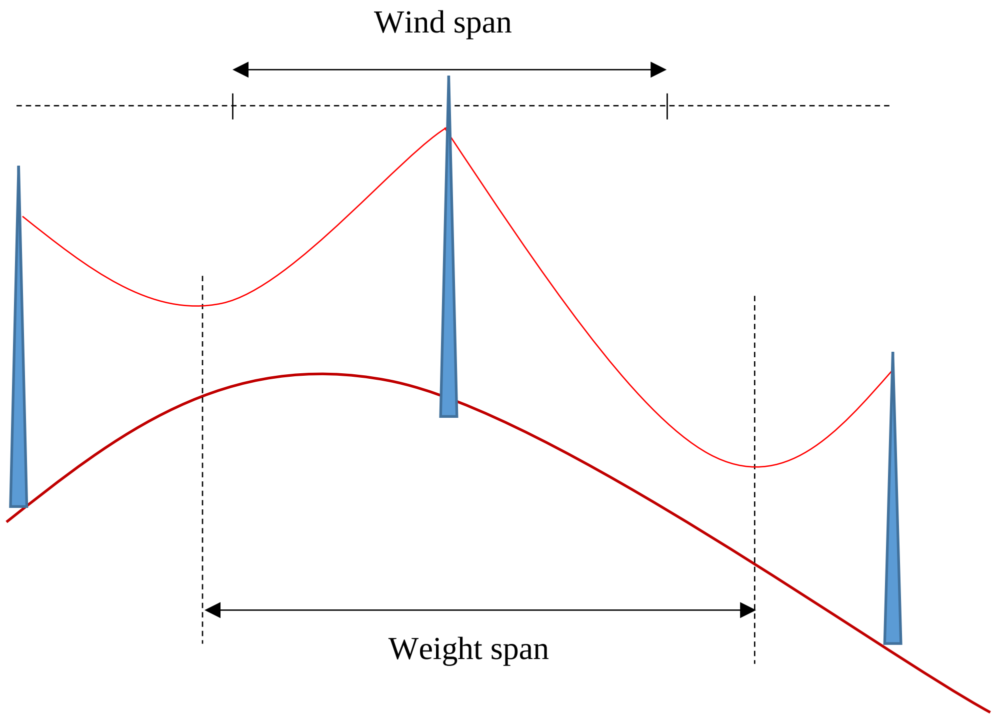


Figure 2.2 – wind span and weight span

2.7 Conductor Properties

Aluminium Conductor Steel Reinforced (ACSR) conductors have been used in almost most all transmission lines in Sri Lanka. In this study, lines with ACSR conductors were used. It is a non-homogeneous conductor. ACSR consists of one or more layers of aluminium strands surrounding a core of 1, 7, 19, 37, etc. galvanized steel strands. Steel is used to provide mechanical strength to the conductor. As a solution to the corrosion, grease will be applied in between the strands.

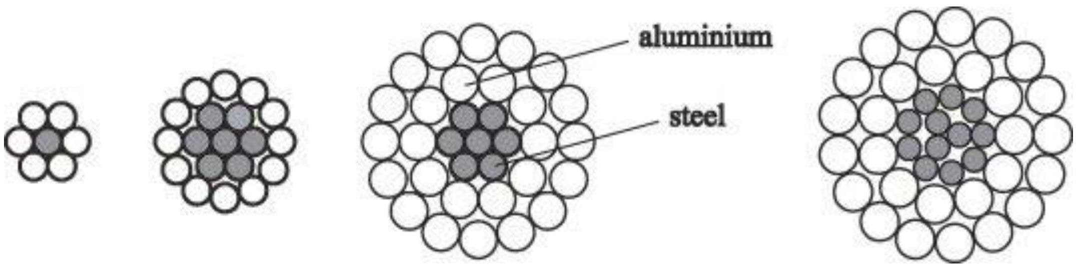


Figure 2.3 – ACSR conductors

Source: https://www.quora.com/Power-Systems-Why-are-ACSR-conductors-named-after-animals-like-Moose-Dog-Peacock-Hen-Zebra-etc - 5th February, 2018

2.8 Creep

Creep is a phenomenon which affects most materials subjected to stress. It manifests itself by a permanent elongation of the material in the direction of the stress. The increase in the conductor length resulting from inelastic stretch produces increased sags which must be taken into account in the overhead line design and installation process so as not to violate clearances.

CHAPTER 3. METHODOLOGY

The CCC of the transmission lines in Sri Lanka has been calculated since ages using STR method. As it underestimates the real line capacity, in this research, the RTTR values of some selected transmission lines were calculated. The objective is to exploit the available capacity of existing overhead transmission lines, thus reducing investments in replacing conductors or constructing new lines. This method can be a practical solution for increasing transmission line capacity in cases of emergency overloading requirement as well.

The RTTR techniques may be applied to overhead transmission lines to increase their ratings, particularly heavily loaded lines. This requires the weather monitoring stations to monitor ambient temperature, wind speed and wind direction near the transmission lines. The solar intensity values used in this research, has been taken from ASHRAE standards for Sri Lanka. The solar intensity values are varying with the month. Values of solar intensity will be reducing if cloud covers the transmission lines. Since this impact helps to increase the line rating further (positive impact), the coverage of clouds has not been taken to this study.

On the other hand, for safely operating a transmission lines, the sag should be carefully reviewed to comply with the increased conductor rating. Sag monitoring techniques have to be done in order to ensure the sag of the critical spans. Before applying RTTR method the sag of the line should be verified with the maximum conductor temperature. In this research, that have been done using PLS CADD software.

3.1 Methodology diagram

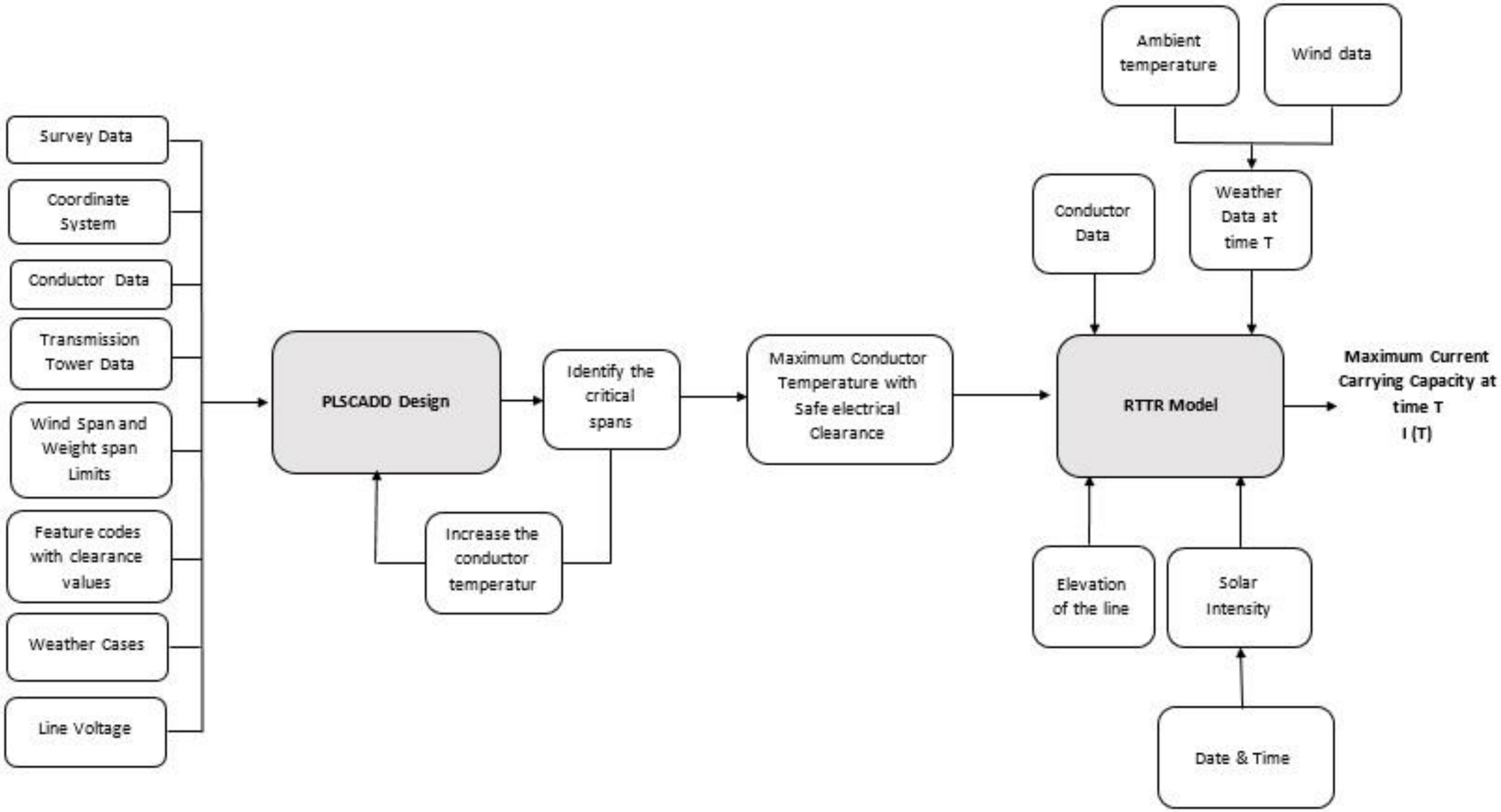


Figure 3.1 – Methodology Diagram

3.2 Selection of transmission lines

Five transmission lines have been selected for this research to analyse the RTTR method in different weather patterns [3].

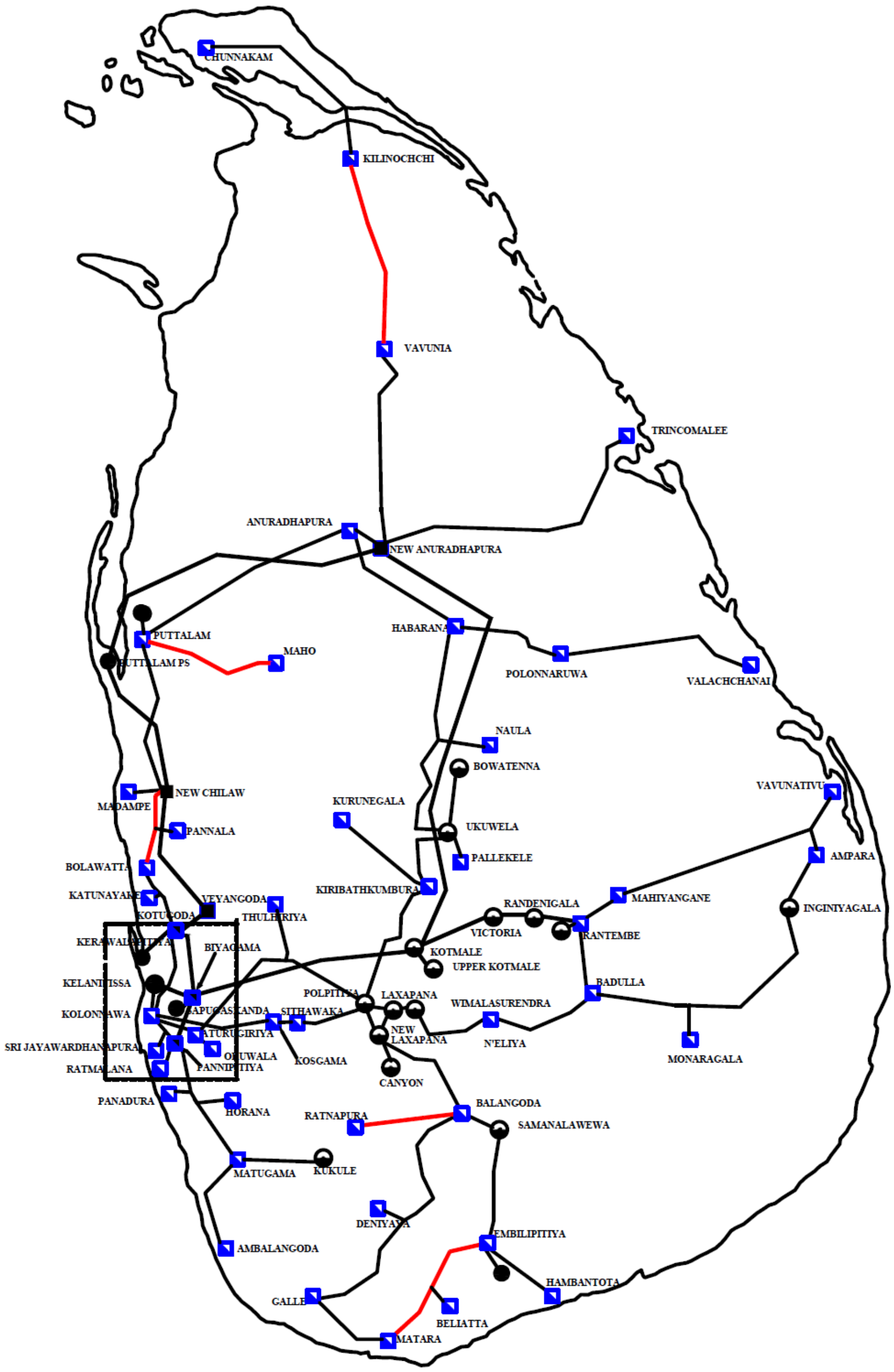


Figure 3.2 – The map of Sri Lanka Transmission network showing selected five transmission lines

Following transmission lines are selected to analyse the dynamic thermal rating values with weather pattern. The lines are selected to cover entire country, to include the weather parameters of different parts of the country into the research. Sri Lanka has two monsoon seasons which are southwest monsoon from May to September and the northeast monsoon from December to February. Some locations have been selected to cover both monsoon seasons of Sri Lanka.

Regional differences in ambient temperature of Sri Lanka are mainly due to altitude of the location. The transmission lines have been selected to cover higher and lower altitude of Sri Lanka to analyse RTTR for different ambient temperatures.

These lines have been selected with both ACSR Zebra and ACSR Lynx conductor to analyse how RTTR method can vary with conductor parameters. Table 3.1 shows the transmission lines which are selected for this research.

Table 3.1 – Transmission line data of selected transmission lines

Transmission Line	**Conductor**	**Voltage (kV)**	**No of Towers**	**Line Length (km)**
Puttalam - Maho Line	Zebra	132	137	42
Embilipitiya - Matara Line	Lynx	132	142	52
Ratnapura - Balangoda Line	Zebra	132	102	40
Bolawatta - New Chilaw Line	Lynx	132	73	23
Vavuniya - Kilinochchi Line	Zebra	132	238	66

As mentioned above, RTTR method is applied to the lines all over the country to analyse in dynamic thermal rating in different weather patterns. These are some specific reason to select these transmission lines.

Table 3.2 – Basis for the selection of transmission lines

Transmission Line	**Reasons for selection**
Puttalam - Maho Line	This line is located in a windy area. The line facing south – west monsoon.
Ratnapura - Balangoda Line	Line is travel through hilly area. Ambient temperature is lower compared to other selected lines. The line is located in the central part of the country.
Bolawatta - New Chilaw Line	Now this line has ACSR Lynx conductor. It gets overloaded regularly. The line has been reconstructing using upper rating conductor (ACSR Lynx to ACSR Zebra).
Embilipitiya - Matara Line	Terrain pattern is variable from Matara to Embilipitiya. This line is facing South-West monsoon. Line is located in southern part of the country.
Vavuniya - Kilinochchi Line	Dry climate and line is facing North-East wind season. Line is located in northern part of the country

3.3 Collect conductor data

Selected transmission lines for this study, have ACSR Zebra and Lynx conductors. These overhead conductors are the mostly used conductors in CEB. Conductor data of those five transmission lines have been collected.

Table 3.3 – Conductor data

Conductor Data		**Unit**	**ACSR Zebra**	**ACSR Lynx**
Nominal Area		mm^2	400	175
No of wires	Aluminium		54	30
	Steel		7	7
Nominal Diameter	Aluminium	mm	3.18	2.79
	Steel	mm	3.18	2.79
Overall Diameter		mm	28.62	19.53
Sectional Area	Aluminium	mm^2	428.9	183.4
	Steel	mm^2	55.6	42.8
Total Area		mm^2	484.5	226.2
Approximate Unit Weight		kg/km	1621	842
Nominal Breaking Load		kN	131.9	79.8
Nominal DC resistance		ohm/km	0.0674	0.1576

3.4 Design data

Design data of transmission lines have been taken from Ceylon Electricity Board technical specification. Following are the design data used for the construction of 132kV and 220kV transmission lines.

3.4.1 Tower types

Table 3.4 – Types of towers used in transmission lines

1	Suspension Tower (0°- 2°)	TDL
2	0° - 10° Line Deviation Tower	TD1*
	0° Section Tower	
	2° Heavy Suspension Tower	
3	10^o - 30^o Line Deviation Tower	TD3
4	30^o - 60^o Line Deviation Tower	TD6
5	Terminal Tower (0°- 45° in line side & 0°- 90° in slack span)	TDT

*TD1 tower shall be designed for following three (03) applications;

(i) Angle tower for 0° - 10° deviation angle

(ii) Section tower of 0° angle with longitudinal load of 15% of the maximum working tensions of all conductors and earthwires on one side

(iii) Heavy Suspension tower of 2° deviation angle

(Tower type in profile drawing and line schedule "TD1S" is applied in order to distinguish from tension tower)

3.4.2 Basic span

Table 3.5 – Basic spans of 132 kV and 220 kV

	132 kV	**220 kV**
BASIC SPAN	300 m	350 m

3.4.3 Wind span

Table 3.6 – Wind span of all types of 132 kV and 220 kV towers

Tower Type	**Condition**	**132 kV**	**220 kV**
All Towers	Normal Working (NW)	360 m	420 m
	Broken Wire (BW)	270 m	315 m

3.4.4 Weight span

Table 3.7 – Weight span of all types of 132 kV and 220 kV towers

Tower Type	**Condition**	**132 kV**		**220 kV**	
		Max. (m)	**Min. (m)**	**Max. (m)**	**Min. (m)**
TDL	NW	600	-	700	-
	BW	450	-	525	-
TD1S	NW	1220	-	1220	-
	BW	915	-	920	-
TD1 [Section Tower]	NW	1220	-600	1220	-600
	BW	915	-450	920	-450
TD1 as an [Angle Tower]	NW	900	-300	1050	-300
	BW	675	-200	790	-200
TD3 & TD6	NW	900	-300	1050	-300
	BW	675	-200	790	-200

TDT	TDT NW	Line Side	250	-200	300	-200
		Slack Span	75	0	75	0
	TDT BW	Line Side	50	0	70	0
		Slack Span	-	-	-	-

3.4.5 Clearances

Table 3.8 – Minimum clearance

Description of Clearance	**Minimum Clearance (m)**	
	132 kV	**220 kV**
To normal ground	6.7	7.0
To normal road crossings	6.7	7.4
To main roads / highway crossings	7.5	8.5
To railway crossings	8.0	8.2
To cradle guards	4.0	4.0
To road surface where cradle guards can be used (Note 1)	8.8	9.8
Between conductors of power line crossings or situated in close proximity (Note 2)	2.7	3.7

To any object on which a person may stand including ladders, access platforms etc. (Note 3)		3.6	4.6
To any object to which access is not required and on which a person cannot stand or lean a ladder (Note 3)		1.4	2.4
Between tower supports of upper line and any conductor of lower line situated in the close proximity		15.0	15.0
Survey and sagging error (Note 4)		0.3	0.3
To trees adjacent to line			
(i)	Unable to support ladders/ climber	1.4	2.4
(ii)	Capable of supporting ladder/ climber	3.6	4.6
(iii)	Trees falling towards line with line conductors hanging vertically only	1.4	2.4
To rivers, non-navigable		10	10
To rivers, navigable		15	15

3.4.6 Safety factors

Table 3.9 – Safety factors

Description	Factor of Safety
Conductors, Earthwires and OPGW at Maximum Working Tension based on Ultimate Strength	2.5
Conductors and Earthwires at Everyday Temperature (EDS) still Air Tension, based on Ultimate Strength	4.5
Tension Clamps and Mid-span Joints, based on Ultimate Strength of Conductor and Earthwire	0.95

3.4.7 Wind pressure

Table 3.10 – Peak wind pressure

ITEM	UNIT	VALUE
Peak Wind Pressure on Conductors and Earthwires	N/m^2	970
Peak Wind Pressure on Insulators	N/m^2	1170
Peak Wind Pressure on Lattice Steel Supports	N/m^2	1640

3.5 Identify critical span

A transmission line may travel through different climatic areas. One section of a transmission line can be in different weather area than the other section. But at a given time only one critical span can be there for the entire line. A normal span is becoming critical span when maximum sag point is closer to the electrical clearance line. This will happen when the conductor meets its highest allowable conductor temperature.

The weather pattern will vary with the time. According to the weather pattern the conductor temperature will vary. Because of this the location of a critical span in a line will vary with time.

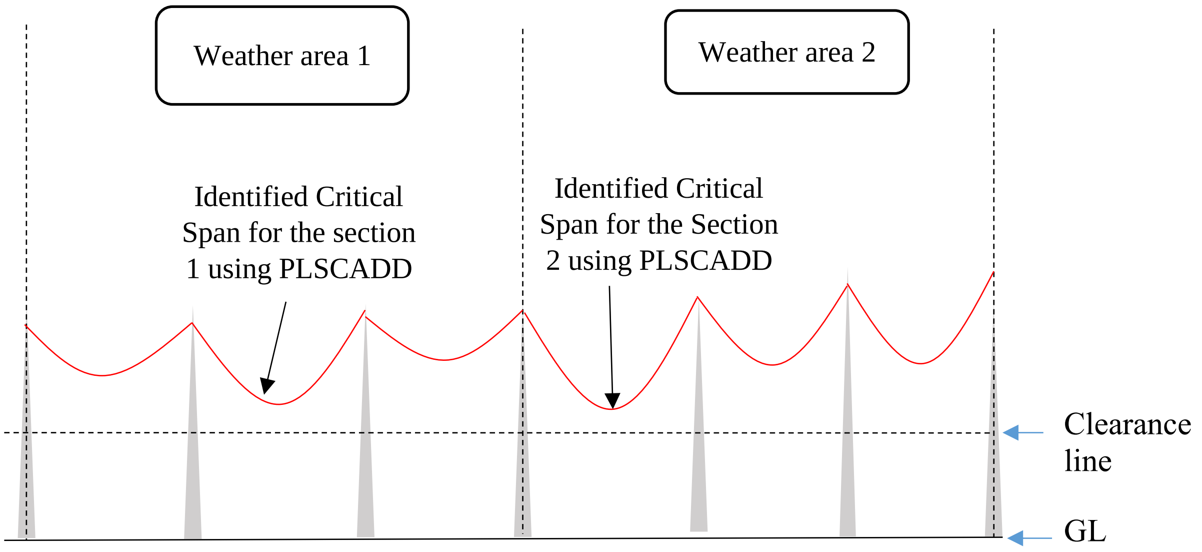


Figure 3.3 – Illustration of variation in critical span according to weather variation

For an example section 1 and section 2 are located in two different weather areas. The critical spans of both sections have been identified using PLS CADD design. If section 2 has the critical span of the entire line at a given time, if weather near section 1 changes (Ex: Ambient temperature increases) then sag of section 1 will increase and section 1 may now has the critical span. Likewise. a critical span can vary with time to time. To overcome this issue all line sections of a selected line should be divided according to the weather areas – If there are 7 weather stations identified for the entire line, 7 such sections should be analyse in PLSCADD design.

3.6 Weather data

Data from www.accuweather.com is used for the weather near transmission lines. Figure 3.4 and 3.5 shows the identified weather stations near the selected transmission lines in Google earth.

3.7 Selecting weather stations

Weather stations near a selected transmission line have been selected using www.accuweather.com. For an example Embilipitiya – Matara line has seven weather stations near the line. To analyse the real time dynamic method, the line has to divide according to the weather stations. Therefore, Embilipitiya-Matara line has to be divided into seven sections.

These weather stations have hourly predicted ambient temperature and wind velocity weather data. Figure 3.4 and 3.5 shows the weather stations near two transmission lines among those five selected transmission lines.

Figure 3.4 – Weather stations near Embilipitiya-Matara 132 kV transmission line

Likewise, Puttalam-Maho 132 kV transmission line has ten weather stations near the line. Hence ten such sections have to be analysed in PLSCADD software. The figure 3.5 shows the weather stations near Puttalam-Maho transmission line which have been taken from Accuweather.

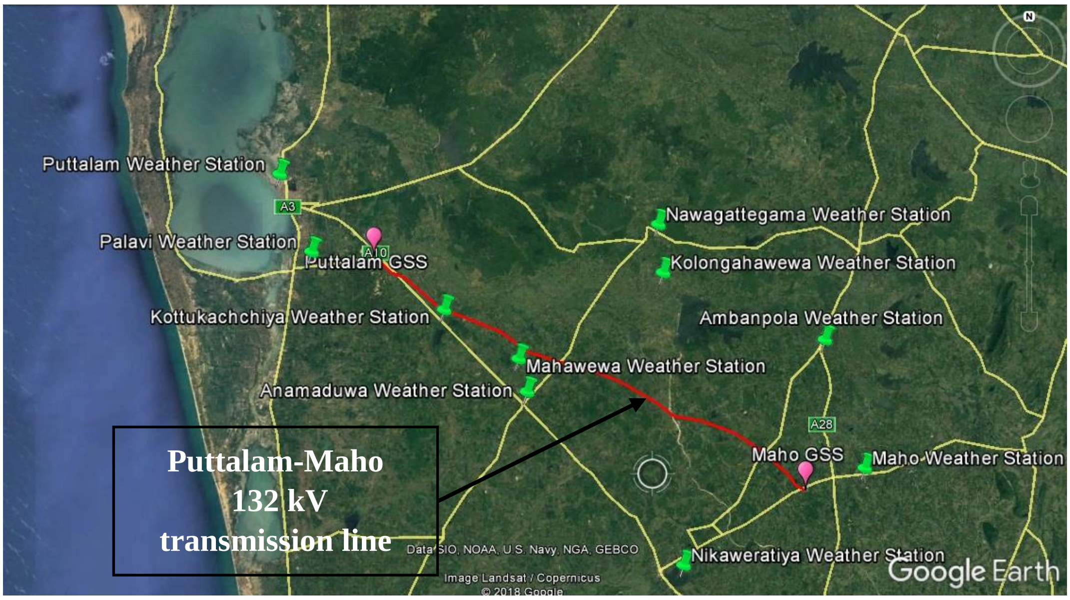


Figure 3.5 – Weather stations near Puttalam-Maho 132 kV transmission line

For the weather station selection, the distance from the transmission line sections to weather stations are measured. The minimum distance value of those weather station, is the selected weather station for a line section. According to this, two-line sections may have one weather station and there may be a weather station which is not closer to any line sections. The figure 3.5 describes the selection criteria used to select weather station of a transmission line.

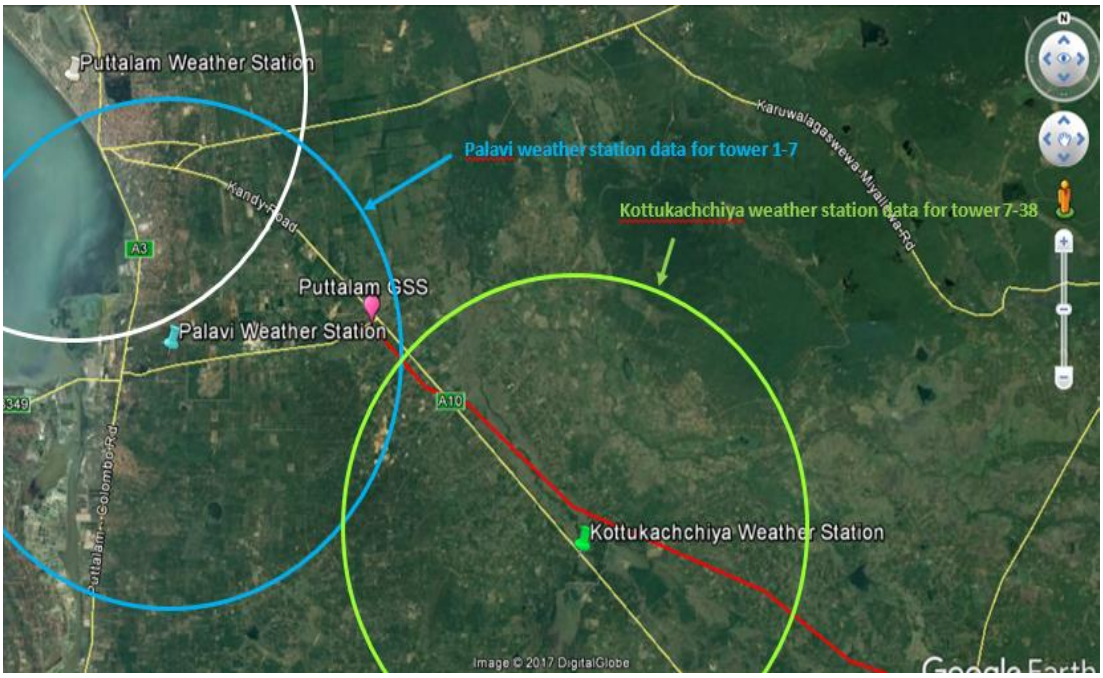


Figure 3.6 – Weather stations selection criteria

Similarly, weather stations have been selected for the entire line. For an example for Puttalam-Maho 132 kV transmission line, for tower no 1-7, Palavi weather station is closer than Kottukachchiya weather station. Thus, for the section of tower no 1-7, Palavi weather station is the nearest weather station. Likewise, for the section 7-38, the Kottukachchiya weather station is the nearest.

This has been done to all selected transmission lines using same criteria. Table 3.11 and 3.12 shows the nearest weather stations for Puttalam-Maho 132 kV and Vavuniya-Kilinochchi 132kV transmission lines.

Table 3.11 – Nearest weather stations of the sections of Puttalam-Maho 132 kV transmission line

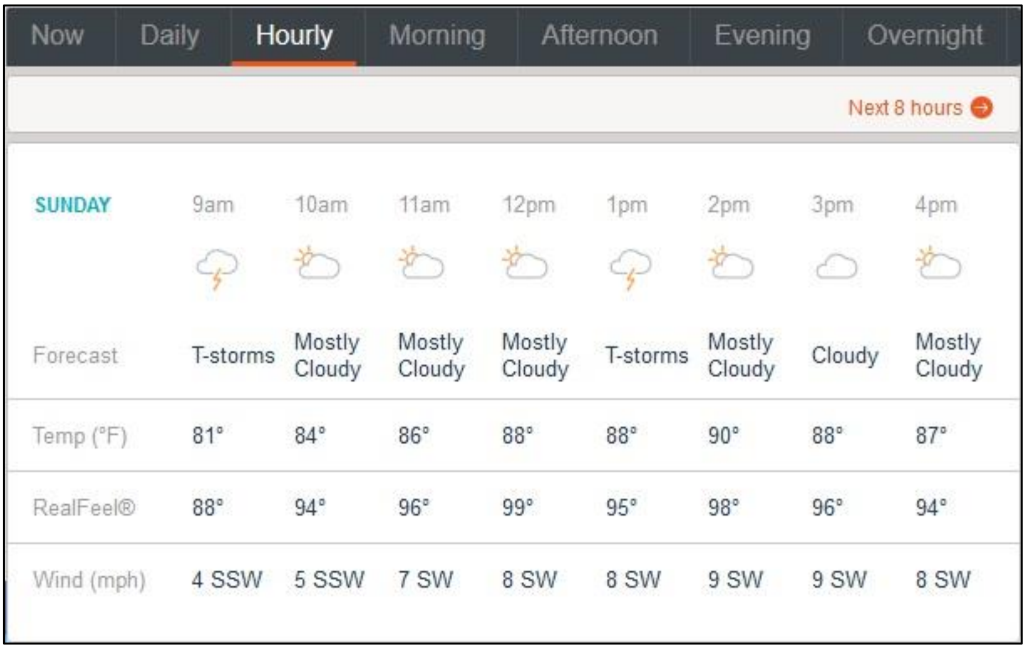
Section	Nearest Weather Station
Tower No. 1-7	Palavi weather station
Tower No. 7-38	Kottukachchiya weather station
Tower No. 38-64	Mahawewa weather station
Tower No. 64-87	Anamaduwa weather station
Tower No. 87-110	Ambanpola weather station
Tower No. 110-137	Maho weather station

Table 3.12 – Nearest weather stations of the sections of Vavuniya-Kilinochchi 132 kV transmission line

Section	Nearest Weather Station
Tower No. 1-53	Vavuniya Weather Station
Tower No. 53-105	Puliyankulam Weather Station
Tower No.105-167	Mankulam Weather Station
Tower No. 167-223	Kokkavil Weather Station
Tower No. 223-238	Kilinochchi Weather Station

3.8 Collecting weather data

Weather data have been collected using www.accuweather.com for 24 hours of a random day with 1 hour interval. The ambient temperature, wind speed and wind angle have been collected for all weather stations of five transmission lines. The figure 3.7 shows weather data from Accuweather website.



Now	Daily	Hourly	Morning	Afternoon	Evening	Overnight	

Next 8 hours

SUNDAY	9am	10am	11am	12pm	1pm	2pm	3pm	4pm
Forecast	T-storms	Mostly Cloudy	Mostly Cloudy	Mostly Cloudy	T-storms	Mostly Cloudy	Cloudy	Mostly Cloudy
Temp (°F)	81°	84°	86°	88°	88°	90°	88°	87°
RealFeel®	88°	94°	96°	99°	95°	98°	96°	94°
Wind (mph)	4 SSW	5 SSW	7 SW	8 SW	8 SW	9 SW	9 SW	8 SW

Figure 3.7 – Hourly weather data of a weather station in www.accuweather .com

The ambient temperature and wind speed data have been taken for the calculation of RTTR. Figure 3.8 shows the variation in ambient temperature with time, which has been taken from Accuweather website.

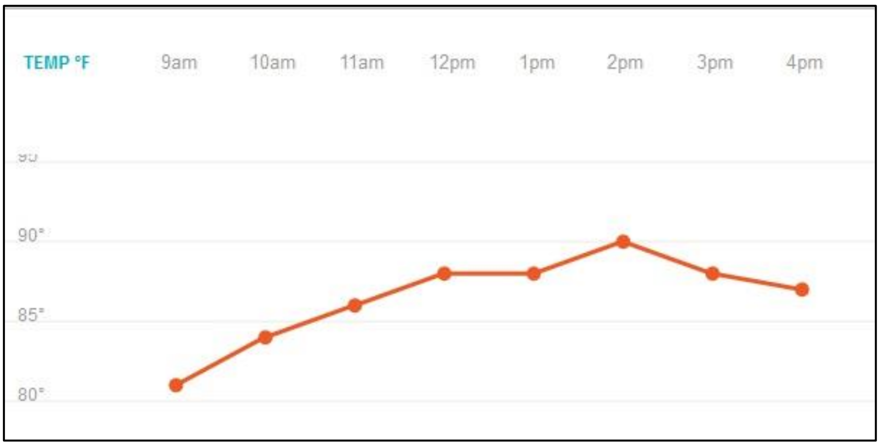


Figure 3.8 –Ambient temperature with time of a weather station in www.accuweather .com

Weather data using Accuweather of all weather station have been collected. The figure 3.9 shows the actual ambient temperature with time of Ratnapura weather station, which is one of the nearest weather station to Ratnapura – Balangoda 132 kV transmission lines. This weather data is taken at 7.00 PM of 19th December, 2017 to 6.00 PM of 20th December, 2017. Thus the graph shows 24 hours temperature variation of the weather station

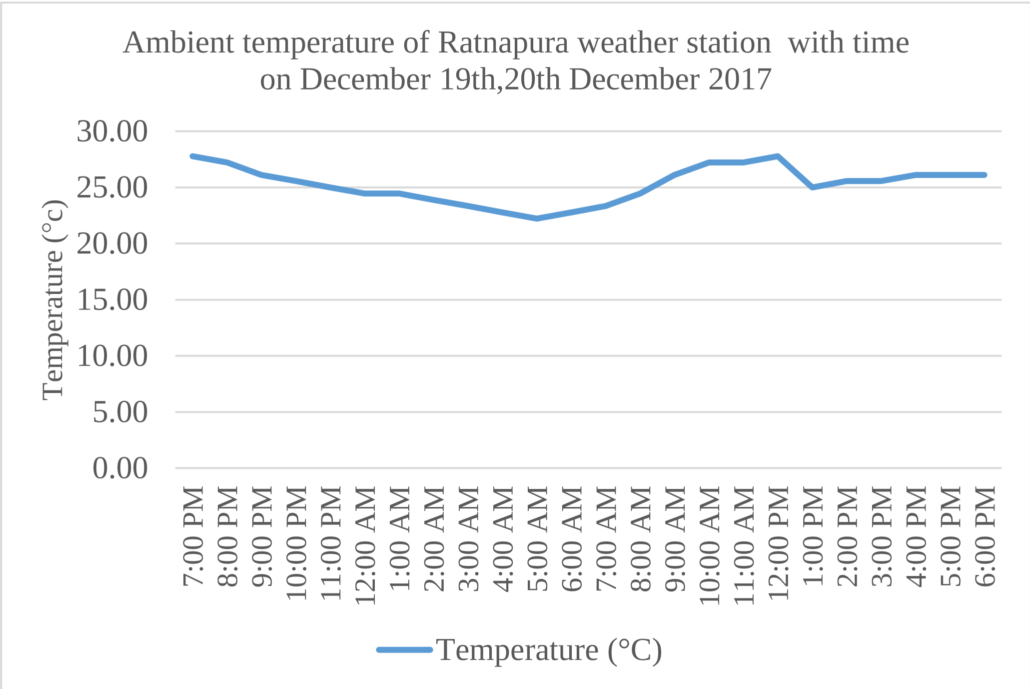


Figure 3.9 – Variation of Ambient temperature of Ratnapura weather station

Similarly, the wind velocity for 24 hour have been plotted against time of Pinnawala weather station, which is used to collect weather data of Ratnapura-Balangoda 132 kV transmission line. The data was collected at 7.00 PM on 19th December, 2017 to 6.00 PM on 20th December, 2017.

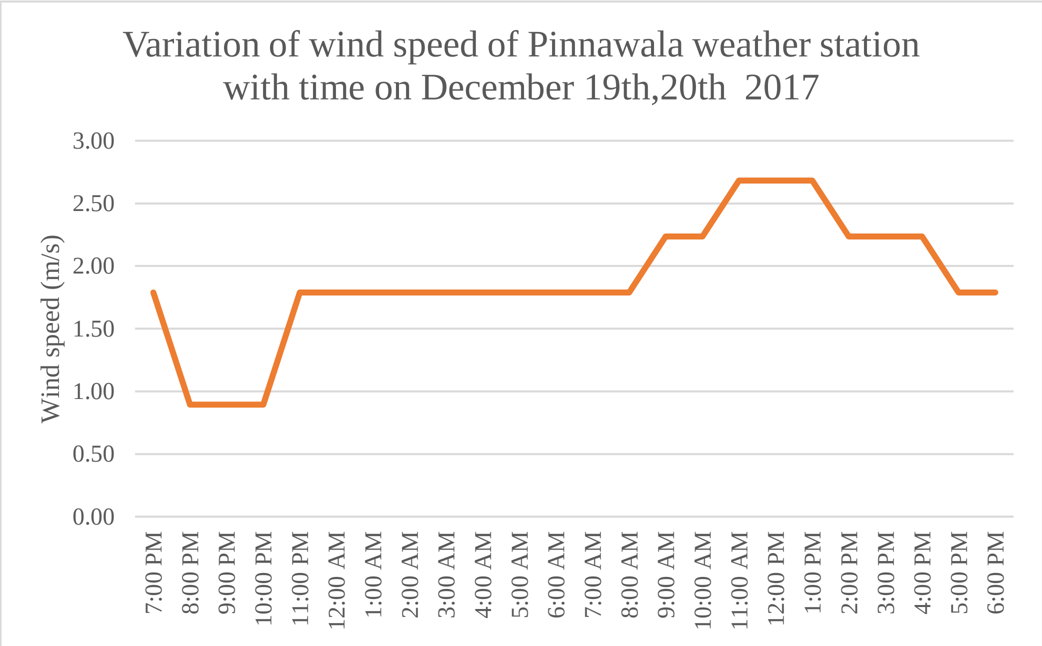


Figure 3.10 – Variation of wind speed of Pinnawala weather station

3.9 Solar intensity

The solar intensity values have been taken from "ASHRAE handbook 1981 fundamentals" for 8° North Latitude, which can be used for Sri Lanka. This hand book provide the hourly solar intensity in Chapter 27. Appendix A shows the solar intensity values as per the book. Using those solar intensity values, the variation in solar intensity with time is plotted as shown in the figure 3.11.

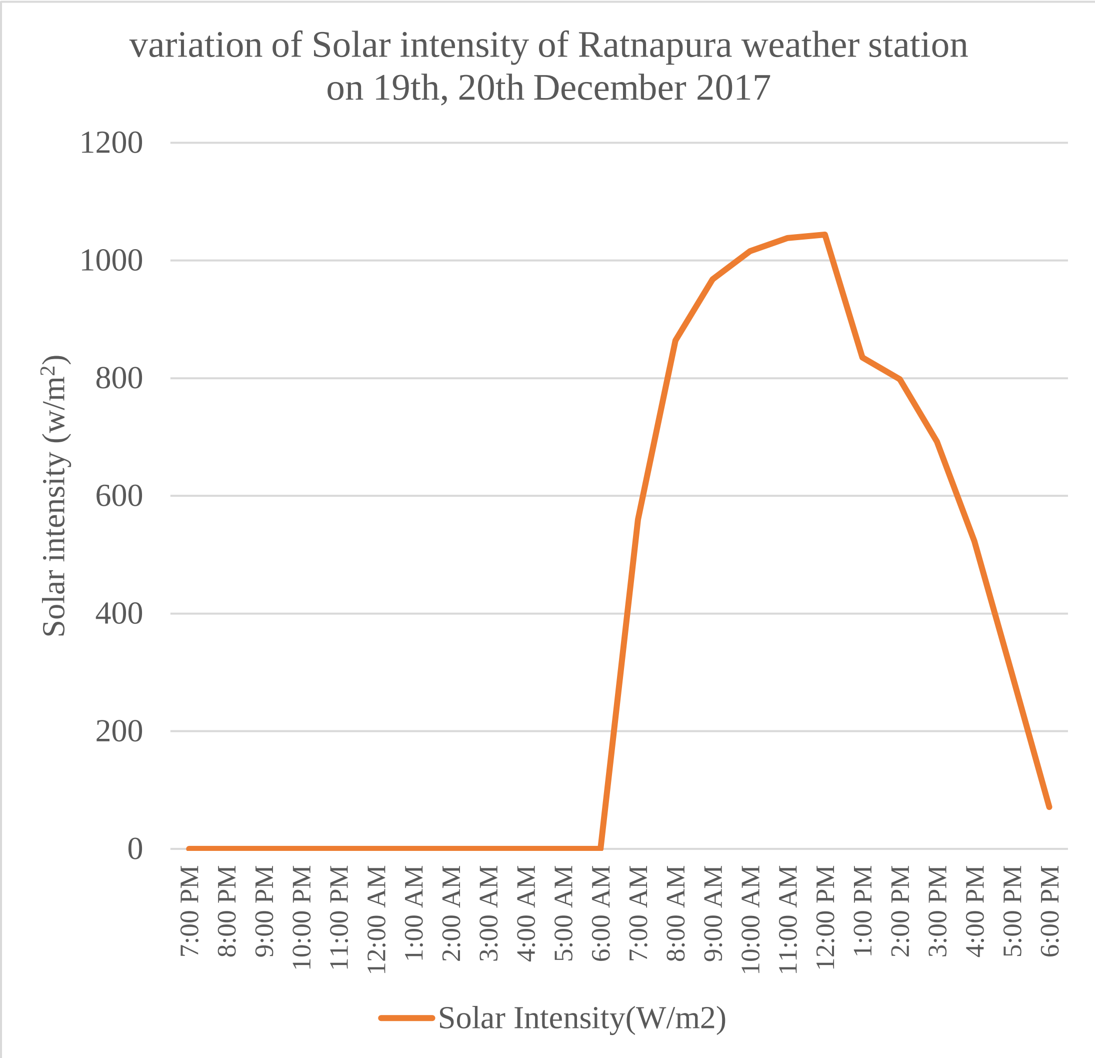


Figure 3.11 – Solar intensity variation with time

3.10 Calculating real time thermal rating

CCC of every line sections which are divided according to weather stations, have been calculated for every hour within 24 hours of a random day. The figure 3.12 shows the solar intensity, wind speed and ambient temperature of Section 37-75 of Ratnaura – Balangoda 132 kV transmission line using Pelmadulla weather station data on 19th, 20th December, 2017. According to the data the RTTR values have been calculated according to IEEE 738 (2012).

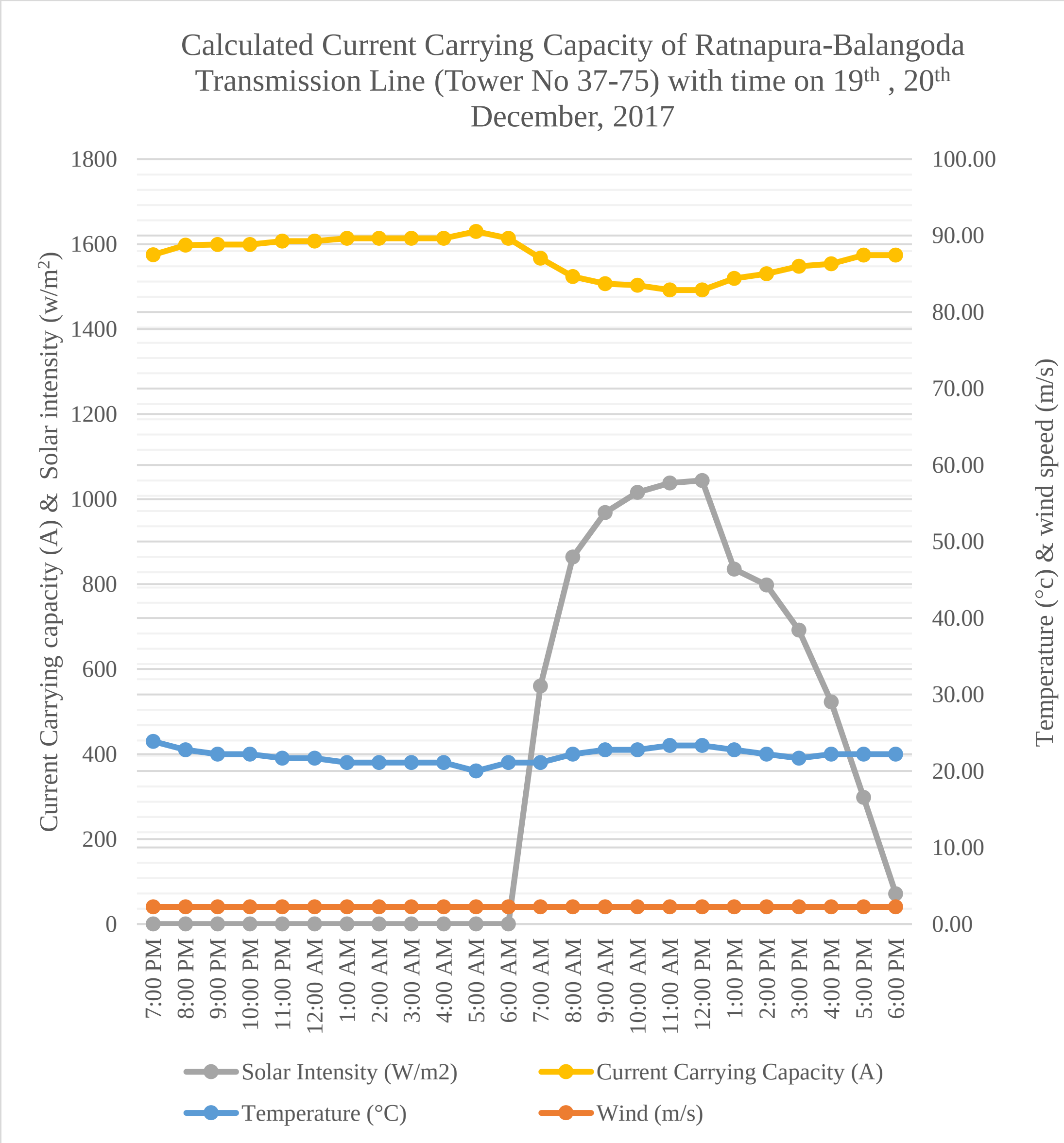


Figure 3.12 – CCC of a section of Ratnapura-Balangoda transmission line

Similarly the CCC using RTTR method have been calculated for other sections of this line. Since the weather varying in one weather station than other, the CCC is also changing. Figure 3.13 shows the CCC using RTTR method of all the sections on 19th, 20th December, 2017 and STR value of Ratnapura – Balangoda 132 kV transmission line.

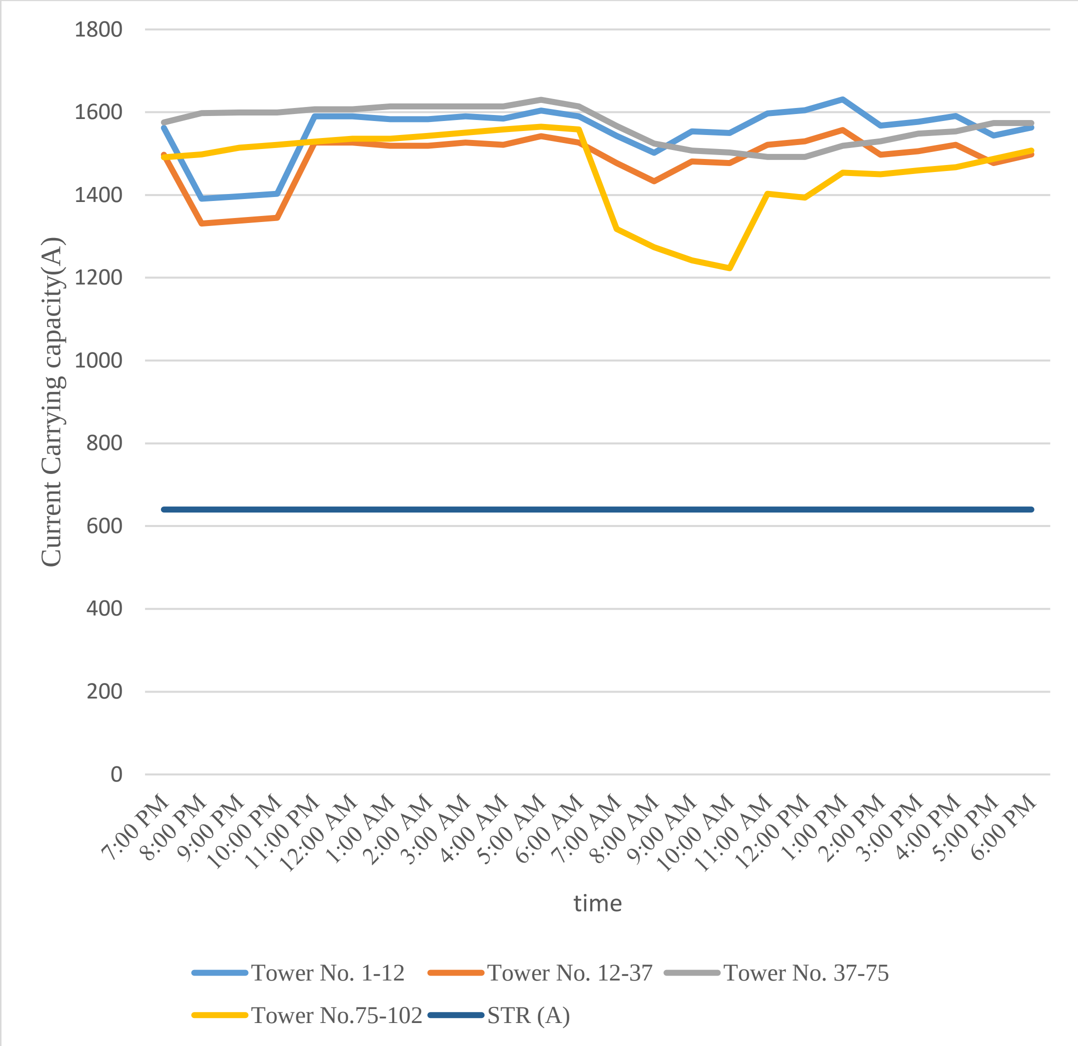


Figure 3.13 – CCC of all sections of Ratnapura – Balangoda line as at 19th, 20th December, 2017

The figure 3.14 shows the calculated CCC of sections of Ratnapura – Balangoda 132 kV transmission line. At a given time the safest (without violating clearance as specified in CEB technical specification) CCC is the lowest CCC of all sections (minimum value of calculated values). When current increases than the lowest CCC, then the conductor touches the electrical clearance line. So further loading will be violating the clearance. Therefore the safest CCC is the lowest CCC of all sections.

Time	Current Carrying Capacity (A)	Current Carrying Capacity (A)	Current Carrying Capacity (A)	Current Carrying Capacity (A)	RTTR
	Tower No. 1-12	Tower No. 12-37	Tower No. 37-75	Tower No.75-102	
7:00 PM	1562	1497	1575	1491	1491
8:00 PM	1391	1331	1598	1498	1331
9:00 PM	1397	1338	1599	1514	1338
10:00 PM	1403	1345	1599	1521	1345
11:00 PM	1590	1527	1607	1529	1527
12:00 AM	1590	1527	1607	1536	1527
1:00 AM	1583	1519	1614	1536	1519
2:00 AM	1583	1519	1614	1543	1519
3:00 AM	1590	1527	1614	1551	1527
4:00 AM	1585	1521	1614	1558	1521
5:00 AM	1604	1542	1630	1565	1542

Figure 3.14 – Hourly calculated value of RTTR for Ratnapura-Balangoda transmission line

As shown in the figure 3.14, same line's sections can have different capacities depending on weather variation. Safest current rating at 9.00 PM on 19th December 2017 of Ratnapura-Balangoda 132 kV transmission line is 1338 A. hence the CCC of entire line is 1338 A, since exceeding this value may violate the electrical clearance of the line.

The figure 3.15 shows the RTTR and STR values of Ratnapura – Balangoda transmission line on 19th and 20th December, 2017.

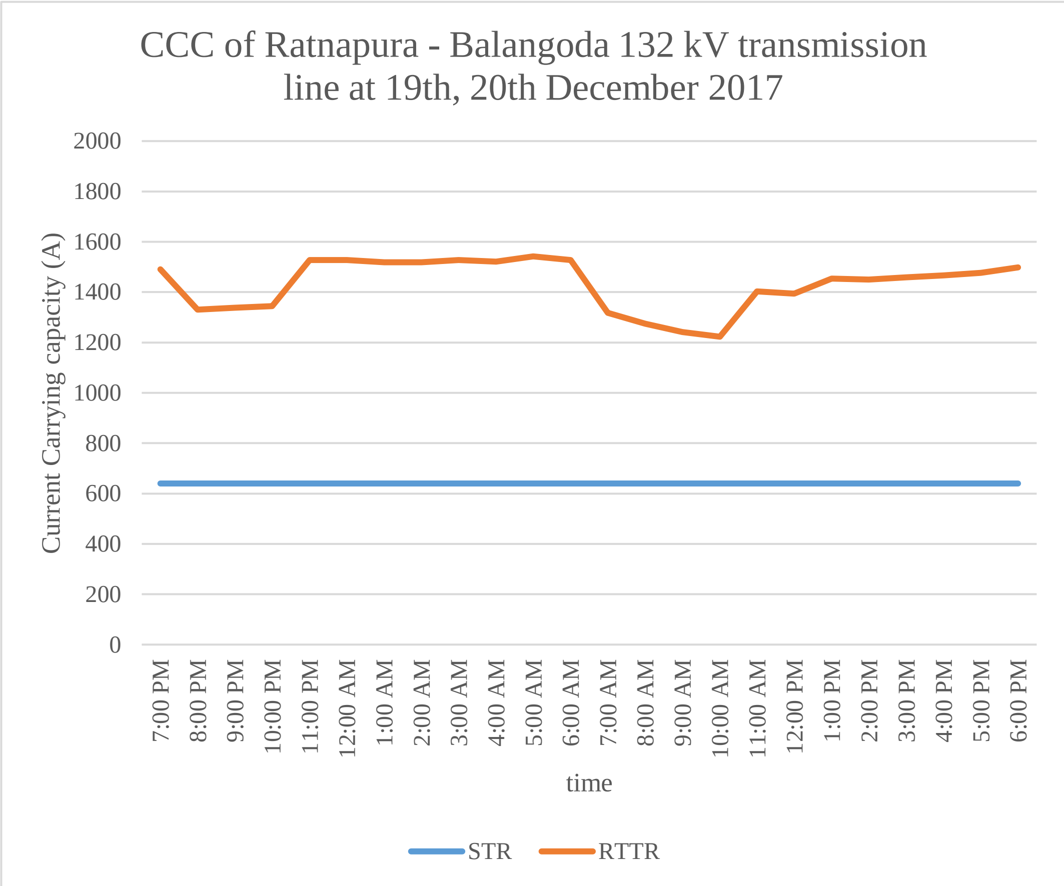


Figure 3.15 – RTTR and STR values of Ratnapura-Balangoda 132 kV transmission line as at 19th, 20th December, 2017

CHAPTER 4. EFFECT OF WEATHER PARAMETERS TO THE CONDUCTOR CURRENT CARRYING CAPACITY

According to the international standards [1], [6], current carrying capacity (CCC) of a given conductor is depends on these weather parameters,

1. Solar Intensity
2. Ambient temperature
3. Wind Speed
4. Wind direction

Real time dynamic thermal rating method has been used to study the influence of CCC with these weather parameters. The CCC has been calculated for ACSR Zebra and ACSR Lynx with above mentioned weather parameters. The results are as below.

4.1 Solar Intensity

The sun provides heat energy to the conductor. Rate of solar heat gain is calculated using conductor's surface condition, orientation of the conductor, sun's position in the sun and solar constant. The bright new conductor with shiny surface reflects more heat energy and dull old conductor with matt surface absorbs more heat energy. According to this, for a given conductor the variable parameter is solar heat intensity. Solar intensity value become maximum at day time (noon) and minimum at night time. CEB uses 1200 W/m^2 of solar intensity value for current ratings of the conductors. The range of solar intensity has been taken from 0 to 1200 W/m^2 which are the minimum and maximum values of solar intensity in Sri Lanka. As per the ASHRAE standards, the peak value of solar intensity vary with the season, as sun's path is varying. The CCC decreases with solar intensity as shown in the figure 4.1 for ACSR Lynx and figure 4.2 ACSR Zebra conductor.

<u>SAMPLE CALCULATION</u>

Current carrying capacity of Lynx conductor with 300 W/m² solar intensity

Solar Radiation Intensity (Q_s) = 300 W/m^2

Air Thermal Conductivity (k_f) = 0.028 $Wm^{-1}K^{-1}$

Ambient Temperature (T_a)	=	32°C
Maximum allowable conductor temperature (T_s)	=	75°C
Wind Speed (V_w)	=	0.25 m/s
Solar absorptivity (α)	=	0.5
Emissivity (ϵ)	=	0.5
Conductor Diameter (D_0)	=	19.53 mm
Elevation above sea level (He)	=	100 m
Angle between the wind direction and the conductor (Ø)	=	90°

The atmosphere is clear

From above data, following parameters have been calculated according to the standard.

Average temperature of the boundary layer

$T_{film} = \frac{Ts+Ta}{2}$ = 53.5 °C

Density of Air

$\rho f = \frac{1.293-1.525\times H_e+6.379\times 10^{-9}\times H_e^2}{1+0.00367\times T_{film}}$ = 1.068 kg/m^3

Thermal conductivity of air

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

= 0.028 W/m °C

The dynamic viscosity of air

$\mu_f = \frac{1.458\times 10^{-6}\times (T_{film}+273)^{1.5}}{T_{film+383.4}}$ = 0.000019688 kg/m-s

Wind direction factor

$$(K_{angle}) = 1.194 - \cos Ø + 0.194 \times \cos 2Ø + 0.368 \times \sin 2Ø$$

= 1.00

Forced convection heat loss

$$q_{c1} = K_{angle} \times (1.01 + 1.35 \times {N_{Re}}^{0.52}) \times k_f \times (T_s - T_a) \quad = \quad 31.057 \text{ W/m}$$

$$q_{c2} = K_{angle} \times 0.754 \times {N_{Re}}^{0.6} \times k_f \times (T_s - T_a) \quad = \quad 25.913 \text{ W/m}$$

Radiated heat loss rate

$$q_r = 17.8 \times D_0 \times \epsilon \times \left[\left(\frac{T_s+273}{100}\right)^4 - \left(\frac{T_a+273}{100}\right)^4\right] \quad = \quad 10.451 \text{ W/m}$$

Solar heat gain

$$q_s = \alpha \,.\, Q_{se}.\sin \hat{O} \,.\, A' \quad = \quad 2.845 \text{ W/m}$$

Heat balance equation

$$Q_c + Q_r = Q_s + I^2.R\ (T_{avg})$$

$$I = \sqrt{\frac{Q_c+Q_r-Q_s}{R\ (T_{avg})}} \quad = \quad 415 \text{ A}$$

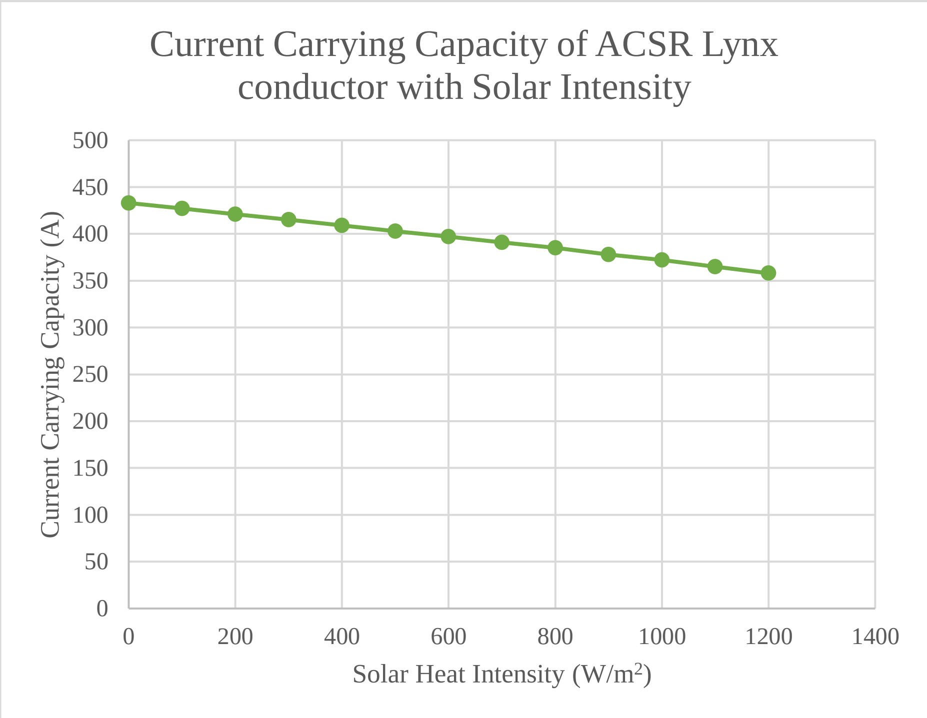


Figure 4.1 – CCC with solar intensity of ACSR Lynx conductor

<u>SAMPLE CALCULATION</u>

Current carrying capacity of Zebra conductor with 500 W/m^2 solar intensity

Solar Radiation Intensity (Q_s)	=	500 W/m^2
Air Thermal Conductivity (k_f)	=	0.028 Wm^{-1}K^{-1}
Ambient Temperature (T_a)	=	32°C
Maximum allowable conductor temperature (T_s)	=	75°C
Wind Speed (V_w)	=	0.25 m/s
Solar absorptivity (α)	=	0.5
Emissivity (ϵ)	=	0.5
Conductor Diameter (D_0)	=	28.62 mm
Elevation above sea level (He)	=	100 m
Angle between the wind direction and the conductor (Ø)	=	90°

The atmosphere is clear

From above data, following parameters have been calculated according to the standard.

Average temperature of the boundary layer

$T_{film} = \frac{Ts+Ta}{2}$ = 53.5 °C

Density of Air

$\rho f = \frac{1.293-1.525\times H_e+6.379\times 10^{-9}\times H_e^2}{1+0.00367\times T_{film}}$ = 1.068 kg/m^3

Thermal conductivity of air

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

= 0.028 W/m °C

The dynamic viscosity of air

$\mu_f = \frac{1.458\times 10^{-6}\times (T_{film}+273)^{1.5}}{T_{film+383.4}}$ = 0.000019688 kg/m-s

Wind direction factor

$(K_{angle}) = 1.194 - \cos\text{Ø} + 0.194\times\cos 2\text{Ø} + 0.368\times\sin 2\text{Ø}$

= 1.00

Forced convection heat loss

$q_{c1} = K_{angle}\times(1.01 + 1.35\times {N_{Re}}^{0.52})\times k_f\times(T_s - T_a)$ = 37.615 W/m

$q_{c2} = K_{angle}\times 0.754\times {N_{Re}}^{0.6}\times k_f\times(T_s - T_a)$ = 32.591 W/m

Radiated heat loss rate

$q_r = 17.8\times D_0\times\epsilon\times\left[\left(\frac{T_s+273}{100}\right)^4 - \left(\frac{T_a+273}{100}\right)^4\right]$ = 15.315 W/m

Solar heat gain

$q_s = \alpha \, . \, Q_{se} . \sin \hat{O} \, . \, A'$ = 6.949 W/m

Heat balance equation

$$Q_c + Q_r = Q_s + I^2 . R \, (T_{avg})$$

$I = \sqrt{\frac{Q_c + Q_r - Q_s}{R \, (T_{avg})}}$ = 728 A

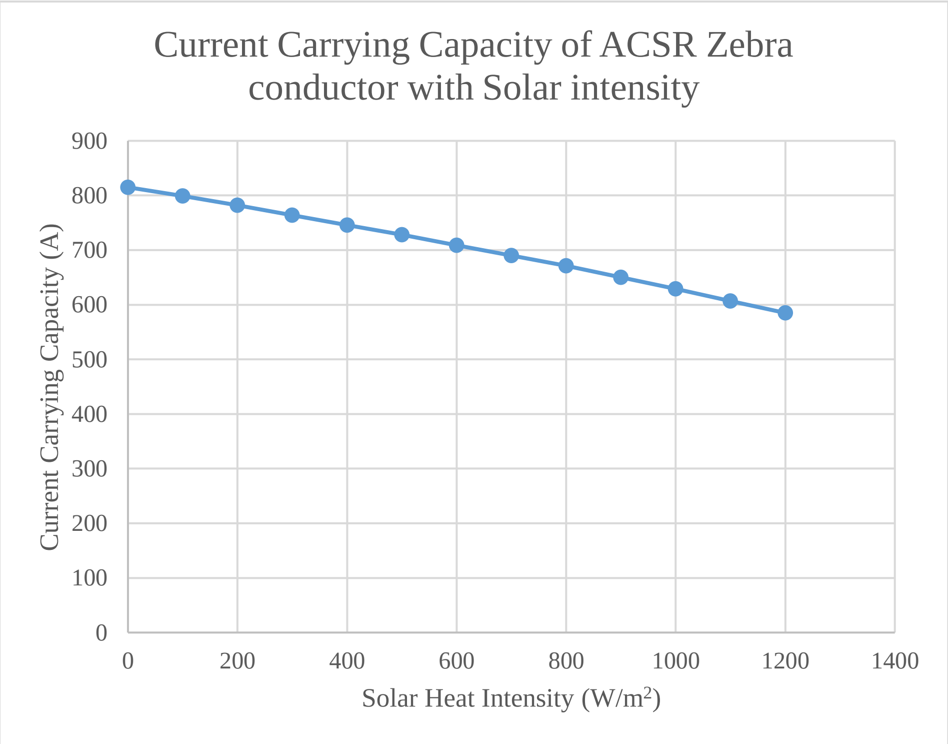


Figure 4.2 – CCC with solar intensity of ACSR Zebra conductor

4.2 Ambient Temperature

Radiated heat loss rate is calculating when heat energy is transmitted to the surroundings of the conductor. This rate is depends with the difference between surrounding ambient temperature and the conductor temperature. When the ambient temperature increases the heat loss rate of a given conductor will reduces. Also when ambient temperature reduces the heat loss rate will be increases. This variation in radiated heat loss rate also determines the maximum possible CCC of a given conductor. The figure 4.3 and 4.4 shows the CCC of ACSR Lynx and ACSR Zebra conductors with ambient temperature. According to the analysis, CCC of a conductor decreases with ambient temperature.

SAMPLE CALCULATION

Current carrying capacity of Lynx conductor with 36°C ambient temperature

Solar Radiation Intensity (Q_s)	=	1200 W/m^2
Air Thermal Conductivity (k_f)	=	0.028 Wm^{-1}K^{-1}
Ambient Temperature (T_a)	=	36°C
Maximum allowable conductor temperature (T_s)	=	75°C
Wind Speed (V_w)	=	0.25 m/s
Solar absorptivity (α)	=	0.5
Emissivity (ϵ)	=	0.5
Conductor Diameter (D_0)	=	19.53 mm
Elevation above sea level (He)	=	100 m
Angle between the wind direction and the conductor (Ø)	=	90°

The atmosphere is clear

From above data, following parameters have been calculated according to the standard.

Average temperature of the boundary layer

$$T_{film} = \frac{Ts+Ta}{2} \qquad = \qquad 55.5\ °C$$

Density of Air

$$\rho f = \frac{1.293 - 1.525 \times H_e + 6.379 \times 10^{-9} \times H_e^2}{1 + 0.00367 \times T_{film}} \qquad = \qquad 1.062\ kg/m^3$$

Thermal conductivity of air

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

$$= \qquad 0.028\ W/m\ °C$$

The dynamic viscosity of air

$\mu_f = \frac{1.458\times10^{-6}\times(T_{film}+273)^{1.5}}{T_{film+383.4}}$ = 0.000019779 kg/m-s

Wind direction factor

$(K_{angle}) = 1.194 - \cos Ø + 0.194 \times \cos 2Ø + 0.368 \times \sin 2Ø$

= 1.00

Forced convection heat loss

$q_{c1} = K_{angle} \times (1.01 + 1.35 \times {N_{Re}}^{0.52}) \times k_f \times (T_s - T_a)$

= 28.165 W/m

$q_{c2} = K_{angle} \times 0.754 \times {N_{Re}}^{0.6} \times k_f \times (T_s - T_a)$ = 23.475 W/m

Radiated heat loss rate

$q_r = 17.8 \times D_0 \times \epsilon \times \left[\left(\frac{T_s+273}{100}\right)^4 - \left(\frac{T_a+273}{100}\right)^4\right]$ = 9.646 W/m

Solar heat gain

$q_s = \alpha \,.\, Q_{se}. \sin \hat{O} \,.\, A'$ = 11.381 W/m

Heat balance equation

$Q_c + Q_r = Q_s + I^2 . R\ (T_{avg})$

$I = \sqrt{\frac{Q_c+Q_r-Q_s}{R\ (T_{avg})}}$ = 353 A

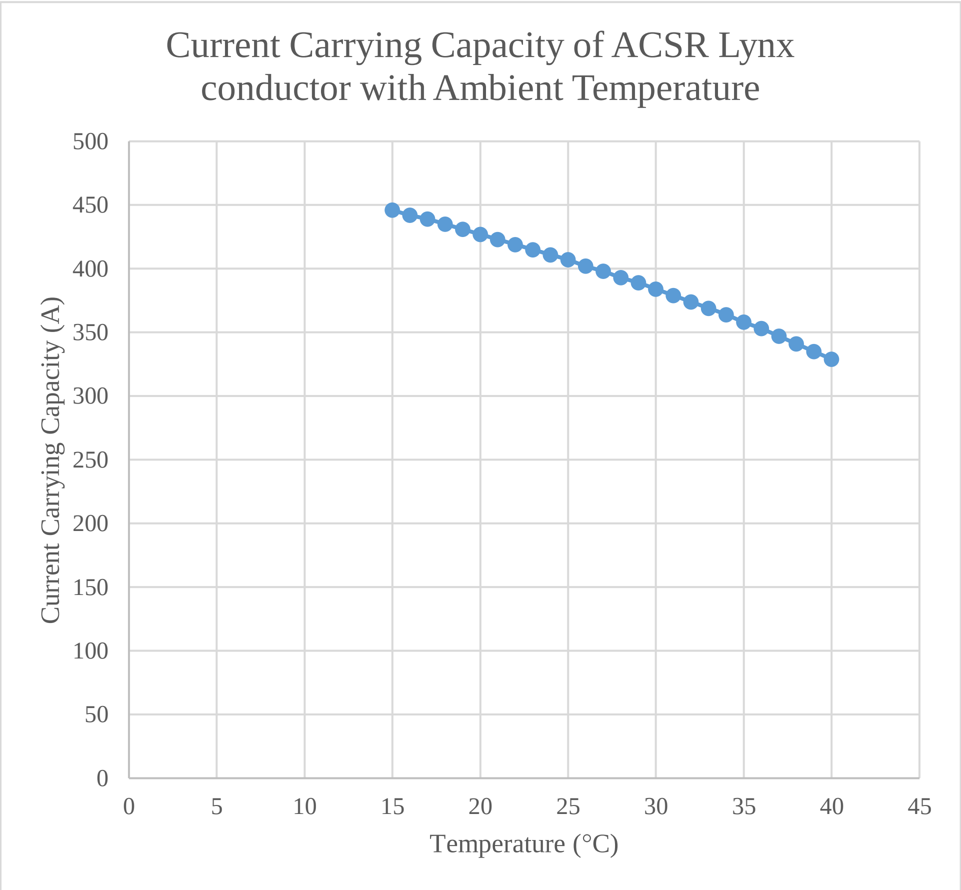


Figure 4.3 – CCC with ambient temperature of ACSR Lynx conductor

<u>SAMPLE CALCULATION</u>

Current carrying capacity of Zebra conductor with 20°C ambient temperature

Solar Radiation Intensity (Q_s)	=	1200W/m^2
Air Thermal Conductivity (k_f)	=	0.028 Wm^{-1}K^{-1}
Ambient Temperature (T_a)	=	20°C
Maximum allowable conductor temperature (T_s)	=	75°C
Wind Speed (V_w)	=	0.25 m/s
Solar absorptivity (α)	=	0.5
Emissivity (ϵ)	=	0.5
Conductor Diameter (D_0)	=	28.62 mm
Elevation above sea level (He)	=	100 m
Angle between the wind direction and the conductor (Ø)	=	90°

The atmosphere is clear

From above data, following parameters have been calculated according to the standard.

Average temperature of the boundary layer

$T_{film} = \frac{Ts+Ta}{2}$ = 47.5 °C

Density of Air

$\rho f = \frac{1.293-1.525\times H_e+6.379\times 10^{-9}\times H_e^2}{1+0.00367\times T_{film}}$ = 1.088 kg/m^3

Thermal conductivity of air

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

= 0.028 W/m °C

The dynamic viscosity of air

$\mu_f = \frac{1.458\times 10^{-6}\times (T_{film}+273)^{1.5}}{T_{film+383.4}}$ = 0.000019414 kg/m-s

Wind direction factor

$(K_{angle}) = 1.194 - \cos Ø + 0.194\times\cos 2Ø + 0.368\times\sin 2Ø$

= 1.00

Forced convection heat loss

$q_{c1} = K_{angle}\times(1.01 + 1.35\times N_{Re}{}^{0.52})\times k_f\times(T_s - T_a)$ = 48.135 W/m

$q_{c2} = K_{angle}\times 0.754\times N_{Re}{}^{0.6}\times k_f\times(T_s - T_a)$ = 41.838 W/m

Radiated heat loss rate

$q_r = 17.8\times D_0\times\epsilon\times\left[\left(\frac{T_s+273}{100}\right)^4 - \left(\frac{T_a+273}{100}\right)^4\right]$ = 18.585 W/m

Solar heat gain

$q_s = \alpha \, . \, Q_{se} . \sin \hat{O} \, . \, A'$ = 16.678 W/m

Heat balance equation

$$Q_c + Q_r = Q_s + I^2 . R \, (T_{avg})$$

$I = \sqrt{\frac{Q_c + Q_r - Q_s}{R \, (T_{avg})}}$ = 733 A

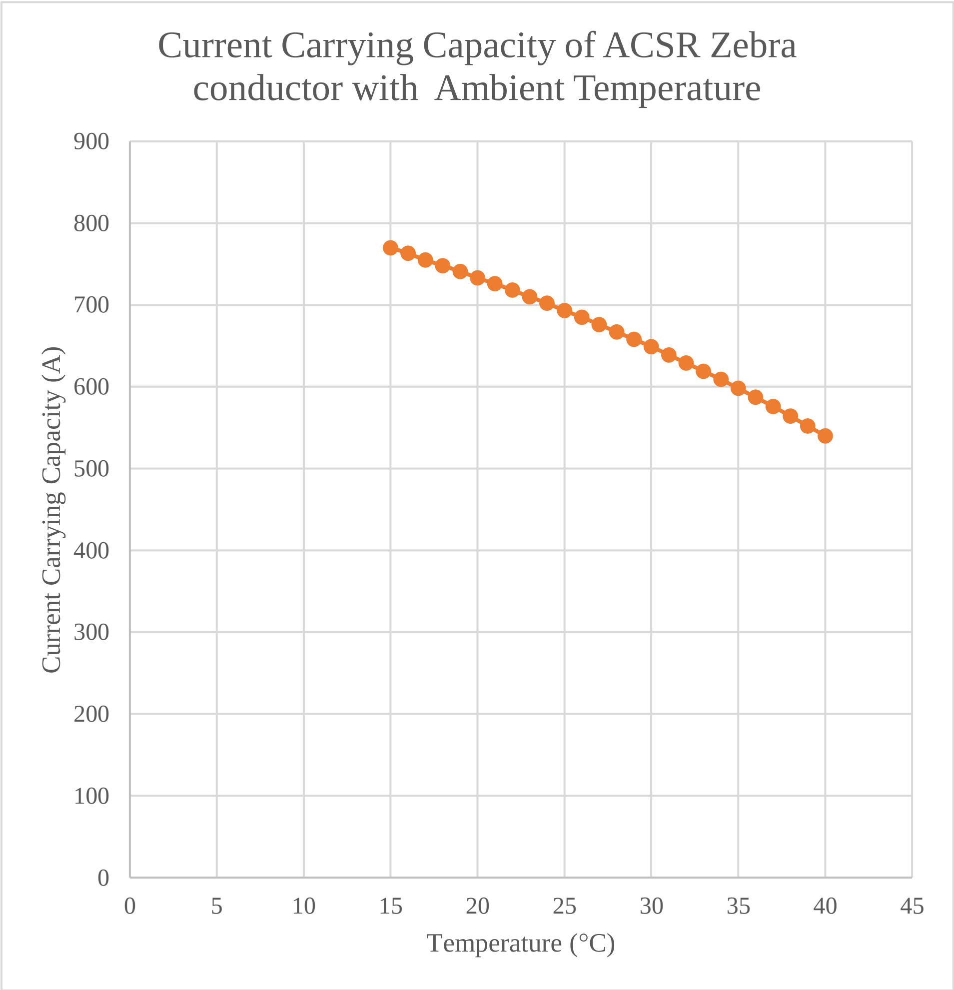


Figure 4.4 – CCC with ambient temperature of ACSR Zebra conductor

4.3 Wind Speed

Forced convection heat loss occurs when moving air carries heated air around the conductor away and cooling down the conductor by reducing its temperature. Higher wind speed will carry more heated air than lower wind speed. Figure 4.5 and 4.6 shows how the CCC is varying with wind speed for ACSR Lynx and ACSR Zebra conductors. CCC is increasing significantly with wind speed.

SAMPLE CALCULATION

Current carrying capacity of Lynx conductor with 4 m/s wind speed

Solar Radiation Intensity (Q_s)	=	1200 W/m^2
Air Thermal Conductivity (k_f)	=	0.028 Wm^{-1}K^{-1}
Ambient Temperature (T_a)	=	32°C
Maximum allowable conductor temperature (T_s)	=	75°C
Wind Speed (V_w)	=	4 m/s
Solar absorptivity (α)	=	0.5
Emissivity (ϵ)	=	0.5
Conductor Diameter (D_0)	=	19.53 mm
Elevation above sea level (He)	=	100 m
Angle between the wind direction and the conductor (Ø)	=	90°

The atmosphere is clear

From above data, following parameters have been calculated according to the standard.

Average temperature of the boundary layer

$$T_{film} = \frac{Ts+Ta}{2} \quad = \quad 53.5\ °C$$

Density of Air

$$\rho f = \frac{1.293-1.525\times H_e+6.379\times 10^{-9}\times H_e^2}{1+0.00367\times T_{film}} \quad = \quad 1.068\ kg/m^3$$

Thermal conductivity of air

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

= 0.028 W/m °C

The dynamic viscosity of air

$\mu_f = \frac{1.458 \times 10^{-6} \times (T_{film} + 273)^{1.5}}{T_{film + 383.4}}$ = 0.000019688 kg/m-s

Wind direction factor

$(K_{angle}) = 1.194 - \cos Ø + 0.194 \times \cos 2Ø + 0.368 \times \sin 2Ø$

= 1.00

Forced convection heat loss

$q_{c1} = K_{angle} \times (1.01 + 1.35 \times {N_{Re}}^{0.52}) \times k_f \times (T_s - T_a)$ = 127.355 W/m

$q_{c2} = K_{angle} \times 0.754 \times {N_{Re}}^{0.6} \times k_f \times (T_s - T_a)$ = 136.771 W/m

Radiated heat loss rate

$q_r = 17.8 \times D_0 \times \epsilon \times \left[\left(\frac{T_s + 273}{100}\right)^4 - \left(\frac{T_a + 273}{100}\right)^4\right]$ = 10.451 W/m

Solar heat gain

$q_s = \alpha \,.\, Q_{se}.\sin \hat{O} \,.\, A'$ = 11.381 W/m

Heat balance equation

$Q_c + Q_r = Q_s + I^2.R\ (T_{avg})$

$I = \sqrt{\frac{Q_c + Q_r - Q_s}{R\ (T_{avg})}}$ = 883 A

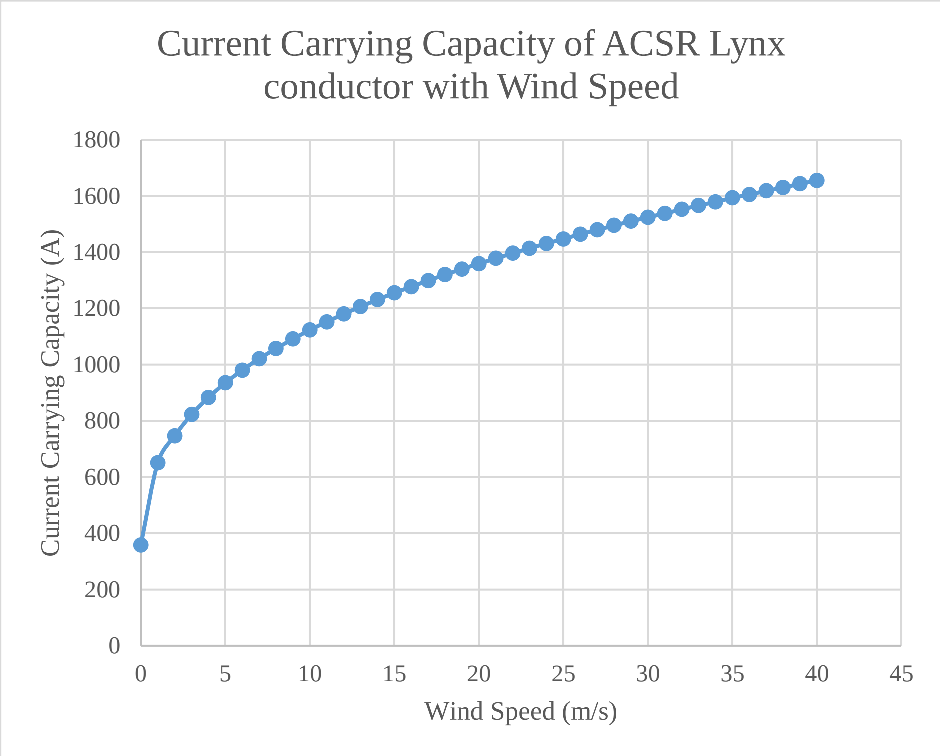


Figure 4.5 – CCC with wind velocity of ACSR Lynx conductor

<u>SAMPLE CALCULATION</u>

Current carrying capacity of Zebra conductor with 3 m/s wind speed

Solar Radiation Intensity (Q_s)	=	1200 W/m^2
Air Thermal Conductivity (k_f)	=	0.028 $Wm^{-1}K^{-1}$
Ambient Temperature (T_a)	=	32°C
Maximum allowable conductor temperature (T_s)	=	75°C
Wind Speed (V_w)	=	3 m/s
Solar absorptivity (α)	=	0.5
Emissivity (ϵ)	=	0.5
Conductor Diameter (D_0)	=	28.62 mm
Elevation above sea level (He)	=	100 m
Angle between the wind direction and the conductor (Ø)	=	90°

The atmosphere is clear

From above data, following parameters have been calculated according to the standard.

Average temperature of the boundary layer

$T_{film} = \frac{Ts+Ta}{2}$ = 53.5 °C

Density of Air

$\rho f = \frac{1.293-1.525\times H_e+6.379\times10^{-9}\times H_e^2}{1+0.00367\times T_{film}}$ = 1.068 kg/m^3

Thermal conductivity of air

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

= 0.028 W/m °C

The dynamic viscosity of air

$\mu_f = \frac{1.458\times10^{-6}\times(T_{film}+273)^{1.5}}{T_{film+383.4}}$ = 0.000019688 kg/m-s

Wind direction factor

$(K_{angle}) = 1.194 - \cos Ø + 0.194 \times \cos 2Ø + 0.368 \times \sin 2Ø$

= 1.00

Forced convection heat loss

$q_{c1} = K_{angle} \times (1.01 + 1.35 \times N_{Re}{}^{0.52}) \times k_f \times (T_s - T_a)$ = 108.522 W/m

$q_{c2} = K_{angle} \times 0.754 \times N_{Re}{}^{0.6} \times k_f \times (T_s - T_a)$ = 113.489 W/m

Radiated heat loss rate

$q_r = 17.8 \times D_0 \times \epsilon \times \left[\left(\frac{T_s+273}{100}\right)^4 - \left(\frac{T_a+273}{100}\right)^4\right]$ = 15.315 W/m

Solar heat gain

$q_s = \alpha \,. Q_{se} . \sin \hat{O} \,. A'$ = 16.678 W/m

Heat balance equation

$Q_c + Q_r = Q_s + I^2 . R\,(T_{avg})$

$I = \sqrt{\frac{Q_c + Q_r - Q_s}{R\,(T_{avg})}}$ = 1034 A

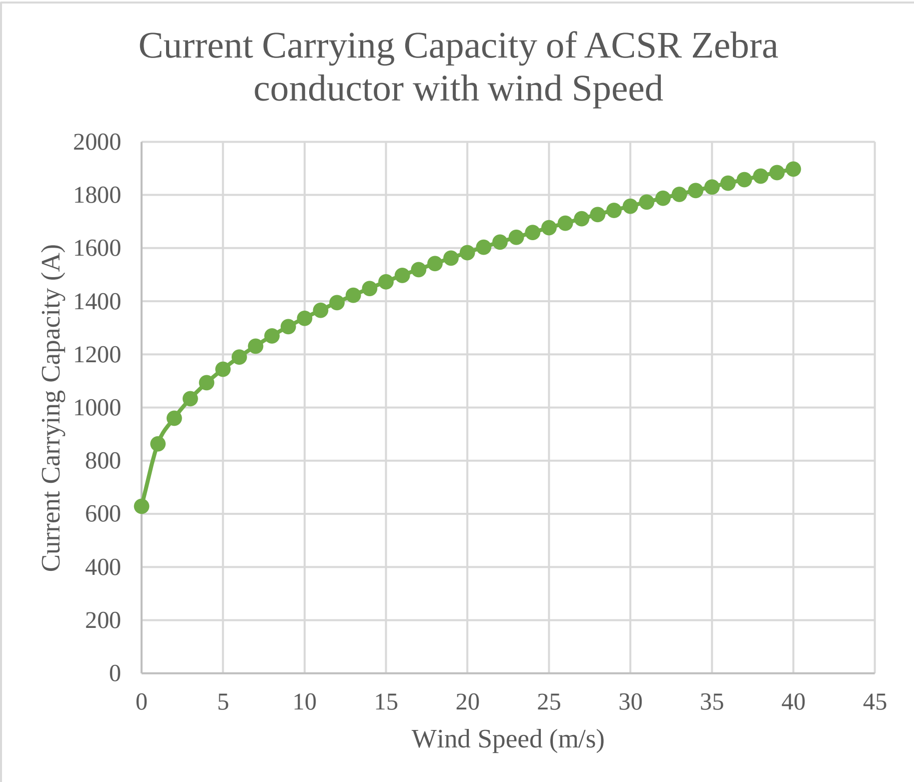


Figure 4.6 – CCC with wind velocity of ACSR Zebra conductor

4.4 Wind Direction

CCC with wind direction for ACSR Zebra and Lynx conductor are shown in the figure 4.7. Wind direction is the angle between wing and axis of the conductor. When the wind is along with the line or parallel to the line the value of the wind angle is 0° and when the wind blows perpendicular to the conductor the wind angle is 90°. CCC is increasing slightly with wind direction for both conductors.

SAMPLE CALCULATION

Current carrying capacity of Lynx conductor with 60° wind angle

Solar Radiation Intensity (Q_s)	=	1200 W/m^2
Air Thermal Conductivity (k_f)	=	0.028 Wm^{-1}K^{-1}
Ambient Temperature (T_a)	=	32°C
Maximum allowable conductor temperature (T_s)	=	75°C
Wind Speed (V_w)	=	0.25 m/s
Solar absorptivity (α)	=	0.5
Emissivity (ϵ)	=	0.5
Conductor Diameter (D_0)	=	19.53 mm
Elevation above sea level (He)	=	100 m
Angle between the wind direction and the conductor (Ø)	=	60°

The atmosphere is clear

From above data, following parameters have been calculated according to the standard.

Average temperature of the boundary layer

$$T_{film} = \frac{Ts+Ta}{2} \qquad = \qquad 53.5\ °C$$

Density of Air

$$\rho f = \frac{1.293 - 1.525 \times H_e + 6.379 \times 10^{-9} \times H_e^2}{1 + 0.00367 \times T_{film}} \qquad = \qquad 1.068\ kg/m^3$$

Thermal conductivity of air

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

$$= \qquad 0.028\ W/m\ °C$$

The dynamic viscosity of air

$$\mu_f = \frac{1.458 \times 10^{-6} \times (T_{film} + 273)^{1.5}}{T_{film + 383.4}} \qquad = \qquad 0.000019688\ kg/m\text{-}s$$

Wind direction factor

$(K_{angle}) = 1.194 - \cos Ø + 0.194 \times \cos 2Ø + 0.368 \times \sin 2Ø$ = 1.00

Forced convection heat loss

$q_{c1} = K_{angle} \times (1.01 + 1.35 \times {N_{Re}}^{0.52}) \times k_f \times (T_s - T_a)$ = 28.439 W/m

$q_{c2} = K_{angle} \times 0.754 \times {N_{Re}}^{0.6} \times k_f \times (T_s - T_a)$ = 23.729 W/m

Radiated heat loss rate

$q_r = 17.8 \times D_0 \times \epsilon \times \left[\left(\frac{T_s+273}{100}\right)^4 - \left(\frac{T_a+273}{100}\right)^4\right]$ = 10.451 W/m

Solar heat gain

$q_s = \alpha \,.\, Q_{se} . \sin \hat{O} \,.\, A'$ = 11.381 W/m

Heat balance equation

$Q_c + Q_r = Q_s + I^2 . R\ (T_{avg})$

$I = \sqrt{\frac{Q_c+Q_r-Q_s}{R\ (T_{avg})}}$ = 358 A

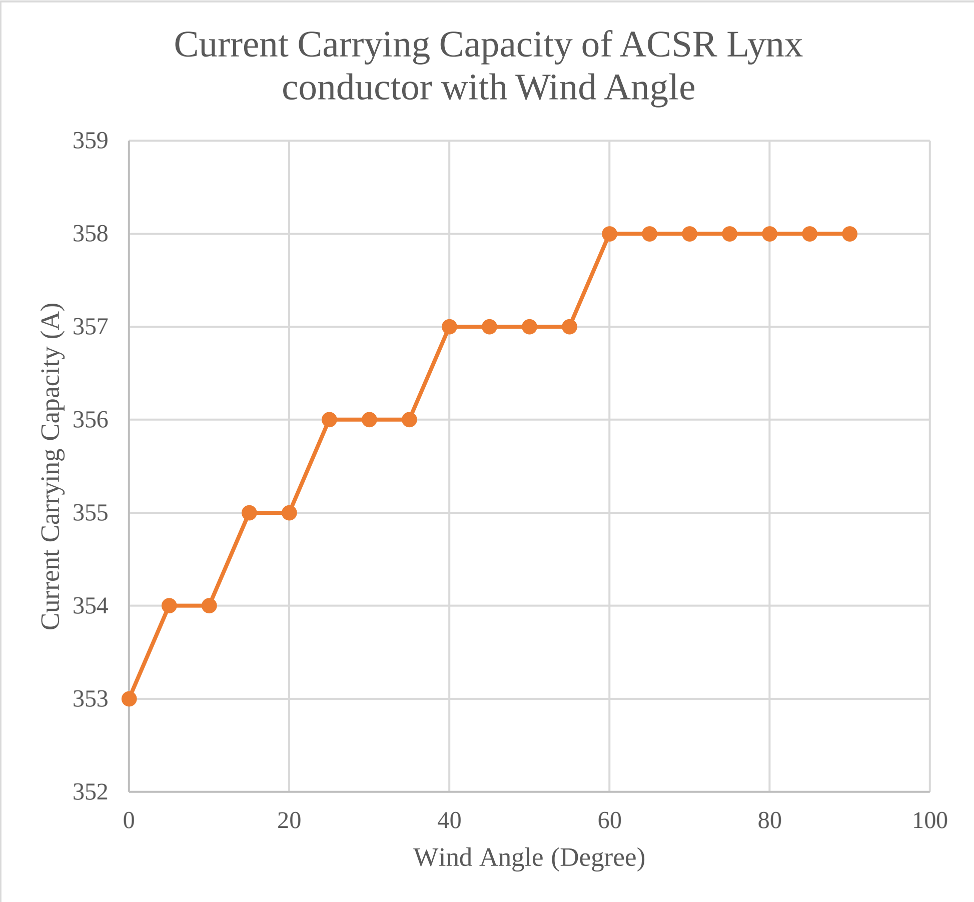


Figure 4.7 – CCC with wind angle of ACSR Lynx conductor

<u>SAMPLE CALCULATION</u>

Current carrying capacity of Zebra conductor with 75° wind angle

Solar Radiation Intensity (Q_s)	=	1200 W/m^2
Air Thermal Conductivity (k_f)	=	0.028 Wm^{-1}K^{-1}
Ambient Temperature (T_a)	=	32°C
Maximum allowable conductor temperature (T_s)	=	75°C
Wind Speed (V_w)	=	0.25 m/s
Solar absorptivity (α)	=	0.5
Emissivity (ϵ)	=	0.5
Conductor Diameter (D_0)	=	28.62 mm
Elevation above sea level (He)	=	100 m

Angle between the wind direction and the conductor (Ø) = 75°

The atmosphere is clear

From above data, following parameters have been calculated according to the standard.

Average temperature of the boundary layer

$T_{film} = \frac{Ts+Ta}{2}$ = 53.5 °C

Density of Air

$\rho f = \frac{1.293-1.525\times H_e+6.379\times 10^{-9}\times H_e^2}{1+0.00367\times T_{film}}$ = 1.068 kg/m^3

Thermal conductivity of air

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

= 0.028 W/m °C

The dynamic viscosity of air

$\mu_f = \frac{1.458\times 10^{-6}\times (T_{film}+273)^{1.5}}{T_{film+383.4}}$ = 0.000019688 kg/m-s

Wind direction factor

$(K_{angle}) = 1.194 - \cos Ø + 0.194\times \cos 2Ø + 0.368\times \sin 2Ø$

= 1.00

Forced convection heat loss

$q_{c1} = K_{angle}\times (1.01 + 1.35\times {N_{Re}}^{0.52})\times k_f\times (T_s - T_a)$ = 35.779 W/m

$q_{c2} = K_{angle}\times 0.754\times {N_{Re}}^{0.6}\times k_f\times (T_s - T_a)$ = 31.000 W/m

Radiated heat loss rate

$q_r = 17.8 \times D_0 \times \epsilon \times \left[\left(\frac{T_s+273}{100}\right)^4 - \left(\frac{T_a+273}{100}\right)^4\right]$ = 15.315 W/m

Solar heat gain

$q_s = \alpha \,.\, Q_{se} . \sin \hat{\text{O}} \,.\, A'$ = 16.678 W/m

Heat balance equation

$Q_c + Q_r = Q_s + I^2 . R\,(T_{avg})$

$I = \sqrt{\frac{Q_c+Q_r-Q_s}{R\,(T_{avg})}}$ = 636 A

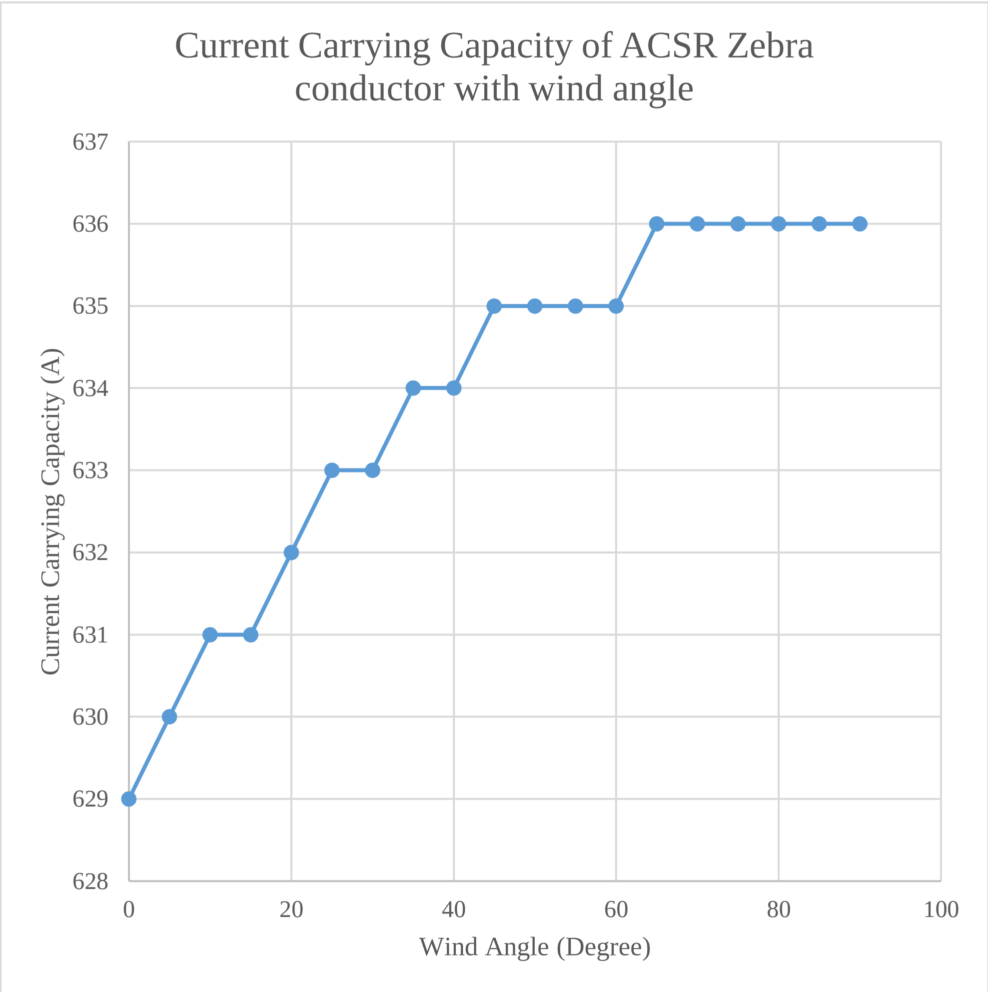


Figure 4.8 – CCC with wind angle of ACSR Zebra conductor

To analyse the dependencies of line rating, all the above plots have been drawn in one plot. It is harder to plot solar intensity in the same x scale, hence the logarithmic value has been taken. For the comparison, CCC with all the weather parameters have been plotted for ACSR Zebra and ACSR Lynx conductors separately.

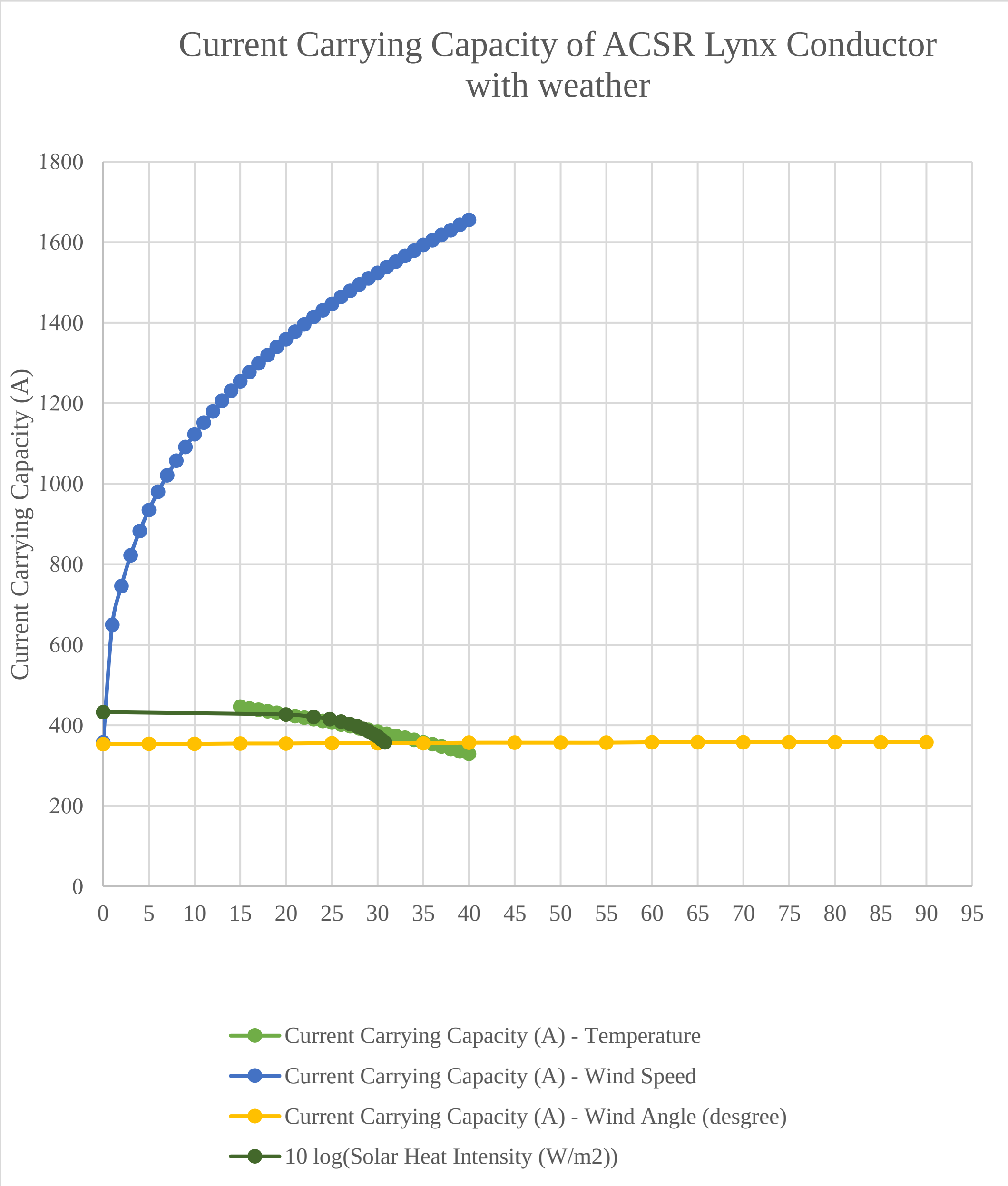


Figure 4.9 – CCC of ACSR Lynx conductor with weather parameters

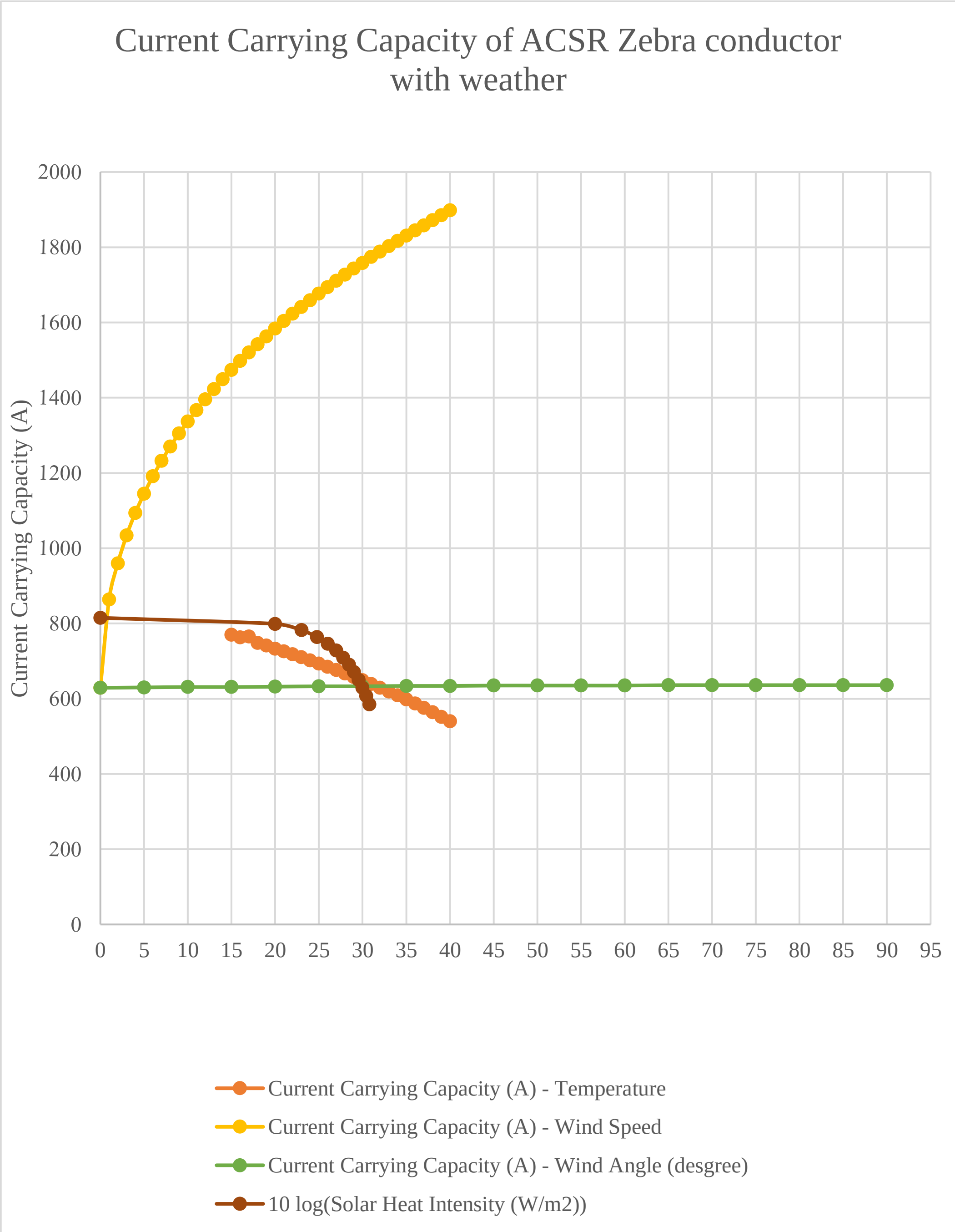


Figure 4.10 – CCC of ACSR Zebra conductor with weather parameters

According to the results, when calculating current carrying capacity of a given conductor, the most significant parameter is wind speed and the least significant parameter is wind angle. Since Wind angle is not having more influence on the CCC like other weather parameters, it is not taken for calculating CCC for this research.

CHAPTER 5. PLS CADD DESIGN

Power Line Systems Computer Aided Design and Drafting (PLS-CADD) is a most power full overhead line design software, which includes terrain modelling, route selection, sag tension, clearance and strength check, optimum structure spotting, plan and profile drafting, structure modelling, etc. This model can be viewed in a profile view, plan view, 3D view and staking lists. The latest version of PLS-CADD 14.4 has been used in this project.

Thermal expansion caused by the increase of conductor temperature can result in the dropping beneath its safety clearance. To ensure safety, the actual line has to modify with actual data. Using these inputs, the PLS CADD design has to be created. Then the critical span of the sections and maximum allowable conductor temperature can be identified.

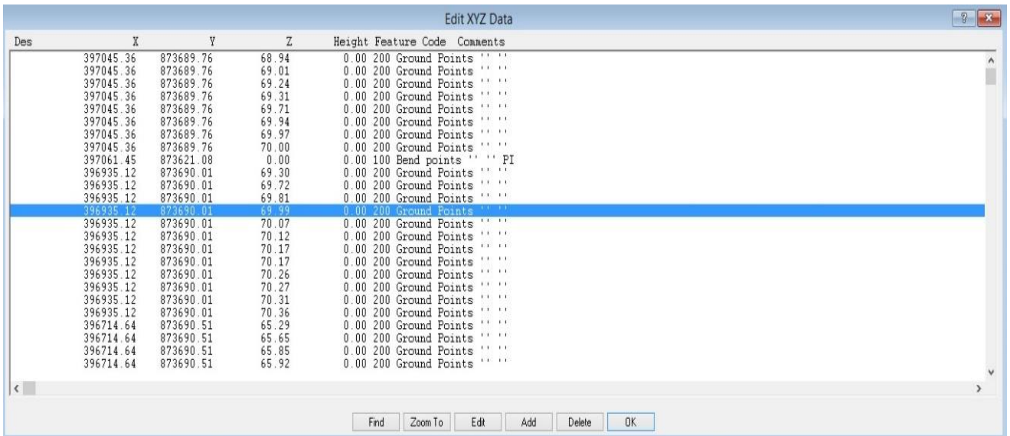
5.1 Survey points

Ground survey has to be carried out at the beginning of the study. As a input PLS CADD needs survey points with following details

I. Latitude and longitude of the survey point (x, y)
II. Elevation of the survey point (z)
III. Height of the obstacle (h)
IV. Feature code of the survey point

Coordinates shall be converted to UTM (Universal Transverse Mercator) if the coordinates are in another format before input to the PLS CADD software. It is always preferred to have maximum amount of coordinates to develop profile of the line. If the actual survey data is not available, Google earth can be used to get the points. Since the points from google earth is in degrees, the coordinate conversion is done using ARCGIS software.

An example of survey points in PLS CADD is shown in figure 5.1. All the coordinates are in meters.

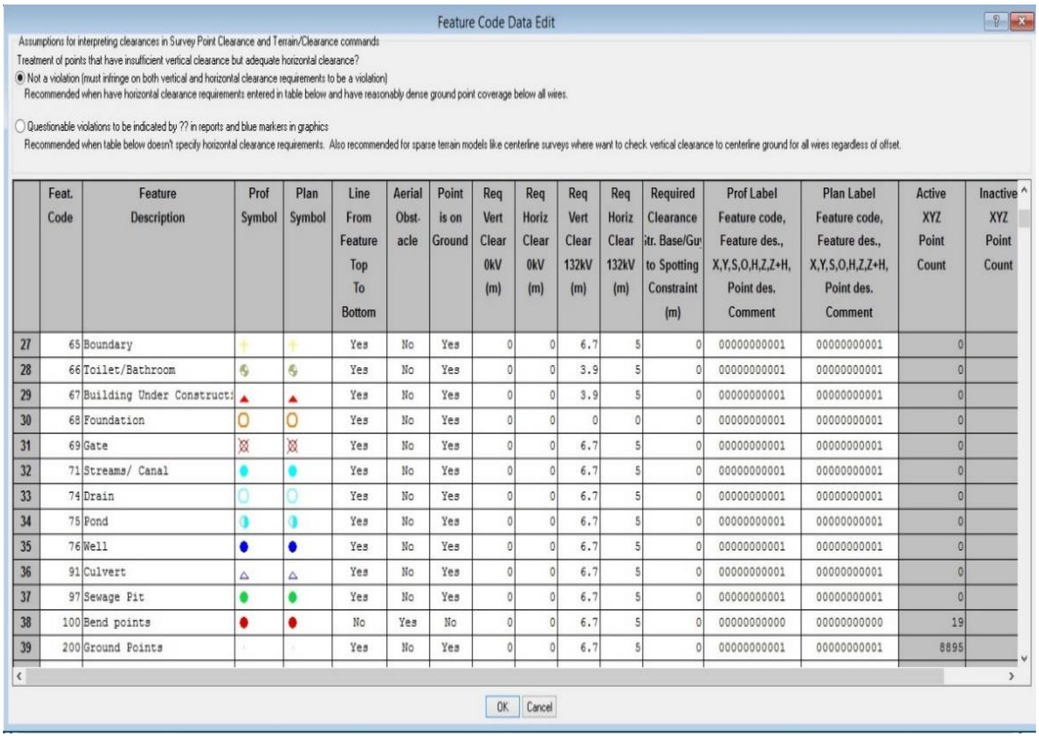


Des	X	Y	Z	Height	Feature Code	Comments
	397045.36	873689.76	68.94	0.00	200 Ground Points	'' ''
	397045.36	873689.76	69.01	0.00	200 Ground Points	'' ''
	397045.36	873689.76	69.24	0.00	200 Ground Points	'' ''
	397045.36	873689.76	69.31	0.00	200 Ground Points	'' ''
	397045.36	873689.76	69.71	0.00	200 Ground Points	'' ''
	397045.36	873689.76	69.94	0.00	200 Ground Points	'' ''
	397045.36	873689.76	69.97	0.00	200 Ground Points	'' ''
	397045.36	873689.76	70.00	0.00	200 Ground Points	'' ''
	397061.45	873621.08	0.00	0.00	100 Bend points	'' '' PI
	396935.12	873690.01	69.30	0.00	200 Ground Points	'' ''
	396935.12	873690.01	69.72	0.00	200 Ground Points	'' ''
	396935.12	873690.01	69.81	0.00	200 Ground Points	'' ''
	396935.12	873690.01	69.99	0.00	200 Ground Points	'' ''
	396935.12	873690.01	70.07	0.00	200 Ground Points	'' ''
	396935.12	873690.01	70.12	0.00	200 Ground Points	'' ''
	396935.12	873690.01	70.17	0.00	200 Ground Points	'' ''
	396935.12	873690.01	70.17	0.00	200 Ground Points	'' ''
	396935.12	873690.01	70.26	0.00	200 Ground Points	'' ''
	396935.12	873690.01	70.27	0.00	200 Ground Points	'' ''
	396935.12	873690.01	70.31	0.00	200 Ground Points	'' ''
	396935.12	873690.01	70.36	0.00	200 Ground Points	'' ''
	396714.64	873690.51	65.29	0.00	200 Ground Points	'' ''
	396714.64	873690.51	65.65	0.00	200 Ground Points	'' ''
	396714.64	873690.51	65.85	0.00	200 Ground Points	'' ''
	396714.64	873690.51	65.92	0.00	200 Ground Points	'' ''

Figure 5.1 – Survey points in PLSCADD software

5.2 Feature codes

Feature codes are used to define survey points. It defines type of obstacle, power line voltage, terrain type and required vertical and horizontal electrical clearances. As per the CEB specification there are more than hundred feature codes available. An example of feature code window in PLS CADD is shown in figure 5.2.



Feature Code Data Edit

Assumptions for interpreting clearances in Survey Point Clearance and Terrain/Clearance commands

Treatment of points that have insufficient vertical clearance but adequate horizontal clearance?

(●) Not a violation (must infringe on both vertical and horizontal clearance requirements to be a violation)
Recommended when have horizontal clearance requirements entered in table below and have reasonably dense ground point coverage below all wires.

( ) Questionable violations to be indicated by ?? in reports and blue markers in graphics
Recommended when table below doesn't specify horizontal clearance requirements. Also recommended for sparse terrain models like centerline surveys where want to check vertical clearance to centerline ground for all wires regardless of offset.

	Feat. Code	Feature Description	Prof Symbol	Plan Symbol	Line From Feature Top To Bottom	Aerial Obst-acle	Point is on Ground	Req Vert Clear 0kV (m)	Req Horiz Clear 0kV (m)	Req Vert Clear 132kV (m)	Req Horiz Clear 132kV (m)	Required Clearance Str. Base/Guy to Spotting Constraint (m)	Prof Label Feature code, Feature des., X,Y,S,O,H,Z,Z+H, Point des. Comment	Plan Label Feature code, Feature des., X,Y,S,O,H,Z,Z+H, Point des. Comment	Active XYZ Point Count	Inactive XYZ Point Count
27	65	Boundary			Yes	No	Yes	0	0	6.7	5	0	00000000001	00000000001	0	
28	66	Toilet/Bathroom			Yes	No	Yes	0	0	3.9	5	0	00000000001	00000000001	0	
29	67	Building Under Construct:			Yes	No	Yes	0	0	3.9	5	0	00000000001	00000000001	0	
30	68	Foundation			Yes	No	Yes	0	0	0	0	0	00000000001	00000000001	0	
31	69	Gate			Yes	No	Yes	0	0	6.7	5	0	00000000001	00000000001	0	
32	71	Streams/ Canal			Yes	No	Yes	0	0	6.7	5	0	00000000001	00000000001	0	
33	74	Drain			Yes	No	Yes	0	0	6.7	5	0	00000000001	00000000001	0	
34	75	Pond			Yes	No	Yes	0	0	6.7	5	0	00000000001	00000000001	0	
35	76	Well			Yes	No	Yes	0	0	6.7	5	0	00000000001	00000000001	0	
36	91	Culvert			Yes	No	Yes	0	0	6.7	5	0	00000000001	00000000001	0	
37	97	Sewage Pit			Yes	No	Yes	0	0	6.7	5	0	00000000001	00000000001	0	
38	100	Bend points			No	Yes	No	0	0	6.7	5	0	00000000000	00000000000	19	
39	200	Ground Points			Yes	No	Yes	0	0	6.7	5	0	00000000001	00000000001	8895	

OK Cancel

Figure 5.2 – Feature code in PLSCADD software

5.3 Criteria files

Criteria files has to be designed as per the CEB specification. Figure 5.3 shows an example of criteria file in PLS CADD.

Weather Cases

See Criteria/Code Specific Wind and Terrain Parameters for more information on height adjustments and gust response factors.

	Description	Air Density Factor (Q) (kg/m^3) (Pa/(m/s)^2)	Wind Velocity (m/s)	Wind Pressure (Pa)	Wire Ice Thickness (cm)	Wire Ice Density (N/m^3)	Wire Ice Load (N/m)	Wire Temp. (deg C)	Ambient Temp. (deg C)	Weather Load Factor	NESC Constant (N/m)	Wire Wind Height Adjust Model	Wire Gust Response Factor
1	Hot	0.613		0	0	0	0	75.0	32.0	1	0	None	1
2	cold	0.613		0	0	0	0	7.0	7.0	1	0	None	1
3	EDS	0.613		0	0	0	0	32.0	32.0	1	0	None	1
4	EDS + mod Wind	0.613	28.5598	500	0	0	0	32.0	32.0	1	0	None	1
5	cold + wind	0.613	39.7792	970	0	0	0	7.0	7.0	1	0	None	1
6	76°C	0.613		0	0	0	0	76.0	32.0	1	0	None	1
7	77°C	0.613		0	0	0	0	77.0	32.0	1	0	None	1
8	78°C	0.613		0	0	0	0	78.0	32.0	1	0	None	1
9	79°C	0.613		0	0	0	0	79.0	32.0	1	0	None	1
10	80°C	0.613		0	0	0	0	80.0	32.0	1	0	None	1
11													
12													
13													
14													
15													
16													
17													
18													
19													

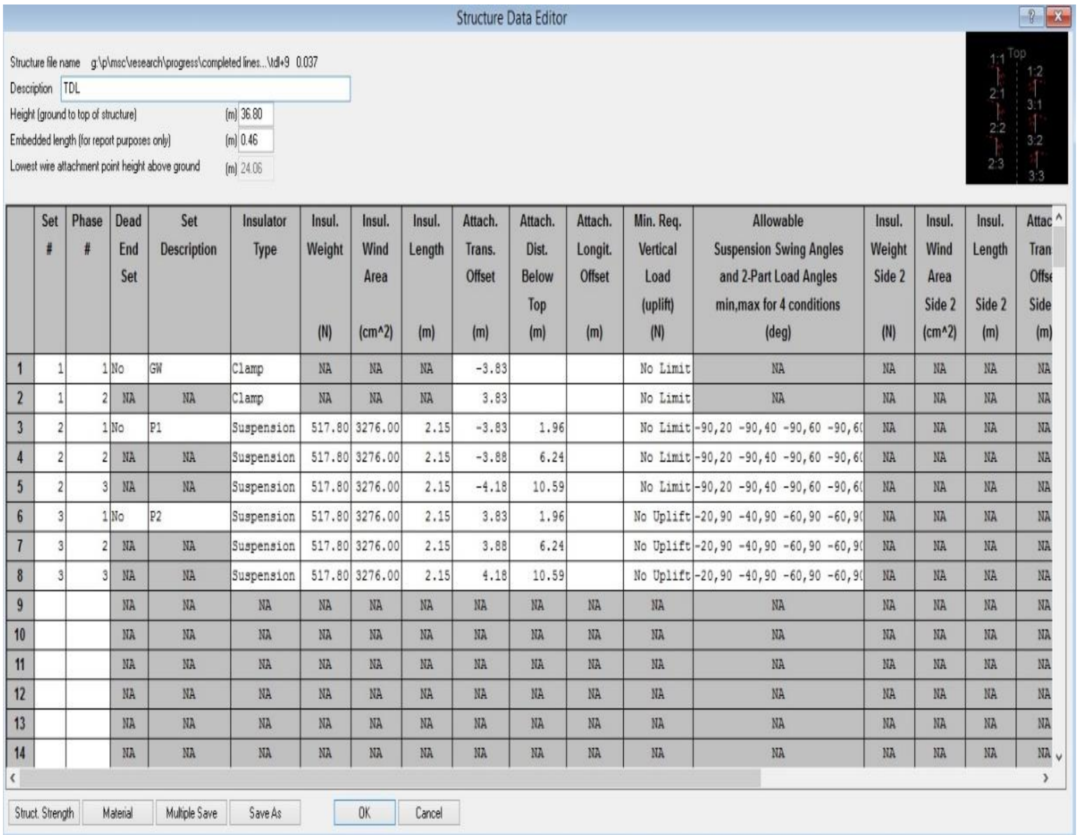
Web site: Wind & ice loading tech. note   OK   Cancel

Figure 5.3 – weather criteria in PLSCADD software

5.4 Structure file

There are 5 types of towers in CEB transmission network as per the technical specification of CEB. Each type of tower has body extensions from -3 m to +18 m with 3 m gap in-between (-3, 0, +3, +6, etc.). Every tower has to be defined in structure files. Method 1 and method 4 are two ways to define the structure in PLS CADD. Method 1 structure files are simple stick figures while method 4 files are accurate models generated either in PLS POLE or PLS TOWER. Method 1 towers have been used for this research since it is adequate to check the clearance of the line.

Method 1 structure files contain insulator details, conductor attachment points, allowable swing angles, etc. An example of structure data is shown in figure 5.4.


Structure Data Editor

Structure file name g:\p\msc\research\progress\completed lines...\tdl+9 0.037
Description TDL
Height (ground to top of structure) (m) 36.80
Embedded length (for report purposes only) (m) 0.46
Lowest wire attachment point height above ground (m) 24.06

	Set #	Phase #	Dead End Set	Set Description	Insulator Type	Insul. Weight (N)	Insul. Wind Area (cm^2)	Insul. Length (m)	Attach. Trans. Offset (m)	Attach. Dist. Below Top (m)	Attach. Longit. Offset (m)	Min. Req. Vertical Load (uplift) (N)	Allowable Suspension Swing Angles and 2-Part Load Angles min,max for 4 conditions (deg)	Insul. Weight Side 2 (N)	Insul. Wind Area Side 2 (cm^2)	Insul. Length Side 2 (m)	Attac Tran Offs Side (m)
1	1	1	No	GW	Clamp	NA	NA	NA	-3.83			No Limit	NA	NA	NA	NA	NA
2	1	2	NA	NA	Clamp	NA	NA	NA	3.83			No Limit	NA	NA	NA	NA	NA
3	2	1	No	P1	Suspension	517.80	3276.00	2.15	-3.83	1.96		No Limit	-90,20 -90,40 -90,60 -90,6	NA	NA	NA	NA
4	2	2	NA	NA	Suspension	517.80	3276.00	2.15	-3.88	6.24		No Limit	-90,20 -90,40 -90,60 -90,6	NA	NA	NA	NA
5	2	3	NA	NA	Suspension	517.80	3276.00	2.15	-4.18	10.59		No Limit	-90,20 -90,40 -90,60 -90,6	NA	NA	NA	NA
6	3	1	No	P2	Suspension	517.80	3276.00	2.15	3.83	1.96		No Uplift	-20,90 -40,90 -60,90 -60,9	NA	NA	NA	NA
7	3	2	NA	NA	Suspension	517.80	3276.00	2.15	3.88	6.24		No Uplift	-20,90 -40,90 -60,90 -60,9	NA	NA	NA	NA
8	3	3	NA	NA	Suspension	517.80	3276.00	2.15	4.18	10.59		No Uplift	-20,90 -40,90 -60,90 -60,9	NA	NA	NA	NA
9			NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
10			NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
11			NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
12			NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
13			NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
14			NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Struct. Strength | Material | Multiple Save | Save As | OK | Cancel

Figure 5.4 – Structure data in PLSCADD software

5.5 Conductor Data

Properties of conductor has been entered in PLS CADD cable data window. The cross section area, Ultimate tensile strength, Unit weight, etc. have been entered. The sample of an ACSR Zebra conductor data has shown in figure 5.5.

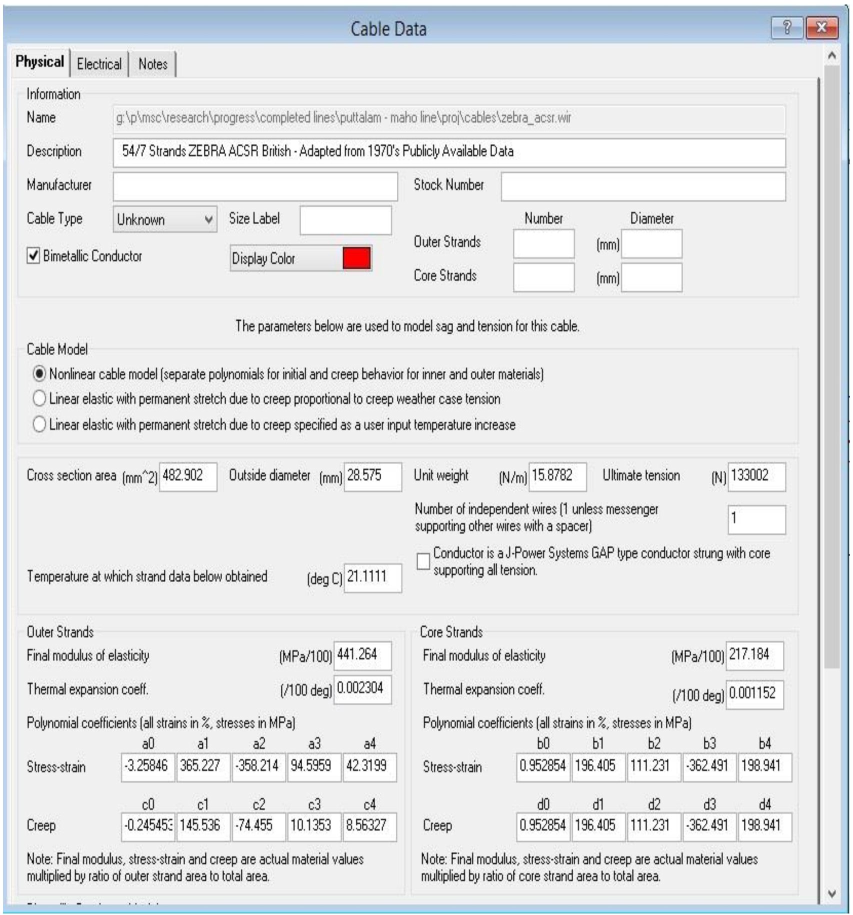
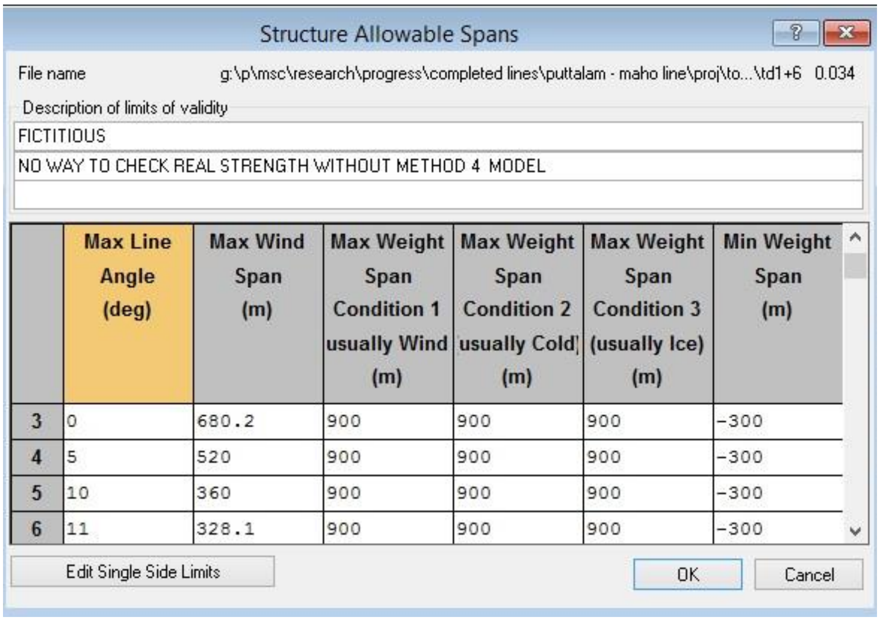


Figure 5.5 – Conductor data in PLSCADD software

5.6 Wind span and weight span limits

Wind span and weight span limits shall be as per the technical specification of CEB. Each type of tower has different wind and weight span limits. An example of wind and weight span limits of TD1 tension tower with angle compensation are as shown in figure 5.6.



	Max Line Angle (deg)	Max Wind Span (m)	Max Weight Span Condition 1 usually Wind (m)	Max Weight Span Condition 2 usually Cold] (m)	Max Weight Span Condition 3 (usually Ice) (m)	Min Weight Span (m)
3	0	680.2	900	900	900	-300
4	5	520	900	900	900	-300
5	10	360	900	900	900	-300
6	11	328.1	900	900	900	-300

Figure 5.6 – Allowable wind span and weight span of TD1 tower in PLSCADD software

5.7 Tower Spotting

After creating the profile, the tower spotting can be carried out.

5.8 Stringing

Stringing has been done using section modify window in PLSCADD for maximum conductor temperature with creep. An example of a section modification is shown figure 5.7.

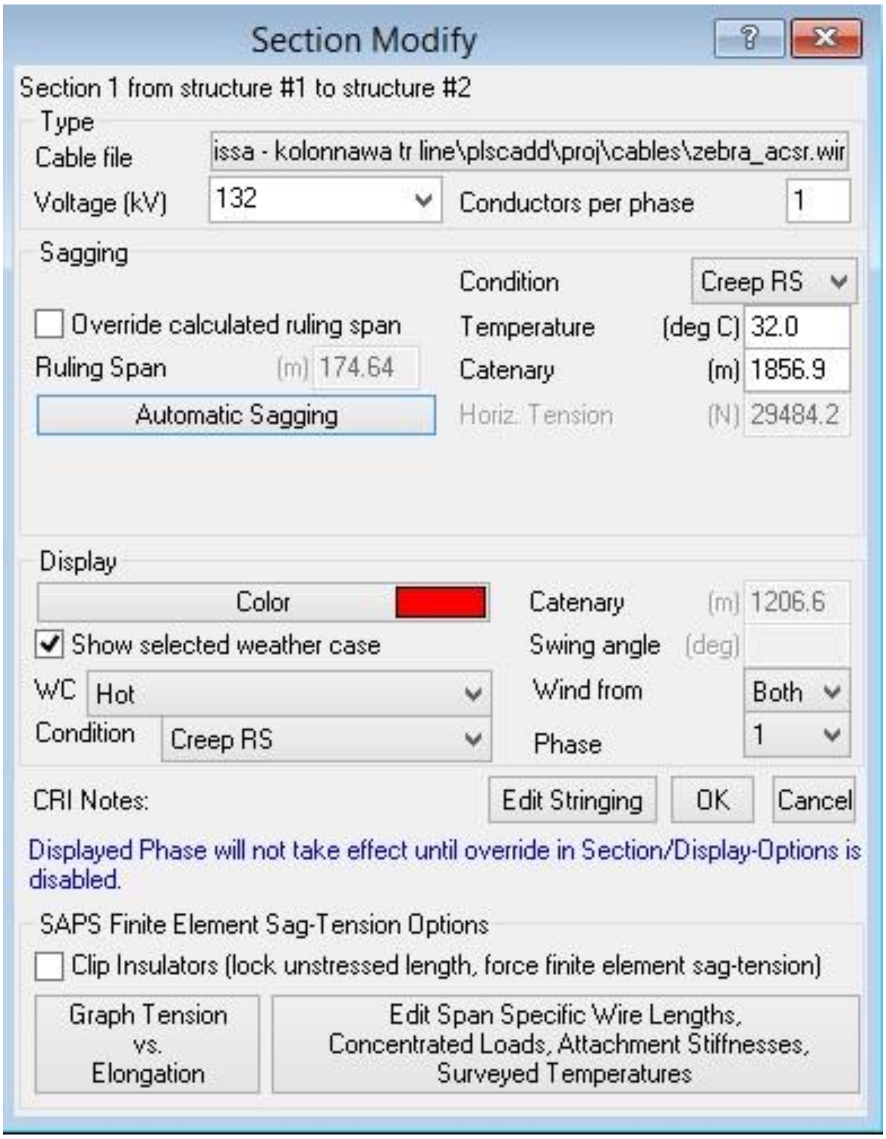


Figure 5.7 – Section modify in PLSCADD Software

5.9 Final design of PLS CADD

Final output of PLSCADD design of a line section is shown in figure 5.8.

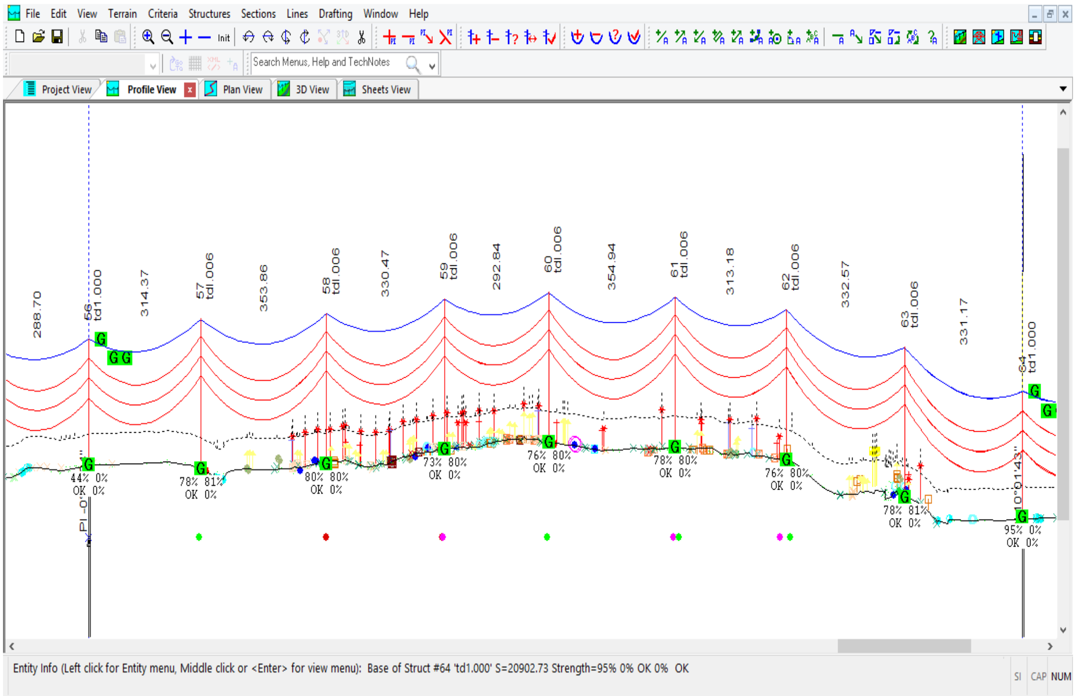


Figure 5.8 – Profile view of Bolawatta-New Chilaw line in PLSCADD Software

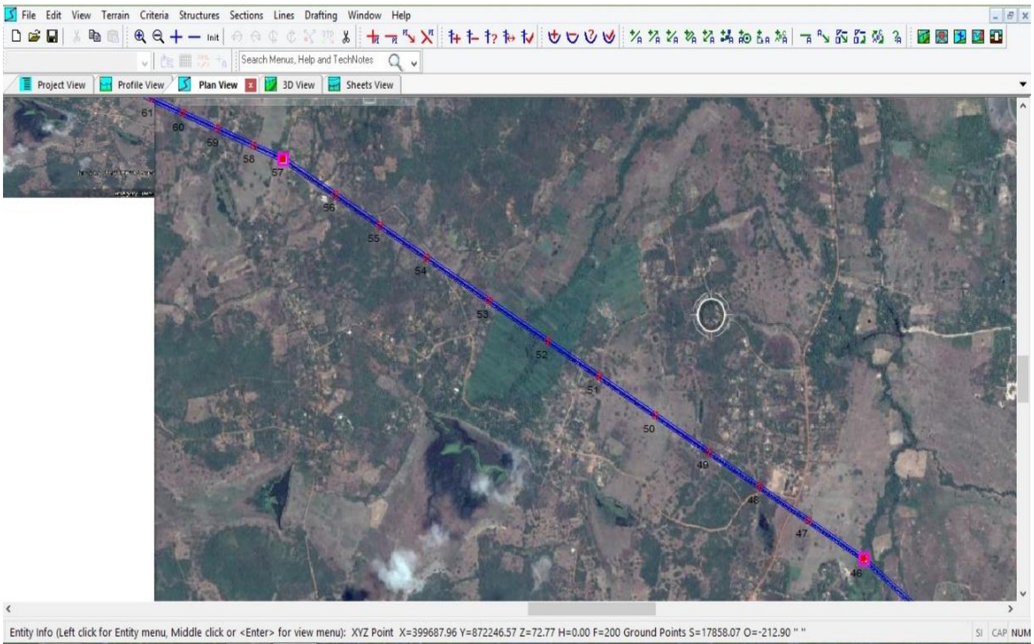


Figure 5.9 – Plan view of Puttalam-Maho line in PLSCADD Software

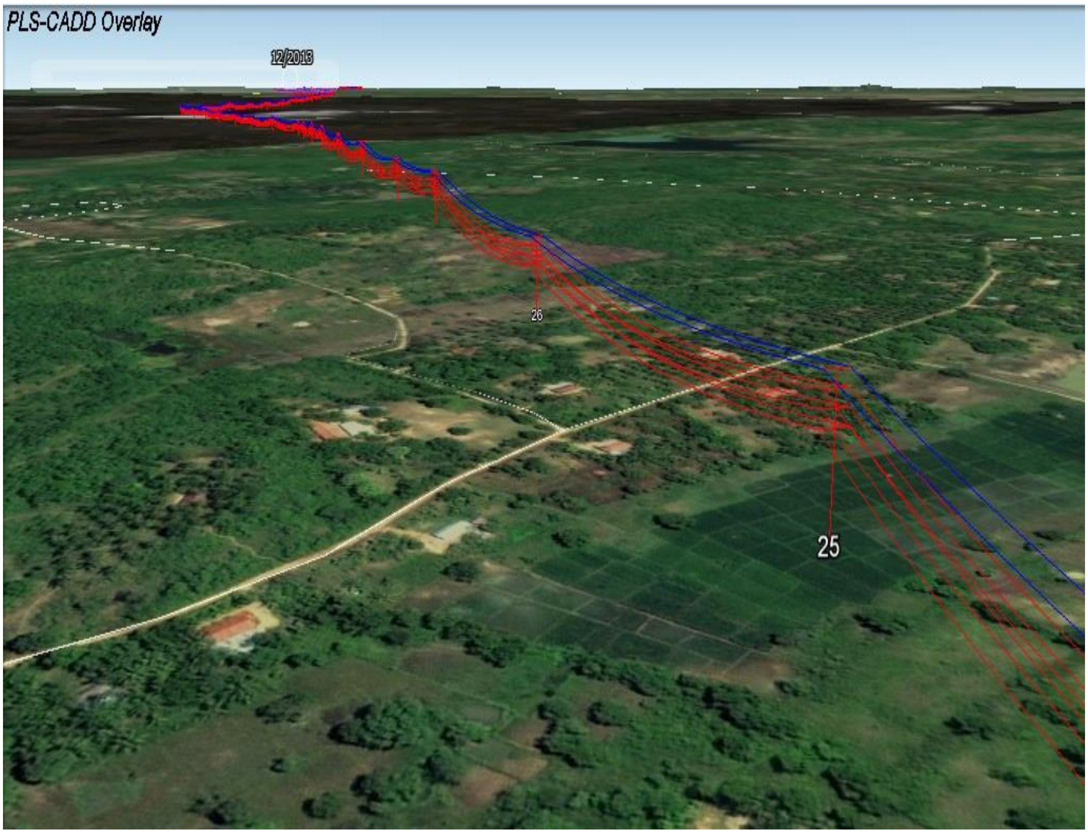


Figure 5.10 – 3D view of Bolawatta-New Chilaw line in PLSCADD Software

5.10 Identify critical span of the selected sections

Critical span of a section can be identified. When sag of a line touches or close to the electrical clearance line that will be the critical span for the section. Likewise, every section has been analysed in PLSCADD.

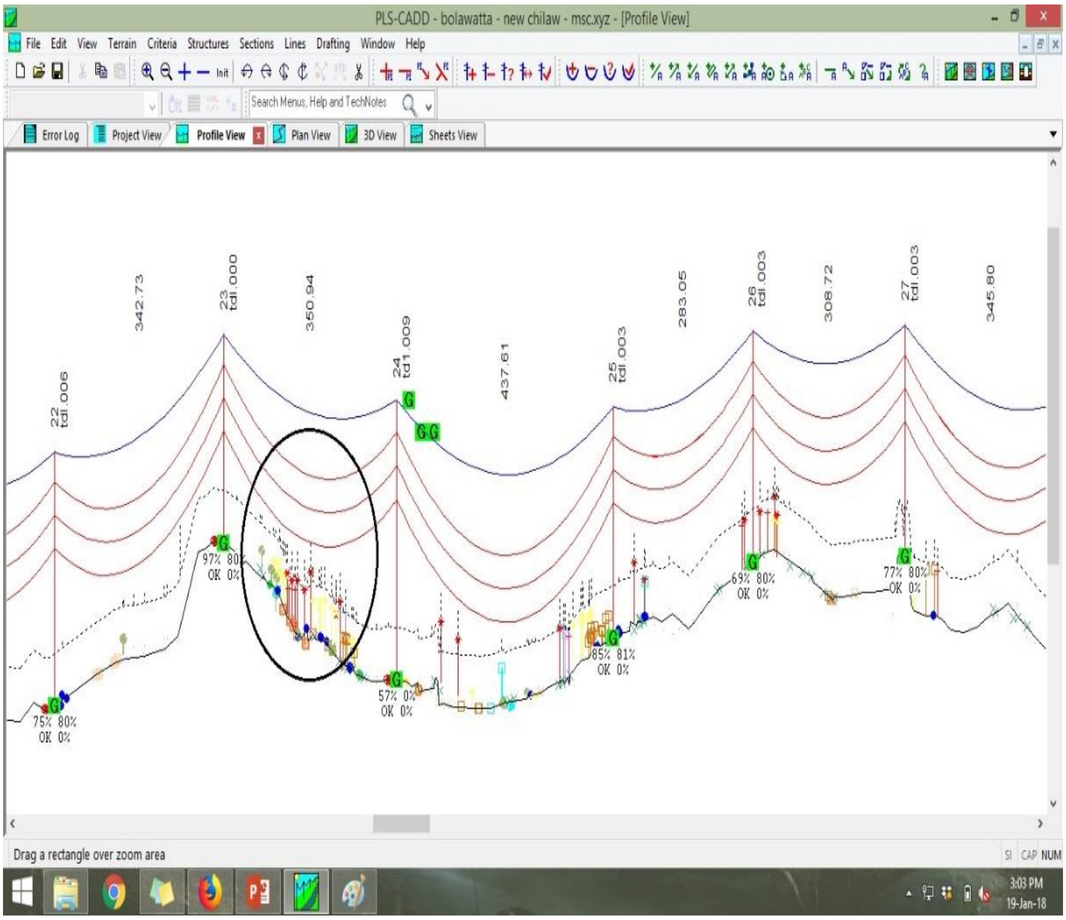


Figure 5.11 – Identify the critical span in PLSCADD software

5.11 Increase the conductor temperature without violating electrical clearance

The conductor temperature has been increased without violating electrical clearances up to 80°C. The safest conductor temperature has been recorded.

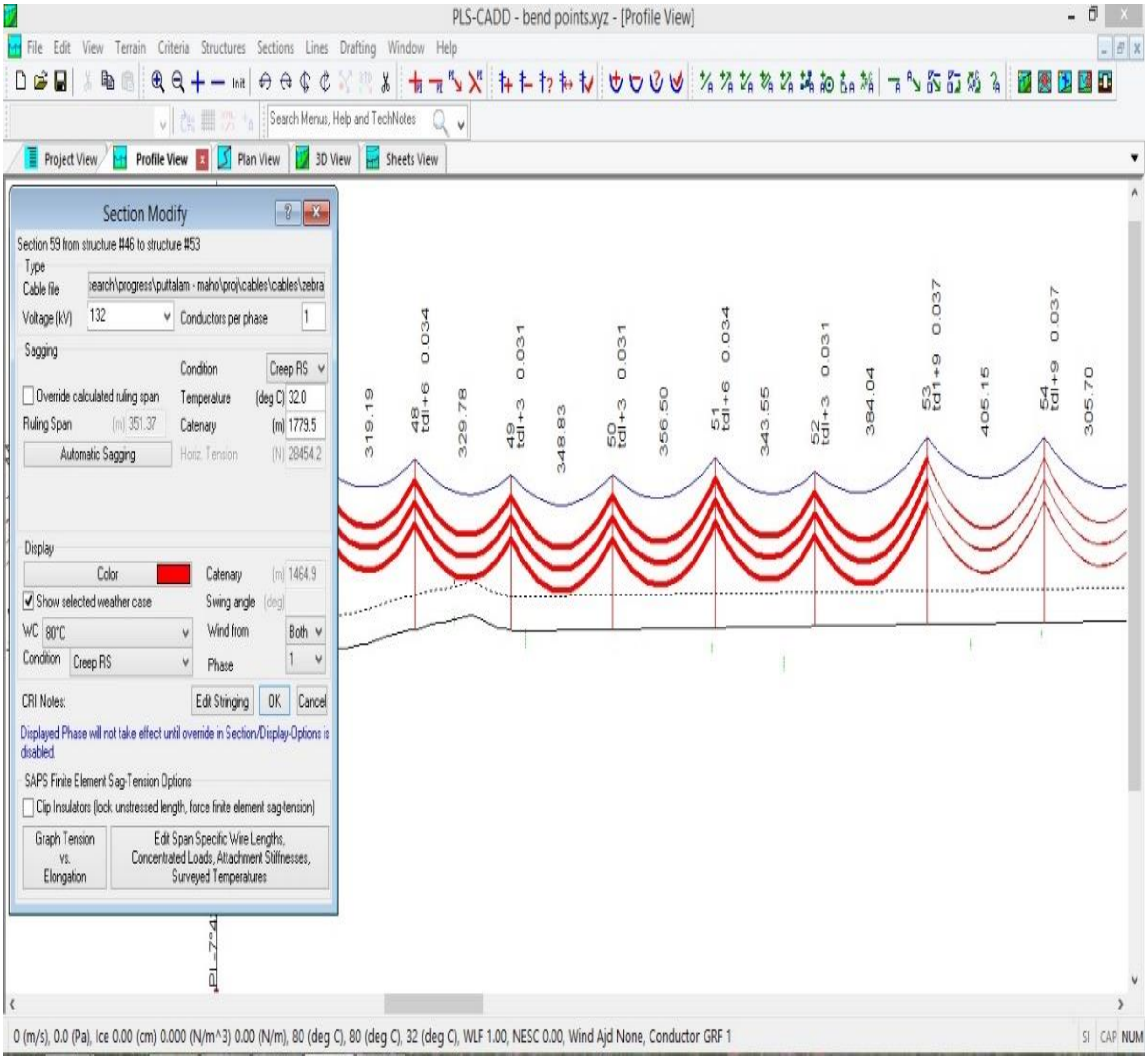


Figure 5.12 – Identify safest conductor temperature in PLSCADD software

CHAPTER 6. SOFTWARE BASED RTTR INTERFACE

Software based RTTR interface has been created including five transmission lines. Likewise, any number of transmission lines can be added to this software model in future. This model can be used to calculate actual CCC using RTTR at a given time.

The software interface has been created using Visual Basic for Application (VBA). There are three windows (User forms) in the model. In the first window transmission line has to be selected, out of five transmission lines. The transmission line data, conductor data and earth wire data will be pop-up after the selecting the line. Figure 6.1 shows an image of the window 1.

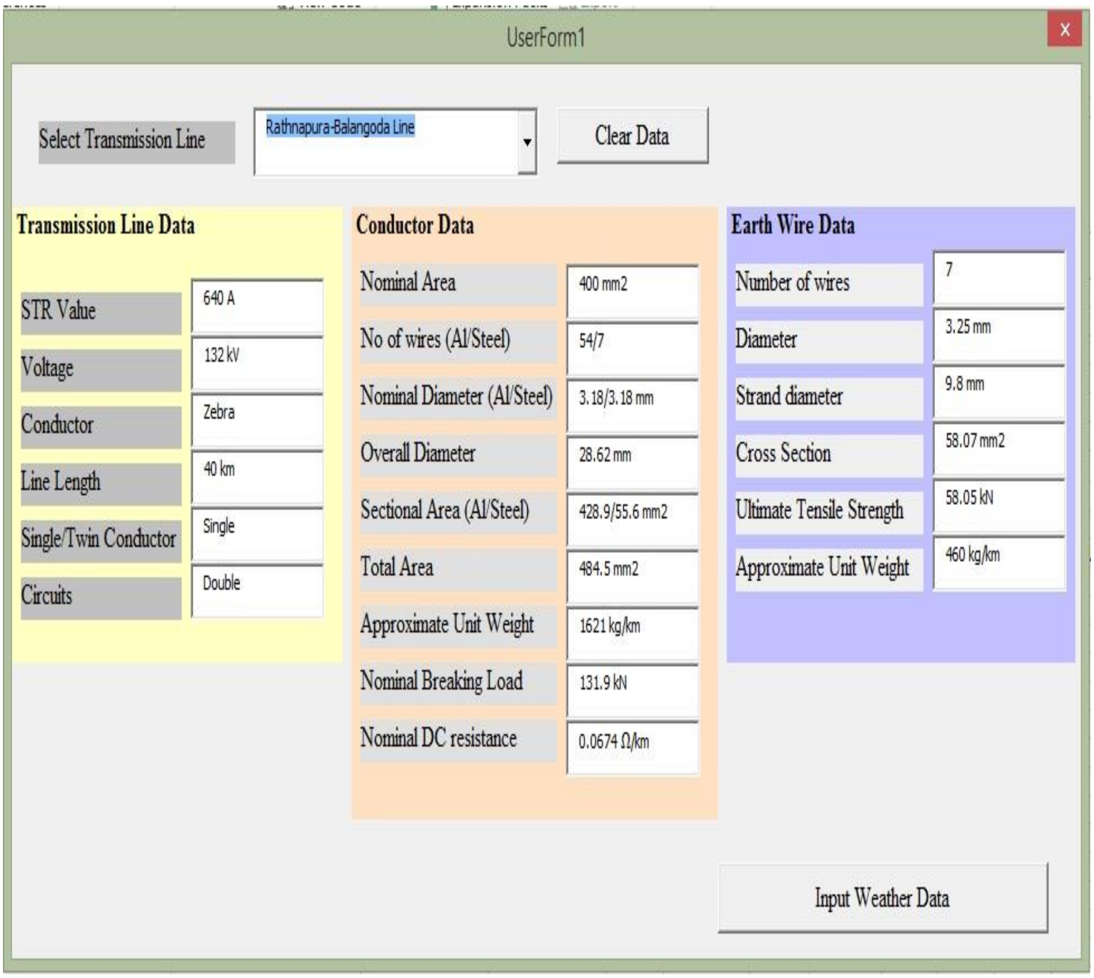


Figure 6.1 – Window 1 of VBA Software

Window 2 will be appearing by clicking the button "Input weather data". Then the weather stations for the selected line sections will be appear. Ambient temperature and wind speed have to be included for those weather stations.

Date and the time have to be included to calculate solar intensity. Then the CCC of those sections can be calculated by clicking "Calculate CCC for the sections". Figure 6.2 shows the User form 2 of the VBA interface.

Figure 6.2 - Window 1 of VBA Software

Here in this window the weather stations for particular line sections will be appeared as shown in the picture. Ambient temperature, wind speed of those weather station have to be included in the given boxes. The date and time of the weather data collected has to be included in specified boxes. After entered the date and time solar intensity will be calculated. When clicking "Calculate CCC for the sections" the CCC for all sections will be displayed in the boxes. Finally, to calculate CCC of the entire selected line, "Calculate CCC for entire line" has to be clicked. After clicking that the third window will be appear. The image of window 3 is shown in figure 6.3.

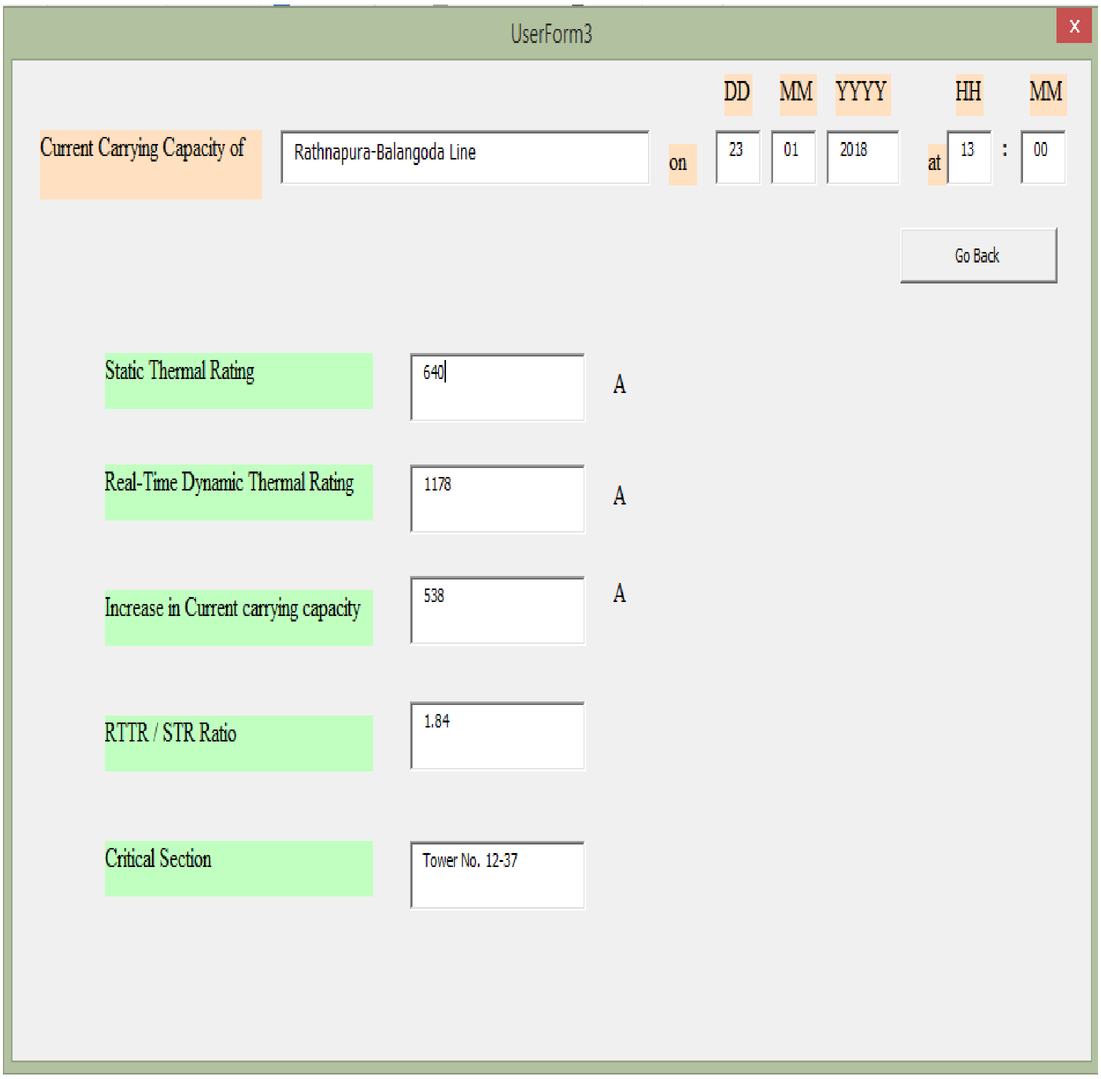


Figure 6.3 - Window 3 of VBA Software

This window shows the results of the study. STR value, RTTR value, increase in CCC, the ratio of RTTR/STR and critical section of the line at that particular time. This can be used in real time applications, if the ambient temperature and wind speed are given.

CHAPTER 7. OBSERVATIONS AND RESULTS

CCC for the five selected transmission lines have been calculated as case study for a random day and results are shown in figure 7.1. Here the RTTR values and STR values have been plotted in the same graph to compare the differences.

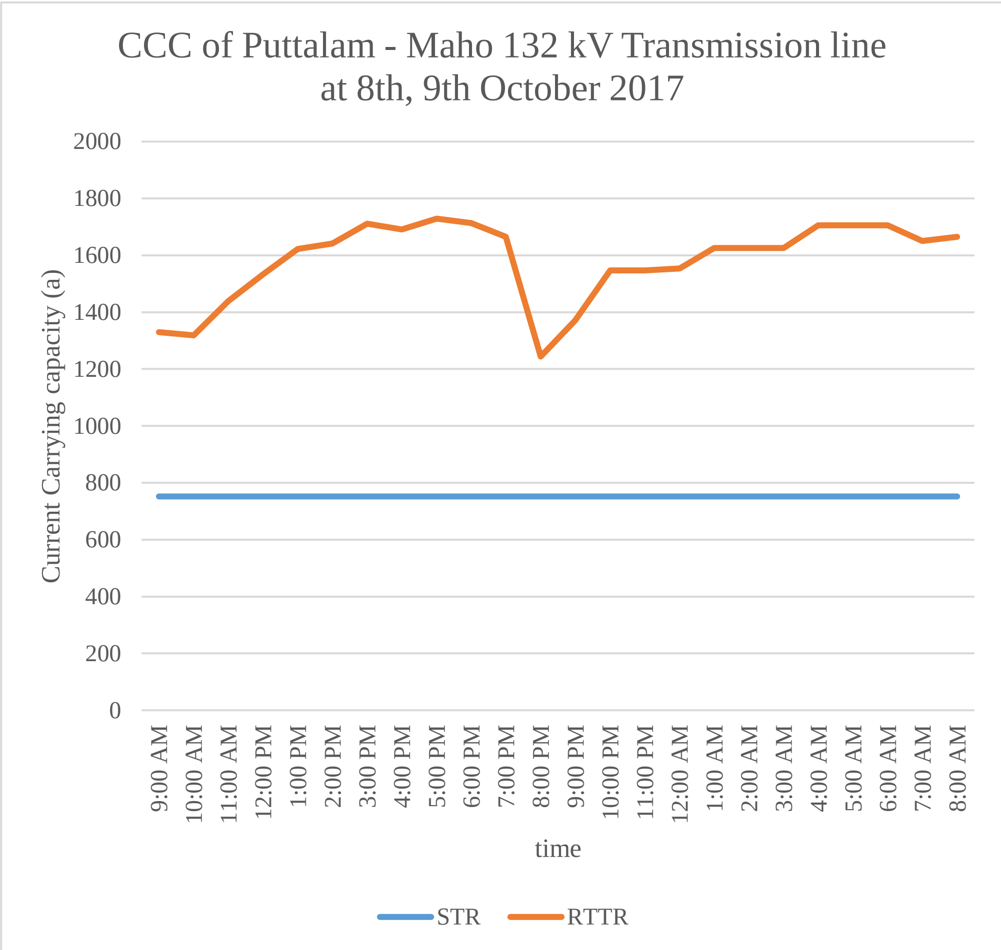


Figure 7.1 – RTTR Vs STR of Puttalam-Maho line

The difference between RTTR and STR values of Puttalam – Maho 132 kV transmission line was calculated. As per the results the minimum ampacity difference is 492 A and maximum difference is 977 A. The minimum ratio in-between RTTR and STR is 1.65 and maximum ratio is 2.29. The lowest CCC is observed at 8.00 pm because of the lowest wind speed value of 0.447 m/s at Ambanpola weather station. These calculations are done based on the weather parameters taken at 9.00 AM of 8th of October, 2017 to 8.00 AM of 9th of October, 2017.

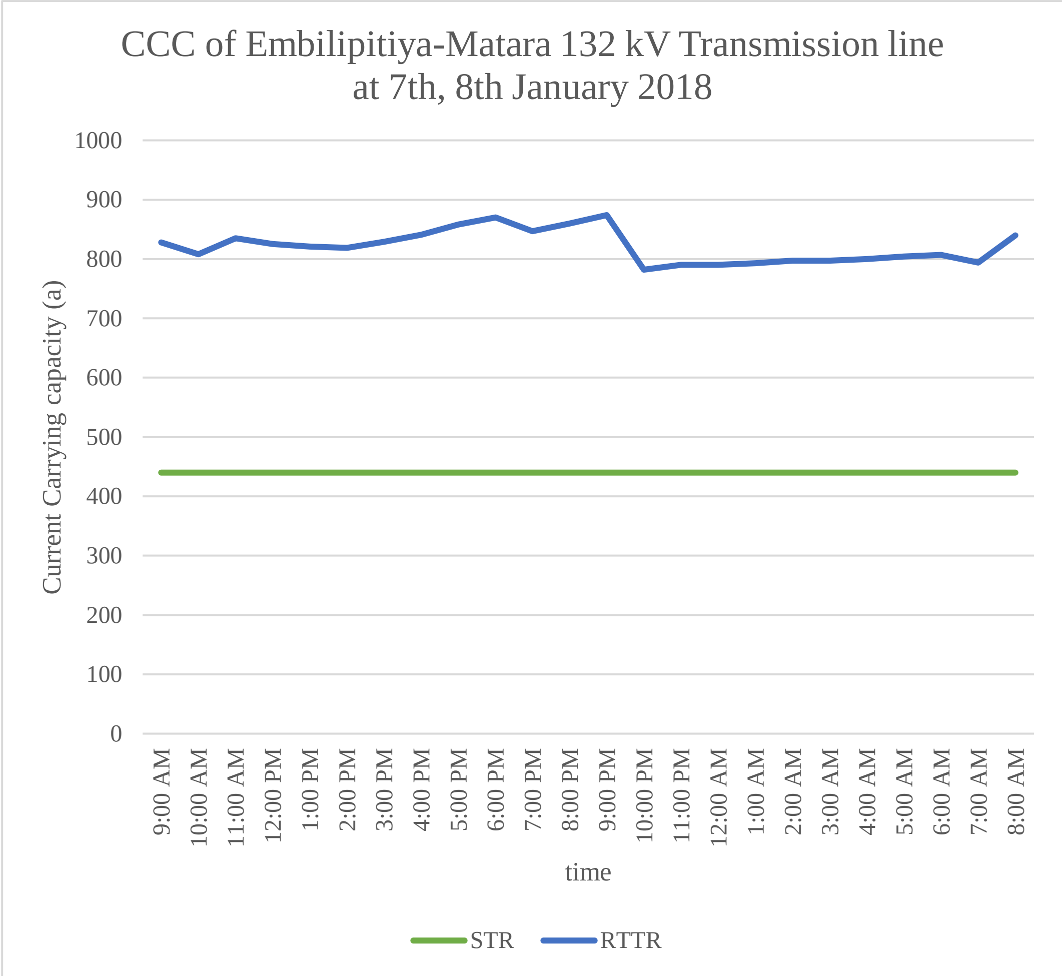


Figure 7.2 – RTTR Vs STR of Embilipitiya-Matara line

The difference between RTTR and STR values of Embilipitiya - Matara 132 kV transmission line was calculated. As per the results the minimum ampacity difference is 342 A and maximum difference is 434 A. The minimum ratio in-between RTTR and STR is 1.77 and maximum ratio is 1.98. These calculations are done based on the weather parameters taken at 9.00 AM of 7th of January, 2018 to 8.00 AM of 8th of January, 2018.

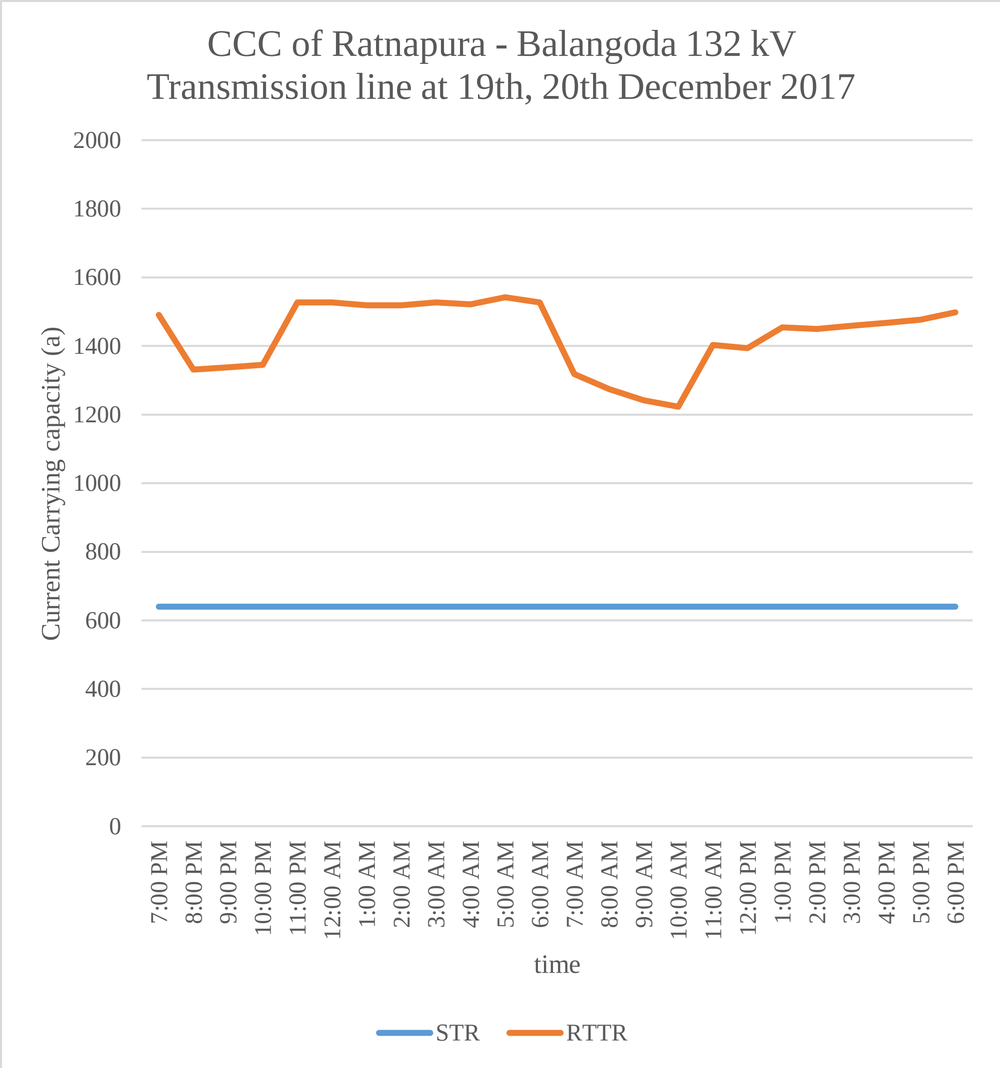


Figure 7.3 – RTTR Vs STR of Ratnapura-Balangoda line

The difference between RTTR and STR values of Ratnapura - Balangoda 132 kV transmission line was calculated. As per the results the minimum ampacity difference is 583 A and maximum difference is 902 A. The minimum ratio in-between RTTR and STR is 1.91 and maximum ratio is 2.40. The lowest CCC is observed at 10.00 am because of the lowest wind speed value of 0.89 m/s and high solar intensity value of 1016 W/m^2 is observed at Ratnapura weather station. These calculations are done based on the weather parameters taken at 7.00 PM of 19th of December, 2017 to 6.00 PM of 20th of December, 2017.

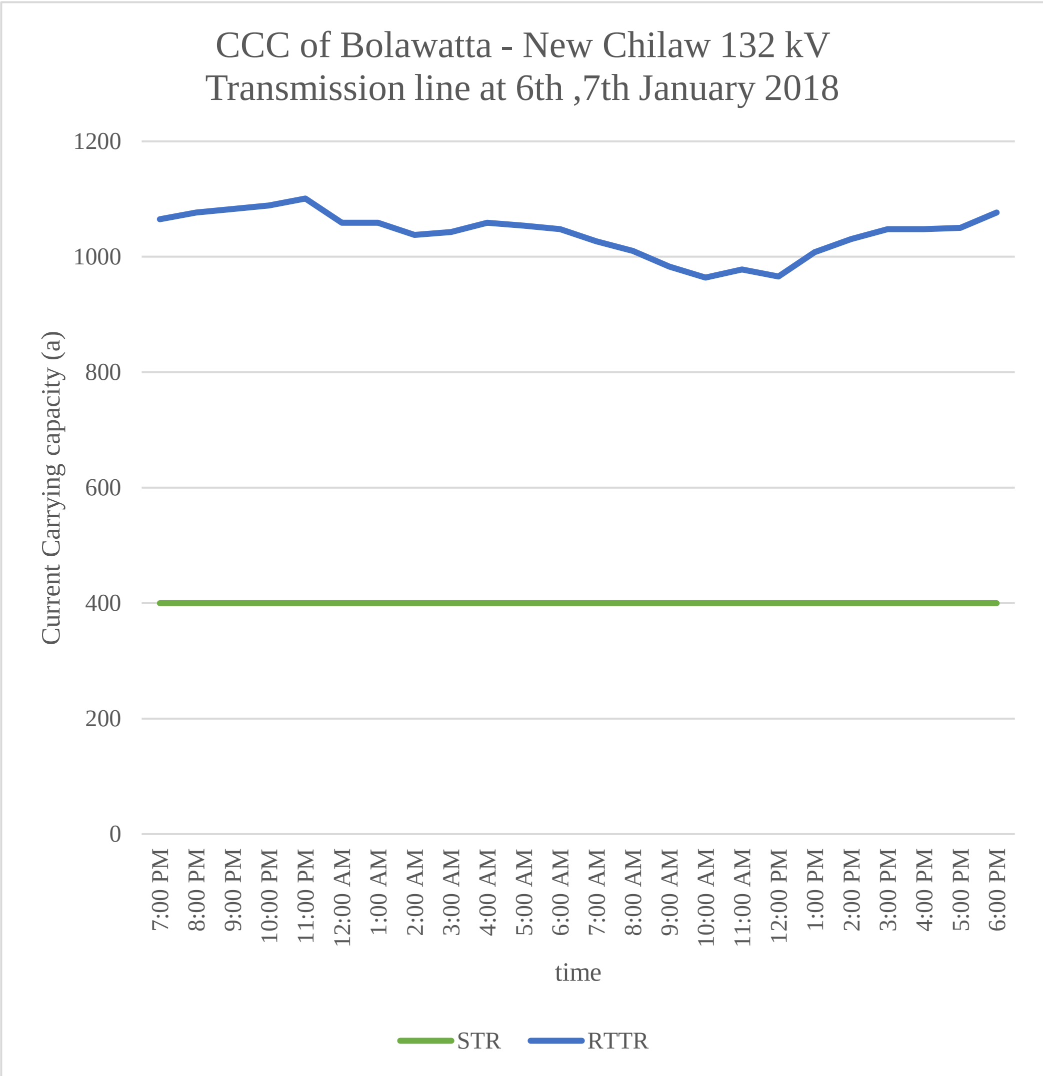


Figure 7.4 – RTTR Vs STR of Bolawatte-New Chilaw line

The difference between RTTR and STR values of Bolawatta – New Chilaw 132 kV transmission line was calculated. As per the results the minimum ampacity difference is 564 A and maximum difference is 701 A. The minimum ratio in-between RTTR and STR is 2.41 and maximum ratio is 2.75. These calculations are done based on the weather parameters taken at 7.00 PM of 6th of January, 2018 to 6.00 PM of 7th of January, 2018.

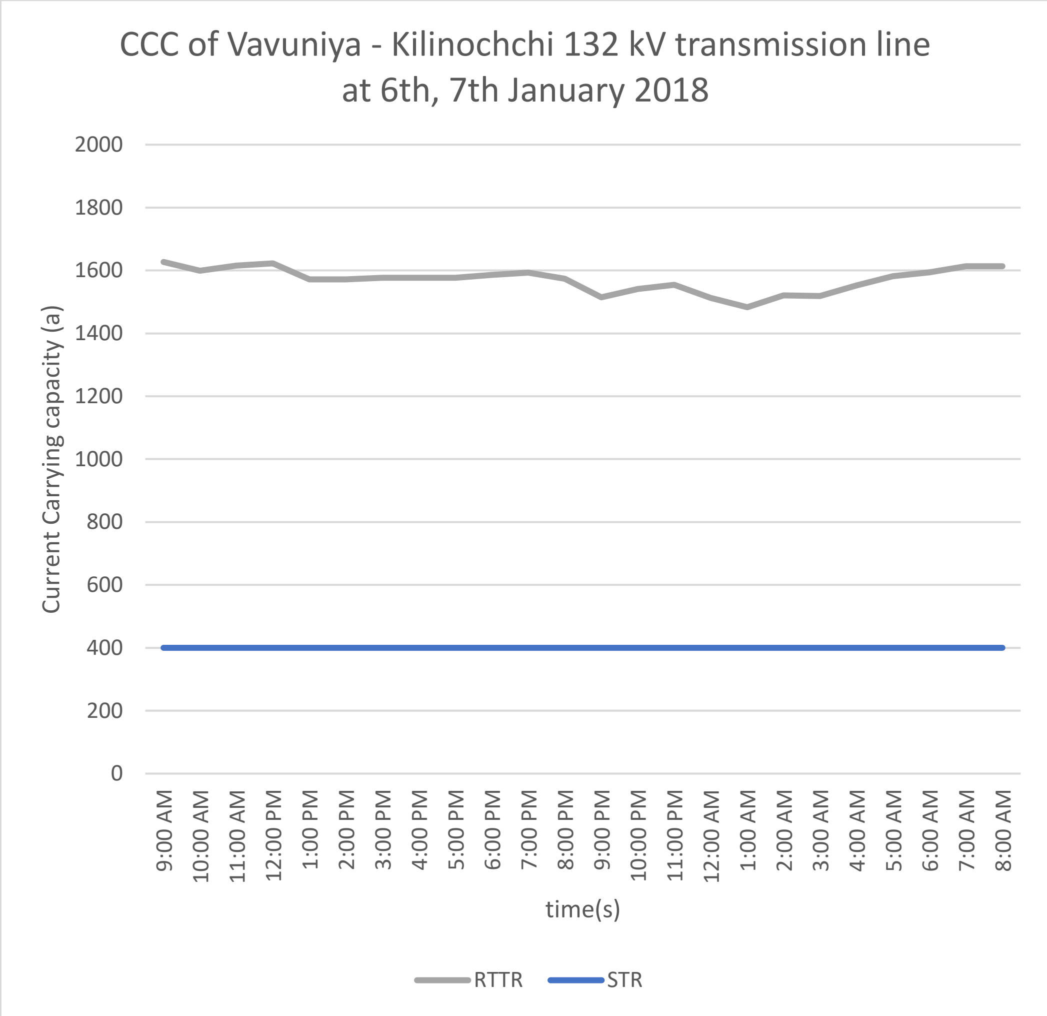


Figure 7.5 – RTTR Vs STR of Vavuniya-Kilinochchi line

The difference between RTTR and STR values of Vavuniya – Kilinochchi 132 kV transmission line was calculated. As per the results the minimum ampacity difference is 1083 A and maximum difference is 1227 A. The minimum ratio in-between RTTR and STR is 3.7 and maximum ratio is 4.06. These calculations are done based on the weather parameters taken at 9.00 AM of 6th of January, 2018 to 8.00 PM of 7th of January, 2018.

Bolawatta-New Chilaw line is in initial stage of re-construction using Zebra conductor while the existing Lynx conductor line is capable of handling more than the STR value of Zebra conductor. Similarly, Embilipitiya-Matara line gets overloaded frequently (ACE Embilipitiya power plant – 100 MW) without taking the advantage of RTTR method.

CHAPTER 8. CONCLUSION

As per the outcomes of this study, the following conclusions were made regarding the usage of RTTR method in transmission network of Sri Lanka.

- RTTR method can increase CCC of a line significantly compared to STR values used for existing transmission lines.
- RTTR method can be applied in an emergency situation until predetermined time span.
- CCC of a given line is highly influenced by wind speed and slightly influenced by wind direction.
- Transmission line construction and uprating can be delayed by permits, funds, social/environmental issues and political influences. In such cases, short-term use of real-time dynamic thermal ratings can be economically and operationally advantageous. Re-conductoring and re-construction of existing lines can be avoided or postponed by adopting RTTR method.
- Wind speeds in transmission corridors have correlation with wind power generation. Real-time ratings can offer the most economical solutions for use of transmission line capacity by using lower rating conductor (smaller diameter).
- If there are generation clusters where in regions connected by lines which have lower capacity than dispatchable combined generation, RTTR method can be used.
- This increases capacity on congested transmission lines and also enables increased power transfers. Most importantly, applying RTTR method reduces the high cost thermal generations which are used only to minimize the transmission constraints as in Sri Lankan system. Using more low-cost power plants would result in a reduced unit price for customers.

Limitations and Future Works

This research was done based on the weather data taken from www.accuweather.com. To increase the reliability of weather data, it is recommended to take the actual weather station data. Also, the system operators should take the extra workload to apply RTTR method to their system.

Since this project has been done to five transmission lines, the entire transmission lines can be taken to the software modelling. The emergency ratings of the lines are not discussed in this research, which the conductor temperature can be increased more than allowable conductor temperature as specified in the standard. Under an emergency situation a line can be loaded for a shorter period.

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APPENDIX A

Solar intensity values from ASHRAE handbook 1981 fundamentals

TIME		January	February	March	April	May	June	July	August	September	October	November	December
AM	1	0	0	0	0	0	0	0	0	0	0	0	0
AM	2	0	0	0	0	0	0	0	0	0	0	0	0
AM	3	0	0	0	0	0	0	0	0	0	0	0	0
AM	4	0	0	0	0	0	0	0	0	0	0	0	0
AM	5	0	0	0	0	0	0	0	0	0	0	0	0
AM	6	0	0	0	0	3	18	27	16	0	0	0	0
AM	7	560	590	642	645	590	560	537	530	540	577	589	566
AM	8	864	876	888	866	800	753	728	725	749	805	843	855
AM	9	968	973	977	949	813	836	811	809	836	894	957	957
AM	10	1016	1020	1018	969	923	878	853	851	878	937	981	1003
AM	11	1038	1041	1037	1008	942	898	874	872	899	957	1001	1025
PM	12	835	1048	1043	1013	948	904	890	878	905	963	908	1032
PM	1	798	831	892	914	882	843	819	828	859	884	873	824
PM	2	692	722	780	806	781	748	726	734	761	780	763	716
PM	3	523	350	602	628	615	592	577	582	599	607	588	545
PM	4	298	320	367	397	398	390	382	383	388	313	358	317
PM	5	71	82	108	133	149	156	157	155	147	129	106	81
PM	6	0	0	0	0	0	0	0	0	0	0	0	0
PM	7	0	0	0	0	0	0	0	0	0	0	0	0
PM	8	0	0	0	0	0	0	0	0	0	0	0	0
PM	9	0	0	0	0	0	0	0	0	0	0	0	0
PM	10	0	0	0	0	0	0	0	0	0	0	0	0
PM	11	0	0	0	0	0	0	0	0	0	0	0	0
AM	12	0	0	0	0	0	0	0	0	0	0	0	0