TECHNO ECONOMIC ANALYSIS ON THE USE OF HTLS CONDUTORS FOR SRI LANKA'S TRANSMISSION SYSTEM

Hewa Buhege Dayan Yasaranga

(118696J)

Degree of Master of Science

Department of Electrical Engineering

University of Moratuwa
Sri Lanka

May 2015

TECHNO ECONOMIC ANALYSIS ON THE USE OF HTLS CONDUTORS FOR SRI LANKA'S TRANSMISSION SYSTEM

Hewa Buhege Dayan Yasaranga

(118696J)

Dissertation submitted in partial fulfillment of the requirement for the Degree of Master of Science

Department of Electrical Engineering

University of Moratuwa
Sri Lanka

May 2015

DECLARATION

I declare that this is my own work and this dissertation does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and 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.

Also, I hereby grant to University of Moratuwa the non-exclusive right to reproduce and distribute my dissertation, in whole or in part in print, electronic or other medium. I retain the right to use this content in whole or part in future works (such as articles or books).

Signature: ________________________________ Date:______________

H.B.D. Yasaranga

The above candidate has carried out research for the Masters Dissertation under our supervision.

Signatures of the supervisors:

__________________________ Date:______________

Eng. W.D.A.S. Wijayapala

__________________________ Date:______________

Dr. K.T.M.U. Hemapala

ACKNOWLEDGEMENT

This dissertation is prepared as a result of the support and guidance provided by various personnel and parties.

First of all, I should be thankful to the supervisors of the research study, Eng.WDAS Wijayapala and Dr. KTMU Hemapala, for their guidance, rendered throughout the study period as well as to the point of finishing of this thesis. Their continuous supervision and advices on the research, pave me the way for successful completion of the scope of work.

Secondly, I should be thankful to Mr. Kusum Shanthi, Deputy General Manager, Transmission Design and Environment Branch of Ceylon Electricity Board for giving me the first glimpse on my research topic. What I have acquired, working under his supervision in Transmission Design branch of CEB, became very useful for the completion of this thesis.

At the same time, I should be thankful to the Head of the Department, Electrical Engineering, Dr. Preenath Dias for arranging the postgraduate course and providing all the facilities required.

My special gratitude shall be given to Dr. Asanka Rodrigo, who is the course coordinator of the MSc Electrical Engineer programme for organizing all the academic activities as well as progress reviews of the research studies. His commentaries during the progress presentations were very vital to the improvement of this research study.

At the same time, I should appreciate the corporation given by all other lecturers of the department of Electrical Engineering, university of Moratuwa for their guidance and constructive criticism during progress presentations.

All my batch mates in the MSc programme shall be given a great appreciation for their support throughout the study period as well as during the research period.

ABSTRACT

High Temperature Low Sag (HTLS) conductors are introduced into the electricity transmission systems by the conductor manufacturers, with the idea of mitigating some of the disadvantages shown by conventional overhead conductors such ACSR (All Aluminium Conductor Steel Reinforced).

Compared to conventional conductors, HTLS conductors have some of the improved electrical and mechanical characteristics, where by employing these conductors in overhead transmission lines, some of the complex issues related to power transmission could be resolved.

However due to their novel appearance and lack of service experiences in the field, most of the utilities in the world are in a dilemma whether to use these conductors instead of ACSR or other conventional types of conductors that have provided a great service to the utilities throughout hundreds of years.

Situation in Sri Lanka is also not that different. Almost the entire Sri Lanka's transmission system is comprising with overhead lines constructed using conventional conductors, especially ACSR. Therefore the knowledge and the experience regarding the use of HTLS or any other types of conductors remain minimal among utility engineers.

Therefore under this study, the use of these so called HTLS conductors for Sri Lanka's electricity system is discussed in terms of technical and economic aspects under three different categories of overhead line construction. Conclusions are drawn based on simulations results and comparisons are also elaborated.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBRIVIATIONS

ROW	-	Right of Way
HTLS	-	High Temperature Low Sag
ACSR	-	Aluminium Conductor Steel Reinforced
AAAC	-	All Aluminium Alloy Conductor
EMF	-	Electromagnetic Field
KPT	-	Knee Point Temperature
TACSR	-	Thermal Resistant Aluminium Alloy Conductor Steel Reinforced
CEB	-	Ceylon Electricity Board
G(Z)TACIR	-	Gap Type (Super) Thermal Resistance Aluminium Conductor Steel Reinforced
ACCC	-	Aluminium Conductor Composite Core
ACSS	-	Aluminium Conductor Steel Supported
CCC	-	Current Carrying Capacity
NPV	-	Net Present Value
IEE	-	Initial Environment Examination

LIST OF APPENDICES

1.0 INTRODUCTION

1.1 BACKGROUND

Rapid growth in electricity demand over the world has prompted utility companies to construct more and more overhead transmission lines from generation stations to load centers to cater bulk power requirement. With urbanization, the acquisition of Right of Way* (ROW) for the construction of overhead lines has become a great challenge to utility companies. Additionally, the power flow requirement of existing lines have to be increased, to meet the increasing demand requirements. Due to the fact that conventional bare type overhead conductors have their limitations in current carrying capacities and mechanical properties, conductors that have superior capabilities compared to conventional overhead conductors are required.

Therefore conductor manufacturers have come up with a different technology called HTLS (High Temperature Low Sag) conductors, to challenge the drawbacks of conventional type conductors. These new conductors are capable of operating at higher temperatures while providing lower sag values. They are also providing lower line losses due to lower unit thermal resistances and have higher tensile strengths.

Now, there are few types of HTLS conductors available in the world and each one of them have set of advantages and disadvantages compared to one another. However, more than 95% of Sri Lanka's transmission lines are made using ACSR (Aluminium conductor steel Reinforced) or AAAC (All Aluminium Alloy Conductors) and the experiences regarding HTLS conductors are minimal.

Therefore in this study, techno economic suitability of using HTLS conductors for the Sri Lanka's transmission system is discussed.

* ROW- this is also known as servitude requirement. This is the width of the line corridor which is dedicated for the transmission line being constructed. This width is 27m for 132kV and 35m for 220kV level in Sri Lanka according to the technical specifications for transmission lines in CEB.

1.2 SCOPE OF WORK

Conventional ACSR (Aluminium Conductor Steel Reinforced) conductors are used to construct overhead transmission lines all over the world for more than a century of years. Its ruggedness, flexibility, strength and cost effectiveness has made it more popular among electrical utilities around the world as a better solution in the construction of overhead transmission lines under different conditions. Other than ACSR, AAAC (All Aluminium Conductor Steel Reinforced) conductors are also used in overhead transmission line construction due to its corrosion resistance and higher current rating compared to the same size ACSR conductors.

However, with the rapid increase in electricity demand, uprating of existing overhead transmission lines have become so difficult with the unavailability of ROW requirements and some of the limitations of conventional conductors and transmission towers. Especially in urban areas, finding out line routes for new transmission lines is very difficult due to clearance issues and even with taller towers it is very difficult to overcome EMF (Electromagnetic Field) requirements with higher sag characteristic of conventional conductors.

As a result of the depletion of natural energy sources and the increase in electricity tariff in the country has made utilities to look for new energy conservation and energy efficient strategies in power transmission. According to the manufacturer's information, HTLS conductors have lower unit resistances compared to conventional conductors where by employing these conductors in transmission lines, utilities can save some of its energy that would have been dissipated in transmission lines.

In this research study, requirement of overhead transmission lines are discussed under different categories and the use of HTLS conductors as a solution for conventional conductor is studied technically and economically.

2.0 LITERATURE REVIEW

2.1 OVERHEAD BARE CONDUCTORS FOR TRANSMISSION LINES

For more than hundred years, ACSR has been the main candidate for overhead transmission lines. There are occasions where AAAC and ACSR/AS conductors are used in construction of overhead lines mainly to get additional corrosion protection for conductors. However ASCR is still the most preferred choice for transmission line construction by most of the designers in the world. When it comes to ACSR, thermal sag is considered one the major disadvantages. With the increase in temperature, the expansion of the conductor gets increased as a result of the increase in current.

In ACSR conductors, the outer layer is made of Hard Drawn Aluminium (1350-H19) and the inner layer is made of steel. 1350-H19 is not heat treated Aluminium and hence it cannot withstand higher operating temperatures. There are number of international standards being used by different utilities in the world for the selection of overhead bare conductors. In Sri Lanka, BS 215 and IEC 61089 are the most common standards being used for conductors [1].

Sri Lankan Transmission System now has more than fifty years of life span. Most of the older lines in the system had been constructed using ACSR Lynx conductors. However, to cater the increasing demand of the system, later the conductors being used for the older transmission lines were shifted to ACSR Zebra. Presently, most of the overhead lines are constructed using ACSR Zebra conductors and summation of these conductors (Lynx and Zebra) in the system is more than 90%.

However with ACSR conductors, the maximum continuous operating temperature that could be achieved is around 90°C. If the conductor is operated at temperatures above this value, it is more susceptible to lose its tensile strength over time. This phenomenon is known as annealing. This will result creep elongation in lines and safety clearances will get violated. Therefore manufacturers have come up with another technology called Low Loss Conductors where it can be operated at higher temperatures such as 150°C [2]. TACSR (Thermal Resistant Aluminium conductor steel reinforced) is a Low Loss conductor, which is especially available in Japanese conductor market. The main disadvantage of this conductor type is its higher thermal sag. Though, it can be operated at higher temperatures, its thermal expansion coefficient remains similar to ACSR. Therefore, this would in turn will result higher sag at higher temperatures and will create a necessity of taller towers.

Therefore HTLS conductors are manufactured, so that they overcome current limitations and thermal elongation issues of ACSR and Low Loss conductors. To improve the current capacity and to reduce thermal sag of these conductors, different techniques are used in each types of HTLS conductors.

2.2 CONDUCTOR PROPERTIES

Selection of a conductor is done based on the requirements of the specific transmission line design. Design requirements can be categorize as electrical, mechanical and civil. Usually all these criterions are met after the study of relevant conductor properties.

In this research study, below mentioned properties are discussed and comparison and selection of conductors will be analyzed based on them [3, 4, 1]

2.2.1 Ultimate Tensile Strength (UTS)

UTS is the maximum stress that a conductor can withstand while being stretched or pulled before failing or breaking. Usually, UTS is given by kilo Newton (kN). It is always preferred to have higher UTS conductors as they can be used to obtain higher span lengths with minimum sag values. However, in order to use higher UTS, transmission line towers shall also be capable of handling the forces exerted by conductors. UTS at times is referred as breaking load of the conductor.

Based on the design specifications of CEB, the maximum tension that could be exerted on conductors is 40% of the UTS of the conductor (Safety Factor of 2.5) [5].

Ex:	UTS of Zebra conductor	=	131.9kN		
	Maximum working tension	=	131.9/2.5	=	52.76kN

2.2.2 Cross Section Area

ACSR conductors are made of two layers, named as Inner and Outer. Outer layer is made of Aluminium strands and the inner layer is made of steel strands or aluminium clad steel strands. Cross section of aluminium and steel are specified separately and as summation in technical catalogues. Total cross section of aluminium or steel layers is equal to the summation of the cross section of each strand.

Ex: Zebra conductor (54/7, 3.18mm, 484.5 mm^2)

54	- total number of aluminium strands
7	- total number of steel strands
3.18 mm	- diameter of the strand

Total cross section $= \pi\,(\frac{d^2}{4}) \times (54 + 7)$

$= \pi(\frac{3.18^2}{4}) \times 61 \quad = \quad 484.5mm^2$

Cross section of the conductor directly effects the current carrying capacity of the conductor and mechanical forces getting applied on the conductor. Higher the cross section, higher will be the current rating and higher will be the wind forces being acted. Forces getting applied on conductors will be discussed in details at a later section of the report.

2.2.3 Modulus of Elasticity

Modulus of Elasticity, is the conductor tendency to be deformed elastically when a force is applied to it. The elastic modulus of a conductor is defined as the slope of its stress-strain curve in the elastic deformation region. Usually conductor manufacturers provide stress strain curves of their products. This is given in GPa or N/mm^2. Since ACSR is non homogeneous conductor, Al layer as well as steel layer has their own modulus of elasticity values. Therefore elastic modulus for the complete cable is found as below [6].

$$E_{AS} = E_{AL}\frac{A_{AL}}{A_{TOTAL}} + E_{ST}\frac{A_{ST}}{A_{TOTAL}}$$

E_{AL}	-	Modulus of Elasticity of Aluminium (GPa)
E_{ST}	-	Modulus of Elasticity of Steel (GPa)
E_{AS}	-	Modulus of Elasticity of Aluminium steel composite (GPa)
A_{TOTAL}	-	Total cross sectional area (mm^2)

A_{AL} - Area of Aluminium strands (mm^2)

A_{ST} - Area of steel strands (mm^2)

Ex: for Zebra conductor:

$$E_{AS} = 55 \times \frac{428.9}{484.5} + 205 \times \frac{55.6}{484.5} = 72\ GPa$$

2.2.4 Linear Thermal Expansion Coefficient

Linear Thermal expansion is the tendency of the conductors to change in length in response to a change in temperature. Since ACSR conductors are made of two elements (Al and Steel), they have two thermal expansion coefficients. However as they are stranded together, at initial temperatures, the expansion occurs simultaneously for the entire conductor [6].

Thermal expansion of ACSR conductors is calculated as mentioned below;

$$\alpha_{AS} = \alpha_{AL}.\left(\frac{A_{AL}}{A_{TOTAL}}\right).\left(\frac{E_{AL}}{E_{AS}}\right) + \alpha_{ST}.\left(\frac{A_{ST}}{A_{TOTAL}}\right).\left(\frac{E_{ST}}{E_{AS}}\right)$$

α_{AS} - Conductor coefficient of thermal expansion

α_{ST} - Steel coefficient of thermal expansion

α_{AL} - Aluminium coefficient of thermal expansion

Ex: for Zebra conductor

$$\alpha_{AS} = 23 \times 10^{-6}.\left(\frac{428.9}{484.5}\right).\left(\frac{55}{72}\right) + 11.5 \times 10^{-6}.\left(\frac{55.6}{484.5}\right).\left(\frac{205}{72}\right)$$

$$\alpha_{AS} = 19.3\ \times 10^{-6}$$

2.2.5 Unit Resistance

Unit resistance of the conductor is given by ohm per kilometers in technical catalogues of conductor manufacturers. With the change in conductor temperature, the unit resistance of the conductor gets varied and this variation is considered nonlinear. However still for some manual calculations, resistance is assumed to be varied linearly. Unit resistances at 25°C and 75°C are usually given In PLSCADD (Power Line Systems and Computer Aided Design and Drafting). According to IEEE 738- Standard for Calculating the Current-Temperature of Bare Overhead Conductors below formula is given to find out the resistance at given temperature [7].

$$R_t = \left[\frac{R_H - R_L}{75 - 25}\right].(T_t - 25) + R_L$$

R_t - Resistance at temperature t

R_H - Resistance at 75°C

R_L - Resistance at 25°C

2.3 CONDUCTOR FORMATION

2.3.1 Conventional Conductors

(a) ACSR Conductor

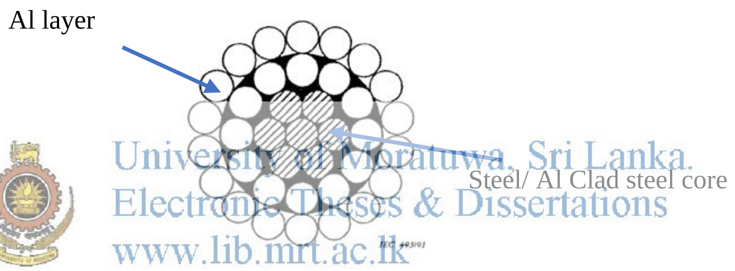


Figure 2.1 - ACSR conductor formation

Source: IEC 61089

ACSR is a non-homogeneous conductor. It has two layers. Outer layer is made of Hard Drawn Aluminium (1350-H19) where its primary purpose is to carry electricity. The inner layer is made of steel where it provides mechanical strength to the conductor. Conductor strands are circular in shape. A thin grease layer is applied on conductor strands. Usually the outer layer is ordered free from grease to make sure it does not catch dust particles which in turn improve corona. Hard drawn aluminium is not heat treated and hence ACSR conductors cannot be operated at higher temperatures than 85°C [8, 9, 10].

(b) AAAC Conductors

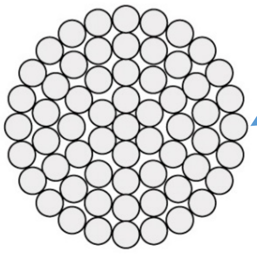


Figure 2.2 - AAAC formation

AAAC is a homogeneous conductor. Alloy aluminum facilitate current carrying as well as mechanical strength to the conductor. Its current carrying capacity is slightly higher compared to the same size ACSR conductor. Currently in Sri Lanka, there is only one AAAC conductor being used for the 220kV transmission line going from Norochcholai Coal power station to Veyangoda grid substation. Compared to ACSR, AAAC provides greater corrosion protection so that it can be used in coastal areas. Alloy aluminium conductors are also not heat treated. Therefore they cannot be operated at higher temperatures.

2.3.2 High Temperature Conductors (Low Loss Conductors)

(a) TACSR (Thermal Resistant Aluminium Alloy Steel Reinforced)

Its construction is similar to ACSR but EC grade outer strands are replaced with hard drawn aluminium of heat treated Al alloy which is denoted as TAL. TACSR can be safely operated at higher temperatures above 150°C enabling to pump more power through the conductor. These conductors are useful when there is a need to transfer more power but restrictions on getting ROW. To maintain its electrical and mechanical power at elevated temperatures, Al wires are doped with Zirconium. Zr is extremely resistant to heat and corrosion.

Though, TACSR is a high temperature conductor. It is not a low sag conductor. Therefore the use of TACSR is limited only for new transmission line constructions.

2.3.3 Low Loss Conductors

(a) GTACSR/ ZGTACR (Thermal/ Super Thermal Resistant Aluminium Alloy conductor Steel Reinforced)

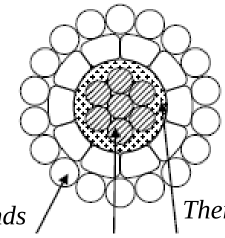


Figure 2.3 - Gap Conductor formation

Source: J Power Systems, conductor catalogue

This conductor is commonly known as Gap Conductor. That is because there is a gap in between outer and inner layers. Outer layer is made of Zirconium doped hard drawn aluminium alloy. Outer most layer strands are circular in shape and the strands in one layer below are trapezoidal in shape. Annular gap is filled with thermal resistant grease. Inner core is made of High strength steel. Steel core and aluminium core can move independently to each other due to the presence of grease [11, 12, 13].

Japanese are the pioneers of Gap conductors. Currently there are many other utilities who are manufacturing these Gap conductors. Main advantage of these Gap conductor is that their ability to operate at high temperatures without having higher sag values as in the case of conventional and low loss conductors.

GTACSR conductors can be operated at 150°C (TAL) and ZGTACSR conductors can be operated at 210°C (ZTAL). Stringing requirements of these conductors are different that of conventional conductors. Two stage stringing is used with Gap conductors where 70% of the conductor is tensioned together with Al and steel core and the rest is tensioned on the steel core along. By doing that, conductor sag can only be subjected to the expansion behavior of steel above knee point temperature.

Knee Point Temperature (KPT) is the temperature that the complete conductor tension is taken by the steel core. Gap conductor has comparatively very low KPT.

(b) ACCC (Aluminium Conductor Composite Core)

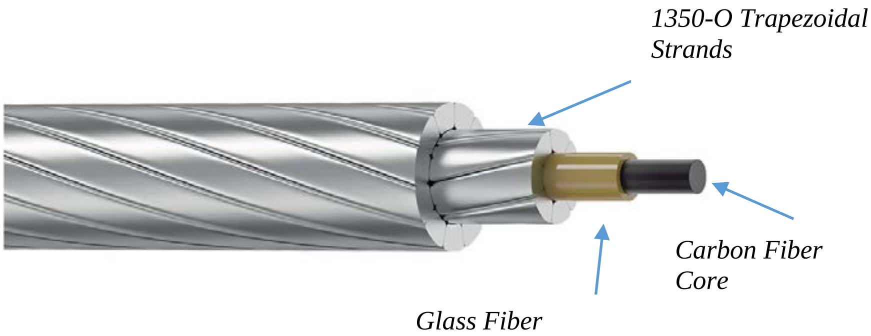


Figure 2.4 - ACCC formation

Source: CTC Global, conductor catalogue

Core of the ACCC conductor is made of hybrid carbon and glass fiber composite core which utilizes a high temperature epoxy resin matrix to bind hundreds of thousands of individual fibers into a unified load bearing tensile member. The central carbon fiber core is surrounded by high grade boron free glass fibers to improve flexibility and toughness. Additionally it prevents galvanic corrosion between carbon fiber core and aluminium strands. Aluminium strands are made of Annealed Aluminium (1350-O) which has a higher conductivity compared to Hard Drawn Aluminium. Aluminium strands are trapezoidal in shape [14].

As in the case of Gap conductors, ACCC also has a very low KPT which helps to have lower sag values with increasing temperature. Thermal expansion of the core is negligible compared to the other types of conductors. ACCC conductors can safely be operated up to 180°C. These conductors require special installation methods and careful handling of the conductor.

(c) ZTACIR (Super Thermal Resistant Aluminium Alloy Invar Reinforced)

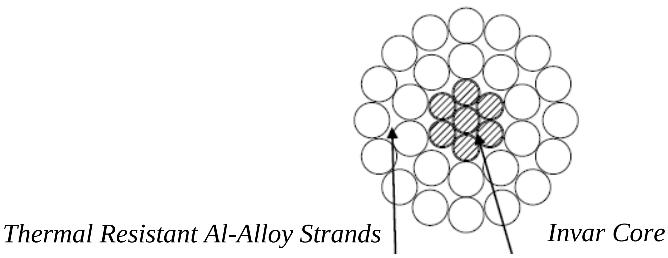


Figure 2.5 - ZTACIR formation

This conductor is commonly known as the Invar Conductor. Shape is more similar to ACSR/AW. Unlike in the case of ACSR, the outer strands of Invar conductor is made of heat treated annealed aluminium strands which can operate at elevated temperatures. The core of the conductor is made of Aluminium Clad High strength steel which has a lower thermal expansion value. These conductors can be operated up to 210°C [15, 2].

One of the advantages of Invar conductors is that their installation and the spares required are more similar to ACSR. These conductors have considerably a higher KPT value, so that the low sag performances cannot be expected at lower operating temperatures.

(d) ACSS (Aluminium Conductor Steel Supported)

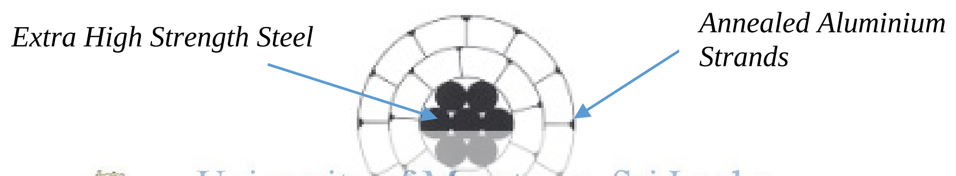


Figure 2.6 - ACSS formation

Outer strands of ACSS conductor is made of heat treated fully annealed Aluminium that has a trapezoidal shape. Core of the conductor is made of extra high strength steel (EHS). This conductor is very popular in USA as well as some of the European countries. This conductor can be operated at 250°C without compromising its tensile strength. Stringing requirements of this conductor is very similar that of conventional conductors.

2.4 CONDUCTOR MATERIAL

All the conductors mentioned in the above clause are different to one another base on the material being used and their formation. Conductor properties that are described such as conductivity, unit resistance, tensile strength, thermal expansion and elasticity have gotten their specific values base on how they are formed.

Table 2.1 - Aluminium Conductor Material

Description	**Type**	**Conductivity (% IACS)***	**Tensile Strength (ksi)**	**Maximum operating Temperature (°C)**
Hard Drawn	1350-H19	61.2	23-25	90
Fully Annealed	1350-O	63	6-14	250
Thermal Resistant	TAL	60	24-27	150
Ultra Thermal Resistant	ZTAL	58	24-27	200

*- *IACS (International Annealed Copper Standards) a value of 100% refers to a conductivity of 5.8 x 10^7 Siemens per meter.*

Source: CTC Engineering manual [6]

It can be seen that when the conductivity of the conductor material is increased, there is a drop of its tensile strength. Therefore the operating temperature of the conductor or the current carrying capacity of the conductor can only be increased by compromising the strength of the conductor material. This is the reason that conductors such as ZTACIR and ACSS, the conductors which are capable of operating at elevated temperatures use fully annealed aluminium. However with the reduction of the tensile strength, material becomes softer which in turn require proper handling during stringing.

Table 2.2 - Core Material

Description	**Weight (g/cm³)**	**Modulus of Elasticity (msi)**	**Tensile Strength (ksi)**	**Coefficient of Thermal Exp. (x 10^{-6}/°C)**
HS steel	7.78	29	200-210	11.50
EHS steel	7.78	29	220	11.50
Aluminium Clad	6.59	23.5	160-195	13.00
Carbon Hybrid Epoxy	0.07	16-21	330-375	1.60
Invar Alloy	7.78	23.5	150-155	3.00

Source: CTC Engineering manual [6]

Core material is responsible for providing mechanical strength for the conductor to be strung between towers. In HTLS conductors, complete conductor tension is taken by the core material after KPT. Therefore it is always useful to have lower thermal expansion value in the core material so that conductor sag will not increase rapidly with the increasing temperatures. This is one reason, why ACCC conductors provide superior sag performances compared to other conductors as it has a very low thermal expansion value. At the same time it is to be noted that conductor performances depend on many variables so that looking at a single property of the conductor could be misleading.

2.5 CONDUCTOR BEHAVIORS

There are two major calculations carried out during the process of selecting conductor material.

1. Current carrying capacity
2. Sag Tension Performances

During system planning and design conductor current rating is calculated under given environmental inputs and then Sag Tension Calculations are performed in order to identify the clearance requirements and forces.

2.5.1 Current Carrying Capacity (CCC)

In this research the current carrying capacity is calculated based on IEEE 738-2006 and IEC 61597. Conductor current rating is not something specific for the particular conductor. Current capacity will be depending mostly on environment inputs of the area being selected.

Heat balance equation is used to calculate the CCC [16].

$$\mathbf{P_J + P_{Sol} = P_{Rad} + P_{Conv}}$$

P_J - Heat generated by joule effect

P_{Sol} - Solar heat gain by the conductor surface

P_{Rad} - Heat Loss by radiation of the conductor

P_{Conv} - Convection Heat Loss

Please refer to Appendix A for sample calculation and formulas of Current Carrying Capacities.

The steady state CCC can be found as;

$$I_{max} = \sqrt{\frac{P_{Rad} + P_{Conv} - P_{Sol}}{R_T}}$$

Where R_T is the conductor unit resistance at given temperature;

Ex: Current Carrying Capacity of Zebra conductor at 75°C is; = 817 A

Given that;

Wind Speed	=	$0.5ms^{-1}$
Solar Radiation absorption coefficient	=	0.5
Emissivity coefficient compared to a black body	=	0.5
Solar Radiation Intensity	=	$1000W/m^2$
Boltzsmann constant (10^{-8})	=	$5.76Wm^{-2}K^{-4}$
Air Thermal Conductivity	=	$0.0248\ Wm^{-1}K^{-1}$
Ambient Temperature	=	32°C

Above calculation is done based on IEC 61597. It can easily be seen that the CCC is heavily dependent on environmental inputs.

2.5.2 Sag Tension Calculation

Although, the primary function of conductors is to transfer electrical load, they shall also be strong enough to withstand the forces coming from its weight, wind and other loads when they are strung on towers [8].

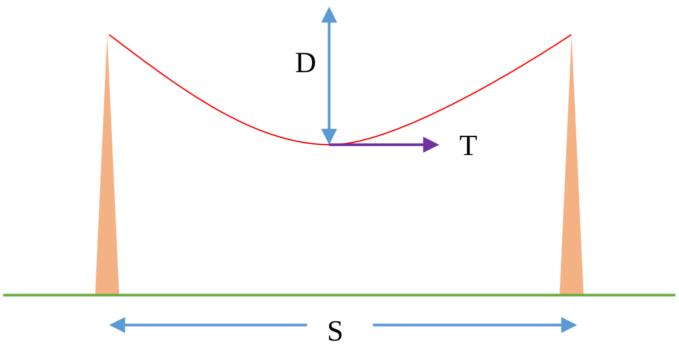


Figure 2.7 - Conductor Sag and Tension

Conductor Sag is given by;

$$D = \frac{WS^2}{8T}$$

D - Conductor Sag (m)

W - Unit Weight of the conductor (N/m)

T - Conductor Tension at given temperature (N)

S - Span (m)

To maintain the required ground clearances, the conductor sag shall be maintained at a certain level. Therefore it is always preferable to have a smaller sag. One way of achieving higher ground clearance is the use of taller towers. However the viability of that option heavily depends on economic factors such as steel cost, foundation cost etc. Reduction of span is also one option but that in turn will increase the number of towers in the line.

Use of lower weight conductor is one another option of reducing conductor sag. By the use of some of the HTLS conductors, this can be achieved and considerable amount of sag can be reduced.

Increase of initial tension is also one option of reducing conductor sag. however due to the fact that higher tension conductors are susceptible for fatigue failure the initial tension is maintained at less than 40% of the UTS of the conductor. With the increase in temperature, the tension of the conductor will reduced. This can be found using the state equation given below;

$$H_2^2\left[H_2 - H_1 + \frac{E.A.(S.m_{c1}.g)^2}{24H_1^2} + E.A.e(t_2 - t_1)\right] = \frac{E.A.(S.m_{c2}.g)^2}{24}$$

H_2 - Stress at given temperature (N/mm^2)

H_1 - Initial Stress (N/mm^2)

E - Modulus of Elasticity (N/mm^2)

A - Conductor Cross Section (mm^2)

m_{c1} - Initial unit mass (kg/m)

m_{c2} - Unit mass at given temperature (kg/m)

g - Gravitational Constant (ms^{-2})

e - Thermal Expansion coefficient ($°C^{-1}$)

t_1 - Initial Temperature (°C)

t_2 - Operating temperature (°C)

It can be seen that, the reduction in tension at higher temperatures can be reduced by having lower thermal expansion coefficient. Conductors such as ACCC and ZTACIR have very lower thermal expansion values compared to ACSR and hence the conductor sag given by these conductors at given temperature is lower than that of ACSR.

At the same time it is to be noted that sag tension calculation for HTLS conductors have to be done in two stages as they have two different expansion coefficient at below and above KPT. Normally, the expansion coefficient of the core material is lower compared to the expansion coefficient of Aluminium material. Complete tension of the conductor is taken only by the core above the KPT. This is one of the advantages of having lower KPT as the conductor expansion could be kept at a lower value at higher temperature so is conductor sag. Conductor sag of Zebra conductors at 75°C for 300m span is 7.79 m. Sample calculation of sag tension values for Zebra is given in Appendix B.

2.6 CONDUCTOR COMPARISON

Table 2.3- Conductor Properties Comparison

Conductor		**ACSR**	**GTACSR**	**ZTACIR**	**ACCC**
Construction	Outer Layer	Hard Drawn Al	Hard Drawn Al	Annealed Al	Fully Annealed Al
		1350-H19	1350-H19	ZTAL	1350-O
	Inner Layer	Steel	Extra High strength Steel	Aluminium Clad Invar	Composite Core (Carbon Hybrid and Glass Fiber)
Core Withstanding Temp.	°C	170	200	300	>300
Tensile Strength (ksi)	Al	23 - 25	23 - 25	24 - 27	6-14
	Core	200- 210	220	160 - 195	330 - 375
Conductivity	%IACS	61	60	60	63
Max. Operating Temp.	°C	75 - 85	150 - 210	210 - 230	180
Knee Point Temperature (KPT)	°C	75 - 85	32	130	35 - 55
Thermal Expansions x 10^{-6}	Al	23.04	23.04	23.04	23.04
	Core	11.52	11.52	3.78	1.609
Modulus of Elasticity (Mpa/100)	Al	427	517	466	480
	Core	351	212	293	128

From Table 2.3, it can be seen that the maximum operating temperatures of HTLS conductors are higher compared to the maximum operating temperature of ACSR. KPT of ACCC and Gap conductors are considerably lower compared to Invar conductor. Therefore when selecting HTLS conductors, this has to be studied because of using Invar conductor at lower temperature will be giving the benefit of lower sag. Therefore in light loaded transmission lines, it is always better to select a conductor which have lower KPT so that complete tension of the conductor can quickly be subjected to the core material.

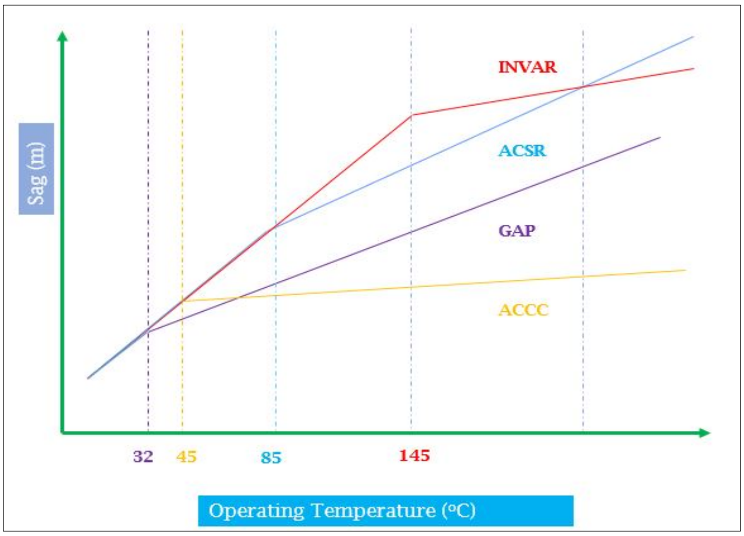


Figure 2.8 - KPT of different conductors

Figure 2.8 shows the change of conductor sag with its operating temperature. ACSR conductors cannot be operated beyond its KPT as its tensile strength will start losing at elevated temperatures. Therefore the advantage of low sag performances cannot be achieved with ACSR. However since HTLS conductors can be operated at higher temperatures, they are capable of showing low sag performances above KPT. It can be seen that with ACCC conductors, the increase in sag above KPT is negligible [6].

Table 2.4 shows a comparison of the same size conductors. There, the diameter of the conductor and the unit weight remain the same. By having the similar physical properties, the forces exerted by the conductor to towers can be maintained the same.

Main forces acting on Towers;

1. Vertical Forces
2. Longitudinal Forces
3. Transverse forces

Vertical load of the tower depends on the weight of the conductor and transverse force exerted by wind forces depends on the projected area (Diameter x unit length) of the conductor. Therefore by taking conductors with similar weight and diameter will help maintaining the constant forces on towers.

Therefore Table 2.4 has compared ACSR and HTLS conductor properties in a common ground. Zebra conductor, which is the most common conductor in Sri Lankan transmission system is selected as the basis and properties and performances of HTLS conductors are discussed.

Table 2.4 - Comparison of conductors

Conductor Type	ACSR	HTLS			
		GTACSR	ACCC	ZTACIR	ACSS
Conductor Name	Zebra	Drake	Drake	413-410	Drake
Cross Section (mm^2)	484.5	469.5	519.7	413.4	402.8
Diameter (mm)	28.62	27.8	28.143	28.5	28.118
Unit Weight (kg/m)	1.621	1.616	1.565	1.625	1.626
UTS (kN)	131.9	149.2	183.3	130.4	124.6
Unit Resistance at 75°C (Ω/km)	0.08149	0.0878	0.06617	0.09681	0.08419
Maximum Operating Temperature (°C)	75	150	180	210	250
Current Carrying Capacity (A)	817	1261	1600	1378	1601

From the Table 2.4 it can be seen that the ability of HTLS conductors to transfer substantial amount of power at elevated temperatures. At the same time it is inevitable that ACCC conductor has the lowest unit resistance hence the highest CCC among others. Therefore in terms of loss reduction, ACCC is the best solution. However Stringing requirements of ACCC and Gap are little troublesome compared to Invar and ACSS.

2.7 ADVANTAGES OF HTLS CONDUCTORS

As mentioned in above clause, HTLS conductors came to market due to their added advantages over conventional conductors. Below are some of the main advantages of HTLS conductors in the market [17];

- Higher Current Carrying Capacity

HTLS conductors can be operated at elevated temperatures around 150°C-250°C. Therefore the amount of current rating of these conductors is high compared to the conventional conductors. Last column of Table 2.4 shows the maximum current rating of some of the HTLS conductors.

Based on the manufacturers' information, GTACSR conductors are able to handle 1.6 times the same size ACSR while ZGTACSR can handle 2.0 times the CCC of similar size ACSR conductors.

At the same time in Table 2.4 it can be observed that for the similar diameter, the amount of Al being used in ACCC conductor is higher (28%) due to its compact formation and in turn will result higher CCC even at lower temperatures.

- ROW saving

Since HTLS conductors can be used to transfer bulk power from one stations to other, it has the potential to reduce number of transmission lines being constructed. Since conventional conductors are restricted to low capacities, there will be a requirement of multiple transmission lines and hence ROW requirements will be large. However HTLS becomes handy in such situations where they can eliminate the requirement of multiple lines by a single tower line.

- Thermal Uprating of Existing Lines

One of the main advantages of HTLS conductors is to use them as a medium for thermal uprating of existing transmission lines. With the increasing demand, older transmission lines are unable to supply the required power demand and construction of new overhead lines became a challenge given the unavailability of ROW. Use of higher cross section line in the existing towers is not an option as the existing towers are not designed for additional forces.

Even if conductors with higher cross section is used, the thermal sag of conductors will violated the required ground clearances. Therefore the best option is to use a suitable HTLS conductor with similar mechanical properties where the existing towers can still be used without violating tower safety requirements as well as minimum ground clearances.

- Energy Efficiency

Another advantages of using HTLS conductors is to achieve energy efficiency during power transmission. As we have seen in Table 2.1, conductivity of the conductors can be improved by the proper composition of elements and proper heat treatment methods. Therefore energy loss (I^2R) during transmission can be reduced by the use of HTLS conductors. This will in turn reduce the amount of power generation requirements to be met and will save fuel and CO_2.

- Long Span Crossing

HTLS conductors can be used for longer spans crossings. This remained a great challenge with ACSR conductors due to its higher thermal expansion coefficient. At the same time, UTS of conventional conductors is low compared to the HTLS. Therefore with conventional conductors, taller towers are required to obtain the ground clearance. This also results in the need of additional steel as well as larger foundations. Conventional conductors cannot be tensioned to higher values as there is a risk of being subjected to fatigue failure due to aeolian vibration. However with lower expansion values and higher UTS values, HTLS conductors have become a good solution for long span crossing.

2.8 DISADVANTAGES OF HTLS

- Low Service Experience

ACSR conductors have more than hundred years of service experience and those conductors are being used all over the world by thousands of contractors and utilities. However HTLS conductors came to the world of transmission line construction at a later stage where no utility or contractor has that much service experience regarding the use of HTLS conductors.

In case of ACCC conductors, it was first developed in 2005 and commercialized in 2006. Therefor the oldest installation of ACCC conductors are only 9 years old by this time. However presently over 100 utilities in more than 30 countries are using ACCC over 24,000km span.

GTACSR conductor first immerge in nineteen seventies in Japan. Still Japanese are considered the pioneers of Gap conductor technology. Use of Gap conductors was merely limited to Japan until the start of 2000. Then it started spreading all over the world and currently more than 11,000km of supply record is there.

All other HTLS conductors such as ACSS, ZTACIR, ACCC have limited experience regarding the service life.

- Special Stringing Requirements and Spares

One of the main disadvantages of some of the HTLS conductors is the requirement of specialized stringing methods. As an example, ACCC and Gap conductors require special trained staff on stringing. Stringing procedure is also little different from conventional methods used with ACSR.

Especially the dead ends used with ACCC and Gap conductors shall be compression type to tackle thermal expansion of Aluminium layer at elevated temperatures. They require special mid span joints unlike in the case of ACSR. Additionally, they must be handled very carefully during stringing and cannot be subjected to rough and rigid handling.

However ZTACIR and ACSS conductors only require conventional spares while their stringing requirements remain the same as in the case of conventional conductors. However, the dependency of the performance of the line on stringing, had made utilities of selecting HTLS conductors less probable.

- High Price of HTLS

Unit cost of HTLS conductors are considerably higher compared to the cost of ACSR and AAAC. Most of the utilities in the world have very strict investment plans on their power systems and additional cost bearing will cause a great challenge. Therefore still in case of a new line construction, use of HTLS will cost additional amount other than the saving of ROW.

However in situations where existing line uprating, HTLS has the ability to cut down the cost of new transmission line only by restring conductors.

3.0 METHODOLOGY

3.1 PROCEDURE

In this research, suitability of the use of HTLS conductors to Sri Lanka's transmission system is studied in terms of their technical and economic behavior. Almost all the overhead lines in Sri Lanka's grid has been constructed with the use of conventional ACSR conductors. Though there are a few occasions where other types of conductors have been used, experience and knowledge in the area of the use of HTLS conductors remained diminutive.

Here in this study, the use of HTLS conductors will be discussed under three basic categories. For each category, a generalize algorithm will be introduced which could be used as a guidance in the process of selecting HTLS conductors. Each algorithm will be described separately with the use of real time transmission line models. PLSCADD software will be used for the design activities, which is considered as the most premium software package used for overhead line designing. Manual calculations are also used where ever possible. Design parameters are selected based on CEB design specifications for overhead line construction and international standards such as IEC, IEEE and BS etc.

3.2 GENERAL GUIDELINES

Still, 100% of the country's transmission system is owned by CEB. Therefore, this study has been carried out based on existing transmission designs of CEB. As an example throughout the study, transmission towers are considered double circuit double peak type that have two circuits and two earthwires. All the towers are lattice type self-supported towers.

All the clearances from conductors other obstacles such as ground, roads, railways etc. are taken based on exiting CEB guide lines. Insulation coordination, accessories and hardware of transmission lines are also selected based on accepted international standards by CEB.

EMF studies are carried out based on regulations stipulated by ICNIRP (International Commission for Non Ionizing Radiation Protection).

Weather inputs, safety factors, basic design spans, wind and weight spans are selected accordingly to existing design as well as current CEB design publications. Further explanations on above substances are provided or referred to relevant sections under later clauses.

3.3 EXTENT OF STUDY

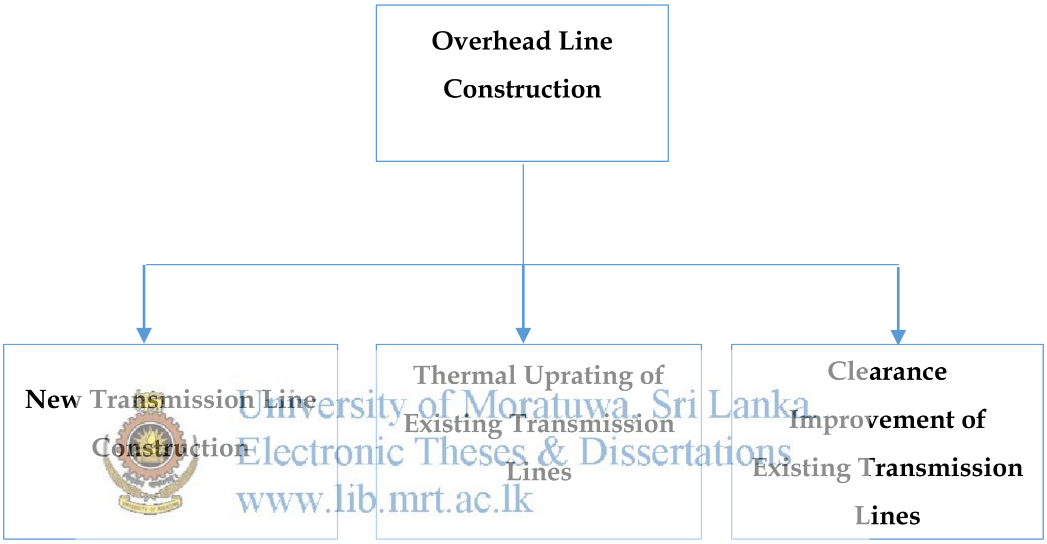


Figure 3.1 - Requirement of new Overhead lines

Study area of this research covers three major categories of conductor requirements. Up to now, most of the conductor requirements arose due to the construction of new transmission lines. However, currently the country’s transmission system has come up to a special juncture where, the capacity of most of the old transmission lines are becoming insufficient to cater increasing demand. Therefore most of the old transmission lines have to be uprated or new transmission lines have to be taken place instead of old lines. However, urbanization and increasing land values have made construction of new lines ever challenging and therefore utilities are more focused on the process of existing transmission line uprating, which is commonly known as thermal uprating.

At the same time, HTLS conductors are more popular and marketed by various suppliers targeting the area of reconductoring. Therefore suitability of HTLS conductors as a reconductoring medium is considered for Sri Lanka's transmission system.

It can be noticed that some of the old transmission lines have violated the safety clearances stipulated by the CEB specifications and had caused safety issued to the public. This phenomenon had taken place due to many reasons such as conductor creep, alteration of original ground profile, land filling etc. Therefore utilities are responsible for taking necessary arrangement by improving clearance without disturbing the electrical performances of the line. Use of HTLS conductor had been identified as one of the options in such occasions and this is also studied under a separate category.

3.4 DESIGN PROCESS OF OVERHEAD LINES

3.4.1 Survey Data Collection

It is always useful to collect whatever the data available in the form of "As Built Drawings" during the study of existing transmission lines. Usually, "As Built drawings" (profile data, structure drawings etc) are not available for some of the old transmission lines. Therefore ground survey has to be carried out at the beginning of the study. To use PLSCADD software, it is required to have ground coordinates to develop the profile view of transmission lines to be studied.

Below are the minimum survey requirements that shall be fed to PLSCADD software;

- Longitude and Latitude
- Elevation
- Height of Obstacles
- Feature Codes

Longitudes and Latitudes shall be provided in meters. When coordinates are given in degrees or decimal, those shall be converted to UTM (Universal Transverse Mericater) format. This was done by using in house software. To develop the profile surface, it is always preferred to have maximum amount of information fed to the PLSCADD software. Each point shall comprise with above coordinates (x,y,z,h and feature code) and thousands of these points shall be given to develop the profile view of the line. Elevation is the height to the point from the mean sea level. Anyway, as this is a relative value, it is possible to select some other level to measure the height if required. Each point has given a specific code. Table 3.1 shows a part of the input .csv file which is used for PLSCADD. In case where these details are unavailable, we can use common software tools such as Google earth and Arc GIS or QGIS to develop the input files. Though Google Earth data has elevations error margin of around few meters, they could still be used for our study as the error is relative.

Table 3.1 - Sample Profile Data Input for PLSCADD Software

#	Y	X	Z	Heights	Feature Code	Description
1	793503.854	394284.714	101.30		100	Ap_1
2	793555.539	394334.236	98.73		80	Stream
3	793605.185	394381.805	99.61		200	Ground
4	793654.980	394429.516	99.75	20	50	Electric post
5	793685.620	394458.873	99.95	20	50	Electric post
6	793713.289	394485.385	100.55		200	Ground
7	793735.471	394506.639	100.00		100	Ap_2
8	793763.485	394524.041	100.48		200	Ground
9	793862.888	394585.790	100.58	10	50	Electric post
10	793872.376	394591.683	99.57		200	Ground
11	793897.956	394607.574	97.57	12	20	Water Tank
12	793984.348	394661.240	97.58		20	Water Tank

3.4.2 Design Data for Supports

Once the survey data gathering is completed, the next step is to finding out design data of transmission line. If it is an existing line, it is required to find out the exact design criteria used by previous designers as the current design specifications used by the utility got updated several times in the past. As the existing structures are designed according to the values governed in that specific period of time, it is very important that the correct values are chosen to the analysis. In case of a new line constructions, present utility specifications can be used. Tables 3.2 to 3.7 show the basic design criteria used in CEB for the construction of 132kV and 220kV transmission line.

Basic Span

Table 3.2 - Basic Spans of Transmission Lines

	132kV	220kV
Basic Span	300	350

Wind Span

Table 3.3 - Wind Span Transmission Lines

	132kV		220kV	
	Normal	Broken	Normal	Broken
Wind Span	360	270	420	215

Weight Span

Table 3.4 - Weight Span of Transmission Lines

Tower Type	132kV				220kV			
	Normal		Broken		Normal		Broken	
	Max	Min	Max	Min	Max	Min	Max	Min
TDL	600	150	450	112.5	700	_	525	_
TD1 TD3 TD6	900	-300	675	-200	1050	-300	790	-200
TDT	250/75	-200/0	50/_	_/_	300/75	-200	70/_	_/_

Source: CEB Technical Specifications [5]

TDL - Line Tower/ Suspension Tower

TD1 - Angle Tower/ Strain Tower used in the range of 0°to 10° angles

TD3 - Angle Tower/ Strain Tower used in the range of 10°to 30° angles

TD6 - Angle Tower/ Strain Tower used in the range of 30°to 60° angles

TDT - Terminal/ Dead End Towers

Transmission towers of existing line are designed using PLSCADD software, according to above values. Installation of new conductors shall be done in a way that these values are not violated.

3.4.3 Weather Data Inputs

It is very important to get the details available with designed weather data of existing overhead line. This is very important due to the fact that the current carrying capacity of existing line is depending heavily on environment details. As explained under 1.3.5, conductor capacity is restricted by operating temperature limits.

However most of the old transmission lines are not designed for maximum operating conditions, due the lack of requirement of electricity at that time. Most of the old transmission lines are designed to be operated at 54°C, though the maximum operating temperature of ACSR conductor is 75°C.

At the same time, weather inputs such as wind data are very useful to simulate the behavior of insulator and conductor swing data. It can be noticed that, there are lot of illegal constructions that have taken place under and in the vicinity of transmission lines. Therefore the ROW which was there at that time of construction is no more available in present condition.

<u>Wind Pressure</u>

Table 3.5 - Wind pressure on components

Item	Value
On conductor and Earthwire	970 N/m^2
On Insulators	1170 N/m^2
On Supports	1640 N/m^2

Source: CEB Technical Specifications [5]

CEB approach into line design is a deterministic one. However, there are occasions where probabilistic approaches is used. In PLSCADD, there is a facility to select method of construction during the process of criteria selection. Most common standard used for overhead transmission line construction is IEC 60826.

Temperature Limits

Table 3.6 - Temperature Limits

Item	Value
Minimum Temperature (°C)	7
Every Day Temperature (°C)	32
Maximum Temperature (°C)	75

Source: CEB Technical Specifications [5]

Table 3.6 shows the present temperature limits for ACSR, ZEBRA conductor according to the Technical Specification of CEB for overhead line design. However, most of the older lines were Lynx, ACSR and those were designed for different temperature limits. As an example, Pannipitiya- Rathmalana Lynx line was constructed to have 15°C as the minimum temperature and 54°C as the maximum temperature. It is very important to find the exact values that the line was designed because the minimum ground clearance is depending on the maximum operating temperature of the conductor. Higher the temperature, higher will be the conductor sag.

3.4.4 Safety Factors

During restringing, it is very important that we do not violate safety factors where the existing line was designed. This is one of the most basic and important phenomenon in thermal uprating of existing lines.

Table 3.7 - Safety Factors for towers

Item	Safety Factor
Conductors, Earthwires and OPGW at Maximum Working Tension based on Ultimate Strength	2.5
Conductors and Earthwires at Everyday Temperature still Air Tension, based on Ultimate Strength	4.5
Anchor Clamps and Mid-span Joints, based on Ultimate Strength of Conductor and Earthwire	0.95
Insulator Strings and Fittings at Maximum Working Tension based on Failing Load	3.0
Towers under Broken Wire Loads	1.25
Cross arms of straight line support under broken wire condition	2.0
Cross arms of angle, section and terminal support under broken wire condition	2.5

Source: CEB Technical Specifications [5]

Table 3.7 shows typical safety factors that are used for overhead line design in CEB presently. It must be ensured that these limits are not exceeded during restringing.

All above factors mentioned under this clause are used during this study. The most important requirement in this study is to prepare a guidance to follow in case there is a requirement of HTLS conductors. Currently in CEB, there is no such guidance used and the experience and the understanding about these conductors within the organization is very little compared to conventional conductors.

Therefore an algorithm was formed to select suitable HTLS conductors over ACSR by depending their technical and economical performances as well as taking many other variables.

4.0 THERMAL UPRATING OF EXISTING TRNAMISSION LINES

4.1 INTRODUCTION

As explained in the previous chapter, HTLS conductors are said to have a great potential to be a solution in the case of thermal uprating of existing transmission lines. However, the selection of HTLS conductors have to be accomplished accordingly to the existing power system. Requirements of each system is unique by country wise and each country has their own issued to be dealt with. Therefore the use of these conductors to Sri Lanka's power system shall be studied based on its unique requirements.

Transmission lines which require thermal uprating, is studied and identified during the process of transmission line planning. Usually these studies and identifications are based on sophisticated computer simulations programmes. In CEB, PSSC software is used for planning purposes.

Currently there are few lines are identified to be thermally uprated,

1. Athurugiriya - Kolonnawa 132kV Transmission line
2. Pannipitiya - Panadura 132kV Transmission line
3. Pannipitiya - Ratmalana 132kV Transmission line
4. Samanalawewa - Embilipitiya 132kV Transmission line

Single Line Diagram of Sri Lanka's transmission system is attached in Appendix C.

4.2 ALTERNATIVES TO UPRATE EXISTING TRANSMISSION LINE

- Construction of a new transmission line using a conductor having higher cross section
- Use of existing transmission line towers with a suitable HTLS conductor after reinforcing towers and foundations if necessary

Average life span of a transmission line can be of 40 to 100 years. This prediction heavily depends on the environment conditions as well as operation and maintenance process being carried out of that line. Therefore other than the change of conductors, the stability of structures and foundations shall be considered.

4.3 ALGORITHM FOR SELECTING CONDUCTORS DURING RESTRINGING

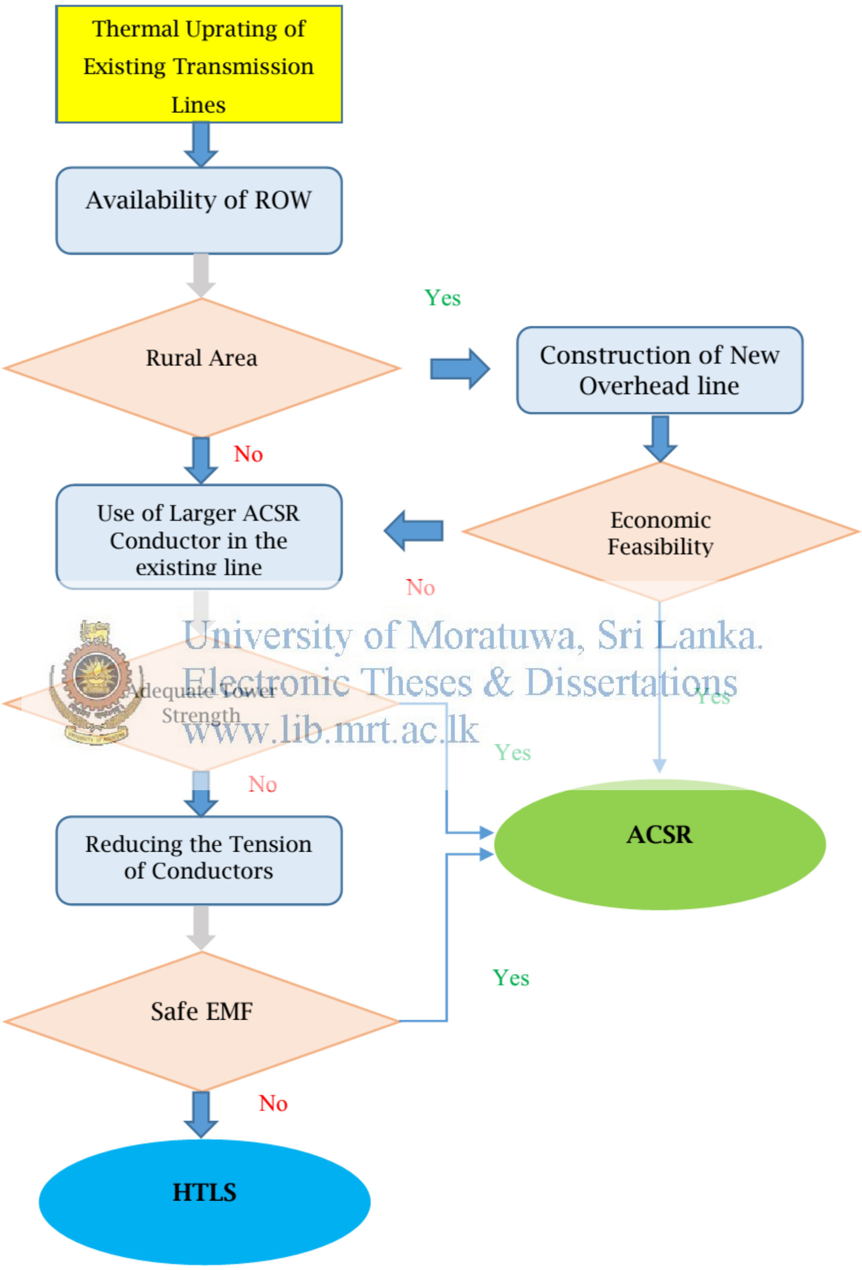


Figure 4.1- Algorithm for Transmission Line Uprating

4.3.1 Study of Reconstruction of Existing Line Using Manual Method

To find out the expedience of the proposed algorithm given in Figure 4.1, a real life example is studied below;

Case 1: Pannipitiya – Ratmalana 132kV Transmission Line

This line is destined to thermally uprated as the existing line capacity is no longer enough due to the increasing demand of respective areas. Below are some of the basic details of the line;

Line Name	:	Pannipitiya – Ratmalana 132kV Trans. line
No. of Circuits	:	2
Conductor Type	:	ACSR, Lynx
Line Length	:	7km
Operating Temp.	:	15°C (Min) and 54°C (Max)

Table 4.1 - Tower Types and Span length of Pannipitiya-Ratmalana Line

Tower No	Tower Type	Span (m)
1	TDT + 0	30
2	TD6 + 3	286
3	TD3 + 3	407
4	TDL + 0	302
5	TDL + 3	353
6	TD3 + 3	391
7	TDL + 3	355
8	TDL + 3	366
9	TDL + 0	341
10	TDL + 3	359
11	TDL + 3	393
12	TDL + 0	355
13	TDL + 0	327
14	TDL + 3	322
15	TD3 + 0	340
16	TDL + 0	324
17	TDL + 0	323
18	TDL + 0	340
19	TDL + 3	356
20	TD3 + 0	314
21	TDT + 0	242

Availability of ROW

Pannipitiya – Ratmalana transmission line is located in western province of Sri Lanka which has a very high population density level. This area has been developed a lot during past few decades and it is very difficult to find unused land areas in the area. There are lots of constructions have taken place under and alongside the existing line violating the ROW requirements.

Figure 4.2 - Aerial view of Pannipitiya – Ratmalana line
Source: Google Earth

From Figure 4.2, it can clearly be seen that the area is heavily populated under the power line and there is no ROW for a construction of new transmission line. However there may be possibilities such as complete demolition of existing line and construction of new line right over where the existing line was. This solution becomes less practicable given that the inability of taking such a long interruption period. At the same time uprooting of existing foundation is a very difficult activity which require additional time and manpower requirements. Therefore the decision becomes “No” for the condition “Rural Area” in the algorithm.

Then the next option is to look for restringing of the existing line with newer ACSR conductor with higher cross section. According to the future transmission planning map of CEB, the requirement of new Pannipitiya - Ratmalana line is to have more than 800 A in a circuit. Therefore new ACSR conductor shall have above CCC to fulfill the given requirement.

Current Carrying Capacity of Zebra Conductor [16];

I_{max}	Current Carrying Capacity	A	**834**
			Outputs
P_{rad}	Radiation Heat Loss	W	15.3260
P_{conv}	Convention Heat Loss	W	55.5927
P_{sol}	Solar Heat Gain	W/m	14.28138
N_u	Nusselt Number		15.920
R_e	Reynolds Number		788.55
R_T	Electrical Resistance of the conductor	Ω/m	0.00008149
			Inputs
Y	*Solar Radiation Absorption Coefficient*		*0.5*
D	*Conductor Diameter*	*m*	*0.02862*
S_i	*Intensity of solar radiation*	W/m^2	*998*
s	*Stefan- Boltzmann Constant*	$Wm^{-2}K^{-4}$	*5.67E-08*
K_e	*Emissivity coefficient*		*0.5*
T_1	*Ambient Temperature*	*K*	*305*
T_2	*Final equilibrium Temperature*	*K*	*348*
λ	*Air thermal Conductivity*	$Wm^{-1}K^{-1}$	*0.02585*
v	*Wind Speed*	*m/s*	*0.5*
T_{25}	*Minimum Operating Temperature*	*°C*	*25*
T_{75}	*Maximum Operating Temperature*	*°C*	*75*
R_{25}	*Resistance of the conductor @25*	*Ω/m*	*0.06841*
R_{75}	*Resistance of the conductor @75°C*	*Ω/m*	*0.08149*
T_θ	*Operating Temperature*	*°C*	*75*

Figure 4.3 - Current Carrying Capacity of Zebra Conductor

Figure 4.3 shows, the current carrying capacity of Zebra conductor based on IEC 61597. According to that ACSR Zebra conductor has the capacity to carry more than 800A in the circuit.

Nonetheless, it is to be checked whether the existing towers are capable of handling the forces exerted by new conductors because of the fact that the initial design had been carried out for Lynx conductors which has lesser unit weight and diameter compared to Zebra conductor. Therefore additional forces exerted by new conductors are calculated to check the safety of the towers.

Checking Tower Strength

Towers are handling three types of forces exerted by conductors [18, 19].

Transverse Forces	-	Due to Wind Pressure on conductors
Longitudinal Forces	-	Due to conductor tension
Vertical Forces	-	Due to conductor weight

These forces are acting right angle to each other.

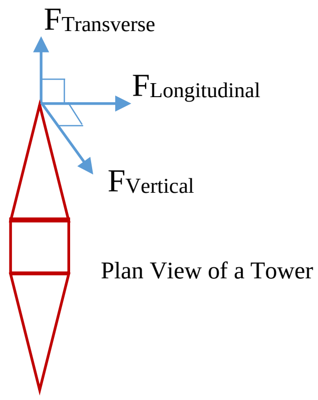


Figure 4.4 - Forces Acting on Towers

<u>Wind Span</u>

The wind span is half the sum of the adjacent span lengths of a particular tower. Transverse force acting on conductor depends on the wind span of towers.

<u>Weight Span</u>

The weight span is the distance between the lowest points on adjacent sag curves on either side of the particular tower. Weight span can be minus, when towers are sitting on mountainous terrains.

However, tower strength is usually restricted by transverse loads and longitudinal loads. Even longitudinal forces become cancelled in suspension towers under normal operation. Steel is good against axial forces and it is becoming vulnerable under bending loads. Therefore, towers are capable of absorbing additional vertical forces but transverse forces.

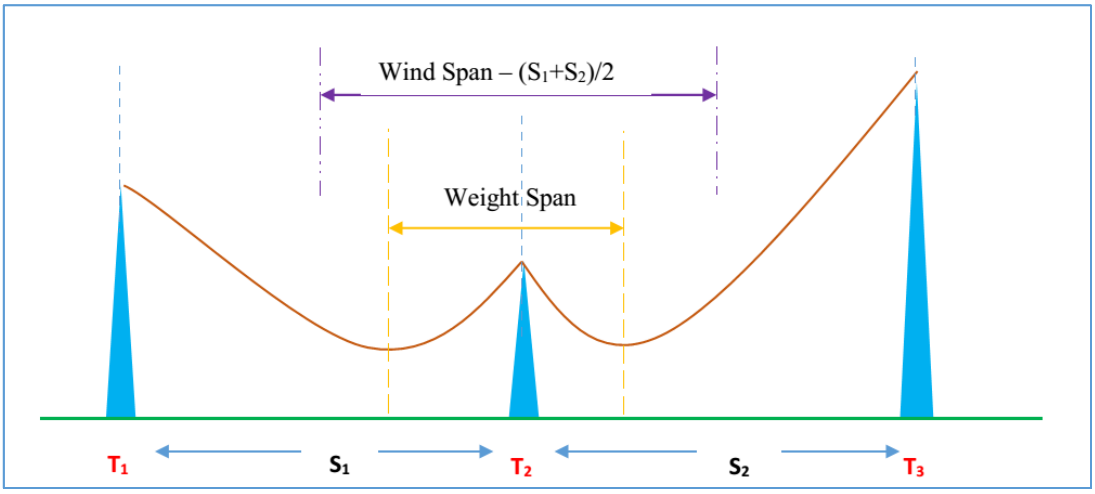


Figure 4.5 - Wind & Weight Span of Towers

$F_{Transverse}$ = ***Wind Pressure (N/mm^2) x Diameter (m) x Wind Span (m)***

Transverse Force exerted by Lynx Conductor,

= *970 N/m^2 x 0.01953 m x 360m*

= *6820 N*

Transverse Force exerted by Zebra Conductor;

= *970 N/m^2 x 0.02862 m x 360 m*

= *9994 N*

% Increase of Transverse Force exerted by New Zebra Conductor;

$$= \frac{(9994-6820)}{6820} \times 100\% = 46.54\%$$

$F_{Vertical}$ = ***Unit Weight (kg/m) x 9.80665 (ms^{-2}) x Weight Span (m)***

Vertical Force exerted by Lynx Conductor;

= *0.842 kg/m x 9.80665 ms^{-2} x 600m*

= *4954 N*

Vertical Forces exerted by Zebra Conductor;

= *1.621kg/m x 9.80665 ms^{-2} x 600 m*

= *9538 N*

% Increase of Vertical Force exerted by New Zebra Conductor;

$$= \frac{(9538-4954)}{4954} \times 100\% = 92.53\%$$

$$F_{Longitudinal} = \frac{\textbf{Ultimate Tensile Strength (kN)}}{\textbf{Safety Factor (2.5)}}$$

Maximum Longitudinal Force exerted by Lynx Conductor;

$$= 78.9/2.5 = 31.4kN$$

Maximum Longitudinal Force exerted by Zebra Conductor;

$$= 131.9/2.5 = 52.76kN$$

% Increase of Longitudinal Forces exerted by New Zebra Conductor;

$$= \frac{(52.76-31.4)}{31.4} \times 100\%$$

$$= 68\%$$

It is obvious that the safety factors are largely violated if new Zebra conductor is installed in place of existing Lynx conductors. However most of the towers are not fully utilized in terms of forces. Due to the restrictions of terrain type and the availability of ROW, tower spotting has been done in some places where, full tower utilization is not achieved.

Load adding to an already utilized tower

(a) Adding Vertical Loads

Unused Weight Spans

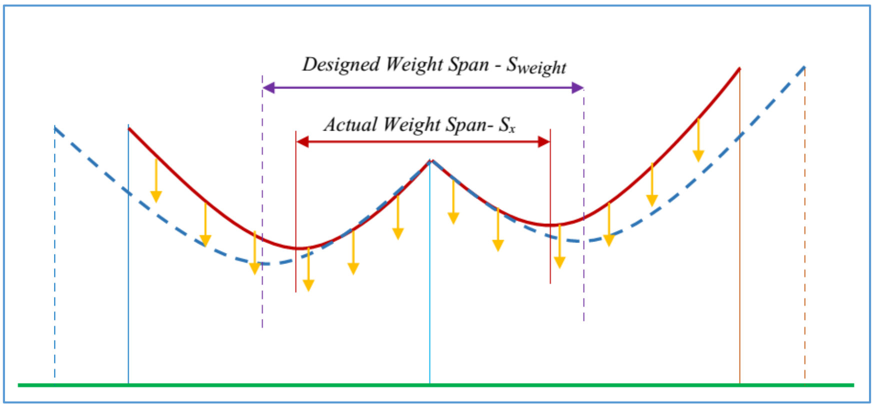


Figure 4.6 - Unused Weight Span of Towers

Unused Weight Span = Tower Designed Weight Span – Actual Weight Span

= $(S_{weight}-S_x)$

Addable longitudinal Force (kg) to the tower = Unused Weight Span x Conductor Unit Weight (m) x Number Conductor runs (n)

= $(S_{weight}-S_x)$ x m x n

Figure 4.6 shows the amount of vertical loads that is addable to the towers which are not using their fullest designed weight spans.

(b) **Adding Transverse Force**

Unused Wind Span

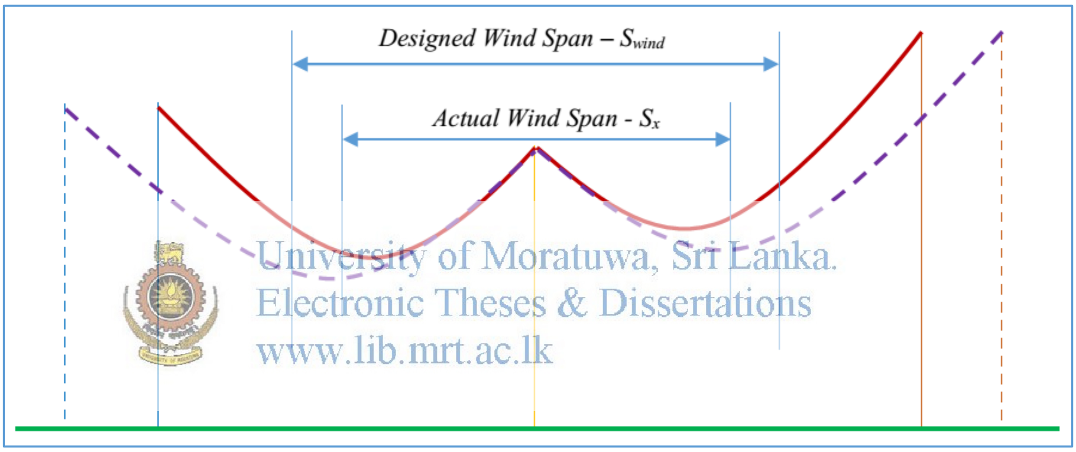


Figure 4.7 - Unused Wind Span of Towers (a)

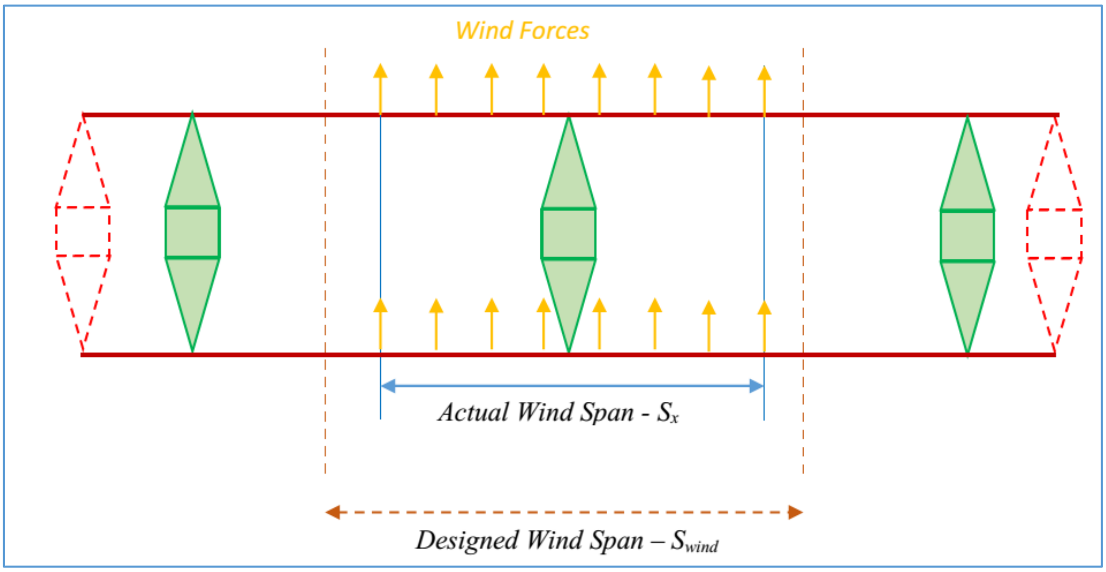


Figure 4.8 - Unused Wind Span of Towers(b)

Unused Wind Span = Tower Designed Wind Span – Actual Wind Span

= $(S_{wind} - S_x)$

Addable vertical Force (kg) to the tower = Unused Wind Span x Conductor Diameter (d) x Wind Pressure (P) x Nos. Conductors (n)

= $(S_{weight} - S_x) \times d \times P \times n$

(c) Angle Compensation

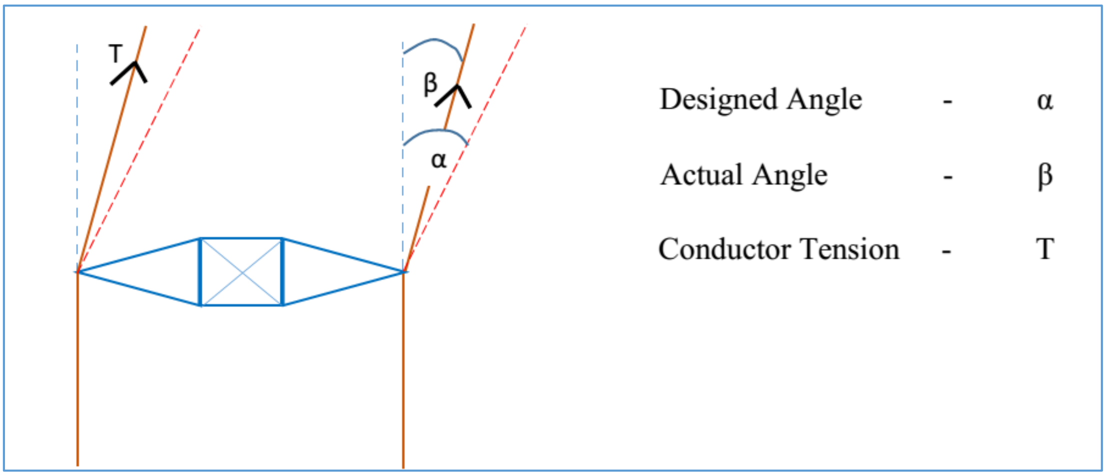


Figure 4.9 - Angle Compensation of angle towers

$$2T_{max}\sin(\alpha/2) - S_{wind} \times P \times d = 2T_{max}\sin(\beta/2) - S_{usable} \times P \times d$$

P - Wind Pressure

D - Diameter of the conductor

T_{max} - Ultimate Tension/ Safety factor @ stringent Con^{n}

Table 4.2 - Loads addable to existing towers

#	Tower Type	Span (m)	Weight Span (m)	Wind Span (m)	Unused Weight Span (m)	Unused Wind Span (m)	Addable Vertical Load (N)	Addable Transverse Load (N)
1	TDT + 0	30	182.36	158.0	67.64	202.0	**3364**	**22993**
2	TD6 + 3	286	347.55	346.5	552.45	13.5	**27477**	**1537**
3	TD3 + 3	407	321.84	354.5	578.16	5.5	**28755**	**626**
4	TDL + 0	302	351.68	327.5	248.32	32.5	**12350**	**3699**
5	TDL + 3	353	368.15	372.0	231.85	-12.0	**11531**	**-1366**
6	TD3 + 3	391	362.26	373.0	537.74	-13.0	**26745**	**-1480**
7	TDL + 3	355	391.35	360.5	208.65	-0.5	**10377**	**-57**
8	TDL + 3	366	315.60	353.5	284.4	6.5	**14145**	**740**
9	TDL + 0	341	382.05	350.0	217.95	10.0	**10840**	**1138**
10	TDL + 3	359	369.25	376.0	230.75	-16.0	**11477**	**-1821**
11	TDL + 3	393	336.90	374.0	263.10	-14.0	**13086**	**-1594**
12	TDL + 0	355	386.06	341.0	213.94	19.0	**10641**	**2163**
13	TDL + 0	327	354.64	324.5	245.36	35.5	**12203**	**4041**
14	TDL + 3	322	265.44	331.0	334.56	29.0	**16640**	**3301**
15	TD3 + 0	340	305.59	332.0	594.41	28.0	**29564**	**3187**
16	TDL + 0	324	413.13	323.5	186.87	36.5	**9294**	**4155**
17	TDL + 0	323	211.33	331.5	388.67	28.5	**19331**	**3244**
18	TDL + 0	340	435.00	348.0	165.00	12.0	**8206**	**1366**
19	TDL + 3	356	340.23	335.0	259.77	25.0	**12920**	**2846**
20	TD3 + 0	314	264.50	278.0	635.50	82.0	**31607**	**9334**
21	TDT + 0	242	151.00	121.0	99.00	239	**4924**	**27205**

Checking Conductor Vertical Loads

Table 4.2 shows, the status of each tower. Calculations are done as explained under above clause and design wind and weight spans are taken from CEB technical specifications. Additional transverse and vertical forces that could be absorbed by the towers are calculated with the help of unused wind and weight spans. It is clear that all the towers are capable of handling additional vertical loads exerted by new Zebra conductor.

Table 4.3 - Additional Vertical Loads on Towers

Tower No	Used Weight Span (m)	Additional Vertical Forces = a (N)	Addable Vertical Forces = b (N)	Tower Strength in terms of Vertical Forces (a<=b)
1	182	1407	3364	Ok
2	348	2682	27477	Ok
3	322	2484	28755	Ok
4	352	2714	12350	Ok
5	368	2841	11531	Ok
6	362	2796	26745	Ok
7	391	3020	10377	Ok
8	316	2436	14145	Ok
9	382	2949	10840	Ok
10	369	2850	11477	Ok
11	337	2600	13086	Ok
12	386	2980	10641	Ok
13	355	2737	12203	Ok
14	265	2049	16640	Ok
15	306	2358	29564	Ok
16	413	3188	9294	Ok
17	211	1631	19331	Ok
18	435	3357	8206	Ok
19	340	2626	12920	Ok
20	265	2041	31607	Ok
21	151	1165	4924	Ok

Table 4.3 has studied whether additional vertical forces provided by the new conductor are accommodated by comparing it with addable vertical loads. All the towers are capable of absorbing the new forces exerted by the new conductor and so there is no violation of safety in terms of vertical forces in this case.

However most of the towers are not capable of absorbing transverse forces that will exert by the new Zebra conductor. Even in the same design, some of the towers are loaded more than they are supposed to, in terms of transverse forces. Therefore it is obvious that safety factors will get violated in a considerable amount with the replacement of existing conductor with a conductor which has two times the diameter.

Checking Conductor Transverse Loads

Table 4.4 - Additional Transverse Forces

Tower No	Used Wind Span (m)	Additional Transverse Forces = c (N)	Addable Transverse Forces = d (N)	Tower Strength in terms of Vertical Forces = (c<=d)
1	158	1393	22993	Ok
2	347	3055	1537	No
3	355	3126	626	No
4	328	2888	3699	Ok
5	372	3280	-1366	No
6	373	3289	-1480	No
7	361	3179	-57	No
8	354	3117	740	No
9	350	3086	1138	No
10	376	3315	-1821	No
11	374	3298	-1594	No
12	341	3007	2163	No
13	325	2861	4041	Ok
14	331	2919	3301	Ok
15	332	2927	3187	Ok
16	324	2852	4155	Ok
17	332	2923	3244	Ok
18	348	3068	1366	No
19	335	2954	2846	No
20	278	2451	9334	Ok
21	121	1067	27205	Ok

From Table 4.4, it is clear that more than 50% of the towers are not capable of absorbing additional transverse forces exerted by the new conductor.

Checking Conductor Longitudinal Loads

Conductor longitudinal loads are acting along the conductor. In line towers or Suspension towers, the resultant longitudinal force acting on towers is zero as the similar forces are acting in opposite directions. However in angle towers, the resultant longitudinal force will not be zero. Therefore with the use of new Zebra conductor, its maximum UTS cannot be used for tensioning as existing structures are not designed to withstand that value. If Zebra conductor's initial tension is selected, the safety factor of the tower will get violated in a considerable amount.

Tower Designed Strength	=	79.8 kN	
Typical Zebra conductor's Initial Tension	=	131.9/2.5	= 52.76kN
New safety Factor	=	79.8/52.76	= 1.5125 (66%)
Reduction in safety factors	=	$\frac{(2.5-1.5125)}{2.5} \times 100\%$	= 39.5%

It can be seen that the safety factor is reduced by almost 40% if the typical Zebra conductor is used on existing towers. Given the aging factor of towers, the use of an ACSR Zebra conductor with a higher cross section seems to be an extremely risky job.

According to the above calculations, we could see that the existing towers are not capable of absorbing the longitudinal forces exerted by Zebra conductor. If we consider a line that could accommodate those additional transverse forces, still the longitudinal forces will not satisfy the required safety factors.

In those circumstances, safety can be improved by employing a lower tension on towers. According to the algorithm given above, once the existing towers are not providing enough strength, a lower tension value can be used for stringing new conductors. Although this method will in turn create some ground clearance issues, as the conductor sag will be increasing at higher temperatures for lower initial tension values.

Conductor Sag for Lynx conductor at 54°C = 6.7 m (for 300m span)

This is the ground clearance value that had been used during the construction of old transmission line. Designers might have kept 0.3 m to 0.5 m for surveying and sagging error. This must be ensured after referring to the existing profile drawing given they are available. Otherwise a simulated design for the initial condition shall be carried out to finding out whether such a clearance is left. If that is available, that will be an advantage as the line could tolerate additional sag without violating required ground clearance.

Therefore, ground clearance that could be achieved by reducing tension of the conductor is discussed.

Sag of new Zebra conductor at Max. Operating Temperature = 7.52m

(Span =300m, Min Tem = 7°C, Max Tem =75°C, Initial Tension = 52.76kN)

Ground Clearance could be achieved = Height to the bottom most conductor – Sag

= 13.7m – 7.52m = 6.18m (< 6.7)

Safety Factor Ratio = 79.8/52.76 = 1.51 (<2.5)

Safety Factor % UTS = 100/1.51 = 66.12%

It can be seen that by using typical initial tension of Zebra conductor (52.76kN) would result a lower safety factor and even the required ground clearance according to the CEB specifications which is 6.7m, cannot be achieved.

Table 4.5 - Tension vs Ground Clearance

Conductor Longitudinal Force (kN)	**Sag @ Maximum Operating Temperature (m)**	**Ground Clearance (m)**	**Safety Factor**	
			Ratio	**% UTS**
52.76	7.52	8.195	1.51	66.12
50	7.96	7.755	1.60	62.66
45	8.85	6.865	1.77	56.39
40	9.91	5.805	2.00	50.13
35	11.22	4.495	2.28	43.86
31.92	12.21	3.505	2.50	40.00

From the Table 4.5, it can be seen that by reducing initial tension to improve safety factor is not a solution as the ground clearance getting minimized with reduced tension.

There are mainly two reasons, that minimized Ground Clearance cannot be used for the new modifications;

1. There are illegally constructed buildings under the power line, where by higher sag values will violate required clearance from obstacles.

2. Lower Ground clearance will increase EMF level under the power line, which would be harmful to human health.

It obvious that first case is violated under the power line where already constructions have taken place.

ICNIRP (International Commission for Non-Ionizing Radiation Protection) is an independent organization, which provides scientific advice and guidance on the health and environmental effects of non-ionizing radiation (NIR) to protect people and the environment from detrimental NIR exposure. Table 4.6 shows the exposure values published by them [20];

Table 4.6 - EMF exposure limits

	Electric Filed (kV/m)	Magnetic Field (μT)
Public	5	100
Occupational	10	500

Source: http://www.icnirp.org/

These are the values that most of the utilities in the world are adhered to. In Sri Lanka also, there are no any country specified values on restricting EMF exposure under overhead lines and therefore values publish by ICNIRP are used. Typically electric field under the power line depends on the voltage and the magnetic field depends on current flowing in the line.

After considering above two factors, it is obvious that the improvement of tower safety factors by reducing tension is not a solution as the safety clearances are getting violated with the increase in conductor sag. Therefore according to the algorithm, the next option shall be considered.

4.3.2 Reconstruction with the use of Design Software – PLS CADD

Without a doubt, PLSCADD has become the most premium software package used for overhead line design in the world. Therefore, the same transmission line (Pannipitiya – Rathmalana 132kV line) is studied using PLSCADD software for its competency to be upgraded based on the algorithm given above [21]. In Appendix D, complete PLS Design is given.

1. Profile Data

Ground coordinate shall be provided in terms of Latitude and Longitude with elevation data, to form a profile of the transmission line route in PLSCADD. Therefore it is always useful to have these data available for the transmission line to be studied. If those data are not available, there are various methods to develop the profile of the line.

- Carrying out a complete ground survey of the line
- Carrying out a LIDAR survey
- Use of Google Earth data

Carrying out a ground survey will require extra amount of time as well as man power. However ground survey data are more accurate compared to other methods given above. LIDAR is a technology that is used for remote sensing and the same have developed in a way that it could be used for transmission line surveying. This requires an air borne flat form, typically a helicopter or a fixed wing aircraft. This method is bit costly and has never been used in Sri Lanka.

Easiest method of developing ground profile is the use of Google Earth data. Google Earth is freeware which popular all around the world as a virtual globe. These data can be extracted with the use of online software and could be converted into preferable geographical coordinate systems. Though the accuracy of google earth data is low compared to ground survey data, they are more than enough for the preliminary studies of developing ground profile. Therefore in this study, Google Earth coordinates were extracted to develop the ground profile of Pannipitiya – Ratmalana overhead line.

2. Feature Code

To develop a line route in PLSCADD, there are minimum set of requirement that shall be input to the programme. From google earth software, we can grab x,y,z (Longitude, Latitude, Elevation) data. Then these set of data have to be assigned with a code called feature code data. Below are the feature code data that have been used for the design;

200 - Ground Points

100 - Angle Points

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 clea

	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 :r. Base/Gu :o Spotting Constraint (m)
1	100	Angle Points	☒	☒	Yes	No	No	0	0	6.7	4	0
2	200	Ground			Yes	No	Yes	0	0	6.7	4	0
3												
4												

Figure 4.10 - Feature Code View

There are other feature code data such as roads, rivers, tanks, buildings could be defined during detailed designed stage of the line. However, initial study shall be done using above two feature code data.

2. Criteria Files

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 (mm)	Wire Ice Density (N/m^3)	Wire Ice Load (N/m)	Wire Temp. (deg C)	Ambient Temp. (deg C)
1	Cold + Wind	0.613	39.7792	970	0	0	0	15.0	15.0
2	Cold	0.613	0	0	0	0	0	15.0	15.0
3	EDS	0.613	0	0	0	0	0	32.0	32.0
4	EDS + Moderate_Wind	0.613	28.5598	500	0	0	0	32.0	32.0
5	Hot	0.613	0	0	0	0	0	54.0	32.0
6	Max. Swing	0.613	39.7792	970	0	0	0	25.0	25.0
7									
8									

Figure 4.11 - Weather Criteria File

When developing an overhead line design using PLSCADD, it is required to develop criteria files (Files that keep design inputs) at the beginning of the programme. This includes safety factors, environment data, cable types, weather data etc.Maximum operating temperature of Pannipitiya – Ratmalana line is 54°C and the minimum operating temperature of the line is 15°C. Therefore the temperature criteria have been designed to be matched with the existing line design.

3. Structure Files

Structures files can be developed using PLSCADD/ PLSTOWER software based on "As built drawings" or ground surveyed measurements.

4. Cable Tension and Automatic sagging

Cable tensioning and sagging of conductors have been done according to the safety limits published under CEB technical Specifications given in Table 3.7.

Automatic Sagging Criteria

	Weather case	Cable condition	% of Ultimate	Maximum Tension (N)	Maximum Catenary (m)
1	Cold	Initial RS	39.990	0.000	0.000
2	EDS	Creep RS	22.210	0.000	0.000
3	EDS	Creep RS	22.210	0.000	0.000

Figure 4.12 - Automatic Sagging Criteria

5. Stringing/ Sagging

Conductor stringing could be done in two ways;

a. Based on the measured/ surveyed sag values

Conductor ground clearance and temperature could be measured using hot line tools and with use of thermal recoding equipment. Conductor maximum sag values can then be calculated and conductors will be strung according to the calculated values using PLSCADD. This method is more accurate, when the design criteria of the existing line is not known.

b. Based on Automatic Sag

Conductors could be strung using automatic sag option in PLSCADD. If the initial line was designed based on the correct design criteria, this method is useful and it can reduce labour hours of collecting ground survey measurements. Pannipitiya- Ratmalana transmission line is modelled using method b.

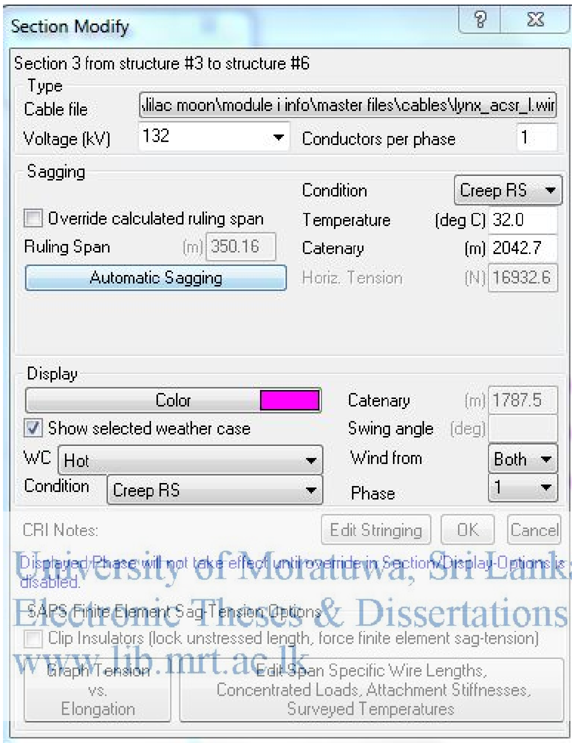


Figure 4.13 - Section Modify window

Figure 4.13 shows the stringing details of the transmission line. Here it could be seen that the catenary value is around 2050m.

Catenary constant (C) =

$$\frac{H}{W} = \frac{\text{Tension}}{\text{Conductor Unit Weight}} = \frac{83.1\times 1000}{S.F \times 8.289} = 2050\text{m}$$

Safety Factor@ EDS = 4.89 (> 4.5)

It can be seen that the conductor tension is satisfying the safety requirement at EDS condition. Stringing is done at 32°C. Output display is selected to be showing the conductors at its maximum temperature. Figure 4.14 shows the simulated profile view of Pannipitiya – Ratmalana 132kV existing Lynx line.

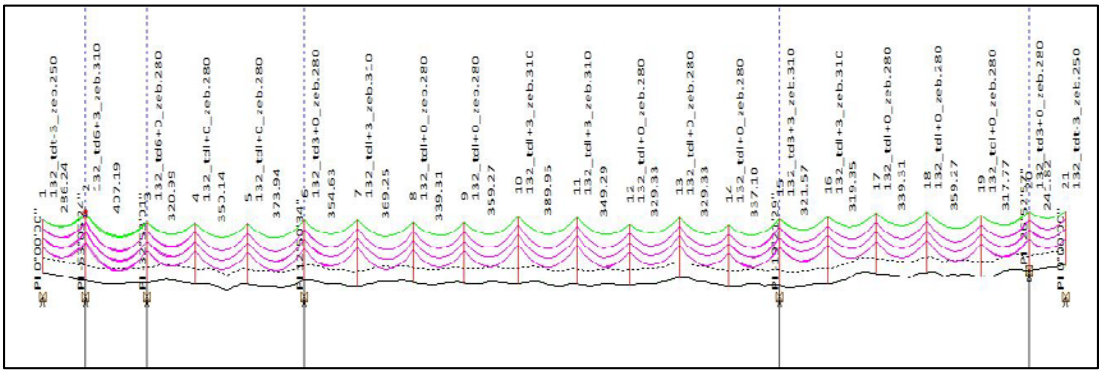


Figure 4.14 - Profile view of Panniptiya –Kolonnawa ACSR Lynx line

Use of ACSR Zebra conductor in the same towers

It was observed that there is no ROW for a new transmission line to be constructed and according to the algorithm it was chosen to upgrade the existing line by introducing a new ACSR conductor with a higher cross section.

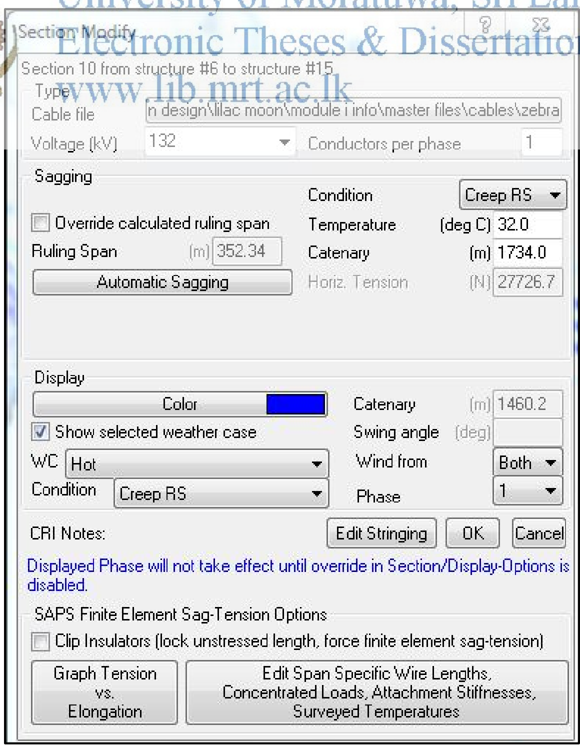


Figure 4.15 - Section Modify window for Zebra conductor

Therefore the same software design was carried out for Zebra conductor using selected operating condition as in the case of Figure 4.3 above.

Here, Operating Temperature is selected as 75°C and minimum temperature was taken as 7°C to be matched with present design requirements.

Horizontal Tension of the conductor = 27730 N

Safety Factor @ EDS Condition

$$= \frac{\text{UTS of Lynx Conductor where existing towers are designed}}{\text{Tension of Zebra @ EDS}}$$

$$= \frac{83.1 \times 1000}{27726.7} = 3\ (<4.5)$$

It can be seen that, with the given criteria, the safety factor could be achieved is less than 4.5 which is the required safety factor based on CEB specifications.

Figure 4.16 shows the profile view of Pannipitiya – Ratmalana 132kV line with Zebra conductor.

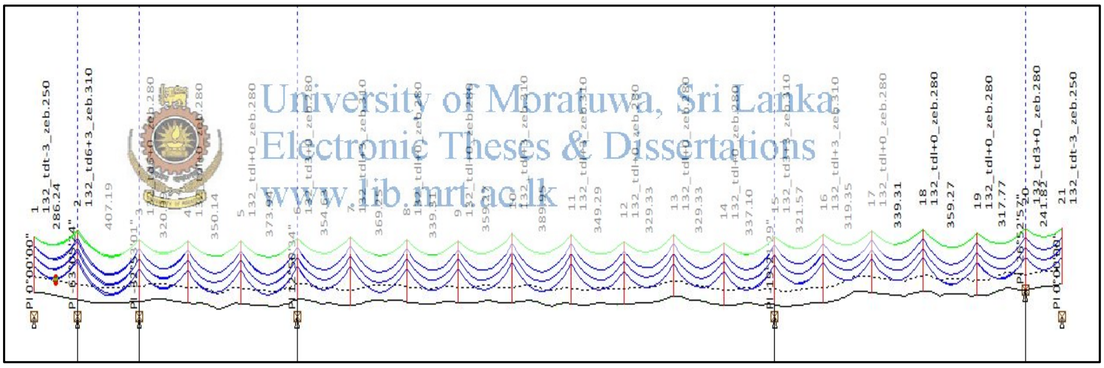


Figure 4.16 - Profile View of Pannipitiya-Ratmalana 132kV Zebra line

It can clearly be seen that even at this tension, the conductor violates clearance curve in many sections of the line. Therefore reduced tension to achieve more safety will not be doing any good as the sag increases with reduced tension.

Checking EMF Level under the power line

Using PLSCADD design software, EMF field study has been carried out and the graphs showing electric and magnetic field level are prepared below.

Electric Fields

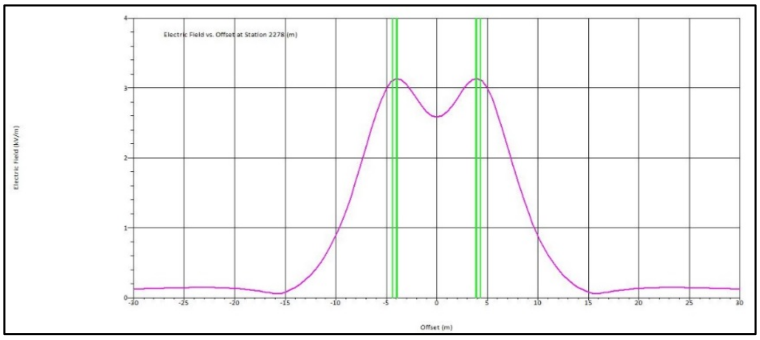


Figure 4.17 - (a) Electric Field of Panniptiya – Ratmalana Existing Lynx Line

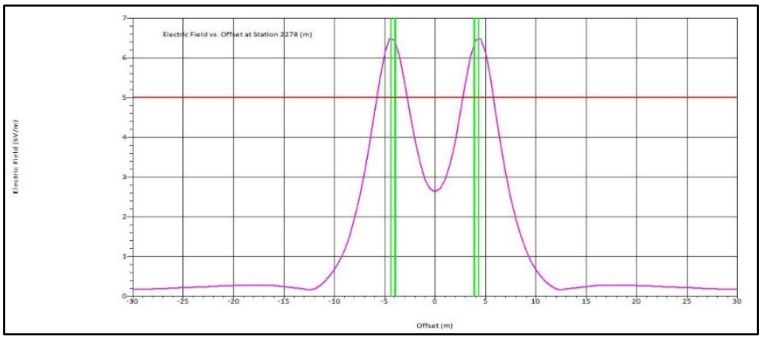


Figure 4.18 - (b) Electric Field of Pannipitiya – Ratmalana Upgraded Zebra line

Magnetic Field

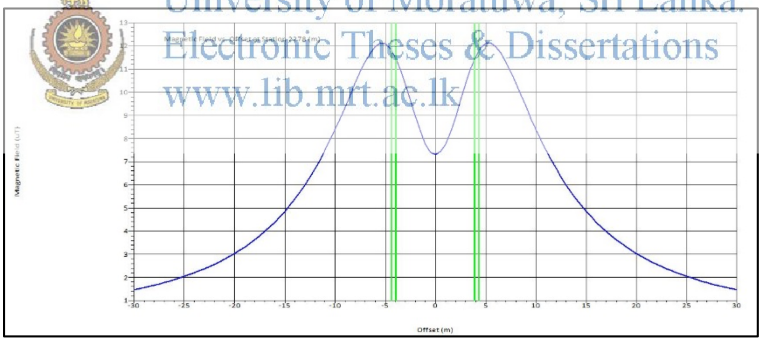


Figure 4.19 - (a) Magnetic Field of Panniptiya – Ratmalana Existing Lynx Line

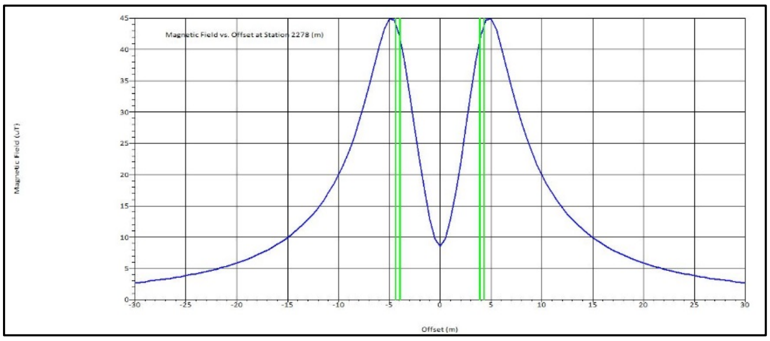


Figure 4.20 - (b) Magnetic Field of Panniptiya – Ratmalana Upgraded Zebra Line

Table 4.7 - EMF comparison

	Field under existing Lynx Line	**Field under uprated Zebra line**
Electric Field	3.2kV/m	6.4kV/m
Magnetic Field	12.2μT	45μT

Figures 4.17, 4.18, 4.19 and 4.20 show the EMF level at the middle point between tower No 7 and 8 of Pannipitiya-Ratmalana line before and after it is uprated. Table 4.7 shows the values of electric and magnetic fields of each case and it can clearly be seen that the electric field value has been risen beyond the allowed level (See Table 4.6) once the line is uprated. Though there is an increase in the magnetic field, it is still not harmful according to the limits published by ICNIRP. This has happened due to the increased sag of Zebra conductors at the operating temperature of 75°C.

It was seen above that the safety factor of the line is around 3.0 which is below the required value of 4.5 at EDS condition. However according to the algorithm, there is no need to go to the next option of reduction of tension of the conductor to increase safety limits as EMF values are already have exceeded the boundary level. Therefore the only option left in this case is to go for reconductoring using HTLS conductors.

Summary Flow Chart of Pannipitiya – Ratmalana existing line uprating case study

Table 4.8 shows the path for selecting the most appropriate solution in the case of Panniptiya – Ratmalana 132kV line uprating based on the algorithm given under the chapter 2.2.3.

Table 4.8 - Summary flow chart of the case study of Pannipitiya- Ratmalana line uprating.

Condition	Check for	Result	Comment
Availability of ROW	Rural Area	No	Line is located in a heavily populated area and there is no ROW availability between respective substations
Use of Larger ACSR conductor in the same line	Adequate tower strength	No	Existing towers are not capable of absorbing additional forces exerted by new ACSR conductor without violating safety factors
Reducing the tension of ACSR conductors	Safe EMF level	No	Further reduction of tension will cause conductors to sag more and in turn will increase the EMF level under the power line beyond its safe limits

During the above case study, most of the factors in the algorithm were discussed that involves in the path above. However it is important to discuss other options that could be resulted in the process of selecting the best solution in line upgrading. As an example, in a case where there is enough ROW availability in between substations to construct a new transmission line, the decision has to be taken based on economic considerations.

Case 2: Samanalawewa - Embilipitiya 132kV transmission line

This line is proposed to be uprated according to the long time transmission planning programme of CEB. The line was constructed with the use of ACSR Lynx conductor and supposed to be thermally uprated to have a current carrying capacity similar to Zebra conductor. This is similar to the case of Pannipitiya – Ratmalana transmission line discussed above.

If the same algorithm is used in this case, it is seen that there is enough ROW near the existing power line to construct a new line unlike in the case of Pannipitiya – Ratmalana line. The line is basically running in an area where there is neither much population nor pile of constructions. However attention shall be given to environmental importance of the area as there are few forest reserves located in the area.

According to the algorithm, it is seen that the availability of ROW leads to checking of economic feasibility of the new line. Economic feasibility shall be studied under different perspectives and this require various approaches.

Economic Feasibility will depend on below factors;

Table 4.9 - Factors to be considered for Economic Feasibility

	Uprating an Existing Line	**Construction of New Line**
Cost of major equipment	Only conductor cost	Total Project cost
Compensation for crop damage	No	Crop damage shall be given
Line interruption cost	Require interruption	No need of interruptions
Conductor energy Loss	High at higher temperatures	Low
Environmental considerations	Very Low	High

Economic feasibility of reconstruction and uprating will be discussed in the next clause under selection of HTLS conductors.

4.3.3 Selection of HTLS Conductors for Restring

It is seen that in the above case studies, uprating of existing Panniptiya – Ratmalana transmission line can only be done with the use of HTLS conductors. The next challenge is to find out the most suitable HTLS conductor, as there are few number of various HTLS conductors are available in the market.

Major Factors to be considered when selecting the most appropriate HTLS conductors.

- Similar Dimension as with the existing Lynx conductor, so that it will not affect the transverse forces being exerted on the line
- Similar unit weight, so as to keep similar vertical forces.
- Similar UTS, so that towers could be tension without violating safety factors.
- Lower KPT, so that conductor sag will increase at a very low rate, from the very beginning.
- Lower unit resistance, so that the conductor I^2R losses could be restricted, at higher operating temperatures.

Pannipitiya – Ratmalana line is to be uprated to have double the capacity of Lynx conductor. CCC of Lynx conductor at 54°C is 400A. Therefore, selected HTLS conductor shall have double the capacity of Lynx conductor and its sag value shall not violate the required ground clearance at the particular temperature. At the same time, conductor tension on conductors shall be similar so that no need of tower modifications.

UTS of Lynx Conductor = 79.8kN

Safety Factor at sagging condition = 4.5

Tension on towers = 79.8/4.5 = 17.73kN

Table 4.10 - Conductor Stringing Tensions

Conductor Type	ACCC	GTACSR	ZTACIR	ACSS
Conductor Name	Oriole	200mm^2	159-160	Lark
UTS	98.3	80	63.7	77.8
Safety Factor	5.54	4.51	3.59	4.39
% RTS	18.05	22.17	27.86	22.78

Table 4.11 - Properties of HTLS conductors

Conductor Type	**ACCC**	**GTACSR**	**ZTACIR**	**ACSS**
Conductor Name	Oriole	200mm^2	159-160	Lark
Diameter (mm)	18.821	19.0	18.2	17.781
Cross Section (mm^2)	222.3	208	159.3	201.4
Unit Weight (kg/km)	688.9	844.8	706.8	925.3
Operating Temp. when CCC is 800A (°C)	114	140	173.5	147.8
Unit Resistance at given operating Temp. (Ω/m) at	0.12831	0.21088	0.27101	0.20721
KPT (°C)	70	32	117	98
Sag @ KPT (m)	5.6	6.14	7.03	7.98
Sag @ operating Temp. (m)	5.72	7.81	7.33	8.84
Annual Energy Loss (MWh)	15,774	18,720	23,295	17,810

From Table 4.11, it could be seen that ACCC conductor provides the best performances as it gives the lowest losses and the lowest sag value. At the same time, ACCC provides higher safety factors during stringing which is 5.54 (>4.5) compared to other types of conductors.

Sag values given by ACSS conductor exceeds the maximum allowable sag value of Lynx conductor 54°C, which is 7.72m. Though ZTACIR conductor has slightly higher sag, this could be reduced by increasing the tension by a small percentage. Therefore, ACCC, GTACSR and TACIR conductors could achieve required clearance levels.

Though, ACCC provides the best performances in terms of losses and mechanical sag, it requires special string methods compared to conventional stringing. GTACSR conductor also requires special two method string and require trained staff. On the other hand, ZTACIR conductor can be strung with conventional methods and no need of trained staff for stringing. Stringing is further described in chapter 6 of this document.

5.0 IMPROVING CLEARANCE OF EXISTING LINES

5.1 INTRODUCTION

Based on Figure 3.1 of chapter 03, one another category where the use of HTLS conductors is considered, is the area of improving electrical and safe clearance of existing transmission lines. The main difference between this category and the previous one (thermal uprating) is that, this does not require improvement in the capacity of the conductor. Most of the older transmission lines have violated their safety clearances due to many reasons.

Some of the reasons are listed below;

- Conductor creep which have taken place for years
- Alteration of ground profile by human activities and weather
- Construction of illegal buildings and houses under power lines

All these cases have made unsafe clearances to phase conductors from the ground and buildings, which require some kind of rectification to improve safety.

Figure 5.1 - Alteration of original ground profile in Kolonnawa – Pannipitiya 132kV line

Table 5.1 - Clearance from conductors

Description of Clearance	*Minimum Clearance (m)*	
	132 kV	***220 kV***
Minimum ground clearance at any point not over roads	*6.7*	*7.0*
Line conductor to road surface	*6.7*	*7.4*
Line conductor to high load route surface	*7.5*	*8.5*
Line conductors 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*
Where power lines cross or are 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*
Support of upper line and any conductor of lower line	*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*

Source: CEB technical Specifications [5]

1. These clearances are possible for situations where skycradle can be used for conductor erection and maintenance. These clearances allow for the positioning of Skycradle and erection of temporary scaffoldings under a live circuit.

2. Clearances shall be defined in a way that the upper conductor at its maximum temperature and coincides with the lower conductor, which at its minimum temperature and deflected by an angle of 45 degrees.

3. Clearances shall be defined with the conductor at its specified maximum temperature and deflected by any angle up to 45 degrees.

4. To account for minor variations in ground in ground topography and foundation installation, the transmission line profile shall be plotted with an additional clearance of 0.3m over those specified in the table 5.1.

5.2 ALGORITHM FOR CLEATANCE IMPROVEMENT OF EXISTING LINES

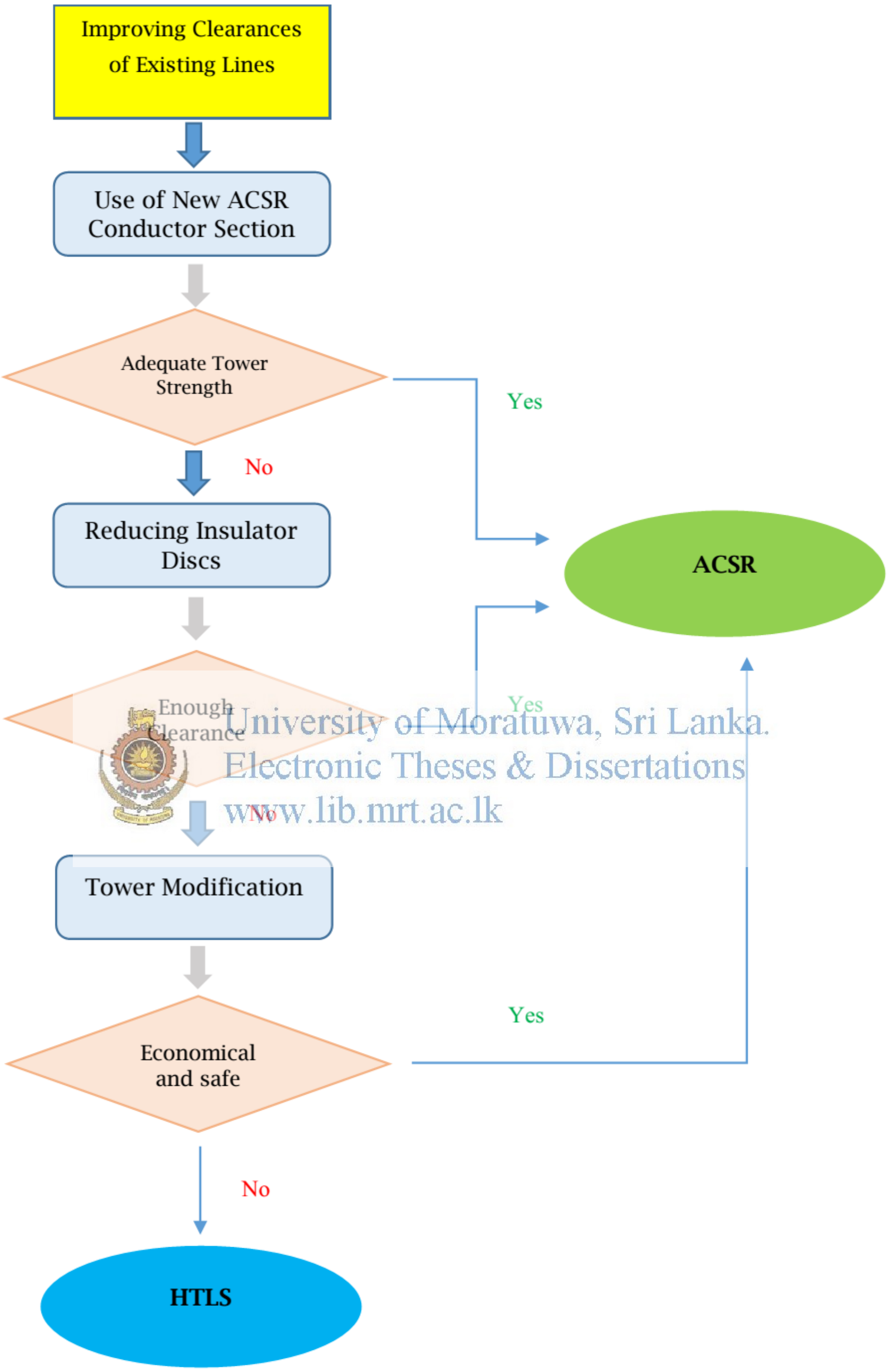


Figure 5.2 - Algorithm for Line Clearance improvement

Figure 5.2 shows the algorithm for the process of improving conductor clearances of existing overhead lines. As discussed in an earlier chapter, most of the old transmission lines in Sri Lankan electricity grid have been disturbed by illegal constructions. Further, the conductor creep has taken place over the years and deformation of Aluminium and Steel had resulted increase in conductor sag. Most of these issues can be seen in overhead lines located in the suburb of Colombo, where highest population density is recorded in the country.

5.2.1 Study of Clearance Improvement of Existing Line

Case 1: Kolonnawa – Pannipitiya 132kV Transmission Line

To describe the above algorithm, a real life example has been selected. This overhead line is constructed more than 40 years ago and there are number of places where, conductor clearance has been violated due to number of reasons.

During the ground survey conducted by the Operation and Maintenance branch of CEB, it was observed that the ground clearance between some of the towers are not satisfying required limits. As an example the clearance between tower No. 11 and 12 is observed as 5.6 meters. Further. This span is located in an area which is highly populated and number of illegal constructions have taken place. Therefore it was decided by the CEB to improve the clearance of that span.

Present Condition of the Line

- **Design Criteria**

Conductor Type	-	ACSR, Lynx
Minimum Operating Temperature	-	15ºC
Maximum Operating Temperature	-	54ºC

- **Conductor Properties**

UTS	-	83.1kN
Nos. of Strands	-	37 (30/7)
Diameter	-	19.53mm
Cross Section	-	226.2mm^2
Modulus of Elasticity	-	84000N/mm^2

Thermal Expansion Coefficient - $19.53 \times 10^{-6}\ ^{o}C^{-1}$

- **Current Carrying Capacity**

Based on IEEE 738-2006;

At $54^{0}C$, 12.00PM - 340 A

At 540C, 00.00AM - 411 A

(Wind Velocity- 0.6m/s, Sun Radiation- 1032W/m^2 @ noon & 0 W/m^2 @ night, Solar Absorption and Emissivity- 0.5, Atmosphere- Clear)

- Present Condition

Ground Clearance at mid span - 5.6m

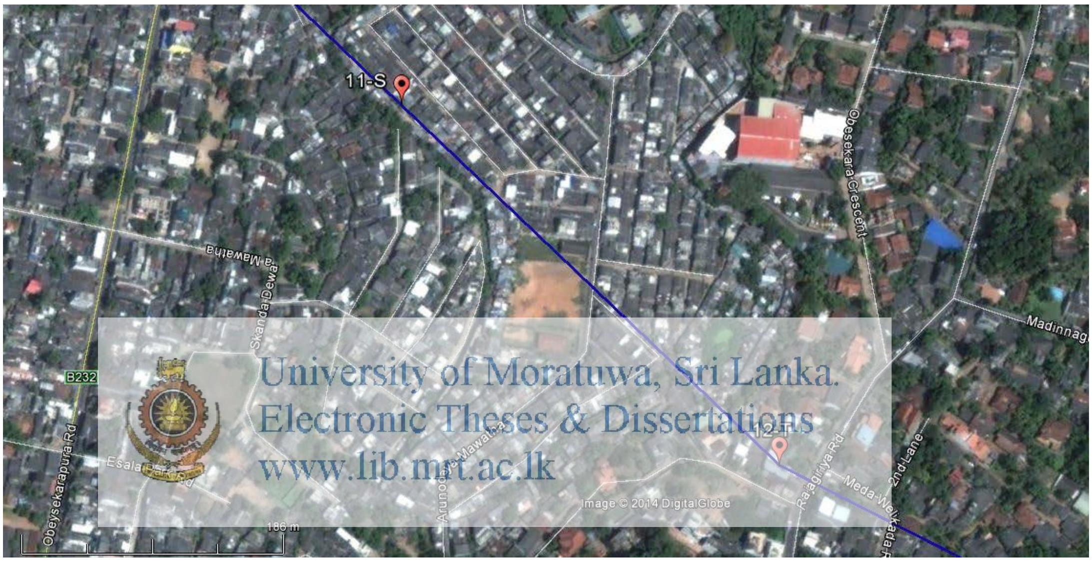


Figure 5.3 - Sky View of the area near tower Number 11 and 12
Source: Google Eaarth

Details of the Section to be modified

Tower Details

Table 5.2 - Section details where ground clearance is violated

Tower No	Tower Type	Angle	Tower Height	Bottom Cross arm Height
10	Angle Tower	17^{o} 09’ 54’’	28.387m	15.759m
11	Suspension Tower	0	26.394m	14.716m
12	Angle Tower	-16^{o} 37’ 40’’	31.463m	18.921m

Span Length & Clearances of the section

Table 5.3 - Span details of the Sections where ground clearance is violated

Tower No	**Length (m)**	**Minimum Ground Clearance (Based on the ground Survey)**
10 -11	268	8.6
11-12	368	5.6

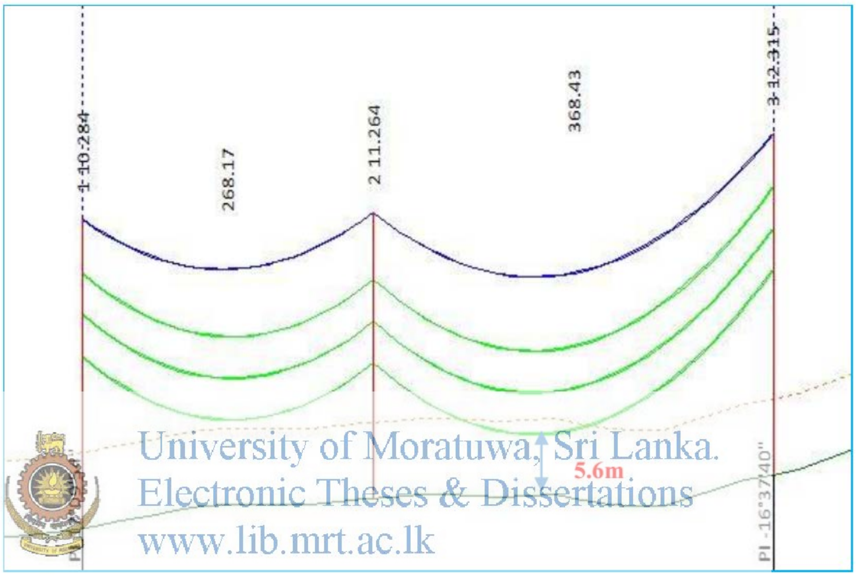


Figure 5.4 - Profile drawing of the present section view

It is assumed that the line is operated at 32°C under Everyday Stress and Sag Tension details of the section is taken from PLSCADD design.

- Catenary constant at EDS condition - 1628.4m
- Horizontal Tension of the section - 15,126.6N
- Designed tension at EDS condition - $\frac{\text{UTS of Lynx}}{\text{Safty Factor @ EDS}}$
  - 83,181.7/4.5
  - 18,484.82N> (15,126.6)
- % Reduction of the section - 18%

Therefore, it could be decided that the line has undergone permanent creep overtime or it had been designed to have a lower initial tension.

(a) Use of new ASCR conductor section

As a solution in the process of line clearance improvement, the algorithm shown under Figure 5.2 is proposed. According to that, the first step to be followed in such occasion is to use of the same conductor between the particular sections that is to be improved.

Therefore, PLSCADD design was carried out for the use of new ACSR Lynx conductor section between the lines.

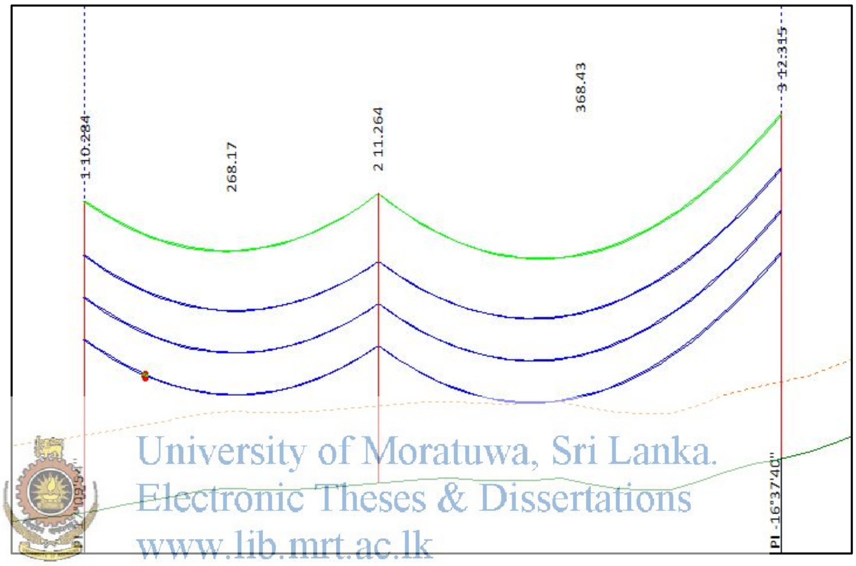


Figure 5.5 - Profile view of the section with new tensioned Lynx Conductor

<u>Condition during Sagging</u>

- Catenary constant at sagging condition	-	2650m
- Horizontal Tension at Initial RS condition	-	21,967N
- Safety Factor at Sagging Condition	-	$\frac{\text{UTS of Lynx}}{\text{Safty Factor @ EDS}}$
	-	83181.7/21,967
	-	3.78 (<4.5)

Initial RS: Conductors during stringing stage are considered at their initial RS condition, where they have not yet undergone average tension over certain period of time.

From above details, it is clear that, required safety factor, which is 4.5 at EDS condition, cannot be maintained during the time of conductor stringing if a new Lynx conductor is laid replacing the existing one.

<u>Condition during Operation</u>

- Catenary constant at EDS condition	-	2073m
- Horizontal Tension at Creep RS condition	-	19,254N
- Safety Factor at Creep RS condition	-	83,181.7/19,254
	-	4.3 (<4.5)

Creep RS: When conductors are subjected to average tension for a certain period of time, it reaches to a stage where the condition of the conductor is in Creep RS.

Even when the conductors have crept, the tension of the conductors are not able to achieve required safety limits and hence this method cannot be used as a solution in improving line clearance of the particular section.

Therefore according to the algorithm, next option has to be selected, which is reduction of Suspension insulators in Line towers.

(b) Reduction of Insulators

Insulator string sets in suspension towers of high voltage lines have a significant creepage distance to withstand particular insulation levels. Insulation design of a particular line is depending on several factors:

(1) Lightning effect
(2) Internal abnormal voltage (switching surge etc)
(3) Insulation coordination with the insulation level of substation equipment connected with the power network
(4) Pollution level surrounding the line facilities
(5) Insulation deterioration due to increase of altitude of the line location

According to CEB technical specification, number of insulators in a string is defined as follows;

Table 5.4 – Number of discs in an insulator string set

Description	**132kV**		**220kV**	
	Nos. of string per set	Nos. of Discs per string	Nos. of string per set	Nos. of Discs per string
Normal Suspension String	1	11	1	16
Heavy Suspension String	2	11	2	16
Jumper Suspension String	1	11	1	16
Normal Tension String	1	12	2	16
Light Duty Tension String	1	12	1	16

Source: CEB technical Specifications [5]

However, values of this Table 5.4 could be subjected to alterations, depending on environmental conditions, as the pollution level becomes the most dominant factor when deciding insulation level of HV lines.

Below calculation is used to determine the number of insulators required in a string based on environmental pollution level [22];

Pollution Level of the area	=	20 mm/kV		
System maximum Voltage	=	145kV		
Total Creepage distance required	=	20 x 145 =	2900 mm	
Creepage distance of an standard insulator	=	320 mm		
Number of Insulators required	=	2900/320	≅	10
Number of Spare insulators	=	1		
Number of discs per string	=	10+1 =	11	
50% flashover voltage (255mm insulator)	=	975 kV		

It is assumed that the minimum pollution level required in the area is around 20mm/kV [8].

Table 5.5 - Requirement of Insulators based on CEB technical specifications

		Unit	132kV	220kV
(a)	Minimum impulse withstand voltage, wet	kV(*)	800	1050
(b)	Power frequency withstand voltage, wet	kV(*)	300	395
(c)	Minimum mechanical breaking strength			
	Normal suspension string set	kN	120	120/160
	Heavy suspension string set	kN	120	120/160
	Jumper suspension string set	kN	70	70
	Normal tension string set	kN	160	160
	Light duty tension string set	kN	70	70

Source: CEB Technical Specifications [5]

The section where clearance to be updated in Pannipitiya – Kolonnawa transmission line, the middle tower (No.11) is a suspension tower, whereby reducing the length of insulator string assembly, the ground clearance of the conductor could be upgraded. At the same time, is noted that amount of suspension insulators in that strings is 12.

However, when reducing number of insulator discs in a string, it should be ensured that the minimum arcing gap clearance is not violated. Based on experiments, flashover and withstand characteristics of rod gaps, minimum clearance for gap is defined for arcing horns.

Table 5.6 - Suspension String details

System Nominal Voltage (kV)	132
System Impulse Withstand Voltage (kV)	650
Required Horn Gap (mm) (Z)	1190
Spacing of an existing Glass Insulator Disc (mm)	146
Total length of the string (mm) (Z_0)	146 x 12 = 1752
Exiting Horn Gap Ratio (Z/Z_0) of the line	1190/1752 =0.68

From experiments, it has been found that the arc to be flashing through air gap between the horns (without the surface of the insulator sets) during flashing over, the maximum arcing gap ration (Z/Z_0) should be maintained around 0.9 at 132kV level. Therefore;

The minimum distance required for insulator strings = 1190/ 0.9 =1322mm

Minimum Nos. of discs required = 1322/146 = 9 Nos.

Insulator length could be reduced = (12-9) x 146 = 438 mm

Therefore, by reducing three number of insulators, 438mm of insulator length could be reduced and hence the conductor attachment point could be uplifted the same. However with the reduction of insulator discs, the total creepage distance of the insulator unit gets reduced.

Total creepage distance based on pollution level = 2900mm

Total creepage distance of the original string = 320 x 12 = 3840mm

Creepage distance, after reducing 3 insulator discs = 3840- (320x3) = 2880mm

% Reduction of creepage distance $= \frac{(2900-2880)}{2900} \times 100\%$ = 0.68%

Therefore by reducing three number of insulators from the string, required creepage level has not been disturbed significantly.

In case where, total creepage distance gets significantly reduced by the reduction of insulators, the rest of the discs could be replaced by discs with higher creepage values, such as fog type insulators. Below Table 5.7 shows different types of possibilities of the use of various types of insulators to achieve the same [23].

Table 5.7 - Alteration of the length of the insulator string

System Nominal Voltage (kV)	132			
Maximum System Voltage (kV)	145			
Required Impulse Withstand Voltage (kV)	650			
Horn Gap Required (mm)	1190			
Insulator Type (Dia/Spacing) (mm)	254/146	320/146	320/170	
Minimum Nos. of Insulators required	8	7	7	7
Nos. of Spare Insulators required	1	1	1	0
No. of Units Required (pcs)	9	8	8	7
Length of Insulator Set	1314	1168	1360	1190
Gap Length/ Length of Set (%)	**90.6**	**101.9**	**87.5**	**100.0**
50% Lightning Impulse Flashover Voltage (kV)	815	825	825	735
Insulator Disc Weight (kg)	5.5	8.9	10.2	10.2
Change in Weight (kg) (Bottom Cross arms)	3	46.4	67.2	46.8
Creepage Distance of the Insulator (mm)	320	550	550	550
Specific Creepage Distance (mm/kV)	19.9	30.3	30.3	**26.6**
Number of Insulators in the existing set	12			
Length of the Insulator set (mm)	1752			
Nos of Insulator discs can be reduced	3	4	4	5
Clearance could be achieved (mm)	**438**	**584**	**392**	**562**

Length of arcing horn gap to length of total string is recommended to be at 0.75 by the past experiences. Therefore minimum number of insulators could accommodated in the string is found above based on that assumptions. It is seen that by using nine (9) numbers of 255mm diameter insulators, the total length of the insulator could be reduced by 438mm and so is conductor attachment point. 50% impulse flashover voltages are given in Appendix E.

Therefore below PLS design was carried out to find out whether it is possible to achieve the required ground clearance by reducing three (3) number of insulators from the original set.

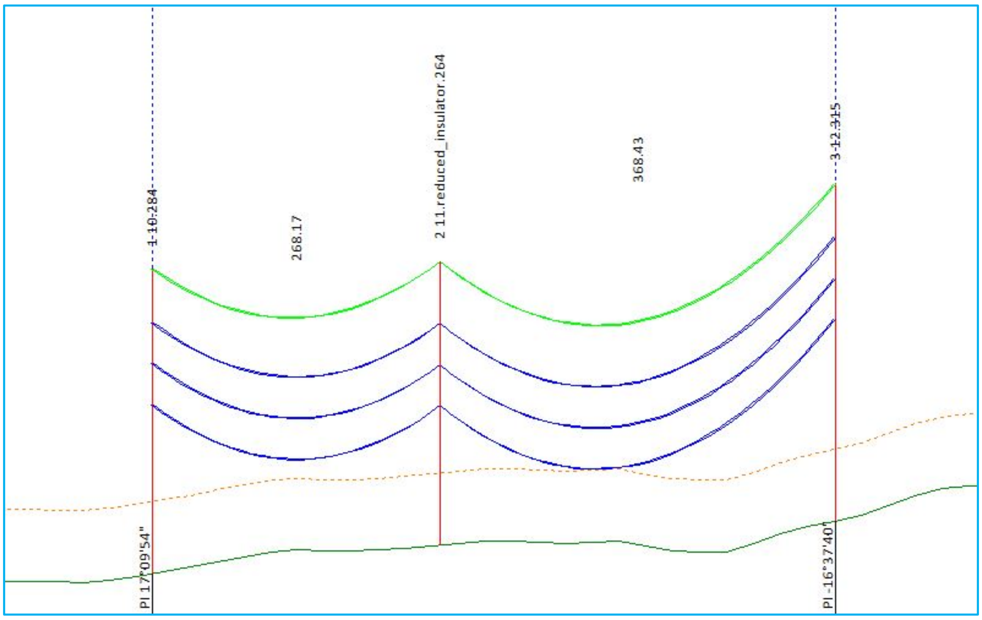


Figure 5.6 - Profile view of the section after reducing insulator discs

<u>Condition during Sagging:</u>

- Catenary constant at sagging condition - 2500m

- Horizontal Tension at Initial RS condition - 20,723N

- Safety Factor at Sagging Condition - $\frac{\text{UTS of Lynx}}{\text{Safty Factor @ EDS}}$

  - 83181.7/20,723

  - 4.01 (<4.5)

<u>Condition during Operation:</u>

- Catenary constant at EDS condition - 1992m

- Horizontal Tension at Creep RS condition - 18,500.2N

- Safety Factor at Creep RS condition - 83,181.7/18,500.2 = 4.5

Therefore it is clear that by elevating conductor attachment point of line towers by reducing insulator discs could improve ground clearance into some extent. However in this case study, still the safety factor during stringing is not providing the desired safety values.

However Line towers are supposed to be designed to have two times the safety factor in terms of tower loadings. Therefore the designer has the freedom to allow slight mitigation of safety factors given he has all the original design details and drawings available.

To move to the next step of the algorithm let's assume that safety factor is not satisfied in this section.

(c) Improving Clearance by Tower Modifications

Modification of existing towers is a challenging task. Especially, old towers are expected to lose its strength with time, due to aging. Life time of a tower is heavily dependent on environmental conditions around and attention shall be given to all the factors when modifying an existing structure [24, 25].

Possible modifications to existing towers when improving ground clearance;

- Adding Body Extensions
- Replacement of suspension insulators by tension insulator sets
- Use of post insulators mounted on cross arms
- Use of insulated cross arms

In the particular section of Pannipitiya – Kolonnawaa transmission line, the middle tower is a line tower (TDL) where suspension insulators are used to hang the conductors. Therefore the easiest of above, which is the replacement of suspension insulator sets by tension insulators is checked as a solution to this case. From this method, TDL tower in the middle becomes a section tower or in other words a tension tower.

PLSCADD design is carried out to check the results of the proposed method.

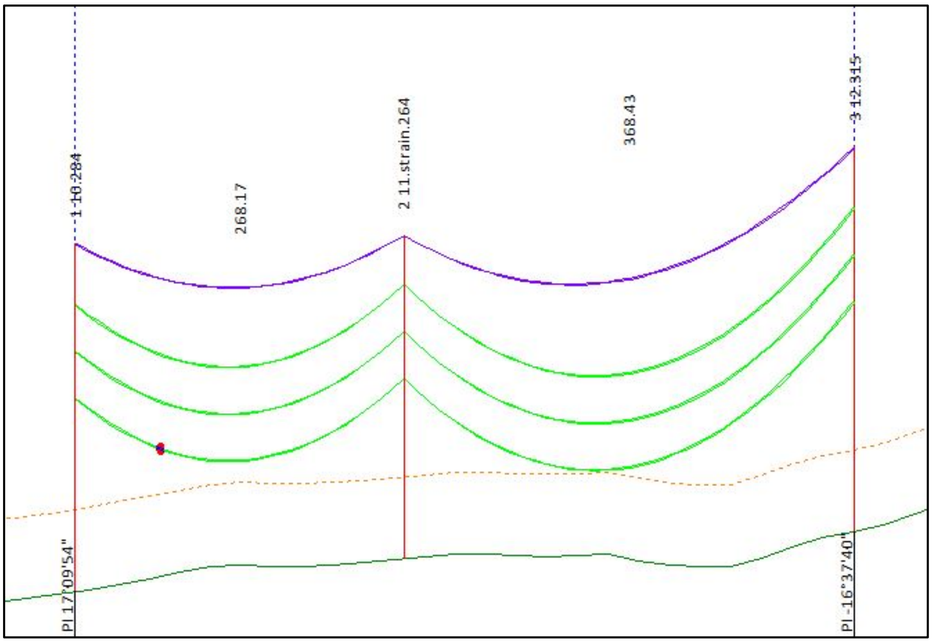


Figure 5.7 - Use of the middle tower as a section tower

<u>Condition during Sagging:</u>

- Catenary constant at sagging condition - 2050m
- Horizontal Tension at Initial RS condition - 16,933N
- Safety Factor at Sagging Condition - $\frac{\text{UTS of Lynx}}{\text{Safty Factor @ EDS}}$
  - 83181.7/16,933
  - 4.91(>4.5)

<u>Condition during Operation:</u>

- Catenary constant at EDS condition - 1768m
- Horizontal Tension at Creep RS condition - 16,425N
- Safety Factor at Creep RS condition - 83,181.7/16,425 = 5.06

Therefore, it can be seen that by using the middle tower as a section tower, the safety factors could be achieved during stringing as well as operation.

However, it should be noted that the Line towers are not originally designed for unbalanced longitudinal forces. Broken wire length of TDL towers is very low compared to Angle towers and therefore during stringing, care must be given that no significant unbalance longitudinal force get exerted on towers by the conductors.

Further, suspension towers (TDL) are not initially designed for uplift forces. Although, there is a possibility that uplift forces are acting on tower foundations under tension conditions. Suitability of existing foundations shall be checked for uplift capacity which require invasive soil/ foundation tests.

However, the method of converting suspension tower into an Angle tower, in this case a Section tower, is a very good solution in the process of clearance improvement of Pannipitiya – Kolonnawa line.

According to the algorithm, the flow will end here. However the next option, which is the use of HTLS conductors as a solution in the case of ground clearance improvement is studied in next sub section.

5.2.2 Use of HTLS conductors to improve clearance of existing lines

HTLS conductors could be used to improve the clearances of existing lines, purely because they have a lower thermal expansion characteristics at higher temperatures hence lower sag. Although, HTLS conductors are generally employed at high temperature operations, they can also provide better performances even at lower temperatures compared to the same size ASCR conductors in terms of its mechanical operations as well as electrical loss reductions.

However, the selection of most suitable HTLS conductor shall be done very carefully, so that most economical and technically accurate performances could be achieved. According to the system control center information, maximum current flowing through the line is around 430 A. Therefore, below analysis in the Table 5.8 was carried out to find out the performances of various HTLS conductors during the operation temperatures that produce 430A.

Table 5.8 - Selection of suitable HTLS conductor for clearance improvement

	ACSR	GTACSR	ZTACIR	ACCC	ACSS
Name	Lynx	Lynx equivalent	159-160	Oriole	Lark
Diameter (mm)	19.53	19.7	18.2	18.821	17.781
UTS (kN)	80.1	79.8	60.2	98.3	77.8
Unit Weight (kg/km)	842	813	706.8	688.9	925.3
Unit Resistance at operating Temperature (Ω/km)	0.18241	0.17856	0.20574	0.14607	0.15983
Thermal Exp. Coefficient of core (x 10^{-6} °C^{-1})	19.3	11.5	3.78	1.6	11.5
Knee Point Temperature (°C)	>75	32	>110	30-80	50-100
Operating Temperature when I = 450A	65	69.6	69.5	60.2	62.9
Sag (m)	6.41	5.82	5.89	4.39	5.91

Note: Ambient Tem 32°C, Emissivity and solar absorption 0.5, Solar Radiation 1000W/m^2, Atmosphere clear, wind speed 0.5ms^{-1}

Here also, attention must be given when selecting different types of HTLS conductors, that they all have similar dimensions to the Lynx conductor to be replaced. This is so, important that by doing so, the forces acting on towers could be kept unchanged where tower will not see any significant change in forces being exerted by new conductor.

From above Table 5.8, it can clearly be seen that ACCC conductor provides the best performances in terms of sag characteristics. Its operating temperature to produce 430A is the lowest among all, as it has the lowest unit resistance value.

5.3 STRINGING REQUIREMENTS

As explained under chapter 2 of this document, material properties of these HTLS conductors are different, and because of that reason, their stringing requirements are also different. Typically GTACSR and ACCC conductors are made up with fully annealed (1350-O) aluminium outer core that require additional care during stringing. Even a little bruise could harm the conductor’s outer complexion.

Even during sagging ACCC and GTACSR conductors use two stage sagging method unlike in the case of ACSR, which require trained staff in stringing. However, in occasions where improving clearances of random sections of an existing line, employing such a trained staff would not be economical and practical unless the utility already have one. At the moment, CEB does not have personnel who have the practice of stringing special conductors and hence the use of those conductors in our system could be questionable.

On the other hand, the stringing method used for ACSS and ZTACIR conductors are more similar to ACSR, hence stringing does not require trained personnel. Quality and the performance of lines are no longer depending on expert workmanship. Though, ACCC provides very good loss reduction performances, it is no longer important, since a single section out of existing ACSR conductor being replaced. Therefore total line loss will remain unchanged.

As discussed under chapter 2 of this document, ZTACIR is a HTLS conductor that has a higher KPT. Therefore its low sag characteristics cannot be used unless the conductor is operated to that temperature. However, as shown in the Table 5.8, it will never reaches its KPT and conductor performances will be very similar to ACSR.

Finally, when selecting the most suitable HTLS conductor, all above factors shall be considered in terms of technical accuracy, financial viability and practicability.

Figure 5.8 shows, PLS criteria file for the use of ACCC conductor for the improvement of ground clearance.

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 (mm)	Wire Ice Density (N/m^3)	Wire Ice Load (N/m)	Wire Temp. (deg C)	Ambient Temp. (deg C)	Weather Load Factor
1	Cold + Wind	0.613	39.7792	970	0	0	0	15.0	15.0	1
2	Cold	0.613	0	0	0	0	0	15.0	15.0	1
3	EDS	0.613	0	0	0	0	0	32.0	32.0	1
4	EDS + Moderate_Wind	0.613	28.5598	500	0	0	0	32.0	32.0	1
5	Hot	0.613	0	0	0	0	0	60.2	32.0	1

Figure 5.8 - PLS Criteria file for the use of ACCC conductor

Accurate design of criteria file is a very important factor, with the use of HTLS conductors. In Table 5.8, it says that ACCC conductor shall be operated at 60.2°C to achieve required CCC. Therefore *Hot condition* of the design shall be named the same in the criteria file.

Results of the design

Condition during Sagging:

- Catenary constant at sagging condition	-	2500m
- Horizontal Tension at Initial RS condition	-	16,892N
- Safety Factor at Sagging Condition	-	$\frac{\text{UTS of Lynx}}{\text{Safty Factor @ EDS}}$
	-	98,300/16,892
	-	5.82 (>4.5)

Condition during Operation:

- Catenary constant at EDS condition	-	1941m
- Horizontal Tension at Creep RS condition	-	15,057N
- Safety Factor at Creep RS condition	-	98,300/15.057 = 6.52

Safety factors are more than satisfied with the use of ACCC conductor. The same design could be implemented to other HTLS conductors and conductors and check the safety factors. At the same time other aspects such as stringing, operation and maintenance requirements shall be considered when selecting optimal conductor. Therefore it is clear that HTLS conductors could be a very good candidate in the process of improving existing overhead line clearances where they are violated due to many reasons.

5.4 SUMMARY

Important factors when selecting HTLS conductors during clearance improvements

- Tower Safety

  Conductors with similar dimensions shall be selected so that transverse forces acting due to the wind effect be the same compared to the existing conductor. Weight of the conductors shall be similar so that no additional vertical forces will be acting on towers. UTS of the HTLS conductors shall not be significantly low compared to the existing conductor so as to maintain the safety requirement of the utility.

- Stringing Requirement

  Some of the HTLS conductors require special stringing methods. It requires trained personnel to carry out stringing works and considerable amount of time will be required to get the job done. Since only a small section of the line is replaced, employing such staff would not be economical as well as practical. Therefore it is always better to use HTLS conductors that have conventional stringing requirements as the better selection.

- Thermal Expansion Coefficient and KPT

  It is desirable to have a lower thermal coefficient and lower KPT value with the conductor being used. That results lower sag values at lower temperatures. However, most of the conductors that do have lower KPT requires special string requirements. Therefore those two factors (KPT and Special string requirements) always stands against each other and designer should get the decision on selecting the most appropriate conductor after compromising.

- Loss Reduction

  This is one another famous slogan of HTLS conductor manufacturers. However, as mentioned under section 5.3, loss reduction should not be a factor that the selection of conductor shall rely on during clearance improvements as only a small section of the line is replaced and for the fact that the overall line loss remain unchanged.

6.0 CONSTRUCTION OF NEW TRANSMISSION LINE

6.1 INTRODUCTION

As shown in Figure 3.1 of this document, the use of HTLS conductors are discussed under three major categories. Under chapters 2 and 5, first two categories were discussed and under this chapter, the third method, which is the use of HTLS conductor in new transmission lines will be discussed.

Under introduction, it was stated that almost all the conductors being used in Sri Lanka's transmission system are ACSR. When the demand was low in the past, designers used ACSR Lynx conductor and later they adopted to Zebra conductors, which has a higher capacity compared to Lynx. However, recently the construction of overhead lines became a challenge as they have to pass through severe environmental conditions and unavailability of ROW. Further with the increase in marginal cost of electricity, and increase in demand most of the utilities in the world started looking of ways from which they could increase the efficiency in bulk power transmission.

As a result of all above reasons, conductor manufacturers came up with a solution called HTLS conductors which they claims to reduce energy loss in conductors as well as provide superior sag tension capabilities during operation. However, most of the utilities have not absorbed HTLS conductors into their existing networks willingly without doing proper analysis.

In Sri Lanka also, the utility does not have much experience and knowledge regarding this new technology and therefore it is very important, to study about this technology and deploy it where necessary in order to achieve efficiency and to have an economically vibrant power system.

However, still in the sector of overhead line construction, most preferred way of constructing lines is with ACSR conductors. In Sri Lankan power system also the trend is the same. Therefore it is very important it is to understand the situations where this technology could be deployed. Therefore an algorithm is prepared to discuss the possibilities of the use of HTLS conductors in Sri Lanka's power system where appropriate.

6.2 ALGORITHM FOR NEW TRANSMISSION LINE CONSTRUCTIONS

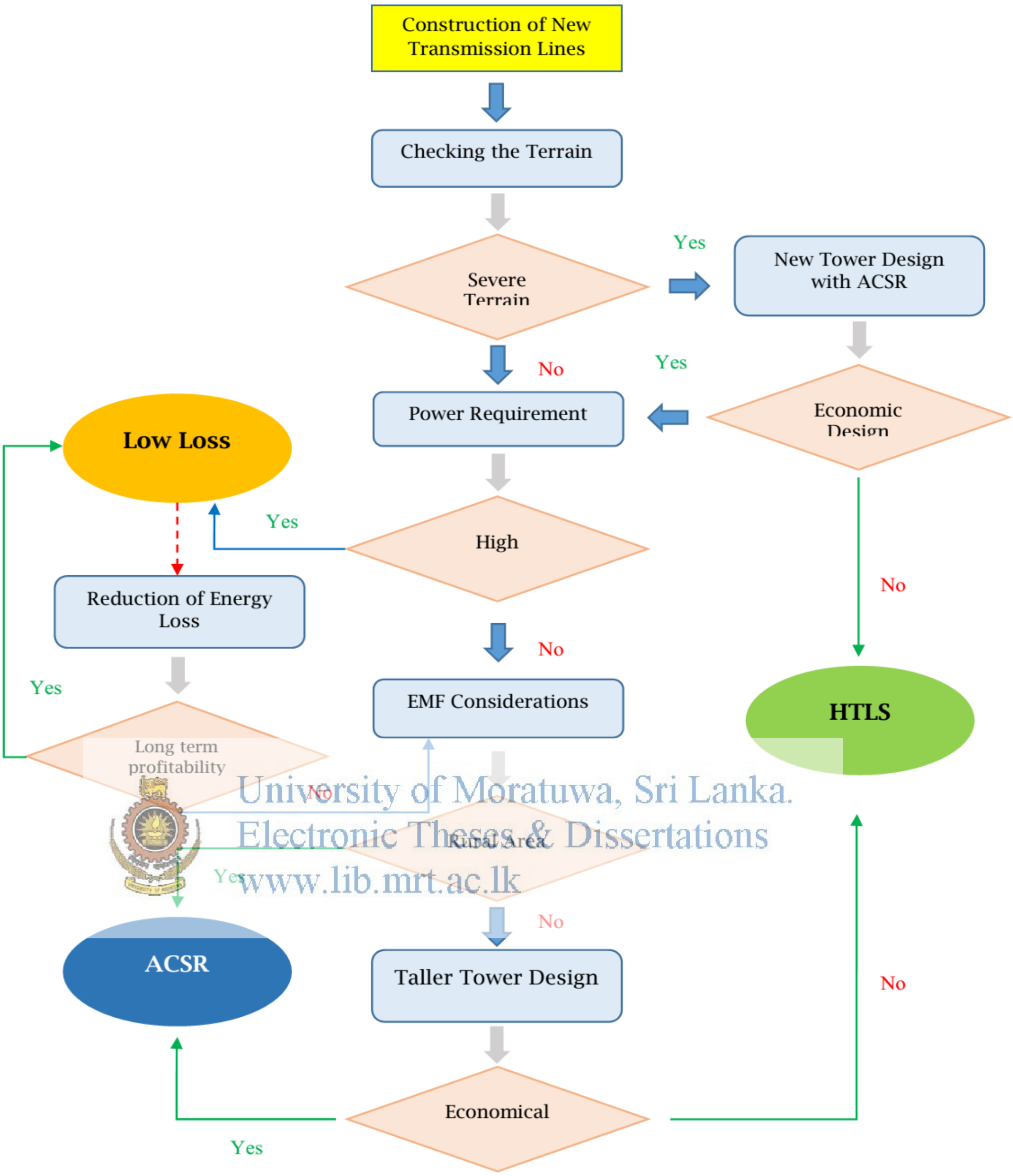


Figure 6.1 - Algorithm for Construction of New Transmission Line

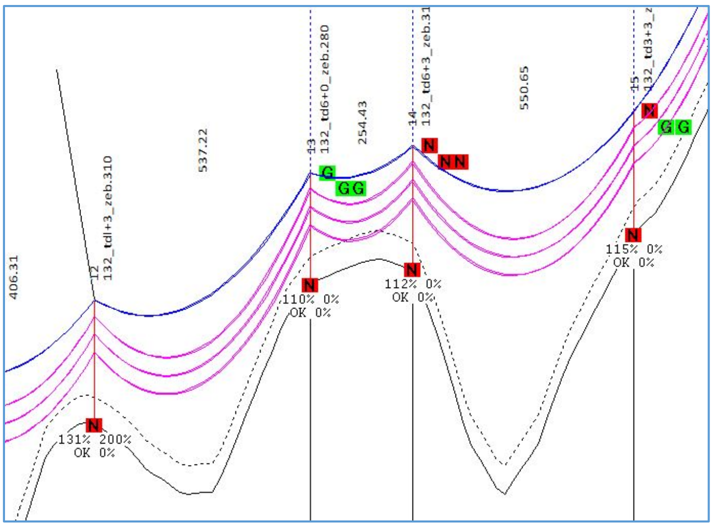
Algorithm shown in Figure 6.1 is prepared with the intention of providing a basic flat form in selecting most appropriate conductor type when constructing newly proposed overhead lines. Unlike in the previous two occasions, where existing conductors were replaced to thermally uprate the old line and to improve clearances of existing line, the algorithm proposed here is somewhat complex. During conductor replacement and clearance improvement, the designers are restricted with limited options and in case of new line constructions, there are plenty of options are left in hands of design engineers.

Below sections of the documents will discuss the algorithm given above in details;

6.2.1 Checking the Terrain

Once a new transmission line is defined, the first activity that should be carried out is the selection of most appropriate line route. Best possible line will be a straight line that connects two ends. However due to many reasons almost always it is impossible to have a transmission line with a straight line. Geographical changes on earth, manmade constructions, weather conditions, and livelihood are some of the factors that influence the shape of the transmission line. Usually other than geographical variations such as mountains, rivers, lakes, marshy areas other factors cannot change the basic design of transmission lines given that types of loadings are the same. Therefore when designing lines routes, the most important factor to be considered in terms of tower design criteria is the geographical variations.

In CEB technical specifications, transmission line design criteria is given (See Table 3.2, 3.3 and 3.4) and all the existing designs are carried out according to them. However there might be situations where these criteria is not matched due to the surface profile of the line route.



N – Not Good

G - Good

Figure 6.2 - PLS profile design of proposed Nawalapitiya line route

From Figure 6.2, it can be seen that tower safety is violated as the wind and weight spans of existing design criteria is violated. This line is located in hilly area of the country where very long span crossing from one top of the mountain to the other top have to be travelled. Such long spans can come into picture when the transmission lines are crossing large rivers and tanks as well. As conventional towers cannot be used in such situation, new tower models have to be designed by engineers. However even with new designs, it is difficult to string conductors between towers as the higher tension could lead to problems with Aeolian Vibrations.

Aeolian vibrations is a resonant phenomenon where steady flow of wind stream blowing across a conductor causes eddies or vortices on the downwind side of the conductor that cause conductor to vibrate at its natural frequency. This generates cyclic bending and tensile stress in the conductor strands which are two major components of fatigue failure. Higher the tension of the conductor, higher the Aeolian vibration of the conductor. Further, it is very difficult to travel higher spans with the use of ACSR conductors as thermal sag values increase largely with spans. To reduce the spans, the only available option with ACSR conductors is to go for higher tensions. However higher tensions are challenged by threats of Aeolian vibrations.

Sag of ACSR Zebra conductor in 1000m span @ 22.22% UTS = 76.13 m

Sag of ACCC Drake conductor in 1000m span @ 22.22% UTS = 52.95 m

Zebra and Drake has similar dimensions and yet ACCC conductor produces lesser sag as the UTS of ACCC conductor is higher compared to ACSR Zebra. At the same time ACCC conductors have self-damping capability due to its ability to absorb remnant vibration energy from wind. Therefore ACCC conductors have a higher resistance to fatigue failure. Due to this reason it is always better to select the conductor being used when it comes to severe spans crossing by analyzing special tower design cost with conventional conductors as well as with HTLS conductors.

Once the line route is selected, decision could be taken based on the above factors, whether to proceed with HTLS conductors or to follow conventional path. Basically, in Sri Lanka it is very rare that engineers have to struggle with heavy mountains and large river crossings. However there may be spans as shown in the Figure 6.2 above, which violate existing design criteria. Anyway these could be achieved by the slight mitigations of safety factors, use of body extensions and special tower designs. However proper cost benefit analysis shall be carried out in each occasion to decide the best option.

6.2.2 Power Requirement

Type of the conductor being used in Sri Lankan overhead transmission lines is presently standardized. It is ACSR Zebra. However with the introduction of bulk power generating stations and with the increase in electricity demand, the maximum capacity driven by Zebra configuration will not be enough.

Table 6.1 shows the maximum power flow of different conductor configurations of Zebra. It should be noted that all the tower configurations are double circuit and the CCC of single Zebra is taken as 645A as given in BS 215. According to (n-1) condition, a single circuit should be capable of carrying 70% of the total power.

Table 6.1 - Power Capacity of Different Zebra Configurations

Nos. of Circuits	1	2	4
Configuration	Single Zebra	Twin Zebra	Quad Zebra
Voltage (kV)	132	220	400
Capacity of a Single Circuit (MW)	145	484	1760
Maximum Capacity (MW)	207	691	2514

Presently in Sri Lanka, all 132kV transmission lines have single Zebra conductors. Although, there are few special occasions where, twin Zebra 132kV are proposed. However, the general practice of using single Zebra will continue in future as well. Almost all 220kV lines in the system use twin Zebra configuration. Although 400kV lines are not yet constructed, plans have been implemented to have one by 2018 to deliver coal power electricity generation of Sampoor, Trincomalee to the load centers.

However when the power requirement is more than the value given in the table 6.1 above, different configurations have to be thought of. According to the algorithm, the next option is to go for Low Loss conductors. TACSR conductors are commonly called as low loss conductors as their unit resistances are lower compared to the same sized

ACSR conductors that result the capability to handle higher current. Typically these conductors could be operated at 150°C (see section 2.3.3).

However the decision of the use of these conductors shall also be done after carrying out a proper cost benefit analysis. Presently, these conductors are proposed to be using in Habarana – Veyangoda transmission line. This line is destined to carry bulk power to which will be generated from proposed Sampoor power station in future.

Figure 6.3 shows a cost benefit analysis carried out to find out the most suitable conductor for Habarana Veyangaoda 220kV transmission line between 4 x Zebra and 2 x TACSR/AS conductor configurations. Maximum expected capacity of the line is 2000MW. However initially the line will be operated at a low capacity and will get loaded gradually with years to come. Below calculations were carried out taking 1000MW power flow.

Current carrying capacities were calculated using IEC 61597. Wind speed is selected as 0.6m/s, which is the most common value selected for the calculation. Cost benefit analysis has been carried out using net present value approach. This has further been explained in section 6.3.

Conductor Comparison

Base Conductor	ACSR	TACSR/AS
Conductor Diameter (mm)	28.62	28.62
Resistance at 25°C (Ω/m)	0.0699	0.053652
Resistance at 75°C (Ω/m)	0.0833	0.064172
Operating Temperature (°C)	45.36	56.84
No. of Parallel Conductors	4	2
Ampacity (A)	**345**	**691**

Power Flow (MW)	1,000	1,000
First year line loss (MWh)	105,459	169,080
Reduction in Line loss (MWh)		-63,621
% Reduction in line loss		-60
Saving (MLKR/year)		-1,272
CO_2 Emission per year (MT)	84,367	135,264
CO_2 Emission Reduction (MT/year)		-50,897
CO_2 Saving (MLKR/year)		-95
Reduction in 10yr losses (MLKR)		-6,878
Initial Cost (MLKR)	10,233	9,736
Saving over 10yr period (MLKR)		-16,614

Linear Coefficient α_C ($^{O}C^{-1}$)	0.000019	0.0000211
Modulus of Elasticity E_C (N/mm^2)	69000	69100
Strength of Conductor (kN)	131.9	140.9
Cross Section area (mm^2)	484.5	590.5
Unit mass of Conductor (kg/m)	1.621	1.814
Initial Tension (N/mm^2)	108.9	95.4
Final Tension (N/mm^2)	54.8	51.9
Sag (m)	9.17	8.89

Environmental Inputs	
0.5	Solar Radiation Absorption Coeff.
1000	Intensity of solar radiation (W/m^2)
5.67E-08	Boltzmann Constant ($Wm^{-2}K^{-4}$)
0.5	Emissivity coefficient
32	Ambient Temperature (°C)
0.0248	Air thermal Conductivity ($Wm^{-1}K^{-1}$)
0.6	Wind Speed (m/s)
Load and Generation Cost Assumptions	
148	Line Length (km)
220	Voltage (kV)
0.573	Load Factor
0.377	Loss Factor
20	Cost of Generation (Rs/kWh)
0.8	CO_2 Emission (kg/kWh)
1860	Carbon Credit (Rs/MT)
Sag Tension Inputs	
970	Wind Pressure (N/m^2)
7	Minimum Operating Tem.(°C)
9.81	Gravitational Constant (m/s^2)
350	Ruling Span (m)
2.5	Safety Factor at Stringent cond.
Economic Saving	
10	Payback Period
1.2	Internal Rate of Return
Conductor Cost Factors	
1	Zebra
2	TACSR/AS
54.82	220 x 2 Zebra (MLKR/km)
69.14	220 x 4 Zebra (MLKR/km)

Figure 6.3 - Cost Benefit Analysis of Habarana – Veyangoda overhead line

Inputs are given to find out Current Carrying Capacity, Sag Tension performances, Power Loss evaluations, CO_2 emissions and economic gain. The same calculations are carried out for three load cases such as 500MW, 1000MW and 2000MW and summary Table 6.2 is given below;

Table 6.2 - Properties of Zebra and TACSR/AS conductors

	4 x Zebra	2 x TACSR/AS
Conductor Diameter (mm)	28.62	28.62
Conductor Cross section (mm^2)	484.5	550.4
DC Resistance at 20°C (Ω/km)	0.0674	0.05626
UTS (kN)	131.9	140.9
Unit Weight (kg/m)	1.621	1.814
Max. Operating Tem. (°C)	75	150
Modulus of Elasticity (N/mm^2)	69000	69100
Thermal Expansion Coefficient ($°C^{-1}$)	0.0000193	0.0000211

Table 6.3 - Summary of Cost Benefit Analysis

	4 x Zebra	2 x TACSR/AS
Initial Line Cost (MLKR)	10,233	169,080
Annual Energy Loss (MWh)		
- 2000MW	703,845	829,353
- 1000MW	105,459	169,080
- 500MW	25,976	40,413
CO_2 Emission		
- 2000MW	563,076	663,482
- 1000MW	84,367	135,264
- 500MW	20,781	32,330
Net Savings (Fuel + CO_2) Over 10 year Period compared to 2xTACSR/AS		
- 2000MW	23,304	
- 1000MW	16,614	
- 500MW	11,297	
Net Benefit of 4 x Zebra configuration in MLKR Compared to 2xTACSR/AS		
- 2000MW	13,071	
- 1000MW	6,381	
- 500MW	1,064	

Therefore by observing the results of the study, it could be concluded that 4 x Zebra configuration is more cost effective for Habarana – Veyangoda 220kV transmission line considering long term operation.

6.2.3 EMF Evaluation

When deciding possible routes for new overhead transmission lines, engineers always try to position the line away from the places where majority of the people are living. This only becomes possible, when the line is running through a rural area. However as mentioned in section 4.2 of this document, the possibility of finding clear line routes are getting more and more difficult due to urbanization and unavailability of ROW has become the greatest challenge faced by line engineers nowadays and time to come.

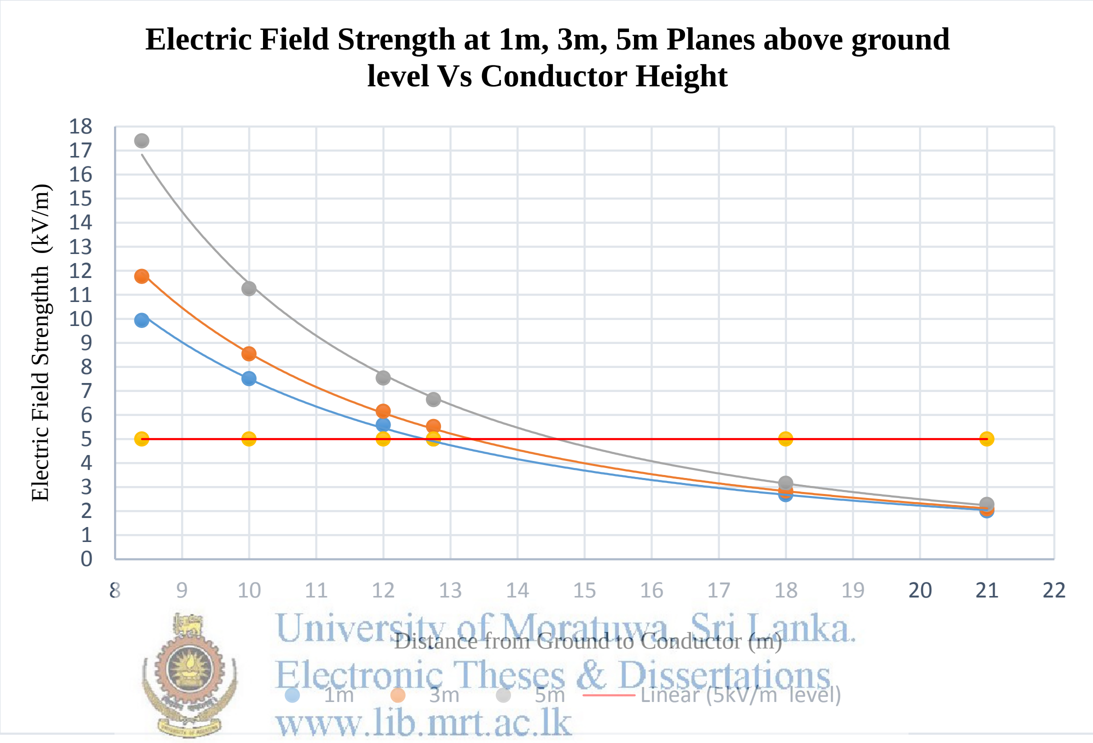
Additionally, the organizations such as forest and wildlife have strengthen their regulations by not allowing any overhead line to traverse their demarcated forest reserves, sanctuaries as a policy of protecting the environment, which is acceptable. However all these regulations and restrictions have made selection of routes difficult and as a result of that length of lines and cost of lines have increased.

The risk when overhead lines are travelling in the vicinity of livelihood is the electromagnetic interferences. This was discussed under section 4.3.1, when thermal uprating of existing lines. EMF field under the power line has to be kept under certain values which are defined by ICNIRP that is given under table 4.6. Table 6.4 shows EMF values of proposed New Habarana-Sampoor 400kV, four Zebra overhead line.

Table 6.4 - EMF details of Proposed New Habarana- Sampoor 400kV line

Minimum Ground Clearance (m)		8.4	10	12	12.75
Height of the Plane is 1m	Electric Field (kV/m)	9.929	7.508	5.581	5
	Magnetic Field (uT)	12.77	10.12	7.97	7.32
	Danger Distance from the Tower (m)	16	15	13	0
Height of the Plane is 3m	Electric Field (kV/m)	11.761	8.536	6.147	5.514
	Magnetic Field (uT)	18.41	13.6	10.17	11.68
	Danger Distance from the Tower (m)	16	15.5	14	12.5
Height of the Plane is 5m	Electric Field (kV/m)	17.4	11.248	7.534	6.638
	Magnetic Field (uT)	31.01	20.07	13.7	15.36
	Danger Distance from the Tower (m)	16.5	16	15	14
Catenary Constant (stringing) (m)		2260	1955	1515	1600
Safety Factor (EDS)		3.67	4.24	5.48	5.19
Tower Height (m)		51.24	54.24	59.24	59.24

Below graph was developed from the above PLSCADD design results of EMF values. It can be seen that, when the bottom point of the conductor is shifted away from the ground surface, the electrical field strength is getting reduced in an inversely proportional manner.



Note: conductor spacing 48cm, Voltage 420kV, Basic Span 450m

Figure 6.4 - EMF Field vs Distance from conductor

Typical ROW for 400kV transmission lines is about 50m. From simulation values given in Table 6.4 it is clear that magnetic field never exceeds the limit specified in ICNIRP guide lines under any given condition. However, to make risk free electrical field under the tower, it is necessary to improve the ground clearance or in other words the height of the tower. However, increase in tower height will result additional cost on steel as well as on foundations. Though increase in conductor tension could reduce the sag of conductors and hence lower the tower height, it violates safety factor of the conductor and safety factor of the tower. If it is not economical to proceed with towers having extensions, the next option based on the algorithm is to go for HTLS conductors and use one of their advantages of low sag feature.

6.3 SELECTION OF HTLS CONDUCTOR FOR NEW TRANSMISSION LINES

It is seen from the above discussions that the necessity of HTLS conductors comes into picture due to some of special requirements that cannot be fulfilled with the use of conventional conductors. Though, there are few alternatives that could be achieved with the use of AAAC and TACSR (Low Loss) conductors, they are limited to particular case or the situation and complete solution is difficult to achieve.

In chapter 2, Properties of HTLS conductors were discussed in details and selection of most appropriate conductor for Sri Lankan transmission system will be discussed under coming section. Loss reduction is the most attractive feature that is said to possess by HTLS conductors. In Sri Lanka's transmission system, most of the new lines are proposed to be using ACSR Zebra conductors. Therefore loss reduction capability of HTLS conductors are discussed over Zebra conductors below.

6.3.1 Conductor Selection

Conductor type and size has a major impact on a transmission line's design and subsequent financial returns. Some of the electrical criteria that effects the selection of conductors were discussed in chapter 2 of this document. Here some of the physical and economic facts that effect the choice of conductors are discussed.

- Conductors with higher unit resistances will raise the cost of electrical losses over the life of the line.
- Increase in diameter yields increase in support structures, increasing initial cost for towers and foundations.
- Decrease in conductor size leads to higher corona noise and tension limitations due to the risk of fatigue failure as a consequence of Aeolian vibration.
- Increase in conductor tension to achieve reduction in sag will yield additional longitudinal loads and transverse loads on angle towers.

Given all above, analysis of proposed transmission project should include capital cost investment as well as long term operating cost and losses.

Life Cycle Cost (LCC)

Life cycle cost associated with a transmission project is the sum of all recurring expenses including annual capital costs and line losses. LCC, by definition, is dependent on dynamic market factors such as escalating energy costs, load growth etc. Therefore Net Present Value (NPV) approach is more appropriate when determining best estimate of long term project feasibility.

Capital Investment Cost

This is the sum of all expenses associated with component purchase, regulatory compliances, and project constructions. Table 6.5 shows some of the recent capital cost on Sri Lankan transmission projects.

Table 6.5 -Transmission line Capital Project Costs

Description	MLKR /km		
	Foreign Cost	Local Cost	Total
132 Zebra, single circuit	15.56	7.55	23.11
132 Zebra, double circuit	19.66	10.06	29.73
132 2x Zebra, double circuit	25.94	12.58	38.51
220 1x Zebra, double circuit	27.92	12.58	40.50
220 2x Zebra, double circuit	39.10	15.72	54.82
220 4x Zebra, double circuit	50.27	18.87	69.14

(Source; Transmission Planning, CEB)

Total Annual Cost

The total annual cost is defined as the sum of annual capital cost and the annual loss cost. This includes total energy lost cost, interest rate for borrowed funds, operation and maintenance cost, depreciation etc.

Annual Energy Lost Cost

(Phase current)^2 x ***Unit Resistance*** x ***Line Length*** x ***Total Nos. of Conductors*** x ***Loss Factor*** x ***8760***

Load Factor = *Average Demand/ Peak Demand*

Loss Factor = *0.2 x Load Factor + 0.8 x Load Factor^2*

Net Present Value

In economic comparison of costs, it is important to find out the present worth of cost components that will be incurring in the future. Normally when analyzing the economic feasibility of transmission line projects, typically 30 to 40 years of life span is considered. Therefore all the cost components, shall be considered in present terms to get the whole idea of the economic feasibility of the project to be implemented.

Below equation will be used to find out NPV;

$$NPV = \left[\frac{\left\{ 1 - \left(\frac{1}{1+i} \right)^n \right\}}{\left\{ 1 - \frac{1}{1+i} \right\}} \right]$$ Where i = discount rate & n = no of years

Reduction of Fuel Consumption and Emission

During transmission, some part of energy is dissipated as in the form of heat energy. In Sri Lanka’s transmission system this is around 2 -3 % of total energy loss. If this could be reduced by the use of a conductor which has a lower unit resistance, that would in turn will reduce the amount of fuel being burnt to generate the electricity and also CO_2 emission.

Below given is details of a hypothetical transmission line where economic analysis has been carried out for several conductors including ACSR Zebra. Here ACSR Zebra has been used as the base conductor and losses are calculated compared to the losses of Zebra conductor.

Inputs for the table 6.6;

Base conductor	=	ACSR, Zebra
Number of Circuits	=	2
Number of Sub Conductors per phase	=	1

Current rating of Zebra at maximum temp. (75°C) = 763A

(Note: Solar radiation 1000W/m^2, ambient tem. 40°C, Wind Angle 90°, solar absorption coeff. 0.5, Emissivity 0.5, wind speed 0.5)

Line Voltage (kV) = 132kV

Line Length (km) = 50

Load Factor (Source; Generation Planning, CEB) = 57.3%

Loss Factor = 37.7%

Generating Cost (Rs/ kWh) = 18

CO_2 Emission (kg/kWh) = 0.5

Then operating temperature of other conductors were calculated so that the maximum capacity of Zebra conductor to be delivered in the line. Therefore, loss of each conductor could be calculated sitting on the same basis. All the other conductors are selected so as they all possess similar dimensions and unit weights which will keep loadings on towers more or less the same as in the case of Zebra.

Table 6.6 - Loss Evaluation of HTLS conductors

Conductor	Operating Tem. (°C)	Unit Resistance (Ω/km)	Annual Energy Loss (MWh)	Annual Energy Saving (MWh)	Annual Financial Saving (MLKR)	CO_2 Saving (kg)
Zebra	75	0.08149	44602	0	0	0
ACCC- Drake	69.7	0.06504	35598	9003	162	4502
AAAC-500	71.7	0.07212	39475	5127	92	2564
STACIR/AW-(413-410)	75.6	0.08285	45350	-748	-13	-374
GTACSR-520	76.1	0.07357	40268	4333	78	2167
ACSS/TW	69.25	0.06853	37506	7096	128	3548

From above Table 6.6 it is clear that ACCC and ACSS conductors provide the best loss reduction performances compared to ACSR Zebra. This is because the fact that both conductors have been developed with 1350-O annealed aluminium that has the lowest unit resistance of any other conductor being used in the industry.

Below Table 6.7 discusses the mechanical properties of the same conductors above.

Table 6.7 - Mechanical Properties of different conductors

Conductor	Zebra	ACCC-Drake	AAAC-500	STACIR/AW - (413-410)	GTACSR-520	ACSS/TW
Diameter (mm)	28.62	28.143	29.12	28.5	29	27.74
Unit Weight (kg/m)	1.621	1.565	1386.9	1.626	1.8857	1.844
UTS (kN)	131.9	183.3	115.7	130.4	152.9	117.4
Thermal Expansion coeff. of Core (°C^{-1})	11.5	1.6	*23.04	3.78	11.5	11.5
KPT	100	32-80	*32	135	32	80
% RTS	22.22	16.04	25.41	22.54	19.23	25.04
Conductor Safety Factor @ EDS	4.50	6.23	3.94	4.44	5.2	4.0
Thermal Sag at Maximum operating Tem. (m)	7.7	7.25	7.08	7.57	7.8	8.31

* - AAAC conductor is made of homogeneous material and so there is no separate core

Table 6.7 compares mechanical properties of each conductor. Percentage Tension (%RTS) of all the conductors were selected to be matched with everyday stress (EDS) of Zebra conductor, so that the tension exerted by each conductor on towers will remain the same. Therefore tower design variables will not take part in the above comparison.

From Table 6.7, it could be observed that AAAC conductor has provided minimum sag at given operating temperature. ACCC conductor has also provided lesser sag value at its respective operating temperature. However tension of AAAC conductor is somewhat elevated in the calculation as specified earlier in this document, to exert similar forces on towers. Therefore its safety factor gets violated (25.4%) slightly. On the other hand ACCC conductor is only tensioned up to 16% where it can go up to 22.22% without violating safety limits. Therefore ACCC conductor provides additional safety in terms of conductor UTS limits. At the same time conductor tension and sag value can further be reduced, if the tension is increased up to the recommended value according to the CEB specifications. However this will result higher longitudinal forces on towers and will require larger foundations.

However, it is always better to do a proper cost benefit analysis during the selection of HTLS conductors to new transmission line projects. During the study, all the costs as well as benefits shall be considered in a timely manner as most of the cost components are time dependent.

In Sri Lankan transmission system ACSR Zebra conductor is almost standardized for new transmission projects. Therefore it is better to analyze other conductors taking Zebra as the base conductor. Normally, the lifetime of a transmission project is considered 30 to 40 years. Therefore NPV of all cost components shall be considered for the total life span.

Typically HTLS conductors are supposed to have lesser losses. Therefore first year line loss difference could be calculated using I^2R, and that could be converted to a cost term by multiplying unit generation cost. At the same time, given the CO_2 emission per kWh, amount of CO_2 emission reduction could be calculated and this could also be converted to a cost component claiming that the project is coming under CDM (Clean Development mechanism) published by Kyoto protocol.

Below excel programme is developed with the idea of comparing feasibility of different types of conductors with the performance of Zebra conductor. Here, the feasibility of the project, could be analyzed by changing inputs given in yellow highlighted cells.

Conductor Comparison

Base Conductor	ACSR	ACCC	GTACSR	ZTACIR
Conductor Diameter (mm)	28.62	28.1432	28.99	28.5
Resistance at 25°C (Ω/m)	0.06841	0.05543	0.0609	0.07045
Resistance at 75°C (Ω/m)	0.08149	0.06618	0.0733	0.08241
Operating Temperature (°C)	75	69.95	72	75.4
No. of Circuits	2	2	2	2
Ampacity (A)	**714**	**714**	**714**	**714**

Power Flow (MW)	326	327	326	326
First year line loss (MWh)	5762	4607	5133	5837
Reduction in Line loss (MWh)		1155	629	-75
% Reduction in line loss		20.04	10.92	-1.31
Saving (MLKR/year)		20	11	-1
CO_2 Emission per year (MT)	4609	3686	4106	4670
CO_2 Emission Reduction (MT/year)		924	503	-60
CO_2 Saving (MLKR/year)		1.7	0.9	-0.1
Reduction in 30 year line losses by (MLKR)		221.3	120.6	-144
Initial Cost	210	273	252	294
Net Saving over 30 year period (MLKR)		-51.7	-131.4	-308.4

Linear Coefficient α_C ($^oC^{-1}$)	0.0000193	0.0000181	0.0000202	0.0000193
Modulus of Elasticity E_C(N/mm^2)	69000	78000	74400	85000
Strength of Conductor (kN)	131.9	183.3	152.9	130.4
Cross Section area (mm^2)	484.5	519.7	567.48	413.4
Unit mass of Conductor (kg/m)	1.621	1.565	1.8557	1.6258
Initial Tension (N/mm^2)	108.9	141.1	107.8	126.2
Final Tension (N/mm^2)	47.4	63.0	48.5	54.5
Sag (m)	**7.79**	**5.27**	**7.44**	**7.97**

Environmental Inputs

0.5	Solar Radiation Absorption Coefficient
1000	Intensity of solar radiation (W/m^2)
5.67E-08	Stefan- Boltzmann Constant ($Wm^{-2}K^{-4}$)
0.5	Emissivity coefficient in respect to black body
40	Ambient Temperature (°C)
0.0248	Air thermal Conductivity ($Wm^{-1}K^{-1}$)
0.5	Wind Speed (m/s)

Load and Generation Cost Assumptions

7	Line Length (km)
132	Voltage (kV)
0.573	Load Factor
0.377	Loss Factor
17	Cost of Energy Generation (Rs/kWh)
0.8	CO_2 Emission (kg/kWh)
1860.2	Carbon Credit (Rs/MT)

Sag Tension Inputs

970	Wind Pressure (N/m^2)
7	Minimum Operating Temperature(°C)
9.81	Gravitational Constant (m/s^2)
300	Ruling Span (m)
2.5	Safety Factor at Stringent condition

Economic Saving

30	Payback Period
1.1	Internal Rate of Return

Conductor Cost Factors

1	ACSR
2.5	ACCC
2	GTACSR
3	ZTACIR

Figure 6.5 - Excel Programme interface of conductor comparison

6.4 CAPACITY IMPROVEMENT USING HTLS CONDUCTORS

Under the example given above, performances of HTLS conductors were discussed for lightly loaded conditions. However, manufacturers of HTLS conductors promote the capability of their conductors to operate at higher temperatures and deliver higher capacities. Therefore the use of HTLS conductors were discussed under high load conditions in Table 6.8.

Here 220kV, 900MW transmission line is selected with the length of 50km. Loss factor is taken as 0.33.

Table 6.8 - Comparison of Losses in HTLS conductors for various sub conductor configurations

	AAAC	**ACSR**	**ACCC**	
Name of the conductor	500mm^2	Zebra	Drake	
Diameter of the conductor (mm)	29.12	28.62	28.143	
Unit Weight (kg/km)	1387	1621	1565	
No. of sub conductors	2	2	1	2
Current per conductor (A)	622	622	1243	622
Operating Temperature (°C)	64.2	66.35	116.1	62.75
Current per conductor (A)	1243	1243	1243	1243
Unit Resistance at Operating Temp. (Ω/km)	0.07062	0.07923	0.07501	0.06354
Annual Loss (MWh)	47,424	53,206	100,743	42,669

It is clear from the table 6.8 that, even ACCC conductor, which is known to have given the best loss reduction features could not reduce the amount of losses as a single conductor configuration over ACSR two bundle configuration. Therefore HTLS conductors are only suitable as a loss reduction method when the number of conductors are the same. Even at higher temperatures, losses made by HTLS conductors become significant compared to ACSR. Therefore it is not a good option to choose HTLS conductors to reduce number of sub-conductors per phase in a transmission line.

Therefore HTLS conductors become competitive only when low/ similar load cases are considered. However, HTLS conductors are providing lesser sag values only after they are operated above KPT. Therefore if the conductors are operated at lower temperatures, there is a risk that KPT of the conductor would never be achieved. As an example TACIR conductor's KPT lies around 130 -150°C and hence it is not advisable to select TACIR conductors as a method of achieving lesser sag values when the conductors are operated at low load cases.

6.5 STRINGING OF HTLS CONDUCTORS

hen it comes to the selection of HTLS conductors, stringing is one of the dominant factors one should take into account. Unlike in the case of conventional stringing as in the case of ACSR, some HTLS conductors require special stringing methods mainly due to the nature of the formation of the conductors. As an example, Gap (GTACSR) conductor requires special stringing methods due to its unique formation.

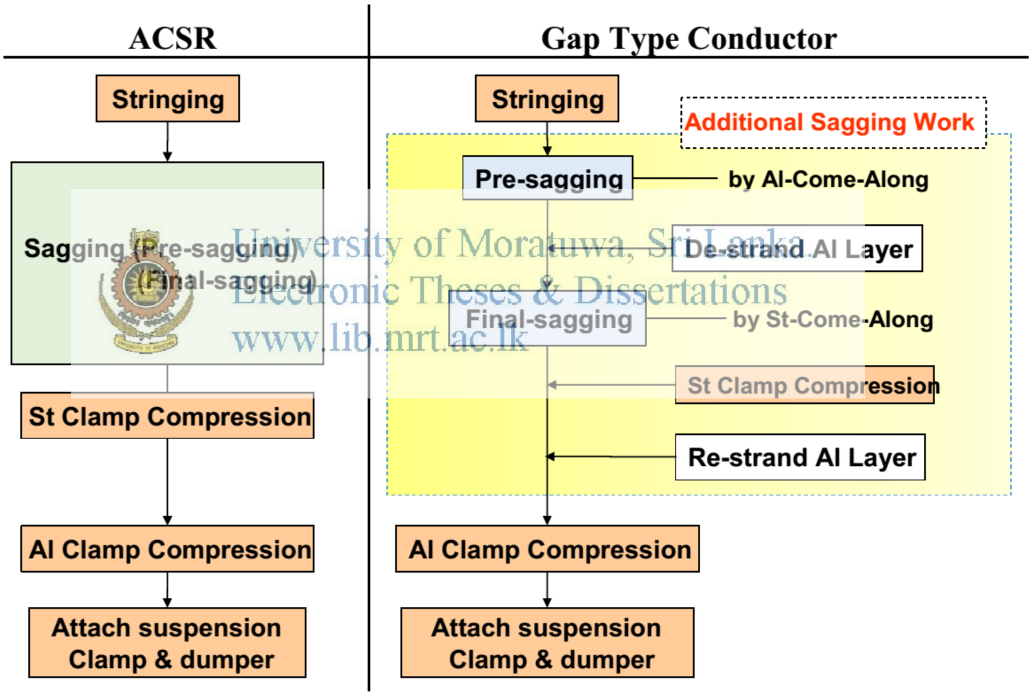


Figure 6.6 - Stringing requirements of ACSR Vs Gap
Source: J power systems, JTD 80-2226, Installation manual

Figure 6.6 above, shows the difference between the conventional stringing and stringing used for Gap conductors. Therefore it is always required to have a trained staff to carryout special stringing works related to Gap conductors as the performance of the line is heavily dependent on stringing. ACCC conductor also require adherence to special stringing methods which requires trained staffs. In Sri Lanka, presently there are no trained personnel and in case of a HTLS project, staffs will have to be imported with expertise supervision, which may in turn increase the project cost. Further, these conductors require special hardware tools such as compression dead ends and splices to match with their superior behavior.

HTLS conductors such as ACSS and ZTACIR have the same stringing requirements as in the case of ACSR conductors and hence there is no need of trained staff to carry out the stringing works. However, as explained in an earlier paragraph, use of ACSS and ZTACIR are discouraged as they have slightly higher KPT values. Therefore, there is always a discrepancy, when selecting HTLS conductors favoring stringing and KPT values.

6.6 REDUCTION OF TOWERS USING HTLS CONDUCTORS

Some of the HTLS conductors possess higher UTS values compared to ACSR conductors that have similar dimensions. Therefore they can be tensioned to higher values and reduce the number of towers being used in a line. This feature becomes very handy when tower spotting becomes restrictive in some places. This could happen in areas where very weak soil is there in the ground. Sometimes based on IEE (Initial Environment Examination) results, there may be directives from various departments prohibiting the tower spotting due to many sensitive reasons. In such occasions designers can think of using HTLS conductors, so that they could be used in longer spans reducing the number of towers being used. Table 6.9 shows, number of towers used to complete proposed Kirindiwela – Kosgama 132kV double circuit transmission line having 11km in length.

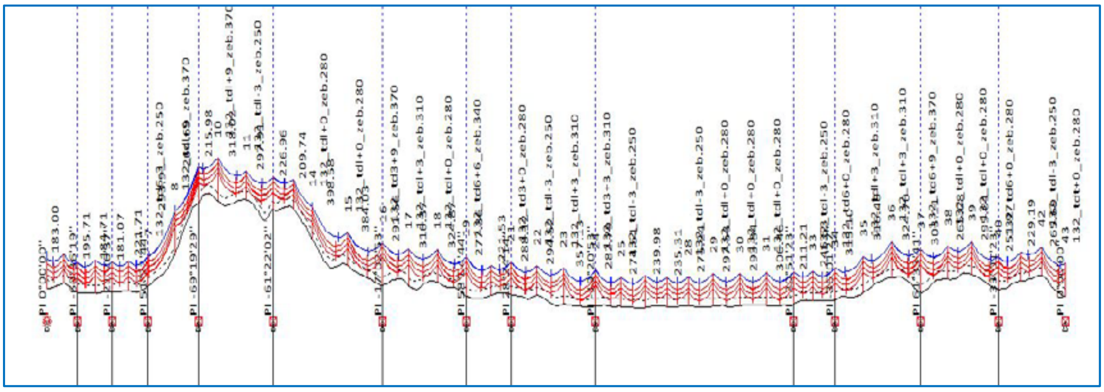


Figure 6.7 - Profile view of Kirindiwela – Kosgama line with Zebra

ACSR Zebra conductor UTS	=	131.9kN
Catenary constant at sagging condition	=	$\frac{131900}{4.5 \times 15.89}$
	=	1844m
Horizontal Tension	=	29,624 N

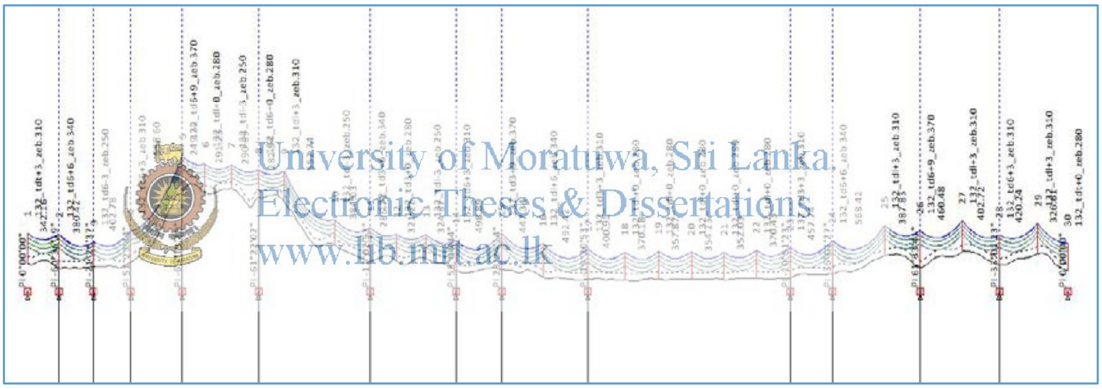


Figure 6.8 - Profile view of Kirindiwela – Kosgama line ACCC- Drake conductor

ACCC- Drake conductor UTS	=	183.267kN	
Catenary constant at sagging condition	=	$\frac{183267}{4.5 \times 15.35}$	= 2653m
Horizontal Tension	=	41,866N	

Table 6.9 - Number of towers used with different conductors

Towers Type	Body Extension	ACSR Zebra	ACCC Drake
TDL	-3	13	3
	0	9	6
	+3	4	4
	+6	1	1
	+9	1	0
TD3	0	2	1
	+3	1	2
	+6	0	1
	+9	1	1
TD6	-3	3	1
	3	3	1
	+3	1	3
	+6	1	2
	+9	1	2
TDT	-3	1	1
	0	1	1
Total Towers		43	30

It can be seen that by using ACCC -Drake conductor, the amount of towers being used in the line could be reduced. However, horizontal tension will get exerted on towers will be more with the use of ACCC. Due to this reason, angle towers will have to be designed for additional longitudinal forces. Though line towers will not share any longitudinal forces in normal conditions, they still have to be designed to withstand additional unbalanced forces under broken wire condition. Therefore definitely the cost of towers and foundations will be higher with the use of ACCC conductors. Anyway, this could be useful in situations where limited land availability is there or when the land value is comparatively high.

7.0 RESULTS

Use of HTLS conductors were discussed under three main categories in this study. They are, thermal Uprating of existing transmission lines, clearance improvement of existing transmission lines and construction of new transmission lines.

7.1 UPRATING EXISTING TRANSMISSION LINES

When it comes to uprating existing transmission lines that have ACSR conductors, designers are restricted with extremely limited number of options. Most of the transmission lines which are proposed to be uprated are typically older ones. Conditions of existing structures and foundations are always questionable due to aging and harsh environment conditions. Therefore further loading of towers using large cross section conductors could be harmful. Hence, conductors which have similar mechanical properties will be the most suitable ones for restringing.

Table 7.1 shows the additional forces acting on towers if ACSR Zebra conductors are used instead of Lynx conductors with existing design criteria.

Table 7.1 - Addition in forces on towers when Zebra conductor is used;

Additional Transverse force	46.54%
Additional Vertical Force	92.53%
Additional Longitudinal Forces	68%
Reduction of Safety Factor	39.50%

If the same longitudinal forces are applied on towers by reducing the tension of new zebra conductors, the sag will increase as a result of lower initial tension. This will result violation of electrical field under the power line as shown in Table 7.2.

Table 7.2 - EMF level under the power line with the use of Zebra conductor

	Field under existing Lynx Line	Field under uprated Zebra line
Electric Field	3.2kV/m	6.4kV/m
Magnetic Field	12.2μT	45μT

Therefore HTLS conductors have become the best candidate in thermal uprating, as they could be operated at higher temperatures and lesser sag values without violating structure safety requirements.

Table 7.3 - Selection of HTLS conductors to replace ACSR Lynx Conductor

Conductor Type	**ACSR**	**ACCC**	**GTACSR**	**ZTACIR**	**ACSS**
Conductor Name	Lynx	Oriole	$200mm^2$	159-160	Lark
Diameter (mm)	19.53	18.821	19.0	18.2	17.781
Cross Section (mm^2)	226	222.3	208	159.3	201.4
Unit Weight (kg/km)	846	688.9	844.8	706.8	925.3

From Table 7.3, it is seen that forces acting on tower could be kept unchanged (due to similar mechanical properties) by proper selection of HTLS conductors.

Table 7.4 - Comparison of performances of HTLS conductors compared to Zebra

Conductor Type	**ACSR**	**ACCC**	**GTACSR**	**ZTACIR**	**ACSS**
Conductor Name	Zebra	Oriole	$200mm^2$	159-160	Lark
Operating Temp. when CCC is 800A (°C)	79.7	114	140	173.5	147.8
Sag @ operating Temp. (m)	7.87	5.72	7.81	7.33	8.84
Annual Energy Loss (MWh)	7,111	15,774	18,720	23,295	17,810

From Table 7.4, it is clear that double the CCC of Lynx conductor could be achieved by the use of HTLS conductors in existing lines. Further they will improve sag characteristics of the line as well. Losses will be higher in HTLS conductors compared to Zebra conductor, as they are operated at higher temperatures. However, compared to capital investment and socio economic issues related to new line constructions, this method has become more economical.

7.2 CLEARANCE IMPROVEMENT IN EXISTING TRANSMISSION LINES

Clearance improvement in existing transmission lines arose mainly as a result of the construction of illegal buildings and houses under the power lines. Further some of the older transmission lines have crept for a long time and subsequently have violated the required clearances. As in the first case, further tensioning of towers to reduce the sag is not an option due to the questionability of tower and conductor safety. Therefore the use of HTLS conductors could be a better solution as with their superior mechanical characteristics and higher ampacity.

Table 7.5 - Comparison of Sag characteristics of HTLS Vs ACSR

	ACSR	GTACSR	ZTACIR	ACCC	ACSS
Thermal Exp. Coefficient of core (x 10^{-6} °C^{-1})	19.3	11.5	3.78	1.6	11.5
Knee Point Temperature (°C)	>75	32	>110	30-80	50-100
Operating Temperature when I = 450A	65	69.6	69.5	60.2	62.9
Sag (m)	6.41	5.82	5.89	4.39	5.91

According to Table 7.5, clearance could be improved, mainly due to the lower expansion coefficient of the core material of HTLS conductors and it is always better to use a conductor with lower KPT, so that the rate of increase of sag could be maintained at a lower value. Pre-stressing could be used as a solution of reducing the KPT of conductors such as ACSS. Gap and ACCC has relatively lower KPTs. Since the conductors are also operated at similar load cases, losses will not effect to the criteria of selection of conductors. Therefore HTLS is a good candidate in the process of clearance improvements.

7.3 CONSTRUCTION OF NEW TRANSMISSION LINES

Unlike in the case of thermal uprating and clearance improvements, during new line constructions, designers are equipped with number of options in selecting the most appropriate conductor for the respective line. Though, the use of HTLS conductors are promoted due to their low loss properties, it could be observed that HTLS conductors became effective only under equal load conditions. Under, high load situations, even HTLS conductors become uneconomical due to high I^2R losses.

Table 7.6 shows the losses of conductors at different load cases and it is seen that losses in HTLS conductors are higher at elevated temperatures even though they have lower unit resistances compared to conventional conductors at similar temperatures.

Table 7.6 - Loss Evaluation of HTLS conductors Vs Conventional conductors

	AAAC	ACSR	ACCC	
Name of the conductor	500mm^2	Zebra	Drake	
Power Flow (MW)	900			
Voltage (kV)	220			
No. of sub conductors	2	2	1	2
Current per conductor (A)	622	622	1243	622
Operating Temperature (°C)	64.2	66.35	116.1	62.75
Unit Resistance at Operating Temp. (Ω/km)	0.07062	0.07923	0.07501	0.06354
Annual Loss (MWh)	47,424	53,206	100,743	42,669

Therefore the use of HTLS conductors in bulk power transmission at elevated temperatures is clearly not advisable.

Though, under low load cases (Table 7.7), HTLS conductors can save some losses during transmission, economic gain of it shall be accounting all the cost components (capital investment, operation and maintenance cost) that may result in the future lifespan of 30 to 40 years.

Table 7.7 - Loss Evaluation at similar low load cases

Conductor	**Operating Tem. (°C)**	**Annual Energy Loss (MWh)**	**1st year Financial Saving (MLKR)**	**Annual CO_2 Saving (kg)**
Zebra	75	44602	0	0
ACCC- Drake	69.7	35598	162	4502
STACIR/AW-(413-410)	75.6	45350	-13	-374
GTACSR-520	76.1	40268	78	2167
ACSS/TW	69.25	37506	128	3548

Due to high initial cost on conductors, erection and stringing have made initial cost to go higher with the selection of HTLS conductors. Table 7.8 shows 30 year cost benefit analysis of few HTLS conductor options.

Table 7.8 - Economic gain over 30 year period

Base Conductor	ACSR	ACCC	GTACSR	ZTACIR
% Reduction in line loss	_	20.04	10.92	-1.31
Saving (MLKR/year)	_	20	11	-1
CO_2 Saving (MLKR/year)	_	1.7	0.9	-0.1
Reduction in 30 year line losses (MLKR)	_	221.3	120.6	-14.4
Initial Cost	210	273	252	294
Net Saving over 30 year period (MLKR)	_	**-51.7**	**-131.4**	**-308.4**

It is seen in the table 7.8, though HTLS conductor saves some energy during transmission, it is not sufficient to cover even the capital cost investment. Therefore use of HTLS as solution in the case of new line construction is not recommended under normal circumstances.

However, still under special conditions such as crossings of longer spans, unavailability of lands, restrictions on EMF levels, HTLS could become handy with its performances. However, it is always better to carry out a proper cost benefit analysis for all the cost components covering the period of interest.

8. CONCLUSION

After observing the results in chapter 7, below conclusions could be made regarding the use of HTLS conductors in Sri Lanka's Transmission system.

- HTLS conductor is the best selection when it comes to thermal uprating of existing transmission lines. Line designers are restricted with limited options during the capacity enhancement of older lines, mainly due to the lack of ROW availability and structure limitations of existing lines. Those have made HTLS conductors the best economical solution in terms of technical and environmental aspects to achieve the desired capacity even at the expense of slightly higher power loss at high temperatures.
- HTLS conductors provide superior performance in clearance improvement of existing transmission lines. As in the case of thermal uprating, the options left with engineers are limited in the process of achieving required clearance of existing lines. Although some options seem to be possible based on engineering calculations, the amount of risk involved with those processes are immense. In such situations, HTLS conductors have the possibility of becoming the best candidate in providing solutions.
- When it comes to the construction of new transmission lines, still the choice of conventional conductors have become the best solution, given there are no abnormal site conditions or system requirements. It was seen that, though HTLS conductors have the capability of withstanding up to higher elevated operating temperatures, the amount of power loss at higher temperatures become significant and initial investment on construction will not pay off in long run operation. HTLS as well as Low Loss conductors have the potential of reaching a breakeven point compared to the investment of conventional conductors in long run operations given they are operated at similar conductor configurations. However this option does not seem to be attractive among utilities due to the especial requirements in operation and maintenance and sensitivity on workmanship during stringing of HTLS conductors.

- HTLS conductors could become economically feasible in situations where tedious environment conditions are there, such as higher span crossings in mountainous terrains, rivers, marshy lands etc. Due to its superior tensile strength and damping performances, the conductors can provide more reliable service compared to conventional conductors. At the same time, HTLS conductors can be used in situations where tower spotting in the respective area becomes restrictive. It has the capability to result lower magnetic field under the power line, avoiding health issues related to electromagnetic interferences.

REFERENCES

[1] IEC, *IEC 60889 - Hard Drawn Aluminium wire for overhead conductors,* 1st ed., 1987.

[2] IEC, *IEC 62004 - Thermal Resistance Aluminium Alloy wire for overhead line conductors,* 1st ed., 2007 - 02.

[3] IEC, *IEC 60104 - Aluminium-magnesium-Sillicone alloy wire for overhead line conductors,* 2nd ed., 1987-12.

[4] IEC, *IEC 60888 - Zinc Coated Steel Wires for stranded conductors,* 1st ed., 1987.

[5] CEB, *CEB Technical Specifications - Employer's Requirements - Part B of Bidding Document,* vol. 5 of 8 .

[6] CTC-Global, *Engineering Transmission Lines with High Capacity Low Sag ACCC conductors,* 1st ed.

[7] IEEE, *IEEE Standard 738 "IEEE Standard for Calculating the Current-Temperature Relationship of Bare Overhead Conductors",* 2006.

[8] C. R. Bayliss (Dr.) and B. Hardy (C Eng), *Transmission and Distribution Electrical Engineering,* 3rd ed.

[9] EPRI, *AC Transmission Line- Reference Book- 200kV and Above,* 3rd ed., Electric Power Research Institute.

[10] IEC, *IEC 61089 - Round wire concentric lay overhead electrical stranded conductors,* 1st ed., 1991-05.

[11] A. J. Mazón, I. Zamora, P. Eguía, E. Torres, S. Miguélez, R. Medina and J. R. Saenz, "Gap - type Conductors: Influence of high temperature in the Compression Clamp Systems," in *IEEE Bologna Power tech-conference,* Bologna, Italy, 2003, June 23-26.

[12] "J Power Systems," [Online]. Available: http://www.jpowers.co.jp/english/product/. [Accessed 31 March 2015].

[13] IEC, *IEC 62420 "Concentric lay stranded overhead electrical conductors containing one or mare gap(s)",* 1st ed., 2008-04.

[14] "CTC Cable Corporation," [Online]. Available: http://www.ctcglobal.com/. [Accessed 31 March 2015].

[15] C. Gianfranco, M. Handel and D. Angeli, *New types of conductors for overhead lines with high thermal resistance.*

[16] IEC, *IEC 61597 "Overhead electrical conductors- Calculation methods for stranded bare conductors,* 1st ed., 1995-05.

[17] J. C. Molburg, J. A. Kavicky and K. C. Picel, *The Design Construction and Operation of Long Distance High Voltage Electricity Transmission Technologies,* Environmental Science Division, Argonne National Laboratory,, November 2007.

[18] S. Bisinath, A. C. Britten, D. H. Cretchley, D. Muftic, T. Pillay and R. Vageth, *Planning, Design & Construction of Overhead Power Lines 132kV and above,,* ESKOM.

[19] IEC, *IEC 60826 "Design Criteria of overhead transmission lines",* 3rd ed., 2003-10.

[20] "International Commission on Non-Ionizing Radiation Protection (ICNIRP)," [Online]. Available: http://www.icnirp.org/. [Accessed 31 March 2015].

[21] "Power Line Systems," [Online]. Available: http://www.powline.com/files/cables.html. [Accessed 31 March 2015].

[22] IEC, *IEC/ TS 60815-1 "Selection and dimensioning of high-voltage insulators intended for use in polluted conditions" Part 1- Definition, information and general principals,* 1st ed., 2008-10.

[23] IEC, *IEC 60383 "Ceramic or glass insulator units for a.c. systems Definitions, test methods and acceptance criteria",* 4th ed., 1993-04.

[24] J. Bodner, M. Hofer, M. Laubegger , G. Stampfer, H. Strobl and H. Wörle, *Use of high thermal limit conductors in the replacement of 220kV overhead lines in the Tirolean Alps,* TIWAG-Netz AG Austria,.

[25] R. Geary, T. Condon, T. Kavanagh, O. Armstrong and J. Doyle, *Introduction of high temperature low sag conductors to the Irish transmission grid*, Esb International, Ireland.

APPENDIX A: Sample Current Carrying Capacity Calculation

ACSR Zebra conductor

Finding out CCC of Zebra conductor at the operating temperature 60°C

Heat Balance Equation

$$P_j + P_{sol} = P_{rad} + P_{conv}$$

P_j	=	heat generated by joule effect
P_{sol}	=	solar heat gain by conductor surface
P_{rad}	=	heat loss by radiation
P_{conv}	=	convection heat loss

Solar heat gain

$$P_{sol} = \gamma D S_i$$

γ	=	Solar radiation absorption coefficient (0.5)
D	=	Conductor Diameter (0.02862m)
S_i	=	intensity of solar radiation (1000W/m^2)

$$P_{sol} = 0.5 \times 0.02862 \times 1000$$

$$P_{sol} = 14.31 \text{ W/m}$$

Radiated heat loss

$$P_{rad} = s\pi D K_e (T_2^4 - T_1^4)$$

S	=	Stefan-Boltzmann constant (5.67 x 10^{-8} W/m^{2}k^4)
D	=	conductor diameter (0.02862m)
K_e	=	emissivity coefficient (0.5)
T_2	=	final equilibrium temperature (60°C)
T_1	=	ambient temperature (32°C)

$$P_{rad} = 5.67 \times 10^{-8} \times \pi \times 0.02862 \times 0.5(333^4 - 305^4)$$

$$P_{rad} = 9.2854 \text{ W/m}$$

Reynolds Number

$$R_e = 1.644 \times 10^9 vD[T_1 + 0.5(T_2 - T_1)]^{-1.78}$$

R_e = Reynolds number

V = wind speed (0.5 m/s)

D = conductor diameter (0.02862m)

T_1 = ambient temperature (32°C)

T_2 = final equilibrium temperature (75°C)

$$R_e = 1.644 \times 10^9 \times 0.5 \times 0.02862[305 + 0.5(333 - 305)]^{-1.78}$$

R_e = 821.85

Nusselt number

$$N_u = 0.65R_e^{0.2} + 0.23R_e^{0.61}$$

Nu = Nusselt Number

Re = Reynolds Number

$$N_u = 0.65 \times 882.46^{0.2} + 0.23 \times 882.46^{0.61}$$

N_u = 16.284

Convection heat lost

$$P_{conv} = \lambda N_u(T_2 - T_1)\pi$$

λ = Thermal conductivity of air (0.02585 W/m.k)

$$P_{conv} = 0.02585 \times 16.284(333 - 305)\pi$$

P_{conv} = 37.0282W/m

AC Resistance

$$\boldsymbol{R(T_C) = \left[\frac{R(T_{high}) - R(T_{low})}{T_{high} - T_{low}}\right](T_c - T_{low}) + R(T_{low})}$$

$R(T_{high})$	=	resistance at 75°C (0.08149Ω/m)
$R(T_{low})$	=	resistance at 25°C (0.06841Ω/m)
T_c	=	conductor operating temperature (60°C)

$$\boldsymbol{R(T_{50}) = \left[\frac{0.08149 - 0.06841}{75 - 25}\right](60 - 25) + 0.06841}$$

$R(T_{50})$ = 0.077566Ω/m

Joule Effect

$$P_j = R_T I^2$$

$$I = \left[\frac{P_{rad} + P_{conv} - P_{sol}}{R_t}\right]^{\frac{1}{2}}$$

$$I = \left[\frac{9.2854 + 37.0282 - 14.31}{0.077566 \times 10^{-3}}\right]^{\frac{1}{2}}$$

I = 624A

APPENDIX B: Sag Tension Calculation

Conductor Properties

Conductor diameter (d)	mm	28.62
Cross section (A)	mm^2	484.5
Unit Weight (m_c)	kg/m	1.632
UTS	kN	131.9
Coefficient of Linear Ex. (α)	$°C^{-1}$	0.0000193
Modulus of Elasticity (E)	N/mm^2	69000

Other Data

Span	m	300
Minimum Temperature	°C	7
Everyday Temperature	°C	32
Maximum Temperature	°C	75
Wind Pressure (P)	N/m^2	970
Factor of Safety at stringent condition		2.5
Factor of Safety at Everyday condition		4.5

Wind load factor on conductor at stringent condition

$$q = \frac{\sqrt{(P.d)^2+(m_c g)^2}}{m_c g}$$

$$q_1 = \frac{\sqrt{(970\times0.02862)^2+(1.632\times9.80665)^2}}{(1.632\times9.80665)}$$

$$q_1 = 2.0022$$

Wind load factor at EDS condition

$$q_2 = \frac{\sqrt{(0\times0.02862)^2+(1.632\times9.80665)^2}}{(1.632\times9.80665)}$$

$$q_2 = 1$$

Maximum allowable working tension = UTS/2.5

= 131.9/2.5 = 52.76kN

Maximum allowable working stress (H_1) = $\frac{52760}{2.5} = 108.9N/mm^2$

Weight of conductor /m/mm^2 (δ)

$$\delta = \frac{m_c g}{A}$$

$$\delta = \frac{1.632 \times 9.80665}{484.5}$$

$$\delta = 0.03303$$

To find tension at Everyday condition; State Change Equation is used;

$$H_2^2[H_2 - \left[H_1 - \left(\frac{S^2\delta^2Q_1^2E}{24H_1^2}\right) - \alpha.E.(t_2 - t_1)\right]] = \frac{L^2\mu^2Q_2^2E}{24}$$

$$H_2^2[H_2 - \left[108.9 - \left(\frac{300^2 \times 0.03303^2 \times 2.022^2 \times 69000}{24 \times 108.9^2}\right) - 0.0000193 \times 69000.(32 - 7)\right] = \frac{300^2 \times 0.03303^2 \times 1 \times 69000}{24}$$

From Newton Raphson Method;

100	73.0309	26.9691
73.0309	61.75963	11.27127
61.75963	59.67795	2.081686
59.67795	59.61054	0.067407
59.61054	59.61047	6.93E-05
59.61047	59.61047	7.33E-11

59.61047	59.61047	0
59.61047	59.61047	0
59.61047	59.61047	0

Tension at EDS condition (H_2) = 59.61 N/mm^2

= 59.61 x 484.5 = 28,881N

Safety Factor @ = $\frac{131,900}{28,881}$ = 4.56 (>4.5)

Safety factor is satisfied

Catenary Constant = $\frac{131,900}{4.56 \times 1.632 \times 9.80665}$

= 1807m

Final Tension at Maximum Operating Temperature;

$$H_2^2\left[H_2 - \left[108.9 - \left(\frac{300^2 \times 0.03303^2 \times 2.022^2 \times 69000}{24 \times 108.9^2}\right) - 0.0000193 \times 69000.(75-7)\right]\right] = \frac{300^2 \times 0.03303^2 \times 1 \times 69000}{24}$$

H_2 at 75°C = 47.58N/mm^2

= 23,055N

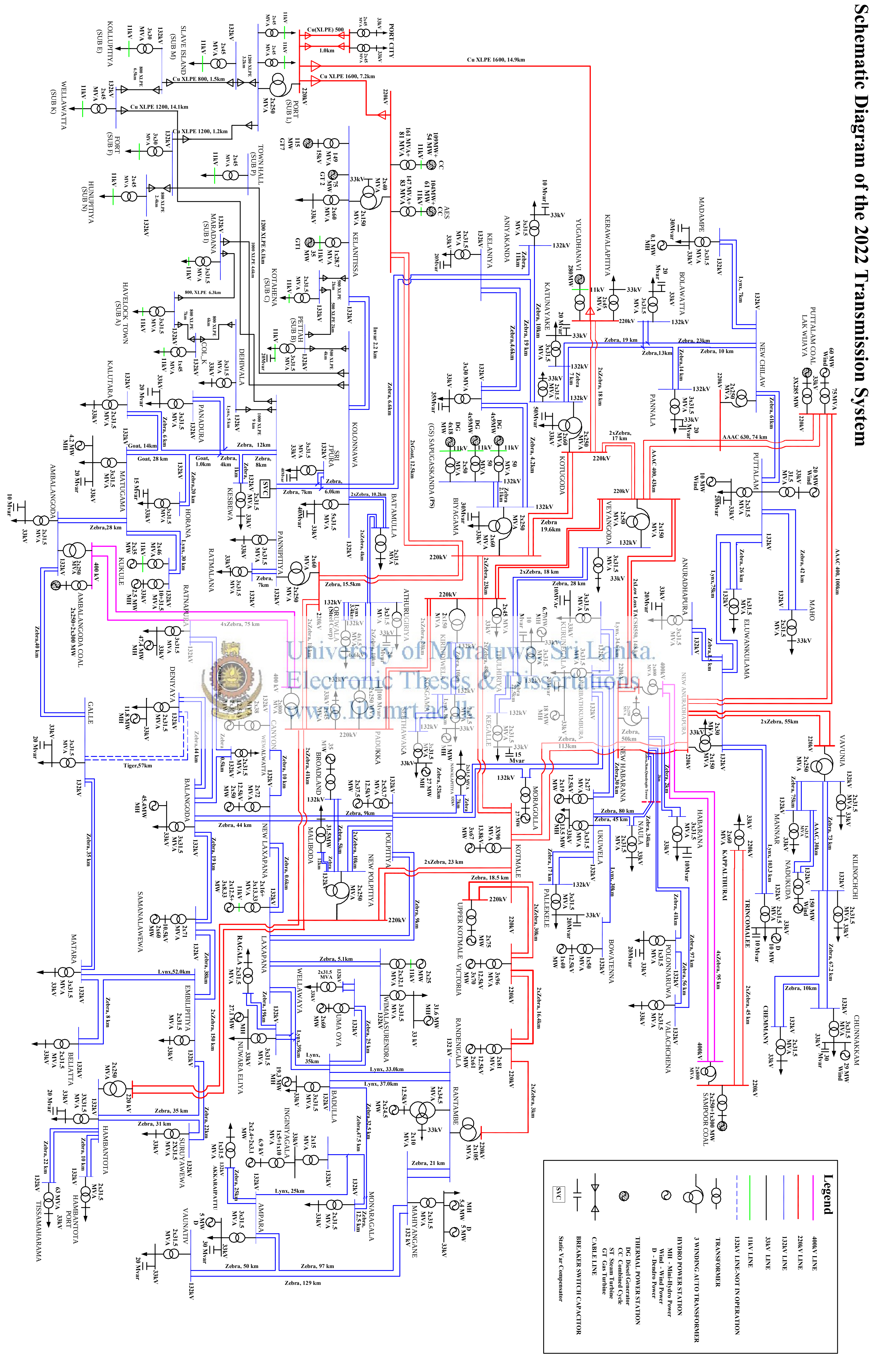
Sag at maximum Operating Temperature;

$$Sag\ (m) = \frac{L^2 \mu Q_2}{8H_2}$$

$$Sag\ (m) = \frac{300^2 \times 0.03303 \times 1}{8 \times 23,055}$$

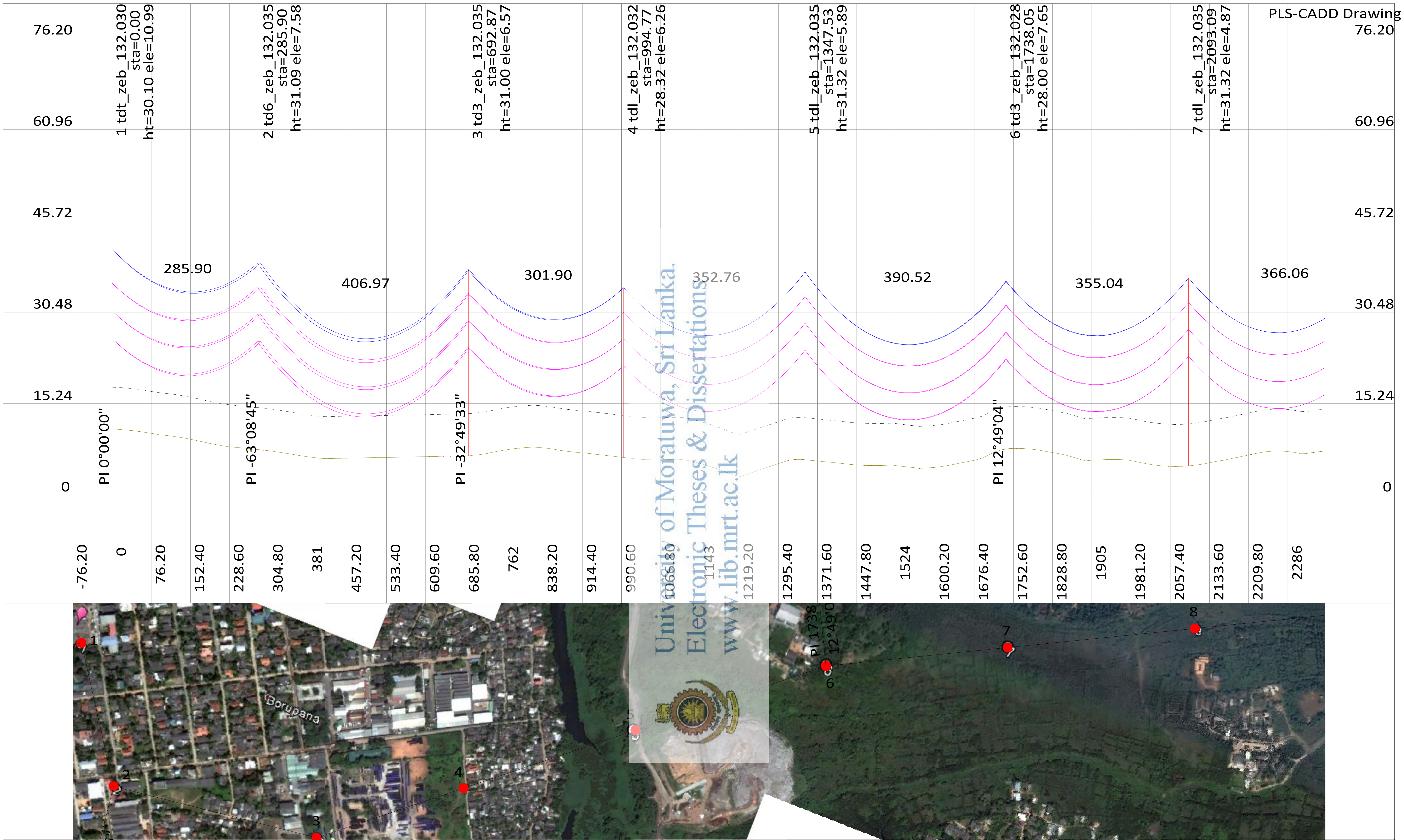
$$Sag\ (m) = 7.8097\text{m}$$

APPENDIX C: SINGLE LINE DIAGRAM OF SRI LANKA'S TRANSMISSION SYSTEM



APPENDIX D: PLS CADD Design of Pannipitiya Rathmalana Line

- Profile View of Panninpitiya – Ratmalana 132kV Existing Lynx Transmission Line
- Summary Data Sheet
- EMF Calculations



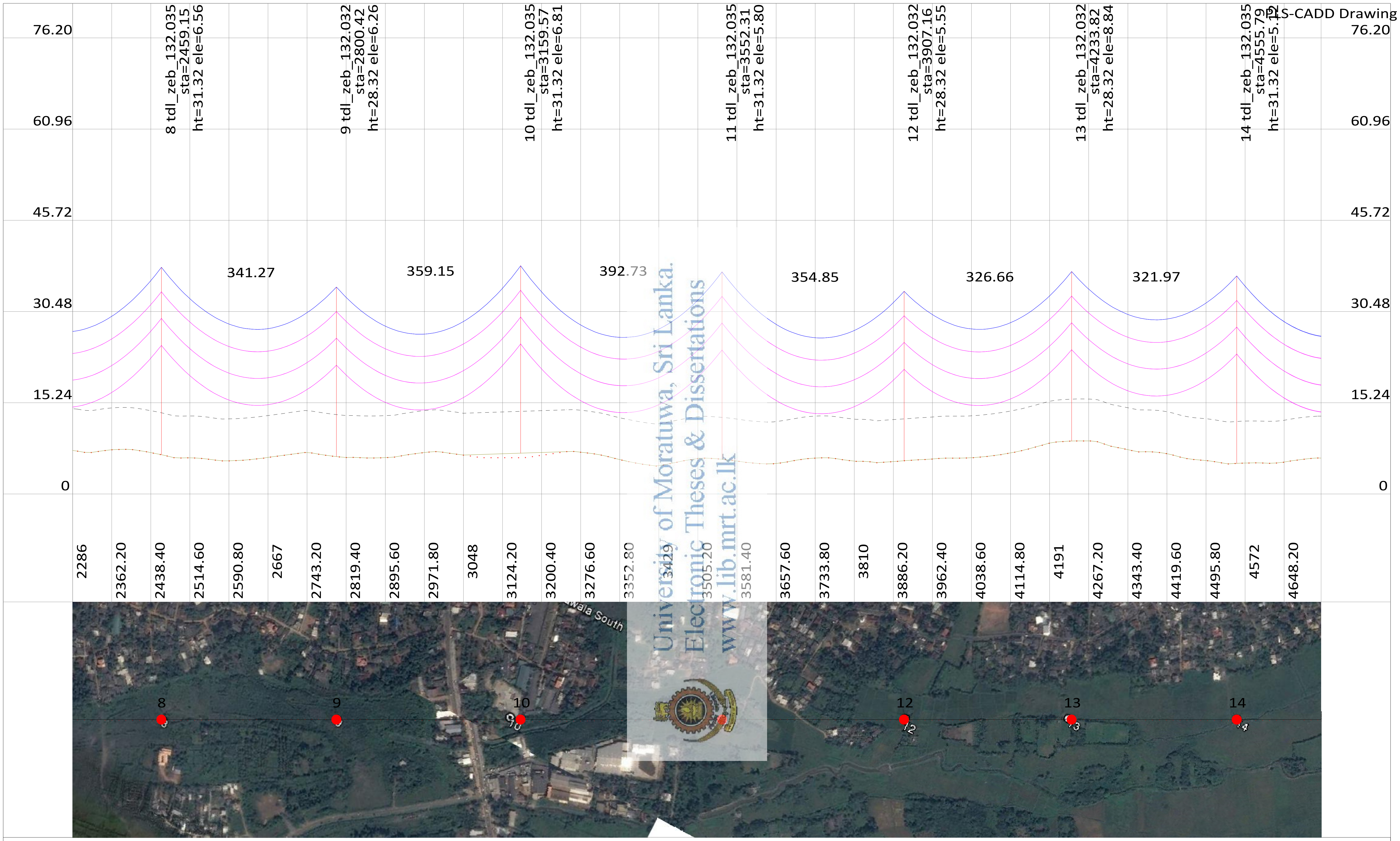
70.0 m Horiz. Scale

6.0 m Vert. Scale

North

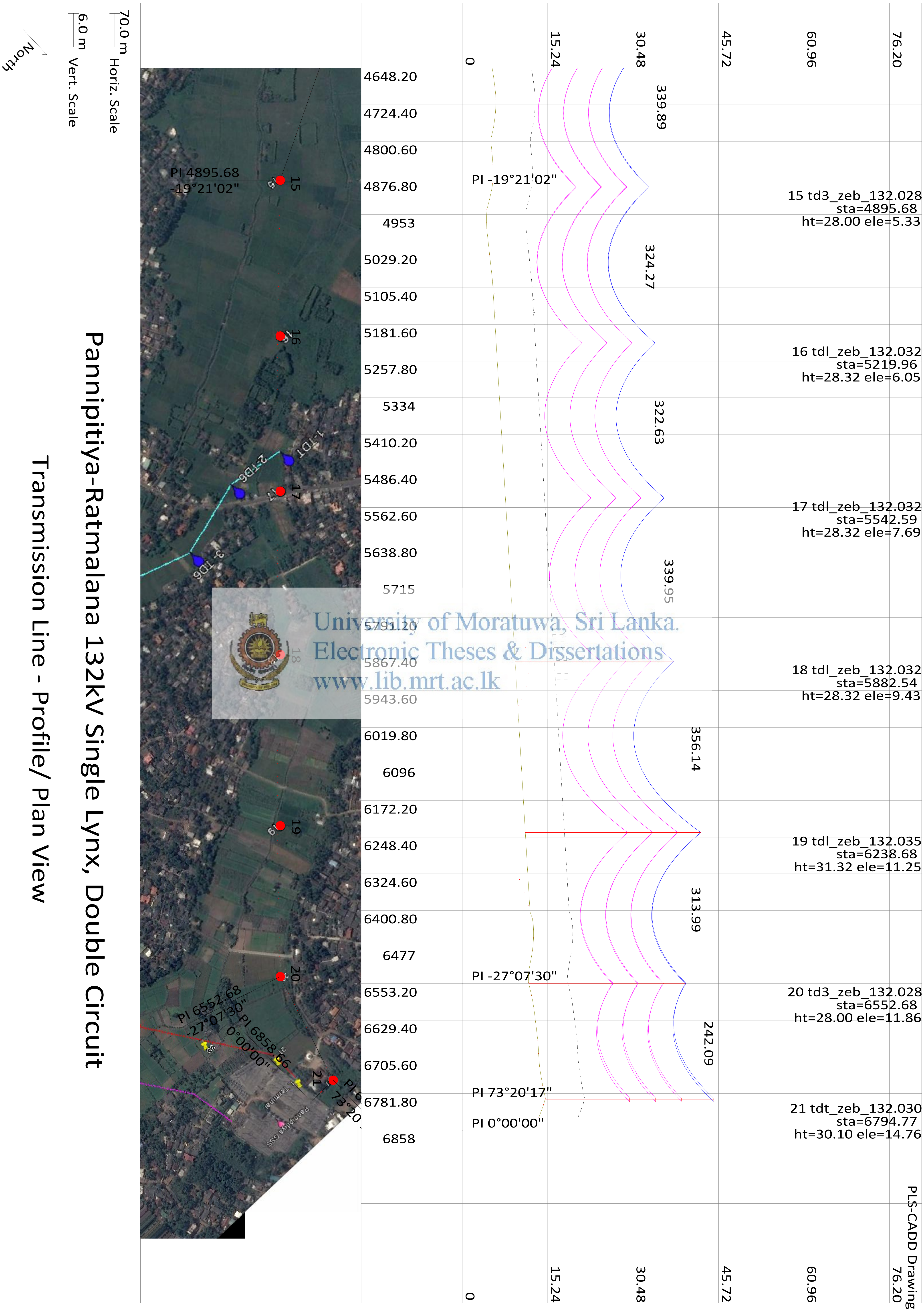
Pannipitiya-Ratmalana 132kV Single Lynx, Double Circuit

Transmission Line - Profile/ Plan View



Pannipitiya-Ratmalana 132kV Single Lynx, Double Circuit

Transmission Line - Profile/ Plan View



Pannipitiya-Ratmalana 132kV Single Lynx, Double Circuit
Transmission Line - Profile/ Plan View
70.0 m Horiz. Scale
6.0 m Vert. Scale
North
PI 4895.68
-19°21'02"
PI 6552.68
-27°07'30"
PI 6858.66
0°00'00"
4648.20
4724.40
4800.60
4876.80
4953
5029.20
5105.40
5181.60
5257.80
5334
5410.20
5486.40
5562.60
5638.80
5715
5791.20
5867.40
5943.60
6019.80
6096
6172.20
6248.40
6324.60
6400.80
6477
6553.20
6629.40
6705.60
6781.80
6858
0
15.24
30.48
45.72
60.96
76.20
339.89
324.27
322.63
339.95
356.14
313.99
242.09
PI -19°21'02"
PI -27°07'30"
PI 73°20'17"
PI 0°00'00"
15 td3_zeb_132.028
sta=4895.68
ht=28.00 ele=5.33
16 tdl_zeb_132.032
sta=5219.96
ht=28.32 ele=6.05
17 tdl_zeb_132.032
sta=5542.59
ht=28.32 ele=7.69
18 tdl_zeb_132.032
sta=5882.54
ht=28.32 ele=9.43
19 tdl_zeb_132.035
sta=6238.68
ht=31.32 ele=11.25
20 td3_zeb_132.028
sta=6552.68
ht=28.00 ele=11.86
21 tdt_zeb_132.030
sta=6794.77
ht=30.10 ele=14.76
PLS-CADD Drawing

PLS-CADD Version 13.20x64 2:28:46 PM Friday, March 27, 2015
Ceylon Electricity Board - Transmission Design
Project Name: 'f:\msc\pls cadd simulations\pannipitiya- panadura transmission line \panni_rath_lynx\pannipitiya ratmalana line.DON'

Line Statistics:

Total line length: 6.79 (km)

Total number of sections: 3
Longest section by linear length: 6.79 (km)
Longest section by number of structures: 21 structures

Total number of structures used: 21
Average number of structures per Km: 3.09

Total number of line angles: 6
Average number of line angles per Km: 0.88
Number of <= 1 deg line angles: 0
Number of <= 5 deg line angles: 0
Number of <= 15 deg line angles: 1
Number of <= 30 deg line angles: 2
Number of <= 90 deg line angles: 3
Number of > 90 deg line angles: 0

Total number of deadend structures: 2
Average number of deadend structures per Km: 0.29
Maximum number of suspension structures between deadend structures: 19
Average number of suspension structures between deadend structures: 9.50

Structure List Report

Struct. Number	Station (m)	Line Angle (deg)	Ahead Span (m)	Height Adjust (m)	Offset Adjust (m)	Orient Angle (deg)	Name/Description/Comments/Material
1	0.00	0.00	285.90	0.00	0.00	0.00	f:\msc\pls cadd simulations\pannipitiya-panadura transmission line\panni_rath_lynx\structures\tdt_zeb_132.030 TDT
2	285.90	-63.15	406.97	0.00	0.00	0.00	f:\msc\pls cadd simulations\pannipitiya-panadura transmission line\structures\td6_zeb_132.035 TD6 embed len=3.00
3	692.87	-32.83	301.90	0.00	0.00	0.00	f:\msc\pls cadd simulations\pannipitiya-panadura transmission line\structures\td3_zeb_132.035 TD3 embed len=3.00
4	994.77	0.00	352.76	0.00	0.00	0.00	f:\msc\pls cadd simulations\pannipitiya-panadura transmission line\panni_rath_lynx\structures\tdl_zeb_132.032 TDL+0
5	1347.53	0.00	390.52	0.00	0.00	0.00	f:\msc\pls cadd simulations\pannipitiya-panadura transmission line\panni_rath_lynx\structures\tdl_zeb_132.035 TDL+0 embed len=0.15
6	1738.05	12.82	355.04	0.00	0.00	0.00	f:\msc\pls cadd simulations\pannipitiya-panadura transmission line\panni_rath_lynx\structures\td3_zeb_132.028 TD3
7	2093.09	0.00	366.06	0.00	0.00	0.00	f:\msc\pls cadd simulations\pannipitiya-panadura transmission line\panni_rath_lynx\structures\tdl_zeb_132.035 TDL+0 embed len=0.15
8	2459.15	0.00	341.27	0.00	0.00	0.00	f:\msc\pls cadd simulations\pannipitiya-panadura transmission line\panni_rath_lynx\structures\tdl_zeb_132.035 TDL+0 embed len=0.15
9	2800.42	0.00	359.15	0.00	0.00	0.00	f:\msc\pls cadd simulations\pannipitiya-panadura transmission line\panni_rath_lynx\structures\tdl_zeb_132.032 TDL+0
10	3159.57	0.00	392.73	0.00	0.00	0.00	f:\msc\pls cadd simulations\pannipitiya-panadura transmission line\panni_rath_lynx\structures\tdl_zeb_132.035 TDL+0 embed len=0.15
11	3552.31	0.00	354.85	0.00	0.00	0.00	f:\msc\pls cadd simulations\pannipitiya-panadura transmission line\panni_rath_lynx\structures\tdl_zeb_132.035

```
                                                            TDL+0
                                                            embed len=0.15
     12 3907.16   0.00  326.66    0.00   0.00   0.00 f:\msc\pls cadd simulations\pannipitiya-
panadura transmission line\panni_rath_lynx\structures\tdl_zeb_132.032
                                                            TDL+0
     13 4233.82   0.00  321.97    0.00   0.00   0.00 f:\msc\pls cadd simulations\pannipitiya-
panadura transmission line\panni_rath_lynx\structures\tdl_zeb_132.032
                                                            TDL+0
     14 4555.79   0.00  339.89    0.00   0.00   0.00 f:\msc\pls cadd simulations\pannipitiya-
panadura transmission line\panni_rath_lynx\structures\tdl_zeb_132.035
                                                            TDL+0
                                                            embed len=0.15
     15 4895.68 -19.35  324.27    0.00   0.00   0.00 f:\msc\pls cadd simulations\pannipitiya-
panadura transmission line\panni_rath_lynx\structures\td3_zeb_132.028
                                                            TD3
     16 5219.96   0.00  322.63    0.00   0.00   0.00 f:\msc\pls cadd simulations\pannipitiya-
panadura transmission line\panni_rath_lynx\structures\tdl_zeb_132.032
                                                            TDL+0
     17 5542.59   0.00  339.95    0.00   0.00   0.00 f:\msc\pls cadd simulations\pannipitiya-
panadura transmission line\panni_rath_lynx\structures\tdl_zeb_132.032
                                                            TDL+0
     18 5882.54   0.00  356.14    0.00   0.00   0.00 f:\msc\pls cadd simulations\pannipitiya-
panadura transmission line\panni_rath_lynx\structures\tdl_zeb_132.032
                                                            TDL+0
     19 6238.68   0.00  313.99    0.00   0.00   0.00 f:\msc\pls cadd simulations\pannipitiya-
panadura transmission line\panni_rath_lynx\structures\tdl_zeb_132.035
                                                            TDL+0
                                                            embed len=0.15
     20 6552.68 -27.12  242.09    0.00   0.00   0.00 f:\msc\pls cadd simulations\pannipitiya-
panadura transmission line\panni_rath_lynx\structures\td3_zeb_132.028
                                                            TD3
     21 6794.77  73.34    0.00    0.00   0.00   0.00 f:\msc\pls cadd simulations\pannipitiya-
panadura transmission line\structures\tdt_zeb_132.030
                                                            TDT
```

Structure Coordinates Report

Struct. Number	Station (m)	Ahead Span (m)	X (m)	Y (m)	Z (m)	Structure Name
1	0.00	285.90	377497.75	753280.32	10.99	tdt_zeb_132.030
2	285.90	406.97	377657.94	753043.51	7.58	td6_zeb_132.035
3	692.87	301.90	378061.68	753094.68	6.57	td3_zeb_132.035
4	994.77	352.76	378292.79	753288.94	6.26	tdl_zeb_132.032
5	1347.53	390.52	378562.82	753515.91	5.89	tdl_zeb_132.035
6	1738.05	355.04	378861.76	753767.19	7.65	td3_zeb_132.028
7	2093.09	366.06	379177.45	753929.65	4.87	tdl_zeb_132.035
8	2459.15	341.27	379502.94	754097.15	6.56	tdl_zeb_132.035
9	2800.42	359.15	379806.39	754253.31	6.26	tdl_zeb_132.032
10	3159.57	392.73	380125.74	754417.65	6.81	tdl_zeb_132.035
11	3552.31	354.85	380474.95	754597.35	5.80	tdl_zeb_132.035
12	3907.16	326.66	380790.47	754759.72	5.55	tdl_zeb_132.032
13	4233.82	321.97	381080.93	754909.20	8.84	tdl_zeb_132.032
14	4555.79	339.89	381367.22	755056.52	5.12	tdl_zeb_132.035
15	4895.68	324.27	381669.44	755212.05	5.33	td3_zeb_132.028
16	5219.96	322.63	381892.32	755447.59	6.05	tdl_zeb_132.032
17	5542.59	339.95	382114.07	755681.93	7.69	tdl_zeb_132.032
18	5882.54	356.14	382347.73	755928.86	9.43	tdl_zeb_132.032
19	6238.68	313.99	382592.51	756187.54	11.25	tdl_zeb_132.035
20	6552.68	242.09	382808.33	756415.61	11.86	td3_zeb_132.028
21	6794.77	0.00	382876.25	756647.97	14.76	tdt_zeb_132.030

Structure Attachment Coordinates

Coordinates and arc lengths along the wire are for weather case 'EDS', Creep RS, wind from the left.
Arc lengths are adjusted for the number of subconductors and to exclude the length of strain insulators.
Arc lengths and slack are computed with any concentrated loads removed. Other columns are with concentrated loads applied.

Struct. Set Phase   Structure   Set ---------Insulator-------- | -----------

```
Wire----------- | ------------Mid----------- | ------------Low----------- | -----TIN Z below----
|  Ahead   Ahead
 Number No.   No.            Name   Label ----------Attach---------- | ----------
Attach---------- | -----------Span----------- | -----------Point---------- |Insulator  Mid
Low |     Span     Span
                                                 -----------Point---------- | -----------
Point---------- | -----------Point---------- |                            | Attach   Span  Point
|     Arc   Slack
                                                         X         Y      Z |         X         Y
Z |         X         Y      Z |        X         Y      Z | ---Point-----          |  Length
                                                 ------------(m)----------- | ------------
(m)----------- | ------------(m)----------- | ------------(m)----------- | ---------(m)--------
|     (m)     (m)
------------------------------------------------------------------------------------------------
------------------------------------------------------------------------------------------------
----
      1   1     1 tdt_zeb_132.030      GW 377502.29 753283.39  41.09   377502.29 753283.39
41.09   377581.27 753166.00  34.61   377590.36 753152.49  34.54     0.00   0.00   0.00   283.239
0.261
                2                         377493.20 753277.24  41.09   377493.20 753277.24
41.09   377574.42 753157.83  34.39   377583.39 753144.63  34.32     0.00   0.00   0.00   289.119
0.278
          2     1                      C1 377502.14 753283.29  35.34   377503.34 753281.51
35.20   377581.19 753165.95  30.34   377584.05 753161.71  30.33     0.00   0.00   0.00   278.873
0.205
                2                         377502.72 753283.68  30.74   377503.91 753281.90
30.60   377581.48 753166.15  25.78   377584.01 753162.37  25.77     0.00   0.00   0.00   278.875
0.205
                3                         377503.38 753284.13  26.09   377504.57 753282.34
25.95   377581.92 753166.61  21.17   377584.10 753163.35  21.17     0.00   0.00   0.00   278.598
0.205
          3     1                      C2 377493.36 753277.35  35.34   377494.56 753275.57
35.20   377574.49 753157.88  30.14   377577.31 753153.73  30.13     0.00   0.00   0.00   284.750
0.218
                2                         377492.78 753276.96  30.74   377493.99 753275.18
30.60   377574.20 753157.68  25.58   377576.70 753154.03  25.58     0.00   0.00   0.00   284.752
0.218
                3                         377492.12 753276.51  26.09   377493.33 753274.74
25.95   377573.76 753157.22  20.96   377575.93 753154.05  20.96     0.00   0.00   0.00   285.031
0.219

      2   1     1 td6_zeb_132.035      GW 377660.25 753048.61  38.67   377660.25 753048.61
38.67   377860.06 753073.71  27.44   377865.17 753074.35  27.43     7.58   0.00   0.00   403.525
0.754
                2                         377655.63 753038.41  38.67   377655.63 753038.41
38.67   377859.56 753064.49  26.99   377864.57 753065.13  26.98     0.00   0.00   0.00   411.980
0.802
          2     1                      C1 377660.25 753048.61  34.67   377662.37 753048.88
34.46   377860.06 753073.71  24.66   377865.84 753074.44  24.65     7.58   0.00   0.00   399.063
0.592
                2                         377660.25 753048.61  30.15   377662.37 753048.88
29.94   377860.04 753073.76  20.15   377865.70 753074.47  20.14     7.58   0.00   0.00   399.034
0.592
                3                         377660.47 753049.10  25.58   377662.59 753049.36
25.37   377860.07 753074.18  15.63   377865.36 753074.85  15.62     7.58   0.00   0.00   398.642
0.590
          3     1                      C2 377655.63 753038.41  34.67   377657.75 753038.68
34.46   377859.56 753064.49  24.26   377865.21 753065.21  24.25     0.00   0.00   0.00   407.508
0.630
                2                         377655.63 753038.41  30.15   377657.75 753038.68
29.94   377859.58 753064.44  19.74   377865.13 753065.15  19.74     0.00   0.00   0.00   407.536
0.630
                3                         377655.41 753037.93  25.58   377657.53 753038.20
25.37   377859.55 753064.02  15.19   377864.74 753064.68  15.18     0.00   0.00   0.00   407.928
0.632

      3   1     1 td3_zeb_132.035      GW 378059.88 753098.80  37.57   378059.88 753098.80
37.57   378175.06 753195.38  30.13   378189.50 753207.49  30.04     6.61   0.00   0.00   300.957
0.314
                2                         378063.49 753090.56  37.57   378063.49 753090.56
37.57   378179.41 753188.24  30.03   378193.71 753200.29  29.94     0.00   0.00   0.00   303.508
0.322
          2     1                      C1 378059.88 753098.80  33.57   378061.52 753100.18
33.40   378175.88 753196.08  26.75   378191.91 753209.53  26.64     6.61   0.00   0.00   298.740
0.246
                2                         378059.84 753098.90  29.07   378061.48 753100.27
28.90   378175.83 753196.15  22.27   378191.59 753209.37  22.17     6.61   0.00   0.00   298.712
```

0.246
3 378059.68 753099.26 24.57 378061.32 753100.64
24.40 378175.65 753196.45 17.78 378191.41 753209.66 17.68 6.61 0.00 0.00 298.599
0.246
3 1 C2 378063.49 753090.56 33.57 378065.12 753091.94
33.40 378180.23 753188.92 26.66 378196.10 753202.28 26.56 0.00 0.00 0.00 301.290
0.253
2 378063.53 753090.47 29.07 378065.16 753091.85
28.90 378180.27 753188.85 22.18 378195.86 753201.98 22.08 0.00 0.00 0.00 301.318
0.253
3 378063.69 753090.10 24.57 378065.32 753091.48
24.40 378180.46 753188.54 17.68 378196.04 753201.68 17.58 0.00 0.00 0.00 301.431
0.253

4 1 1 tdl_zeb_132.032 GW 378290.24 753291.96 34.58 378290.24 753291.96
34.58 378425.26 753405.45 27.71 378414.44 753396.35 27.65 0.00 0.00 0.00 353.272
0.507
2 378295.33 753285.91 34.58 378295.33 753285.91
34.58 378430.34 753399.40 27.71 378419.52 753390.31 27.65 0.00 0.00 0.00 353.272
0.507
2 1 P1 378290.24 753291.96 32.63 378290.23 753291.97
30.48 378425.25 753405.46 24.54 378413.04 753395.20 24.48 0.00 0.00 0.00 353.164
0.398
2 378290.20 753292.01 28.18 378290.19 753292.03
26.03 378425.20 753405.52 20.09 378413.00 753395.26 20.03 0.00 0.00 0.00 353.164
0.398
3 378290.00 753292.25 23.68 378289.98 753292.27
21.53 378425.00 753405.76 15.59 378412.80 753395.50 15.53 0.00 0.00 0.00 353.164
0.398
3 1 378295.33 753285.91 32.63 378295.34 753285.90
30.48 378430.35 753399.39 24.54 378418.15 753389.13 24.48 0.00 0.00 0.00 353.164
0.398
2 378295.37 753285.86 28.18 378295.38 753285.84
26.03 378430.40 753399.33 20.09 378418.20 753389.07 20.03 0.00 0.00 0.00 353.164
0.398
3 378295.57 753285.62 23.68 378295.59 753285.60
21.53 378430.60 753399.09 15.59 378418.40 753388.83 15.53 0.00 0.00 0.00 353.164
0.398

5 1 1 tdl_zeb_132.035 GW 378560.28 753518.94 37.21 378560.28 753518.94
37.21 378709.77 753644.94 26.37 378715.55 753649.80 26.35 0.00 0.00 0.00 391.717
0.690
2 378565.36 753512.89 37.21 378565.36 753512.89
37.21 378714.81 753638.17 26.42 378720.62 753643.04 26.40 0.00 0.00 0.00 390.707
0.685
2 1 P1 378560.28 753518.94 35.26 378560.27 753518.95
33.11 378708.95 753644.25 23.47 378715.87 753650.09 23.45 0.00 0.00 0.00 389.419
0.542
2 378560.23 753518.99 30.81 378560.22 753519.00
28.66 378708.90 753644.32 18.99 378716.02 753650.33 18.97 0.00 0.00 0.00 389.430
0.542
3 378560.03 753519.23 26.31 378560.02 753519.24
24.16 378708.69 753644.61 14.49 378715.81 753650.61 14.47 0.00 0.00 0.00 389.475
0.542
3 1 378565.36 753512.89 35.26 378565.37 753512.88
33.11 378713.99 753637.47 23.51 378720.95 753643.30 23.49 0.00 0.00 0.00 388.410
0.538
2 378565.41 753512.84 30.81 378565.42 753512.82
28.66 378714.04 753637.40 19.04 378721.20 753643.40 19.02 0.00 0.00 0.00 388.399
0.538
3 378565.61 753512.60 26.31 378565.62 753512.58
24.16 378714.25 753637.12 14.54 378721.41 753643.11 14.52 0.00 0.00 0.00 388.354
0.538

6 1 1 td3_zeb_132.028 GW 378859.27 753770.94 35.65 378859.27 753770.94
35.65 379017.46 753852.05 27.60 379014.90 753850.74 27.60 0.00 0.00 0.00 356.061
0.519
2 378864.26 753763.44 35.65 378864.26 753763.44
35.65 379021.76 753844.79 27.65 379019.21 753843.47 27.65 7.16 0.00 0.00 355.052
0.514
2 1 C1 378859.27 753770.94 31.65 378861.18 753771.91
31.48 379018.41 753852.55 24.50 379015.11 753850.86 24.50 0.00 0.00 0.00 353.800
0.407
2 378859.21 753771.02 27.15 378861.12 753772.00
26.98 379018.36 753852.62 20.02 379014.80 753850.79 20.02 0.00 0.00 0.00 353.811
0.407
3 378858.99 753771.35 22.65 378860.90 753772.33
22.48 379018.18 753852.92 15.52 379014.62 753851.10 15.52 0.00 0.00 0.00 353.856

```
0.408
         3     1                       C2 378864.26 753763.44  31.65   378866.16 753764.43
31.48    379022.71 753845.27  24.54   379019.42 753843.57  24.54    7.16   0.00   0.00   352.792
0.404
               2                          378864.31 753763.36  27.15   378866.21 753764.34
26.98    379022.76 753845.20  20.07   379019.19 753843.36  20.06    7.14   0.00   0.00   352.781
0.404
               3                          378864.53 753763.03  22.65   378866.44 753764.01
22.48    379022.94 753844.89  15.57   379019.38 753843.05  15.57    0.00   0.00   0.00   352.736
0.404

     7   1     1 tdl_zeb_132.035       GW 379175.65 753933.16  36.19   379175.65 753933.16
36.19    379338.39 754016.91  28.21   379330.59 754012.90  28.19    0.00   0.00   0.00   366.631
0.566
               2                          379179.26 753926.14  36.19   379179.26 753926.14
36.19    379342.01 754009.89  28.21   379334.21 754005.87  28.19    0.00   0.00   0.00   366.631
0.566
         2     1                       P1 379175.65 753933.16  34.24   379175.64 753933.18
32.09    379338.39 754016.92  25.12   379329.60 754012.40  25.10    0.00   0.00   0.00   366.509
0.445
               2                          379175.61 753933.22  29.79   379175.60 753933.24
27.64    379338.35 754016.98  20.67   379329.56 754012.46  20.65    0.00   0.00   0.00   366.509
0.445
               3                          379175.47 753933.50  25.29   379175.46 753933.52
23.14    379338.21 754017.26  16.17   379329.42 754012.74  16.15    0.00   0.00   0.00   366.509
0.445
         3     1                          379179.26 753926.14  34.24   379179.27 753926.12
32.09    379342.01 754009.88  25.12   379333.22 754005.35  25.10    0.00   0.00   0.00   366.509
0.445
               2                          379179.29 753926.07  29.79   379179.30 753926.05
27.64    379342.04 754009.81  20.67   379333.25 754005.29  20.65    0.00   0.00   0.00   366.509
0.445
               3                          379179.43 753925.80  25.29   379179.45 753925.78
23.14    379342.18 754009.54  16.17   379333.39 754005.01  16.15    0.00   0.00   0.00   366.509
0.445

     8   1     1 tdl_zeb_132.035       GW 379501.14 754100.66  37.88   379501.14 754100.66
37.88    379652.86 754178.74  28.56   379669.19 754187.14  28.47    0.00   0.00   0.00   341.747
0.459
               2                          379504.75 754093.64  37.88   379504.75 754093.64
37.88    379656.48 754171.71  28.56   379672.80 754180.12  28.47    0.00   0.00   0.00   341.747
0.459
         2     1                       P1 379501.14 754100.66  35.93   379501.14 754100.66
33.78    379652.86 754178.74  25.34   379671.28 754188.22  25.24    0.00   0.00   0.00   341.648
0.360
               2                          379501.10 754100.72  31.48   379501.10 754100.72
29.33    379652.83 754178.80  20.89   379671.25 754188.28  20.79    0.00   0.00   0.00   341.648
0.360
               3                          379500.96 754101.00  26.98   379500.96 754101.00
24.83    379652.69 754179.08  16.39   379671.11 754188.56  16.29    0.00   0.00   0.00   341.648
0.360
         3     1                          379504.75 754093.64  35.93   379504.75 754093.64
33.78    379656.48 754171.71  25.34   379674.89 754181.19  25.24    0.00   0.00   0.00   341.648
0.360
               2                          379504.78 754093.57  31.48   379504.78 754093.57
29.33    379656.51 754171.65  20.89   379674.93 754181.13  20.79    0.00   0.00   0.00   341.648
0.360
               3                          379504.92 754093.30  26.98   379504.92 754093.30
24.83    379656.65 754171.38  16.39   379675.07 754180.86  16.29    0.00   0.00   0.00   341.648
0.360

     9   1     1 tdl_zeb_132.032       GW 379804.59 754256.82  34.58   379804.59 754256.82
34.58    379964.26 754338.99  27.86   379947.57 754330.40  27.77    0.00   0.00   0.00   359.706
0.535
               2                          379808.20 754249.79  34.58   379808.20 754249.79
34.58    379967.87 754331.96  27.86   379951.18 754323.37  27.77    0.00   0.00   0.00   359.706
0.535
         2     1                       P1 379804.59 754256.82  32.63   379804.59 754256.82
30.48    379964.26 754338.99  24.73   379945.40 754329.28  24.63    0.00   0.00   0.00   359.591
0.420
               2                          379804.55 754256.88  28.18   379804.55 754256.88
26.03    379964.23 754339.05  20.28   379945.37 754329.35  20.18    0.00   0.00   0.00   359.591
0.420
               3                          379804.41 754257.16  23.68   379804.41 754257.16
21.53    379964.09 754339.33  15.78   379945.23 754329.62  15.68    0.00   0.00   0.00   359.591
0.420
         3     1                          379808.20 754249.79  32.63   379808.20 754249.79
30.48    379967.87 754331.96  24.73   379949.02 754322.26  24.63    0.00   0.00   0.00   359.591
```

```
0.420
              2                         379808.23 754249.73  28.18   379808.23 754249.73
26.03    379967.91 754331.90  20.28   379949.05 754322.20  20.18     0.00   0.00   0.00   359.591
0.420
              3                         379808.37 754249.46  23.68   379808.37 754249.46
21.53    379968.05 754331.63  15.78   379949.19 754321.92  15.68     0.00   0.00   0.00   359.591
0.420

     10    1     1 tdl_zeb_132.035      GW 380123.93 754421.16  38.13   380123.93 754421.16
38.13    380298.54 754511.01  27.47   380302.88 754513.24  27.47     0.00   0.00   0.00   393.434
0.699
              2                         380127.55 754414.13  38.13   380127.55 754414.13
38.13    380302.15 754503.99  27.47   380306.49 754506.22  27.47     0.00   0.00   0.00   393.434
0.699
           2     1                      P1 380123.93 754421.16  36.18   380123.93 754421.16
34.03    380298.54 754511.01  24.53   380303.45 754513.54  24.52     0.00   0.00   0.00   393.284
0.549
              2                         380123.90 754421.22  31.73   380123.90 754421.22
29.58    380298.51 754511.07  20.08   380303.42 754513.60  20.07     0.00   0.00   0.00   393.284
0.549
              3                         380123.76 754421.50  27.23   380123.76 754421.50
25.08    380298.36 754511.35  15.58   380303.28 754513.88  15.57     0.00   0.00   0.00   393.284
0.549
           3     1                      380127.55 754414.13  36.18   380127.55 754414.13
34.03    380302.15 754503.99  24.53   380307.07 754506.52  24.52     0.00   0.00   0.00   393.284
0.549
              2                         380127.58 754414.07  31.73   380127.58 754414.07
29.58    380302.18 754503.93  20.08   380307.10 754506.45  20.07     0.00   0.00   0.00   393.284
0.549
              3                         380127.72 754413.80  27.23   380127.72 754413.80
25.08    380302.33 754503.65  15.58   380307.24 754506.18  15.57     6.08   0.00   0.00   393.284
0.549

     11    1     1 tdl_zeb_132.035      GW 380473.14 754600.86  37.12   380473.14 754600.86
37.12    380630.90 754682.05  27.21   380646.34 754689.99  27.13     0.00   0.00   0.00   355.383
0.516
              2                         380476.76 754593.84  37.12   380476.76 754593.84
37.12    380634.52 754675.03  27.21   380649.95 754682.97  27.13     0.00   0.00   0.00   355.383
0.516
           2     1                      P1 380473.14 754600.86  35.17   380473.14 754600.86
33.02    380630.90 754682.05  24.05   380648.34 754691.02  23.96     0.00   0.00   0.00   355.272
0.405
              2                         380473.11 754600.93  30.72   380473.11 754600.93
28.57    380630.87 754682.11  19.60   380648.31 754691.09  19.51     0.00   0.00   0.00   355.272
0.405
              3                         380472.97 754601.20  26.22   380472.97 754601.20
24.07    380630.73 754682.39  15.10   380648.17 754691.36  15.01     0.00   0.00   0.00   355.272
0.405
           3     1                      380476.76 754593.84  35.17   380476.76 754593.84
33.02    380634.52 754675.03  24.05   380651.96 754684.00  23.96     0.00   0.00   0.00   355.272
0.405
              2                         380476.79 754593.78  30.72   380476.79 754593.78
28.57    380634.55 754674.96  19.60   380651.99 754683.94  19.51     0.00   0.00   0.00   355.272
0.405
              3                         380476.93 754593.50  26.22   380476.93 754593.50
24.07    380634.69 754674.69  15.10   380652.13 754683.66  15.01     0.00   0.00   0.00   355.272
0.405

     12    1     1 tdl_zeb_132.032      GW 380788.67 754763.24  33.87   380788.67 754763.24
33.87    380933.89 754837.97  28.49   380916.86 754829.21  28.40     0.00   0.00   0.00   327.079
0.402
              2                         380792.28 754756.21  33.87   380792.28 754756.21
33.87    380937.51 754830.95  28.49   380920.47 754822.18  28.40     0.00   0.00   0.00   327.079
0.402
           2     1                      P1 380788.67 754763.24  31.92   380788.67 754763.24
29.77    380933.89 754837.97  25.19   380914.69 754828.09  25.09     0.00   0.00   0.00   326.992
0.316
              2                         380788.63 754763.30  27.47   380788.63 754763.30
25.32    380933.86 754838.03  20.74   380914.66 754828.15  20.64     0.00   0.00   0.00   326.992
0.316
              3                         380788.49 754763.57  22.97   380788.49 754763.57
20.82    380933.72 754838.31  16.24   380914.52 754828.43  16.14     0.00   0.00   0.00   326.992
0.316
           3     1                      380792.28 754756.21  31.92   380792.28 754756.21
29.77    380937.51 754830.95  25.19   380918.31 754821.07  25.09     0.00   0.00   0.00   326.992
0.316
              2                         380792.31 754756.15  27.47   380792.31 754756.15
25.32    380937.54 754830.89  20.74   380918.34 754821.01  20.64     0.00   0.00   0.00   326.992
```

```
0.316
            3                    380792.45 754755.87  22.97   380792.45 754755.87
20.82   380937.68 754830.61  16.24   380918.48 754820.73  16.14     0.00   0.00   0.00   326.992
0.316

     13   1     1 tdl_zeb_132.032      GW 381079.12 754912.71  37.16   381079.12 754912.71
37.16   381222.27 754986.37  29.98   381226.09 754988.34  29.97     0.00   0.00   0.00   322.358
0.385
            2                    381082.74 754905.68  37.16   381082.74 754905.68
37.16   381225.88 754979.35  29.98   381229.71 754981.32  29.97     0.00   0.00   0.00   322.358
0.385
        2     1                    P1 381079.12 754912.71  35.21   381079.12 754912.71
33.06   381222.26 754986.38  26.65   381226.58 754988.60  26.65     0.00   0.00   0.00   322.275
0.302
            2                    381079.09 754912.77  30.76   381079.09 754912.77
28.61   381222.23 754986.44  22.20   381226.54 754988.66  22.20     0.00   0.00   0.00   322.275
0.302
            3                    381078.95 754913.05  26.26   381078.95 754913.05
24.11   381222.09 754986.72  17.70   381226.40 754988.94  17.70     0.00   0.00   0.00   322.275
0.302
        3     1                    381082.74 754905.68  35.21   381082.74 754905.68
33.06   381225.88 754979.34  26.65   381230.20 754981.56  26.65     0.00   0.00   0.00   322.275
0.302
            2                    381082.77 754905.62  30.76   381082.77 754905.62
28.61   381225.92 754979.28  22.20   381230.23 754981.50  22.20     0.00   0.00   0.00   322.275
0.302
            3                    381082.91 754905.35  26.26   381082.91 754905.35
24.11   381226.06 754979.00  17.70   381230.38 754981.22  17.70     0.00   0.00   0.00   322.275
0.302

     14   1     1 tdl_zeb_132.035      GW 381365.41 755060.04  36.44   381365.41 755060.04
36.44   381516.07 755137.84  27.31   381531.51 755145.81  27.23     0.00   0.00   0.00   339.600
0.450
            2                    381369.02 755053.01  36.44   381369.02 755053.01
36.44   381520.58 755130.73  27.25   381535.97 755138.62  27.17     0.00   0.00   0.00   341.119
0.456
        2     1                    P1 381365.41 755060.04  34.49   381365.40 755060.05
32.34   381515.12 755137.36  24.14   381532.93 755146.55  24.04     0.00   0.00   0.00   337.353
0.353
            2                    381365.38 755060.10  30.04   381365.37 755060.12
27.89   381515.07 755137.43  19.66   381533.17 755146.78  19.56     0.00   0.00   0.00   337.336
0.353
            3                    381365.24 755060.37  25.54   381365.22 755060.39
23.39   381514.88 755137.73  15.16   381532.97 755147.08  15.07     0.00   0.00   0.00   337.269
0.353
        3     1                    381369.02 755053.01  34.49   381369.03 755052.99
32.34   381519.63 755130.23  24.08   381537.40 755139.35  23.98     0.00   0.00   0.00   338.870
0.358
            2                    381369.06 755052.95  30.04   381369.07 755052.93
27.89   381519.68 755130.16  19.60   381537.72 755139.41  19.50     0.00   0.00   0.00   338.887
0.358
            3                    381369.20 755052.67  25.54   381369.21 755052.65
23.39   381519.87 755129.86  15.10   381537.92 755139.11  15.00     0.00   0.00   0.00   338.955
0.359

     15   1     1 td3_zeb_132.028      GW 381666.74 755215.65  33.33   381666.74 755215.65
33.33   381778.09 755332.97  26.96   381773.89 755328.55  26.95     5.22   0.00   0.00   323.911
0.391
            2                    381672.14 755208.45  33.33   381672.14 755208.45
33.33   381783.67 755326.66  26.90   381779.51 755322.26  26.89     0.00   0.00   0.00   325.429
0.396
        2     1                    C1 381666.74 755215.65  29.33   381668.21 755217.20
29.18   381778.82 755333.76  23.70   381773.81 755328.48  23.69     5.22   0.00   0.00   321.677
0.307
            2                    381666.68 755215.73  24.83   381668.15 755217.28
24.68   381778.77 755333.82  19.22   381773.54 755328.32  19.21     5.21   0.00   0.00   321.660
0.307
            3                    381666.44 755216.05  20.33   381667.91 755217.60
20.18   381778.53 755334.09  14.73   381773.28 755328.56  14.71     5.17   0.00   0.00   321.593
0.307
        3     1                    C2 381672.14 755208.45  29.33   381673.61 755210.01
29.18   381784.41 755327.43  23.64   381779.45 755322.17  23.63     0.00   0.00   0.00   323.193
0.311
            2                    381672.20 755208.37  24.83   381673.67 755209.93
24.68   381784.46 755327.37  19.17   381779.26 755321.85  19.15     0.00   0.00   0.00   323.211
0.311
            3                    381672.44 755208.05  20.33   381673.91 755209.61
20.18   381784.70 755327.10  14.66   381779.49 755321.58  14.65     0.00   0.00   0.00   323.278
```

```
0.311

     16   1     1 tdl_zeb_132.032      GW 381889.45 755450.30  34.37   381889.45 755450.30
34.37   382000.33 755567.47  28.34   381993.66 755560.42  28.31     0.00   0.00   0.00   323.026
0.388
                2                         381895.19 755444.87  34.37   381895.19 755444.87
34.37   382006.07 755562.04  28.34   381999.39 755554.99  28.31     0.00   0.00   0.00   323.026
0.388
          2     1                      P1 381889.45 755450.30  32.42   381889.44 755450.32
30.27   382000.32 755567.48  25.02   381992.81 755559.54  24.99     0.00   0.00   0.00   322.943
0.304
                2                         381889.40 755450.35  27.97   381889.38 755450.37
25.82   382000.27 755567.53  20.57   381992.76 755559.59  20.54     0.00   0.00   0.00   322.943
0.304
                3                         381889.18 755450.56  23.47   381889.16 755450.58
21.32   382000.04 755567.74  16.07   381992.53 755559.81  16.04     0.00   0.00   0.00   322.943
0.304
          3     1                         381895.19 755444.87  32.42   381895.21 755444.86
30.27   382006.07 755562.04  25.02   381998.56 755554.10  24.99     0.00   0.00   0.00   322.943
0.304
                2                         381895.24 755444.82  27.97   381895.26 755444.81
25.82   382006.13 755561.99  20.57   381998.61 755554.05  20.54     0.00   0.00   0.00   322.943
0.304
                3                         381895.47 755444.61  23.47   381895.48 755444.59
21.32   382006.35 755561.77  16.07   381998.84 755553.83  16.04     0.00   0.00   0.00   322.943
0.304

     17   1     1 tdl_zeb_132.032      GW 382111.21 755684.65  36.01   382111.21 755684.65
36.01   382228.03 755808.11  29.27   382221.37 755801.06  29.25     0.00   0.00   0.00   340.409
0.453
                2                         382116.94 755679.22  36.01   382116.94 755679.22
36.01   382233.77 755802.68  29.27   382227.10 755795.63  29.25     0.00   0.00   0.00   340.409
0.453
          2     1                      P1 382111.21 755684.65  34.06   382111.21 755684.65
31.91   382228.03 755808.11  26.04   382220.51 755800.16  26.01     0.00   0.00   0.00   340.311
0.356
                2                         382111.15 755684.69  29.61   382111.15 755684.69
27.46   382227.98 755808.16  21.59   382220.46 755800.21  21.56     0.00   0.00   0.00   340.311
0.356
                3                         382110.93 755684.91  25.11   382110.93 755684.91
22.96   382227.76 755808.37  17.09   382220.23 755800.42  17.06     0.00   0.00   0.00   340.311
0.356
          3     1                         382116.94 755679.22  34.06   382116.94 755679.22
31.91   382233.77 755802.68  26.04   382226.25 755794.73  26.01     0.00   0.00   0.00   340.311
0.356
                2                         382116.99 755679.17  29.61   382116.99 755679.17
27.46   382233.82 755802.63  21.59   382226.30 755794.68  21.56     0.00   0.00   0.00   340.311
0.356
                3                         382117.22 755678.96  25.11   382117.22 755678.96
22.96   382234.05 755802.42  17.09   382226.53 755794.47  17.06     0.00   0.00   0.00   340.311
0.356

     18   1     1 tdl_zeb_132.032      GW 382344.86 755931.57  37.75   382344.86 755931.57
37.75   382467.25 756060.91  31.81   382449.60 756042.26  31.63     0.00   0.00   0.00   356.694
0.521
                2                         382350.60 755926.14  37.75   382350.60 755926.14
37.75   382472.99 756055.48  31.81   382455.34 756036.83  31.63     0.00   0.00   0.00   356.694
0.521
          2     1                      P1 382344.86 755931.57  35.80   382344.86 755931.57
33.65   382467.25 756060.92  28.66   382447.33 756039.86  28.46     0.00   0.00   0.00   356.582
0.409
                2                         382344.81 755931.62  31.35   382344.81 755931.62
29.20   382467.20 756060.97  24.21   382447.27 756039.91  24.01     0.00   0.00   0.00   356.582
0.409
                3                         382344.59 755931.83  26.85   382344.59 755931.83
24.70   382466.97 756061.18  19.71   382447.05 756040.12  19.51     0.00   0.00   0.00   356.582
0.409
          3     1                         382350.60 755926.14  35.80   382350.60 755926.14
33.65   382473.00 756055.48  28.66   382453.07 756034.42  28.46     0.00   0.00   0.00   356.582
0.409
                2                         382350.65 755926.09  31.35   382350.65 755926.09
29.20   382473.05 756055.43  24.21   382453.13 756034.37  24.01     0.00   0.00   0.00   356.582
0.409
                3                         382350.88 755925.88  26.85   382350.88 755925.88
24.70   382473.28 756055.21  19.71   382453.35 756034.16  19.51     0.00   0.00   0.00   356.582
0.409

     19   1     1 tdl_zeb_132.035      GW 382589.65 756190.25  42.57   382589.65 756190.25
```

```
42.57   382697.04 756304.05  34.77   382708.30 756315.98  34.70     0.00   0.00   0.00   313.305
0.354
                2                         382595.38 756184.82  42.57   382595.38 756184.82
42.57   382703.81 756299.10  34.68   382715.02 756310.91  34.61     0.00   0.00   0.00   315.423
0.361
          2     1                       P1 382589.65 756190.25  40.62   382589.63 756190.26
38.47   382696.29 756303.28  31.46   382709.28 756317.03  31.38     0.00   0.00   0.00   311.078
0.278
                2                         382589.59 756190.30  36.17   382589.58 756190.31
34.02   382696.23 756303.33  26.99   382709.44 756317.33  26.90     0.00   0.00   0.00   311.055
0.278
                3                         382589.37 756190.51  31.67   382589.35 756190.53
29.52   382695.94 756303.53  22.49   382709.14 756317.53  22.40     0.00   0.00   0.00   310.961
0.277
          3     1                         382595.38 756184.82  40.62   382595.40 756184.81
38.47   382703.08 756298.31  31.38   382716.00 756311.93  31.30     0.00   0.00   0.00   313.195
0.283
                2                         382595.43 756184.77  36.17   382595.45 756184.76
34.02   382703.15 756298.26  26.91   382716.31 756312.13  26.82     0.00   0.00   0.00   313.219
0.283
                3                         382595.66 756184.56  31.67   382595.67 756184.55
29.52   382703.43 756298.06  22.41   382716.60 756311.93  22.32     0.00   0.00   0.00   313.313
0.284

     20   1     1 td3_zeb_132.028       GW 382804.43 756417.85  39.86   382804.43 756417.85
39.86   382838.69 756535.10  38.43   382827.79 756497.82  38.04    12.02   0.00   0.00   244.530
0.168
                2                         382812.23 756413.37  39.86   382812.23 756413.37
39.86   382845.90 756528.48  38.57   382834.79 756490.50  38.16     0.00   0.00   0.00   240.075
0.159
          2     1                       C1 382804.43 756417.85  35.86   382805.03 756419.91
35.77   382838.74 756535.03  34.01   382830.73 756507.67  33.82    12.02   0.00   0.00   240.051
0.132
                2                         382804.34 756417.90  31.36   382804.94 756419.96
31.27   382838.49 756535.33  29.45   382830.79 756508.84  29.27    12.03   0.00   0.00   240.445
0.133
                3                         382803.99 756418.10  26.86   382804.59 756420.16
26.77   382838.08 756535.75  24.86   382830.77 756510.54  24.70    12.06   0.00   0.00   240.828
0.133
          3     1                       C2 382812.23 756413.37  35.86   382812.84 756415.43
35.77   382845.84 756528.56  34.13   382837.71 756500.70  33.93     0.00   0.00   0.00   235.825
0.125
                2                         382812.32 756413.32  31.36   382812.93 756415.38
31.27   382846.09 756528.25  29.59   382838.15 756501.23  29.40     0.00   0.00   0.00   235.428
0.125
                3                         382812.67 756413.12  26.86   382813.28 756415.18
26.77   382846.51 756527.83  25.02   382838.90 756502.05  24.86     0.00   0.00   0.00   235.042
0.124

     21   1     1 tdt_zeb_132.030       GW 382872.94 756652.35  44.86   382872.94 756652.35
44.86        0.00      0.00   0.00        0.00      0.00   0.00     0.00   0.00   0.00     0.000
0.000
                2                         382879.56 756643.59  44.86   382879.56 756643.59
44.86        0.00      0.00   0.00        0.00      0.00   0.00    14.63   0.00   0.00     0.000
0.000
          2     1                       C1 382873.06 756652.20  39.11   382872.46 756650.14
38.96        0.00      0.00   0.00        0.00      0.00   0.00     0.00   0.00   0.00     0.000
0.000
                2                         382872.64 756652.76  34.51   382872.04 756650.70
34.36        0.00      0.00   0.00        0.00      0.00   0.00     0.00   0.00   0.00     0.000
0.000
                3                         382872.16 756653.40  29.86   382871.56 756651.34
29.71        0.00      0.00   0.00        0.00      0.00   0.00     0.00   0.00   0.00     0.000
0.000
          3     1                       C2 382879.44 756643.74  39.11   382878.84 756641.68
38.96        0.00      0.00   0.00        0.00      0.00   0.00    14.64   0.00   0.00     0.000
0.000
                2                         382879.87 756643.18  34.51   382879.26 756641.12
34.36        0.00      0.00   0.00        0.00      0.00   0.00    14.61   0.00   0.00     0.000
0.000
                3                         382880.35 756642.54  29.86   382879.74 756640.49
29.71        0.00      0.00   0.00        0.00      0.00   0.00    14.58   0.00   0.00     0.000
0.000
```


Section Sagging Data

Sec. No.	Cable File Name	From Str.	To Str.	Voltage (kV)	Ruling Span (m)	Sagging Data Condition	Temp. (deg C)	Catenary Constant (m)	Horiz. Tension (N)	Weather Case	Display Condition	Display Catenary Constant (m)
1	steelwire_7_335	1	21	0	345.6	Creep RS	32.0	2000.0	9740.0	Hot	Creep RS	1684.3
2	lynx_acsr.wir	1	21	132	345.1	Creep RS	32.0	2230.0	18485.2	Hot	Creep RS	1756.9
3	lynx_acsr.wir	1	21	132	346.1	Creep RS	32.0	2230.0	18485.2	Hot	Creep RS	1758.2

Section Stringing Data

Section Number	Cable Name	Struct. Number	Set Number	Phasing	Set Label
1	steelwire_7_335	1	1	12	GW
		2	1	12	GW
		3	1	12	GW
		4	1	12	GW
		5	1	12	GW
		6	1	12	GW
		7	1	12	GW
		8	1	12	GW
		9	1	12	GW
		10	1	12	GW
		11	1	12	GW
		12	1	12	GW
		13	1	12	GW
		14	1	12	GW
		15	1	12	GW
		16	1	12	GW
		17	1	12	GW
		18	1	12	GW
		19	1	12	GW
		20	1	12	GW
		21	1	12	GW
2	lynx_acsr.wir	1	2	123	C1
		2	2	123	C1
		3	2	123	C1
		4	2	123	P1
		5	2	123	P1
		6	2	123	C1
		7	2	123	P1
		8	2	123	P1
		9	2	123	P1
		10	2	123	P1
		11	2	123	P1
		12	2	123	P1
		13	2	123	P1
		14	2	123	P1
		15	2	123	C1
		16	2	123	P1
		17	2	123	P1
		18	2	123	P1
		19	2	123	P1
		20	2	123	C1
		21	2	123	C1
3	lynx_acsr.wir	1	3	123	C2
		2	3	123	C2
		3	3	123	C2
		4	3	123	P1
		5	3	123	P1
		6	3	123	C2
		7	3	123	P1
		8	3	123	P1
		9	3	123	P1
		10	3	123	P1
		11	3	123	P1
		12	3	123	P1

13	3	123 P1
14	3	123 P1
15	3	123 C2
16	3	123 P1
17	3	123 P1
18	3	123 P1
19	3	123 P1
20	3	123 C2
21	3	123 C2

Section Geometry Data

Notes: Lengths are arc lengths along the wire at 32 (deg C), Creep.
Lengths are adjusted for the number of phases, the number of subconductors and to exclude the length of strain insulators.
Lengths are computed with any concentrated loads removed.

Sec. No.	Cable File Name	From Str.	To Str.	Number of Phases	Wires Per Phase	Min. Span (m)	Max. Span (m)	Ruling Span (m)	Total Cable Length (m)
1	steelwire_7_335	1	21	2	1	242.1	407.0	345.6	13606.9
2	lynx_acsr.wir	1	21	3	1	244.6	402.6	345.1	20304.3
3	lynx_acsr.wir	1	21	3	1	239.6	411.3	346.1	20351.5

Structure Material List Report

Structure File Name	**Number in Selected Line**	**Number in All Lines**
f:\msc\pls cadd simulations\pannipitiya- panadura transmission line\panni_rath_lynx\structures\td1_zeb_132.028	0	0
f:\msc\pls cadd simulations\pannipitiya- panadura transmission line\panni_rath_lynx\structures\td3_zeb_132.028	3	3
f:\msc\pls cadd simulations\pannipitiya- panadura transmission line\panni_rath_lynx\structures\td3_zeb_132.035	0	0
f:\msc\pls cadd simulations\pannipitiya- panadura transmission line\panni_rath_lynx\structures\td6_zeb_132.028	0	0
f:\msc\pls cadd simulations\pannipitiya- panadura transmission line\panni_rath_lynx\structures\td6_zeb_132.035	0	0
f:\msc\pls cadd simulations\pannipitiya- panadura transmission line\panni_rath_lynx\structures\td6_zeb_132.038	0	0
f:\msc\pls cadd simulations\pannipitiya- panadura transmission line\panni_rath_lynx\structures\tdl_zeb_132.028	0	0
f:\msc\pls cadd simulations\pannipitiya- panadura transmission line\panni_rath_lynx\structures\tdl_zeb_132.032	7	7
f:\msc\pls cadd simulations\pannipitiya- panadura transmission line\panni_rath_lynx\structures\tdl_zeb_132.035	7	7
f:\msc\pls cadd simulations\pannipitiya- panadura transmission line\panni_rath_lynx\structures\tdl_zeb_132.038	0	0
f:\msc\pls cadd simulations\pannipitiya- panadura transmission line\panni_rath_lynx\structures\tdt_zeb_132.030	1	1
f:\msc\pls cadd simulations\pannipitiya- panadura transmission line\panni_rath_lynx\structures\tdt_zeb_132.034	0	0
f:\msc\pls cadd simulations\pannipitiya- panadura transmission line\panni_rath_lynx\structures\tdt_zeb_132.037	0	0
f:\msc\pls cadd simulations\pannipitiya- panadura transmission line\panni_rath_lynx\tdt_zeb.0	0	0
f:\msc\pls cadd simulations\pannipitiya- panadura transmission line\panni_rath_lynx\tdt_zeb.035	0	0
f:\msc\pls cadd simulations\pannipitiya- panadura transmission line\structures\td3_zeb_132.032	0	0
f:\msc\pls cadd simulations\pannipitiya- panadura transmission line\structures\td3_zeb_132.035	1	1
f:\msc\pls cadd simulations\pannipitiya- panadura transmission line\structures\td6_zeb_132.032	0	0

f:\msc\pls cadd simulations\pannipitiya- panadura transmission line\structures\td6_zeb_132.035
1 1
f:\msc\pls cadd simulations\pannipitiya- panadura transmission line\structures\td6_zeb_132.038
0 0
f:\msc\pls cadd simulations\pannipitiya- panadura transmission line\structures\tdt_zeb_132.030
1 1
Total number of structures =
21 21

Cable Material List Report

Notes: Lengths are arc lengths along the wire at 32 (deg C), Creep.
Lengths are adjusted for the number of phases, the number of subconductors and to exclude the length of strain insulators.
Lengths are computed with any concentrated loads removed.

Cable File Name	Number Of Sections	Cable Length At Stringing Condition (m)
f:\msc\pls cadd simulations\pannipitiya- panadura transmission line\panni_rath_lynx\cables\steelwire_7_335	1	13607
f:\msc\pls cadd simulations\pannipitiya- panadura transmission line\panni_rath_lynx\lynx_acsr	2	40656

PLS-CADD Version 13.20x64   2:30:52 PM Friday, March 27, 2015
Ceylon Electricity Board - Transmission Design
Project Name: 'f:\msc\pls cadd simulations\pannipitiya- panadura transmission line \panni_rath_lynx\pannipitiya ratmalana line.DON'

EMF Calculation Notes:
1) All calculations based on the EPRI Red Book methods (2nd Edition, 1982 - infinite straight wire with flat earth approximation).
2) These approximations are only valid for low frequency (50-60Hz) AC transmission lines.
3) Bundles are modeled with an equivalent conductor as per EPRI Red Book 8.3.1.
4) The effects of earth return currents (earth resistivity) are ignored when calculating the magnetic field.
5) Wire position is determined by the currently displayed weather case.
6) Wire height used is the height of the wire where the target point is projected upon it.
7) All calculations assume ground is flat with same elevation as that of centerline.

Meter height above centerline ground: 1.00 (m)
Cross section offset for graph +/-:   27.00 (m)
Result interval for graph: 1.00 (m)
Electric field limit: 5.00 (kV/m)
Magnetic field limit: 100.00 (uT)

EMF calculation includes only wires going from structure 4 to structure 5

EMF Circuit Data:

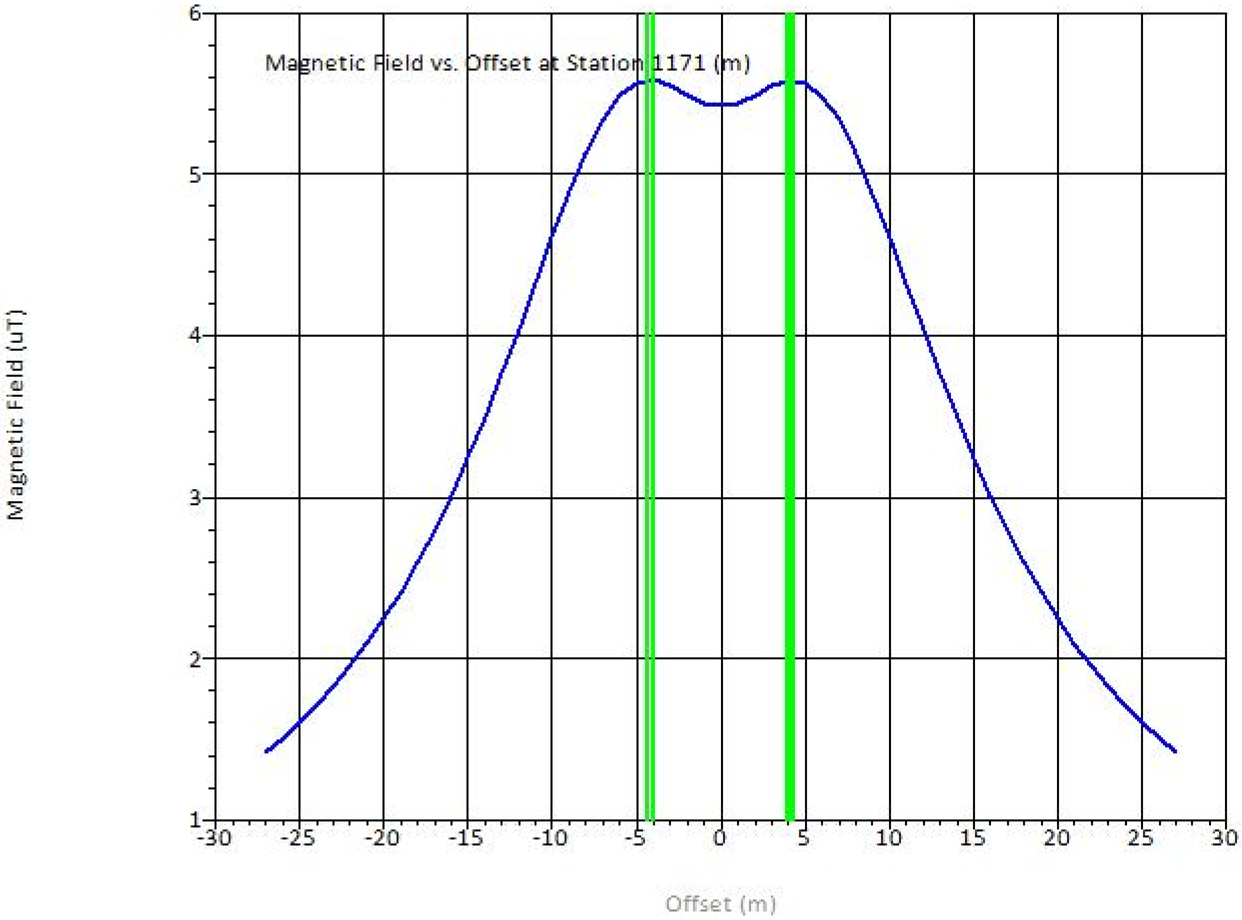
Set #	Phase #	Conductors Per Phase	Voltage Ph-Ph (kV)	Current (Amps)	Phase Angle (deg)	Bundle Diameter (cm)
1	1	1	0	0.000	0	0.000
1	2	1	0	0.000	0	0.000
2	1	1	132	400.000	0	0.000
2	2	1	132	400.000	120	0.000
2	3	1	132	400.000	-120	0.000
3	1	1	132	400.000	0	0.000
3	2	1	132	400.000	120	0.000
3	3	1	132	400.000	-120	0.000

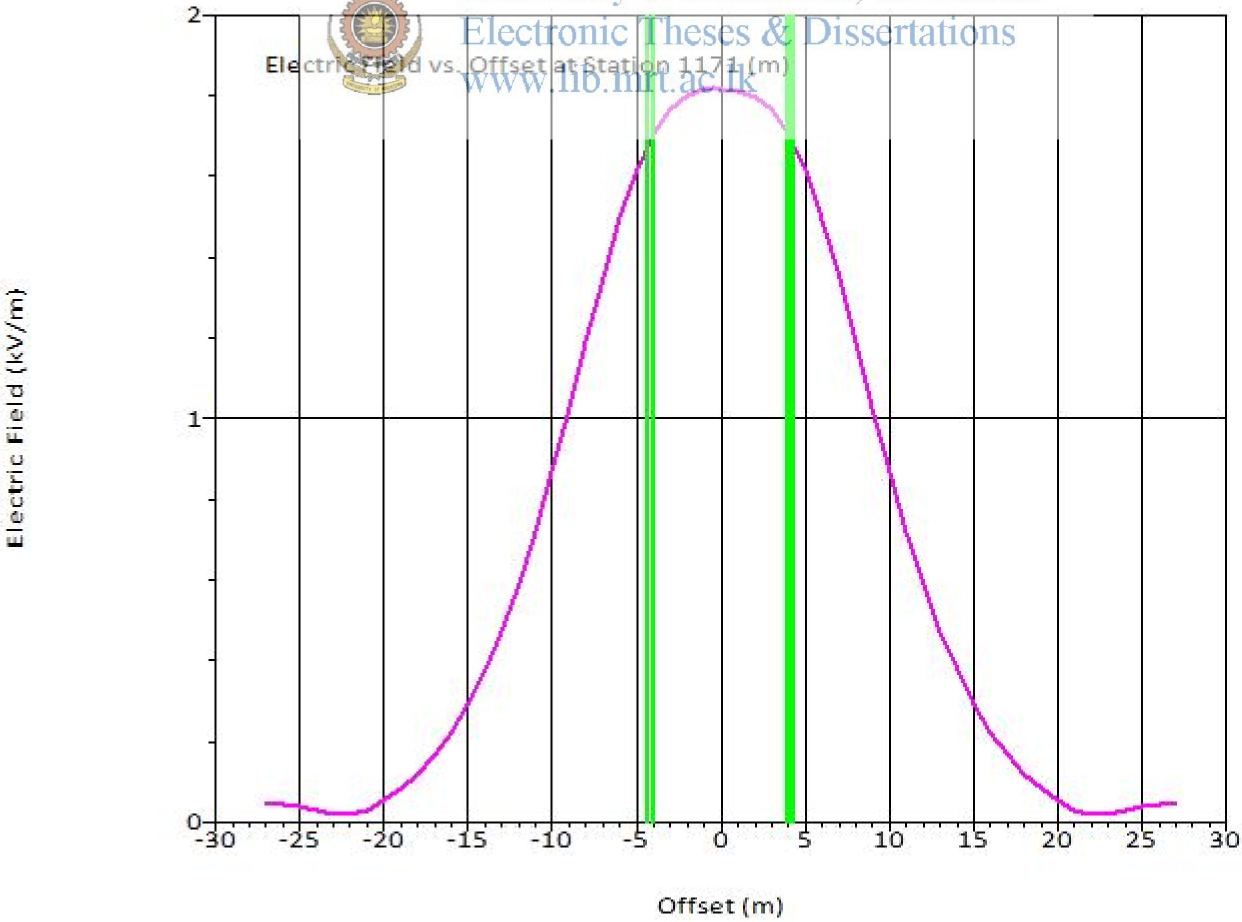
Calculated EMF Circuit Data For Last Point:

Wire station and offset are based on alignment closest to point on wire.
In the case of wires that are not parallel, this may result in different stations for the wires and centerline.

Set #	Phase #	Weather Case	Cable Condition	Wind From	Wire X (m)	Wire Y (m)	Wire Z (m)	Wire Station (m)	Wire Offset (m)	Eqv. Wire Diameter (cm)	Voltage To Gnd. (kV)
1	1	Hot	Creep RS	Left	378425.26	753405.45	26.65	1171.15	-3.95	1.023	0
1	2	Hot	Creep RS	Left	378430.34	753399.40	26.65	1171.15	3.95	1.023	0
2	1	Hot	Creep RS	Left	378425.25	753405.46	22.94	1171.15	-3.96	1.956	76.21
2	2	Hot	Creep RS	Left	378425.21	753405.51	18.49	1171.15	-4.04	1.956	76.21
2	3	Hot	Creep RS	Left	378425.00	753405.75	13.99	1171.15	-4.35	1.956	76.21
3	1	Hot	Creep RS	Left	378430.35	753399.39	22.94	1171.15	3.96	1.956	76.21
3	2	Hot	Creep RS	Left	378430.40	753399.34	18.49	1171.15	4.04	1.956	76.21
3	3	Hot	Creep RS	Left	378430.60	753399.10	13.99	1171.15	4.35	1.956	76.21

Maximum magnetic field of 5.58 (uT) found at station 1171.15, offset -4.00 (m)
Maximum electric field of 1.816 (kV/m) found at station 1171.15, offset -0.00 (m)





EMF Calculation Results:

Station (m)	Offset (m)	X (m)	Y (m)	Z (m)	B Real (uT)	B Img. (uT)	B Phase Angle (deg)	B rms Res. (uT)	E Real (kV/m)	E Img. (kV/m)	E Phase Angle (deg)	E Axis Angle (deg)	E rms Res. (kV/m)
1171.15	-27.00	378410.43	753423.09	4.53	1.191	0.76529	32.7	1.416	0.045	0.02449	28.5	95.8	0.051
1171.15	-26.00	378411.07	753422.33	4.53	1.265	0.81768	32.9	1.506	0.040	0.02214	29.0	98.5	0.046
1171.15	-25.00	378411.72	753421.56	4.53	1.345	0.87520	33.1	1.604	0.034	0.01898	29.4	103.1	0.039
1171.15	-24.00	378412.36	753420.80	4.53	1.431	0.93848	33.3	1.711	0.026	0.01499	30.0	111.8	0.030
1171.15	-23.00	378413.00	753420.03	4.53	1.525	1.00819	33.5	1.828	0.018	0.01064	30.5	132.4	0.021
1171.15	-22.00	378413.65	753419.27	4.53	1.628	1.08511	33.7	1.956	0.015	0.00919	31.2	180.5	0.018
1171.15	-21.00	378414.29	753418.50	4.53	1.739	1.17007	33.9	2.096	0.025	0.01569	31.9	221.7	0.030
1171.15	-20.00	378414.93	753417.73	4.53	1.859	1.26398	34.2	2.248	0.044	0.02805	32.6	238.1	0.052
1171.15	-19.00	378415.58	753416.97	4.53	1.991	1.36778	34.5	2.415	0.068	0.04502	33.4	245.4	0.082
1171.15	-18.00	378416.22	753416.20	4.53	2.133	1.48248	34.8	2.597	0.099	0.06708	34.2	249.5	0.119
1171.15	-17.00	378416.86	753415.44	4.53	2.286	1.60899	35.1	2.796	0.136	0.09524	35.1	252.0	0.166
1171.15	-16.00	378417.51	753414.67	4.53	2.452	1.74813	35.5	3.011	0.180	0.13079	36.0	253.8	0.223
1171.15	-15.00	378418.15	753413.91	4.53	2.630	1.90042	35.9	3.244	0.233	0.17525	37.0	255.1	0.291
1171.15	-14.00	378418.79	753413.14	4.53	2.819	2.06588	36.2	3.495	0.295	0.23022	38.0	256.1	0.374
1171.15	-13.00	378419.44	753412.38	4.53	3.018	2.24368	36.6	3.761	0.367	0.29730	39.0	257.1	0.472
1171.15	-12.00	378420.08	753411.61	4.53	3.226	2.43175	37.0	4.040	0.450	0.37772	40.0	258.0	0.587
1171.15	-11.00	378420.72	753410.85	4.53	3.438	2.62623	37.4	4.326	0.543	0.47196	41.0	258.9	0.719
1171.15	-10.00	378421.37	753410.08	4.53	3.649	2.82091	37.7	4.612	0.645	0.57915	41.9	259.9	0.866
1171.15	-9.00	378422.01	753409.31	4.53	3.852	3.00686	38.0	4.886	0.753	0.69646	42.8	260.9	1.026
1171.15	-8.00	378422.65	753408.55	4.53	4.036	3.17254	38.2	5.134	0.864	0.81856	43.5	262.1	1.190
1171.15	-7.00	378423.30	753407.78	4.53	4.192	3.30492	38.2	5.338	0.971	0.93773	44.0	263.5	1.350
1171.15	-6.00	378423.94	753407.02	4.53	4.311	3.39199	38.2	5.486	1.070	1.04486	44.3	264.8	1.495
1171.15	-5.00	378424.58	753406.25	4.53	4.387	3.42661	38.0	5.566	1.154	1.13161	44.4	266.2	1.616
1171.15	-4.00	378425.23	753405.49	4.53	4.420	3.41053	37.7	5.583	1.220	1.19303	44.4	267.4	1.706
1171.15	-3.00	378425.87	753404.72	4.53	4.419	3.35675	37.2	5.549	1.266	1.22941	44.2	268.5	1.765
1171.15	-2.00	378426.52	753403.96	4.53	4.400	3.28817	36.8	5.493	1.296	1.24617	43.9	269.2	1.798
1171.15	-1.00	378427.16	753403.19	4.53	4.380	3.23181	36.4	5.443	1.311	1.25137	43.7	269.7	1.812
1171.15	-0.00	378427.80	753402.42	4.53	4.371	3.20979	36.3	5.423	1.316	1.25207	43.6	270.0	1.816
1171.15	1.00	378428.45	753401.66	4.53	4.379	3.23074	36.4	5.442	1.311	1.25102	43.7	270.3	1.812
1171.15	2.00	378429.09	753400.89	4.53	4.399	3.28615	36.8	5.491	1.295	1.24551	43.9	270.8	1.797
1171.15	3.00	378429.73	753400.13	4.53	4.417	3.35396	37.2	5.546	1.266	1.22851	44.1	271.5	1.764
1171.15	4.00	378430.38	753399.36	4.53	4.417	3.40721	37.6	5.578	1.219	1.19199	44.4	272.6	1.705
1171.15	5.00	378431.02	753398.60	4.53	4.384	3.42302	38.0	5.562	1.153	1.13054	44.4	273.8	1.615
1171.15	6.00	378431.66	753397.83	4.53	4.308	3.38837	38.2	5.481	1.069	1.04386	44.3	275.2	1.494

1171.15	7.00	378432.31	753397.07	4.53	4.189	3.30146	38.2	5.334	0.971	0.93688	44.0	276.5	1.349
1171.15	8.00	378432.95	753396.30	4.53	4.033	3.16938	38.2	5.130	0.863	0.81790	43.5	277.9	1.189
1171.15	9.00	378433.59	753395.54	4.53	3.849	3.00406	38.0	4.883	0.752	0.69599	42.8	279.1	1.025
1171.15	10.00	378434.24	753394.77	4.53	3.647	2.81850	37.7	4.609	0.644	0.57885	41.9	280.1	0.866
1171.15	11.00	378434.88	753394.00	4.53	3.436	2.62418	37.4	4.323	0.543	0.47179	41.0	281.1	0.719
1171.15	12.00	378435.52	753393.24	4.53	3.224	2.43003	37.0	4.037	0.450	0.37766	40.0	282.0	0.587
1171.15	13.00	378436.17	753392.47	4.53	3.017	2.24225	36.6	3.759	0.367	0.29732	39.0	282.9	0.472
1171.15	14.00	378436.81	753391.71	4.53	2.818	2.06469	36.2	3.493	0.295	0.23029	38.0	283.9	0.374
1171.15	15.00	378437.45	753390.94	4.53	2.629	1.89944	35.9	3.243	0.233	0.17534	37.0	284.9	0.292
1171.15	16.00	378438.10	753390.18	4.53	2.451	1.74732	35.5	3.010	0.180	0.13090	36.0	286.2	0.223
1171.15	17.00	378438.74	753389.41	4.53	2.286	1.60832	35.1	2.795	0.136	0.09535	35.1	288.0	0.166
1171.15	18.00	378439.38	753388.65	4.53	2.132	1.48191	34.8	2.596	0.099	0.06720	34.2	290.5	0.120
1171.15	19.00	378440.03	753387.88	4.53	1.990	1.36732	34.5	2.414	0.068	0.04513	33.4	294.5	0.082
1171.15	20.00	378440.67	753387.11	4.53	1.859	1.26358	34.2	2.248	0.044	0.02814	32.6	301.9	0.052
1171.15	21.00	378441.31	753386.35	4.53	1.738	1.16974	33.9	2.095	0.025	0.01576	31.9	318.1	0.030
1171.15	22.00	378441.96	753385.58	4.53	1.627	1.08483	33.7	1.956	0.015	0.00920	31.2	359.0	0.018
1171.15	23.00	378442.60	753384.82	4.53	1.525	1.00796	33.5	1.828	0.018	0.01058	30.5	47.3	0.021
1171.15	24.00	378443.24	753384.05	4.53	1.431	0.93827	33.3	1.711	0.026	0.01492	29.9	68.1	0.030
1171.15	25.00	378443.89	753383.29	4.53	1.344	0.87502	33.1	1.604	0.034	0.01892	29.4	76.9	0.038
1171.15	26.00	378444.53	753382.52	4.53	1.264	0.81753	32.9	1.506	0.040	0.02207	29.0	81.5	0.046
1171.15	27.00	378445.17	753381.76	4.53	1.191	0.76517	32.7	1.416	0.045	0.02444	28.5	84.2	0.051

Appendix E – 50% Lightning Impulse Flashover Voltage

No of Units per String	250 mm unit	280 mm unit	320 mm unit
2	240	250	255
3	330	350	375
4	410	445	465
5	495	540	555
6	575	630	645
7	655	725	735
8	735	810	825
9	815	910	920
10	895	990	1010
11	975	1085	1105
12	1050	1165	1200
13	1130	1255	1300
14	1210	1350	1390
15	1290	1445	1480
16	1370	1535	1580
17	1450	1625	1675
18	1525	1715	1775
19	1605	1805	1870
20	1685	1895	1965
21	1765	1985	2060
22	1850	2080	2155
23	1930	2170	2245
24	2010	2265	2340
25	2095	2360	2435
26	2175	2445	2520
27	2260	2540	2615
28	2340	2625	2710
29	2425	2720	2805
30	2510	2810	2895