IMPACT OF NEW GENERATION CONDUCTORS ON TECHNO ECONOMICS OF 132kV TRANSMISSION LINES.

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Degree of Master of Science

Department of Electrical Engineering

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Thesis/Dissertation submitted in partial fulfillment of the requirements for the degree Master of Science

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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.

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

Signatures of the supervisors:

………………………………………. ………………………………..

Prof. H.Y. Ranjith Perera Date

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Eng. W.D.A.S. Wijayapala Date

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ABSTRACT

Demand for the electric power has been increasing rapidly due to human activities all over the world. It is essential to generate, transmit and distribute the power requirement to load centers as they demand. Therefore, Capacity of transmission network needs to be increased frequently either by uprating, upgrading of existing transmission lines or/and adding of transmission lines to the transmission network.

It is getting harder and harder to find routes for transmission lines due to increased social objection cause due to their uncountable social impact and environmental damage during the construction which cannot be totally compensated.

Therefore, requirement of delivering more power to the load centers through overhead conductors has come to a discussion and large variety of new generation conductors (HTLS - High Temperature Low Sag Conductors and LL-Low Loss conductors) are introduced with the intention of mitigating some of the disadvantages shown by the conventional conductors and to uprate and upgrade the existing transmission lines. Among them, enhanced power capacity, low loss performance, improved conductor sag behavior and anti-cohesiveness behaviors can be considered vital.

However, it can be observed that, conventional conductors are still used more frequently for new transmission lines by power utilities around the world due to lack of service experience in use of new generation conductors over conventional conductors that have been given a greater service in power transmission.

Therefore, impact of new generation conductors for on techno economics of 132kV double circuit transmission lines is studied by designing and modelling of transmission lines for different ground terrains with different types of new generation conductors over conventional conductor.

Accordingly, new generation conductors show promising results in overall techno economic viability of transmission line over conventional conductors, and among them low loss conductors show superior performance.

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LIST OF ABBRIVIATIONS

Abbreviation		Description
ACSR	-	Aluminium Conductor Steel Reinforced
AAAC	-	All Aluminium Alloy Conductor
ACCC	-	Aluminum Conductor Composite Core Conductor
ACCR	-	Aluminum Conductor Composite Reinforced
ACSS	-	Aluminum Conductor Steel Supported Conductor
CEB	-	Ceylon Electricity Board
TCR/L	-	Top Conductor Right/Left Side
MCR/L	-	Middle Conductor Right/Left Side
BCR/L	-	Bottom Conductor Right/Left Side
ROW	-	Right of Way
HTLS	-	High Temperature Low Sag
LL	-	Low Loss
EMF	-	Electromagnetic Field
KPT	-	Knee Point Temperature
TACSR	-	Thermal Resistant Aluminium Alloy Conductor Steel Reinforced
ZTACIR	-	Thermal Resistance Aluminium Conductor Steel Reinforced
CCC	-	Current Carrying Capacity
NPV	-	Net Present Value
IEE	-	Initial Environment Examination
PGR/L	-	Peak Ground Right/Left Side
POR/L	-	Peak OPGW Right/Left Side

1.0 INTRODUCTION

1.1 BACKGROUND

Transmission network plays a major role by keeping the power system reliable, stable and economical to maintain. It also helps to carry out load transformation, fault management, capacity reservation, equipment maintenance, equipment redundancy, etc. Existing transmission network needs to be enhanced due to rapid growth in electricity demand, changes in load flow patterns and expansion of electrification level. Therefore, transmission network need to be upgraded, uprated, or/and new transmission lines to be constructed to cater the future demand.

Due to robustness, easy installation and maintenance process and services over hundreds of years in transmission sector, conventional conductors, e.g., ACSR; Aluminium Conductor Steel Reinforced, have become the most reliable and economical conductor among the power utilities around the world, and they keep using conventional type of conductors for new transmission line construction even though large variety of new generation conductors are available in the market.

Due to CCC limitations, electrical clearance issues (conductor sag) and energy losses of conventional conductors, manufacturers have come up with different conductor technologies, i.e., Low Loss conductors (LL) and High Temperature Low Sag conductors (HTLS), etc. Each technology changes their electrical and mechanical behavior of conductors; operating temperatures (allows more power to be delivered), tensile strength (enables to have lower sag and higher electrical clearance), low unit resistance (reduces energy losses), etc.

Low loss conductors and HTLS conductors have their own advantages and disadvantages. Therefore, selection of proper conductor for a particular transmission line is a critical factor, and proper cost benefit analysis needs to be carried out before going for construction of transmission lines.

Many related studies can be found in using of new generation conductors for uprating and upgrading of existing lines with new generation conductors. Therefore, this study investigates the impact of new generation conductors on techno economics of new132kV transmission line construction.

1.2 OBJECTIVE

Most of transmission lines in Sri Lanka have been constructed using conventional type of overhead bare conductors, and over 95% of transmission lines have strung with ACSR conductors, and in some occasions with AAAC.

With the rapid demand growth in power demand, expansion of level of electrification and changes in load flow pattern in the transmission network, power capacity of transmission lines is the major limiting factor faced by the power utilities to deliver power requirement. Therefore, one way or another way new transmission lines are to be constructed to maintain the system stability and reliability. ROW is the major issue for a new transmission line. Many government and non-government organizations raise their objection because of social and environmental impact due to construction of new transmission line.

Many manufactures with their R&Ds have come up with new generation conductors with superior properties such as high CCC, low energy loss, low conductor sag, etc., and according to them many problem faced by utilities can be overcome by using these conductors. However, power utilities are still showing less or no interest in using new generation conductors even if these conductors show better performance.

Therefore, the objective of this study is to conduct a proper techno economic analysis considering the performance of both type of new generation and conventional conductors, and provide economical guidance to select construction for new transmission lines.

1.3 SCOPE OF WORK

Under the scope of this study; electrical, mechanical and structural behavior of 132kV transmission line concerning seven types of revolutionized new generation conductors (HTLS and LL) are studied and discussed over ACSR conductor.

Supporting structures and foundations are designed based on the sag tension calculations of respective conductors and profile designed are carried out for six distinctive ground profiles. Cost model is developed for 132kV double circuit transmission lines for respective conductors, and impact of new generation conductors on techno economics of transmission lines is discussed.

2.0 LITERATURE REVIEW

2.1 OVERHEAD TRANSMISSION LINES

Overhead transmission lines are the most economical way of transferring bulk electrical energy over long distance. Basically a transmission line consists of one or more circuits (a circuit consists of three bare conductors; i.e. R, Y, B), suspended to the support structures. Air is used as the insulation medium between conductors and ground, however porcelain or toughened glass insulators are used between conductors and supporting structures.

Overhead bare conductors are generally made of aluminum strands (either plain or reinforced with steel, or composite materials such as carbon and glass fiber). Electrical and mechanical behavior of conductors decides the overall performance of the transmission line, and its techno-economic viability. Around 65% of the capital cost is allocated for support foundations and structures in conventional type transmission lines. However, this figure may vary with the cost of conductor.

Large variety of over-head bare conductors are manufactured using different technologies in order to overcome the challenges in delivering power to load centers due to rapid growth of demand.

Basically support structures of transmission lines are made of steel with lattice or tubular arrangement. The height and the strength of towers are designed based on the selected conductors, and operation voltage. Five type of support structures are specified based on loads and their usage.

The required electrical clearances need to be provided in order to prevent dangerous contact with the line and to avoid unnecessary electric flash overs. The supporting structures provide a reliable support throughout its life time (around 40 years), and shall also withstand adverse environmental conditions, such as storms.

Foundations are the base which makes the bond between supporting structures and the ground. Size of foundations depends on the tower reactions and the bearing capacity of the soil, and are classified in to seven major types.

2.2 CONDUCTORS

2.2.1 Conductor Formation

Overhead bare conductors used in transmission lines consist of aluminum wires stranded in one or more helical layers around a core consisting of one or more galvanized steel strands. Over 80 % aluminium wire are made out of 1350-H19 (nearly pure aluminum - 1350 - drawn to the highest temper possible - H19). By varying the size of the steel core and aluminium wires, the composite tensile strength, modulus of elasticity, CCC, conductor resistance, etc. can be varied to meet different requirement.

ACSR and all aluminium conductors show quite stable mechanical and electrical properties with time as long as the temperature of the aluminum strands remains below 90^{o}C. Above 90^{o}C, the work-hardened aluminum strands lose tensile strength at an increasing rate with temperature.

The thermal elongation rate of aluminium (1350-H19) is 23 microstrain per ^{0}C, and for steel it is 11.5 microstrain per ^{0}C. So the sag behavior with respect to conductor temperature also depends on the size of the steel core and size of aluminium layer at moderate temperatures. But at higher temperatures, that is beyond knee-point temperature, the elongation of conductor fully depends on the properties of core material. BS 215 and IEC 61089 are the most frequently used standards for stranded bare conductors [1], [2], [3].Table 2.1 and

Table 2.2 show the properties of different kind of material used for outer layers and core layers of conductors. New generation types of conductors such High Temperature Low Sag (HTLS) conductors and Low Loss Conductors are fabricated using advantages of these properties of material. Annealed aluminium can withstand temperature up to 210 ^{o}C without any deterioration in conductivity. So the new generation conductors are capable of continuous operation at temperatures in excess of 100^{0}C with stable electrical and mechanical properties [9], [15].

Same as conventional type of conductors, the new generation conductors consist of a high strength core surrounded by one or more layers of aluminum wires which carry most of the electrical current. The composite conductor strength and stiffness depends on both the reinforcing core and the aluminum strand layers.

Except carbon fiber composite core, all other core wire are typically in round form with diameter of the order of 2.54 to 5.08 mm, and properties of wires vary with wire diameter. In certain designs, in order to maximize the aluminium area for a given diameter, aluminum wires are provided with a trapezoidal cross-section. Properties of the conducting aluminum wires and the reinforcing core wires are dramatically different. These differences can be used to take advantage in various applications of conductors [2], [6], [7], [5].

Table 2.1 - Properties of Outer Layers Materials, [6]

Type of Aluminium		Minimum Conductivity [%IACS]	Tensile Strength [Mpa]	Allowable Operating Temperature(ºC)	
				Continuous	Emergency*
Hard Drawn 1350 aluminum	**1350-H19 (HAL)**	61.2	159- 200	90*	125*
Thermal Resistant Zirconium aluminum	**TAL**	60	159- 176	150	180
Extra Thermal Resistant Zirconium aluminum	**ZTAL**	60	159- 176	210	240
Fully Annealed 1350 aluminum	**1350-0**	61.8**	59 - 97	350	350

* - Manufacturers often suggest performing rating calculations at 75ºC/100ºC

** - Typical conductivity for annealed aluminum is 63.0%.

Table 2.2 - Properties of Core Materials, [6]

Core material	Min. Tensile Strength @tensile failure (kpsi)	Modulus of Elasticity (GPa)	Min. elongation at tensile failure (%)	Coef. Of Linear Expansion (μ/ ºC)	Allowable Operating Temperature(ºC)	
					Continuous	Emergency
A Galv. Steel Zn-5Al-MMSteel(B802)	200-210	206	3.0-4.0	11.5	180 250	200 350
A Galv. HS (B606) Zn-5Al-MM HS (B803)	220-235	206	3.0-3.5	11.5	180 250	200 350
A Galv. UHS Zn-5Al-MM UHS	265-285	206	3-3.5	11.5	180 250	200 350
Carbon Fiber composite core	310-360	114	2.0	1.6	180	200
Ceramic Fiber reinforced aluminum	200	220	0.64	6.0	250	300
Alum. Clad (AW) 20.3% IACS	150-195	162	3.0	13.0	150	200
Alum. Clad Invar Steel 14% IACS	175-185	152	3.0	3.7	210	240

2.2.1.1 Conventional Conductors

Aluminium Conductor Steel Reinforced Conductors - ACSR

ACSR conductor is formed by a steel core, consisting of one or more steel wires, surrounded by one or more layers of hard drawn (1350-H19) aluminum wires (see Figure 2.1). 99% of electrical behavior of the conductor mainly depends on the properties of aluminium strands, and 65% of the strength is due to steel core depending on the relative size of steel core and aluminium strands. 1350-H19 aluminum wires, which are nearly pure aluminum, begin to anneal slowly at around 93^{o}C, hence ACSR conductors are not recommend to operate beyond 90 ^{0} [2], [11].

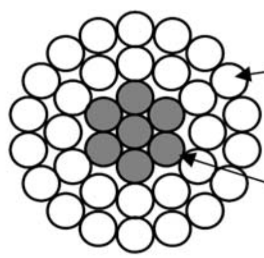


Figure 2.1- Cross Section of ACSR Conductor

2.2.1.2 Low Loss Type Conductors

Thermal Resistant Aluminium Alloy Steel Reinforce - LL-TACSR/AS

Construction of both LL-ACSR/AS and LL-TACST/AS (see Figure 2.2) is almost same except aluminum wires are replaced with Hard Drawn Aluminum wires of Heat Resistant Aluminum Alloy (TAL). TACSR can be safely operated continuously above 150^{o}C enabling to pump more current through the conductor. Where there is a need to transmit higher power but restrictions on getting new power corridors approved, various Types of TAL conductors are one of the best creative solution options to utilities. Ability of the Zirconium doped aluminum alloy to maintain its electrical and mechanical properties at elevated temperatures makes these conductors a very cost effective solution in refurbishing the existing lines with enhanced capacity.

The mechanical properties of ACSR/AS conductors are similar to ACSR conductors but offer improved ampacity and resistance to corrosion because of the presence of aluminium clad steel wires in the core. These conductors are better replacement for ACSR conductors where corrosive conditions are severe [4].

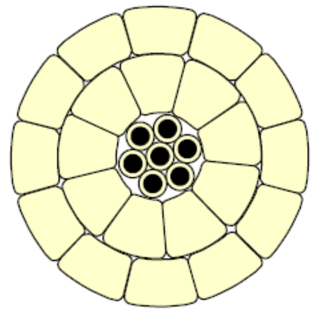


Figure 2.2- Cross-section of LL-ACSR/AS Conductor

2.2.1.3 High Temperature Low Sag Conductors

Thermal Resistant Aluminum Alloy ACSR Conductor - G(Z)TACSR

Small gap between the steel core and the innermost trapezoidal-shaped aluminum layer make this conductor unique. So the core can move independently from the aluminum layer, and whole tension can be exerted on steel core only (see Figure 2.3). Outer layers are made of trapezoidal shape wire in the new design of G(Z)TACSR conductor to maintain compact stranding and to minimize electrical resistance and increase the effective cross-sectional area on aluminum strands.

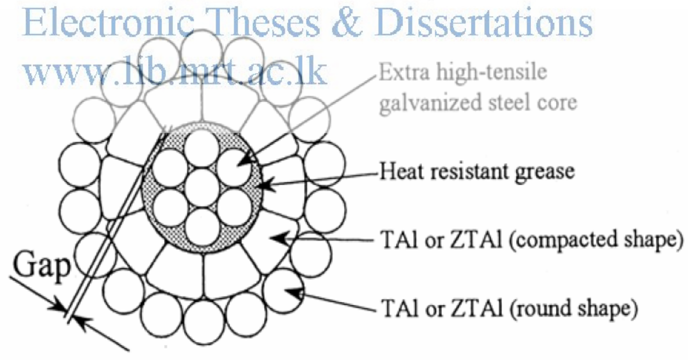


Figure 2.3 - Cross Section of G(Z)TACSR Conductor

TAL (150oC) or ZTAL (210oC) heat-resistant zirconium alloy aluminum are used to make outer aluminium strands. Both zirconium aluminum alloy has a conductivity which is only slightly less than 1350-H19. The steel core is especially strengthened in order to withstand the entire tensile load at high temperature. Heat-resistant grease (filler) are used to fill the gap to reduce friction between the steel core and the aluminum layer and to prevent water penetration [12].

Aluminum Conductor Composite Core Conductor - ACCC

Trapezoidal-shaped, fully annealed 1350-0 aluminum strands fit well around the circular surface of the core in a helical shape with minimum interstices compared to the conventional ACSR conductor (see Figure 2.4). This leads to increase the effective cross sectional area for aluminum strands, increasing the current carrying capacity.

Composite core is designed using carbon/glass fiber and polymer matrix and can be seen as a single piece of rod. The annealed aluminum strands allow operating continuously at elevated temperatures of up to 200°C with dramatically less sag [9], [15].

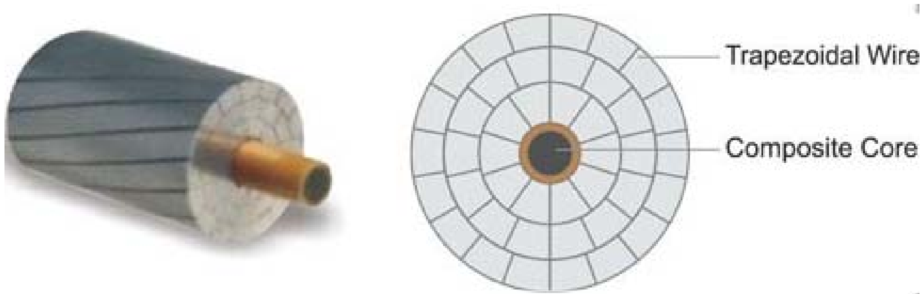


Figure 2.4 - Cross Section of ACCC Conductor

Aluminum Conductor Invar Steel Reinforced (Invar) - (Z)TACIR/AW

Looks like same as ACSR conductor (see Figure 2.5), but conventional steel wires are replaced with high strength invar alloy wires. Invar is an alloy of steel (64%) and nickel (36%). Excellent sag control performance at high temperature beyond the knee point is provided by the properties of material. As this preform relatively low sag at higher temperature, it is recommended to operate beyond the knee point. Maximum continuous operating temperature of 210°C allows the conductor carry twice the current capacity of ACSR conductor [6], [13].

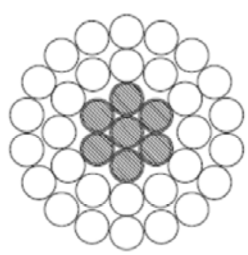


Figure 2.5 - Cross Section of ZTACIR/AW Conductor

Aluminum Conductor Steel Supported/Trapezoidal Wire - ACSS/TW

Fully annealed aluminum wires (1350-O) stranded over the core, and core is made out either high-strength (HS) or extra high strength (EHS) or ultra-high strength (UHS) steel (see Figure 2.6). Standard round strand ACSS (similar to standard ACSR conductor), trapezoidal wire of equal area, and trapezoidal wire of equal diameter are the available designs of ACSS conductor. Steel core wire can be applied with an anti-corrosion coating of hot-dipped zinc, aluminum cladding, or zinc-5% aluminum-mischmetal alloy (Zn-5Al-MM).

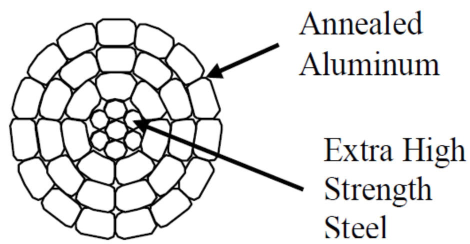


Figure 2.6 - Cross Section of ACSS Conductor

Thermal elongation over a wide range of temperatures, ACSS show comparatively lower elongation, and with Zn-5Al- MM Galfan coating on the steel core wires it can operate up to 300°C.

Depending upon original design conditions and conductor design, in most cases, re-conductoring with ACSS/TW allows an increase of at least 30% in thermal rating of an existing line. The splicing, installation, and termination of ACSS or ACSS/TW is no more complicated than for ACSR conductors, however, the annealed strands, being very soft, should be handled with care [6].

Aluminum Conductor Composite Reinforced - ACCR

Heat-resistant aluminum-zirconium (Al-Zr) wires (round or trapezoidal) are used to form outer strands and a proprietary fiber-reinforced aluminum matrix are used to form the composite core (see Figure 2.7). Overall strength of the conductor and conductivity is born by both composite core and the outer Al-Zr strands. The outer alloy aluminum wires are round and of the same construction type as ACSR conductors. The Al-Zr layers and the core wires are helically stranded as in ACSR conductors. The composite core has a lower thermal elongation property and equal or greater strength than galvanized steel. The core wire looks physically similar to steel core, but it is eight times stronger than aluminum and about the same stiffness as the steel core.

It can operate continuously at 210ºC. The outer wires surrounding the composite core are made up of high temperature-resistant ZTAL strands. ZTAL aluminum limits the maximum operating temperature of the ACCR conductor [6], [14].

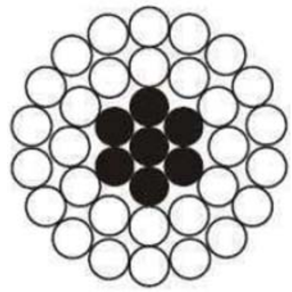


Figure 2.7 - Cross Section of ACCR Conductor

2.2.2 Conductor Properties

Electrical, mechanical and structural behavior of a transmission line entirely depend on the properties of selected conductor. The whole design process of a transmission line starts after selecting a proper conductor for that particular line.

In order to construct a transmission line, viability of project shall be emphasized. Life span cost benefit analysis of transmission line is done base on the energy loss evaluation and initial capital cost calculation. Energy loss evaluation is done base on electrical properties of conductor whereas capital cost mainly depends on mechanical characteristics of the conductor [1], [2], [3].

Under this section conductor properties their behavior are discussed.

2.2.2.1 Unit Resistance

Per kilometer resistance of conductor is known as unit resistance. Unit resistance varies with its operating temperature, and observed non-linear changes with temperature.

However, over moderate temperature changes (0^0C to 120 ^{0}C), the resistance of a conductor increases linearly with increase of temperature, thus conductor resistance can be expressed as follows [2], [5], [10].

$$R_2 = R_1[1 + \alpha_1(T_2 - T_1)]$$

Where,

R_1 - Resistance at temperature 1

R_2 - Resistance at temperature 2

α_1 - Temperature coefficient of resistance at T_1

2.2.2.2 Cross Section Area

Conductor consists two major cores; outer core and inner core. Inner core generally reinforces the conductor and made of high strengthened materials, whereas outer core passes the current and made of aluminium materials. Cross section area of conductor is formed by cross-section area of individual strands of both inner and outer cores.

Cross-section area of the conductor is directly coordinated with CCC of conductor and its resistance.

$$\mathbf{R} = \frac{\boldsymbol{\rho}\mathbf{L}}{\mathbf{A}}$$

So higher cross-section would always better to have in conductor so it can pass large amount of power with minimum energy loss. However higher the cross-section area higher weight of conductor and higher the wind load exert, so support structures and foundation needs to be strengthen according to the conductor loads. Also the cost conductor also going higher and higher for higher cross-section area [5].

2.2.2.3 Ultimate Tensile Strength

The UTS is defined as the maximum stress that conductor can withstand before breaking. For higher UTS, conductor sag can be reduced, and tower height can be minimized. However for higher UTS, support structures also need to be strengthen in order to withstand extra forces exerted on cross arm by conductors. But according to the CEB specification, maximum working tension on structures is 40% of UTS of conductor [1], [8].

e.g.; UTS of ACSR Zebra conductor = 132.3kN

Maximum working tension = 132.3/2.5 = 52.92kN

2.2.2.4 Modulus of Elasticity

The modulus of elasticity is resistance to being deformed elastically when a force is applied on the conductor, and measured in measure in GPa or N/mm^2. The elastic modulus of an object is defined as the slope of its stress-strain curve in the elastic deformation region.

Except AAC and AAAC conductors, all other conductors are non-homogenous, and different layers of conductor show different modulus of elasticity. Thus the modulus of elasticity of conductor is combination of respective elasticity of two layers [5], [9].

2.2.2.5 Linear Thermal Expansion Coefficient

Linear Thermal expansion is the response in length of the conductor relating to its operating temperature. Homogeneous conductors do have a single linear thermal expansion coefficient, however conductor which has two layers or more layers fabricated with different type of material have combination of liner thermal expansion coefficient at the initial temperatures. Liner thermal expansion coefficient of aluminium and steel is 23×10^{-6} and 11.5×10^{-6} respectively. So at higher temperatures, total load of the conductor is transferred to the steel core due high thermal coefficient compared to steel [5], [9].

2.2.3 Conductor Behavior

2.2.3.1 Current Carrying Capacity (CCC)

Conductor have a maximum operating temperature, which may be limited by the physical makeup of the cable, or may be limited by a maximum amount of allowable sag. High current in a conductor will cause significant resistive heating. At the same time, direct sunlight will also heat the cable. The cable will be cooled by wind, through convective heat transfer. All of these factors impact the temperature of the cable, so to establish a thermal current-carrying limit, some operating conditions must be assumed.

IEEE 738-2006 and IEC 61597 are the standards used for calculating the current carrying capacities of conductors, and Current carrying capacity will depend mostly on climatic factors of the region selected [10], [22].

Heat Balance Equation

The thermal behavior of a conductor can be calculated using a heat-balance equation. The simple steady-state model of a cable is described as follows.

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

Where;

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

The maximum allowable continuous current that corresponds to the maximum allowable conductor temperature is called the steady state thermal rating of the line. According to the manufacturer's data the ACSR Zebra conductor can operate up to 750C without any problem. Calculated values for current carrying capacity of ACSR Zebra (400mm^2) are tabulated below.

Table 2.3 - Current Carrying Capacity of ACSR Zebra Conductor

Temperature (^{0}C)	**Current Carrying Capacity (A), ACSR Zebra**
50	444
55	549
60	635
65	709
70	774
75	833

Calculation Conditions;

Intensity of solar radiation : 1000 W/m2

Emissivity & solar absorption : 0.5

Wind velocity : 0.5 m/s

Angle of wind to conductors : 45 degrees

Ambient temperature : 32°C

2.2.3.2 Sag Tension Performance

In practice, for overhead transmission line design, the general theory for Sag-tension is based on the fact that if a flexible wire of uniform weight is suspended at two points at the same level, it sags and assumes the shape of a catenary curve. For short spans normally adopted for transmission and distribution lines the catenary is very nearly a parabola and hence the sag is calculated by the following formula [11].

$$\boldsymbol{S = \frac{w \times l^2}{8 \times T}}$$

Where,

- S : sag in meter
- w : weight of loaded conductor in kg per meter run
- ℓ : span length in meters
- T : maximum working tension of conductor in kg.

For supports at different levels, the distance ℓ' of the point where the maximum sag S which occurs from taller or shorter support is given by

$$\boldsymbol{l' = \frac{l}{2} + \frac{T \times h}{W \times l'}}$$

$$\boldsymbol{Sag = \frac{w \times l'^2}{2T}}$$

Where,

- ℓ' : span length in meter
- h : difference in level between supports in meter
- w : weight of loaded conductor in kg per meter run
- T : maximum working tension of conductor in kg

For calculating sag and tension, it is necessary to consider two set of loading conditions:

a. Maximum wind pressure and minimum temperature, and

b. No wind with the conductors at maximum temperature

It is necessary to determine the load factors for both the above conditions.

Loading factor for wind is given by;

$$q_1 = \sqrt{\frac{w^2 + w_1{}^2}{w}}$$

Where,

q_1 : loading factor

w : weight of loaded conductor in kg per meter run, and

w_1 : wind load on conductor in kg/m

Wind load is given by:

$$w_1 = \frac{P \times d}{1000}$$

Where,

d : diameter of conductor in mm, and

P : wind pressure in kg / m²

q_2 : 1 (Loading factor in still air)

Sag at Worst Load Conditions of Wind

T_1 : maximum allowable tension in kg / m of conductor at temperature t_1° C

ℓ : span length in meters

Then the sag at worst loading condition is given by;

$$S = \frac{q_1 \times w \times l^2}{8 \times T_1}$$

Sag and Tension in Conductor under Still Air Conditions

Since conductors will be erected under still air conditions at a temperature t_2 °C, it is essential that the erection tension should be such that final tension is less than or equal to design tension.

The tension T_2 in the conductor at temperature t_2 °C is determined from the following formula;

$$T_2{}^2[T_2 - (K - \alpha \times t \times \lambda)] = \frac{l^2 \times w^2 \times q_2{}^2 \times \lambda}{24}$$

Also, we can write as,

$$f^2[f - (K - \alpha \times t \times E)] = \frac{l^2 \times w^2 \times q_2{}^2 \times E}{24}$$

Where,

f	:	T / A, i.e. stress in conductor in kg/cm²,
T_2	:	tension of conductor in kg at temperature t2 °C,
E	:	modulus of elasticity in kg/cm²,
A	:	area of conductor in cm²,
α	:	coefficient of linear expansion per °C,
t	:	difference in temperature between the dif. loading conditions = (t_2 - t_1) °C

$$K = \frac{T_1 - l^2 \times w^2 \times q_1{}^2 \times \lambda}{24 \times T_1{}^2}$$

$$\lambda = E \times A$$

After determining the value of T_2 in accordance with above clause, the sag may be calculated as follows;

$$S = \frac{w \times l^2}{8 \times T_2}$$

Sag tension calculation is basically done to calculate height of the basic tower relating to conductor. Different method of calculation is used for finding the sag of conductor where tower bases are rest in different contour levels.

2.3 SUPPORT STRUCTURES

2.3.1 Structure

In order to provide the required electrical clearances to transmission line conductors from objects along ROW, conductor are suspended to tower via insulator strings. Various shapes of towers are used with the opinion of conservation the environment and the public becoming more & more conscious of the detrimental effects of transmission line towers on the environment and occupation of land. Transmission line tower designers have been endeavoring to develop towers with such shapes which blend with the environment.

The types of towers based on their constructional features, which are in use on the power transmission lines are given below.

a. Self-Supporting Towers
b. Conventional Guyed Towers
c. Chainette Guyed Towers

Self-Supporting Towers

Self-supporting broad-based / narrow based latticed steel towers are commonly used. These types of tower have been in use from the beginning of this century for transmission lines. These are fabricated, using tested quality mild steel material or a combination of tested quality mild steel and high tensile steel material.

Self-supporting towers usually have square / rectangular base and four separated footings. Self-supporting towers as compared to guyed towers have higher steel consumption. Self-supporting towers are also used for compact line design. Tower may comprise fabricated steel body, cage and ground wire peak, fitted with insulated cross-arms. Compaction is also achieved by arrangement of phases, using V insulator string, etc. Compact towers have reduced dimensions and require smaller right-of-way and are suitable for use in congested areas and for upgrading the voltage of the existing Transmission Lines also.

Tower Designation

a. Suspension Tower
b. Tension Tower
c. Transposition Tower
d. Special Tower

Suspension Tower

These towers are used on the lines for straight run or for small angle of deviation up to 2° or 5°. Conductor on suspension towers may be supported by means of I-string, V-string, or a combination of I & V Strings.

Tension Tower

Tension towers also known as angle towers are used at locations where the angle of deviation exceeds that permissible on suspension towers and/or where the towers are subjected to uplift loads. These towers are further classified as 2°/5°-10°, 10°-30°, 30°-60°/Dead-end towers and are used according to the angle of deviation of line. One of the classes of angle towers depending on the site conditions is also designated as Section Tower. The section tower is introduced in the line after certain distance to avoid cascade failure or series failure of towers.

Transposition Tower

Transposition towers are used to transpose the phase conductors in three sections in such a way that each phase by rotation occupies each of the three phase positions in a circuit.

In another transposition arrangement called 'on span transposition' the transposition is carried out near a tension tower due to greater ground clearance available near the tower than in the mid span. Two multiple tension insulator strings are connected back-to-back through a strain plate. In the central phase strain plate, a single suspension insulator string having almost doubled the no. of insulator discs and air gap distance is suspended. The balance work comprises placement of jumpers.

Special Towers

These towers are used at locations such as those involving long Span River crossing, valley crossings, power line crossings from above existing line, power line crossing below existing line (Gantry type structures), tapping to existing lines, special termination towers, etc. falling on the line route.

Tower Anatomy

A tower is constituted of the following components as shown in Figure 2.8.

1. Peak
2. Cage
3. Cross Arm
4. Boom
5. Tower Body
6. Body Extension
7. Leg Extension

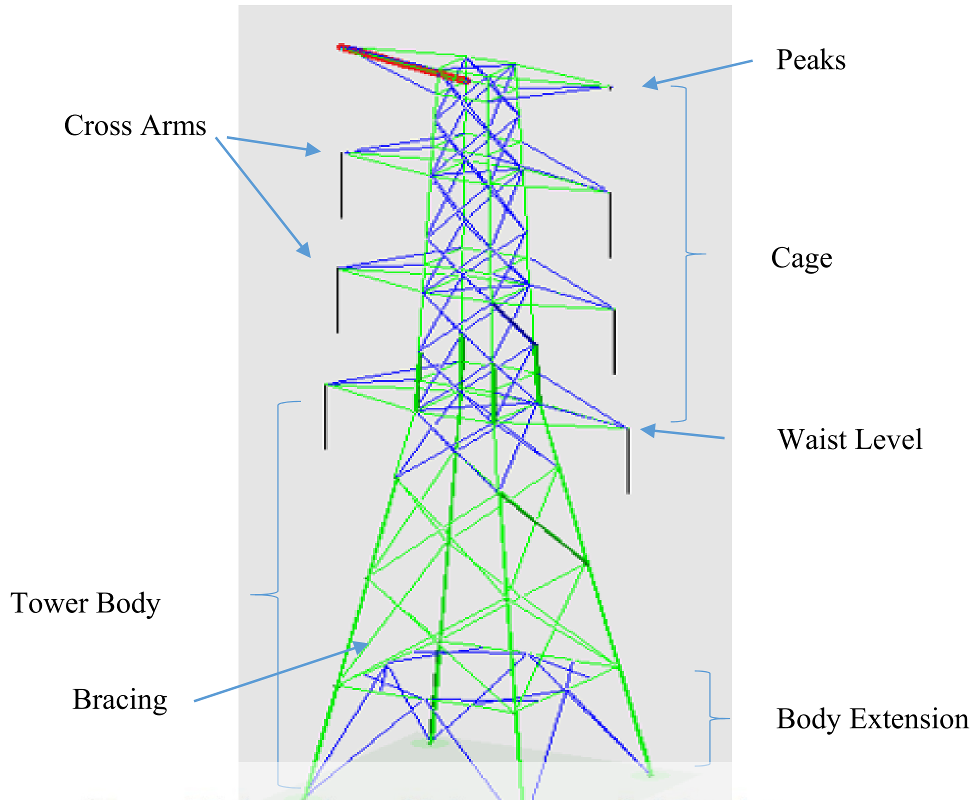


Figure 2.8 - Tower Anatomy

Peak

It is the portion of tower above the top cross arm in case of vertical configuration tower and above the boom in case of horizontal configuration tower. The function of the peak is to support the ground wire in suspension clamp and tension clamp at suspension and angle tower locations respectively. The height of the peak depends upon specified angle of shield and mid span clearance.

Cage

The portion between peak and tower body in vertical configuration towers is called cage. The cross-section of cage is generally square and it may be uniform or tapered throughout its height depending upon loads. It comprises tower legs interconnected by bracings used in the panel of cage where cross arms are connected to the cage or where, slope changes for proper distribution of torsion.

Cross Arm

The function of a cross-arm in case of vertical configuration tower is to support conductors, ground wires and OPGW. The number of cross arms depends upon number of circuits, tower configuration and conductor / ground wire arrangement. The cross- arm for ground wire consists of fabricated steel work and that for conductor may be insulated type or consist of fabricated steel work. The dimensions of a cross-arm depend upon the line voltage, type and configuration of insulator string, minimum-framing angle from the requirement of mechanical stress distribution etc. At large angle line deviation, rectangular / trapezoidal cross-arm with pilot string on outer side is used to maintain live conductor to grounded metal clearance.

Boom

It is generally a rectangular beam of uniform cross-section in the middle, but tapered in the end sections and forms part of horizontal configuration towers (self-supporting, guyed etc.). The boom is attached to the lower body and it supports power conductors.

Tower Body

Tower body is the main portion of the tower for connecting cage/boom to the tower foundation or body extension or leg extension. It comprises tower legs inter-connected by bracings and redundant members. It is generally square in shape. In another arrangement, a tower body comprises two columns connected at one of their ends to the foundations and at the other to the boom to which conductors are attached through the insulator strings.

Bracing Systems

Peak, cage, tower body, body extension, leg extension, etc. comprise legs, bracings and redundant. The bracing and redundant are provided for interconnecting the legs as also to achieve desired slenderness ratio for economical tower design. The Framing Angle between bracings, main leg members and (both bracing and leg member) shall not be less than 15° bracing patterns are Single Web System, Double Web or Warren System, Pratt System, Portal System, Diamond Bracing System, and Multiple Bracing System.

Tower Extensions (Body Extension)
Body extension is used to increase the height of tower (i.e. -3m, +3 m, +6 m, +9 m, +12 m, …. , +25 m height) with a view to obtaining the required minimum ground clearance over road crossing, river crossings, power line crossings, ground obstacles etc.

Practice in the tower industry is also to specify negative body extension i.e. a portion of the tower body is truncated. For lines traversing in hilly terrain, negative body extensions can be used in tension towers from the consideration of economy.

Leg Extensions
Leg extensions are used either with anyone leg or any pair of legs at locations where footings of the towers are at different levels. Leg extensions are generally used in hilly regions to reduce benching or cutting. The alignment of leg extension is done with the first section of a tower. For unequal leg extensions special care required to set the individual stubs using prop type stub setting template [8], [16], [17], [18], [24].

2.3.2 Loading Cases of Towers

Transmission lines are subjected to various loads during their lifetime. These loads are;

Loads Due to Wind Pressure
The wind pressure to be applied on towers and conductors shall be as given in client specification and assumed acting horizontally on tower or conductor. In case of towers wind pressures shall be calculated on the projected area of the members on windward face.

In case of conductors and ground-wires / OPGW the pressures shall be assumed as acting on the full projected area. Projected area of wire can be calculated as (wind span * diameter of wire). For the purpose of computing the wind load on bundle conductors (more than one conductor per phase) wind pressure shall be assumed as acting on full projected area of each conductor in a bundle. For the purpose of computing the wind load on insulator strings, the effective projected area of the string shall be the projected area of the cylinder with a diameter equal to that of the insulator skirt.

Wind Load on Tower

In order to determine the wind load on tower, the tower is divided into different panels having a height 'h‘. These panels should normally be taken between the intersections of the legs and bracings. For a lattice tower of square cross-section, the resultant wind load in Newton, for wind normal to the longitudinal face of tower. But the availability of sophisticated software exact wind load can be applied to the tower member with equal distribution to whole body of the tower.

Transverse Load

The transverse load due to wind shall be calculated on the wind span. Under broken-wire conditions, broken span shall be considered from client specification. These loads are in addition to the transverse load due to line deviation, wind loads on insulator, etc. Wind Span: The wind span is the sum of the two half spans adjacent to the supports.

Longitudinal Load

The unbalanced pull due to broken conductors in the case of supports with suspension strings, may be assumed reduced value of maximum working tension of the conductor as per client specification requirement. Normally, 50% reduction in maximum conductor tension considered for design of tower.

For the ground wire broken condition, maximum working tension shall be considered for the purpose of design of tower. The unbalanced pull due to broken conductor or ground wire in case of tension strings, shall be equal to the component of the maximum working tension of conductor or the ground wire as the case may be, in longitudinal direction along with its components in the transverse direction. This will be taken for the maximum as well as minimum angle of deviation for which the tower is designed and the condition which is most stringent for a member shall be adopted. When there is a possibility of the tower being used with a longer span by reducing the angle of line deviation, the tower member needs to be checked for maximum longitudinal and transverse components arising out of the reduced angle of deviation.

Vertical Load

The vertical loads due to conductors and ground wires shall be based on appropriate weight span. A provision of150 kg may be made for the weight of a lineman with tools. These loads are in addition to the vertical loads due to insulators and fittings and dead weight of the structure. The stringing / construction procedure shall ensure that the vertical loads are not exceeded.

Note: The weight span is the horizontal distance between the lowest points of the conductor, on the two spans adjacent to the tower. The lowest point is defined as the point at which the tangent to the sag curve or to the sag curve produced is horizontal.

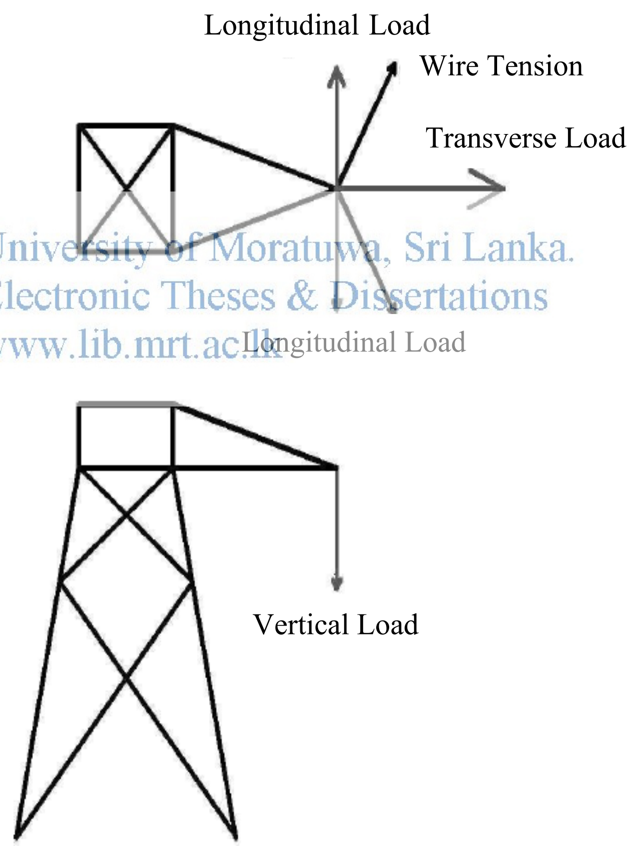


Figure 2.9 - Loads on Tower

2.4 SUPPORT FOUNDATIONS

2.4.1 Types of Loads on Foundations

The foundations of towers are normally subjected to three types of forces.

These are;

a. The compression or downward thrust;
b. The tension or uplift; and
c. The lateral forces or side thrusts in both transverse and longitudinal directions.

2.4.2 Basic Design Requirements

To meet the varying needs in respect of soil conditions and loading quantum, several types of tower foundations have been used for the transmission line towers. Design philosophy of tower foundation should be closely related to the principles adopted for the design of the tower which the foundation has to support. A weak or unsound foundation can make a good tower design useless while a very strong foundation for a weak tower means a wasteful expenditure. Functionally, the foundation should be strong and stable. It should take care of all the loads such as dead loads, live loads, wind loads, etc. causing vertical thrust, uplift as well as horizontal reactions. For satisfactory performance, it should be stable and structurally adequate and be able to transmit these forces to the soil such that the limit soil bearing capacities are not exceeded.

2.4.3 Soil Parameters

Bearing Capacity of Soil

This parameter is vital from the point of view of establishing the stability of foundation against shear failure of soil and excessive settlement of foundation, when foundation is subjected to total downward loads and moments due to horizontal shears and / or eccentricities as applicable.

Density of soil

This parameter is required to calculate the uplift resistance of foundation.

Angle of Earth Frustum

This parameter is required for finding out the uplift resistance of the foundation.

Level of Ground Water

This parameter is required to calculate respective density for the uplift resistance & select proper bearing capacity & angle of earth frustum of soil.

2.4.4 Types of Soil

Non Cohesive Soils

This group of soils includes gravel and sands which are composed mainly of larger sized grains resulting from weathering of rocks. The engineering behavior of these soils under loading depends primarily on their friction qualities which vary with their density, degree of lateral confinement, ground water level and flow of water through them.

The non-cohesive soils do not get unified with the parent soil after back filling with the passage of time. The following types of soils come under this category;

a. Sandy Soils which have no clay/silt or have very little clay/silt.
b. Soft and hard murrum. These can be excavated using normal tools and these get disintegrated into pieces.

Cohesive Soils

These comprise clays, silts and soft shale, etc. having comparatively fine grain size particles. The strength of this group of soils is derived primarily from cohesion between their particles. The most important characteristic of cohesive soils from engineering point of view is their susceptibility for slow volume changes due to their low permeability.

When this type of soils is subjected to loads, the contained water in the voids is expelled very slowly with consequent diminution of volume resulting in consolidation settlement. Unlike settlement in non-cohesive soils which is immediate, the settlement in cohesive soils may take many years to reach its final value.

The cohesive soils get unified with the parent soil after back filling with the passage of time. The following soils come under this category.

a. Normal soil having mixture of silt and clay (clay not exceeding 15%). When this type of soil is made wet and rolled between the palms, only short threads can be made.

b. Clayey soils having high percentage of clay (more than 15%), When this type of soil is made wet and rolled between the palms, long threads can be made.

c. Marshy soil having sea mud (marine soil) which is very sticky in nature.

2.4.5 Types of Rocks

Rocks derive their strength from permanent bond of cohesive forces among their particles. They are usually classified as hard, and soft. Rocks have high bearing capacity except when decomposed, heavily shattered or stratified. On uneven site, however, dangerous conditions may develop with rocks if they dip towards cuttings. Tower foundations are usually built on the upper area of the rock formations which are often found to be weathered and disintegrated.

2.4.6 Structural Arrangement of Foundations

Based on structural arrangement of foundations, the various types of foundations are possible.

P.C.C. Type

It consists of a plain concrete fooling pad. In this type of foundation, the stub angle is taken inside and effectively anchored to the bottom pad by Cleat angles, and the chimney with stub angle inside works as a composite member.

The pad may be either pyramidal in shape as shown in Figure 2.10 or stepped. Stepped footings will require less shuttering materials but need more attention during construction to avoid cold-joints between the sleeps, the pyramidal footings on the other hand, will require somewhat costlier form work.

In this pad & chimney type footing, where the chimney is comparatively slender, the lateral load acting at the top of the chimney will cause bending moment and, therefore, the chimney should be checked for combined stresses due to direct pull / thrust and bending.

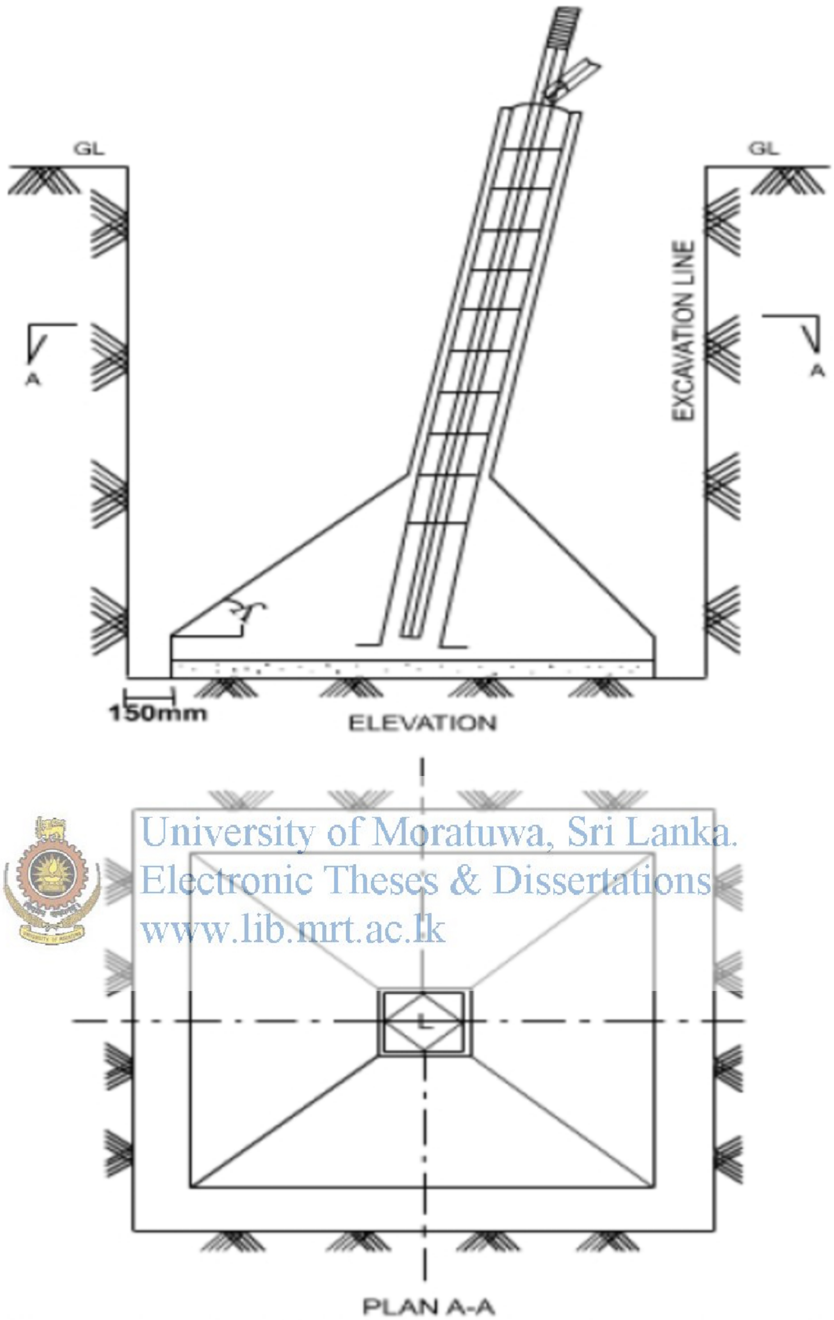


Figure 2.10 - Pyramidal Type Chimney Foundation

R.C.C. Spread Type

There are several types of R.C.C. spread footings which can be designed for tower foundations. Figure 2.11 shows the most common type of RCC foundation. This type of foundation can be either single step type or multiple step type and / or chamfered step type. It consists of a R.C.C. base slab and a square chimney [8], [19], [20].

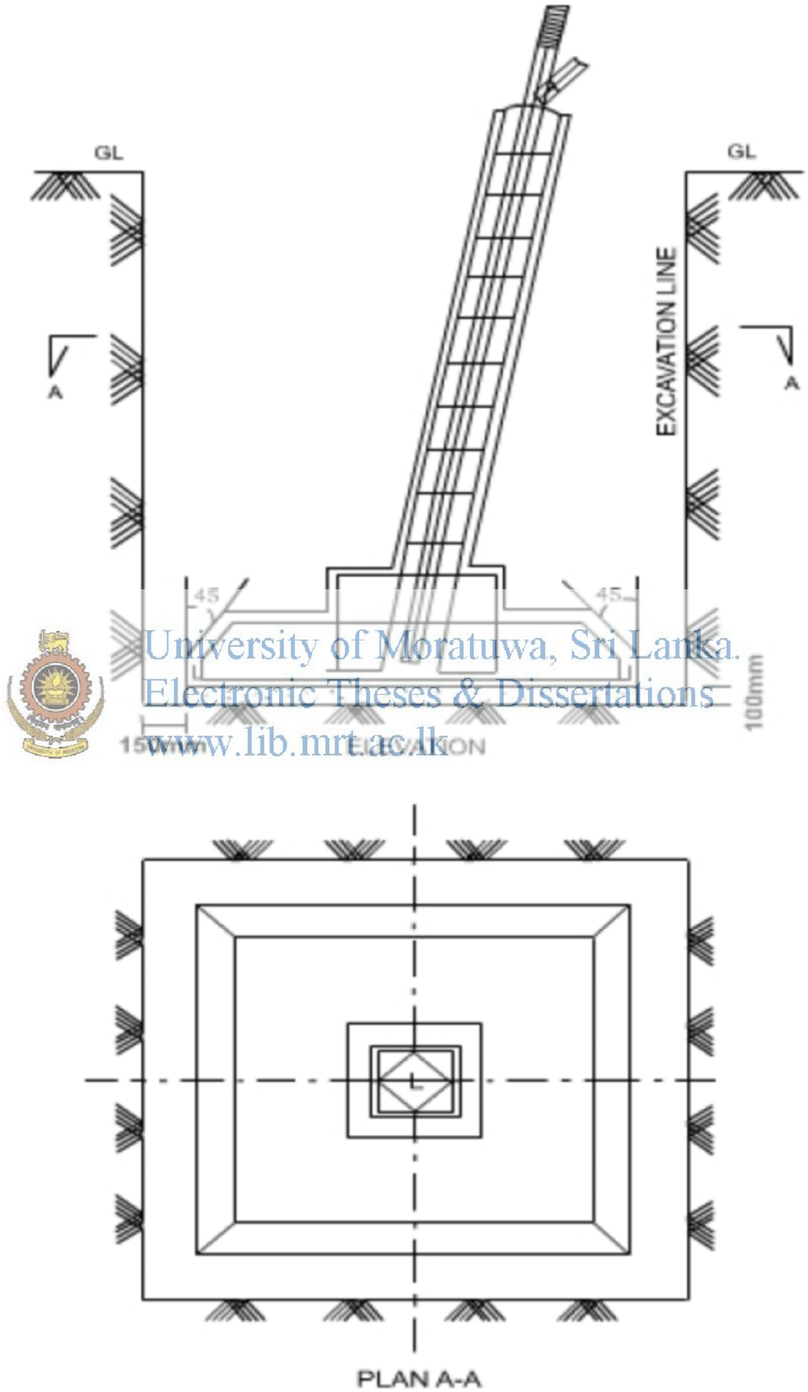


Figure 2.11 - R.C.C Spread Type Foundation

3.0 METHODOLOGY

3.1 PROCEDURE

Under this research, seven type of new generation conductors and a conventional ACSR conductor are considered, and their behavior on techno economics of 132kV transmission line is studied by designing and modeling transmission lines for different ground terrains.

Cost models are developed for eight types of conductors, i.e., ACSR, ACCC, ZTACIR, ACSS/TW, ACCR, G(Z)TACSR, LL-ACSR/AS and LL-TACSR/AS conductors which are revolutionized overhead bare conductor technologies in the modern overhead conductor industries.

Conductor selection is done under two cases, and energy loss evaluation is done respective conductors. Towers and foundations are also design based on the mechanical loads of respective conductors. Profile designs are carried out for 6 distinctive ground terrains; paddy terrain, Populated terrain and non-populated terrain, and considered those terrains under both hilly and flat terrain scenario.

Electrical behavior of conductors and viability will be discussed by taking ACSR Zebra conductor as the base conductor, which is the dominant conductor in overhead transmission network in Sri Lanka. Mechanical and civil aspects are also discussed for conductors, structures and foundations.

Designing and costing of structures and foundations, PLSTOWER and Prokon software packages will be used respectively. Transmission line profile design works will be done with the aid of PLSCADD software [24]. All the designs are carried out complying with the applicable CEB specifications and international standards, e.g., IEC, BS, IEEE, etc.

Electrical behavior and energy loss calculations are done for respective conductors, and financial evaluation is done considering the cost of power transmission and cost of construction of 132kV transmission lines.

3.2 GENERAL GUIDELINES

This study only concentrates on 132kV double circuit transmission lines, and towers are considered double circuit, double peak and self-supporting lattice structures. At the peaks Optical Fibre Ground Wire (OPGW) and Ground Steel Wire (GSW) are strung.

ACSR Zebra Conductor; (400mm^2, Al 54/3.18mm + St 7/3.18mm steel core greased) has been used for construction of 132kV transmission lines as a convention in Sri Lanka, therefore ACSR Zebra conductor (and its' CCC) is used conductor as the base in this study. Technical and financial aspects are discussed with different types of new conductors, which have different fabricating technologies.

Environmental conditions used for calculations are based on climatic condition of Sri Lanka, and kept constant throughout the study. In order to achieve more realistic outcomes, ground terrain models are developed based on existing and currently undergoing transmission lines route terrain data.

CEB specifications and international standards are used for designing of transmission lines and profiles. Towers and foundations are designed using applicable standards and sophisticated software packages.

EMF behavior is studied and the required clearances are maintained base on guide line specified by the International Commission for Non Ionizing Protection (ICNIRP).

3.3 EXTENT OF STUDY

This study covers the detail techno economic analysis for 132kV transmission lines with different conductors. Conductors are selected from new generation conductors (HTLS and LL), and ACSR Zebra conductor is used as the base which is presently standardized in Sri Lanka overhead transmission network.

Electrical and mechanical behavior is studied by carrying out detailed design on towers and foundations. Then, transmission line models are developed for unique type of ground terrains and generalized cost models are developed for different conductors.

3.4 DESIGN PROCEDURE OF TRANSMISSION LINE

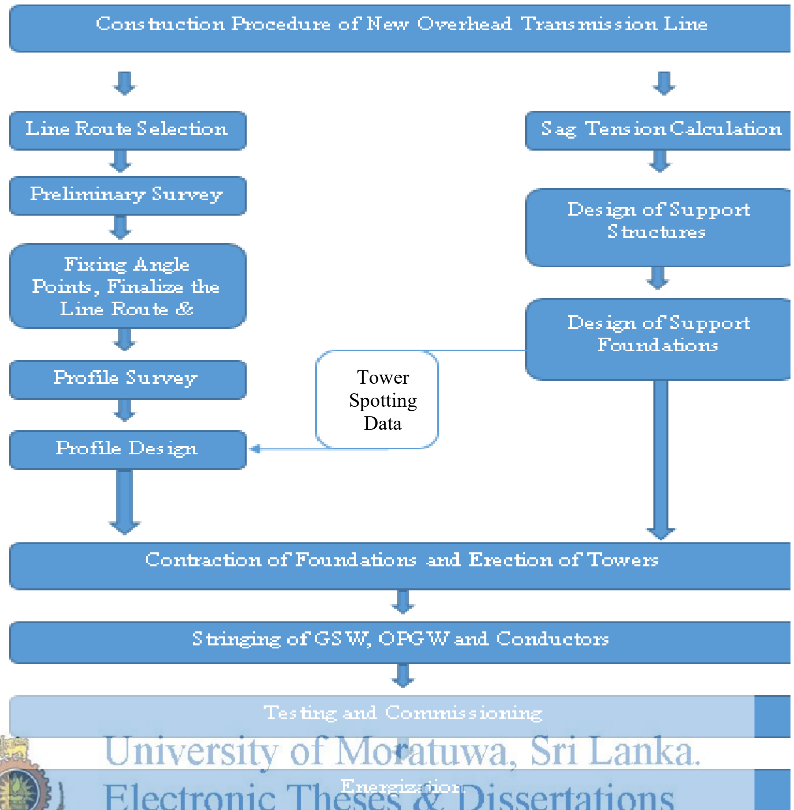


Figure 3.1 – Design Procedure of Transmission Lines

3.4.1 Line Route Selection

Considering the demand growth and expansion of the distribution network, new transmission lines are proposed by the Long Term Transmission Expansion Plan (LTTEP), CEB. Accordingly, substations are located at load centers, and new transmission line are constructed by connecting them with existing transmission network. Configuration of the transmission lines is decided according to the power requirement.

Tentative line route options are drawn with the support of Google Earth maps, Survey Maps (1:50000), GIS satellite maps while giving priorities to economical, sociological and ecological aspects. Then, Tentative route options are inspected in physically by using Global Positioning System (GPS), and route changes are made accordingly. If any physical difficulty in locating towers, alternative routes are considered.

3.4.2 Preliminary Survey

Preliminary survey is conducted in order to develop the survey plan of the selected line corridor up to 100m. All ground features, except profile of the ground are taken in to plan view, e.g., houses, building, structures, hedges, fences, ditches, roads, railways, rivers, canals, water reservoirs, power lines, pipe lines, cultivation lands, etc.

3.4.3 Fixing Angle Point, Finalizing the Line Route and Wayleaves

With availability of preliminary survey data, exact physical locations, critical locations and angle points can be visited, and finer adjustments can be carried out with minimum disturbances to the public and the environment.

3.4.4 Profile Survey

Then, ground profile surveying can be started, and all the profile features along the line route are recorded within the corridor of 30m, such as ground terrain, power lines, buildings, telephone lines, etc. Accordingly, ground profile drawings are produced in order to design the transmission line profile.

3.4.5 Sag Tension Calculations

As described in the section 2.2.4.2 sags and tensions are calculated for conductors, GSW and OPGW according to specification shown in Table 3.1.

Table 3.1 - Loading and Temperature for Conductor, GSW and OPGW

Temperature		
	Minimum (T min)	7°C
	Every day(T)	32°C
	Maximum (T max), ACSR	75°C
Wind pressure (p) conductors and earth wire		970 N/m^2
Minimum factor of safety for conductors & earth wires based on ultimate strength		
	At maximum working tension	2.5
	Everyday temperature, still air	4.5
	Basic span (m)	300m

Based on the sag tension results, tower heights and tower loading trees are decided for respective conductors.

3.4.6 Designing of Support Structures

Double circuit towers are designed for single Zebra conductor in vertical formation and one overhead 7/3.25mm galvanized steel earth wire and an OPGW above the conductors. They are of self-supporting broad based lattice steel structures.

General specifications for design of 132kV double circuit transmission line structures are as follows.

Table 3.2 - Line Clearance [8]

Features	Clearances (m)
Minimum clearance from conductor: to ground	6.7
Metal clad or roofed buildings, or other buildings or structures upon which a man may stand	4.1
To earthed cradle guard wires	4.0
To electric power line wires (line to earth)	3.7
To be added to the above clearance to allow for survey and sagging error	0.3
Minimum horizontal spacing between outermost conductor of adjacent power line in still air	15.3
Spacing between p – t line and cradle guard	1.8

Loadings and Temperatures

Table 3.3 - Temperatures of Conductors and GSW, [8]

Assumed Wind Loading	Unit	Speed
Wind pressure on conductors and earth wires	N/m^2	970
Wind pressure on insulators	N/m^2	1170
Wind pressure on lattice steel supports	N/m^2	1640

Table 3.4 - Assumed Wind Loading, [8]

Temperatures of Conductors & Earth wires	Temperature
Minimum temperature	7^0C
Everyday temperature	32^0C
Maximum temperature, ACSR	75^0C

Design Spans

Wind Span

The wind span is the sum of the two half spans adjacent to the support under consideration.

Table 3.5 - Wind Span, [8]

Basic Span (m)		300
Wind Span (m)		
All towers	Normal working (m)	360
	Broken wire (m)	270

Weight Span

Following weight span specifications are followed.

Table 3.6 - Weight Span for TDL Tower, [8]

Weight Span (m)		**Maximum**	**Minimum**
Suspension Towers	Normal working	600	150
	Broken Wire	450	112.5

Table 3.7 - Weight Spans for Angle Towers, [8]

Weight Span (m)			**Maximum**	**Minimum**
0^0-10^0, 10^0-30^0, 30^0-60^0 Tower with full Angle	Normal working		900	- 300
	Broken Wire		675	- 200
0^0-10^0 Angle Tower with 0^0Angle	Normal working		1220	- 600
	Broken Wire		915	- 450
Terminal Towers.	Normal working	Line Side	450	0
		Substation side	75	0
	Broken wire	Line Side	300	0
		Substation side	75	0

Types of Supports

The standard double circuit structures are designated as follows;

1. Suspension Tower; TDL
2. section tower TD1 0^0 - 10^0 and
3. Angle tower TD3 10^0 - 30^0
4. Angle tower TD6 30^0 - 60^0
5. Terminal tower TDT

Towers are provided with body extension of -03m, +03m, +06m, +09m and +12m, and each type designation carries the construction i.e.,TDL+03, TD6+12 etc. +01m, +02m, +03m, +04m and +06m leg extensions are provided where presents of uneven ground terrains.

Table 3.8 - Electrical Clearances for Supporting Structures. [8]

Minimum clearance from 132 kV live metal to earthed metal for suspension towers			
(a) (b)	From still air to 10^0 swing of insulator From 10^0 to 40^0 swing of insulator	mm mm	1650 1550
Minimum clearance from live metal to earthed metal at tension towers			
(a)	Jumper loops from still air to 10^0 swing	mm	1650
(b)	Jumper loops from 10^0 to 40^0 swing	mm	1550
(c)	Minimum plan clearance from arc horn tip to tower steelwork	mm	1650
Assumed maximum transverse swing from vertical of			
(a) (b)	Jumper loops Jumper suspension towers insulator strings At tension	Deg	40^0 20^0
Minimum separation between phases in down leads		mm	2500
Maximum ratio of unsupported length of steel compression members to their least radius of gyration (L/R)			
(a)	Main members in the cross arm in compression and legs		120
(b)	Bracing carrying computed stresses		200
(c)	Redundant		250
(d)	Bracing loaded in tension only		350

3.4.7 Designing of Support Foundations

Different type of foundations are designed base on the supporting towers. Those foundations are further classified based on the coil condition. Soil conditions are classified in to several classes base on their baring capacity. As per the CEB specification following classifications are used for designing of foundations [8], [20].

Soil Classification

Table 3.9 - Schedule of Foundation Design. [8]

Foundation	**Foundation types**	**Soil Classification**	**Presumed allowable bearing value kN/m^2**	**Design uplift frustum angle**	**Level of Water table (*see note below)**	**Concrete density kg/m3**	**Soil density kg/m3**
1	Rock Anchor	S1	> 2000	45		2240/ 1200 **	2000/ 1000 **
2	Concrete pad & chimney	S2	>600	30	Below Datum level*	2240	1800
3	Concrete pad & chimney	S3	>200	20	Below Datum level*	2240	1600
4	Concrete pad & chimney	S4	>100	10	Below Datum level*	2240	1500
4A	Concrete pad & chimney	S4A	>100	10	Above datum level*	2240/1200 **	1500/1000 **
5	Concrete pad & chimney	S5	>50	0	Below Datum level*	2240	1400
5A	Concrete pad & chimney	S5A	>50	0	Above datum level*	2240/1200 **	1400/960 **
6	Piling	S6	Subject to soil investigation	0	Above datum level*	2240/1200 **	Subject to soil investigation
7	Any other special	S7	-do-	0	Above datum level*	2240/1200 **	Subject to detailed soil investigation

S1 Homogeneous rock
S2 Fractured rock / dense sand and Gravel
S3 Medium dense gravel / medium dense gravel with sand / Compact sand / Very stiff to stiff clay/ hard clay
S4 Loose sand and gravel /Medium dense sand / stiff clay / Firm clay
S4 A Loose sand and gravel /medium dense sand / stiff clay / Firm clay
S5 Soft clay, silt / loose sand
S5A (Water logged) soft clay, silt / loose sand
S6 Very soft clays and silts / peat and organic soils/ made ground or fill

Note: *Datum level is 0.5m below the level of the bottom of the pad
** submerged density

3.4.8 Profile Design

Following the design criteria, appropriate towers are located along the line section. Angle towers are placed on angle location according to angle of deviation, and line towers are located and moved back and forth to find out best economical locations of line towers. Body extensions are added when necessary to maintain required electrical clearance from obstacles (see Table 3.10 for electrical clearance). Likewise all the sections are completed section by section.

Table 3.10 - Electrical Clearances. [8]

Features Codes	Clearances (m)
Minimum Clearance from Conductor: To Ground	6.7
Metal Clad or Roofed Buildings, or other Buildings or Structures upon which a man may stand	4.1
To earthed cradle Guard Wires	4.0
To Electric power Line Wires (Line to Earth)	3.7
To be added to the above Clearance to allow for Survey and sagging error	0.3
Minimum horizontal spacing between outermost conductor of adjacent power line in still air	15.3
Spacing between P + T Line and cradle guard	1.8

4.0 CONSTRUCTION OF NEW TRANSMISSOIN LINES

4.1 INTRODUCTION

Often due to various reasons, power utilities have to construct new transmission lines. Construction of a transmission line is a massive task, and many difficulties need to be overcome during the construction, i.e., social objections, environmental damage issues, construction difficulties (poor access and bad weather), etc. Therefore, special attention need to be paid all the time of the construction process.

4.2 ALGORITHM FOR TRANSMISSION LINE CONSTRUCTION

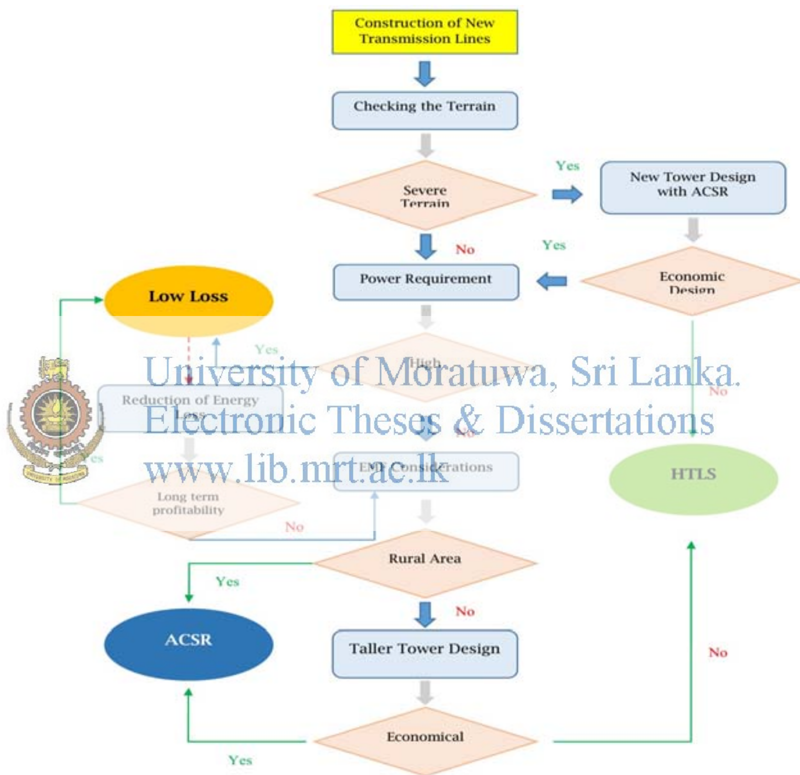


Figure 4.1 - Algorithm for Construction of New Transmission Lines. [21]

According to the algorithm [21], there are five major factors emphasized when designing a transmission line, and techno economic of 132kV transmission line is evaluated based on following factors.

1. Power requirement
2. Long term profitability
3. Economic profile design
4. EMF consideration
5. Economic viability

4.3 POWER REQUIREMENT

ACSR Zebra Conductor; (400 sqmm, Al 54/3.18mm + St 7/3.18mm steel core greased) have been used for construction of 132kV transmission lines as a convention in Sri Lanka, so in this study ACSR Zebra conductor and its properties are used as the base, and quantitative evaluation is carried out in order to check the viability of using new generation conductors for new 132kV transmission lines.

CCC of conductors are heavily depend on the environmental factors described in Table 4.1, which are based on the Sri Lanka's climatic conditions and CEB specifications.

Table 4.1 - Environmental Factors

S_i	Intensity of solar radiation	W/m^2	1000
v	Wind Speed	m/s	0.5
ϒ	Solar Radiation Absorption Coefficient		0.5
K_e	Emissivity coefficient in respect to black body		0.5
T_1	Ambient Temperature	°C	32
λ	Air thermal Conductivity	$Wm^{-1}K^{-1}$	0.02585
s	Stefan- Boltzmann Constant	$Wm^{-2}K^{-4}$	5.67E-08

Following conductor properties must be available in order to calculate the CCCs of conductor, and see APPENDIX I for a sample calculation.

Table 4.2 - ACSR Conductor Properties

D	Conductor Diameter	m	0.02862
R25	Electrical Resistance of the conductor @25	Ω/m	0.06841
R75	Electrical Resistance of the conductor @75	Ω/m	0.08149
T2	Final equilibrium Temperature	°C	75

Based on IEC 61597, CCC of ACSR Zebra conductor is calculated [22].

Table 4.3 - CCC Results for ACSR Zebra

P_{rad}	Radiation Heat Loss	W	15.3260
P_{conv}	Convention Heat Loss	W	55.5927
P_{sol}	Solar Heat Gain	W/m	14.31
N_u	Nusselt Number		15.920
R_e	Reynolds Number		788.55
R_T	Electrical Resistance of the conductor	Ω/m	0.00008149
$\mathbf{I_{max}}$	**Current Carrying Capacity**	**A**	**833**

Under climatic conditions of Sri Lanka, ACSR Zebra conductor can carry maximum of 833A, and based on this, power capacities of different configurations of transmission lines are tabulated in the Table 4.4.

Table 4.4 - CCCs of Different Transmission Line Configuration

Voltage System (kV)			**132**	**220**	**400**
Single Circuit (MW)	Single Conductor	1	190.4	317.4	577.1
	Twin Conductors	2	380.9	634.8	1154.2
	Quad Conductors	4	761.8	1269.7	2308.5
Double Circuit (MW)	Single Conductor	1	380.9	634.8	1154.2
	Twin Conductors	2	761.8	1269.7	2308.5
	Quad Conductors	4	1523.6	2539.3	4617.0

In this study, 132kV double circuit single conductor configuration is considered for further calculations, and maximum power carrying capacity of the transmission line is then considered as 380.9MW.

4.3.1 Conductor Selection

Large variety of conductors are available in the market, and behavior of conductors is mainly based on their electrical and mechanical properties. Behavior of conductors critically affects the performance of transmission lines during its life span. Capital cost of construction and energy loss cost are the two main factors, which affects the long term viability of transmission lines. Therefore, selection of conductors are carried out cautiously, considering the following factors.

1. Current carrying capacity.
2. Performance and quantity usage in the transmission line industry.
3. Technical specification of conductors.
4. Behavior of conductor for past few year.
5. Conductor manufacture’s recommendation.

However, based on the long term profitability evaluation, conductor selection is carried out under two categories;

1. Rated Load Condition.
2. Low Load Condition.

4.3.1.1 Rated Load Condition

Conductors are selected based on their rated CCC to deliver the same amount of power as ACSR Zebra conductor. Smallest available conductor is selected when the rated CCC is higher than the rated CCC of ACSR Zebra. Table 4.5 shows the selected conductors and their properties.

Table 4.5 - Conductors' Properties (Rated Load Condition)

Conductor Type	**ACSR**	**ACCC**	**ZTACIR /AW**	**ACSS/TW**	**ACCR**	**GTACSR**
Conductor	ACSR	194-OCEANSIDE	159 - 160	152 - OSTRICH	150 - OSTRICH	240-HAWK
Diameter (mm)	28.62	17.272	18.2	17.272	17.196	20.5994
AC Resistance at 25°C (ohms/km)	0.06841	0.14751	0.17784	0.18481	0.18697	0.121913
AC Resistance at 75°C (ohms/km)	0.08149	0.17653	0.20922	0.22215	0.224	0.145587
Ultimate Tensile Strength (kN)	131.9	71.2	60.2	44.5	53.8	86.8026
Unit Mass of Conductor (kg/m)	1.632	.589.2	.706.8	0.6135	0.5014	0.9550744
Cross Sectional Area (mm²)	484.5	194.2	159.3	152	150.5	279.612

According to the environmental conditions of Sri Lanka (see Table 4.6), CCCs of conductors are calculated, and their operation temperatures are noted.

Table 4.6 - Environmental Factors

Environmental Condition	
1000	Sun Radiation (W/m²)
0.5	Wind Speed (ms^{-1})
0.5	Solar Radiation Absorption Coefficient
0.5	Emissivity coefficient
32	Ambient Temperature (°C)
0.02585	Air thermal Conductivity ($Wm^{-1}K^{-1}$)
5.67E-08	Stefan- Boltzmann Constant ($Wm^{-2}K^{-4}$)

According to the CCC, it can be seen that all conductors can carry the same amount of power as ACSR Zebra, even though they are having lesser conductive area as ACSR Zebra, however operating temperatures of conductors are well above the operating temperature of ACSR Zebra conductor.

Table 4.7 - CCC Calculations (Rated Load Condition)

Conductor Type		ACSR	ACCC		ZTACIR/ AW		ACSS/TW		ACCR		GTACSR	
Conductors per phase		1	1		1		1		1		1	
Circuits		2	2		2		2		2		2	
Ampacity (A) at Temperature (°C)	75	833.0	157	833	175	833	197	833	198	833	128.8	833
Ampacity (A) at Rated Operating Temp (°C)	75	833	180	895	210	917	200	840	210	858	150	570
Ampacity (A) at Maximum Temp (°C)	100	1054	200	945	240	983	250	938	240	917	150	903
Steady-State Temperature (ºC) at 833A		75.0	157.0		175.0		197.0		198.0		128.8	
Resistance at Peak Operating Amps (ohm/km)		0.08149	0.22426		0.27208		0.31308		0.31511		0.17106	

$$R(T_c) = \left[\frac{R(T_h) - R(T_l)}{T_h - T_l}\right] * (Tc - T_l) + R(T_l)$$

According to the equation, the conductive resistance goes higher for higher operating temperatures. High conductive resistance causes to waste more energy in power transmission. Therefore, high energy loss is caused due to high resistance and that ultimately affects the viability of transmission line.

$$Energy\ Loss = i^2R$$

Techno economic viability of transmission lines mainly depends on loss of energy during it life span and the capital cost, and discussed under section 4.4.

4.3.1.2 Low Load Condition

Selection of conductors under this category is done considering several factor. ACSR Zebra is selected as base conductor, and other conductor are selected such a way that area of the conductor same as the area of ACSR Zebra conductor. Conductor manufactures always encourage to use their new conductor products instead of well-established conductors in power sector, and their R&D focuses on developing new conductors by adopting new technologies to mitigate problems prevailing in current transmission systems , but maintains the conductors diameter same in order to adopt those to the existing transmission system easily.

Lots of line material are associated with conductors, so if new conductor with the same diameter would be an added advantage to power utilities to easily adopt to new conductor without much variations of its hardware., i.e., availability of line material stocks, no need to separate stocks and storage facility, reduces the complexity of maintaining separated line material and hardware, no need to train people for construction and maintenance of transmission lines, etc. However, in order to use the same line material, clamping and suspending methods of the new conductor need to be same as the previous conductor.

Therefore, conductor selection under the second category is done by keeping the area of the selected conductors, same as the area of the base conductor. However, it would not be possible to find exactly the same sized conductors, but it is possible to select conductors with slight differences of its area.

Considering above factors, seven different new generation conductors are selected for study, and properties are tabulated in table 4.5.

Table 4.8 - Conductor Properties (Low Load Condition)

Conductor Type	ACSR	ACCC	ZTACIR /AW	ACSS/TW	ACCR	GTACSR	**LL-ACSR/AS**	**LL-TACSR/AS**
Diameter (mm)	28.62	28.143	28.5	28.677	28.651	28.9992	28.62	28.62
AC Resistance at 25°C (ohms/km)	0.06841	0.05534	0.07045	0.05474	0.06742	0.0609	0.052948	0.053663
AC Resistance at 75°C (ohms/km)	0.08149	0.06596	0.08271	0.06543	0.08078	0.0733	0.063432	0.06428
Ultimate Tensile Strength (kN)	132.3	183.3	124.7	125.4	143.2	152.899	140.9	140.9
Unit Mass of Conductor (kg/m)	1.621	1.5832	1.6258	1.9731	1.3838	1.8551	1.814	1.814
Cross Sectional Area (mm^2)	429.1	524.5	413.4	523.9	417.5	567.483	590.5	590.5
Modulus of Elasticity (N/mm^2)	69000	78000	85000	73790	85000	74400	69100	69100
Linear Coefficient ($^0C^{-1}$)	$19.3E^6$	$18.6E^6$	$17.9\ E^6$	$18.9E^6$	$19.3\ E^6$	$20.2\ E^6$	$21.2\ E^6$	$21.2\ E^6$

As per the IEC 61597, CCC at rated and maximum temperatures are calculated for the selected conductors under same environmental condition, and results are summarized in Table 4.9.

Table 4.9 - CCC Calculations (Low Load Condition)

Conductor Type	ACSR	ACCC	ZTACIR/AW	ACSS/TW	ACCR	GTACSR	LL-ACSR/AS	LL-TACSR/AS
Conductors per phase	1	1	1	1	1	1	1	1
Circuits	2	2	2	2	2	2	2	2
Operating Temperature @ 833A	75.00°C	68.27°C	75.59°C	67.76°C	74.61°C	70.84°C	66.57°C	66.96°C
Ampacity at Rated Operating Temp	833A @ 75°C	1712 A @ 180°C	1689 A @210°C	1828 A @ 200°C	1685 A @ 210°C	1415 A @ 150°C	1105 A @ 90°C	1508 A @150°C
Ampacity at Maximum Temperature (°C)	1070A @100°C	1813A @ 200°C	1817A @240°C	2058 A @ 250°C	1808 A @ 240°C	1550 A @ 180°C	1341 A @ 120°C	1653 A @ 180°C

As per the results, it can be observed that rated CCCs of conductors are considerably higher than the rated CCC of ACSR Zebra conductor. Hence the operating temperatures at 833A (rated CCC of ACSR Zebra conductor) are showed lower values compared to rated temperature of ACSR Zebra conductor.

4.4 LONG TERM PROFITABILITY

There are several factors to be evaluated for the period of life time in order to check the long term profitability of transmission lines, [25].

Life Cycle Cost (LCC)

LCC is a powerful tool in helping the decision maker for selecting a particular design configuration among the various available alternative options of transmission line

[25]. Large amount of data is required to LCC analysis, and it is impossible to account all the cost factors which occur during the life time of a transmission line. Life cycle cost associated with a transmission line is the sum of all recurring expenses including annual capital costs and line losses. Net present value (NPV) analysis is a widely accepted form for LCC evaluation which helps in analyzing alternatives of capital cost of transmission lines.

Annual Energy Loss

$$\text{Annual Energy Loss} = (\text{Phase current})^2 * \text{Unit Resistance} * \text{Line Length} * \text{Total Nos. of Conductors} * \text{Loss Factor} * 8760$$

$$Load\ Factor = \frac{Average\ Demand}{Maximum\ Demand}$$

$$Loss\ Factor = 0.2 * Load\ Factor + 0.8 * Load\ Factor^2$$

Net Present Value

$$Net\ Present\ Value\ =\ \sum_{t=1}^{n}\frac{1}{\left(\frac{1}{1+i}\right)^{n}}$$

$where;\ i = discount\ rate$

$n = nos. of\ years$

Factors used for long term energy loss evaluation for conductors are based on the CEB specifications, and summarized in the Table 4.10.

Table 4.10 - Factors for Energy Evaluation

132	Voltage (kV)
1	Line Length (km)
833	Peak Operating Amps (A)
57.3%	Load Factor
37.7%	Loss Factor
190	Peak Power per Circuit (MW)
3	Phases/Circuit
19.97	Cost of Energy Generation (LKR/kWh)
0.8	CO_2 Emission (kg/kWh)

Source – (Source; Statistics Digest 2014,CEB)).

Long term energy loss calculations are done by keeping the power flow at the rated capacity of ACSR Zebra, so losses of each conductor is calculated sitting in the same basis. Life span of transmission lines is considered as 40 years. Results obtained are summarized in Table 4.11, and see the APPENDIX III for a sample calculation.

Table 4.11 - Line Loss Evaluation (Rated Load Condition)

Conductor Type	ACSR	ACCC	ZTACIR /AW	ACSS /TW	ACCR	GTACSR
Conductors per phase	1	1	1	1	1	1
Circuits	2	2	2	2	2	2
Power Flow (MW)	380.9	380.9	380.9	380.9	380.9	380.9
First Year Line Losses (MWh)	1121.09	2985	3622	4168	4195	2354
Reduces First Year Line Losses by (MWh)		-1864	-2501	-3047	-3074	-1233
Reduces First Year Line Losses by (%)		-166.26%	-223.08%	-271.78%	-274.19%	-109.94%
Saving (MLKR/Year/km)		-37.22	-49.94	-60.85	-61.39	-24.62
First Year CO_2 Generated by (MT/km)	897	2388	2898	3334	3356	1883
Reduces First Year CO_2 Emission by (MT/km)		-1491	-2001	-2438	-2459	-986
Total Saving (MLKR/km/Year)		-37.22	-49.94	-60.85	-61.39	-24.62
Reduction in 40 Year Losses (MLKR/km)		-364.00	-488.40	-595.02	-600.30	-240.77

It is clear that ACSR Zebra conductor would be the most economically viable conductor compared to the new generation conductors under rated load condition. New generation conductors have smaller conductive area to deliver the rated power capacity of ACSR Zebra conductor, so their current density is higher compared to base conductor. They do dissipate more energy due to conductive resistance, so the temperatures of conductors are rising. The conductive resistance rises with the conductor temperature, and cause to dissipate more energy as temperatures rises.

The average estimated capital cost of double circuit ACSR Zebra transmission line is 29.73 MLKR/km [21], and the capital cost of other conductors can be expected slightly lesser than ACSR Zebra transmission line.

However, It could be observed that the cost due to energy loss is much higher than the per kilometer capital cost. Therefore, further calculation are not carried out due to non-viability of using new generation conductors under the category of rated load condition.

Under the same conditions, long term energy loss calculation is carried out for conductors under low load condition, and results are tabulated in Table 4.12.

Table 4.12 - Line Loss Evaluation (Low Load Condition)

Conductor Type	ACSR	ACCC	ZTACIR/AW	ACSS/TW	ACCR	GTACSR	LL-ACSR/AS	LL-TACSR/AS
Steady State Temp. (°C) at Peak Ampacity of ACSR Zebra	75.00	68.27	75.59	67.76	74.61	70.84	66.57	66.96
Resistance at Peak Operating Amps (Ω/km)	0.08148	0.06453	0.08285	0.06388	0.08067	0.07227	0.06166	0.06258
Power Flow (MW)	380.90	380.90	380.90	380.90	380.90	380.90	380.90	380.90
First Year Line Losses (MWh)	1121.09	887.87	1139.94	878.93	1109.95	994.35	848.45	861.03
Reduces First Year Line Losses by (MWh)	0.00	233.22	-18.85	242.16	11.14	126.74	272.64	260.06
Reduces First Year Line Losses by (%)	0.00	20.80%	-1.68%	21.60%	0.99%	11.31%	24.32%	23.20%
Saving (MLKR/Year)	0.00	4.66	-0.38	4.84	0.22	2.53	5.44	5.19
First Year CO_2 Generated by (MT)	896.87	710.30	911.95	703.14	887.96	795.48	678.76	688.83
Reduces First Year CO_2 Emission by (MT)	0.00	186.57	-15.08	193.73	8.92	101.39	218.11	208.05
Total Saving (MLKR/Year)	0.00	4.66	-0.38	4.84	0.22	2.53	5.44	5.19
Reduction in 40 Year Losses Comp. to ACSR (MLKR)	0.00	45.54	-3.68	47.29	2.18	24.75	53.24	50.79

Positive results are obtained for the per kilometer line loss reductions as a result of using new generation conductors compared to ACSR Zebra conductor. The best loss reduction capability is shown by the LL-ACSR/AS conductor, and it is around 53.24 MLKR/km. Other conductors also show positive figures, except ZTACIR/AW conductor. Therefore, it can be clearly seen that considerable amount of money can be saved by using of new generation conductors over conventional ACSR conductors.

However, techno-economic viability of a transmission line depends on not only line losses but also operation and maintenance costs and capital costs. Capital cost of transmission lines heavily depends on the mechanical behavior of the conductor, i.e., strength of support structures and foundations changes as conductors' mechanical properties change, and hence cost of support structures and foundations are also subjected to change as conductor changes.

Therefore, detailed capital cost calculation is carried out in order to evaluate the overall techno economic behavior of transmission lines.

4.5 DESIGN OF SUPPORT STRUCTURES

Under this section design of support structures are carried out for respective conductors, and cost of support structures are estimated.

4.5.1 Sag Tension Calculation

Sag Tension calculation is the first step to be taken at the beginning of the design process of support structures and foundations, and all forces exerted by conductor are taken as the loading conditions of support structures. Section 2.2.3.2 describes the sag tension calculation process, and sample calculation is shown in APPENDIX I.

Sag tension behavior of conductors entirely depends on its' mechanical properties of the conductor and design specification of the utility. Table 4.13 summaries properties of conductor, GSW and OPGW, and sag tension results are summarized in Tables 4.14, 4.15 & 4.16.

Table 4.13 - Properties of Conductor, GSW and OPGW

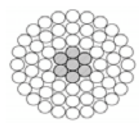
Description		Units	ACSR Zebra	Ground Steel Wire	OPGW
Type of conductor			54/7/3.18	7/3.25	-
Cross Sectional Area	Al	mm^2	428.9	-	-
	Core (st.)		55.6	-	-
	Total		484.5	58.07	80.2
Nominal Weight		kg/km	1632	460	460
Ultimate Tensile Strength		kN	131.9	58	76.9
Max AC Resistance at 20℃		Ω/km	0.0681	-	-
Max DC Resistance at 20℃		Ω/km	0.0674	-	-
Modulus of Elasticity		GPa	69	193	141.84
Co-efficient of Linear Exp.		10^{-6}/℃	19.3	11.5	14.3
Max. Operating Temp.		℃	75	-	-
Cross Sectional		-			

Table 4.14 - Sag Tension Summary - Conductor

Conductor Temperature		Equivalent Span (m) 200	300	400	500
32°C No wind	**Sag (m)**	2.81	6.32	11.62	18.49
	Tension (N)	28,503.00	28,503.00	27,546.00	27,053.00
	FOS	4.63	4.63	4.79	4.88
32°C Full wind	**Sag (m)**	1.19	3.83	6.57	10.06
	Tension (N)	42,549.00	47,077.00	48,725.00	49,737.00
	FOS	3.10	2.80	2.71	2.65
7°C No wind	**Sag (m)**	2.15	5.36	10.55	17.37
	Tension (N)	37,314.00	33,579.00	30,362.00	28,804.00
	FOS	3.54	3.93	4.35	4.58
7°C Full wind	**Sag (m)**	1.60	3.45	6.13	9.57
	Tension (N)	49,979.00	52,920.00	52,257.00	52,257.00
	FOS	2.64	2.53	2.53	2.53
75°C No wind	**Sag (m)**	4.05	7.81	13.36	20.32
	Tension (N)	19,759.00	22,834.00	23,967.00	24,619.00
	FOS	6.68	5.78	5.51	5.36

Table 4.15 - Sag Tension Summary - GSW

Ground Steel Wire		Equivalent Span (m)			
Temperature		200	300	400	500
32°C No wind	Sag (m)	2.14	4.82	9.47	15.61
	Tension (N)	10,535.00	10,535.00	9,536.00	9,036.00
	FOS	5.51	5.51	6.09	6.42
32°C Full wind	Sag (m)	1.45	2.88	5.00	7.71
	Tension (N)	15,572.00	17,649.00	18,037.00	18,285.00
	FOS	3.73	3.29	3.22	3.17
7°C No wind	Sag (m)	1.78	4.23	8.75	14.85
	Tension (N)	12,692.00	11,994.00	10,318.00	9,497.00
	FOS	4.57	4.84	5.62	6.11
7°C Full wind	Sag (m)	1.31	2.68	4.77	7.45
	Tension (N)	17,238.00	18,931.00	18,931.00	18,931.00
	FOS	3.37	3.07	3.07	3.07
75°C No wind	Sag (m)	2.89	5.86	10.66	16.86
	Tension (N)	7,807.00	8,669.00	8,470.00	8,364.00
	FOS	7.43	6.69	6.85	6.94

Table 4.16 - Sag Tension Summary - OPGW

OPGW		Equivalent Span (m)			
Temperature		200	300	400	500
32°C No wind	Sag (m)	2.14	4.82	9.83	16.48
	Tension (N)	10,535.00	10,535.00	9,184.00	8,559.00
	FOS	7.30	7.30	8.38	8.99
32°C Full wind	Sag (m)	1.30	2.53	4.40	6.77
	Tension (N)	17,343.00	20,069.00	20,537.00	20,836.00
	FOS	4.44	3.83	3.75	3.69
7°C No wind	Sag (m)	1.71	4.10	8.95	15.57
	Tension (N)	13,224.00	12,374.00	10,086.00	9,060.00
	FOS	5.82	6.22	7.63	8.49
7°C Full wind	Sag (m)	1.17	2.35	4.18	6.52
	Tension (N)	19,300.00	21,620.00	21,620.00	21,620.00
	FOS	3.99	3.56	3.56	3.56
75°C No wind	Sag (m)	3.07	6.10	11.27	17.97
	Tension (N)	7,345.00	8,327.00	8,008.00	7,846.00
	FOS	10.47	9.24	9.61	9.81

Table 4.17 shows the summary of sag tension results for the respective conductors at their rated temperatures.

Table 4.17 - Sag Tension Summary

Conductor	Rated Temp.(ºC)	Max Sag (m)	Max Tension (kN)
ACSR	75	7.81	52.92
ACCC	180	6.11	73.32
ZTACIR/AW	210	9.43	49.88
ACSS/TW	200	11.63	50.16
ACCR	210	7.82	57.28
GTACSR	150	10.13	61.16
LL- ACSR/AS	90	8.67	56.36
LL-TACSR/AS	150	10.70	56.36

Tower heights are decided for the basic span of 300m at the maximum sag of the conductor, and sag of ACSR Zebra conductor is 7.81m at the temperature of 75 °C and no wind condition. So the conductor clamping or suspension height of tower shall be decided considering required ground clearances specified for 132kV voltage level (see Figure 4.2).

Thus,

Bottom X-Arm height = Ground clearance + Max sag of conductor

= 7 m +7.81 m

= 14.81 m

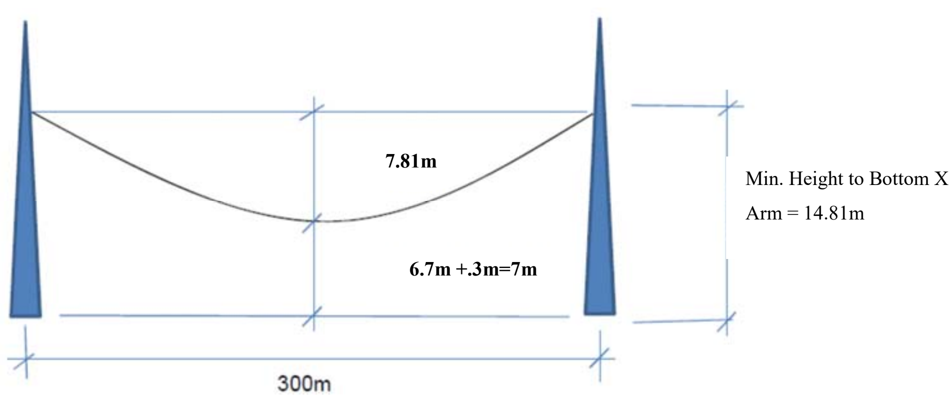


Figure 4.2 - Conductor Sag and Minimum Tower Height

Types of Support Structures

Support structures used in this case study double circuit towers, designed for single Zebra conductor in vertical formation and one overhead 7/3.25mm GSW and one OPGW above the conductors, and shall be of self-supporting broad based lattice steel construction. General specifications for design of 132kV double circuit transmission line structures are mentioned in section 02.

According to the given specification line clearances diagram for a towers are shown in Figure 4.3, 4.4 and 4.5.

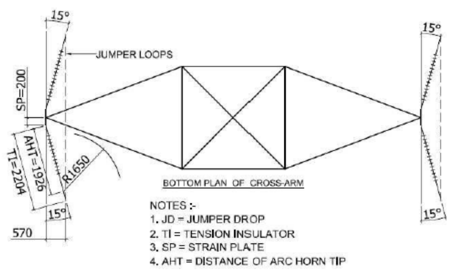


Figure 4.3 - Plan view of Line Clearances of TD3 Tower

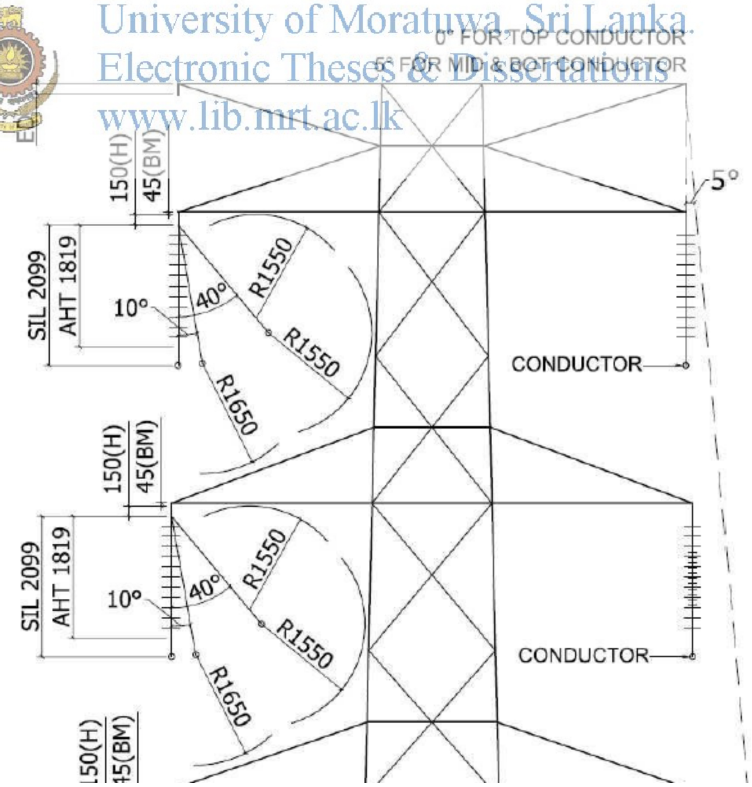


Figure 4.4 - Line Clearance Diagram, TDL Tower

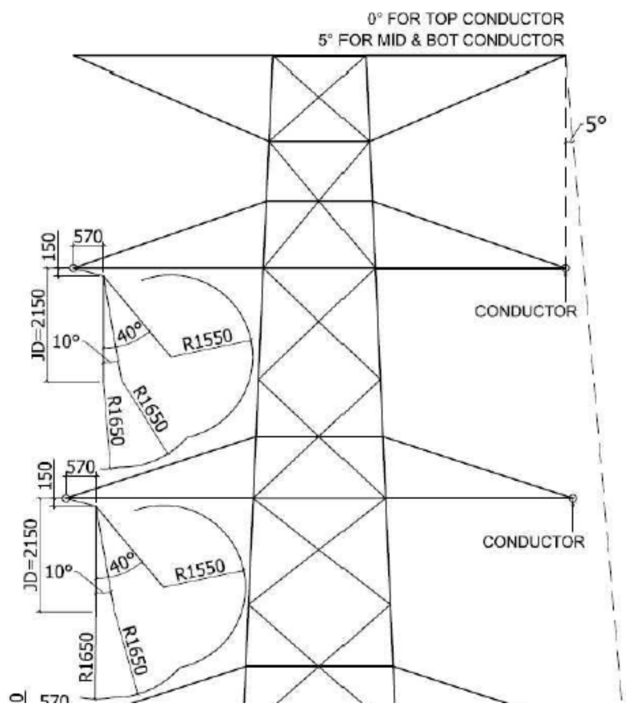


Figure 4.5 - Line Clearance Diagram, TD3 Tower

Total height of the towers is determined by maintaining the specified electrical clearances for 132kV system, and Table 3.8 shows the design specifications. Accordingly TDL towers heights are summarized in Table 4.18, and tower heights of TD1, TD3, TD6 and TDT towers are also designed following the same method, but insulator string lengths are not considered.

Table 4.18 - TDL Towers Heights

Conductor Type	**ACSR**	**ACCC**	**ZTACIR/ AW**	**ACSS/TW**	**ACCR**	**GTACSR**	**LL-ACSR/AS**	**LL-TACSR/AS**
Conductor Max Sag	7.81	6.11	9.43	11.63	7.82	10.13	8.67	10.70
Ground Clearance	6.70	6.70	6.70	6.70	6.70	6.70	6.70	6.70
Survey Error	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Insulator String Length	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10
Hanger	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Back Mark	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Stub	-0.45	-0.45	-0.45	-0.45	-0.45	-0.45	-0.45	-0.45
Height to bottom Arm	16.65	14.95	18.27	20.47	16.66	18.98	17.51	19.54
Bottom Conductor Suspension Point Height	14.81	13.11	16.43	18.63	14.82	17.13	15.67	17.70
Tower Cage Height	10.95	10.95	10.95	10.95	10.95	10.95	10.95	10.95
Total Tower Height	27.60	25.90	29.22	31.42	27.61	29.93	28.46	30.49

Towers Design using PLS-TOWER

3D tower prototypes are developed according to the given specification (see Figure 4.6), then towers are tested and simulated to the calculated loads, and modifications are made accordingly [24].

Figure 4.6 - 3D Tower Models

Structure Materials

Large number of steel material are required to form a transmission tower, and it is a complex process of designing a most economical tower by optimizing the tower parts. Some of material are summarized in, 4.8 and 4.9, e.g., main members, bracings, redundant members, nut and bolts, etc.

	Steel Material Label	Modulus of Elasticity (MPa)	Yield Stress Fy (MPa)	Ultimate Stress Fu (MPa)
1	MS-IS(t<=16)	200000	275	410
2	MS-IS(t>16)	200000	265	410
3	HT-IS(t<=16)	200000	355	490
4	HT-IS(t>16)	200000	345	490

Figure 4.7 - Tower Member Material

	Angle Type	Angle Size	Long Leg (cm)	Short Leg (cm)	Thick. (cm)	Unit Weight (N/m)	Gross Area (cm^2)	w/t Ratio	Radius of Gyration Rx (cm)	Radius of Gyration Ry (cm)	Radius of Gyration Rz (cm)	Number of Angles	Wind Width (cm)	Short Edge Dist. (cm)	Long Edge Dist. (cm)	Optimize Cost Factor	Section Modulus (cm^3)
176	A45	150X150X20	15	15	2	1730.40	224.0	5.9	6.58013	6.58013	6.57405	2	30	0	0	1	0
177	A45	175X175X12	17.5	17.5	1.2	1247.83	162.08	12.3333	7.3604	7.3604	7.3604	2	35	0	0	1	0
178	A45	175X175X15	17.5	17.5	1.5	1546.06	200.84	9.66667	7.42981	7.42981	7.42914	2	35	0	0	1	0
179	A45	200X200X12	20	20	1.2	1447.96	187.6	14.4167	8.44957	8.44957	8.44768	2	40	0	0	1	0
180	A45	200X200X16	20	20	1.6	1903.14	247.2	10.5625	8.52579	8.52579	8.5201	2	40	0	0	1	0
181	A45	200X200X20	20	20	2	2354.4	305.6	8.25	8.59165	8.59165	8.58784	2	40	0	0	1	0
182	A45	200X200X22	20	20	2.2	2574.14	334	7.27273	8.58659	8.58659	8.58659	2	40	0	0	1	0
183	A45	200X200X25	20	20	2.5	2899.84	376.4	6.4	8.67846	8.67846	8.67846	2	40	0	0	1	0
184	A45	250X250X25	25	25	2.5	3672.86	476	8.2	10.6616	10.6616	10.6616	2	50	0	0	1	0
185	A45	250X250X35	25	25	3.5	5022.72	652	5.57143	10.8372	10.8372	10.831	2	50	0	0	1	0

Figure 4.8 - Structure Member List

	Bolt Label	Bolt Diameter (cm)	Hole Diameter (cm)	Ultimate Shear Capacity (kN)
4	22DIA(5.6)	2.2	2.4	117.841
5	24DIA(5.6)	2.4	2.6	140.24
6	12DIA(5.8)	1.2	1.35	36.417
7	16DIA(5.8)	1.6	1.75	64.741
8	20DIA(5.8)	2	2.15	101.159
9	22DIA(5.8)	2.2	2.4	122.402

Figure 4.9 - Nuts and Bolts Sizes

4.5.2 Loading of Support Structures

Towers are subjected to large varieties of loads by conductors, GSW, OPGW, wind and tower members, and it is vital to consider each and every loads for designing stage. Loads on a tower can be classified in to three main loads, i.e., vertical, transvers and longitudinal loads, so it makes easier work at the design of towers by simplifying the loads in to three such vectors. Figure 4.10 shows how the loads are applied on a tower.

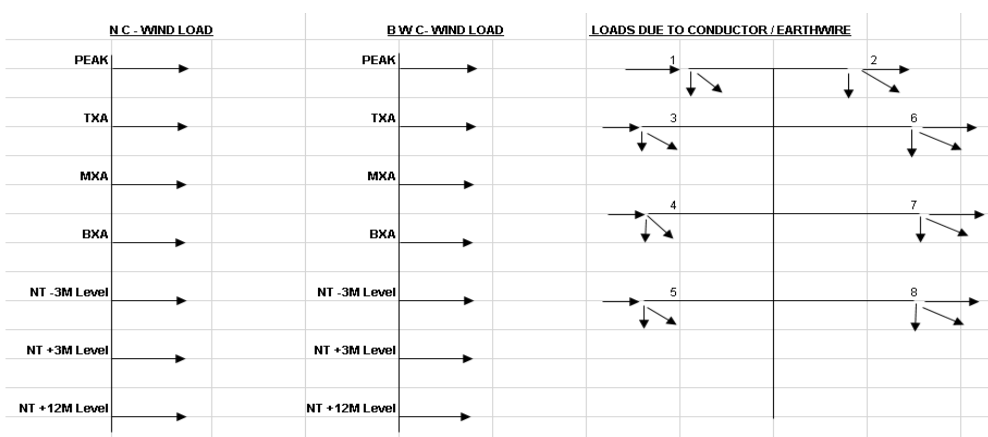
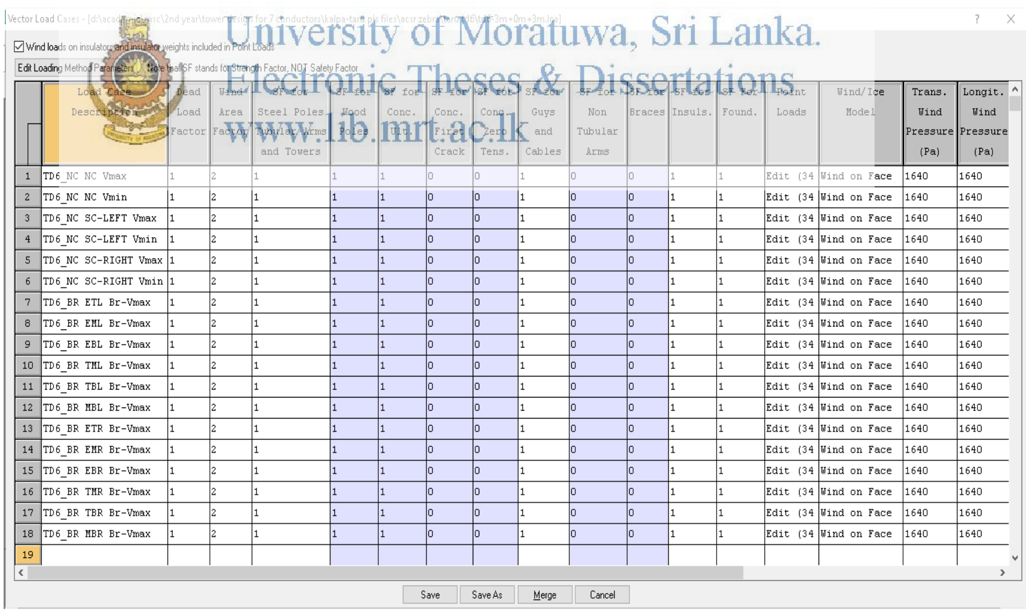


Figure 4.10 - Loading Tree Model of a Transmission Tower

Each and every tower needs to be checked with their withstand ability to different loading cases, e.g., maximum and minimum wind conditions are applied to the tower under normal condition, only single circuit-left / right stringing condition, different cases of broken wires, etc. All the members of the tower are checked for their strength under each loading cases and failed members are replaced with higher strength members.

Loading cases for towers change with its type, and towers are checked for its maximum body extension, i.e., 12m body extension. Towers are designed to withstand for vertical and transverse loads plus the unbalanced longitudinal loads at its maximum working tension due to the simultaneous breakage of two adjacent conductors on the same side of the tower, or of one earth wire and a conductor. Further, loading cases of single side stringing, heavy suspension, and angle tower with 00 angle conditions also need to be tested for given towers. Sample loading case calculation done for the TDL tower is shown in APPENDIX IV, and Figure 4.11 and

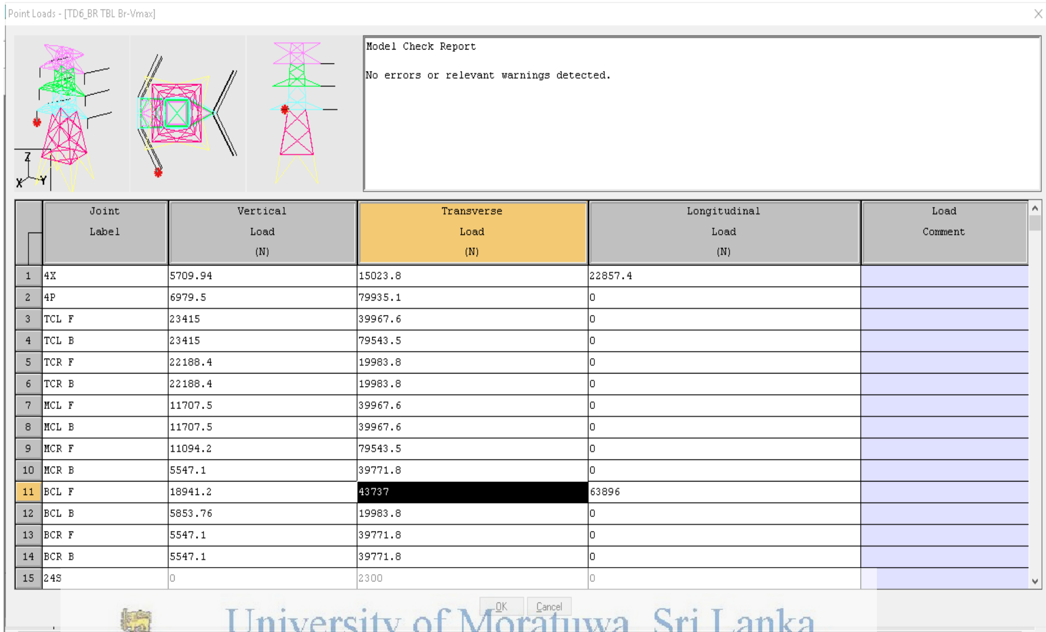
Figure 4.12 show the loading cases of TD6 and point of application on a tower.



	Load Case Description	Dead Load Factor	Wind Area Factor	SF for Steel Poles Tubular Arms and Towers	SF for Wood Poles	SF for Conc. Ult.	SF for Conc. First Crack	SF for Conc. Zero Tens.	SF for Guys and Cables	SF for Non Tubular Arms	SF for Braces	SF for Insuls.	SF for Found.	Point Loads	Wind/Ice Model	Trans. Wind Pressure (Pa)	Longit. Wind Pressure (Pa)
1	TD6_NC NC Vmax	1	2	1	1	1	0	0	1	0	0	1	1	Edit (34	Wind on Face	1640	1640
2	TD6_NC NC Vmin	1	2	1	1	1	0	0	1	0	0	1	1	Edit (34	Wind on Face	1640	1640
3	TD6_NC SC-LEFT Vmax	1	2	1	1	1	0	0	1	0	0	1	1	Edit (34	Wind on Face	1640	1640
4	TD6_NC SC-LEFT Vmin	1	2	1	1	1	0	0	1	0	0	1	1	Edit (34	Wind on Face	1640	1640
5	TD6_NC SC-RIGHT Vmax	1	2	1	1	1	0	0	1	0	0	1	1	Edit (34	Wind on Face	1640	1640
6	TD6_NC SC-RIGHT Vmin	1	2	1	1	1	0	0	1	0	0	1	1	Edit (34	Wind on Face	1640	1640
7	TD6_BR ETL Br-Vmax	1	2	1	1	1	0	0	1	0	0	1	1	Edit (34	Wind on Face	1640	1640
8	TD6_BR EML Br-Vmax	1	2	1	1	1	0	0	1	0	0	1	1	Edit (34	Wind on Face	1640	1640
9	TD6_BR EBL Br-Vmax	1	2	1	1	1	0	0	1	0	0	1	1	Edit (34	Wind on Face	1640	1640
10	TD6_BR TML Br-Vmax	1	2	1	1	1	0	0	1	0	0	1	1	Edit (34	Wind on Face	1640	1640
11	TD6_BR TBL Br-Vmax	1	2	1	1	1	0	0	1	0	0	1	1	Edit (34	Wind on Face	1640	1640
12	TD6_BR MBL Br-Vmax	1	2	1	1	1	0	0	1	0	0	1	1	Edit (34	Wind on Face	1640	1640
13	TD6_BR ETR Br-Vmax	1	2	1	1	1	0	0	1	0	0	1	1	Edit (34	Wind on Face	1640	1640
14	TD6_BR EMR Br-Vmax	1	2	1	1	1	0	0	1	0	0	1	1	Edit (34	Wind on Face	1640	1640
15	TD6_BR EBR Br-Vmax	1	2	1	1	1	0	0	1	0	0	1	1	Edit (34	Wind on Face	1640	1640
16	TD6_BR TMR Br-Vmax	1	2	1	1	1	0	0	1	0	0	1	1	Edit (34	Wind on Face	1640	1640
17	TD6_BR TBR Br-Vmax	1	2	1	1	1	0	0	1	0	0	1	1	Edit (34	Wind on Face	1640	1640
18	TD6_BR MBR Br-Vmax	1	2	1	1	1	0	0	1	0	0	1	1	Edit (34	Wind on Face	1640	1640
19																	

Figure 4.11 - Loading Cases for TD6 Tower

After configuring the loading cases, PLS-TOWER simulates towers with the loads specified by each loading case, and check tower withstand ability. Tower members which cannot withstand for specific loads, i.e., red colored members, shall be replaced with higher strengthened member or add more members to withstand for loads. Figure 4.13 shows the unhealthy tower after applying the loads, and Figure 4.14 Figure 4.14 shows after strengthening and optimizing the tower.



	Joint Label	Vertical Load (N)	Transverse Load (N)	Longitudinal Load (N)	Load Comment
1	4X	5709.94	15023.8	22857.4	
2	4P	6979.5	79935.1	0	
3	TCL F	23415	39967.6	0	
4	TCL B	23415	79543.5	0	
5	TCR F	22188.4	19983.8	0	
6	TCR B	22188.4	19983.8	0	
7	MCL F	11707.5	39967.6	0	
8	MCL B	11707.5	39967.6	0	
9	MCR F	11094.2	79543.5	0	
10	MCR B	5547.1	39771.8	0	
11	BCL F	18941.2	43737	63896	
12	BCL B	5853.76	19983.8	0	
13	BCR F	5547.1	39771.8	0	
14	BCR B	5547.1	39771.8	0	
15	248	0	2300	0	

Figure 4.12 - Loading Points of Tower

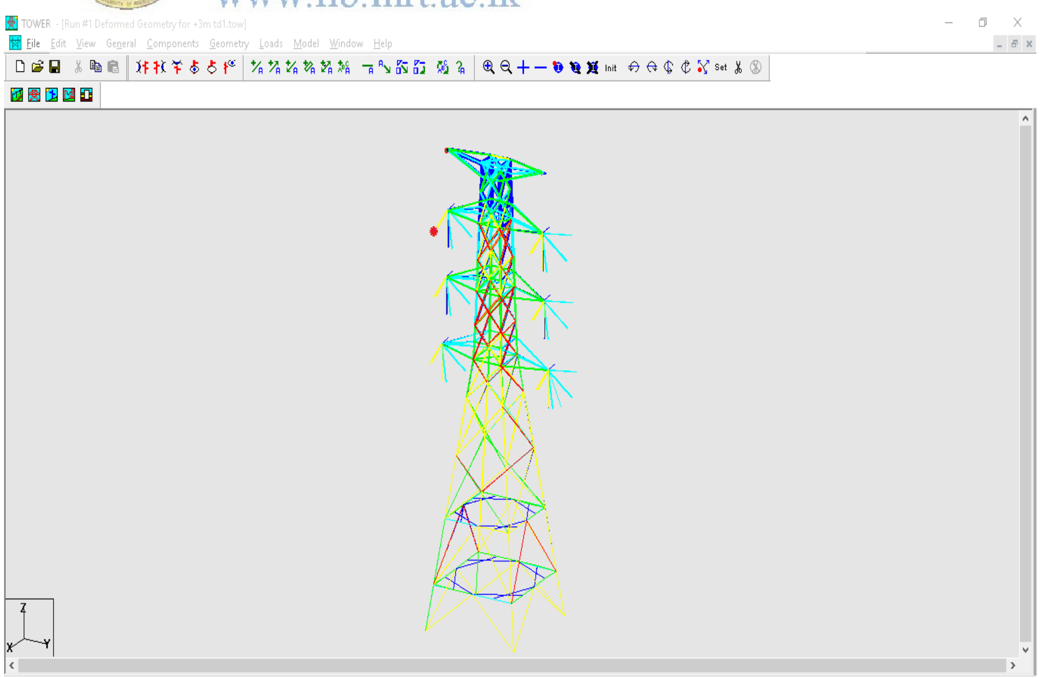


Figure 4.13 - Failure of Tower Members due to Application of Loads

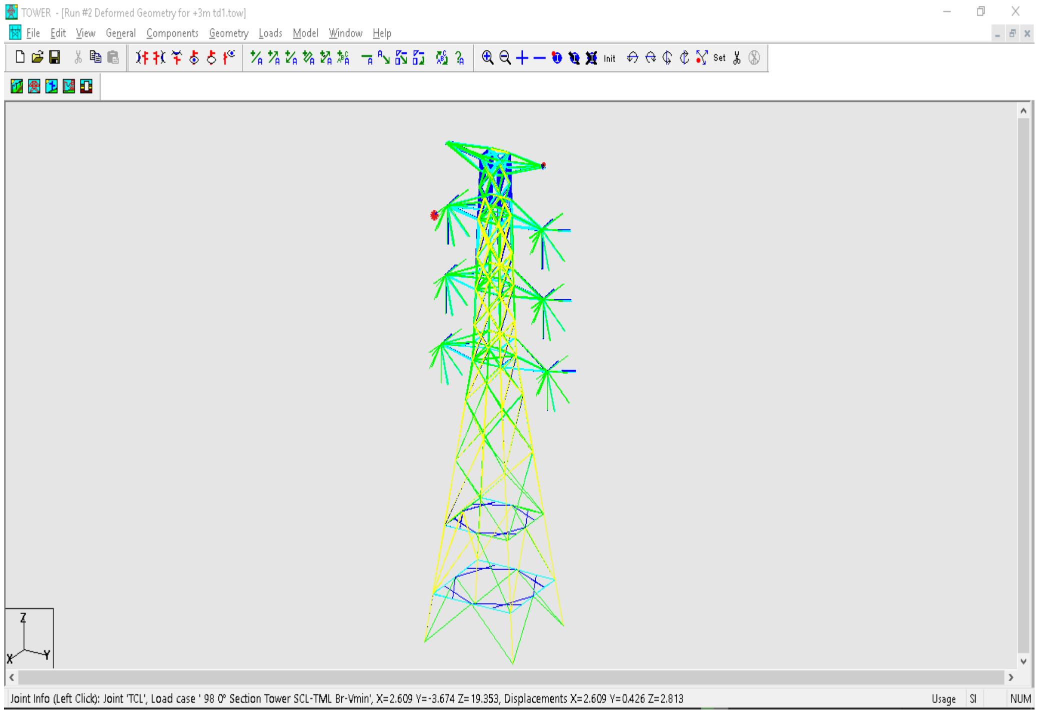


Figure 4.14 - Optimized Tower, After Replacing Failed Members

Table 4.19 - Simulated Tower Weights

	ACSR	ACCC	ZTACIR /AW	ACSS /TW	ACCR	GTACSR	LL-ACSR /AS	LL-TACS /AS
TDL	Tons / tower							
-03	4.19	4.26	4.50	5.32	4.55	4.66	4.85	5.02
+00	4.65	4.63	4.87	5.49	4.66	5.24	4.89	5.39
+03	5.17	5.14	5.42	6.06	5.19	5.67	5.44	5.97
+06	5.68	5.70	5.98	6.57	5.75	6.38	5.95	6.41
+09	6.25	6.26	6.57	7.23	6.29	7.00	6.53	7.06
+12	7.00	6.96	7.30	7.92	7.05	7.72	7.28	7.77
TD1	Tons / tower							
-03	5.48	5.35	5.29	6.01	5.20	5.76	5.34	5.80
+00	5.85	5.74	5.65	6.36	5.51	6.19	5.71	6.19
+03	6.51	6.43	6.28	7.02	6.14	6.84	6.35	6.85
+06	6.87	6.78	6.60	7.33	6.45	7.23	6.66	7.16
+09	7.48	7.38	7.12	7.93	7.00	7.81	7.27	7.79
+12	7.94	7.82	7.57	8.38	7.47	8.25	7.68	8.21

	ACSR	ACCC	ZTACIR /AW	ACSS/TW	ACCR	GTACSR	LL-ACSR/AS	LL-TACSR/AS
TD3	Tons / tower							
-03	8.22	9.47	9.44	9.19	9.24	10.10	9.53	10.16
+00	9.47	11.13	11.19	10.63	11.04	12.12	10.97	12.40
+03	10.27	12.76	12.67	11.53	12.32	13.50	12.84	13.67
+06	11.08	13.92	13.72	12.28	13.49	14.57	13.62	14.59
+09	12.08	15.00	15.00	13.39	14.66	15.84	15.01	15.83
+12	12.90	16.36	15.97	14.19	15.68	17.03	16.04	17.07
TD6	Tons / tower							
-03	9.76	11.31	9.88	11.67	9.84	11.62	10.31	11.24
+00	10.92	12.74	11.43	12.75	12.04	13.08	11.51	12.97
+03	12.74	14.30	13.83	13.97	13.31	14.48	13.86	14.37
+06	14.26	16.52	14.77	16.17	14.40	16.75	15.14	16.37
+09	15.95	18.59	16.16	17.59	16.19	18.30	16.61	18.07
+12	17.51	20.45	18.07	19.63	17.84	20.47	18.55	19.92

Likewise, all towers with their extensions are modeled and simulated under specified loading cases, and tower weights are recorded (see Table 4.19). It can be observed that there is no significant change in tower weights except tower weights of ACSS/TW conductor compared to tower weights of ACSR Zebra conductor. Sample simulation report is attached in APPENDIX V.

In order to proceed the financial evaluation, all the tower weights are converted into its cost element. Metal prices are referred typically used prices in transmission line projects in CEB, and CEB has been referred prices from London Metal exchange. It is taken as Rs.250000.00 per ton, and Table 4.20 shows the calculated price schedule for towers.

Table 4.20 - Tower Price Schedule

Conductor	ACSR	ACCC	ZTACIR /AW	ACSS / TW	ACCR	GTACSR	LL-ACSR/AS	LL-ACSR/AS
TDL								
-03	1.05	1.07	1.13	1.33	1.14	1.16	1.21	1.25
+00	1.16	1.16	1.22	1.37	1.17	1.31	1.22	1.35
+03	1.29	1.29	1.36	1.51	1.30	1.42	1.36	1.49
+06	1.42	1.43	1.49	1.64	1.44	1.59	1.49	1.60
+09	1.56	1.56	1.64	1.81	1.57	1.75	1.63	1.76
+12	1.75	1.74	1.82	1.98	1.76	1.93	1.82	1.94

Conductor	ACSR	ACCC	ZTACIR /AW	ACSS / TW	ACCR	GTACSR	LL-ACSR/AS	LL-ACSR/AS
TD1								
-03	1.37	1.34	1.32	1.50	1.30	1.44	1.33	1.45
+00	1.46	1.44	1.41	1.59	1.38	1.55	1.43	1.55
+03	1.63	1.61	1.57	1.76	1.54	1.71	1.59	1.71
+06	1.72	1.69	1.65	1.83	1.61	1.81	1.66	1.79
+09	1.87	1.85	1.78	1.98	1.75	1.95	1.82	1.95
+12	1.99	1.95	1.89	2.10	1.87	2.06	1.92	2.05
TD3								
-03	2.06	2.37	2.36	2.30	2.31	2.53	2.38	2.54
+00	2.37	2.78	2.80	2.66	2.76	3.03	2.74	3.10
+03	2.57	3.19	3.17	2.88	3.08	3.38	3.21	3.42
+06	2.77	3.48	3.43	3.07	3.37	3.64	3.41	3.65
+09	3.02	3.75	3.75	3.35	3.67	3.96	3.75	3.96
+12	3.22	4.09	3.99	3.55	3.92	4.26	4.01	4.27
TD6								
-03	2.44	2.83	2.47	2.92	2.46	2.90	2.58	2.81
+00	2.73	3.18	2.86	3.19	3.01	3.27	2.88	3.24
+03	3.18	3.57	3.46	3.49	3.33	3.62	3.47	3.59
+06	3.57	4.13	3.69	4.04	3.60	4.19	3.78	4.09
+09	3.99	4.65	4.04	4.40	4.05	4.58	4.15	4.52
+12	4.38	5.11	4.52	4.91	4.46	5.12	4.64	4.98

4.6 DESIGNING OF SUPPORT FOUNDATIONS

As described in section 2.4, designs are carried out according to the CEB specifications and other applicable standards. As per the soil baring capacity classifications, there are seven types of foundations used in transmission line construction, but out of these only two foundations are used more frequently. Good soil and paddy soil are the common soil types encountered, and type 3 and water log (type 4A) foundations are used in such conditions respectively. Other foundation types are used in special soil conditions, e.g., marshy lands, rock area, etc., and therefore usage of those type of foundations in transmission lines is infrequent. So the impact on capital cost of transmission line is minor as they used. Therefore, this study only focuses on type 3 and type 4A foundations types to evaluate the impact on capital cost of transmission lines.

4.6.1 Loading on Foundations

Different types of methods and models are practiced for designing of tower foundations by different utilities, but recently software packages dominate in designing of tower foundations as more precise and optimized design can be achieved over manual methods. PROKON STRUCTURAL DESIGN software package is used for designing of foundations, and BS 8110 -1997 standard is followed.

As explained earlier, different foundation types are used in transmission lines, and pad and angled chimney foundations are the most widely used due to their cost effectiveness and proven durability. Vertical types of pad and chimney foundations are also used in transmission lines, and same designs procedure is followed for foundation designs in this study.

Size and cost of the foundations are mainly depends on two factors, i.e., loads exerted to the foundation stubs by support structures and baring capacity of the soil. Leg reactions are taken from simulation results of tower design, and two standard soil baring capacities are specified for good soil and water log soil for the design purpose of foundations. Table 4.21 shows the reactions for the TDL tower from PLS-TOWER simulation results.

Table 4.21 - Leg Reaction of Foundation for TDL Tower

TDL	Longitudinal	Transverse	Vertical	Sher	Trans. Moment	Long. Moment	Bending Moment	Vert. Moment
MAX	46.13	-7.48	363.83	87.16	0.33	0.31	0.51	0.10
MIN	-57.59	-65.43	-443.00	15.19	-0.26	-0.39	0.01	-0.09
TD1								
MAX	109.45	34.63	630.95	164.20	3.81	2.88	5.42	0.83
MIN	-109.93	-122.40	-723.23	9.74	-2.52	-3.85	0.03	-0.86
TD3								
MAX	175.6	-24.83	1015.65	295.19	2.56	2.14	3.83	0.85
MIN	-197.34	-219.53	-1121.87	50.45	-1.66	-2.88	0.12	-0.75
TD6								
MAX	471.71	-79.7	2426.5	809.86	11.18	2.32	11.57	3.32
MIN	-527.31	-614.67	-2635.26	98	-0.46	-7.33	0.64	-4.2

Loads and bearing capacity of soil are fed to Prokon structural design package, and optimized design of foundation are simulated. Figure 4.15 and Figure 4.16 show example of inputs and outputs type 3 foundation design for TDL tower.

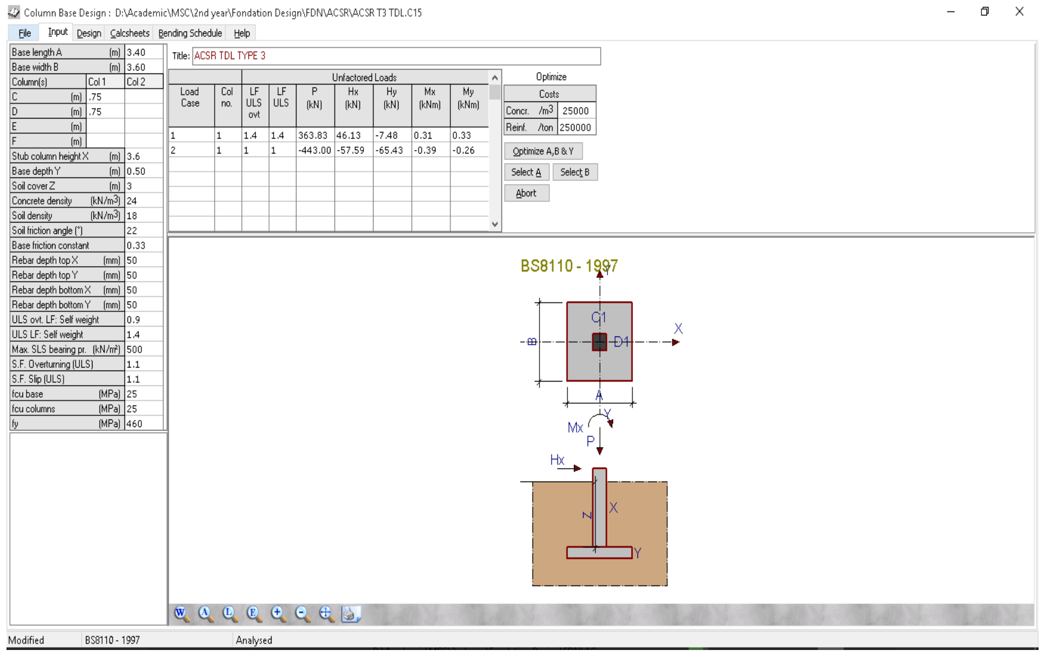


Figure 4.15 - Data feeding for Type 3 Foundation for TDL Tower

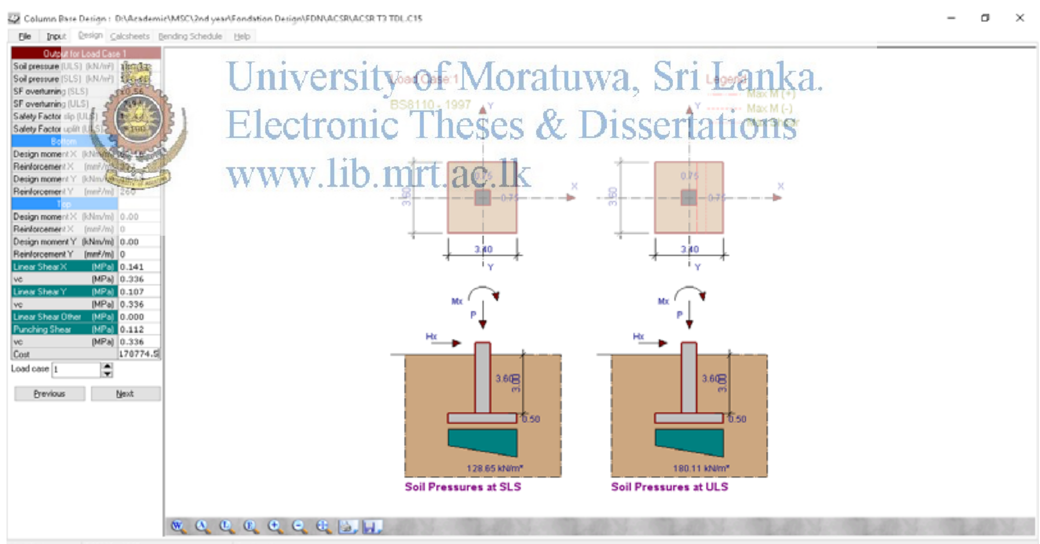


Figure 4.16 - Design Output for Type 3 Foundation for TDL Tower

Likewise leg reactions of tower designs of TDL, TD1, TD3, and TD6 with their extensions are taken, and 56 numbers of foundations are designed for respective conductor types as shown in the Figure 4.17.

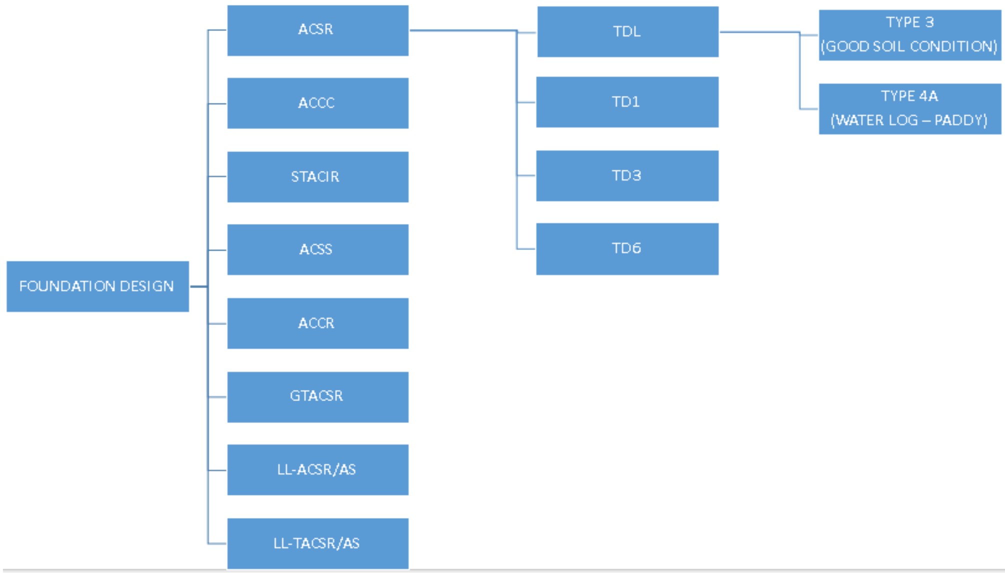


Figure 4.17- Foundations Schedule

Same rate (Rs. 250,000.00 per ton) is referred for ton of steel as in the tower pricing, and cost of concrete cube (Rs. 25,000.00/m^3) is referred from the Building Schedule of Rates (BSR) publication of Western Province, Sri Lanka. Table 4.22 shows the cost schedule of foundations.

Table 4.22- Foundation Price Schedule

Foundation Type	Tower Type	ACSR	ACCC	ZTACIR /AW	ACSS /TW	ACCR	GTACSR	LL-ACSR/AS	LL-TACSR/AS
Rs. (Mn)									
Foundation type 3	TDL	0.72	0.71	0.75	0.81	0.72	0.79	0.74	0.79
	TD1	1.09	1.08	1.04	1.16	1.03	1.14	1.06	1.13
	TD3	1.59	2.02	1.97	1.75	1.94	2.10	1.98	2.11
	TD6	4.05	4.73	4.18	4.54	4.13	4.74	4.29	4.61
Foundation type 4A	TDL	2.03	2.02	2.12	2.29	2.05	2.24	2.11	2.25
	TD1	2.81	2.76	2.67	2.96	2.64	2.91	2.71	2.90
	TD3	3.45	4.38	4.27	3.79	4.19	4.55	4.29	4.56
	TD6	8.11	9.48	8.37	9.10	8.27	9.49	8.60	9.23

4.7 EMF CONSIDERATION

Considerable amount of electromagnetic field is generated by the overhead transmission lines due to voltage and flow of current. Electric and magnetic fields are generated by the voltage and current respectively. International Commission for Non-Ionizing Radiation Protection (ICNIRP) is one who provide guidance to protect people and environment from the non-ionizing radiation exposure. Table 4.23 shows the EMF exposure limits published by the ICNIRP [23].

Table 4.23 - EMF Exposure Limits

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

EMF levels of the designed transmission lines are also calculated, and Table 4.24 and Table 4.25 show inputs and the outputs of the simulation results.

Table 4.24 - Setting Data for 132kV Transmission Line

Conductor Set #	Phase #	Conductors Per Phase	Voltage Ph-Ph (kV)	Current (A)	Phase Angle (deg)
1	1	1	0	0	0
1	2	1	0	0	0
2	1	1	145	833	0
2	2	1	145	833	120
2	3	1	145	833	-120
3	1	1	145	833	0
3	2	1	145	833	120
3	3	1	145	833	-120

Table 4.25 - EMF Simulation Results for 132kV Transmission Line

Minimum Ground Clearance (m)	7	8.5	10
Plane 1m above the Ground level			
Electric Field (kV/m)	2.651	2.094	1.744
Magnetic Field (uT)	16.16	12.53	10.23
Danger Zone from Line Route Center (m)	0	0	0
Plane 3m above the Ground level			
Electric Field (kV/m)	3.264	2.375	1.88
Magnetic Field (uT)	25.99	17.87	13.55
Danger Zone from Line Route Center (m)	0	0	0
Plane 5m above the Ground level			
Electric Field (kV/m)	**5.916**	3.341	2.314
Magnetic Field (uT)	59.58	30.62	19.94
Danger Zone from Line Route Center (m)	+9 to -9	0	0
Tower Height (m)	31.55	33.05	34.55

Protection against EMF is assured during profile design stage of transmission lines, and it is clearly observed that EMF exposure limits are well maintained under the transmission lines. However, 5m plane from ground with 7m ground clearance, the exposure limit exceeds than 5kV/m. this 5m height living plane can be considered as two story building under the transmission line, and in such unavoidable situations, additional clearances are normally provided to the top of the building. Figure 4.18 shows the variation of electric field for different plane from the ground with respect to ground clearance to the conductor.

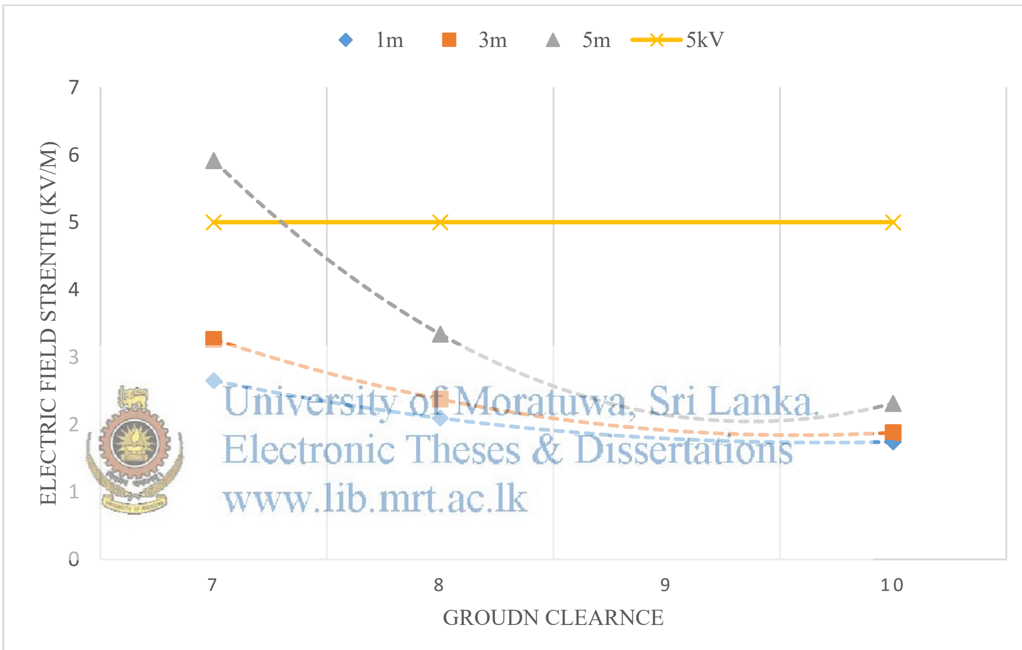


Figure 4.18 - Electric Field Strength vs. Ground Clearance

4.8 TRANSMISSION LINE GROUND TERRAINS

As described in sections 3.4.1 to 3.4.4, transmission lines need connect the specified destinations with minimum environmental and social impact. While selecting the line route, it also needs to minimize the capital cost of the transmission line to an acceptable level in order to maintain the viability of the project.

Best line route would be the straight line connecting two destinations, but due to many reasons, route of the transmission line deviate from a straight line. i.e., geographical shape of the earth, environmental factors and social influences (e.g., forest reservations, wildlife sanctuaries, water bodies, manmade creation, etc.).

Geographical variations and water bodies such as mountains, rivers, water reservoirs and marshy lands, influence the transmission line designs, i.e., route of the transmission line and designs of support foundations and structures. Most of other obstacles cause to change the route of the transmission line but not the design of support foundations and structures.

In such extreme loadings which exceeds the design specifications, special towers are designed for selected locations. So the cost of the design and fabrication of tower is much higher than the normal towers. However, occurrence of such situation is infrequent in transmission lines, so the impact for the final cost of transmission line is minimum.

So in such situation, the normal practice is to construct the line with normal towers, and utilize more supporting towers either sides and reduces the tension of the conductors, subjected to tension difference is maintained under specified values. Therefore, such arrangements are used in this study, rather than going for a special design if such situations arise.

Design and construction cost of foundation in marshy lands changes from location to location. Separate designs are carried out for pile foundations based on the locations. Even if the towers are same, the cost of construction and erection changes drastically based on number of piles, water table and accessibility of the location. Therefore, marshy land are not considered under this study due to cost fluctuation.

Based on the requirement, transmission line needs to be constructed on different geographical terrains. Basically terrains can be divided in to two main categories, i.e., Flat and Hilly terrains. Based on the land usage, terrains can be further categorized in to populated, non-populated and paddy terrains. So any types of transmission line terrain can be modeled using combination of these models. Figures 4.11 shows terrain categories used for developing the transmission line terrain models.

Physically available ground terrains are used to design the transmission lines' profiles in order to obtain more realistic figures for transmission line cost models, so following existing and under construction transmission lines are considered;

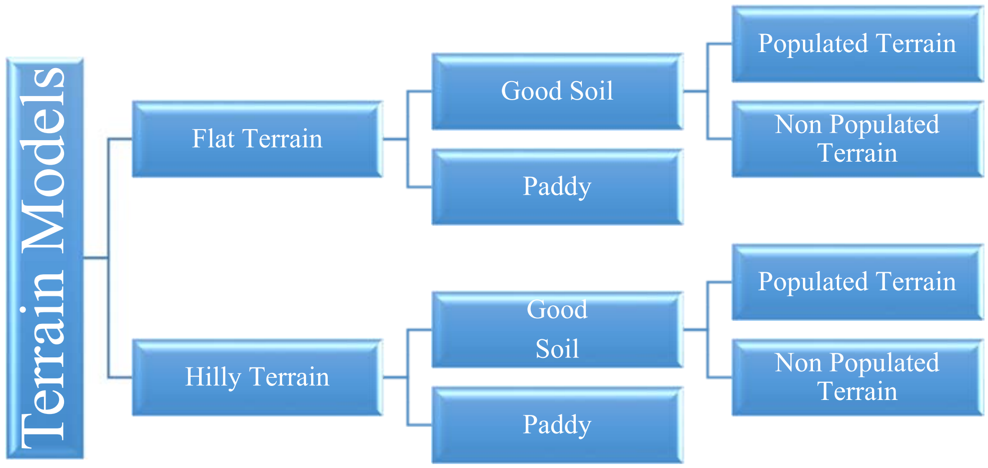


Figure 4.19 - Type of Terrain Models

1. Mahiyangana - Vavunathivu Transmission Line
2. Victoria - Kotmale Transmission Line
3. Maliboda - Polpitiya Transmission Line
4. Ragala - Pallekele Transmission Line
5. Pannipitiya - Padukka Transmission Line

The method of survey data collection is very important as whole designing process entirely depends on the profile survey data along the line. There are several ways of collecting survey data, and can be listed as follows.

1. Real Time Kinetic (RTK)
2. Total Station (TS)
3. Unmanned Areal Vehicle images (UAV)
4. Satellite Images
5. Google Earth Profile Elevation

Transmission line profile design process is done based on the survey data. So, following features of survey data need to be included, in order to locate and identify objects along the line corridor.

1. Longitude, Latitude and Elevation (X, Y, Z).
2. Feature label (e.g. ground level, road, electric pole, canal, etc.).
3. Height of the feature (H).

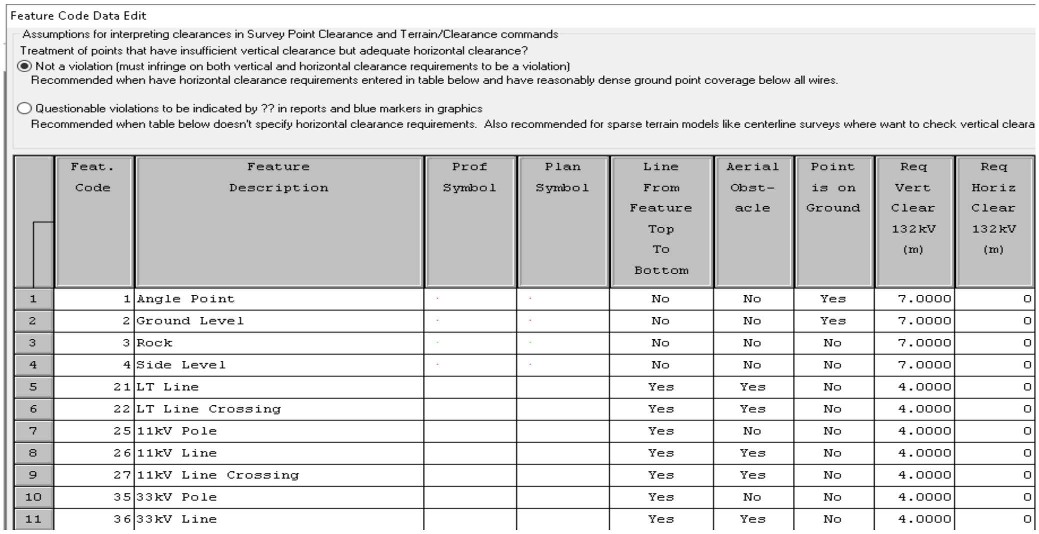
Power Line Systems - Computer Aided Design and Drafting (PLS-CADD™) software is used to develop the terrain surface of the line route. It integrates all aspects of line design into a single stand-alone program with a simple, logical, consistent interface. This sophistication and integration leads to more cost-effective designs being produced in only a fraction of the time required by traditional methods [24].

Survey data (herein after refers as coordinates) need to be in the format of Universal Transverse Mercator (UTM) to understand by the PLS-CADD. So the coordinates in other format needs to be transformed in to SLD99 coordinated system. All the features along the line route need to represent at the terrain surface developed in the PLS-CADD. So, each feature needs to be assigned with a unique code that is recognized by the PLS-CADD. So each feature can be defined with their electrical clearance requirements and restrictions clearly. Table 4.26 shows the input table of coordinates to the PLS-CADD. Figure 4.20 shows some of the feature codes define to survey data according to the given specification in the PLS-CADD.

Figure 4.21 shows the developed terrain surface model from the PLS-CADD for a given transmission line. The dashed line indicates the ground clearance line with an offset of 7m above the ground. PIs are angle tower locations where PLS-CADD develop the profile between these PI points. By inputting more survey data to the PLS-CADD, more smooth and accurate profile can be developed.

Table 4.26 - Survey Data and Feature Codes

ID	X	Y	Z	H	Feature Code	Feature
1	494711.9	531225.2	458.69	0	45	220kV Tower
146	495052.1	530616.3	515.52	18.5	21	33kV Tower
162	494946.4	530936.3	523.24	0	1	Angle Point
590	496871.3	525954.3	480.08	4.5	90	Building
1638	498521.6	520777.6	539.69	0	155	Canal
4688	499059.5	519520.5	621.73	0	120	Gravel Road
5529	497532.1	523156.9	697.31	0	2	Ground
5726	496785.7	524367.8	639.2	0	2	Ground
5727	496791.7	524366.9	637.76	0	2	Ground
11548	500186.7	517052.1	909.12	0	2	Ground
11549	500178.4	517050	912.37	0	2	Ground
15096	499481.3	519477.3	635.75	0	119	Road
15097	499485.6	519477.9	636.27	0	119	Road
15977	500338.5	515401.4	1008.77	0	3	Rock
15978	500333.1	515408.8	1008.06	0	3	Rock
17321	497758.8	522247.8	678.4	0	168	Water Tank



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 cleara

	Feat. Code	Feature Description	Prof Symbol	Plan Symbol	Line From Feature Top To Bottom	Aerial Obst- acle	Point is on Ground	Req Vert Clear 132kV (m)	Req Horiz Clear 132kV (m)
1	1	Angle Point			No	No	Yes	7.0000	0
2	2	Ground Level			No	No	Yes	7.0000	0
3	3	Rock			No	No	No	7.0000	0
4	4	Side Level			No	No	No	7.0000	0
5	21	LT Line			Yes	Yes	No	4.0000	0
6	22	LT Line Crossing			Yes	Yes	No	4.0000	0
7	25	11kV Pole			Yes	No	No	4.0000	0
8	26	11kV Line			Yes	Yes	No	4.0000	0
9	27	11kV Line Crossing			Yes	Yes	No	4.0000	0
10	35	33kV Pole			Yes	No	No	4.0000	0
11	36	33kV Line			Yes	Yes	No	4.0000	0

Figure 4.20 - Feature Code List

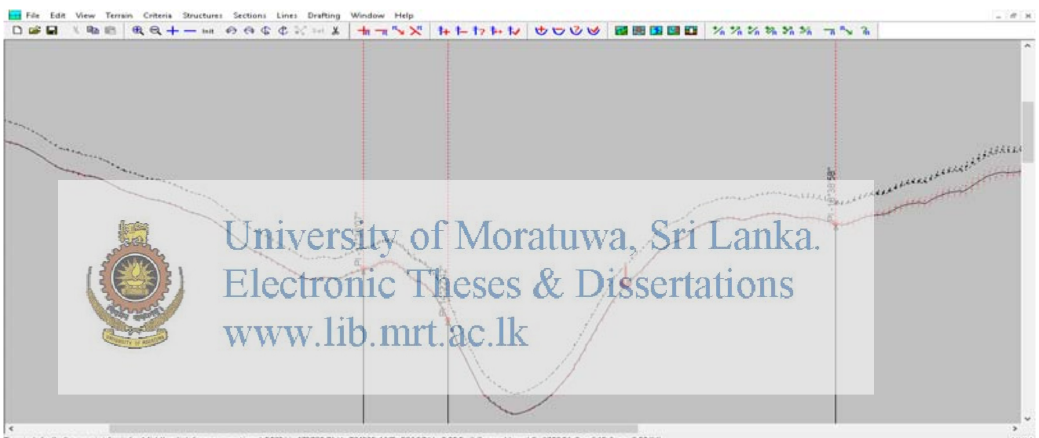
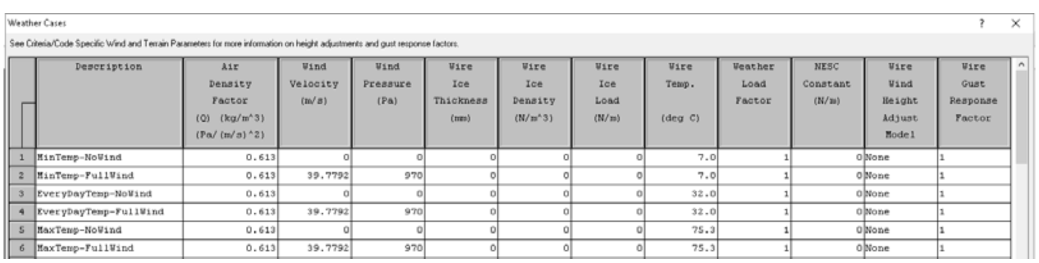


Figure 4.21 - Profile Generated form PLS-CADD

It is required to define criteria files for further processing, which check the design limitation and safety factors of structures, conductors, GSW and OPGW. Behavior of the transmission line can also be simulated according to the specific weather criteria (see Figure 4.22).



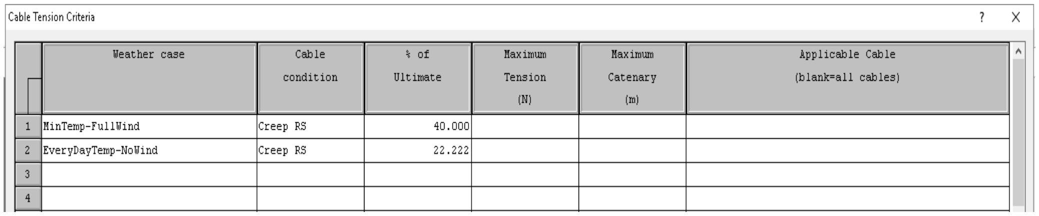
Weather Cases

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)	Weather Load Factor	NESC Constant (N/m)	Wire Wind Height Adjust Model	Wire Gust Response Factor
1	MinTemp-NoWind	0.613	0	0	0	0	0	7.0	1	0	None	1
2	MinTemp-FullWind	0.613	39.7792	970	0	0	0	7.0	1	0	None	1
3	EveryDayTemp-NoWind	0.613	0	0	0	0	0	32.0	1	0	None	1
4	EveryDayTemp-FullWind	0.613	39.7792	970	0	0	0	32.0	1	0	None	1
5	MaxTemp-NoWind	0.613	0	0	0	0	0	75.3	1	0	None	1
6	MaxTemp-FullWind	0.613	39.7792	970	0	0	0	75.3	1	0	None	1

Figure 4.22 - Weather Cases

Cable tension and sag specifications are placed under tension criteria, and cable file is defined base on the properties of respective conductors (see Figure 4.23 Figure 4.24).



Cable Tension Criteria

	Weather case	Cable condition	% of Ultimate	Maximum Tension (N)	Maximum Catenary (m)	Applicable Cable (blank=all cables)
1	MinTemp-FullWind	Creep RS	40.000			
2	EveryDayTemp-NoWind	Creep RS	22.222			
3						
4						

Figure 4.23 - Cable Tension Criteria

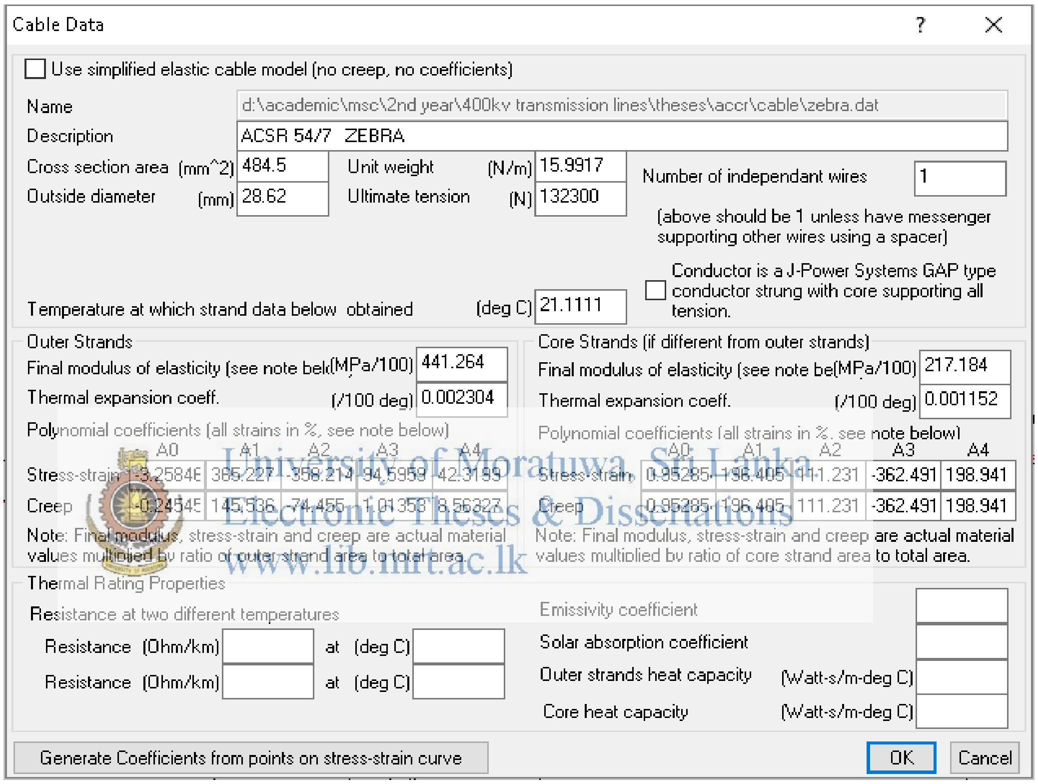


Figure 4.24 - ACSR Zebra Cable File

After define the safety clearances, environmental conditions, safety factors, conductor files and structure files in PLS-CADD, tower spotting can be carried out following the limitation specified under 3.4.6.

Initially, angle towers are placed at angle coordinates based on their degree of angle, and intermediate line towers are placed in-between at random locations at a distance of 300m.

Then conductor, GSW and OPGW are strung between towers, and using section modifier, profile display setting are set as specified (see Figure 4.25). After setting out of cable criteria, conductors are tensioned for its allowable limitations.

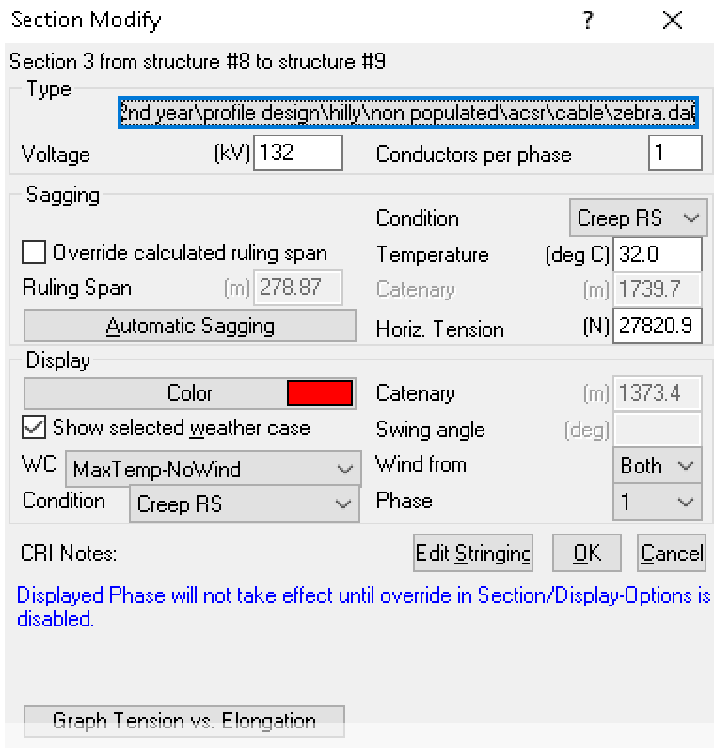


Figure 4.25 - Section Modifier

Then, intermediate towers are placed, and add tower extensions where necessary to maintain the required electrical clearance to ground and its' features. Locations of towers are also checked for suitability. Different places are considered for weak ground locations, and electrical clearances are checked.

In addition to electrical clearance and suitability of location, wind and weight span of towers must also be satisfied in both normal and broken wire conditions for towers. Following methods can be followed to rectify issues that may arise in profile design. APPENDIX VI shows summary report of profile design of Mahiyangana-Vavunathivu Transmission Line.

1. Move towers back and forth.
2. Add or remove tower extensions.
3. Reduce the conductor tension manually up to acceptable limit.
4. Add one or more towers around to support over load tower.
5. Replaced with higher strengthened tower.
6. Change the line route.
7. Go for a specific tower design (infrequent), etc.

4.8.1 Non Populated Flat Terrain

Non populated flat terrain is selected from Mahiyangana-Vavunathivu 132kV transmission line in Aranthalawa area. Access to the transmission line is very important for regular maintenance, therefore line route is selected along the nearest road. Line route is almost straight and section towers are placed at every 3km to avoid cascade failure. Among the few obstacles encountered along the line, trees and rock boulders are the commonest in this kind of terrains.

Since, soil condition of this sort of terrain is normally good, and type 3 foundations can widely be used for construction.

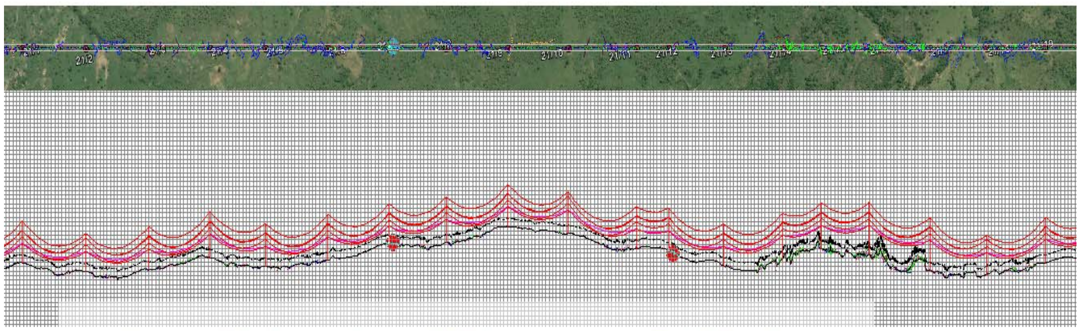


Figure 4.26 - Flat None Populated Terrain (Mahiyangana-Vavunathivu Line at Aranthalawa)

Profile design is carried out for 8 conductors considering the relevant specifications, and tower, foundation and material schedules' summary is shown in APPENDIX VII.

4.8.2 Populated Flat Terrain

This line section is selected from Pannipitiya-Padukka transmission line in Pannipitiya area, and this line passes through a heavy populated area. It is an essential requirement to construct transmission line in order to cater the increased demand in urban area. Therefore transmission lines are constructed along the populated area despite of social objections.

Many physical obstacles come across in this type of terrains, i.e., houses, high rise buildings, roads, power lines, telecommunication towers, etc. Line route is placed in such a way that occurring minimum disturbance to the public. Therefore large numbers of angle towers need to be introduced to avoid houses. Soil condition of this sort of terrain is normally good, therefore type 3 foundations can be used. However due to high demand for lands, high rate of compensations asked to be paid.

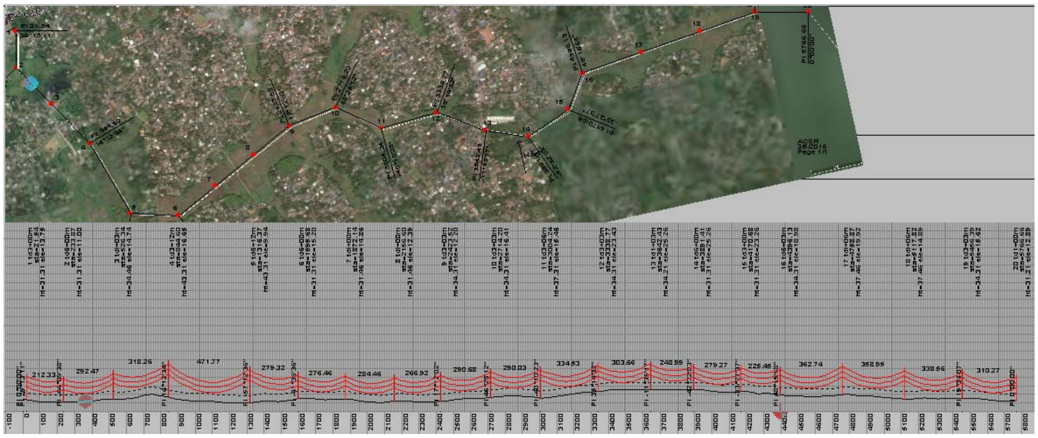


Figure 4.27 - Flat Populated Terrain (Pannipitiya - Padukka Line at Pannipitiya)

Profile design is carried out for 8 conductors considering the relevant specifications, and tower, foundation and material schedules' summary is shown in APPENDIX VII.

4.8.3 Paddy Flat Terrain

This line section is selected from Mahiyangana-Vavunathivu transmission line in Mahaoya area and line passes through a paddy area. Due to ROW issues, power utilities prefer to construct lines along paddy fields, away from home gardens. Line route is almost straight, however due to water tank, canal and access issues, angle towers are introduced.

Soil condition of this kind of terrain is normally water log, therefore type 4A foundations are used for construction. Construction of foundations and erection of towers are difficult in rainy season, therefore cost of construction is high in such seasons. So normally excavation work is scheduled in dry seasons.

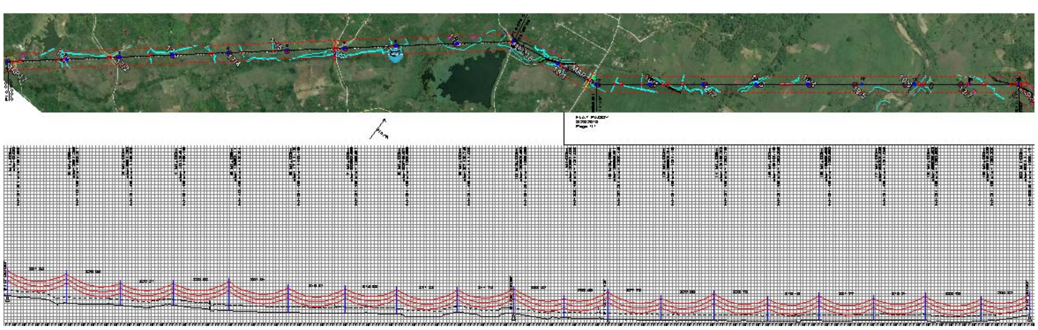


Figure 4.28 - Flat Paddy Terrain (Mahiyangana-Vavunathivu Line at Mahaoya)

Profile design is carried out for 8 conductors considering the relevant specifications, and tower, foundation and material schedules' summary is shown in APPENDIX VII.

4.8.4 Non Populated Hilly Terrain

This line section is selected from Maliboda-Polpitiya 132kV transmission line (under construction) in Deraniyagala area. The terrain is hilly and heavily forested area, so terrains are much difficult for construction mainly due to poor access to the line route. Heavy environmental damage is caused due to 30m way-leave clearing process.

Loading conditions of support structures are violated frequently in such terrains, so allocation of section towers and angle towers can be seen regularly throughout the line. Therefore large numbers of angle towers and section towers are placed to overcome the extreme loads exerted on towers. Finding locations for towers are also very difficult, and several route options are normally considered to find out the best route due to technical difficulties. Therefore selecting a route for this kind of terrain is a complicated process.

Soil condition of this sort of terrains is normally good, therefore type 3 foundation are used for construction. Rock boulders are found frequently, but rock anchor foundation come in rare situations only. Head loading is the only way of transportation of materials, so construction cost is higher compared to the flat terrains.

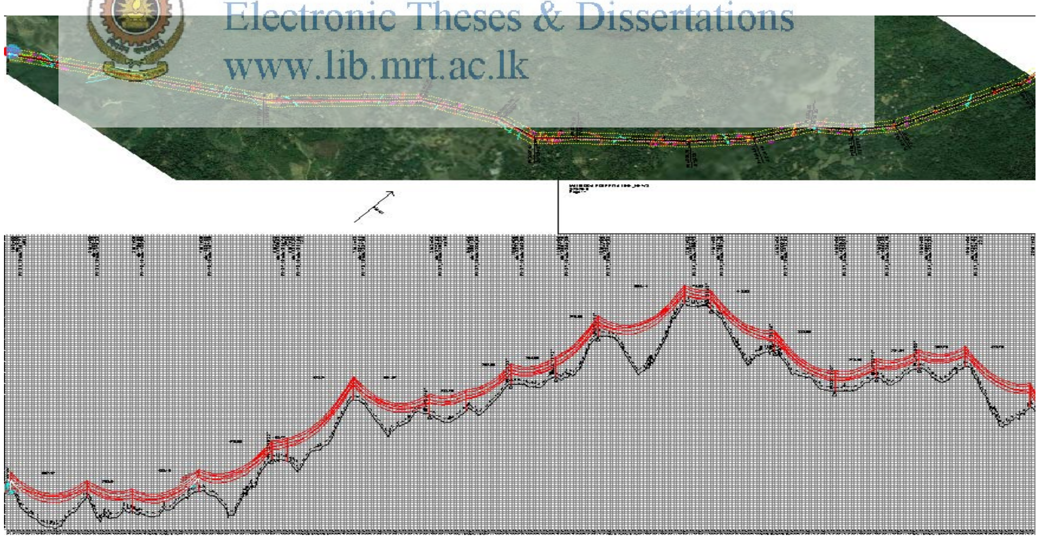


Figure 4.29 - Hilly Non Populated Terrain (Maliboda-Polpitiya Line at Polpitiya)

Profile design is carried out for 8 conductors considering the relevant specifications, and tower, foundation and material schedules' summary is shown in APPENDIX VII.

4.8.5 Populated Hilly Terrain

This line section is selected from Ragala - Pallekele 132kV transmission line (under construction) in Rikillagaskada area. The terrain is hilly, but populated due to close by town, schools and factories. Population is not as much as that in flat terrain due to geographical behavior of lands. Line route is placed with minimum social and environmental disturbances.

Loading conditions of support structures in this type of terrain are violated frequently, so allocation of section towers and angle towers can be seen regularly throughout the line. Therefore large numbers of angle towers and section towers are placed to overcome the extreme loads exerted on towers and to maintain the required clearance to man-made features. i.e., buildings. Therefore situation is much sever in both technical as well as social aspects. Sometimes the route has to be changed due to technical difficulties, but it may give rise to more social objections.

Soil condition of this kind of terrain is normally good, therefore type 3 foundation are used for construction. Rock boulders are found frequently, but rock anchor foundations are used only in rare situations. Material transportation for construction is very difficult and head loading method is normally used such situations.

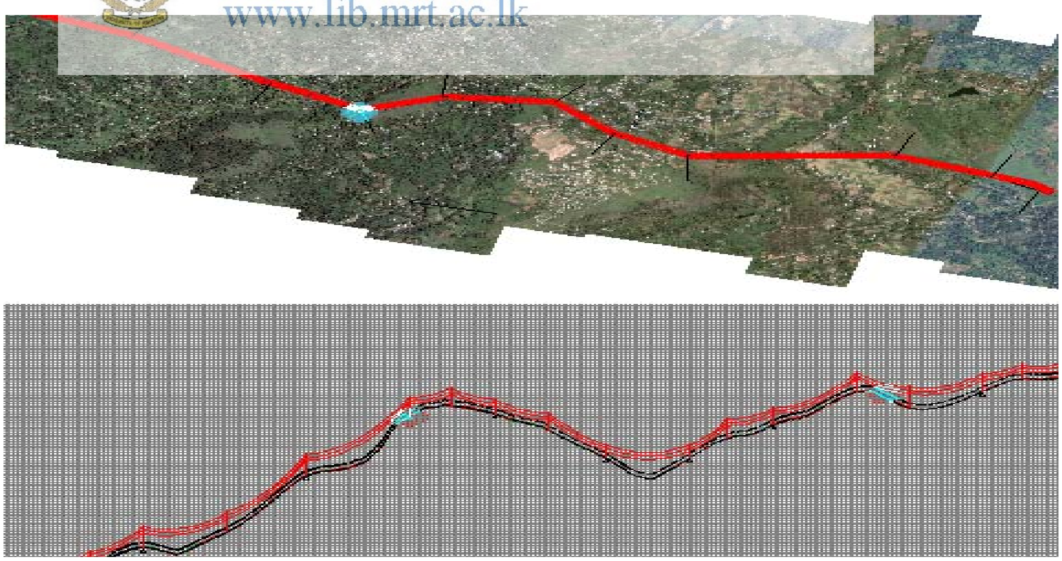


Figure 4.30 - Hilly Populated Terrain (Ragala -Pallekele Line at Rikillagaskada)

Profile design is carried out for 8 conductors considering the relevant specifications, and tower, foundation and material schedules' summary is shown in APPENDIX VII.

4.8.6 Paddy Hilly Terrain

This line section is selected from Ragala-Pallekele transmission line (under construction) in Hanguranketha area. The terrain of this area is hilly, and route laying along a paddy field. Same as other terrains, due to ROW issues utilities prefer to locate the line on paddy fields, away from home gardens. Angle and section towers are frequently introduced due to technical and physical requirement. Social objections are also raised due to damage caused to paddy fields and their cultivation, and those can to be compensated at reasonable manner.

Soil condition of this sort of terrains is normally water log, therefore type 4A foundation are normally used for construction. Construction of foundations and erection of towers are difficult in rainy season, as head loading is used for material barrowing to the tower locations. Sometime construction work can only be done after harvesting crops. Therefore construction cost increases in addition to foundation cost.

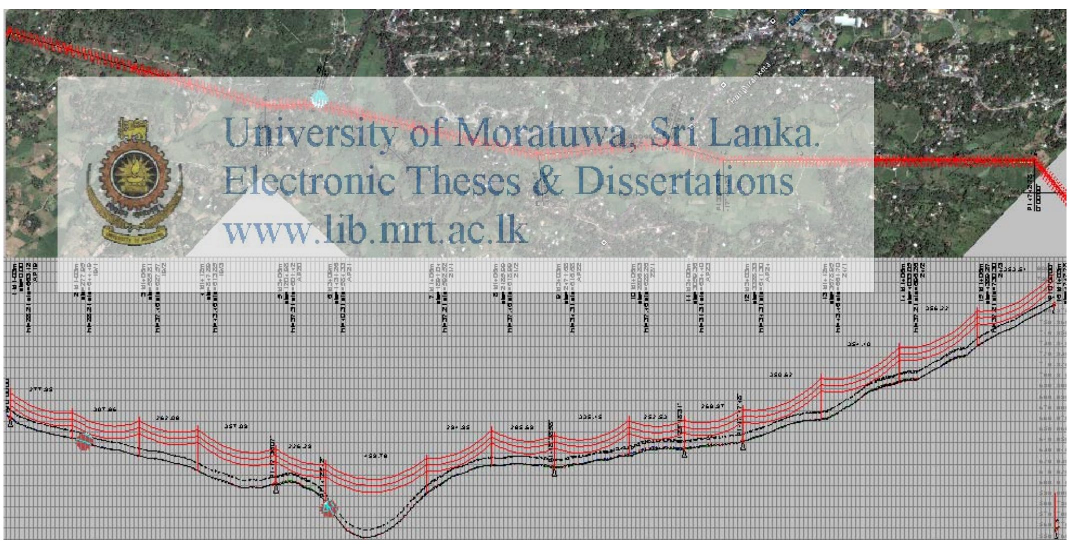


Figure 4.31 - Hilly Paddy Terrain (Ragala - Pallekele Line at Hanguranketha)

Profile design is carried out for 8 conductors considering the relevant specifications, and tower, foundation and material schedules' summary is shown in APPENDIX VII.

4.9 REDUCTION OF TOWERS

Reduce the numbers of towers would help to minimize social impact up to some extent due to reduction in private land usage, and also reduces the material and cost of construction.

Based on the tower schedules of different type of transmission lines, it is clear that the reduction of number of towers cannot be achieved other than in special cases, and which are infrequent. It is because the towers are designed based on the same specifications.

In order to reduce the number of towers for a transmission line, specifications of towers and foundations such as basic span, wind span, weight span, and limitation of their angle of deviation, etc. need to be adjusted, and extra body extensions need to be introduced.

However, reasonable amount of body extensions can be reduced by using new generation conductors which are having low sag behavior.

4.10 TRANSMISSION LINE FINANCIAL EVALUATION

Based on the towers, foundations and material schedules obtained from profile designs financial calculations are done for transmission lines with different types of ground terrains, and transmission lines costs are summarized in APPENDIX VIII.

Cost of support structures and foundations are taken based on previous calculations in the design stage of support structures and foundations, and those values may be subjected to minor changes depending on the optimization of the design.

All other prices are taken from the average prices from recently completed transmission lines projects in CEB. Only dead end clamps, suspension clamps and related material may change with respective to conductor, and cost changes due to change in line material are considered minor, and cost of line material is taken as same as those of ACSR Zebra conductors.

Due to different UTS of conductors safety factor of tension insulators is changed within 2 -2.5, so same type of 70kN, 120kN and 160kN insulator strings are used for cost calculation.

Average cost of construction of transmission lines heavily depends on the terrain selected, so well classified terrains are used for the respective ground terrain, so the cost fluctuation due to variation in ground profile is kept to minimum. Tables in APPENDIX IX are summarized the prices of construction cost of transmission lines.

5.0 RESULTS

This study concentrates on 132kV double circuit transmission lines, and well stablished conventional ACSR Zebra conductor and its' power capacity is taken as the base to evaluate the impact of new generation conductors on techno economics of 132kV transmission lines.

Conductor selection and long term profitability are carried out under two conductor selection categories. Table below shows the energy loss evaluation of new generation conductors whose rated current capacities are almost equal to the rated current capacity of ACSR Zebra conductor. As noted, new generation conductors developed to withstand high temperatures, so same amount of power can be delivered with significantly reduced conductor area. But the energy loss is higher than the energy loss of ACSR zebra conductor due to a fact that high resistance goes higher at higher operating temperatures.

Table 5.1 - Energy Loss Evaluation for Rated load Conditions.

Conductor Type	ACSR	ACCC	ZTACIR /AW	ACSS / TW	ACCR	GTACSR
Conductor per phase	1					
Nos. of circuits	2					
Power flow (MW)	380.9					
Conductor diameter (mm)	28.6	17.3	18.2	17.3	17.2	20.6
Operating temp. (°C)	75.0	157.0	175.0	197.0	198.0	128.8
Unit resistance (Ω/km)	0.0815	0.2243	0.2721	0.3131	0.3151	0.1711
Initial cost (MLKR)	-29.73	-22.03	-24.03	-18.02	-32.04	-18.02
Reduction in 40 year losses (MLKR)	0	-371	-495	-602	-607	-248
Net saving over 40 yrs. to deliver the same amount of power (MLKR)	0	-363	-490	-590	-610	-236

It is clearly observed that the cost of per kilometer line losses over 40 years of life span are massive. Hence design of new transmissions with new generation conductors with their rated current capacity is not advisable.

However, it can be observed that considerable amount of cost can be saved in long term energy loss evaluation under the low loading condition of conductors (see Table 5.2).

Table 5.2 - Energy Loss Evaluation for Low Loading Conditions.

Conductor Type	ACSR	ACCC	ZTACIR/ AW	ACSS/TW	ACCR	GTACSR	LL-ACSR/AS	LL-TACSR/AS
Conductors per Phase	1							
Nos. of Circuits	2							
Power Flow (MW)	380.9							
Conductor Diameter (mm)	28.62	28.14	28.50	28.68	28.65	29.00	28.62	28.62
Operating Temp.(°C)	75.0	68.3	75.6	67.8	74.6	70.8	66.6	67.0
Unit Resistance (Ω/km)	0.08148	0.06453	0.08285	0.06388	0.08067	0.07227	0.06166	0.06258
Energy Loss (MWh)	1121	888	1140	879	1110	994	848	861

Table 5.3 summarized results of detailed design of transmission line for respective conductors for different ground terrain. Conventional ACSR Zebra conductor still shows the best average per kilometer capital cost among new generation conductors.

Table 5.3 - Capital Cost Model for Terrain Models

Terrain Types	Flat Non Populated	Flat Populated	Flat Paddy	Hilly Non Populated	Hilly Populated	Hilly Paddy	Total Line Cost Rs. (Mn)	Rs. (Mn) / km
Line Section Length (km)	1	1	1	1	1	1	1	
ACSR	17.98	25.41	23.11	26.99	28.65	33.75	155.88	25.98
ACCC	25.24	32.44	30.43	35.26	37.47	42.94	203.79	33.96
ZTACIR/AW	28.61	36.88	33.94	37.74	40.24	45.91	223.32	37.22
ACSS/TW	22.01	29.41	27.77	31.51	33.42	38.68	182.80	30.47
ACCR	38.46	46.46	43.64	47.59	49.57	55.79	281.50	46.92
GTACSR	21.38	29.97	27.06	31.33	33.82	40.20	183.76	30.63
LL-ACSR/AS	20.38	28.35	25.72	29.67	33.04	37.92	175.09	29.18
LL-TACSR/AS	21.51	29.92	22.33	31.38	33.83	40.13	179.11	29.85

In order to evaluate the overall techno economic viability of transmission lines, it should consist all the cost components that's are occurring over the life span. Table 5.4 shows the 40 years of cost benefit analysis for transmission lines.

Table 5.4 - 40 Year Cost Benefit Analysis Compared to ACSR Zebra Conductor.

Conductor Type	ACSR	ACCC	ZTACIR /AW	ACSS /TW	ACCR	GTACSR	LL-ACSR /AS	LL-TACSR /AS
Conductor per Phase	1							
Nos. of Circuits	2							
Power Flow (MW)	380.9							
Conductor Diameter (mm)	28.62	28.14	28.5	28.677	28.651	28.999	28.62	28.62
Operating Temp. (°C)	75.00	68.27	75.59	67.76	74.61	70.84	66.57	66.96
Unit Resistance (Ω/km)	0.081	0.064	0.0829	0.0639	0.0807	0.0723	0.061	0.062
Initial Cost (MLKR)	25.98	33.96	37.22	30.47	46.92	30.63	29.18	29.85
Reduction in 40 Year Losses (MLKR)	0.00	45.54	-3.68	47.29	2.18	24.75	53.24	50.79
Net Saving over 40 yrs. to deliver the same amount of power	0.00	37.56	-14.92	42.80	-18.76	20.10	50.04	46.91

According to the results, it can be clearly observed that best techno economically viable conductor is LL-ACSR/AS conductor, even if conventional ACSR conductor shows lowest capital cost.

Table 5.6 show the 40 years cost benefit analysis done for Medagama -Monaragala (16km, hilly terrain) and Mahiyangana - Vavunathivu (129km, flat terrain) transmission lines. LL-ACSR/AS conductor shows the best net saving over 40 years in both cases.

Table 5.5 - 40 Year Cost Benefit Analysis for Medagama Monaragala Line

Conductor Type	ACSR	ACCC	ZTACIR/ AW	ACSS/TW	ACCR	GTACSR	LL-ACSR /AS	LL-TACSR /AS
Conductor per Phase	1							
Nos. of Circuits	2							
Power Flow (MW)	380.9							
Conductor Diameter (mm)	28.62	28.143	28.5	28.67	28.65	28.99	28.62	28.62
Operating Temp. (°C)	75.00	68.27	75.59	67.76	74.61	70.84	66.57	66.96
Unit Resistance (Ω/km)	0.0815	0.0645	0.0829	0.0639	0.0807	0.0723	0.0617	0.0626
Initial Cost (MLKR)	444.30	580.19	621.68	518.26	776.36	519.40	497.39	519.89
Reduction in 40 Year Losses (MLKR)	0.00	728.71	-58.90	756.65	34.82	396.02	851.90	812.58
Net Saving over 40 yrs. to deliver the same amount of power (MLKR)	0.00	592.81	-236.28	682.69	-297.24	320.92	798.80	736.99

Table 5.6 - 40 Year Cost Benefit Analysis for Mahiyangana Vavunathivu Line

Conductor Type	ACSR	ACCC	ZTACIR/ AW	ACSS/TW	ACCR	GTACSR	LL-ACSR/AS	LL-TACSR/AS
Conductors per Phase	1							
Nos. of Circuits	2							
Power Flow (MW)	380.9							
Conductor Diameter (mm)	28.62	28.14	28.5	28.677	28.651	28.999	28.62	28.62
Operating Temp. (°C)	75.00	68.27	75.59	67.76	74.61	70.84	66.57	66.96
Unit Resistance (Ω/km)	0.0815	0.065	0.0829	0.0639	0.0807	0.0723	0.0617	0.0626
Initial Cost (MLKR)	2644.05	3583.2	4032.18	3195.95	5293.17	3120.6	2969.34	2893.1
Reduction in 40 Year Losses (MLKR)	0.00	5875.2	-474.87	6100.52	280.76	3192.9	6868.42	6551.4
Net Saving over 40 yrs. to deliver the same amount of power (MLKR)	0.00	4936.0	-1863.00	5548.62	-2368.36	2716.3	6543.12	6302.33

Variation of cost components of transmission lines is summarized in Table 5.7 and Table 5.8. It can be observed that the total cost variation without the conductor cost is around 115% compared to ACSR conductor transmission lines, but the conductor cost varies almost 480% compared to ACSR conductor. So, it can be clearly concluded that to total cost is mainly dependent upon the conductor cost.

Table 5.7 - Cost Percentage Summary for Hilly Populated Terrain Line

Conductor Type			ACSR	ACCC	ZTACIR/ AW	ACSS /TW	ACCR	GTACSR	LL-ACSR/AS	LL-TACSR/AS
A	Conductor Cost	Rs.(Mn)	28.06	68.04	81.37	41.39	134.68	41.39	38.72	41.39
		%	100%	243%	290%	148%	480%	148%	138%	148%
B	Cost Except conductor Cost	Rs.(Mn)	137.23	148.17	150.83	151.43	151.30	153.75	151.94	153.80
		%	100%	108%	110%	110%	110%	112%	111%	112%
C	Total Cost	Rs.(Mn)	165.29	216.21	232.20	192.82	285.98	195.14	190.66	195.19
		%	100%	131%	140%	117%	173%	118%	115%	118%

Table 5.8 - Cost Percentage Summary for Flat Non-Populated Transmission Line

Conductor Type			ACSR	ACCC	ZTACIR/AW	ACSS/TW	ACCR	GTACSR	LL-ACSR/AS	LL-TACSR/AS
A	Conductor	Rs.(Mn)	30.35	73.60	88.02	44.77	145.69	44.77	41.88	44.77
		%	100%	243%	290%	148%	480%	148%	138%	148%
B	Cost Except Conductor Cost	Rs.(Mn)	81.85	83.94	90.51	92.58	94.33	88.68	85.33	89.48
		%	100%	103%	111%	113%	115%	108%	104%	109%
C	Total Cost	Rs.(Mn)	112.20	157.54	178.53	137.35	240.01	133.45	127.21	134.24
		%	100%	140%	159%	122%	214%	119%	113%	120%

Tower reduction capability is also studied for different types of conductors, and Table 5.9 summarized the tower schedule for transmission lines. The number of towers cannot be reduced by using new generation type of conductors, however reduction of tower extension can be achieved with ACCC and ACCR conductors, which show low sag behavior.

Therefore, In order to reduce number of towers for a line, specifications of towers such as basic span, wind span, weight span, and limitation of their angle of deviation, etc. need to be adjusted, and extra body extensions can be introduced, i.e., +15m,+18m,etc.

Table 5.9 - No of Tower Usage for Different Conductors

Tower type	Tower Extension	Unit	ACSR	ACCC	ZTACI/AW	ACSS /TW	ACCR	GTACSR	LL-ACSR/AS	LL-TACSR/AS
TDL	-3	Nos	1	9	1	0	1	2	2	2
	± 0	Nos	7	5	6	5	7	7	6	6
	+ 3	Nos	5	2	6	6	5	4	5	6
	+ 6	Nos	1	0	1	3	2	2	3	2
	+ 9	Nos	2	0	2	2	1	1	0	0
	+ 12	Nos	0	0	0	0	0	0	0	0
TD1	-3	Nos	1	1	1	1	1	1	1	1
	± 0	No	0	1	0	0	0	0	0	0
	+ 3	Nos	2	1	2	1	2	2	2	2
	+ 6	Nos	0	0	0	0	0	0	0	0
	+ 9	Nos	0	0	0	0	0	0	0	0
	+ 12	Nos	0	0	0	0	0	0	0	0
TD3	-3	Nos	0	0	0	0	0	0	0	0
	± 0	Nos	0	0	0	1	0	0	0	0
	+ 3	Nos	0	1	0	1	0	0	0	0
	+ 6	Nos	1	0	1	0	1	1	1	1
	+ 9	Nos	0	0	0	0	0	0	0	0
	+ 12	Nos	0	0	0	0	0	0	0	0
	Nos. of towers	Nos	20	20	20	20	20	20	20	20

6.0 CONCLUSION

Following conclusions and recommendations are made for use of new generation conductors (HTLS and Low Loss conductors) over conventional ASCR conductors for 132kV transmission lines, based on the results of this study.

Merely being a conductor with new manufacturing technology, it cannot be always considered as the best conductor for transmission lines. Proper utilization of their behavior is the whole mark for the best performance of both conventional and new generation conductors, i.e., electrical behavior (CCC, operating temperature and unit resistance), and their mechanical behavior (UTS and elongation).

In order to select the best suitable conductor for a given transmission line, it is always suitable to carry out a detailed study on techno economic of transmission lines. However, it is a difficult and time consuming task to carryout detailed designs of transmission lines for conductor available in the conductor market.

The selection of best suitable conductor for a new overhead transmission line may depend on several factors, such as capital cost, cost of energy loss, operation and maintenance cost, etc. Designed to operate new generation conductors at their rated capacity would severely affect the overall performance of the transmission line, even though the capital costs of construction for new generation conductors are fairly low compared to capital cost of construction for ACSR conductor.

Compared to conventional type, new generation conductors (LL-ACSR/AS, LLTACSR/AS, ACSS/TW, ACCC, GTACSR and ACCR) showed promising results with regard to overall techno-economic viability, and among them Low Loss type conductor are superior, under low load condition.

Both capital cost and cost of energy losses over life span of a transmission line would affect viability of a transmission line, but the cost of energy lost is more significantly influences overall performance of the line. The developed cost models in this study can be used to calculate the capital costs 132kV double circuit transmission lines along any combination of line ground terrains.

The main factor of changing capital cost of transmission line is the cost of the conductor. The impact of cost of material except conductor and civil works shows maximum variation of 15% over cost of ACSR conductor. So if the conductor price is known, rough estimate for the capital cost can be calculated without going in to detailed design.

ZTACIR/AW and ACCR type of conductors would not be economical to construct new transmission lines under any conditions. However they might be useful in thermal uprating of existing lines due to their high CCC.

Utilization of tower strength is in a transmission line is normally over 80% of its strength, so using of new generation type of conductors would not help to reduce the number of towers in a transmission line, unless specifying new design criteria for support structures. However, tower body extension can be reduced up to some extent, if the conductor shows low sag performance. Therefore, ACCC and ACCR conductors can be used in improving the ground clearance of existing transmission lines.

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APPENDIX I: Sample Result Steps for Sag Tension Calculation

S	**Sag (m)**	**7.809**
H_2	Final Tension (N/mm^2)	47.73
UTS	Tensile Strength (kN)	131.9
m_c	Unit mass of the conductor (kg/m)	1.632
A	Cross section Area (mm^2)	484.5
E	Modulus of Elasticity (N/mm^2)	69000
α	Linear Coefficient (C^{-1})	0.0000193
P	Wind pressure on conductor (N/m^2)	970
d	Diameter of the conductor (mm)	28.62
H_1	Initial Tension (N/mm^2)	109.23
g	Gravitational Constant (m/s^2)	9.80665
S	Ruling Span Length (m)	300
t1	Initial Temperature (°C)	7
t2	Final Temperature (°C)	75
h	Level Difference (m)	0

APPENDIX II: Sample Calculation for CCC

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

$P_{sol} = 14.31 W/m$

γ	=	Solar radiation absorption coefficient (0.5)
D	=	Conductor Diameter (0.02862m)
S_i	=	intensity of solar radiation (1000W/m2)

Radiated Heat Loss; $P_{rad} = S \pi D K_e (T_2^4 - T_1^4)$

$P_{rad} = 15.3260W$

S	=	Stefan-Boltzmann constant (5.67 x 10-8 W/m2k4)
D	=	conductor diameter (0.02862m)
K_e	=	emissivity coefficient (0.5)
T_2	=	final equilibrium temperature (75°C)
T_1	=	ambient temperature (32°C)

Reynolds Number; $R_e = 1.644 * 10^9 vD [T_1 - 0.5(T_2 - T_1)]^{-1.78}$

$R_e = 788.55$

R_e	=	Reynolds number
v	=	wind speed (0.5 m/s)
D	=	conductor diameter (0.02862m)

Nusselt Number; $N_u = 0.65 R_e^{0.2} + .023 R_e^{0.61}$

$N_u = 15.920$

Conventional Heat Loss; $\mathbf{P_{conv} = \lambda N_u (T_2 - T_1)\,\pi}$

$\mathbf{P_{conv} = 55.5927}$

λ = Thermal Conductivity of Air (0.02585W/m.k)

Joule Effect; $\mathbf{P_j = R_t I^2}$

R_t = Resistance at t ^{0}C (R_{25}=0.06841, R_{75}=0.06841)

$$I = \left(\frac{\text{Prad} + \text{Pconv} - Psol}{R_t}\right)^{0.5}$$

I= 833A

APPENDIX III: Energy Loss Calculation

Conductor	ACSR		ACCC
	ZEBRA		**DUBLIN**
Diameter (mm)	28.62		28.143
AC Resistance at 25°C (ohms/km)	0.06841		0.05534
AC Resistance at 75°C (ohms/km)	0.08149		0.06596
Ultimate Tensile Strength (kN)	132.3		183.3
Unit Mass of Conductor (kg/m)	1.621		1.5832
Cross Sectional Area (mm^2)	429.1		524.5
Modulus of Elasticity (N/mm^2)	69000		78000
Linear Coefficient ($^0C^{-1}$)	0.0000193		0.0000186
Conductors per phase:	1		1
Circuits:	2		2
@75	833.0	***@68.27***	833.0
@75	833	***@180***	1712
@100	1070	**@200**	1813
S-S Temp. (°C) at Peak Ampacity of ACSR Zebra:	75.00		68.27
Resistance at Peak Operating Amps (ohm/km)	0.08148		0.06453

Environmental Factors	
1000	Sun Radiation (W/m^2)
0.5	Wind Speed (ms^{-1})
0.5	Solar Radiation Absorption Coefficient
0.5	Emissivity coefficient
32	Ambient Temperature (°C)
0.02585	Air thermal Conductivity ($Wm^{-1}K^{-1}$)
5.67E-08	Stefan- Boltzmann Constant ($Wm^{-2}K^{-4}$)

Load and Generation Cost (Source; Statistics Digest2014,CEB)	
1	Line Length (km)
132	Voltage (kV)
833	Peak Operating Amps (A)
57.3%	Load Factor
37.7%	Loss Factor
190	Peak Power per Circuit (MW)
3	Phases/Circuit
19.97	Cost of Energy Generation (LKR/kWh)
0.8	CO_2 (kg/kWh)
0	Carbon Credit (LKR/MT)

$$First\ Year\ Line\ Loss$$
$$= Phase\ current^2 * Unit\ Resistance * Line\ Lenght * no.of\ concutors * Line\ Loss\ Factor * 8760$$

$$Load\ Factor = \frac{Average\ Demand}{Maximum\ Demand}$$

$$Loss\ Factor = 0.2 * Load\ Factor + .8 * Load\ Factor^2$$

For ACSR Zebra Conductor;

Load Factor = 57.3%; from CEB Sources

Loss Factor = 37.7%

$$First\ Year\ Line\ Loss = 833^2 * .08148 * 1 * 6 * .377 * 8760$$

$$First\ Year\ Line\ Loss = 1121.09\ MWh$$

For ACCC Dublin Conductor;

$$First\ Year\ Line\ Loss = 833^2 * .06453 * 1 * 6 * .377 * 8760$$

$$First\ Year\ Line\ Loss = 887.87\ MWh$$

$$Reduces\ First\ Year\ Line\ Losses\ by = 1121.09 - 887.87$$

$$= 233.22\ MWh$$

$$Reduces\ First\ Year\ Line\ Losses\ by\ (\%) = 233.22/1121.09$$

$$= 20.80\%$$

$$Saving\left(\frac{MLKR}{Year}\right) = Line\ Loss\ Saving * Cost\ of\ Energy\ Generation$$

$$= 233.22 * 19.97$$

$$= 4.66$$

$$Net\ Present\ Value = \sum_{t=1}^{n} \frac{C}{\left(\frac{1}{1+i}\right)^n}$$

$; i = discount\ rate (10\%),$

$n = nos.of\ years\ (40)$

$$= \sum_{t=1}^{40} \frac{4.66}{\left(\frac{1}{1+.1}\right)^n}$$

$$Reduction\ in\ 40yrs\ Losses\ (MLKR) = 45.54$$

APPENDIX IV: Sample Load Calculation for TDL Tower

TOWER: TDL

BASIC DATA

Deviation Angle = 0

Basic Span = 300 m

Wind/Weight Span

Condition	Wind Span (m)	Weight Span (m) Maximum	Weight Span (m) Maximum
Normal Condition	360	600	150
Broken wire Condition	270	450	112.5

Wind Load on Tower = 1640 N/m^2*Projected Area

Wind Load Wires = 970 N/m^2*Projected Area

Wind Load Insulator = 1170 N/m^2*Projected Area

sag-Tension Calculation" for mechanical properties and wire tension under different conditions for Conductor ACSR - Zebra (400mm^2)/OPGW/GSW 7/3.25 (1000 Grade)

Information Relevant to Element Design

All dimensions are in mm and Loads are in N (Newton) wherever not specified.

Loading calculation for Conductor/ Earth wire / OPGW are done as per technical specification requirements.

Members indicated as MS are as per ISO 630 1995(E) Gr. E 275

With minimum Yield stress = 275 MPa (Thickness<16mm)

265MPa (Thickness 16 to 40mm)

Member indicated as "HT' are as per ISO 630 1995(E) Gr. E 355

With minimum Yield stress = 355 MPa (Thickness<16mm)

345MPa (Thickness 16to40mm)

Bolt & Nuts are as per ISO 898 - 1.1999 (E) Class 5.6

For design of bolts and nuts the following stresses are used.

Ultimate shearing stress = 0.25*FU1 = 0.62*500 = 310N/mm^2

As per clauses 4.3.2 of ASCE 10-97

Tower Design Performed as per ASCE 10-97 using 3D models in "PLC Tower" version 12.0

Loads applied in PLS - TOWER software by multiplying with Factor of Safety as furnished in Specification.

Condition	**Normal Condition**	**Broken Wire Condition**
Factor of Safety	2.50	1.25

Enough safety margin maintained in Broken Wire Condition for Cross Arm members to achieve 2.00 factor of safety in main cross arm members (PKLM, TCLM, MC LM & BC LM)

For design of each member, maximum forces are derived from multiple analysis of tower with all loading conditions and all 3D models with various body extensions.

Design Data

Earth Wire	**7/3.25**	**Conductor ACSR 61/3.18**		**Insulators**	
Number Ne	1.00	Number Nc	1.00	Number Ni	1.00
Diameter De (mm)	9.75	Diameter Dc (mm)	28.62	Diameter Di (mm)	255
Weight We (kg/m)	0.46	Weight Wc (kg/m)	1.62	Weight Wi (kg/m)	47.6
Tension Te (N)	18931	Tension Tc (N)	52920	Length Li (m)	2.10
OPGW				Insulators	
Number Ne	1.00	Clamp weight GSW	5.00	Number Ni	1.00
Diameter De (m)	12.50	Clamp weight OPGW	5.00	Diameter Di (mm)	255
Weight We (kg/m)	0.46			Weight Wi (kg/m)	47.6
Tension Te (N)	21620			Length Li (m)	2.10
Spans in m		Wind Pressure in kg/sqmm		Line Deviation	
Normal Sn (m)	300	Earth wire Pe (N/m^2)	970	Angle	0.00
Wind Span (m)	360	Conductor Pc (N/m^2)	970	Safety Factors	
Max. Wt. Swt1 (m)	600	Insulator Pi (N/m^2)	1170	Normal Case	2.50
Min. Wt. Swt2 (m)	150	Man with Tools in KGS	150	Broken Wire	1.25

Formulae Used In Load Calculation

Wind load on Conductor /Earth wire/ OPGW = Diameter * Wind Span*970N/m^2

Angle pull Conductor / Earth wire = 2*Maximum Working Tension * sin (Deviation Angle/2)

Wind Load on insulator = 0.5*Length of Insulator String * Diameter of Insulator String *1170N/m^2

Weight of conductor/ Earth wire = Unit weight * weight span

Earth wire Tension at broken wire condition = 1.0* Maximum Working Tension

Conductor Tension at broken wire condition =0.7*Maximum Working Tension

For Earth wire loads OPGW considered on Left Side & Earth wire GS 7/3.25(1000 Grade) Considered on Right Side.

Formulae Used In Tower Design

L/R = Maximum of Lxx/Rxx or Lw/Rw

KL/R	= L/R if (curve No. = 1) and (0<=L/R<=120)	ASCE 10 Eq 3.7.5
	=30+ (0.75*(L/R)) if (curve No. = 2) and (0<=L/R<=120)	ASCE 10 Eq 3.7.6
	=50+ (0.5*(L/R)) if (curve No. = 3) and (0<=L/R<=120)	ASCE 10 Eq 3.7.7
	= L/R if (curve No. = 3) and (0<=L/R<=120)	ASCE 10 Eq 3.7.8
	= 28.6+ (0.762*(L/R)) if (curve No. 5))and (0<=L/R<=120)	ASCE 10 Eq 3.7.9
	=46.2+ (0.615*(L/R)) if (curve No. 6)) and (120<=L/R<=250)	ASCE10Eq3.7.10

Allowable compression stress Fa

Fa	= (1.0.5*(KL/R/Cc^2)*Fy)	if KL/R< = Cc	ASCE 10 Eq . 3.6.1
Fa	= (π^2*E) KL)	if KL/R> = Cc	ASCE 10 Eq . 3.6.2
Cc	= Fa (2*E) FY)$^{1/2}$		ASCE 10 Eq . 3.6.3

Allowable tension stress on net cross section area Ft.

Ft = 0.9*Fy

Applied shear stress on a bolt S.

S = Applied maximum force (minimum cross sectional area of bolt * number of bolts)

Applied Bearing Stress for one bolt B

B= Applied maximum force/ (Thickness of connected part * bolt normal diameter * Number of bolts)

Loading Calculation for Conductor

Condition	Normal Condition		Broken wire Condition	
Transverse Load				
Wind on wire	1*360*(28.62/1000)*970*2.5	24985.26	1*270(28.62/1000)*970*1.25	9369.47
Wind on Insulator string	1*1*0.5*255* 1170*2.5	783.17	1*1*.5*2.1*255*1170*1.25	391.58
Deviation load/Angle pull	1*2*52920*SIN(0)*2.5	0.00	1*2*52920*SIN(0)*1.25	0.00
Total (N)		25768.43		9761.06
Max Vertical Load				
Weight of Wire	1*600*(1.62*9.8.1)*2.5	23860.31	1*450(1.62*9.81)*1.25	8947.62
Weight of insulator stringing	1*(100*9.381)*2.5	2453.25	1*(100*9.81)* 1.25	1226.63
Weight of man with toolkit	(150*9.8.1)*2.5	3679.88	(150 *9.81)* 1.25	1839.94
Total (N)		29993.43		12014.18
Min Vertical load				
Weight of wire	1*150* (1.62*9.81)*2.5	5965.08	1*1125*(1.62*9.81)*1.25	2236.90
Weight of insulator string	1*(100*9.8.1)*2.5	2453.25	1*(100*9.8.1)*1.25	1226.63
TOTAL (N)		8418.33		3463.53
Longitudinal load				
Deviation load/Angle pull			1*52257*Cos (0)	46305.00
Total (N)				46305.00

Notes :-

1) F.O.S. for NC = 2.5

2) F.O.S for BWC = 1.25 and cross Arm Member in BWC = 2.0

3) Tower to be designed for single Circuit strung condition

Loading Calculation for GSW

Condition	Normal Condition		Broken wire Condition	
Transverse Load				
Wind on wire	1*360*(9.75/1000)*970*2.5	8511.75	1*270* (9.75/1000)*970*1.25	3191.91
Deviation load/Angle pull	1*2*18931*SIN(0)*2.5	0.00	1*8931*1.25	0.00
Total (N)		8511.75		3191.91
Max Vertical Load				
Weight of Wire	1*600*(1.632*9.81)*2.5	6770.97	1*450(1.632*9.81)*1.25	2539.11
Clamp	1*(100*9.81)*2.5	122.66	1*(100*9.81)*1.25	61.33
Weight of man with toolkit	(150*9.81)*2.5	3679.88	(150 *9.81)*1.25	1839.94
Total (N)		10573.51		4440.38
Min Vertical load				
Weight of wire	1*150* (1.632*9.81)*2.5	1692.74	1*1125*(1.632*9.81)*1.25	634.78
Weight of Clamps	1*(100*9.8.1)*2.5	122.66	1*(100*9.8.1)*1.25	61.33
TOTAL (N)		1815.41		696.11
Longitudinal load				
Deviation load/Angle pull			1*18931* Cos (0)*1.25	23663.75
Total (N)		0.00		23663.75

Notes :-
1) F.O.S. for NC = 2.5
2) F.O.S for BWC = 1.25 and cross Arm Member in BWC = 2.0
3) Tower to be designed for single Circuit strung condition

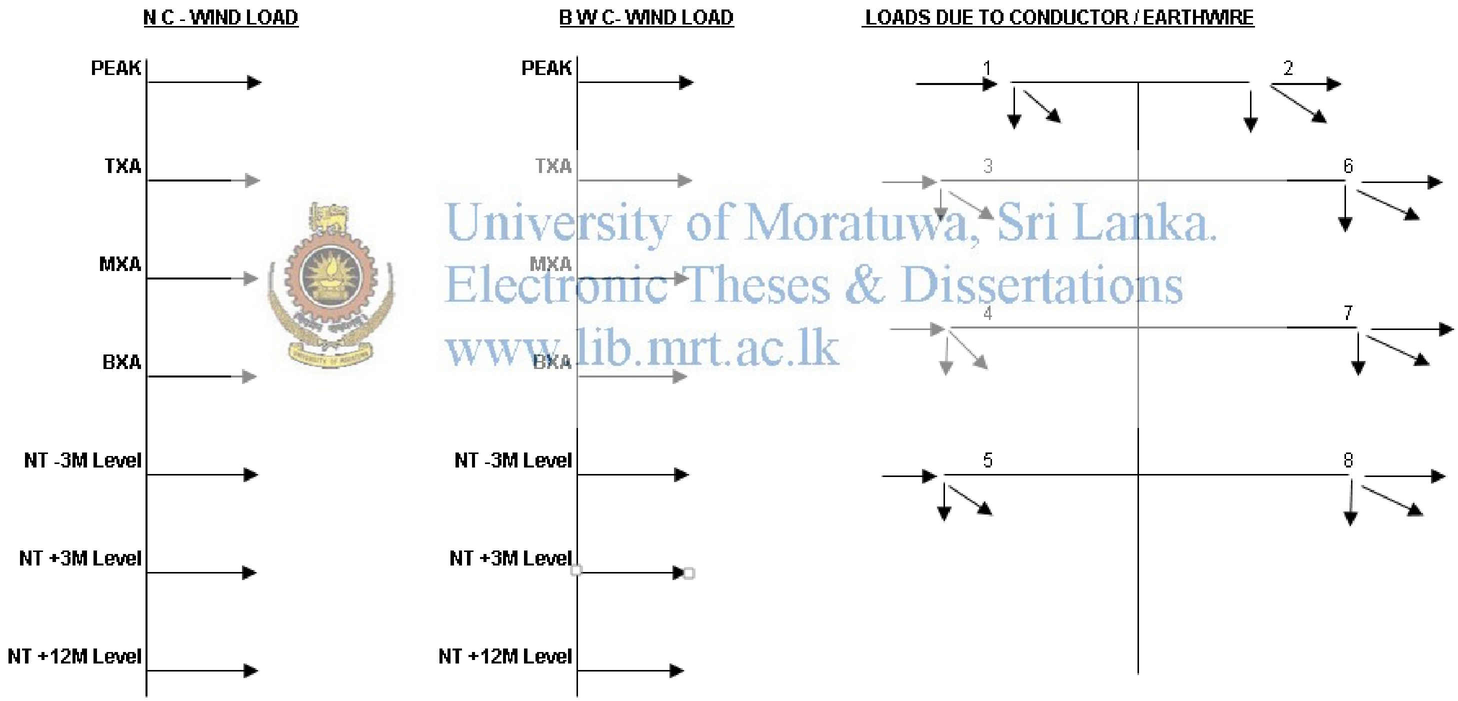
Loading Calculation for OPGW

Condition	Normal Condition		Broken wire Condition	
Transverse Load				
Wind on wire	1*360*(12.5/1000)*970*2.5	10912.50	1*270*12.5/1000*970*1.25	4092.19
Deviation load/Angle pull	1*2*21620*SIN(0) *2.5	0.00	1*21620*SIN(0)* 1.25	0.00
Total (N)		10912.50		4092.19
Max Vertical Load				
Weight of Wire	1*600*(0.46*9.81) *2.5	6770.97	1*450*(0.460*9.81) 1.25	2539.11
Clamp	1*(5*9.81) *2.5	122.66	1*(5*9.81) 1.25	61.33
Weight of man with toolkit	(150*9.81) *2.5	3679.88	(150*9.81) 1.25	1839.94
Total (N)		10573.51		4440.38
Min Vertical load				
Weight of wire	1*150*(0.46*9.81) *2.5	1692.74	1*112.5*(0.46*9.81) 1.25	634.78
Weight of Clamps	1*(5*9.81) *2.5	122.66	1*(5*9.81) 1.25	61.33
TOTAL (N)		1815.41		696.11
Longitudinal load				
Deviation load/Angle pull			1*21620*COS(0) 1.25	27025.00
Total (N)		0.00		27025.00

Notes :-
1) F.O.S. for NC = 2.5
2) F.O.S for BWC = 1.25 and cross Arm Member in BWC = 2.0
3) Tower to be designed for single Circuit strung condition

Loading Trees and Loading Cases.

Load tree shows the loading points of the tower. Calculated loads will be applied respective points on the tower. In each load case different loads will be applied, and tower strength is modified accordingly.



Following table shows different loading cases due to breakage of different wires of the tower.

Broken (GSW and Top Conductor)					Broken (OPGW and Top Conductor)			
Join Label	Vertical Load/(N)	Transverse Load /(N)	Longitudinal Load /(N)		Join Label	Vertical Load/(N)	Transverse Load /(N)	Longitudinal Load /(N)
PGR	4440.38	3191.91	23663.75		PGR	5286.75	5456.25	0.00
POL	5286.75	5456.25	0.00		POL	4440.38	4092.19	27025.00
TCR	12014.18	9761.06	46305.00		TCR	14996.72	12884.21	0.00
TCR	14996.72	12884.21	0.00		TCR	14996.72	12884.21	0.00
TCL	14996.72	12884.21	0.00		TCL	12014.18	9761.06	46305.00
TCL	14996.72	12884.21	0.00		TCL	14996.72	12884.21	0.00
MCR	14996.72	12884.21	0.00		MCR	14996.72	12884.21	0.00
MCR	14996.72	12884.21	0.00		MCR	14996.72	12884.21	0.00
MCL	14996.72	12884.21	0.00		MCL	14996.72	12884.21	0.00
MCL	14996.72	12884.21	0.00		MCL	14996.72	12884.21	0.00
BCR	14996.72	12884.21	0.00		BCR	14996.72	12884.21	0.00
BCR	14996.72	12884.21	0.00		BCR	14996.72	12884.21	0.00
BCL	14996.72	12884.21	0.00		BCL	14996.72	12884.21	0.00
BCL	14996.72	12884.21	0.00		BCL	14996.72	12884.21	0.00

Broken (GSW and Middle Conductor)					Broken (OPGW and Middle Conductor)			
Join Label	Vertical Load/(N)	Transverse Load /(N)	Longitudinal Load /(N)		Join Label	Vertical Load/(N)	Transverse Load /(N)	Longitudinal Load /(N)
PGR	4440.38	3191.91	23663.75		PGR	5286.75	5456.25	0.00
POL	5286.75	5456.25	0.00		POL	4440.38	4092.19	27025.00
TCR	14996.72	12884.21	0.00		TCR	14996.72	12884.21	0.00
TCR	14996.72	12884.21	0.00		TCR	14996.72	12884.21	0.00
TCL	14996.72	12884.21	0.00		TCL	14996.72	12884.21	0.00
TCL	14996.72	12884.21	0.00		TCL	14996.72	12884.21	0.00
MCR	12014.18	9761.06	46305.00		MCR	14996.72	12884.21	0.00
MCR	14996.72	12884.21	0.00		MCR	14996.72	12884.21	0.00
MCL	14996.72	12884.21	0.00		MCL	12014.18	9761.06	46305.00
MCL	14996.72	12884.21	0.00		MCL	14996.72	12884.21	0.00
BCR	14996.72	12884.21	0.00		BCR	14996.72	12884.21	0.00
BCR	14996.72	12884.21	0.00		BCR	14996.72	12884.21	0.00
BCL	14996.72	12884.21	0.00		BCL	14996.72	12884.21	0.00
BCL	14996.72	12884.21	0.00		BCL	14996.72	12884.21	0.00

Broken (GSW and Middle Conductor)			
Join Label	Vertical Load/(N)	Transverse Load /(N)	Longitudinal Load /(N)
PGR	4440.38	3191.91	23663.75
POL	5286.75	5456.25	0.00
TCR	14996.72	12884.21	0.00
TCR	14996.72	12884.21	0.00
TCL	14996.72	12884.21	0.00
TCL	14996.72	12884.21	0.00
MCR	12014.18	9761.06	46305.00
MCR	14996.72	12884.21	0.00
MCL	14996.72	12884.21	0.00
MCL	14996.72	12884.21	0.00
BCR	14996.72	12884.21	0.00
BCR	14996.72	12884.21	0.00
BCL	14996.72	12884.21	0.00
BCL	14996.72	12884.21	0.00

Broken (OPGW and Middle Conductor)			
Join Label	Vertical Load/(N)	Transverse Load /(N)	Longitudinal Load /(N)
PGR	5286.75	5456.25	0.00
POL	4440.38	4092.19	27025.00
TCR	14996.72	12884.21	0.00
TCR	14996.72	12884.21	0.00
TCL	14996.72	12884.21	0.00
TCL	14996.72	12884.21	0.00
MCR	14996.72	12884.21	0.00
MCR	14996.72	12884.21	0.00
MCL	12014.18	9761.06	46305.00
MCL	14996.72	12884.21	0.00
BCR	14996.72	12884.21	0.00
BCR	14996.72	12884.21	0.00
BCL	14996.72	12884.21	0.00
BCL	14996.72	12884.21	0.00

Broken (GSW and Bottom Conductor)			
Join Label	Vertical Load/(N)	Transverse Load /(N)	Longitudinal Load /(N)
PGR	4440.38	3191.91	23663.75
POL	5286.75	5456.25	0.00
TCR	14996.72	12884.21	0.00
TCR	14996.72	12884.21	0.00
TCL	14996.72	12884.21	0.00
TCL	14996.72	12884.21	0.00
MCR	14996.72	12884.21	0.00
MCR	14996.72	12884.21	0.00
MCL	14996.72	12884.21	0.00
MCL	14996.72	12884.21	0.00
BCR	12014.18	9761.06	46305.00
BCR	14996.72	12884.21	0.00
BCL	14996.72	12884.21	0.00
BCL	14996.72	12884.21	0.00

Broken (OPGW and Bottom Conductor)			
Join Label	Vertical Load/(N)	Transverse Load /(N)	Longitudinal Load /(N)
PGR	5286.75	5456.25	0.00
POL	4440.38	4092.19	27025.00
TCR	14996.72	12884.21	0.00
TCR	14996.72	12884.21	0.00
TCL	14996.72	12884.21	0.00
TCL	14996.72	12884.21	0.00
MCR	14996.72	12884.21	0.00
MCR	14996.72	12884.21	0.00
MCL	14996.72	12884.21	0.00
MCL	14996.72	12884.21	0.00
BCR	14996.72	12884.21	0.00
BCR	14996.72	12884.21	0.00
BCL	12014.18	9761.06	46305
BCL	14996.72	12884.21	0.00

Broken (Top and Bottom Conductor)					Broken (Top and Bottom Conductor)			
Join Label	**Vertical Load/(N)**	**Transverse Load /(N)**	**Longitudinal Load /(N)**		**Join Label**	**Vertical Load/(N)**	**Transverse Load /(N)**	**Longitudinal Load /(N)**
PGR	5286.75	5456.25	0.00		**PGR**	5286.75	5456.25	0.00
POL	5286.75	5456.25	0.00		**POL**	5286.75	5456.25	0.00
TCR	12014.18	9761.06	46305		**TCR**	14996.72	12884.21	0.00
TCR	14996.72	12884.21	0.00		**TCR**	14996.72	12884.21	0.00
TCL	14996.72	12884.21	0.00		**TCL**	12014.18	9761.06	46305
TCL	14996.72	12884.21	0.00		**TCL**	14996.72	12884.21	0.00
MCR	12014.18	9761.06	46305		**MCR**	14996.72	12884.21	0.00
MCR	14996.72	12884.21	0.00		**MCR**	14996.72	12884.21	0.00
MCL	14996.72	12884.21	0.00		**MCL**	12014.18	9761.06	46305
MCL	14996.72	12884.21	0.00		**MCL**	14996.72	12884.21	0.00
BCR	14996.72	12884.21	0.00		**BCR**	14996.72	12884.21	0.00
BCR	14996.72	12884.21	0.00		**BCR**	14996.72	12884.21	0.00
BCL	14996.72	12884.21	0.00		**BCL**	14996.72	12884.21	0.00
BCL	14996.72	12884.21	0.00		**BCL**	14996.72	12884.21	0.00

Broken (Middle and Bottom Conductor)					Broken (Middle and Bottom Conductor)			
Join Label	**Vertical Load/(N)**	**Transverse Load /(N)**	**Longitudinal Load /(N)**		**Join Label**	**Vertical Load/(N)**	**Transverse Load /(N)**	**Longitudinal Load /(N)**
PGR	5286.75	5456.25	0.00		**PGR**	5286.75	5456.25	0.00
POL	5286.75	5456.25	0.00		**POL**	5286.75	5456.25	0.00
TCR	14996.72	12884.21	0.00		**TCR**	14996.72	12884.21	0.00
TCR	14996.72	12884.21	0.00		**TCR**	14996.72	12884.21	0.00
TCL	14996.72	12884.21	0.00		**TCL**	14996.72	12884.21	0.00
TCL	14996.72	12884.21	0.00		**TCL**	14996.72	12884.21	0.00
MCR	12014.18	9761.06	46305		**MCR**	14996.72	12884.21	0.00
MCR	14996.72	12884.21	0.00		**MCR**	14996.72	12884.21	0.00
MCL	14996.72	12884.21	0.00		**MCL**	12014.18	9761.06	46305
MCL	14996.72	12884.21	0.00		**MCL**	14996.72	12884.21	0.00
BCR	12014.18	9761.06	46305		**BCR**	14996.72	12884.21	0.00
BCR	14996.72	12884.21	0.00		**BCR**	14996.72	12884.21	0.00
BCL	14996.72	12884.21	0.00		**BCL**	12014.18	9761.06	46305
BCL	14996.72	12884.21	0.00		**BCL**	14996.72	12884.21	0.00

Broken (Top and Bottom Conductor)					**Broken (Top and Bottom Conductor)**			
Join Label	**Vertical Load/(N)**	**Transverse Load /(N)**	**Longitudinal Load /(N)**		**Join Label**	**Vertical Load/(N)**	**Transverse Load /(N)**	**Longitudinal Load /(N)**
PGR	5286.75	5456.25	0.00		**PGR**	5286.75	5456.25	0.00
POL	5286.75	5456.25	0.00		**POL**	5286.75	5456.25	0.00
TCR	12014.18	9761.06	46305		**TCR**	14996.72	12884.21	0.00
TCR	14996.72	12884.21	0.00		**TCR**	14996.72	12884.21	0.00
TCL	14996.72	12884.21	0.00		**TCL**	12014.18	9761.06	46305
TCL	14996.72	12884.21	0.00		**TCL**	14996.72	12884.21	0.00
MCR	14996.72	12884.21	0.00		**MCR**	14996.72	12884.21	0.00
MCR	14996.72	12884.21	0.00		**MCR**	14996.72	12884.21	0.00
MCL	14996.72	12884.21	0.00		**MCL**	14996.72	12884.21	0.00
MCL	14996.72	12884.21	0.00		**MCL**	14996.72	12884.21	0.00
BCR	12014.18	9761.06	46305		**BCR**	14996.72	12884.21	0.00
BCR	14996.72	12884.21	0.00		**BCR**	14996.72	12884.21	0.00
BCL	14996.72	12884.21	0.00		**BCL**	12014.18	9761.06	46305
BCL	14996.72	12884.21	0.00		**BCL**	14996.72	12884.21	0.00

APPENDIX V : Sample of Tower Simulation Report

Note: Only Three pages of 645pages simulation report are attached.

```
******************************************************************************\par
*                                                                            *\par
* TOWER - Analysis and Design - Copyright Power Line Systems, Inc. 1986-2013 *\par
*                                                                            *\par
******************************************************************************\par
\par
Project Name: MCs\par
Project Notes: Tower\par
Project File: H:\\ACSR ZEBRA\\TD1\\+6M TD1.tow\par
Date run     : 3:12:57 PM Thursday, March 10, 2016\par
by           : Tower Version 13.20\par
Licensed to: Ceylon Electricity Board - Transmission Design\par
\par
Successfully performed linear analysis\par
}\par
\par
Member check option: ASCE 10\par
Connection rupture check: ASCE 10\par
Crossing diagonal check: Fixed  \par
Included angle check: None  \par
Climbing load check: None\par
Redundant members checked with: Actual Force\par
\par
\par
\b Joints Geometry:\b0\par
\par
\b  Joint     Symmetry X Coord. Y Coord. Z Coord. X Disp. Y Disp. Z Disp.  X Rot.  Y
Rot.  Z Rot.\b0\par
\b  Label          Code      (m)       (m)       (m)   Rest.   Rest.   Rest.   Rest.
Rest.   Rest.\b0\par
\b ---------------------------------------------------------------------------------
------------\b0\par
    1P  XY-Symmetry     2.73     2.73        0   Free     Free     Free     Free     Free
Free \par
    2P  XY-Symmetry     1.19     1.19    10.19   Free     Free     Free     Free     Free
Free \par
    3P  XY-Symmetry     0.75     0.75    23.04   Free     Free     Free     Free     Free
Free \par
    4P   X-Symmetry        0      4.1    23.04   Free     Free     Free     Free     Free
Free \par
    5P   X-Symmetry        0      4.1    19.04   Free     Free     Free     Free     Free
Free \par
    6P   X-Symmetry        0     4.23    14.64   Free     Free     Free     Free     Free
Free \par
    7P   X-Symmetry        0     4.62    10.19   Free     Free     Free     Free     Free
```

```
Free \par
    1X      X-GenXY     2.73    -2.73        0   Free    Free    Free    Free    Free
  Free \par
    7X        X-Gen        0    -4.62    10.19   Free    Free    Free    Free    Free
Free \par
\par
\b Secondary Joints:\b0\par
\par
\b     Joint     Symmetry Origin   End Fraction Elevation X Disp. Y Disp. Z Disp.  X
Rot.  Y Rot.  Z Rot.\b0\par
\b     Label         Code  Joint Joint                       Rest.   Rest.   Rest.
Rest.   Rest.   Rest.\b0\par
\b                                      (m)                                    \b0
\par
\b ---------------------------------------------------------------------------------
---------------------\b0\par
       30S  XY-Symmetry     1P    2P        0         4    Free    Free    Free    Free
Free    Free \par
       31S  XY-Symmetry     1P    2P        0      7.72    Free    Free    Free    Free
Free    Free \par
       32S  XY-Symmetry     2P    3P        0     11.34    Free    Free    Free    Free
Free    Free \par
       33S  XY-Symmetry     2P    3P        0      12.4    Free    Free    Free    Free
Free    Free \par
       34S  XY-Symmetry     2P    3P        0     14.64    Free    Free    Free    Free
Free    Free \par
       35S  XY-Symmetry     2P    3P        0      15.7    Free    Free    Free    Free
Free    Free \par
       36S  XY-Symmetry     2P    3P        0     16.68    Free    Free    Free    Free
Free    Free \par
       37S  XY-Symmetry     2P    3P        0     19.04    Free    Free    Free    Free
Free    Free \par
       41Y        Y-Gen    40S   40X      0.5         0    Free    Free    Free    Free
Free    Free \par
       42X        X-Gen    40S   40Y      0.5         0    Free    Free    Free    Free
Free    Free \par
       43Y        Y-Gen    38S   38X      0.5         0    Free    Free    Free    Free
Free    Free \par
       44X        X-Gen    38S   38Y      0.5         0    Free    Free    Free    Free
Free    Free \par
       45Y        Y-Gen    35S   35X      0.5         0    Free    Free    Free    Free
Free    Free \par
       46X        X-Gen    35S   35Y      0.5         0    Free    Free    Free    Free
Free    Free \par
       47Y        Y-Gen    32S   32X      0.5         0    Free    Free    Free    Free
Free    Free \par
       48X        X-Gen    32S   32Y      0.5         0    Free    Free    Free    Free
Free    Free \par
```

```
       49X       X-GenXY     1P     2P         0      -4.17    Free     Free     Free     Free
Free     Free \par
      49XY      XY-GenXY     1P     2P         0      -4.17    Free     Free     Free     Free
Free     Free \par
       49Y       Y-GenXY     1P     2P         0      -4.17    Free     Free     Free     Free
Free     Free \par
       50X       X-GenXY     1P     2P         0     -10.17    Fixed    Fixed    Fixed    Free
Fixed    Fixed\par
      50XY      XY-GenXY     1P     2P         0     -10.17    Fixed    Fixed    Fixed    Free
Fixed    Fixed\par



 0i0.44E2X         X-Gen    30S     1Y    0.4377         0    Free     Free     Free     Free
Free     Free \par
\par
The model contains 20 primary and 100 secondary joints for a total of 120 joints.\par
\par
\b Steel Material Properties:\b0\par
\par
\b          Steel     Modulus   Yield Ultimate      Member       Member   Member   Member
Member   Member\b0\par
   C-LG-3       g31X    -1.074    82.478   -19.620    79.007   -16.428    12.237     7.785\par
   C-LG-3      g31XY    -0.779   -82.535    17.298   -79.571    13.996   -13.001    -9.014\par
   C-LG-3       g31Y   -34.625    17.268   -82.550    13.955   -79.479    -8.904   -13.036\par
   D-LG-4       g32P    27.752   -14.589    67.094   -11.931    64.344     6.802    10.380\par
   D-LG-4       g32X     0.593   -67.540   -14.151    64.876   -11.503    10.837     7.375\par
   D-LG-4      g32XY     0.811   -67.402    15.872   -64.460    13.330   -10.152    -6.454\par
   D-LG-4       g32Y   -26.872    16.887   -66.395    14.355   -63.538    -5.574    -9.155\par
   D-LG-4      g32BP   -28.189     7.544   -74.966     7.454   -61.455   -10.359   -22.780\par
   D-LG-4      g32BX    -3.332   -75.859     6.644   -62.261     6.544   -23.660   -11.122\par
   D
```

....

```
\par
*** Weight of structure (N)\par
    Weight of Angles*Section DLF:     50857.9\par
    Weight of Suspensions:            16600.0\par
    Total:                            67457.9\par
\par
\par
*** End of Report\par
\par
```

APPENDIX VI: Profile Design Summary Report

```
PLS-CADD Version 9.20    7:49:01 AM Sunday, March 27, 2016
Project Name: 'D:\Academic\MSC\2nd year\Profile Design\Flat\paddy\ACSR\flat
paddy.DON'

Structure List Report

Struct. Station   Line   Ahead  Height Offset Orient
Name/Description/Comments/Material
 Number          Angle    Span  Adjust Adjust  Angle
            (m)  (deg)     (m)     (m)    (m)  (deg)
-------------------------------------------------------------------------------------
-----------------------------------
      1    0.00   0.00  361.35    0.00   0.00   0.00 d:\academic\msc\2nd year\profile
design\flat\paddy\acsr\td1\td1+03m
                                             TD1+03
                                                     embed len=0.30
      2  361.35   0.00  329.95    0.00   0.00   0.00 d:\academic\msc\2nd year\profile
design\flat\paddy\acsr\tdl\tdl+09m
                                                     TDL+09
                                                     embed len=0.30
      3  691.30   0.00  322.21    0.00   0.00   0.00 d:\academic\msc\2nd year\profile
design\flat\paddy\acsr\tdl\tdl+00m
                                                     TDL+00
                                                     embed len=0.30
      4 1013.51   0.00  336.63    0.00   0.00   0.00 d:\academic\msc\2nd year\profile
design\flat\paddy\acsr\tdl\tdl+00m
                                                     TDL+00
                                                     embed len=0.30
      5 1350.14   0.00  361.04    0.00   0.00   0.00 d:\academic\msc\2nd year\profile
design\flat\paddy\acsr\tdl\tdl+09m
                                                     TDL+09
                                                     embed len=0.30
      6 1711.18   0.00  349.81    0.00   0.00   0.00 d:\academic\msc\2nd year\profile
design\flat\paddy\acsr\tdl\tdl+03m
                                                     TDL+03
                                                     embed len=0.30
      7 2060.99   0.00  315.88    0.00   0.00   0.00 d:\academic\msc\2nd year\profile
design\flat\paddy\acsr\tdl\tdl+03m
                                                     TDL+03
                                                     embed len=0.30
      8 2376.87   0.00  371.88    0.00   0.00   0.00 d:\academic\msc\2nd year\profile
design\flat\paddy\acsr\tdl\tdl+03m
                                                     TDL+03
                                                     embed len=0.30
      9 2748.75   0.00  344.75    0.00   0.00   0.00 d:\academic\msc\2nd year\profile
design\flat\paddy\acsr\tdl\tdl+00m
```

```
                                                    TDL+00
                                                    embed len=0.30
     10 3093.50  29.55  303.52    0.00    0.00    0.00 d:\academic\msc\2nd year\profile
design\flat\paddy\acsr\td3\td3+03m
                                                    TD3+03
                                                    embed len=0.30
     11 3397.02   0.00  268.59    0.00    0.00    0.00 d:\academic\msc\2nd year\profile
design\flat\paddy\acsr\tdl\tdl-03m
                                                    TDL-03
                                                    embed len=0.30
     12 3665.61 -27.25  327.73    0.00    0.00    0.00 d:\academic\msc\2nd year\profile
design\flat\paddy\acsr\td3\td3+06m
                                                    TD3+06
                                                    embed len=0.30
     13 3993.34   0.00  322.99    0.00    0.00    0.00 d:\academic\msc\2nd year\profile
design\flat\paddy\acsr\tdl\tdl+00m
                                                    TDL+00
                                                    embed len=0.30
     14 4316.33   0.00  323.79    0.00    0.00    0.00 d:\academic\msc\2nd year\profile
design\flat\paddy\acsr\tdl\tdl+06m
                                                    TDL+06
                                                    embed len=0.30
     15 4640.12   0.00  316.40    0.00    0.00    0.00 d:\academic\msc\2nd year\profile
design\flat\paddy\acsr\tdl\tdl+00m
                                                    TDL+00
                                                    embed len=0.30
     16 4956.52   0.00  331.77    0.00    0.00    0.00 d:\academic\msc\2nd year\profile
design\flat\paddy\acsr\tdl\tdl+03m
                                                    TDL+03
                                                    embed len=0.30
     17 5288.29   0.00  318.24    0.00    0.00    0.00 d:\academic\msc\2nd year\profile
design\flat\paddy\acsr\tdl\tdl+00m
                                                    TDL+00
                                                    embed len=0.30
     18 5606.53   0.00  338.76    0.00    0.00    0.00 d:\academic\msc\2nd year\profile
design\flat\paddy\acsr\tdl\tdl+03m
                                                    TDL+03
                                                    embed len=0.30
     19 5945.29   0.00  295.82    0.00    0.00    0.00 d:\academic\msc\2nd year\profile
design\flat\paddy\acsr\tdl\tdl+00m
                                                    TDL+00
                                                    embed len=0.30
     20 6241.11   0.00    0.00    0.00    0.00    0.00 d:\academic\msc\2nd year\profile
design\flat\paddy\acsr\td1\td1-03m
                                                    TD1-03
                                                    embed len=0.30
```

Structure Coordinates Report

Struct. Number	Station (m)	Ahead Span (m)	X (m)	Y (m)	Z (m)	Structure Name
1	0.00	361.35	261408.32	256824.92	161.62	td1+03m
2	361.35	329.95	261675.56	257068.13	152.21	tdl+09m
3	691.30	322.21	261919.59	257290.21	149.28	tdl+00m
4	1013.51	336.63	262157.88	257507.09	149.49	tdl+00m
5	1350.14	361.04	262406.85	257733.66	142.84	tdl+09m
6	1711.18	349.81	262673.86	257976.67	140.49	tdl+03m
7	2060.99	315.88	262932.57	258212.12	139.91	tdl+03m
8	2376.87	371.88	263166.19	258424.73	138.66	tdl+03m
9	2748.75	344.75	263441.22	258675.03	141.08	tdl+00m
10	3093.50	303.52	263696.19	258907.08	139.39	td3+03m
11	3397.02	268.59	263992.22	258974.08	134.02	tdl-03m
12	3665.61	327.73	264254.19	259033.37	132.45	td3+06m
13	3993.34	322.99	264505.25	259244.03	131.18	tdl+00m
14	4316.33	323.79	264752.68	259451.63	130.76	tdl+06m
15	4640.12	316.40	265000.72	259659.75	130.25	tdl+00m
16	4956.52	331.77	265243.10	259863.13	130.90	tdl+03m
17	5288.29	318.24	265497.26	260076.38	131.05	tdl+00m
18	5606.53	338.76	265741.05	260280.93	130.98	tdl+03m
19	5945.29	295.82	266000.56	260498.68	130.22	tdl+00m
20	6241.11	0.00	266227.18	260688.82	138.17	td1-03m

Structure Attachment Coordinates

Coordinates are for weather case 'MaxTemp-NoWind', Initial RS, wind from the left

```
Struct. Set PhaseStructure    Set ---------Insulator-------- | -----------Wire-------
---- | ------------Mid----------- | ------------Low----------- | -----TIN Z below----
|
 Number No.   No.    Name   Label ----------Attach---------- | ----------Attach------
---- | -----------Span----------- | -----------Point---------- |Insulator  Mid    Low
|
                                  -----------Point---------- | -----------Point------
---- | -----------Point---------- |                          | Attach   Span  Point
|
                                          X         Y      Z |         X         Y
Z |         X         Y      Z |         X         Y      Z | ---Point-----        |
                                  ------------(m)----------- | ------------(m)-------
---- | ------------(m)----------- | ------------(m)----------- | ---------(m)--------
|
-----------------------------------------------------------------------------------
-----------------------------------------------------------------------------------
--
```

```
      1    3      1 td1+03m     P1-R 261412.17 256820.69 191.33    261414.97 256823.24
190.89    261547.02 256943.76 179.76    261558.57 256954.30 179.68      0.00    0.00
6.80 154.59    265874.28 260385.66 144.15    265888.51 260397.60 144.05      0.00    0.00
                3                  265744.78 260276.49 150.89    265744.78 260276.49
148.79    265874.54 260385.35 138.35    265888.77 260397.29 138.25      0.00    0.00

     19    3      1 tdl+00m     P1-R 266003.90 260494.69 158.68    266003.91 260494.68
156.58    266115.93 260588.34 152.68    266094.34 260570.29 152.44      0.00    0.00
                2                  266004.03 260494.54 152.93    266004.04 260494.53
150.83    266116.07 260588.17 146.85    266095.13 260570.67 146.63      0.00    0.00
                3                  266004.29 260494.23 147.13    266004.30 260494.21
145.03    266116.39 260587.79 140.95    266096.31 260571.03 140.75      0.00    0.00
```

Section Sagging Data

```
Sec.     Cable  From    To  Voltage  Ruling -----------Sagging Data-------------
Display
 No.      File  Str.  Str.             Span  Condition  Temp.  Catenary   Horiz.
Catenary
          Name                                                 Constant  Tension
Constant
                              (kV)      (m)          (deg C)       (m)       (N)
(m)
-------------------------------------------------------------------------------------
-----
   1 zebra.dat    1     10      132    344.9   Creep RS    32.0    1785.6  28554.9
1488.3
   2 zebra.dat    10    12      132    287.1   Creep RS    32.0    1785.6  28554.9
1412.2
   3 zebra.dat    12    20      132    322.8   Creep RS    32.0    1785.6  28554.9
1461.6
```


Section Stringing Data

```
 Section     CableStruct.     Set  Phasing Set
  Number       Name Number Number          Label
-------------------------------------------------
       1 zebra.dat      1      3      123 P1-R
                        2      3      123 P1-R
                        3      3      123 P1-R
                        4      3      123 P1-R
                        5      3      123 P1-R
                        6      3      123 P1-R
                        7      3      123 P1-R
                        8      3      123 P1-R
                        9      3      123 P1-R
                       10      3      123 P1-R
       2 zebra.dat     10      3      123 P1-R
```

		11	3	123 P1-R
		12	3	123 P1-R
3	zebra.dat	12	3	123 P1-R
		13	3	123 P1-R
		14	3	123 P1-R
		15	3	123 P1-R
		16	3	123 P1-R
		17	3	123 P1-R
		18	3	123 P1-R
		19	3	123 P1-R

Section Geometry Data

Notes: Lengths are arc lengths along the wire at 32 (deg C), Initial.
Lengths are adjusted for the number of phases, the number of subconductors and the length of strain insulators..

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	zebra.dat	1	10	3	1	315.9	371.9	344.9	9263.9
2	zebra.dat	10	12	3	1	270.2	301.7	287.1	1694.5
3	zebra.dat	12	20	3	1	295.8	338.8	322.8	7716.9

Structure Material List Report

Structure File Name	Count
d:\academic\msc\2nd year\profile design\flat\paddy\acsr\td1\td1+03m	1
d:\academic\msc\2nd year\profile design\flat\paddy\acsr\td1\td1-03m	1
d:\academic\msc\2nd year\profile design\flat\paddy\acsr\td3\td3+03m	1
d:\academic\msc\2nd year\profile design\flat\paddy\acsr\td3\td3+06m	1
d:\academic\msc\2nd year\profile design\flat\paddy\acsr\tdl\tdl+00m	7
d:\academic\msc\2nd year\profile design\flat\paddy\acsr\tdl\tdl+03m	5
d:\academic\msc\2nd year\profile design\flat\paddy\acsr\tdl\tdl+06m	1
d:\academic\msc\2nd year\profile design\flat\paddy\acsr\tdl\tdl+09m	2
d:\academic\msc\2nd year\profile design\flat\paddy\acsr\tdl\tdl-03m	1
Total number of structures =	20

Cable Material List Report

Notes: Lengths are arc lengths along the wire at 32 (deg C), Initial.
Lengths are adjusted for the number of phases, the number of subconductors and the length of strain insulators.

Cable **Number**
Cable Length

APPENDIX VII : Material Schedules of Transmission Lines

Non Populated Flat Terrain

	Description	Unit	ACSR	ACCC	ZTACIR /AW	ACSS/TW	ACCR	GTACSR	LL-ACSR/ AS	LL-TACSR/ AS
Supply of Conductors including joints and jumper leads										
	400 mm^2 Zebra 61/3.18 mm ACSR conductor (Including mid span joints) units	km	37.4	37.4	37.4	37.4	37.4	37.4	37.4	37.4
	7/3.25 MM Galvanized earth wire including mid span units	km	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2
	OPGW Conductors and OPGW Accessories	km	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2
Supply of Damping System (Vibration dampers)										
	Vibration dampers for 400 mm^2 Zebra (61/3.18 mm) conductor	Nos	450	450	462	462	450	450	450	450
	Vibration dampers for OPGW	Nos	76	76	76	76	76	76	76	76
	Vibration dampers for GSW	Nos	75	75	77	77	75	75	75	75
Supply of Insulator sets										
	Normal suspension insulator sets for 400 mm^2 ACSR conductor	Nos	96	96	96	96	96	96	96	96
	Normal tension insulator sets for 400 mm^2 ACSR conductor	Nos	48	48	48	48	48	48	48	48
	Jumper suspension insulator sets	Nos	0	0	0	0	0	0	0	0
	Light duty tension insulator sets for 400 mm^2 ACSR conductor	Nos	12	12	12	12	12	12	12	12
Supply of self-supporting towers and extended towers of the suspension type complete with all fittings										
	Type TDL towers with -3m extension	Nos	1	9	1	0	1	2	2	2
	Type TDL towers with ± 0m extension	Nos	7	5	6	5	7	7	6	6
	Type TDL towers with +3m extension	Nos	5	2	6	6	5	4	5	6
	Type TDL towers with +6m extension	Nos	1	0	1	3	2	2	3	2
	Type TDL towers with +9m extension	Nos	2	0	2	2	1	1	0	0
	Type TDL towers with +12m extension	Nos	0	0	0	0	0	0	0	0
Supply of self-supporting towers and extended towers of the Tension (TD1) type complete with all fittings										
	Type TD1 towers with -3m extension	Nos	1	1	1	1	1	1	1	1
	Type TD1 towers with ± 0m extension	No	0	1	0	0	0	0	0	0
	Type TD1 towers with +3m extension	Nos	2	1	2	1	2	2	2	2
	Type TD1 towers with +6m extension	Nos	0	0	0	0	0	0	0	0
	Type TD1 towers with +9m extension	Nos	0	0	0	0	0	0	0	0
	Type TD1 towers with +12m extension	Nos	0	0	0	0	0	0	0	0
Supply of self-supporting towers and extended towers of the Tension (TD3) type complete with all fittings										
	Type TD3 towers with -3m extension	Nos	0	0	0	0	0	0	0	0
	Type TD3 towers with ± 0m extension	Nos	0	0	0	1	0	0	0	0
	Type TD3 towers with +3m extension	Nos	0	1	0	1	0	0	0	0
	Type TD3 towers with +6m extension	Nos	1	0	1	0	1	1	1	1
	Type TD3 towers with +9m extension	Nos	0	0	0	0	0	0	0	0
	Type TD3 towers with +12m extension	Nos	0	0	0	0	0	0	0	0
CIVIL WORKS										
Foundation complete for TDL towers and all extensions										
	Foundation type 3	Nos	16	16	16	16	16	16	16	16
	Foundation type 4A	Nos	0	0	0	0	0	0	0	0
Foundation complete for TD1 towers and all extensions										
	Foundation type 3	Nos	3	3	3	2	3	3	3	3
	Foundation type 4A	Nos	0	0	0	0	0	0	0	0
Foundation complete for TD3 towers and all extensions										
	Foundation type 3	Nos	1	1	1	2	1	1	1	1
	Foundation type 4A	Nos	0	0	0	0	0	0	0	0

Survey										
	Preliminary Survey *	km	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2
	Profile Survey	km	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2
TOTAL										
INSTALLATIONS										
Erection of self-supporting towers and extended towers of the suspension type complete with all fittings & including Earthing System										
	Type TDL towers with ± 0m extension	Nos	1	9	1	0	1	2	2	2
	Type TDL towers with -3m extension	Nos	7	5	6	5	7	7	6	6
	Type TDL towers with +3m extension	Nos	5	2	6	6	5	4	5	6
	Type TDL towers with +6m extension	Nos	1	0	1	3	2	2	3	2
	Type TDL towers with +9m extension	Nos	2	0	2	2	1	1	0	0
	Type TDL towers with +12m extension	Nos	0	0	0	0	0	0	0	0
Erection of self-supporting towers and extended towers of the Tension (TD1) type complete with all fittings including Earthing System										
	Type TD1 towers with ± 0m extension	Nos	1	1	1	1	1	1	1	1
	Type TD1 towers with -3m extension	Nos	0	1	0	0	0	0	0	0
	Type TD1 towers with +3m extension	Nos	2	1	2	1	2	2	2	2
	Type TD1 towers with +6m extension	Nos	0	0	0	0	0	0	0	0
	Type TD1 towers with +9m extension	Nos	0	0	0	0	0	0	0	0
	Type TD1 towers with +12m extension	Nos	0	0	0	0	0	0	0	0
Erection of self-supporting towers and extended towers of the Tension (TD3) type complete with all fittings including Earthing System										
	Type TD3 towers with ± 0m extension	Nos	0	0	0	0	0	0	0	0
	Type TD3 towers with -3m extension	Nos	0	0	0	1	0	0	0	0
	Type TD3 towers with +3m extension	Nos	0	1	0	1	0	0	0	0
	Type TD3 towers with +6m extension	Nos	1	0	1	0	1	1	1	1
	Type TD3 towers with +9m extension	Nos	0	0	0	0	0	0	0	0
	Type TD3 towers with +12m extension	Nos	0	0	0	0	0	0	0	0
Stringing										
		km	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2

Populated Flat Terrain

	Description	Unit	ACSR	ACCC	ZTACIR /AW	ACSS/TW	ACCR	GTACSR	LL-ACSR/AS	LL-TACSR/AS
Supply of Conductors including joints and jumper leads										
	400 mm^2 Zebra 61/3.18 mm ACSR conductor (Including mid span joints) units	km	34.6	34.6	34.6	34.6	34.6	34.6	34.6	34.6
	7/3.25 MM Galvanized earth wire including mid span units	km	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8
	OPGW Conductors and OPGW Accessories	km	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8
Supply of Damping System (Vibration dampers)										
	Vibration dampers for 400 mm^2 Zebra (61/3.18 mm) conductor	No	342	342	318	318	378	342	342	342
	Vibration dampers for OPGW	No	70	70	66	66	74	70	70	70
	Vibration dampers for GSW	No	57	57	53	53	63	57	57	57
e) Supply of Insulator sets										
	Normal suspension insulator sets for 400 mm^2 ACSR conductor	No	30	30	36	36	30	30	30	30
	Normal tension insulator sets for 400 mm^2 ACSR conductor	No	180	180	168	168	180	180	180	180
	Jumper suspension insulator sets	No	6	6	6	6	6	6	6	6
	Light duty tension insulator sets for 400 mm^2 ACSR conductor	No	12	12	12	12	12	12	12	12

Supply of self-supporting towers and extended towers of the suspension type complete with all fittings									
	Type TDL towers with -3m extension	No	0	2	2	2	0	1	1	1
	Type TDL towers with ± 0m extension	No	2	2	0	1	2	0	0	0
	Type TDL towers with +3m extension	No	1	1	1	0	1	3	2	2
	Type TDL towers with +6m extension	No	2	0	2	1	2	0	2	2
	Type TDL towers with +9m extension	No	0	0	0	1	0	1	0	0
	Type TDL towers with +12m extension	No	0	0	1	1	0	0	0	0
Supply of self-supporting towers and extended towers of the Tension (TD1) type complete with all fittings									
	Type TD1 towers with -3m extension	No	0	1	0	0	0	0	0	0
	Type TD1 towers with ± 0m extension	No	1	4	0	0	1	1	1	1
	Type TD1 towers with +3m extension	No	3	0	6	6	4	4	4	4
	Type TD1 towers with +6m extension	No	0	1	0	0	0	0	0	0
	Type TD1 towers with +9m extension	No	0	0	0	0	1	0	0	0
	Type TD1 towers with +12m extension	No	1	0	0	0	0	1	1	1
Supply of self-supporting towers and extended towers of the Tension (TD3) type complete with all fittings									
	Type TD3 towers with -3m extension	No	0	1	0	1	1	1	1	1
	Type TD3 towers with ± 0m extension	No	3	4	3	2	3	3	3	4
	Type TD3 towers with +3m extension	No	3	1	2	3	1	1	1	0
	Type TD3 towers with +6m extension	No	1	0	1	1	1	1	1	1
	Type TD3 towers with +9m extension	No	0	0	1	0	0	0	0	0
	Type TD3 towers with +12m extension	No	1	0	0	0	1	1	1	1
Supply of self-supporting towers and extended towers of the Tension (TD6) type complete with all fittings									
	Type TD6 towers with -3m extension	No	0	1	1	1	0	2	2	2
	Type TD6 towers with ± 0m extension	No	2	1	1	0	2	0	0	0
	Type TD6 towers with +3m extension	No	0	0	0	1	0	0	0	0
	Type TD6 towers with +6m extension	No	0	0	0	0	0	0	0	0
	Type TD6 towers with +9m extension	No	0	0	0	0	0	0	0	0
	Type TD6 towers with +12m extension	No	0	0	0	0	0	0	0	0
CIVIL WORKS									
Foundation complete for TDL towers and all extensions									
	Foundation type 3	No	5	5	6	6	5	5	5	5
	Foundation type 4A	No	0	0	0	0	0	0	0	0
Foundation complete for TD1 towers and all extensions									
	Foundation type 3	No	5	6	6	6	6	6	6	6
	Foundation type 4A	No	0	0	0	0	0	0	0	0
Foundation complete for TD3 towers and all extensions									
	Foundation type 3	No	8	6	7	7	7	7	7	7
	Foundation type 4A	No	0	0	0	0	0	0	0	0
Foundation complete for TD6 towers and all extensions									
	Foundation type 3	No	2	2	2	2	2	2	2	2
	Foundation type 4A	No	0	0	0	0	0	0	0	0
Survey									
	Preliminary Survey *	km	6	6	6	6	6	6	6	6
	Profile Survey	km	6	6	6	6	6	6	6	6
TOTAL									
INSTALLATIONS									
Erection of self-supporting towers and extended towers of the suspension type complete with all fittings & including Earthing System									
	Type TDL towers with ± 0m extension	No	0	2	2	2	0	1	1	1
	Type TDL towers with -3m extension	No	2	2	0	1	2	0	0	0
	Type TDL towers with +3m extension	No	1	1	1	0	1	3	2	2
	Type TDL towers with +6m extension	No	2	0	2	1	2	0	2	2
	Type TDL towers with +9m extension	No	0	0	0	1	0	1	0	0
	Type TDL towers with +12m extension	No	0	0	1	1	0	0	0	0

Erection of self-supporting towers and extended towers of the Tension (TD1) type complete with all fittings including Earthing System										
	Type TD1 towers with ± 0m extension	No	0	1	0	0	0	0	0	0
	Type TD1 towers with -3m extension	No	1	4	0	0	1	1	1	1
	Type TD1 towers with +3m extension	No	3	0	6	6	4	4	4	4
	Type TD1 towers with +6m extension	No	0	1	0	0	0	0	0	0
	Type TD1 towers with +9m extension	No	0	0	0	0	1	0	0	0
	Type TD1 towers with +12m extension	No	1	0	0	0	0	1	1	1
Erection of self-supporting towers and extended towers of the Tension (TD3) type complete with all fittings including Earthing System										
	Type TD3 towers with ± 0m extension	No	0	1	0	1	1	1	1	1
	Type TD3 towers with -3m extension	No	3	4	3	2	3	3	3	4
	Type TD3 towers with +3m extension	No	3	1	2	3	1	1	1	0
	Type TD3 towers with +6m extension	No	1	0	1	1	1	1	1	1
	Type TD3 towers with +9m extension	No	0	0	1	0	0	0	0	0
	Type TD3 towers with +12m extension	No	1	0	0	0	1	1	1	1
Erection of self-supporting towers and extended towers of the Tension (TD6) type complete with all fittings including Earthing System										
	Type TD6 towers with ± 0m extension	No	0	1	1	1	0	2	2	2
	Type TD6 towers with -3m extension	No	2	1	1	0	2	0	0	0
	Type TD6 towers with +3m extension	No	0	0	0	1	0	0	0	0
	Type TD6 towers with +6m extension	No	0	0	0	0	0	0	0	0
	Type TD6 towers with +9m extension	No	0	0	0	0	0	0	0	0
	Type TD6 towers with +12m extension	No	0	0	0	0	0	0	0	0
Stringing										
		km	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8

Paddy Flat Terrain

	Description	Unit	ACSR	ACCC	ZTACIR /AW	ACSS/TW	ACCR	GTACSR	LL-ACSR/ AS	LL-TACSR/ AS
Supply of Conductors including joints and jumper leads										
	400 mm² Zebra 61/3.18 mm ACSR conductor (Including mid span joints) units	km	36	36	36	36	36	36	36	36
	7/3.25 MM Galvanized earth wire including mid span units	km	6	6	6	6	6	6	6	6
	OPGW Conductors and OPGW Accessories	km	6	6	6	6	6	6	6	6
Supply of Damping System (Vibration dampers)										
	Vibration dampers for 400 mm² Zebra (61/3.18 mm) conductor	No	450	450	462	462	450	450	450	450
	Vibration dampers for OPGW	No	76	76	76	76	76	76	76	76
	Vibration dampers for GSW	No	75	75	77	77	75	75	75	75
Supply of Insulator sets										
	Normal suspension insulator sets for 400 mm² ACSR conductor	Nos	96	96	96	96	96	96	96	96
	Normal tension insulator sets for 400 mm² ACSR conductor	No	48	48	48	48	48	48	48	48
	Jumper suspension insulator sets	No	0	0	0	0	0	0	0	0
	Light duty tension insulator sets for 400 mm² ACSR conductor	No	12	12	12	12	12	12	12	12
Supply of self-supporting towers and extended towers of the suspension type complete with all fittings										
	Type TDL towers with -3m extension	No	1	9	1	0	1	2	2	2
	Type TDL towers with ± 0m extension	No	7	5	6	5	7	7	6	6
	Type TDL towers with +3m extension	No	5	2	6	6	5	4	5	6
	Type TDL towers with +6m extension	No	1	0	1	3	2	2	3	2

	Type TDL towers with +9m extension	No	2	0	2	2	1	1	0	0
	Type TDL towers with +12m extension	No	0	0	0	0	0	0	0	0
Supply of self-supporting towers and extended towers of the Tension (TD1) type complete with all fittings										
	Type TD1 towers with -3m extension	No s	1	1	1	1	1	1	1	1
	Type TD1 towers with ± 0m extension	No	0	1	0	0	0	0	0	0
	Type TD1 towers with +3m extension	No	2	1	2	1	2	2	2	2
	Type TD1 towers with +6m extension	No	0	0	0	0	0	0	0	0
	Type TD1 towers with +9m extension	No	0	0	0	0	0	0	0	0
	Type TD1 towers with +12m extension	No	0	0	0	0	0	0	0	0
Supply of self-supporting towers and extended towers of the Tension (TD3) type complete with all fittings										
	Type TD3 towers with -3m extension	No	0	0	0	0	0	0	0	0
	Type TD3 towers with ± 0m extension	No	0	0	0	1	0	0	0	0
	Type TD3 towers with +3m extension	No	0	1	0	1	0	0	0	0
	Type TD3 towers with +6m extension	No	1	0	1	0	1	1	1	1
	Type TD3 towers with +9m extension	No	0	0	0	0	0	0	0	0
	Type TD3 towers with +12m extension	No	0	0	0	0	0	0	0	0
CIVIL WORKS										
Foundation complete for TDL towers and all extensions										
	Foundation type 3	No	0	0	0	0	0	0	0	0
	Foundation type 4A	No	16	16	16	16	16	16	16	16
Foundation complete for TD1 towers and all extensions										
	Foundation type 3	No	0	0	0	0	0	0	0	0
	Foundation type 4A	No	3	3	3	2	3	3	3	3
Foundation complete for TD3 towers and all extensions										
	Foundation type 3	No	0	0	0	0	0	0	0	0
	Foundation type 4A	No	1	1	1	2	1	1	1	1
Survey										
	Preliminary Survey *	km	6	6	6	6	6	6	6	6
	Profile Survey	km	6	6	6	6	6	6	6	6
TOTAL										
INSTALLATIONS										
Erection of self-supporting towers and extended towers of the suspension type complete with all fittings & including Earthing System										
	Type TDL towers with ± 0m extension	No	1	9	1	0	1	2	2	2
	Type TDL towers with -3m extension	No	7	5	6	5	7	7	6	6
	Type TDL towers with +3m extension	Ns	5	2	6	6	5	4	5	6
	Type TDL towers with +6m extension	No	1	0	1	3	2	2	3	2
	Type TDL towers with +9m extension	No	2	0	2	2	1	1	0	0
	Type TDL towers with +12m extension	No	0	0	0	0	0	0	0	0
Erection of self-supporting towers and extended towers of the Tension (TD1) type complete with all fittings including Earthing System										
	Type TD1 towers with ± 0m extension	No	1	1	1	1	1	1	1	1
	Type TD1 towers with -3m extension	No	0	1	0	0	0	0	0	0
	Type TD1 towers with +3m extension	No	2	1	2	1	2	2	2	2
	Type TD1 towers with +6m extension	No	0	0	0	0	0	0	0	0
	Type TD1 towers with +9m extension	No	0	0	0	0	0	0	0	0
	Type TD1 towers with +12m extension	No	0	0	0	0	0	0	0	0
Erection of self-supporting towers and extended towers of the Tension (TD3) type complete with all fittings including Earthing System										
	Type TD3 towers with ± 0m extension	No	0	0	0	0	0	0	0	0
	Type TD3 towers with -3m extension	No	0	0	0	1	0	0	0	0
	Type TD3 towers with +3m extension	No	0	1	0	1	0	0	0	0
	Type TD3 towers with +6m extension	No	1	0	1	0	1	1	1	1
	Type TD3 towers with +9m extension	No	0	0	0	0	0	0	0	0
	Type TD3 towers with +12m extension	No	0	0	0	0	0	0	0	0
Stringing										
		km	6	6	6	6	6	6	6	6

Non Populated Hilly Terrain

	Description	Unit	ACSR	ACCC	ZTACIR /AW	ACSS/TW	ACCR	GTACSR	LL-ACSR/ AS	LL-TACSR/ AS
Supply of Conductors including joints and jumper leads										
	400 mm^2 Zebra 61/3.18 mm ACSR conductor (Including mid span joints) units	km	36.6	36.6	36.6	36.6	36.6	36.6	36.6	36.6
	7/3.25 MM Galvanized earth wire including mid span units	km	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1
	OPGW Conductors and OPGW Accessories	km	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1
Supply of Damping System (Vibration dampers)										
	Vibration dampers for 400 mm^2 Zebra (61/3.18 mm) conductor	Nos	336	348	336	336	336	336	348	336
	Vibration dampers for OPGW	Nos	64	64	64	66	64	64	64	64
	Vibration dampers for GSW	Nos	56	58	56	56	56	56	58	56
Supply of Insulator sets										
	Normal suspension insulator sets for 400 mm^2 ACSR conductor	Nos	12	12	12	12	12	12	12	6
	Normal tension insulator sets for 400 mm^2 ACSR conductor	Nos	204	204	204	204	204	204	204	216
	Jumper suspension insulator sets	Nos	6	6	6	6	6	6	6	6
	Light duty tension insulator sets for 400 mm^2 ACSR conductor	Nos	12	12	12	12	12	12	12	12
Supply of self-supporting towers and extended towers of the suspension type complete with all fittings										
	Type TDL towers with -3m extension	Nos	0	1	0	0	1	1	1	1
	Type TDL towers with ± 0m extension	Nos	1	1	1	0	0	0	0	1
	Type TDL towers with +3m extension	Nos	1	0	1	1	0	1	1	0
	Type TDL towers with +6m extension	Nos	0	0	0	1	1	0	0	0
	Type TDL towers with +9m extension	Nos	0	0	0	0	0	0	0	0
	Type TDL towers with +12m extension	Nos	0	0	0	0	0	0	0	0
Supply of self-supporting towers and extended towers of the Tension (TD1) type complete with all fittings										
	Type TD1 towers with -3m extension	Nos	1	3	1	0	0	1	0	1
	Type TD1 towers with ± 0m extension	No	0	2	0	1	2	1	2	1
	Type TD1 towers with +3m extension	Nos	3	0	3	1	1	3	1	3
	Type TD1 towers with +6m extension	Nos	2	2	1	2	2	1	2	1
	Type TD1 towers with +9m extension	Nos	1	1	1	0	2	2	2	2
	Type TD1 towers with +12m extension	Nos	4	3	5	7	4	3	4	3
Supply of self-supporting towers and extended towers of the Tension (TD3) type complete with all fittings										
	Type TD3 towers with -3m extension	Nos	1	2	1	0	1	1	1	1
	Type TD3 towers with ± 0m extension	Nos	2	2	3	2	3	2	3	3
	Type TD3 towers with +3m extension	Nos	1	0	0	1	0	1	0	0
	Type TD3 towers with +6m extension	Nos	0	0	0	0	0	0	0	0
	Type TD3 towers with +9m extension	Nos	0	0	0	1	0	0	0	0
	Type TD3 towers with +12m extension	Nos	0	0	0	0	0	0	0	0
Supply of self-supporting towers and extended towers of the Tension (TD6) type complete with all fittings										
	Type TD6 towers with -3m extension	Nos	1	1	0	0	1	1	1	1
	Type TD6 towers with ± 0m extension	Nos	0	0	1	1	0	0	0	0
	Type TD6 towers with +3m extension	Nos	0	1	1	0	1	1	1	0
	Type TD6 towers with +6m extension	Nos	1	0	0	1	0	0	0	1
	Type TD6 towers with +9m extension	Nos	0	0	0	0	0	0	0	0
	Type TD6 towers with +12m extension	Nos	0	0	0	0	0	0	0	0
	Type TDT towers with +12m extension(TDT + 12)	Nos	0	0	0	0	0	0	0	0

CIVIL WORKS										
Foundation complete for TDL towers and all extensions										
	Foundation type 3	Nos	2	2	2	2	2	2	2	2
	Foundation type 4A	Nos	0	0	0	0	0	0	0	0
Foundation complete for TD1 towers and all extensions										
	Foundation type 3	Nos	11	11	11	11	11	11	11	11
	Foundation type 4A	Nos	0	0	0	0	0	0	0	0
Foundation complete for TD3 towers and all extensions										
	Foundation type 3	Nos	4	4	4	4	4	4	4	4
	Foundation type 4A	Nos	0	0	0	0	0	0	0	0
Foundation complete for TD6 towers and all extensions										
	Foundation type 3	Nos	2	2	2	2	2	2	2	2
	Foundation type 4A	Nos	0	0	0	0	0	0	0	0
Survey										
	Preliminary Survey	km	6	6	6	6	6	6	6	6
	Profile Survey	km	6	6	6	6	6	6	6	6
TOTAL										
INSTALLATIONS										
Erection of self-supporting towers and extended towers of the suspension type complete with all fittings & including Earthing System										
	Type TDL towers with ± 0m extension	Nos	0	1	0	0	1	1	1	1
	Type TDL towers with -3m extension	Nos	1	1	1	0	0	0	0	1
	Type TDL towers with +3m extension	Nos	1	0	1	1	0	1	1	0
	Type TDL towers with +6m extension	Nos	0	0	0	1	1	0	0	0
	Type TDL towers with +9m extension	Nos	0	0	0	0	0	0	0	0
	Type TDL towers with +12m extension	Nos	0	0	0	0	0	0	0	0
Erection of self-supporting towers and extended towers of the Tension (TD1) type complete with all fittings including Earthing System										
	Type TD1 towers with ± 0m extension	Nos	1	3	1	0	0	1	0	1
	Type TD1 towers with -3m extension	Nos	0	2	0	1	2	1	2	1
	Type TD1 towers with +3m extension	Nos	3	0	3	1	1	3	1	3
	Type TD1 towers with +6m extension	Nos	2	2	1	2	2	1	2	1
	Type TD1 towers with +9m extension	Nos	1	1	1	0	2	2	2	2
	Type TD1 towers with +12m extension	Nos	4	3	5	7	4	3	4	3
Erection of self-supporting towers and extended towers of the Tension (TD3) type complete with all fittings including Earthing System										
	Type TD3 towers with ± 0m extension	Nos	1	2	1	0	1	1	1	1
	Type TD3 towers with -3m extension	Nos	2	2	3	2	3	2	3	3
	Type TD3 towers with +3m extension	Nos	1	0	0	1	0	1	0	0
	Type TD3 towers with +6m extension	Nos	0	0	0	0	0	0	0	0
	Type TD3 towers with +9m extension	Nos	0	0	0	1	0	0	0	0
	Type TD3 towers with +12m extension	Nos	0	0	0	0	0	0	0	0
Erection of self-supporting towers and extended towers of the Tension (TD6) type complete with all fittings including Earthing System										
	Type TD6 towers with ± 0m extension	Nos	1	1	0	0	1	1	1	1
	Type TD6 towers with -3m extension	Nos	0	0	1	1	0	0	0	0
	Type TD6 towers with +3m extension	Nos	0	1	1	0	1	1	1	0
	Type TD6 towers with +6m extension	Nos	1	0	0	1	0	0	0	1
	Type TD6 towers with +9m extension	Nos	0	0	0	0	0	0	0	0
	Type TD6 towers with +12m extension	Nos	0	0	0	0	0	0	0	0
Stringing										
		km	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1

Hilly Populated Hilly Terrain

Description	Unit	ACSR	ACCC	ZTACIR /AW	ACSS/TW	ACCR	GTACSR	LL-ACSR/ AS	LL-TACSR/ AS
Supply of Conductors including joints and jumper leads									
400 mm^2 Zebra 61/3.18 mm ACSR conductor (Including mid span joints) units	km	34.6	34.6	34.6	34.6	34.6	34.6	34.6	34.6
7/3.25 MM Galvanized earth wire including mid span units	km	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8
OPGW Conductors and OPGW Accessories	km	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8
Supply of Damping System (Vibration dampers)									
Vibration dampers for 400 mm^2 Zebra (61/3.18 mm) conductor	Nos	336	336	336	342	342	336	354	336
Vibration dampers for OPGW	Nos	64	66	64	64	64	64	64	64
Vibration dampers for GSW	Nos	56	56	56	57	57	56	59	56
Supply of Insulator sets									
Normal suspension insulator sets for 400 mm^2 ACSR conductor	Nos	6	6	6	6	12	6	6	6
Normal tension insulator sets for 400 mm^2 ACSR conductor	Nos	216	216	216	216	204	216	228	216
Jumper suspension insulator sets	Nos	6	6	6	6	6	6	6	6
Light duty tension insulator sets for 400 mm^2 ACSR conductor	Nos	12	12	12	12	12	12	12	12
Supply of self-supporting towers and extended towers of the suspension type complete with all fittings									
Type TDL towers with -3m extension	Nos	0	0	0	0	1	0	0	1
Type TDL towers with ± 0m extension	Nos	1	1	0	0	0	1	1	0
Type TDL towers with +3m extension	Nos	0	0	1	1	0	0	0	0
Type TDL towers with +6m extension	Nos	0	0	0	0	1	0	0	0
Type TDL towers with +9m extension	Nos	0	0	0	0	0	0	0	0
Type TDL towers with +12m extension	Nos	0	0	0	0	0	0	0	0
Supply of self-supporting towers and extended towers of the Tension (TD1) type complete with all fittings									
Type TD1 towers with -3m extension	Nos	0	1	0	0	2	0	0	0
Type TD1 towers with ± 0m extension	No	1	2	1	0	1	2	1	2
Type TD1 towers with +3m extension	Nos	1	1	1	1	1	3	3	1
Type TD1 towers with +6m extension	Nos	3	1	3	1	1	0	2	2
Type TD1 towers with +9m extension	Nos	3	2	2	3	1	3	3	2
Type TD1 towers with +12m extension	Nos	3	4	5	7	5	4	4	5
Supply of self-supporting towers and extended towers of the Tension (TD3) type complete with all fittings									
Type TD3 towers with -3m extension	Nos	1	4	1	0	2	1	1	1
Type TD3 towers with ± 0m extension	Nos	1	0	1	1	1	2	1	1
Type TD3 towers with +3m extension	Nos	1	1	1	1	0	1	2	2
Type TD3 towers with +6m extension	Nos	1	0	1	1	1	0	0	0
Type TD3 towers with +9m extension	Nos	0	0	0	0	0	0	0	0
Type TD3 towers with +12m extension	Nos	1	0	0	1	0	0	0	0
Supply of self-supporting towers and extended towers of the Tension (TD6) type complete with all fittings									
Type TD6 towers with -3m extension	Nos	1	1	1	0	1	1	1	1
Type TD6 towers with ± 0m extension	Nos	0	0	0	1	0	0	0	0
Type TD6 towers with +3m extension	Nos	0	1	0	0	0	0	0	1
Type TD6 towers with +6m extension	Nos	1	0	1	1	0	1	1	0
Type TD6 towers with +9m extension	Nos	0	0	0	0	1	0	0	0
Type TD6 towers with +12m extension	Nos	0	0	0	0	0	0	0	0
CIVIL WORKS									
Foundation complete for TDL towers and all extensions									
Foundation type 3	Nos	1	1	1	1	2	1	1	1
Foundation type 4A	Nos	0	0	0	0	0	0	0	0

Foundation complete for TD1 towers and all extensions									
	Foundation type 3	Nos	11	11	12	12	11	12	13	12
	Foundation type 4A	Nos	0	0	0	0	0	0	0	0
Foundation complete for TD3 towers and all extensions									
	Foundation type 3	Nos	5	5	4	4	4	4	4	4
	Foundation type 4A	Nos	0	0	0	0	0	0	0	0
Foundation complete for TD6 towers and all extensions									
	Foundation type 3	Nos	2	2	2	2	2	2	2	2
	Foundation type 4A	Nos	0	0	0	0	0	0	0	0
Foundation complete for TDT towers and all extensions									
	Foundation type 3	Nos	0	0	0	0	0	0	0	0
	Foundation type 4A	Nos	0	0	0	0	0	0	0	0
Survey									
	Preliminary Survey *	km	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8
	Profile Survey	km	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8
TOTAL									
INSTALLATIONS									
Erection of self-supporting towers and extended towers of the suspension type complete with all fittings & including Earthing System									
	Type TDL towers with ± 0m extension	Nos	0	0	0	0	1	0	0	1
	Type TDL towers with -3m extension	Nos	1	1	0	0	0	1	1	0
	Type TDL towers with +3m extension	Nos	0	0	1	1	0	0	0	0
	Type TDL towers with +6m extension	Nos	0	0	0	0	1	0	0	0
	Type TDL towers with +9m extension	Nos	0	0	0	0	0	0	0	0
	Type TDL towers with +12m extension	Nos	0	0	0	0	0	0	0	0
Erection of self-supporting towers and extended towers of the Tension (TD1) type complete with all fittings including Earthing System									
	Type TD1 towers with ± 0m extension	Nos	0	1	0	0	2	0	0	0
	Type TD1 towers with -3m extension	Nos	1	2	1	0	1	2	1	2
	Type TD1 towers with +3m extension	Nos	1	1	1	1	1	3	3	1
	Type TD1 towers with +6m extension	Nos	3	1	3	1	1	0	2	2
	Type TD1 towers with +9m extension	Nos	3	2	2	3	1	3	3	2
	Type TD1 towers with +12m extension	Nos	3	4	5	7	5	4	4	5
Erection of self-supporting towers and extended towers of the Tension (TD3) type complete with all fittings including Earthing System									
	Type TD3 towers with ± 0m extension	Nos	1	4	1	0	2	1	1	1
	Type TD3 towers with -3m extension	Nos	1	0	1	1	1	2	1	1
	Type TD3 towers with +3m extension	Nos	1	1	1	1	0	1	2	2
	Type TD3 towers with +6m extension	Nos	1	0	1	1	1	0	0	0
	Type TD3 towers with +9m extension	Nos	0	0	0	0	0	0	0	0
	Type TD3 towers with +12m extension	Nos	1	0	0	1	0	0	0	0
Erection of self-supporting towers and extended towers of the Tension (TD6) type complete with all fittings including Earthing System									
	Type TD6 towers with ± 0m extension	Nos	1	1	1	0	1	1	1	1
	Type TD6 towers with -3m extension	Nos	0	0	0	1	0	0	0	0
	Type TD6 towers with +3m extension	Nos	0	1	0	0	0	0	0	1
	Type TD6 towers with +6m extension	Nos	1	0	1	1	0	1	1	0
	Type TD6 towers with +9m extension	Nos	0	0	0	0	1	0	0	0
	Type TD6 towers with +12m extension	Nos	0	0	0	0	0	0	0	0
Stringing									
		km	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8

Paddy Hilly Terrain

	Description	Unit	ACSR	ACCC	ZTACIR /AW	ACSS/TW	ACCR	GTACSR	LL-ACSR/ AS	LL-TACSR/ AS
Supply of Conductors including joints and jumper leads										
	400 mm^2 Zebra 61/3.18 mm ACSR conductor (Including mid span joints) units	km	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5
	7/3.25 MM Galvanized earth wire including mid span units	km	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7
	OPGW Conductors and OPGW Accessories	km	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7
Supply of Damping System (Vibration dampers)										
	Vibration dampers for 400 mm^2 Zebra (61/3.18 mm) conductor	Nos	288	288	288	288	288	288	288	288
	Vibration dampers for OPGW	Nos	58	58	58	58	58	58	58	58
	Vibration dampers for GSW	Nos	48	48	48	48	48	48	48	48
Supply of Insulator sets										
	Normal suspension insulator sets for 400 mm^2 ACSR conductor	Nos	30	24	30	24	24	24	24	24
	Normal tension insulator sets for 400 mm^2 ACSR conductor	Nos	132	144	132	144	144	144	144	144
	Jumper suspension insulator sets	Nos	0	0	0	0	0	0	0	0
	Light duty tension insulator sets for 400 mm^2 ACSR conductor	Nos	12	12	12	12	12	12	12	12
Supply of self-supporting towers and extended towers of the suspension type complete with all fittings										
	Type TDL towers with -3m extension	Nos	0	0	0	0	0	0	0	0
	Type TDL towers with ± 0m extension	Nos	0	1	0	0	0	0	0	0
	Type TDL towers with +3m extension	Nos	0	1	0	1	0	1	1	1
	Type TDL towers with +6m extension	Nos	3	1	3	2	3	2	2	2
	Type TDL towers with +9m extension	Nos	0	0	0	0	0	0	0	0
	Type TDL towers with +12m extension	Nos	2	1	2	1	1	1	1	1
Supply of self-supporting towers and extended towers of the Tension (TD1) type complete with all fittings										
	Type TD1 towers with -3m extension	Nos	2	3	2	2	2	2	2	2
	Type TD1 towers with ± 0m extension	No	0	2	0	1	1	1	1	1
	Type TD1 towers with +3m extension	Nos	1	1	1	1	1	1	1	1
	Type TD1 towers with +6m extension	Nos	3	1	3	2	3	3	3	3
	Type TD1 towers with +9m extension	Nos	0	0	0	1	0	0	0	0
	Type TD1 towers with +12m extension	Nos	0	0	0	0	0	0	0	0
Supply of self-supporting towers and extended towers of the Tension (TD3) type complete with all fittings										
	Type TD3 towers with -3m extension	Nos	0	2	0	0	0	0	0	1
	Type TD3 towers with ± 0m extension	Nos	1	1	1	1	1	1	2	0
	Type TD3 towers with +3m extension	Nos	2	1	2	2	2	2	1	2
	Type TD3 towers with +6m extension	Nos	1	1	1	1	1	1	1	1
	Type TD3 towers with +9m extension	Nos	1	0	1	1	1	1	1	1
	Type TD3 towers with +12m extension	Nos	0	0	0	0	0	0	0	0
CIVIL WORKS										
Foundation complete for TDL towers and all extensions										
	Foundation type 3	Nos	0	0	0	0	0	0	0	0
	Foundation type 4A	Nos	5	4	5	4	4	4	4	4
Foundation complete for TD1 towers and all extensions										
	Foundation type 3	Nos	0	0	0	0	0	0	0	0
	Foundation type 4A	Nos	6	7	6	7	7	7	7	7
Foundation complete for TD3 towers and all extensions										
	Foundation type 3	Nos	0	0	0	0	0	0	0	0
	Foundation type 4A	Nos	5	5	5	5	5	5	5	5

Survey										
	Preliminary Survey *	km	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7
	Profile Survey	km	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7
TOTAL										
INSTALLATIONS										
Erection of self-supporting towers and extended towers of the suspension type complete with all fittings & including Earthing System										
	Type TDL towers with ± 0m extension	Nos	0	0	0	0	0	0	0	0
	Type TDL towers with -3m extension	Nos	0	1	0	0	0	0	0	0
	Type TDL towers with +3m extension	Nos	0	1	0	1	0	1	1	1
	Type TDL towers with +6m extension	Nos	3	1	3	2	3	2	2	2
	Type TDL towers with +9m extension	Nos	0	0	0	0	0	0	0	0
	Type TDL towers with +12m extension	Nos	2	1	2	1	1	1	1	1
Erection of self-supporting towers and extended towers of the Tension (TD1) type complete with all fittings including Earthing System										
	Type TD1 towers with ± 0m extension	Nos	2	3	2	2	2	2	2	2
	Type TD1 towers with -3m extension	Nos	0	2	0	1	1	1	1	1
	Type TD1 towers with +3m extension	Nos	1	1	1	1	1	1	1	1
	Type TD1 towers with +6m extension	Nos	3	1	3	2	3	3	3	3
	Type TD1 towers with +9m extension	Nos	0	0	0	1	0	0	0	0
	Type TD1 towers with +12m extension	Nos	0	0	0	0	0	0	0	0
Erection of self-supporting towers and extended towers of the Tension (TD3) type complete with all fittings including Earthing System										
	Type TD3 towers with ± 0m extension	Nos	0	2	0	0	0	0	0	1
	Type TD3 towers with -3m extension	Nos	1	1	1	1	1	1	2	0
	Type TD3 towers with +3m extension	Nos	2	1	2	2	2	2	1	2
	Type TD3 towers with +6m extension	Nos	1	1	1	1	1	1	1	1
	Type TD3 towers with +9m extension	Nos	1	0	1	1	1	1	1	1
	Type TD3 towers with +12m extension	Nos	0	0	0	0	0	0	0	0
Stringing										
		km	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7

APPENDIX VIII: Sample Price Schedule

	Description	Unit	Qty.	Unit Price	Total Price
	ACSR			**LKR**	**LKR**
Supply of Conductors including joints and jumper leads					
	400 mm^2 Zebra 61/3.18 mm ACSR conductor (Including mid span joints) units	km	6.24	770,000.00	28,833,928.20
	7/3.25 MM Galvanized earth wire including mid span units	km	6.24	243,000.00	1,516,589.73
	OPGW, Conductors and OPGW Accessories	km	6.24	675,778.00	4,217,604.83
Supply of Damping System (Vibration dampers)					
	Vibration dampers for 400 mm^2 Zebra (61/3.18 mm) conductor	Nos	450.00	5,198.62	2,339,379.00
	Vibration dampers for OPGW	Nos	76.00	7,328.62	556,975.12
	Vibration dampers for GSW	Nos	75.00	4,772.62	357,946.50
Supply of Insulator sets					
	Normal suspension insulator sets for 400 mm^2 ACSR conductor	Nos	96.00	46,718.00	4,484,928.00
	Normal tension insulator sets for 400 mm^2 ACSR conductor	Nos	48.00	63,190.00	3,033,120.00
	Jumper suspension insulator sets	Nos	0.00	44,674.62	
	Light duty tension insulator sets for 400 mm^2 ACSR conductor	Nos	12.00	104,740.62	1,256,887.44
Supply of self-supporting towers and extended towers of the suspension type complete with all fittings					
	Type TDL towers with -3m extension	Nos	1.00	1,047,938.96	1,047,938.96
	Type TDL towers with ± 0m extension	Nos	7.00	1,162,088.56	8,134,619.89
	Type TDL towers with +3m extension	Nos	5.00	1,292,983.80	6,464,918.99
	Type TDL towers with +6m extension	Nos	1.00	1,420,151.84	1,420,151.84
	Type TDL towers with +9m extension	Nos	2.00	1,562,552.23	3,125,104.45
	Type TDL towers with +12m extension	Nos	0.00	1,748,828.09	
Supply of self-supporting towers and extended towers of the Tension (TD1) type complete with all fittings					
	Type TD1 towers with -3m extension	Nos	1.00	1,369,897.08	1,369,897.08
	Type TD1 towers with ± 0m extension	No	0.00	1,462,065.63	
	Type TD1 towers with +3m extension	Nos	2.00	1,627,929.79	3,255,859.57
	Type TD1 towers with +6m extension	Nos	0.00	1,718,585.04	
	Type TD1 towers with +9m extension	Nos	0.00	1,871,023.13	
	Type TD1 towers with +12m extension	Nos	0.00	1,985,534.50	
Supply of self-supporting towers and extended towers of the Tension (TD3) type complete with all fittings					
	Type TD3 towers with -3m extension	Nos	0.00	2,056,200.96	
	Type TD3 towers with ± 0m extension	Nos	0.00	2,367,693.37	
	Type TD3 towers with +3m extension	Nos	0.00	2,567,637.32	
	Type TD3 towers with +6m extension	Nos	1.00	2,768,788.85	2,768,788.85
	Type TD3 towers with +9m extension	Nos	0.00	3,020,926.32	
	Type TD3 towers with +12m extension	Nos	0.00	3,224,775.81	
Supply of self-supporting towers and extended towers of the Tension (TD6) type complete with all fittings			0.00		
	Type TD6 towers with -3m extension	Nos	0.00	2,439,113.93	
	Type TD6 towers with ± 0m extension	Nos	0.00	2,730,981.86	
	Type TD6 towers with +3m extension	Nos	0.00	3,184,089.98	
	Type TD6 towers with +6m extension	Nos	0.00	3,565,410.68	
	Type TD6 towers with +9m extension	Nos	0.00	3,987,399.37	
	Type TD6 towers with +12m extension	Nos	0.00	4,377,555.28	
	ACSR Zebra Conductors and Earth Wires-7/3.25				**30,350,517.93**
	OPGW Conductors and OPGW Accessories				**4,774,579.95**
	Insulator sets, and Insulator h/w + conductor, GSW h/w				**11,472,260.94**
	Towers				**27,587,279.63**
	Other Supply (6% of Total Supply)				**4,451,078.31**
CIVIL WORKS					

Foundation complete for TDL towers and all extensions				
Foundation type 3	Nos	16	715,098.25	11,441,572.00
Foundation type 4A	Nos		2,028,051.56	
Foundation complete for TD1 towers and all extensions				
Foundation type 3	Nos	3	1,094,929.11	3,284,787.33
Foundation type 4A	Nos		2,805,487.45	
Foundation complete for TD3 towers and all extensions				
Foundation type 3	Nos	1	1,594,323.59	1,594,323.59
Foundation type 4A	Nos		3,449,671.00	
Foundation complete for TD6 towers and all extensions				
Foundation type 3	Nos	0	4,051,615.75	
Foundation type 4A	Nos		8,113,809.00	
Survey				
Preliminary Survey	km	6.24	27,898.57	174,118.07
Profile Survey	km	6.24	127,773.33	797,447.43
INSTALLATIONS				
Erection of self-supporting towers and extended towers of the suspension type complete with all fittings & including Earthing System				
Type TDL towers with ± 0m extension	Nos	1	181,111.31	181,111.31
Type TDL towers with -3m extension	Nos	7	166,155.45	1,163,088.17
Type TDL towers with +3m extension	Nos	5	206,778.53	1,033,892.65
Type TDL towers with +6m extension	Nos	1	232,278.39	232,278.39
Type TDL towers with +9m extension	Nos	2	261,929.04	523,858.07
Type TDL towers with +12m extension	Nos	0	291,970.45	
Erection of self-supporting towers and extended towers of the Tension (TD1) type complete with all fittings including Earthing				
Type TD1 towers with ± 0m extension	Nos	1	265,284.96	265,284.96
Type TD1 towers with -3m extension	Nos	0	237,872.79	
Type TD1 towers with +3m extension	Nos	2	297,830.76	595,661.51
Type TD1 towers with +6m extension	Nos	0	335,666.26	
Type TD1 towers with +9m extension	Nos	0	386,379.99	
Type TD1 towers with +12m extension	Nos	0	416,938.05	
Erection of self-supporting towers and extended towers of the Tension (TD3) type complete with all fittings including Earthing				
Type TD3 towers with ± 0m extension	Nos	0	312,698.75	
Type TD3 towers with -3m extension	Nos	0	276,653.03	
Type TD3 towers with +3m extension	Nos	0	352,311.47	
Type TD3 towers with +6m extension	Nos	1	402,209.61	402,209.61
Type TD3 towers with +9m extension	Nos	0	453,742.78	
Type TD3 towers with +12m extension	Nos	0	499,597.84	
Erection of self-supporting towers and extended towers of the Tension (TD6) type complete with all fittings including Earthing System				
Type TD6 towers with ± 0m extension	Nos	0	444,588.25	
Type TD6 towers with -3m extension	Nos	0	403,846.84	
Type TD6 towers with +3m extension	Nos	0	501,771.85	
Type TD6 towers with +6m extension	Nos	0	576,441.59	
Type TD6 towers with +9m extension	Nos	0	661,230.14	
Type TD6 towers with +12m extension	Nos	0	718,526.96	
Stringing				
Stringing	km	6.24	784,705.35	4,897,432.43

Summary Table

Foundation and Surveying	**17,292,248.41**
Tower Erection	**4,397,384.68**
Stringing	**4,897,432.43**
Other Works	**2,658,706.55**

		Conductor Cost	**30,350,517.93**
		Total Supply	**48,285,198.83**
		Total Civil Works	**29,245,772.07**
		Total Other Services	**4,315,259.55**
		Total Cost	**112,196,748.39**
		Per Km Cost	**17,977,050.30**

Conductor Cost Factor for same sized conductors; Source [6]	
1.0	ACSR
2.5	ACCC
3.0	ZTACIR/AW
1.5	ACSS/TW
5.0	ACCR
1.5	GTACSR
1.4	LL ACSR
1.5	LL TACSR

APPENDIX IX : Total Cost Summary for Respective Terrain Models

Non Populated Flat Terrain

Conductor Type		ACSR	ACCC	ZTACIR/ AW	ACSS/ TW	ACCR	GTACSR	LL-ACSR/AS	LL-TACSR/AS
Description		Rs.(Mn)							
Total Supply	Conductor	30.35	73.60	88.02	44.77	145.69	44.77	41.88	44.77
	Other Supply	48.29	48.69	53.56	55.27	55.61	52.36	50.42	53.05
Total Civil Works		29.25	29.19	30.08	32.03	29.48	31.19	30.02	31.26
Total Other Services		4.32	6.06	6.87	5.28	9.23	5.13	4.89	5.16
Total Cost		112.20	157.54	178.53	137.35	240.01	133.45	127.21	134.24
Per km Cost		17.98	25.24	28.61	22.01	38.46	21.38	20.38	21.51

Populated Flat Terrain

Conductor Type		ACSR	ACCC	ZTACIR/ AW	ACSS /TW	ACCR	GTACSR	LL-ACSR/AS	LL-TACSR/AS
Description		Rs.(Mn)							
Total Supply	Conductor	28.04	68.01	81.33	41.36	134.61	41.36	38.70	41.36
	Other Supply	67.20	65.52	73.99	72.28	75.66	73.58	69.91	73.63
Total Civil Works		45.63	46.33	49.16	49.43	47.36	51.25	48.56	50.92
Total Other Services		5.63	7.19	8.18	6.52	10.31	6.65	6.29	6.64
Total Cost		146.51	187.05	212.65	169.6	267.93	172.85	163.46	172.55
Per km Cost		25.41	32.44	36.88	29.41	46.46	29.97	28.35	29.92

Paddy Flat Terrain

Conductor		ACSR	ACCC	ZTACIR/ AW	ACSS/TW	ACCR	GTACSR	LL-ACSR/ AS	LL-TACSR/AS
Description		Rs.(Mn)							
Total Supply	Conductor	30.35	73.60	88.02	44.77	145.69	44.77	41.88	44.77
	Other Supply	48.29	48.69	53.56	55.27	55.61	52.36	50.42	23.79
Total Civil Works		60.04	60.33	62.10	66.64	60.58	65.24	62.06	65.47
Total Other Services		5.55	7.30	8.15	6.67	10.48	6.49	6.17	5.36
Total Cost		144.22	189.92	211.83	173.34	272.35	168.86	160.54	139.39
Per km Cost		23.11	30.43	33.94	27.77	43.64	27.06	25.72	22.33

Non Populated Hilly Terrain

Conductor		ACSR	ACCC	ZTACIR/ AW	ACSS/ TW	ACCR	GTACSR	LL-ACSR/ AS	LL- TACSR/ AS
Description		Rs.(Mn)							
Total Supply	Conductor	28.06	68.04	81.37	41.39	134.68	41.39	38.72	41.39
	Other Supply	63.89	65.92	68.40	71.36	70.40	68.68	65.66	69.43
Total Civil Works		57.77	61.67	59.59	62.07	58.91	63.74	60.22	63.25
Total Other Services		5.99	7.83	8.37	6.99	10.56	6.95	6.58	6.96
Total Cost		155.71	203.46	217.74	181.81	274.56	180.76	171.18	181.03
Per km Cost		26.99	35.26	37.74	31.51	47.59	31.33	29.67	31.38

Populated Hilly Terrain

Conductor		ACSR	ACCC	ZTACIR/A W	ACSS/TW	ACCR	GTACSR	LL-ACSR/ AS	LL- TACSR/AS
Description		Rs.(Mn)							
Total Supply	Conductor	28.06	68.04	81.37	41.39	134.68	41.39	38.72	41.39
	Other Supply	69.47	72.53	76.59	77.75	76.59	76.92	76.83	77.20
Total Civil Works		61.40	67.32	65.31	66.27	63.71	69.33	67.77	69.09
Total Other Services		6.36	8.32	8.93	7.42	11.00	7.51	7.33	7.51
Total Cost		165.29	216.21	232.20	192.82	285.98	195.14	190.66	195.19
Per km Cost		28.65	37.47	40.24	33.42	49.57	33.82	33.04	33.83

Paddy Hilly Terrain

Conductor		ACSR	ACCC	ZTACIR /AW	ACSS/T W	ACCR	GTACS R	LL- ACSR/A S	LL- TACSR/ AS
Description		Rs.(Mn)							
Total Supply	Conductor	23.06	55.93	66.89	34.02	110.71	34.02	31.83	34.02
	Other Supply	51.13	52.98	56.99	55.52	58.81	57.49	54.40	57.14
Total Civil Works		79.74	86.93	85.51	86.86	84.90	91.80	86.72	91.87
Total Other Services		6.16	7.83	8.38	7.06	10.18	7.33	6.92	7.32
Total Cost		160.09	203.68	217.76	183.46	264.60	190.64	179.87	190.35
Per km Cost		33.75	42.94	45.91	38.68	55.79	40.20	37.92	40.13