REDEFINING RIGHT-OF-WAY WIDTH OF 33kV TOWER LINE BY MINIMIZING DISTURBANCES TO THE VEGETATION

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Degree of Master of Science

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University of Moratuwa
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DECLARATION OF THE CANDIDATE AND SUPERVISORS

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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06th November, 2015

The above candidate has carried out research for the Masters dissertation under my supervision.

Dr. Asanka Rodrigo

06th November, 2015

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J C G Dissanayakege

ABSTRACT

With the economic development in the country the demand for electricity is becoming important so that the government needs to achieve 100% electrification in the country in near future. Here, providing a safe & reliable power supply to all sectors in the country has become a great challenge to the utility company.

To cater this requirement, planning branches of Ceylon Electricity Board (CEB) do preliminary studies of new power lines, reliability evaluations, load flow studies, etc. Thereafter, medium voltage line is designed including the line length, current rating, circuit type (Four circuit/Double Circuit/Single Circuit), conductor parameters, staring & end points, etc.

As the first step of this research study, a survey was done regarding the available line design techniques, design criteriae, details of the selected tower line, valuation methods of vegetation, conductor types used in tower line applications, right-of-way width of a transmission line, etc. The prime concern was drawn in collecting as much as possible data on vegetation distribution along the line, payment made on vegetation clearing, classification of trees, tree related information, locations of removed trees of the selected line, available structure types, most recent structure costs, foundation costs and erection costs, etc.

With the rapid urbanization, finding a route for a new transmission line across a populated area is a major difficulty to be faced by the utility. In this study, width of a 33kV transmission line Right-Of-Way (ROW) is proposed. Internationally used vegetation management techniques for transmission line was studied, since a well-defined, eco-friendly methodology for vegetation compensation process has not been adhered to the conventional practice.

Most of the countries in the world pay much attention in the construction of eco-friendly overhead power lines. Hence, application on Covered Conductors on 33kV transmission line construction in CEB was studied while ensuring the adoptability of newly developed CC in Sri Lanka. The existing line was re-designed using the LYNX equivalent covered conductor. The ROW widths and the per km cost of a 33kV tower

line were calculated for three different cases considering the different equivalent spans. Considerable amount of cost could be saved by the utility while concerning the designed equivalent span and the conductor type for properly maintaining the ROW width.

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LIST OF ABBREVIATIONS

Term	Definition or Clarification
4CCT	Four Circuit
ABC	Aerial Bundled Conductors
ACSR	Aluminum Conductor Steel Reinforced
ANSI	American National Standards Institute
BZ	Border Zone
° C	Celsius
CC	Covered Conductor
CEB	Ceylon Electricity Board
CENELEC	European Committee for Electro-technical Standardization (French Standard)
CO_2	Carbon Dioxide
DBB	Double Bus Bar
DBH	Diameter at Breast Height
DC	Double Circuit
DS	Divisional Secretariat
EDT	Every Day Temperature
EMF	Electro Magnetic Force
ENATS	Energy Networks Association Technical Specifications
f.o.s	factor of safety

GPS	Global positioning System
GN	Grama Niladhari
GSS	Grid Sub Station
HV	High Voltage
IUCN	International Union for Conservation of Nature
kN	Kilo Newton
kV	Kilo Volts
LiDAR	Light Detection And Ranging
LSHP	Lighting Sri Lanka Hambantota Project
MV	Medium Voltage
NESC	Network Embedded Systems C
PLSCADD	Power Line Systems Computer Aided Design and Drafting
PPC	Project Procurement Committee
ROW	Right Of Way
SC	Single Circuit
UK	United Kingdom
UTS	Ultimate Tensile Strength
WZ	Wire Zone

Chapter 1

Introduction

1.1 Background

The objective of the electrical network is to transfer electrical power generated in power plants to the customers. Electric power is today playing an increasingly important role in the life of the community and development of various sectors of a country's economy. Developing countries like Sri Lanka are therefore giving a high priority to power developments. Also, the availability of reliable power supply is an essential precondition for the functioning of the modern economies, both in developed and developing countries.

Energy is intrinsically linked to environmental, social and economic dimensions of sustainable development. Providing reliable and secure electricity supplies, minimizing associated environmental impacts, and providing access to electricity for people currently without it are key challenges of the electricity sector.

Moreover, environmental problems such as higher levels of carbon emissions that go along with economic development increase the complexity of electric-power decision making in developing countries. For example, the agreement at the United Nations Conference on Environment and Development in June 1992 that all countries should adopt programs to limit increases in greenhouse gas emissions is an example of an environmental obstacle to developing the power sectors of many developing countries.

The transmission line route selection process enables the selection of a line route that minimizes a range of environmental and social impacts associated with the project [1]. If the line can be designed such that the vegetation clearing is done selectively while retaining most of native vegetation along the corridor, then it will be a most environmentally economical line design.

The main ecological problems associated with transmission lines are the possible bird collision with the conductors/earth wire and effects of tree clearing and removal of vegetation within Right-of-Way [2].

Typical vegetation management program for tower line deals with the scheduled maintenance cycle to identify the trees that could fall and contact the transmission lines. Such trees are trimmed to obtain clearances that will last for the duration of the cycle, or they are removed altogether to provide the required clearance, improve access to the lines, and reduce future costs. The instituted ROW of the utility company determines which trees the company has access to for this maintenance. Scheduled vegetation management should be based on an analysis of the workload and current conditions.

Compensatory value for vegetation clearing is regularly used to determine monetary settlement for damage of trees due to line construction and is an estimate of the amount of money the land owner should be compensated for tree loss in his land.

Environmental and safety issues have grown in importance in these days. Therefore, more and more pressure is put to network owners to use environmentally acceptable and safer electricity lines. Also, utilities are faced with increasing demands to supply energy without any disruptions. This challenge can be tackled by increasing reliability of the network. Covered conductor technology is the answer to all above questions. This conclusion is supported by Finnish and Slovene experience on applying of CC technology in their power network [3].

1.2 Motivation

For the development of electricity infrastructure in Sri Lanka, distribution and transmission planning divisions of CEB propose the requirement of network development. Mainly, transmission division is responsible for 132kV & 220kV lines, while Distribution Divisions accounts for 33kV & 11kV power lines. In addition, several transmission line projects carried out by CEB are funded by the Government of Sri Lanka and by foreign donations as well with the primary objective of providing

100% electrification in the country. Lighting Sri Lanka Hambantota (LSHP) was implemented to cater the requirement within the Hambantota District.

At the beginning of a transmission line construction, once the line route is finalized, necessary land clearance has to be obtained from the respective land owners. Then wayleave clearing within the corridor is done. Accordingly, the time taken to commence the line construction differs based on the time taken to settle the objections received from the land owners. Valuation of cleared vegetation is done by the Divisional Secretariats with the assistance of the respective Grama Niladhari and the recommended way leave payment to the land owner is made by the CEB.

During LSHP, I could notice a considerable variation in valuation amounts of a same type and same size tree in several DS divisions. Due to non availability of a proper methodology, the Grama Niladhari valuated compensation based on their own criteriae which posed CEB at a difficulty in making compensation. The land owners, who were recommended considerably low valuations, refused the wayleave clearing. This motivated me in finding a proper method for tree valuation on transmission line construction.

At present, an uniform value is not practiced for ROW width of 33kV transmission lines by all the responsible branches of CEB where different branches clear different ROW widths varies from 20m to 30m. Therefore, having a consensus value for ROW width of a 33kV line is beneficial for CEB in terms of wayleave clearing. The value of ROW width is calculated in this study.

At the tower line construction using bare conductors, the vegetation along the corridor is totally cleared in the routine practice. Several objections against tree removal are received from land owners. Additionally, it carries a risk on environmental diversification. Most of the developing countries use systematic methods of vegetation management associated with the ROW and those methods will be studied. The possibility of adopting these methods to transmission line construction in Sri Lanka will then be revised. This will provide for better understanding on the basics of vegetation management along the ROW of a transmission line.

The safety of the line should also be considered. Touching of a bare conductor line frequently causes fatal accidents. Therefore, it is required to reduce probable accidents with the bare conductors so that the use of covered conductors is becoming more popular in the world. The possibility of applying the covered conductor technology in MV transmission line applications in Sri Lanka has never been studied. The main reason behind this is the novelty of covered conductor technology to Sri Lankan power sector compared to conventional bare conductor technology. However now, most of the countries such as Australia, UK, Sweden, Norway, etc are using covered conductor technology especially for voltages higher than 33kV with pole line applications.

Therefore, covered conductor technology will be widely available in the world in a few years. It is forecasted that, this technology will soon be popular as an environmentally feasible solution and more reliable than the conventional bare conductor technology. Hence, the possibility of the application of covered conductor technology in 33kV tower line projects requires and needs to be studied.

1.3 Objective

To study and develop a method for the valuation of trees, calculate ROW width for 33kV transmission line while introducing proper vegetation management program, and re-design the existing tower line using covered conductor, and examine the economic viability of the project.

1.4 Scope of work

For this research, the scope of the work is given below.

(1) In this study, the vegetation distribution along the selected tower line will be assessed while analyzing the conventional tree valuation method done by Divisional Secretariats.

(2) The internationally used tree valuation methods will be studied. Also, adopting an internationally accepted method for tree valuation in Sri Lankan context will be studied by defining relevant terms. A simplified, user friendly tree

valuation computerized application will be developed for the usage of responsible parties.

(3) Compare the prevailed method and the proposed method of tree valuation.

(4) ROW of a 33kV transmission line will be calculated. The study will include sag-tension calculation for 33kV transmission line with LYNX conductor.

(5) In this study, a proper vegetation management program will be introduced by taking matured tree height in to consideration.

(6) The application of covered conductors worldwide in overhead power lines will be discussed and the viability of re-designing the existing line using a Covered conductor will be checked.

(7) Finally cost comparison will be done for existing line with conventional bare conductor and designed CC line.

Introduction to the Case study

2.1 Introduction to Lighting Sri Lanka Hambnatota Project

Electricity to all is one of the key development initiatives spelt out in the government development program. Accordingly, the government of Sri Lanka implemented 100% electrification project named "Lighting Sri Lanka Hambantota Project (LSHP)" with the aim of developing electricity infrastructure in Hambantota District.

The project scope was consisted of the construction of 06 nos. of 33kV switching gantries at Tissamaharamaya, Mirijjawila, Nonagama, Tangalle, Walamulla & Kamburupiitiya and 108km of 33kV express double circuit tower lines as follows.

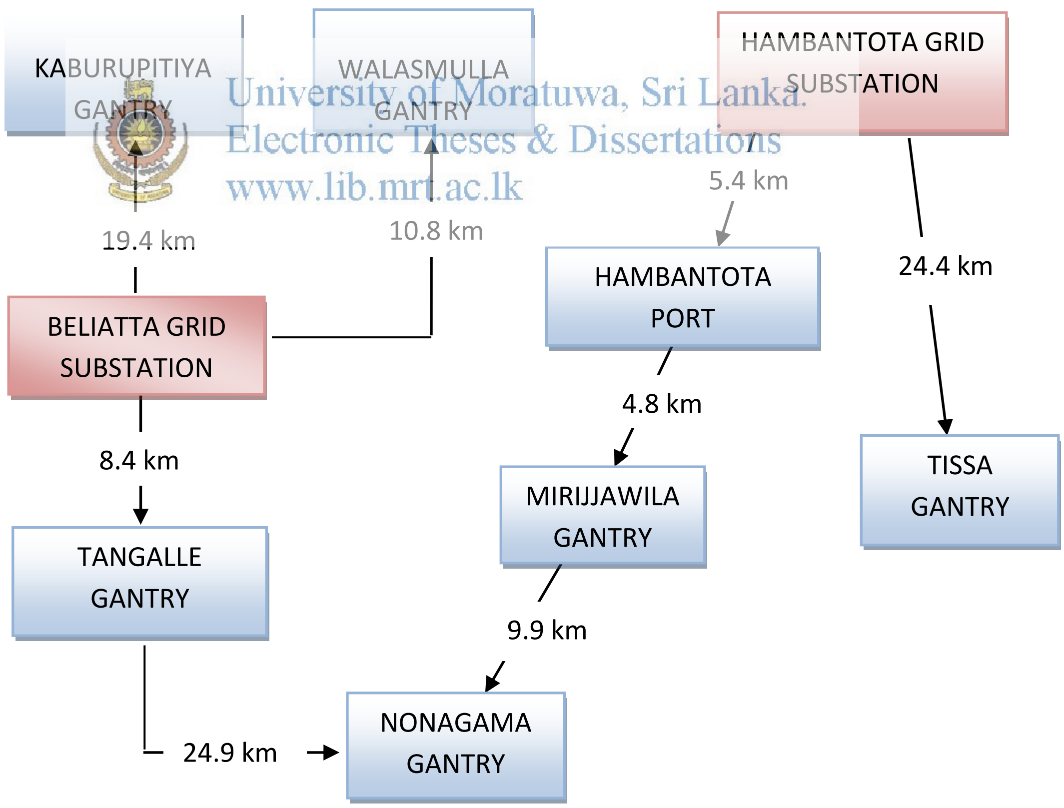

Figure 2.1: Gantry locations and Tower lines constructed by LSHP

2.2 Compensation on cleared vegetation in LSHP

Transmission line routing requires a thorough investigation and study of several different alternate routes in order to assure that the most practical route is selected, taking into account the environmental issues, cost of the construction, land use, impact to the public, maintenance, engineering considerations, etc.

The first actual work to be done on a transmission line is clearing the right-of-way. LSHP used 20m ROW width where total vegetation clearing was done within this area and the compensation had been made for the land owners accordingly. The total way leave costs recommended by DSs w.r.t. 08 nos of tower lines in LSHP are as follows.

Table 2.1: Payment made for cleared vegetation

#	Tower line	Length (km)	Recommended cost for vegetation clearing by DSs (LKR)
1	Hambantota GSS to Thissa Gantry	24.4	1,869,614.16
2	Hambantota GSS to Hambantota Port	5.4	14,500.00
3	Hambantota Port to Mirijjawila gantry	4.8	48,900.00
4	Mirijjawila gantry toNonagama gantry	9.9	10,846,583.76
5	Nonagama gantry to Tangalle gantry	24.9	22,882,985.00
6	Beliatta GSS to Tangalle gantry	8.4	506,000.00
7	Beliatta GSS to Walasmulla gantry	10.8	5,979,050.01
8	Beliatta GSS to Kamburupituya gantry	19.4	10,041,916.62
Total		**108.0**	**52,189,549.55**

Source: Data was taken from Lighting Sri Lanka Hambantota Project

Accordingly, more than 52 million rupees were spent for the compensation on vegetation clearing within which more than 22 million has been paid for Tangalle – Nonagama line.

Apart from providing a safe and reliable electric service to the consumers, having a proper vegetation management program enables the utility company to operate at the lowest reasonable cost. It also allows the workers to safely access the facilities for inspection, maintenance, and repair. Power interruptions by tree contacts have contributed to over 20% of service interruptions (Eckert, 2004). This may reflect in momentary interruptions or current diversions, but the varying power quality can add up to huge monetary losses.

2.3 Introduction to the selected transmission line

LSHP was the first Rural Electrification project that aimed to achieve 100% electrification in a district in Sri Lanka.

Among 108km length transmission line, 24.9km length 33kV ACSR LYNX double circuit tower line with 95 nos of tower locations was constructed from Tangalle Gantry to Nongama Gantry. The line route lies on a flat terrain closer to the Tangalle – Hambantota main road. Due to the population density and other environment/social factors, the line was designed using “Tower” type lattice steel structures.

Line route of Tangalle – Nonagama 33kV tower line is shown below in green color.

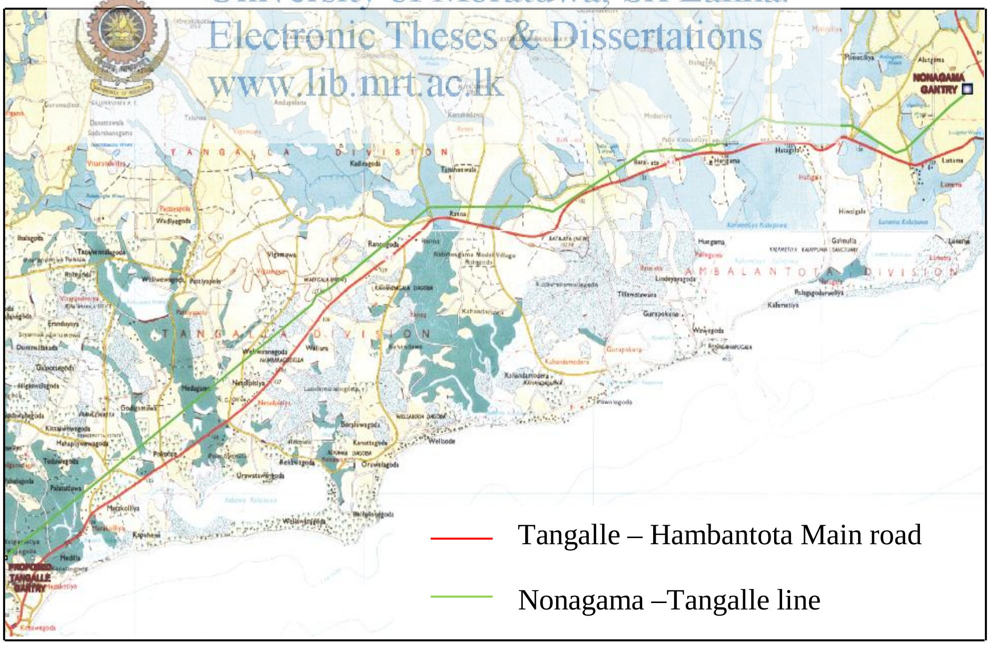

Figure 2.2: Line route of Tangalle – Nonagama 33kV tower line

According to the details available at LSHP, more than 4,000 trees in different types were removed at the construction of Tangalle – Nonagama 33kV line. Matured heights of those removed trees were considered based on the information available at the Forest Department in order to have an idea of the tree distribution. The following graph shows most of the removed trees along the line corridor have the matured tree height of 17.5m while very few numbers of trees have the mature height more than 17.5m.

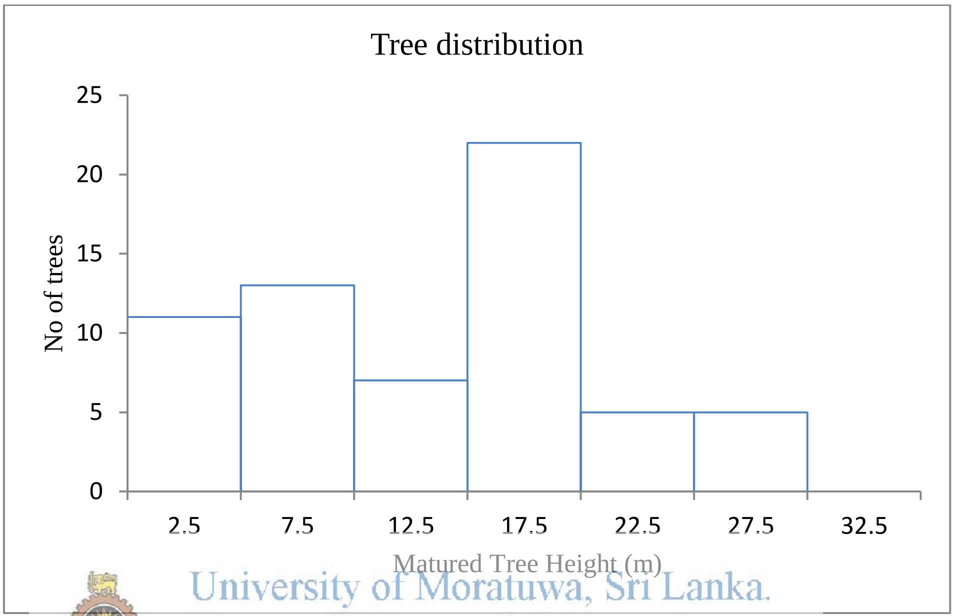

Figure 2.3: Tree distribution along the line corridor

Chapter 3

Technical Background

3.1 Transmission Line Design

3.1.1 Selection of Line route

The CEB distribution planning units carry out a computer aided network modeling and analysis study to evaluate the performance of its MV distribution networks with the future demand growth and decide new power line requirement with the features of them. 33kV tower line design and construction of CEB is done by the Projects and Heavy Maintenance Branches of Distribution Divisions and in addition to the several projects implemented by CEB.

3.1.1.1 Survey

As transmission lines have to traverse a long distance, the topographical & geographical nature of the terrains play significant role in the project cost and implementation time. Hence, it is essential that at the planning stage itself various alternative routes and technical solutions for transmission lines are examined in detail. During implementation of the project, it is required to obtain elaborate details about the terrain, soil conditions, constraints of the route for proper resource planning, costing etc. as well as reduction in implementation time.

3.1.1.2 Map study

After deciding the staring and end points of the transmission line, then the possible alternative line routes are roughly marked on the topographical map (1:50,000 scale). Here, the main focus is given to use paddy areas as much as possible and reduce the usage of marshy lands where soil condition is not in a good level because it takes high foundation cost and timing for the foundation. It is an experience that, several objections are received when a line is drawn across densely populated areas, schools, etc and to avoid these issues, it tries to draw the line along paddy fields.

Further, the line has to take deviations from the straight line route at certain locations along the route to maintain necessary clearances from permanent establishments, to avoid forest areas wherever possible , if not, minimize involvement of reserve forests and minimize major crossings such as river crossings, power line crossings, railway crossings, etc. Transmission line should not involve any human rehabilitation and should avoid wildlife sanctuaries, national parks, monuments of cultural or historical importance etc. When routing of line through forest areas cannot be avoided, it should be aligned in such a manner that tree cutting requirement is minimum.

3.1.1.3 Walkover survey

Then, a walkover survey is carried out in those alternate routes selected on the map. During the walkover survey, collect the features observed in the locations other than those existing on the map such as existing power lines/communication lines, reserve forests and high tree areas, National parks and wildlife sanctuaries, etc. Normally, in CEB the line route is surveyed using Total Station and there are several technological advanced methods such as GPS method, LiDAR technology, Air borne Terrain Mapping Technique, etc used by some other countries.

3.1.1.4 Preliminary survey

After the walkover survey, the most suited line route is proposed for the preliminary survey. The main objective of the preliminary survey is to transfer the route to ground with such deviations as may be necessary as per field constraints. It includes fixing angle points of towers, route alignment, identification of major crossings, general classification of soils, measurement of route length etc. In CEB, the preliminary survey is normally done by a licensed surveyor and he produces a preliminary drawing of the plan view and profile view through selected line route in 1:2000 horizontal scales.

3.1.1.5 Detailed survey

The next step is to do detailed survey. At the detailed survey, it is determined the number and type of the towers required, extensions required (if any), type of foundations, levels in different sections of the line, etc. The levels are plotted on a graph sheet on a scale 1:200 (vertical) and 1:2,000 (horizontal). The line route is fixed after the detailed survey.

3.1.2 Profile Design

Sag tension calculation is done and sag templates are prepared for possible equivalent spans using Auto Cad computer software. Angle of deviation verses span charts are also prepared to use in tower spotting. Computer software is used for all the calculation works.

A sag template is consisted of three curves, namely ground clearance curve, hot conductor curve and cold conductor curve.

The corresponding sag template is selected by calculating the ruling span for the section. Tower positions are located in between the angle towers using sag templates. AutoCAD software is used for this exercise. This is an iterative exercise. Towers between sections are to be shifted, removed or added with possible tower extensions to get the optimal solutions. Optimal solution is to have least number of towers and least number of tower body extensions, while keeping the required clearances and design limits. Design limits are checked at the same time by calculating the weight span, wind span etc. The profile drawings are prepared and towers are located on the plans.

Presently, profile design is carried out by some branches in CEB using PLSCADD (Power Line Systems Computer Aided Design and Drafting) software and the survey data. It can be done manually too using AutoCAD as explained above.

3.1.3 Transmission line components

The continuity of operation in a transmission line depends upon the judicious choice of its main components. Normally, a transmission line consists of the following components.

1. Towers - Towers are the supporting structures for transmission lines. Steel towers have greater mechanical strength, longer life, can withstand most severe climatic conditions, and permits the use of longer spans. Tower footings are usually

grounded by driving rods into the earth. This minimizes the lightning troubles as each tower acts as a lightning conductor.

2. Conductors- The conductor is one of the important items and proper choice of material and the size of the conductor are of considerable importance. All conductors used for overhead lines are preferably stranded in order to increase the flexibility.
3. Insulators- The conductors are supported on the towers in such a way that currents from conductors do not flow to earth through towers. This is achieved by securing line conductors to towers with the help of insulators. The insulators provide necessary insulation between line conductors and towers and thus prevent any leakage current from conductors to earth.
4. Cross arms - Cross arms provide support to the insulators.
5. Miscellaneous items- Overhead transmission lines use some miscellaneous items such as phase plates, danger plates, anti-climbing gates etc.

3.1.4 Selection of conductor supports

Self-supporting broad based lattice steel structures are commonly used by CEB for medium voltage backbone lines and there are two types called “Tower” and “Mast”. Applications of two support types are determined with terrain features along the line route.

3.1.4.1 Long Span Supports

The double circuit steel support type “Tower” is used with “Aluminum Conductor Steel Reinforced (ACSR 30/7/2.79) Lynx” conductor and 7/3.25 Galvanized Steel Earth Wire, in 33 kV lines for longer spans. These are mainly used in urban and mountainous areas. The basic span for “Tower” type lines are 300m.

All towers are provided with 3m and 6m body extensions above standard height where required. Leg extensions are provided to give -3m, -1m, 0m, +1m, +2m, +3m difference in height either in equal or unequal combinations [4].

Table 3.1: “Tower” type steel structures

Structure type	Description	Horizontal Angle
TDL	Suspension (line) tower	0^0
TDM	Medium angle section tower	0^0 - 30^0
TDH	Heavy angle section tower	30^0 - 60^0
TDT	Terminal tower	0^0 - 45^0 entry on line side

3.1.4.2 Medium Span Supports

The double circuit steel support type “Mast” is used with “Aluminum Conductor Steel Reinforced (ACSR 30/7/2.79) Lynx” conductor and 7/3.25 Galvanized Steel Earth Wire, in 33 kV lines for medium spans. These are mainly used in non-urban and low country areas. The basic span for “Mast” type lines are 200m.

Each type of supports shall consist of a common portion to which body extensions may be added as necessarily. The body extensions shall be provided 1m to 6m with 1m interval for the type MDL. In case of types MDM, MDH and MDT provision shall be made for body extensions of +3m and +6m. MDL shall be equipped with suspension insulator sets and all others with tension insulator sets [4].

Table 3.2: “Mast” type steel structures

Structure type	Description	Horizontal Angle
MDL	Suspension (line) mast	0^0
MDM	Light angle section mast	0^0 - 30^0
MDH	Heavy angle section mast	30^0 - 60^0
MDT	Terminal mast	0^0- 45^0 entry on line side

Summary of the support types with their approximate height to the bottom conductor attachment point is shown in Table 3.3.

Table 3.3: Medium voltage line support types and heights

Support Type		Height to bottom conductor
Tower	TDL+0, TDM+0, TDH+0, TDT+0	14 m
	TDL+3, TDM+3, TDH+3, TDT+3	17 m
	TDL+6, TDM+6, TDH+6, TDT+6	20 m
Mast	MDL+0, MDM+0, MDH+0, MDT+0	10 m
	MDL+3, MDM+3, MDH+3, MDT+3	13 m
	MDL+6, MDM+6, MDH+6, MDT+6	16 m

The first letter “T” – The support is TOWER

“M” - The support is MAST

The second letter “D” – Support is DOUBLE CIRCUIT TYPE

The third letter “L” - Support is INTERMEDIATE TYPE

“M” - Support is 0^0 – 30^0 MEDIUM ANGLE TYPE

“H” - Support is 30^0 – 60^0 HEAVY ANGLE TYPE

“T” - Support is TERMINAL TYPE

3.2 Right-of-Way of a transmission line

A Right-of-Way is a corridor of land over which electric transmission lines are located. It is something that the utility use another person’s property to construct and maintain electric power transmission facilities, mainly lines and towers. Utility also needs access to its facilities to perform maintenance. Land owners generally can continue to use their property in the right of way if the use is compatible with the purpose of the easement, (i.e. the transmission of electricity).

If the transmission line is constructed using bare conductors, it is necessary to clear an area on either side of the overhead line to avoid conductors being blown by wind into contact with the trees. If it uses insulated conductors, the insulation prevents faults developing should the cable touch a branch of a tree, or from conductor clashing.

Therefore, safety clearance can be reduced, as can the width of the cleared area around the line.

Therefore, in tower line applications, it is required to mark on all trees that are within the ROW at the time of actual execution of the line construction. After finalizing the profile design, notice for construction of 33kV tower line is issued to the land owners according to the Sri Lanka Electricity Act of 2009 to obtain the right of way clearance. If any objections are received, they will be inquired by the Divisional Secretariat of the respective division. Finally, the right of way clearance is obtained from the Public Utility Commission of Sri Lanka.

3.2.1 Vegetation Clearing &Compensation on Vegetation within the ROW

When an electricity line is proposed through afforestation and it is considered that the electricity structures are likely to be permanently required, their presence effectively sterilizes the ground in perpetuity along the length of the wayleave. As a result, the landowner loses all future earning capability on the land occupied by the apparatus and under the conductors, and the land value effectively reduces. The land owners are not allowed to plant trees under the ROW, but when an electricity line is proposed across arable land, only the area of ground physically occupied by the apparatus is sterilized, with the farmer able to grow crops and carry out normal agricultural operations under the flying wires.

The compensation for the removing of vegetation and for the loss of crops will only be paid, but the compensation for the land area under the power line is not paid so far.

3.2.2 Conventional method of compensation on vegetation clearing in CEB

In CEB, no compensation is made for the land owners for the area under the line, but they will be paid for the compensation with respect to the vegetation cleared along the ROW. No exact figure for ROW width for 33kV transmission lines is currently available in CEB and different branches/projects use different ROW width varies between 20m to 30m. Distribution division 1, 2 & 3 use 30m ROW while distribution division 4 uses 20m ROW. LSHP also maintained 20m ROW. Therefore, it is a requirement to derive an exact figure for ROW width for 33kV transmission lines.

Payment of compensation for cutting trees within the ROW is made for the land owners at the outset. In CEB, compensation so payable on cutting trees are done based on the valuation given by the respective DS. A list of trees which contains the circumferences, name and quantity is prepared by site ES and copies of this report are submitted to the CEB and Grama Niladhari. Then, valuation is made by GS and forwarded it to the respective DS. This recommended list is then received by CEB for the payment.

Presently, no exact method is available to calculate the compensation for vegetation clearing. Since having no exact methodology, it can be seen a variation of the compensation values from GS division to GS division for the same size and same type of tree. Because of this reason, lots of complaints are received from the land owners' w.r.t. the amount they received and CEB on the other hand face lot of difficulties when objections are received from the land owners.

3.3 Benefits of trees

Trees play a vital role in local economic development and quality of life in the urban environment. Beside the aesthetic scenic value, trees improve property values, air and water quality, reduce energy costs and increase water retention thereby reducing local flooding. Trees also reduce noise levels while creating wildlife habitat and buffer zones. Along with an increase in community pride, studies have shown that trees in an urban environment have a positive impact on behavior of the people. The mentioned services provided by vegetation can be explained as follows.

1. Aesthetic

People naturally find areas with trees more attractive and peaceful than areas without trees. Trees beautify the area and add a sense of nature to dense city landscapes.

2. Educational

Trees create suitable places for learning, discovery, and play. Trees in the lands provide habitat for wildlife and therefore serve as ideal spaces to watch birds, study biodiversity, and engage in other educational activities.

3. Carbon Sequestration

Trees are able to absorb atmospheric carbon, which reduces the green house gases and contribute to global warming. The carbon related function of trees is measured in two ways: storage (the total amount currently stored in tree biomass) and sequestration (the rate of absorption per year). Tree age greatly affects the ability to store and sequester carbon. Older trees store more total carbon in their wood and younger trees sequester more carbon annually.

Trees help by sequestering CO_2 from the atmosphere during photosynthesis to form carbohydrates that are used in plant function and return oxygen back into the atmosphere as a byproduct. Roughly half of the greenhouse effect is caused by CO_2. Therefore, trees act as carbon sinks, alleviating the greenhouse effect.

4. Energy savings

Energy is an essential ingredient for quality of life and for economic growth. Trees help to modify local climate by lowering air temperature, increasing humidity, influencing wind speeds and reducing glare. These trees provide shade and evaporation of water through the transpiration process. Trees also help with energy costs in the cold season by blocking cold winds thereby reducing the strain on heating units and reducing the need for air conditioning in hot season. These energy savings, when spread over many houses, can reduce the demand for power production by utility plants, which also reduce the amount of air pollutants produced by fossil fuels burned to produce electricity.

5. Reduce noise pollution

Noise from traffic and other sources may lead to stress and other health problems. Vegetation helps to dampen noise.

6. Reduce soil erosion

Trees reduce topsoil erosion by catching precipitation with their leaf canopies. This lessens the force of storms and slows down water runoff which in turn ensures that our groundwater supplies are continually being replenished. Leaves that have fallen from the trees and begun to decay form an organic layer that allows water to percolate into the soil which also aids in the reduction of runoff and soil erosion.

7. Improve water quality

Trees have been shown to influence the flow of water. If it is considered an urban environment, large areas of the city are covered with hard surfaces such as concrete that do not absorb water. During rainy season, high volumes of rainwater run off into the sewer system, causing overflow of sewage into rivers. Rain also washes pollutants from roadways into rivers. Vegetation reduces water runoff by enhancing water absorption by soil, and transpiring water from their leaves.

8. Habitat loss conservation

It is only natural that wherever trees are planted, wildlife and other plants are sure to follow. Trees provide shelter and food for a variety of birds and small animals. Enhancing growth diversity, trees create an environment that allows the growth of plants that otherwise would not be there. Flowers, fruits, leaves, buds and woody parts of trees are used by many different species.

Trees also provide shade, reduce water and air temperatures and contribute to the overall health of aquatic ecosystems by providing habitat, shelter and food for aquatic species such as turtles, fish, etc.

9. Improve air quality

Trees improve air quality by filtering some gaseous pollutants and small particles in the air people breathe. While trees will only remove a small percent of the total amount of pollutants, they can serve as a barrier, redirecting pollutants away from their canopies.

Trees also remove other gaseous pollutants through the stomata in the leaf surface by absorbing them with normal air components.

Therefore, trees in the area will be valuable asset for the land owners and hence, the compensation for removing trees shall be made by considering all the factors discussed above. Therefore, a proper tree valuation method is required to be introduced to Sri Lanka by considering the services/benefits mentioned above.

3.4 Internationally used tree valuation methods

Before designing a transmission line, a thorough analysis on vegetation shall be done [5]. Action needs to be taken to remove all trees and vegetation that will at some time interfere with the safe, reliable operation of its transmission lines and branches that overhang into the ROW may be trimmed rather than removing the entire tree. The value of a tree in the home, farm or urban landscape is worth because they add beauty, function and value to the property.

Initially, it was studied tree trimming practices for transmission lines, environmental & social impacts on transmission line construction and how to reduce these effects.

Tree valuation systems are widely used by some countries in the world. A monetary value is placed on trees, usually for the purpose of compensation. Most of the publications of Universities of developed countries have been relieved their intension to valuation on urban trees. According to the Horticulture report on Ornamental Tree and shrub evaluation published by Kansas State University, there are mainly three methods to establish the value of an ornamental landscape plant. [6]

1. Replacement cost method
2. The decrease in the assessed value of the real estate method
3. The computed method

3.4.1 Replacement Cost Method

Small trees normally 4 inches of diameter that can be easily transplanted at their full size are valued using this method. Removal of damaged or dead trees, digging planting hole, cost of new tree, post transplanting care and maintenance, survival guarantee costs are the factors considered in this method. If the plant was in poor condition prior to the loss, the appraised value may be less than the full cost of replacement.

3.4.2 The decrease in the assessed value of the real estate

If many plants are affected or when a dominant landscape element is lost, this is the best method to assess the landscape value. Therefore, in most of the cases, it is better to get the support of a realtor or a land appraiser to value the landscape with and without trees.

3.4.3 The computed method

This is the widely use method which is used for large, individual trees, which exceed the size that is usually transplanted. It is a hybrid of the replacement cost method and a process of extending that cost to larger plants. This method is developed by the International Society for Arboriculture and approved by the Council of Tree and Landscape appraisers.

The formula used in this method is:

Tree Value = Base Value x Cross Sectional Area x Species Class x Condition Class x Location Class [4.1]

Where,

Base Value = Amount assigned to one cross-section unit of a tree's trunk cross-section area

Species Class = Assigned value based on all the landscape tree species and its accompanying potential for problems

Condition Class = Factor indicating the health, vigor and life expectancy of a tree

Location Class = Factor based on functional and aesthetic contribution, which tree makes to the site

Tree trunk area is used to determine the base value, which is then multiplied by cross section area, species, condition and location ratings (0–1) to estimate the final compensatory value of the tree. Species class, Condition class and Location Class are described later in this chapter.

3.5 Adopting a suitable tree valuation method to Sri Lanka

An ecosystem is a community of living organisms (plants, animals and microbes) in conjunction with the nonliving components of their environment (things like air, water and mineral soil), interacting as a system. There are two types of ecosystems as Natural ecosystem and artificial ecosystems.

A natural ecosystem is a biological environment that is found in nature (e.g. a forest) rather than created or altered by man. Artificial ecosystems are the ecosystems modified by humans for their own benefit. They can be terrestrial (crop fields and gardens) or aquatic (aquariums, dams, and manmade ponds).

The pattern of life in Sri Lanka depends directly on the availability of rainwater. Therefore, by considering the changes in the seasonality of rainfall and temperature, the areas of the country have been categorized into two zones as wet zone and dry zone. Vegetation distribution in these two zones is different to each other. Typical ground cover is normally a scrub forest, interspersed with tough bushes and cactuses in the dry zone while, the dominant vegetation of the wet zone is a tropical evergreen forest, with tall trees, broad foliage, and a dense undergrowth of vines and creepers.

Power transmission lines can be drawn across all these ecosystems and the selected 33kV tower line has been drawn across an artificial ecosystem in the dry zone. When it is considered the vegetation distribution along the tower line, there could be seen different species which provides different benefits and services to the environment.

Accordingly, two DSs responsible for valuation of trees on this line has informed that, due to the unavailability of an exact method for tree valuation, it was done based on the tree value of the area. But, actual payment documents were proved that, the values estimated by DSs for the same size, same type tree at nearby locations had been different to each other. The Coconut Development Authority of Sri Lanka has defined a method to value coconut trees only.

The market value is widely employed as the best estimate of property value, and hence of appropriate compensation for its loss (e.g. to transmission lines) [7]. This compensatory value can be viewed as the value of a tree in place in the area to its owner. Here, the value of the tree is considered as a structural asset.

If a transmission line is taken into consideration, trees to be cleared along the corridor are normally large individual trees which exceed the size that is transplanted. Therefore, by considering the above facts, the Computed method prescribed by the Horticulture report on Ornamental Tree and shrub evaluation published by Kansas State University [6] which is mentioned in 4.7.3 can be adopted to Sri Lanka to value compensation on removing trees along the transmission line corridor.

Since, DSs are responsible for tree valuation by the Act; this method can be introduced to them with the help of the Forest Department of Sri Lanka.

3.5.1 Defining factors of the proposed method

Initially, field data such as type of the tree, number of trees, location, stem diameter (DBH), canopy condition, etc, related to the selected tower line were collected to analyze the vegetation distribution. Due to the lack of researches done on Sri Lankan tree species, much information is presently not available.

The factors mentioned in the equation 4.1 were separately considered to check the applicability of them to the proposed method for Sri Lanka.

3.5.1.1 Species class

The ratings for species class have been defined by other countries considering the factors related to a tree such as color, growth habit, flowering and fruiting characteristics, structural strength, longevity, etc.

According to the Forest Department of Sri Lanka, no species class ratings have still been defined for species in Sri Lanka. Therefore, in this study, the above stated tree based characteristics were classified as, life expectancy value, food value, medicinal value, standard wood density, conservation value, aesthetic value, and timber value in order to define the ratings for each tree.

The actual values of those characteristics for each tree species were found from some sources such as internet, research papers, Forest Department of Sri Lanka, books, etc and based on the weight and the value of the characteristic, it was given a value between 0-1.

The characteristics used for defining species class rating are described below.

Conservation value

Conservation of dry zone terrestrial ecosystems is of prime importance for conserving the species in these habitats. Species are classified by the IUCN Red List into nine groups set through criteria such as rate of decline, population size, area of geographic distribution, and degree of population and distribution fragmentation [8]. Following five are the main status found in the vegetation along the tower line.

- Critically endangered (CR) – Extremely high risk of extinction.
- Endangered (EN) – High risk of extinction.
- Vulnerable (VU) – High risk of endangerment.
- Near threatened (NT) – Likely to become endangered in the near future.
- Least concern (LC) – Lowest risk. Does not qualify for more at risk category

The conservation of biological diversity is of special significance to Sri Lanka in the context of its predominantly agriculture-based economy and the high dependence on many plant species for food, medicines and domestic products [9]. Therefore, conservation value is rated as follows considering the priority to be given for conserving the species. High conservation value was given to species with high importance of conserving.

Table 3.4: Conservation value

Type	Value
Critically endangered	1.0
Endangered	0.8
Vulnerable	0.6
Near threatened	0.4
Least concern	0.2

Medicinal Value

Sri Lanka is a country with a very old civilization and Ayurveda has been a widely practiced medical system throughout the ages. Plants have been used from ancient times to attempt cures for diseases and to relive physical suffering. Most of the trees in Sri Lankan environment can be used for medicinal purpose. Therefore, medicinal value of tree is also considered for providing a value to a tree and the ratings for medicinal value is given as follows.

Table 3.5: Medicinal value

Usage	Value
Medicinal usage present	1
No medicinal usage	0

Aesthetic value

Many benefits attributed to urban trees are difficult to price (e.g., beautification, privacy, wildlife habitat, sense of place, well-being). Property values mainly depend on the aesthetic value of the landscape. Therefore, we can determine how property values increase if they have trees on the land and thereby the value of trees on aesthetic point of view. Most of the time, flowers and fruits are decorative and these qualities make trees ideal for beautifying gardens, cities, and even industrial estates.

Therefore, to provide a rating for aesthetic value, the color and the fragrance of the flowers were considered and the ratings are given as follows.

Table 3.6: Aesthetic value

Feature	Value
Flowers with color and fragrant	1.00
Flowers with color	0.75
Flowers with white color but with fragrant	0.50
Flowers with white color and no fragrant	0.25
No flowers	0.00

Food Value

Trees act as food sources which are called edible trees. Fruits, flowers, leaves, seeds, etc can be taken as food. Based on the tree is edible or non-edible, the rating is given for food value.

Table 3.7: Food value

Type	Value
Edible	1
Non-edible	0

Timber value

The market value is considered in many cases for estimation better and prevailing method of tree valuation is roughly done considering the market value of the timber. State Timer Corporation has classified trees into eight categories as follows based on the timber value in the market as shown in Annex I.

Accordingly; the ratings for timber value were given based on the timber class.

Table 3.8: Timber value

Timber class	Value
Super luxury	1.00
Luxury	0.85
Special class upper	0.70
Class I	0.55
Class II	0.40
Class III	0.25
Class III Lower Grade	0.10

Life Expectancy value

This value took into account the projected useful life expectancy of the species. Value of a tree depends on the life expectancy and the ratings give is as follows.

Table 3.9: Life expectancy value

Useful life expectancy ranges	Value
> 50 years	1.0
40 – 49 Years	0.9
30 – 39 Years	0.8
20 – 29 Years	0.7
10 – 19 Years	0.6
< 10 Years	0.5

Finally, each characteristic was tabulated against each tree species as in Annex II. By giving equal priorities for each characteristic, the weighted average summation method was used to calculate the species class ratings. Then, this value is used in the equation 4.1 for the tree valuation.

The species class ratings which were calculated as above for trees along the line corridor of Tangalle – Nonagama tower line is indicated below.

Table 3.10: Species class ratings

	Common name	Botanical Name	Species class
1	Kohomba	Azadirachta indica	0.71
2	Tamarind	Tamarindus indica	0.82
3	Pihibiya	Filicium decipiens	0.64
4	Teak	Tectona grandis	0.67
5	Mango	Magnifera Indica	0.68
6	Jak	Artocarpus heterophyllus	0.78
7	Sooriyamaara	Albizia lebbeck	0.73
8	Mahogany	Swietenia macrophylla	0.58
9	Halmilla	Berrya cordifolia	0.55
10	Breadfruit	Artocarpus Incisus	0.57
11	Beli	Aeglemar melos	0.72
12	Hik	Lannea coromandelica	0.41
13	Kumbuk	Terminalia arjuna	0.59
14	Ehela	Cassia Fistula	0.69
15	Nedun	Pericopsis Mooniana	0.70
16	Ambarella	Spondias dulcis	0.58
17	Acacia	Acacia auriculiformis	0.41
18	Ipil	Laucaena Leucocephala	0.41
19	Lunuweraliya	Photinia Integrifolia var. sublanceolata	0.16
20	Kithul	Caryota urens	0.70
21	Alipera	Persea Americana	0.56
22	Jam	Muntingia Calabura	0.56
23	Kottamba	Terminalia catappa	0.55
24	Lawalu	Chrysophyllum roxburghii	0.66
25	Ketakala	Bridelia retusa	0.74
26	Koon	Xylocarpus rumphil	0.79
27	Puwak	Areca catechu	0.50
28	Madatiya	Adenanthera pavonina	0.63

29	Magulkaranda	Pongamia pinnata	0.56
30	Giniseeriya	Exacum trinervium ssp.Trinervium	0.47
31	Kaju	Anacardium occidentale	0.55
32	Damuna	Grewia Asiatica	0.63

The equation 4.1 includes two other class ratings as Location class and condition class. Following location class and condition class ratings were extracted from the journal paper on Landscape Tree Appraisal by Michael N. Dana, of Purdue University Cooperative Extension Service.

3.5.1.2 Location class

Location class is based on functional and aesthetic contribution, which the tree makes to the site, the placement of the tree on the site and the importance of the location in the landscape context of the community. The class is expressed as a decimal value in the formula.

Table 3.11: Location class ratings

Site Location	**Location Class**
Specimen or historical trees	1.00
Average residential, landscape trees	0.85
Park and recreation trees	0.75
Golf court trees	0.65
City street trees, shopping malls	0.55
Industrial area trees	0.45
Out-of-city highway trees	0.35
Native, open woods trees	0.25
Undesirable location	0.15

3.5.1.3 Condition class

Condition class is the factor indicating the health, vigor and life expectancy of a tree as well as its quality of form relative to a "perfect specimen" of that species. The rating is based on such defects such as wounds, decay, insect damage and poor form. The class is expressed as a decimal value in the formula.

Table 3.12: Condition Class ratings

Condition	Description	Condition class
Excellent	Perfect specimen. Excellent form and vigor for species. No pest problems or mechanical injuries. No corrective work required. Minimum life expectancy 30 years beyond the time of inspection.	1.0
Good	Healthy and vigorous. No apparent signs of insect. Diseases or mechanical injury. Little or no corrective work required. Form representative of species. Minimum life expectancy 20 years.	0.8
Fair	Average condition and vigor for area. May be in need of some corrective pruning or repair. May lack desirable form characteristics of species. May show minor insect, disease or physiological problems. Minimum life expectancy 10 years.	0.6
Poor	General state of decline. May show severe mechanical, insect or disease injury, but death not imminent. May require major repair or renovation. Minimum life expectancy 5 years.	0.2
Dead or Dying	Dead or death imminent within 5 years.	0.0

The proposed method is actually a benefit-based tree valuation method where this provides alternative estimates of the fair and reasonable value of trees while illustrating the relative contribution of different benefit types.

3.6 Vegetation Management

Vegetation management is a specialized field that goes far beyond the trimming of trees. Vegetation management involves right of way ground clearance, as well as, line clearance issues. However, for overhead distribution facilities, the lineman normally only has to resolve tree trimming concerns. Tree trimming must be completed in a manner that is environmentally acceptable.

Considering the safety clearance required between the vegetation and the conductor, it allows some vegetation to grow to its maximum height and selective vegetation trimming or removal is done otherwise [1].

3.6.1 Objective of vegetation clearing

Vegetation clearance is preventive line maintenance to ensure that the utility's service to its customers is not interrupted as a result of interference with conductors or circuit equipment by growing trees. Elements include removal of dangerous trees and overhangs, trimming to clear the conductors, and clearing transmission right of way. Natural tree growth and some branches can ground or break transmission lines, interrupting electric service and endangering the public. The trimming process is intended to anticipate such a possibility by removing this hazard. Lines are checked and cleared on a planned time cycle. The amount of clearance should be accomplished while maintaining the health and beauty of the trees involved the goodwill of property owners and public authorities, and the safety of the trimming crew and the public.

Proper planting is essential in areas adjacent to power lines. The planting of vegetation in the areas adjacent to power lines must be carefully considered as large or fast growing species can lead to network operations, local councils and other land managers committing additional resources in the future to ensure effective management.

3.6.2 Wire – Zone Border - Zone Approach

According to [10], the Wire Zone–Border Zone (WZ/BZ) approach to vegetation management on electric transmission line rights-of-way (ROWs) was formally introduced by Drs. Bramble and Byrnes in the mid-1980s (Bramble et al. 1985, 1986). Also, [10] says that, the U.S. Federal Energy Regulatory Commission (FERC) and the North American Electric Reliability Corporation has effectively endorsed the use of the WZ/BZ approach for management of ROW vegetation by recognizing the American National Standards Institute (ANSI) A300 Tree Care Operations standards as an “industry best practice”.

Scientific research has demonstrated this method to cause the lowest impact to the environment while being beneficial to wildlife [11]. According to [12], this approach has defined three distinct zones from edge to edge as Wire zone, Border zone and another Border zone (Off-ROW) as shown below.

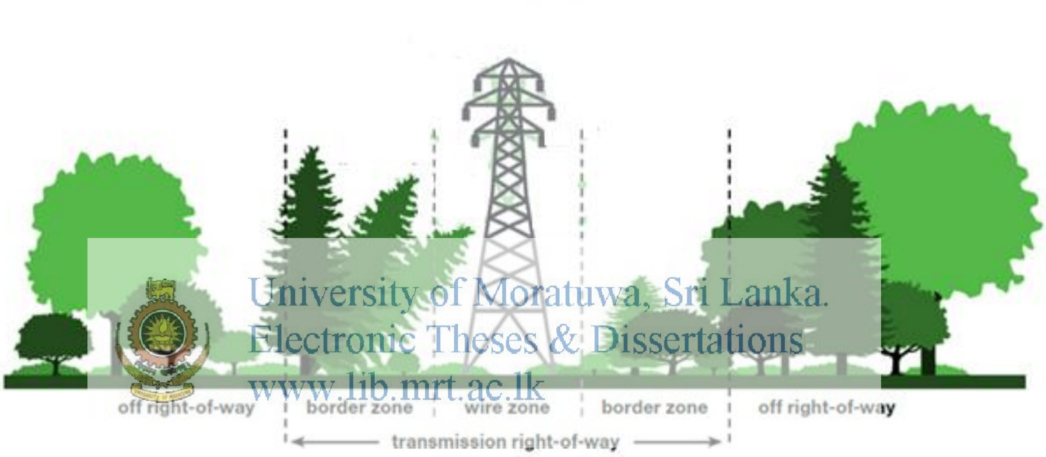

Figure 3.1: Transmission ROW – WZ/BZ approach [12]

Wire Zone - ROW area directly under the conductors and extending outward about 10 feet on each side. Allow a low-growing plant community dominated by grasses, herbs and small shrubs.

Border Zone – The remainder of the ROW and allow small trees and tall shrubs

Off- ROW – Mature trees and normal vegetation growth

The ROW vegetation is managed differently in these zones, purportedly to optimize the safe and reliable transmission of electricity. Considering the mature height of the tree, some vegetation can remain under the power line; however a working area around the structure must remain clear to allow access for maintenance and repair. A corridor of low growing vegetation may be retained to allow connectivity of wildlife habitat.

Vegetation management requires having a thorough analysis on height of the trees along and closer to the ROW.

3.7 Tower line design using covered conductors

3.7.1 Introduction to Covered Conductor Technology

According to [13] Covered conductor (CC) lines have been widely used in medium voltage networks by several countries since early 1980's.

Since the use of covered conductors in HV lines is a relatively new idea, there are no directly applicable standards available. The first installations of CC in Europe were in Finland and that country was the first to produce a CC standard, quickly followed by Sweden and Norway. In the UK all utilities use the three UK standards ENATS 43-120, 121 and 122 but will use prEN50397 when it is finalized [13].

The current European CENELEC draft standard for Covered conductors defines CC as follows.

> *"Covered conductors consist of a conductor surrounded by a covering made of insulating material as protection against accidental contacts with other CCs and with grounded parts such as tree branches, etc. In comparison with insulated conductors, this covering has reduced properties, but is sufficient to withstand the phase-to-earth voltage temporarily."*

As CC phases tolerate contact with each other and also with other objects there is less outage due to special weather conditions like wind gusts, uneven ice loads, ice shedding or snow covered trees leaning on the line. This feature makes it also possible to reduce the right of way of covered conductor lines. With MV CC lines the line corridor required is about 40% of the bare conductor line [3].

The failure rate (number of outages) of covered conductor lines is closer to that of underground cables. Furthermore, the phase distances in CC lines are smaller than in bare lines, which will reduce the EMF effect and also allow narrower wayleave. It is evident that, if one takes into account also these factors, the CC overhead lines produce smallest environmental impact and thus can be considered as an eco-line [14].

3.7.2 Advantages on Covered conductors

1. Smaller frequency of interruptions caused by, for example, trees bending or falling on the line than the bare conductor line.
2. Mitigation of environmental impact of power lines and reduction of costs related to the right-of-way. The line structure is compact; on 110 kV lines the right-of-way is approximately 12 m wide while the most common bare conductor line structure in Finland with portal towers requires 46 m.
3. Due to smaller phase clearances, the electric and magnetic fields caused by the line are significantly reduced.
4. Increased reliability cuts maintenance costs - show higher reliability because the conductor cover reduces momentaries during contact with tree branches. Higher reliability means you spend less money per pole on maintenance, and your total distribution system life-cycle costs drop. The covered conductors are individually insulated, resulting in fewer outages caused by events like storms or falling branches. Conductor covering reduces outages from phase to phase and phase to ground contact. Less maintenance is required on the system.
5. Dramatically cut vegetation management costs - Managing vegetation to avoid conductor contact is an expensive, recurring maintenance operation. If a tree limb brushes a CC cable, the conductor covering has the electrical strength to limit momentaries. Tighter clearances may be allowed in some instances, resulting in less frequent trimming. Utilities using CC Systems have seen a significant savings in vegetation management budgets.
6. Less damage caused by animals
7. Reduced tree trimming - Because the Covered Conductor System has a compact design that can tolerate temporary contact, trees can be allowed to grow much closer to the conductors. This greatly reduces the initial tree

clearing necessary to install the circuit and the periodic trimming required in order to maintain the circuit.

8. Safety – According to [3], while touching of a bare conductor line cause frequently fatal accidents, this is not the case with a CC line. According to the statistics of Finnish Safety Technology Authority [15] there has been on average one fatal accident per year in recent ten-year period related to bare MV overhead lines.

3.7.3 Disadvantages

High start-up costs - CC is relatively expensive to install and can lead to high start-up costs, but because maintenance and service interruptions are reduced, the long term benefits are attractive.

3.7.4 Covered conductor technology in Sri Lanka

In Sri Lanka, bare conductors are used in 220kV, 132kV and 33kV transmission voltages while CC and ABC conductors are used in 33kV pole line applications other than bare conductors.

In the distribution network, environment friendly partially insulated medium voltage line of about 5km has been drawn by Lighting Sri Lanka Hambantota Project for the first time in Sri Lanka to save vegetation in the forest reserves. At present, other divisions of CEB have also used CC technology in the terrains where clearing of way leaves are restricted.

Currently, a CC for 33kV transmission line application has been developed in Sri Lanka and this was used for re-designing the line in this study.

3.7.4.1 Introduction to the proposed covered conductor

The newly introduced covered conductor is named as "LYNX Covered Conductor" and the same accessories such as insulators which are used with LYNX conductors can be utilized. No earth conductor is used and Arc Protective Devices are used instead. The ACSR LYNX conductor is covered by 3.3mm insulation layer of cross linked polyethylene (XLPE) and this insulation is sufficient to avoid earth faults or a short circuit for a considerable time when a tree falls on the line or the phases clashes.

The technical specification of this CC is attached in Annex III.

3.7.5 Comparison on conductor types in overhead power lines

A more recent development has been the use of overhead conductors which are insulated. These conductors are more expensive than bare overhead but cheaper than full underground, as full cable outer mechanical protection is not needed, nor is expensive trenching and restoration. Being insulated provides some protection against wind-blown debris short-circuiting conductors together or conductor clashing.

Aerial bundled cable, or ABC for short, consisting of fully insulated (i.e. safe to touch) conductors tightly wrapped around a mechanical bearer wire (usually steel). Covered conductors, consisting of 'partly insulated' conductors mounted on insulators similar to bare overhead lines. These are cheaper than ABC and offer most of the protection features against wind-blown debris as does ABC but are not touch safe. ABC in particular is heavy and unsightly requiring more poles than bare-wire overhead, but trees can grow around it and hide it almost completely from view in due course. Covered conductor can also tolerate trees near it, but not to the same extent as ABC. It is less heavy and less unsightly when not shielded by trees.

The fact that the conductors are not self-supporting means that vibration risks are reduced and reliability increased. Aerial cable is essentially a fully insulated 3-core cable with an earth screen used for overhead applications. It's low susceptibility to lightning and the inherent reliability of the cable design means that this system is the most expensive, but also the most reliable. In very general terms, the reliability of bare wire distribution systems and the three basic types of CC described here is shown schematically in Figure 3.2.

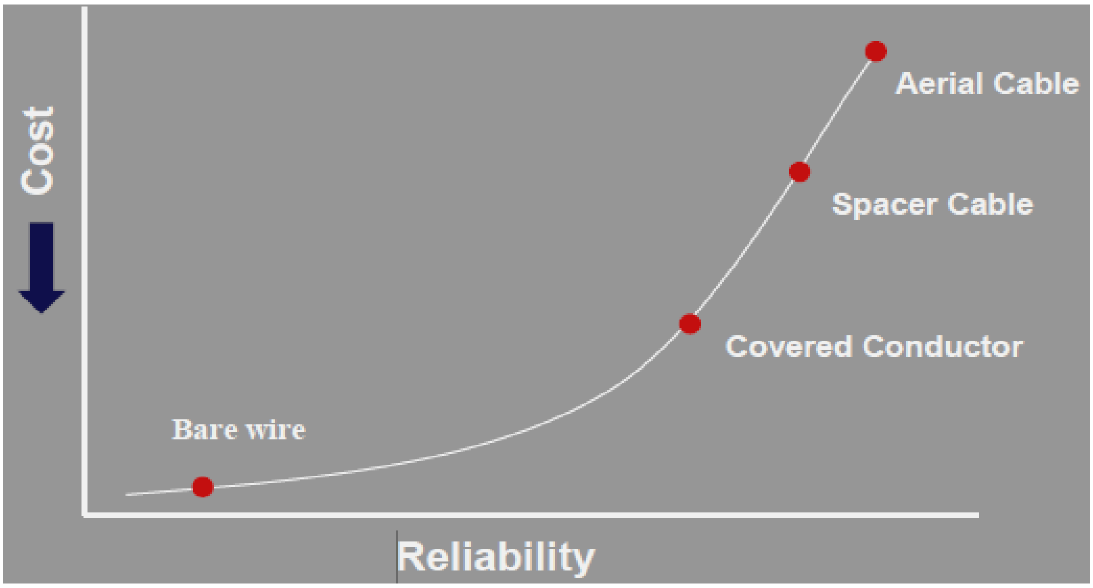

Figure 3.2: Schematic reliability of various distribution systems

Chapter 4

Theoretical Development

4.1 Sag-tension calculations

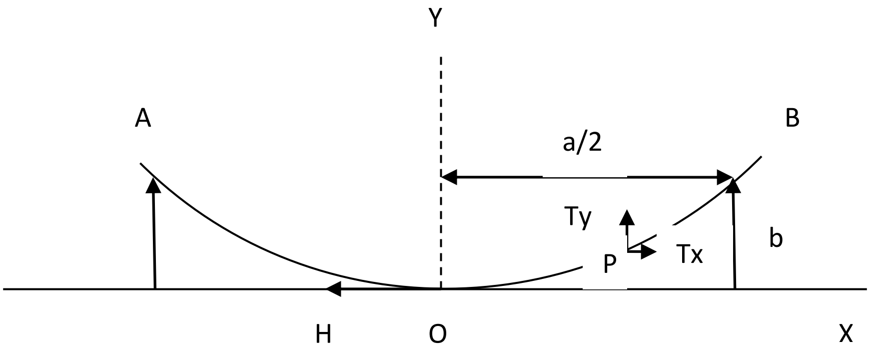

Figure 4.1: Transmission line conductor strung between two points

w - Weight of the conductor per unit length

p - Horizontal wind pressure per unit length

q - Resultant force per unit length

$$q = \sqrt{w^2 + p^2}$$

$$\tan\theta = p/w$$

L- Length of the conductor

a – Span AB

b- Sag of the conductor at its lowest point with reference to the points of supports

T- Tension at either point of support

H- Horizontal tension at the lowest point O

4.1.2 Catenary Formulae

The length, sag and tension of the conductor are given by the following catenary formulae.

$$L = \frac{2H}{q} \sinh \frac{aq}{2H} \quad [1]$$

$$b = \frac{H}{q} [\cosh \frac{aq}{2H} -1] \quad [2]$$

$$\frac{T}{q} = \frac{H}{q} [\cosh \frac{aq}{2H}] \quad [3]$$

$$\frac{T}{q} = b + \frac{H}{q} \quad [4]$$

For spans of the order 300 m and less, the above characteristics of the conductor are given with sufficient degree of accuracy by the following simpler parabolic formulae.

$$L = a + \frac{a^3 q^2}{24 H^2} \quad [5]$$

$$b = \frac{qa^2}{8H} \quad [6]$$

$$\frac{T}{q} = \frac{qa^2}{8H} + \frac{H}{q} \quad [7]$$

t_1 - Initial temperature

t_2 - Final temperature

$t = t_1 - t_2$

α - coefficient of linear expansion of the conductor per deg C

E - Modulus of Elasticity of conductor

a - Area of cross section of conductor

At initial temperature t_1

$$L_1 = a + \frac{a^3 q_1^2}{24 H_1^2} \quad [8]$$

At final temperature t_2,

$$L_2 = a + \frac{a^3 q_2^2}{24 H_2^2} \quad [9]$$

Unstressed length of the conductor at initial temperature $L_1 - \frac{L_1 H_1}{EA}$

Unstressed length of the conductor at final temperature $L_2 - \frac{L_2 H_2}{EA}$

$$\left(L_1 - \frac{L_1 H_1}{EA}\right)(1 + \alpha t) = L_2 - \frac{L_2 H_2}{EA}$$

$$\left(L_1 - \frac{L_1 H_1}{EA}\right) + (\alpha t L_1) = L_2 - \frac{L_2 H_2}{EA}$$

Neglecting terms $\frac{L_1 H_1}{EA} . \alpha t$

$$L_2 - L_1 + \frac{L_1 H_1}{EA} - \frac{L_2 H_2}{EA} - \alpha t L_1 = 0 \quad [10]$$

From equation (8) (9) and (10)

$$\frac{a^3 q_2^2}{24 H_2^2} - \frac{a^3 q_1^2}{24 H_1^2} + \frac{H_1}{EA}\left(a + \frac{a^3 q_1^2}{24 H_1^2}\right) - \frac{H_2}{EA}\left(a + \frac{a^3 q_2^2}{24 H_2^2}\right) - \alpha t\left(a + \frac{a^3 q_1^2}{24 H_1^2}\right) = 0$$

$$\frac{a^2}{24}\left(\frac{q_2^2}{H_2^2} - \frac{q_1^2}{H_1^2}\right) + \frac{H_1 - H_2}{EA} + \frac{a^2}{24EA}\left(\frac{q_1^2}{H_1} - \frac{q_2^2}{H_2}\right) - \alpha t - \alpha t \frac{a^2 q_1^2}{24 H_1^2} = 0$$

Neglecting products of small quantities

$$\frac{a^2}{24}\left(\frac{q_2^2}{H_2^2} - \frac{q_1^2}{H_1^2}\right) + \frac{H_1 - H_2}{EA} - \alpha t = 0$$

Putting

$$\delta = \frac{w}{A}, f_1 = \frac{H_1}{A}, f_2 = \frac{H_2}{A}, Q_1 = \frac{q_1}{w}, Q_2 = \frac{q_2}{w}$$

$$\frac{a^2 \delta^2}{24}\left(\frac{Q_2^2}{f_2^2} - \frac{Q_1^2}{f_1^2}\right) + \frac{f_1 - f_2}{E} - \alpha t = 0$$

$$f_2^2\left[f_2 - \left(f_1 - \frac{a^2 \delta^2 Q_1^2 E}{24 f_1^2} - \alpha t E\right)\right] = \frac{a^2 \delta^2 2E}{24} \quad [11]$$

Having determined the value of f_2 from the equation (11), the sag can be found from,

$$b = \frac{qa^2}{8H}$$

$$b = \frac{wa^2Q}{8H}$$

OR $$S = \frac{a^2\delta Q_2}{8f_2} \quad [12]$$

By using the above equation [11] the value of f_2 is determined for equivalent spans, the sag (Basic sag) has to be found using the equation [12] for the following conditions.

- 7 ^{0}C with Wind and no wind
- 32 ^{0}C with Wind and no wind
- 75 ^{0}C with Wind and no wind

Working stress f_2 is calculated for a particular temperature to calculate the Sag at that temperature. The sag is needed to draw the catenary of the line at that temperature.

The cold curve or minimum vertical sag line at the coldest specified conditions is used to detect cases of direct uplift on insulators at low lying positions.

Working stress f_2 is calculated for every day temperature (32^{0}C) to check whether the working stress is within the limits of maximum allowable stress. Safety factor at every day temperature is 5.

Working stress f_2 is calculated for Maximum operating temperature (75^{0}C) with no wind, to calculate the sag at this temperature. The sag is needed to draw the catenary of the line at this temperature which indicates the maximum possible sag of the transmission line (Hot curve). All the clearance curves are drawn based on this curve. This curve is used to position the towers on the profile.

$$\text{Catenary constant} = \frac{\text{H}}{\text{q}}$$

$$\text{K Factor} = \frac{\text{Sag at equivalent span x 4 x}10^5}{(\text{equivalent span})^2}$$

4.1.3 Wind span calculation

The maximum wind span of any structure is equal to the distance measured from center to center of the two adjacent spans supported by the structure. The wind span is used to determine the maximum horizontal force a structure must withstand under high wind conditions. The wind span is not depending on conductor sag or tension. It depends only on horizontal span length.

4.1.4 Weight Span Calculation

The weight span of a structure is a measure of the maximum vertical force a structure must withstand. The weight span is equal to conductor weight per unit length times the horizontal distance between the low points of sag of the two adjacent spans.

Wind span and weight span limits related to tower & mast supports are stated below.

Table 4.1: Wind span and weight span limits for MV line supports [4]

Tower Type	Normal Condition		Broken Wire Condition	
	Wind Span(m)	Weight Span(m)	Wind Span(m)	Weight Span(m)
MDL	240	400	-	-
MDM	240	600	180	450
MDH	240	600	180	450
MDT	240	600	180	450
TDL	360	600	270	450
TDM	360	-600 to 1200	270	-600 to 675
TDH	360	-600 to 1200	270	-600 to 675
TDT	360	-600 to 1200	270	-600 to 675

4.2 Creep Calculation

As a result of creep strain, there is an increase in length and hence in sag of an overhead line conductor with time, which should be considered at the design stage.

Based on a large number of laboratory tests at different tensions and temperatures, Bradbury, Harvey and Larson have suggested the use of the three predictor equations which correlate tension, temperature, time and creep strain. The equation suggested by Larson and Harvey for all aluminium, aluminium alloy and ACSR conductors are:

$$v = K\left(\frac{Tx100}{UBS}\right)^{b} . Q^{F} . h^{g} \qquad [13]$$

A – Cross sectional area of the conductor in mm

T – Tension in conductor 32 degC, kg

UBS – Ultimate Breaking Strength, kg

h – Time in hours

v – Creep strain, mm/km

Q – Conductor temperature, °C

K – Creep constant

F, b, g – Creep indices

Where,

$K = 1.4$

$b = 1.3$

$F = 0$

$g = 0.16$

If the tension to be applied to create above creep is DT

$$DT = \frac{12xvxT_1^3}{(wg)^2xa^2} \qquad [14]$$

Where w– Weight of the conductor per meter

a – Equivalent Span

T_2 – Initial tension to be applied

Therefore the Initial tension to be applied

$$T_2 = T_1 + DT \qquad [15]$$

Conversion of Tension to temperature differences is calculated from the equation of sag calculations.

$$\frac{W^2ES^2}{4T_2^2} - \frac{T_2}{A} = \frac{W^2ES^2}{24T_1^2} - \frac{T_1}{A} + \alpha Et \qquad [16]$$

Where, W	=	Unit weight of conductor (kg/m)
S	=	Span Length (m)
E	=	Young's Modulus of conductor (kg/cm²)
T_1	=	Final Tension of Conductor (kg)
T_2	=	Initial Tension of Conductor (kg)
A	=	Cross sectional Area of Conductor (cm²)
α	=	Co-efficient of Linear Expansion of Conductor (per °C)
t	=	Temperature Difference (°C)

$$t = \frac{\frac{W^2EAS^2}{24}\left(\frac{1}{T_2^2} - \frac{1}{T_1^2}\right) - (T_2 - T_1)}{aEA} \qquad [17]$$

Chapter 5

Design & Calculation

5.1 Overhead line design

At the line design, sag tension calculation is done initially and the sag template is prepared for the equivalent spans (eg: 200m, 300m) using Auto CADD software. The sag of a transmission cable is impacted by several phenomena – including changes in heating, changes in loading, etc. The distance that a cable will sag depends on the length of the conductor span, the weight of the conductor, its initial tension, and its material properties. The cable itself will have a unit weight, core cross-section and diameter, conductor cross-section and diameter, etc. It will also have a coefficient of linear expansion.

In this chapter, the sag-tension for ACSR LYNX conductor and LYNX covered conductor will be calculated in order to design the overhead lines using them.

5.2 Line design using ACSR LYNX conductor

5.2.1 Sag - tension calculation for ACSR LYNX conductor

Conductor properties and the design data used for the calculations are tabulated below.

Table 5.1: Conductor properties and design data

Conductor Properties	**Values**	**Unit**
Conductor material	ACSR - LYNX	
Conductor Size	30/7/2.79	
Overall Diameter of the conductor (D)	19.53	mm
Area of conductor (for all stands) (A)	226.20	mm^2
Weight of the conductor with grease (W)	0.8424	kg/m
Coefficient of Linear Expansion	0.0000178	per ^oC
Modulus of Elasticity (E)	80.00	kN/mm^2

Ultimate Breaking Strength (UTS)	79.80	kN
Design data		
Equivalent Span (L)	300	m
Temperature Minimum (T min) Every day (T) Maximum (T max)	 7 32 75	 ^{0}C ^{0}C ^{0}C
Wind Pressure (P)	970	N/m²

Minimum factor of safety for Conductors & Earth wire based on Ultimate Strength

At maximum working tension - 2.5

At everyday temperature with no load - 5.0

5.2.2 Calculations

Wind force on conductor per meter run,

$p = 970\ X\ 19.53\ X 10^{-3}$ N/m

$= 18.94410$ N/m

Loading factor at 7 ^{o} C, with wind,

$$Q_1 = \frac{\sqrt{p^2 + w^2}}{w}$$

Where, p - wind force on conductor per meter run

w - Weight of the conductor per meter

$$Q_1 = \frac{\sqrt{(\frac{18.944}{9.8067})^2 + 0.8424^2}}{0.8424}$$

$$Q_1 = 2.50171$$

Loading factor at given temperature without wind,

$$Q_2 = \frac{\sqrt{0 \ + 0.8424^2}}{0.8424}$$

$$Q_1 = 1.0$$

Maximum allowable working tension of the conductor $= \frac{UTS}{2.5}$

$$= \frac{79.80 * 10^3}{2.5}$$

$$= 31{,}920 \text{ N}$$

However, in order to satisfy the design condition at 32°C and safety factor of 5, maximum allowable working tension is assumed as 31,920 N. (at 32°C Tension should be less or equal to UTS / 5 = 15960 N)

Maximum allowable working stress of the conductor

$$f_1 = \frac{31920}{226.2} \text{ N/mm}^2$$

$$= 141.114 \text{ N/mm}^2$$

Weight of conductor with grease/m/mm²

$$\S = \frac{0.8424 \ x \ 9.8067}{226.2}$$

$$= 0.0365215 \quad \text{N/m/mm}^2$$

Then the working stress f_2 can be determined by the following formula

$$\frac{f_2^2[f_2 - (f_1 - a^2\S^2Q_1^2E - \text{æ}t\text{E})]}{24f_1^2} = \frac{a^2\S^2Q_2^2E}{24}$$

Where,

$a =$ Conductor span in meters

$E =$ Modulus of elasticity in N/mm²

æ = Coefficient of linear expansion in per °C

$t =$ Temperature difference , $(t_{req} - t_{min})$

Then, the Sag can be determined by the following formula,

$$Sag = \frac{a^2 § Q_2}{8f_2}$$

Case 1

Sag at 7°C with wind load

$$Initialtension = 31{,}920\ N$$

$$Sag = \frac{w * span^2 * Q_1}{8T}$$

Where, w – unit weight of the conductor, N/m

T - Initial Tension, N

$$Sag = \frac{0.8424 * 9.8067 * 300^2 * 2.502}{8 * 31920}$$

= 7.28 m

Case II

Sag at 7°C without wind load

$$\frac{f_2^2[f_2 - (f_1 - a^2§^2 Q_1^2 E - \text{æ}tE)]}{24f_1^2} = \frac{a^2§^2Q_2^2E}{24}$$

$$t = (7 - 7)℃$$

$$t = 0\ ℃$$

$$\frac{(f_1 - a^2§^2 Q_1^2 E - \text{æ}tE)]}{24f_1^2}$$

$$= 141.114 - \frac{(300^2 * 0.0365^2 * 2.502^2 * 80 * 10^3)}{24 * 141.114^2} - (0.0000178 * 0 * 80 * 10^3)$$

$$= 141.114 - 125.6439$$

$$= 15.4701$$

$$\frac{a^2 \S^2 Q_2^2 E}{24} = \frac{300^2 * 0.0365^2 * 1^2 * 80 * 10^3}{24}$$

$$= 400146.0642$$

Therefore the equation,

$$f_2^3 - 15.4701 \; f_2^2 = 400146.0642$$

Solving by Newton Raphsan methods

$$f_2 = \sqrt[3]{\{(4.00146 * 10^5) + 15.4701 \; f_2^2\}}$$

Starting,

$$f_2 = 79.17849$$

$$f_2 = 79.21799$$

$$f_2 = 79.22313$$

$$f_2 = 79.22380$$

$$f_2 = 79.22389$$

$$f_2 = 79.22390$$

$$f_2 = 79.22390$$

Then,

$$T = 79.22390 \text{ x } 226.2 \text{ N}$$

$$= 17920.45 \text{ N}$$

$$Sag = \frac{300^2 * 0.0365 * 1}{8 * 79.22390}$$

$$= 5.18 \text{ m}$$

Case III

SAG at 32ºC without wind load

$$\frac{f_2^2[f_2 - (f_1 - a^2§^2Q_1^2E - ætE)]}{24f_1^2} = \frac{a^2§^2Q_2^2E}{24}$$

$$t = (32 - 7)℃ \quad t = 25 ℃$$

$$\frac{(f_1 - a^2§^2Q_1^2E - ætE)]}{24f_1^2}$$

$$= 141.114 - \frac{(300^2 * 0.0365^2 * 2.502^2 * 80 * 10^3)}{24 * 141.114^2} - (1.78 * 10^{-5} * 25 * 80 * 10^3)$$

$$= 141.114 - 125.6439 - 35.60$$

$$= -20.12984$$

$$\frac{a^2§^2Q_2^2E}{24} = \frac{300^2 * 0.0365^2 * 1^2 * 80 * 10^3}{24}$$

$$= 400146.0642$$

Therefore the equation,

$$f_2^3 + 20.12984\, f_2^2 = 400146.0642$$

Solving by Newton Raphsan methods

$$f_2 = \sqrt[3]{\{(4.00146 * 10^5) - 20.12984 f_2^2\}}$$

Starting,

$$f_2 = 67.52085155$$

$$f_2 = 67.56037085$$

$$f_2 = 67.55252229$$

$$f_2 = 67.55408153$$

$$f_2 = 67.55377179$$

$$f_2 = 67.55383332$$

$$f_2 = 67.55382109$$

$$f_2 = 67.55382352$$

Then,

$$T = 67.55382 \text{ x } 226.2 \text{ N}$$

$$= 15{,}280.67 \text{ N}$$

Note : at 32°C Tension should be less UTS/5 = 15,960.0 N

$$Sag = \frac{300^2 * 0.0365 * 1}{8 * 67.55382} = 6.08 \text{ m}$$

Case IV

SAG at 32°C with wind load

$$\frac{f_2^2[f_2 - (f_1 - a^2§^2 Q_1^2 E - \text{ætE})]}{24 f_1^2} = \frac{a^2§^2 Q_2^2 E}{24}$$

$$t = (32 - 7)\text{°C}$$

$$t = 25\text{ °C}$$

$$\frac{(f_1 - a^2§^2 Q_1^2 E - \text{ætE})]}{24 f_1^2}$$

$$= 141.114 - \frac{(300^2 * 0.0365^2 * 2.502^2 * 80 * 10^3)}{24 * 141.114^2} - (1.78 * 10^{-5} * 25 * 80 * 10^3)$$

$$= 141.114 - 125.6439 - 35.60$$

$$= -20.12984$$

$$\frac{a^2 \S^2 Q_2^2 E}{24} = \frac{300^2 * 0.0365^2 * 2.502^2 * 80 * 10^3}{24}$$

$$= 2504331.492$$

Therefore the equation,

$$f_2^3 + 20.12984\, f_2^2 = 2504331.492$$

Solving by Newton Raphsan methods

$$f_2 = \sqrt[3]{\{(2.504331 * 10^5) - 20.12984 f_2^2\}}$$

Starting,

$$f_2 = 129.374103$$

$$f_2 = 129.41363285$$

$$f_2 = 129.40953420$$

$$f_2 = 129.40995924$$

$$f_2 = 129.40991516$$

$$f_2 = 129.40991973$$

$$f_2 = 129.40991926$$

$$f_2 = 129.40991931$$

$$f_2 = 129.40991930$$

Then,

$$T = 129.409919 \text{ x } 226.2 \text{ N}$$

$$= 29{,}272.524 \text{ N}$$

$$Sag = \frac{300^2 * 0.0365 * 2.502}{8 * 129.409919}$$

$$= 7.93 \ \text{m}$$

Case V

SAG at 75ºC without wind load

$$\frac{f_2^2[f_2 - (f_1 - a^2§^2Q_1^2E - ætE)]}{24f_1^2} = \frac{a^2§^2Q_2^2E}{24}$$

$$t = (75 - 7)℃$$

$$t = 68 ℃$$

$$\frac{(f_1 - a^2§^2Q_1^2E - ætE)]}{24f_1^2}$$

$$= 141.114 - \frac{(300^2 * 0.0365^2 * 2.502^2 * 80 * 10^3)}{24 * 141.114^2} - (1.78 * 10^{-5} * 68 * 80 * 10^3)$$

$$= 141.114 - 125.6439 - 96.83$$

$$= -81.3599$$

$$\frac{a^2§^2Q_2^2E}{24} = \frac{300^2 * 0.0365^2 * 1^2 * 80 * 10^3}{24}$$

$$= 400146.0642$$

Therefore the equation,

$$f_2^3 + 81.3599 f_2^2 = 400146.0642$$

Solving by Newton Raphsan methods

$$f_2 = \sqrt[3]{\{(4.00146 * 10^5) - 81.3599f_2^2\}}$$

Starting,

$$f_2 = 54.28862$$

$$f_2 = 54.32814$$

$$f_2 = 54.28867$$

$$f_2 = 54.32809$$

$$f_2 = 54.28872$$

$$f_2 = 54.32804$$

$$f_2 = 54.28877$$

$$f_2 = 54.32799$$

$$f_2 = 54.28882$$

Then,

$$\mathrm{T} = 54.28882 \ \mathrm{x}\ 226.2\ \mathrm{N}$$

$$= 12880.131 \ \mathrm{N}$$

$$Sag = \frac{300^2 * 0.0365 * 1}{8 * 54.28882}$$

$$= 7.56 \ \mathrm{m}$$

Case VI

SAG at 75°C with wind load

$$\frac{\mathrm{f}_2^2[\mathrm{f}_2 - (\mathrm{f}_1 - \mathrm{a}^2 §^2 \mathrm{Q}_1^2 \mathrm{E} - \text{æ}\mathrm{tE})]}{24\mathrm{f}_1^2} = \frac{\mathrm{a}^2 §^2 \mathrm{Q}_2^2 \mathrm{E}}{24}$$

$$\mathrm{t} = (75 - 7)℃$$

$$\mathrm{t} = 68\ ℃$$

$$\frac{(f_1 - a^2 §^2 Q_1^2 E - \text{ætE})]}{24 f_1^2}$$

$$= 141.114 - \frac{(300^2 * 0.0365^2 * 2.502^2 * 80 * 10^3)}{24 * 141.114^2} - (1.78 * 10^{-5} * 68 * 80 * 10^3)$$

$$= 141.114 - 125.6439 - 96.83$$

$$= -81.3599$$

$$\frac{a^2 §^2 Q_2^2 E}{24} = \frac{300^2 * 0.0365^2 * 2.502^2 * 80 * 10^3}{24} = 2504331.492$$

Therefore the equation,

$$f_2^3 + 81.3599 f_2^2 = 2504331.492$$

Solving by Newton Raphsan methods

$$f_2 = \sqrt[3]{\{(2.504331 * 10^5) - 81.3599 f_2^2\}}$$

Starting,

$$f_2 = 113.3694003$$

$$f_2 = 113.40957530$$

$$f_2 = 113.39036115$$

$$f_2 = 113.39955221$$

$$f_2 = 113.39515606$$

$$f_2 = 113.39725886$$

$$f_2 = 113.39625305$$

$$f_2 = 113.39673415$$

$$f_2 = 113.39650403$$

Then,

$$T = 113.3965 \text{ x } 226.2 \text{ N}$$

$$= 25650.288 \quad \text{N}$$

$$Sag = \frac{300^2 * 0.0365 * 2.502}{8 * 113.3965}$$

$$= 9.06 \quad \text{m}$$

Catenary constant,

$$C = \frac{11995.625}{0.8424 \text{ x } 9.8067}$$

$$= 1452.1 \text{ m}$$

At 75 ^{0}C,

$$K = \frac{7.74309 * 4 * 10^5}{300^2}$$

$$= 34$$

At 7 ^{0}C,

$$K = \frac{5.385 * 4 * 10^5}{300^2}$$

$$= 24$$

The results of sag-tension calculation are shown below.

Table 5.2: Results of the calculation (LYNX conductor, 300m span)

Temperature ^{0}C	Wind Pressure, N/m²	Tension (N)	Sag (m)	K factor
7	970	31,920	7.285	
7	0	17,920	5.183	24
32	970	29,272	7.939	
32	0	15,280	6.078	
75	970	25,650	9.060	
75	0	12,880	7.564	34

Similarly, sag-tension was calculated for same ACSR LYNX (30/7/2.79) conductor with the equivalent span of 200m and results are tabulated below.

Table 5.3: Results of the calculation (LYNX conductor, 200m span) - 1

Temperature ^{0}C	**Wind Pressure, N/m²**	**Tension (N)**	**Sag (m)**	**K factor**
7	970	31,920	3.24	
7	0	23,076	1.79	18
32	970	27,842	3.71	
32	0	17,751	2.33	
75	970	22,598	4.57	
75	0	11,902	3.47	35

But, it can be seen that for 200m span conductor, tension is larger than the safety limit. (It violates the EDT limit). Therefore, sag –tension was recalculated for the 200m equivalent span by back calculating the required factor of safety at 7^{0}C as follows to have the limit state at every day temperature.

Tension limit at 32^{0}C is 31,300 N.

Required f_2 at 32^{0}C and Span 200m == $\frac{15960.0}{226.2}$ 70.55702918 N/mm^2

Substituting this value in equation (11)

$$f_2^2\left[f_2-\left(f_1-\frac{a^2.\delta^2.Q_1^2.E}{24.f_1^2}-\alpha.t.E\right)\right]=\frac{a^2\delta^2.Q_2^2.E}{24}$$

f_1 = 133.1264368 N/mm^2

Corresponding tension = 30,113.20 N

New f. o. s. = $\frac{79800}{30113.20}$

= 2.6500

Therefore, results of the sag-tension which was calculated accordingly for same ACSR LYNX (30/7/2.79) conductor for the equivalent span of 200m considering the f.o.s of 2.65 and results are tabulated below.

Table 5.4: Results of the calculation (LYNX conductor, 200m span) -2

Temperature ^{0}C	Wind Pressure, N/m²	Tension (N)	Sag (m)	K factor
7	970	30,113.20	3.43	
7	0	20,707	1.99	20
32	970	26,374	3.92	
32	0	15,948	2.59	
75	970	21,604	4.78	
75	0	11,004	3.75	38

Sag- tension can be calculated for earth wire also by following the same procedure.

5.3 Line design using Covered Conductor

Presently in CEB, ACSR LYNX conductor is used for 33kV tower line applications. The proposed covered conductor which can be used for 33kV tower lines is similar to the LYNX conductor apart from the insulation covering. It is named as “ACSR (LYNX) Covered Conductor”.

Considering the conductor properties given in the specification in Annex III, the sag – tension calculations were done and sag templates were prepared for possible equivalent spans (100m, 200m and 300m) using AutoCAD computer software. Angle of deviation verses span charts were also prepared to use in tower spotting. Computer software was used for all the calculation works. Sag template is consisted of three curves, namely ground clearance curve, hot conductor curve and cold conductor curve.

Towers between sections are to be shifted, removed or added with possible tower extensions to get the optimal solutions. Optimal solution is to have least number of towers and least number of tower body extensions, while keeping the required clearances and design limits. Design limits were checked at the same time by calculating the weight span, wind span etc. The profile drawings were prepared and towers were located on the plans.

The results of the sag – tension calculations of CC for basic span of 200m are as follows.

Table 5.5: Results of Sag-tension calculations of LYNX CC

Temperature ^{0}C	Wind Pressure, N/m²	Tension (N)	Sag (m)	K factor
7	970	31,920	4.52	
7	0	13,873	3.86	39
32	970	27,386	5.27	
32	0	11,785	4.58	
75	970	23,993	6.01	
75	0	9,572	5.63	56

5.3.1 Selection of available T type structures for the line design

The calculated sag for 75^{0}C temperature with no wind condition was 5.63m for 200m span as shown in the Table 5.5. According to [16], the ground clearance is 6.1mfor medium voltage 33 kV. In addition, 0.3m is kept for survey errors. Accordingly, the height to the bottom cross arm was 12.03m at basic span 200m and this showed that it needed to go for T type structures among the CEB available 33kV line structure types.

In transmission line construction, the structure should be designed for the loads imposed on it by the conductors. Therefore, effective forces on T type structures due to LYNX Covered conductor (F_{CC}) was checked against the effective forces on T type structures due to available LYNX conductor (F_{LYNX}) at normal condition. The calculated transverse, vertical and longitudinal loads for LYNX bare conductor line and equivalent CC line is shown in table 5.6 and 5.7 respectively.

Table 5.6: Effective forces on tower due to LYNX conductor

Tower Type	Conductor	Condition	Transverse Load (kg)	Vertical Load (kg)		Longitudinal Load (kg)
				Max	Min	
TDL	Conductor	NC	718	675	100	N/A
		BWC	526	549	100	5,378
	Earth Wire	NC	349	431	2	N/A
		BWC	262	361	2	2,453
TDM	Conductor	NC	3,573	1,361	0	N/A
		BWC	2,008	919	0	5,195
	Earth Wire	NC	1,619	710	-277	N/A
		BWC	897	466	-277	2,370
TDH	Conductor	NC	6,168	1,361	0	N/A
		BWC	3,305	919	0	4,657
	Earth Wire	NC	2,802	710	-277	N/A
		BWC	1,488	466	-277	2,125

Table 5.7: Effective forces on tower due to LYNX Covered conductor

Tower Type	Condition	Transverse Load (kg)	Vertical Load (kg)		Longitudinal Load (kg)
			Max	Min	
TDL	NC	678	665	29	N/A
	BWC	496	445	29	5,378
TDM	NC	3,489	1,341	0	N/A
	BWC	1,934	813	0	5,195
TDH	NC	6,084	1,341	0	N/A
	BWC	3,231	813	0	4,657

Accordingly,

Effective forces on T type structures due to available LYNX CC (F_{CC})	<	Effective forces on T type structures due to available LYNX conductor (F_{LYNX})

Therefore, it can be concluded that, the available T type structures can be used for the line design with LYNX equivalent CC, by assuming the following wind and weight span limits.

Table 5.8: Assumed wind and weight spans for the supports with LYNX Covered conductor

Tower Type	Normal Condition		Broken Wire Condition	
	Wind Span(m)	**Weight Span(m)**	**Wind Span(m)**	**Weight Span(m)**
TDL	240	450	180	250
TDM	240	-600 to 1030	180	-600 to 550
TDH	240	-600 to 1030	180	-600 to 550
TDT	240	-600 to 1030	180	-600 to 550

Also, since this new conductor is not available in PLSCADD software, the line design was done by manually using AutoCAD software. Also, according to [17], CC is considered to be similar to the bare conductors for all clearance requirements.

The next step was to calculate co-ordinates of the catenary curve. Since, the weight, w and the tension, T is constant for all the spans between two dead end points (Same catenary constant),

From the catenary equation for required span l_2

$$Sag \qquad S_2 = \frac{Wl_2^2}{8T}$$

For the equivalent span l_1

$$Sag \qquad S_1 = \frac{Wl_1^2}{8T}$$

Solving the above equations,

$$Sag\ (required\ at\ t^oC) = \frac{(Equivalent\ span\ sag\ at\ t^oC)x(required\ Span)^2}{(Equivalent\ Span)^2}$$

With the help of the above equation and data in Table 5.5, sags for 200m span length were calculated at 7°C and 75°C with no wind condition and results are tabulated in table 5.6. Then catenary template was designed using AutoCAD and data in table 5.9.

Table 5.9: Details of Catenary Template

Equivalent Span (m)		**200**	
Temperature in ^{0}C		**7^0**	**75^0**
Basic Sag (m)		**3.86**	**5.63**
Factor		**9.65E-05**	**1.41E-04**
Span, a (m)		**SAG (m)**	**SAG (m)**
a	**a/2 (X)**		
0.0	0.0	0.0000	0.0000
25.0	12.5	0.0603	0.0880
50.0	25.0	0.2413	0.3519
75.0	37.5	0.5428	0.7917
100.0	50.0	0.9650	1.4075
125.0	62.5	1.5078	2.1992
150.0	75.0	2.1713	3.1669
175.0	87.5	2.9553	4.3105
200.0	100.0	3.8600	5.6300
225.0	112.5	4.8853	7.1255
250.0	125.0	6.0313	8.7969
275.0	137.5	7.2978	10.6442
300.0	150.0	8.6850	12.6675
325.0	162.5	10.1928	14.8667
350.0	175.0	11.8213	17.2419
375.0	187.5	13.5703	19.7930
400.0	200.0	15.4400	22.5200
425.0	212.5	17.4303	25.4230
450.0	225.0	19.5413	28.5019
475.0	237.5	21.7728	31.7567
500.0	250.0	24.1250	35.1875
525.0	262.5	26.5978	38.7942
550.0	275.0	29.1913	42.5769

575.0	287.5	31.9053	46.5355
600.0	300.0	34.7400	50.6700
625.0	312.5	37.6953	54.9805
650.0	325.0	40.7713	59.4669
675.0	337.5	43.9678	64.1292
700.0	350.0	47.2850	68.9675
725.0	362.5	50.7228	73.9817
750.0	375.0	54.2813	79.1719
775.0	387.5	57.9603	84.5380
800.0	400.0	61.7600	90.0800
825.0	412.5	65.6803	95.7980
850.0	425.0	69.7213	101.6919
875.0	437.5	73.8828	107.7617
900.0	450.0	78.1650	114.0075
925.0	462.5	82.5678	120.4292
950.0	475.0	87.0913	127.0269
975.0	487.5	91.7353	133.8005
1000.0	500.0	96.5000	140.7500

Sag template for equivalent span 200m was used for designing of the tower line. Accordingly, the existing line was re-designed using CC and the line design done for three separate tower sections of existing line(T11- T14, T54-T59 & T80 – T84) is attached in Annex IV. The existing line design of the selected three sections is in Annex V.

Chapter 6

Results and analysis

6.1 Tree valuation method

As described in 3.4.3, the so called “Computation Method” is proposed for tree valuation in Sri Lanka by defining required factors associated with it. At the beginning of this chapter, the compensatory value which is calculated using the proposed method was compared with the actual compensatory values recommended by DSs for some tree species and it verified the adaptability of the proposed method to Sri Lanka.

The compensatory value can be estimated considering the structural asset value of a tree with a specific species, size, condition, and location. Also, the values of trees can be estimated based on the functions that they perform such as aesthetics, pollution removal, temperature modification, etc. In general, the greater the compensatory value of a forest (i.e., increased numbers of trees, tree size, and better tree health), greater the ability of the forest to produce functional benefits. When it is defined species ratings for the proposed computation method in this study to suit Sri Lankan community, these functional values are also considered. Therefore, the proposed method is an accurate method for tree evaluation which considers all characteristics and benefits of a tree.

6.1.1 Sample calculation of compensatory value for trees

The formula proposed for tree valuation is:

Tree Value = Base Value x Cross Sectional Area x Species Class x Condition Class x Location Class

The compensatory value of 35-in. circumference of Teak which is located in residential area and is in good condition with healthy and vigorous with no apparent signs of insect can be calculated as:

Circumference of Teak = 35-in

Therefore, trunk cross sectional area = 97.53 in^2

Species class rating of Teak = 0.67

Condition class rating = 0.9

Location class rating = 0.85

Price of 0.5"diameter teak plant in 9x4 pot = Rs. 25

Therefore, Base value = Rs. 127.39/ in^2

Then, the compensatory value of teak

$$= 127.39 \text{ (Rs/ in}^2\text{)} \text{ x } 97.53 \text{ (in}^2\text{)} \text{ x } 0.67 \times 0.9 \times 0.85$$

$$= \text{Rs. } 6{,}368.10$$

Similarly, data for individual trees along the ROW can be used to determine the total compensatory value to be made for the land owners.

Total tree value for each land owner will vary based on the quantity and the location of trees along the line, species composition, diameter distribution, and condition of the tree, etc. Increased number of trees and a greater proportion of healthy trees, large diameter trees, high-value species, and/or trees in more valuable locations will lead to greater urban forest compensatory values.

The computed method was applied for some trees along the line and the results were compared with the compensation recommended by two DS divisions. The similar pattern of unit costs estimated by DSs can be seen with the unit cost calculated using the computed method and it varies exponentially with the circumference of the tree. Also, noted that the in each graph shown below, R-squared value is greater than 0.8 and hence there is a good fit of the line to the data.

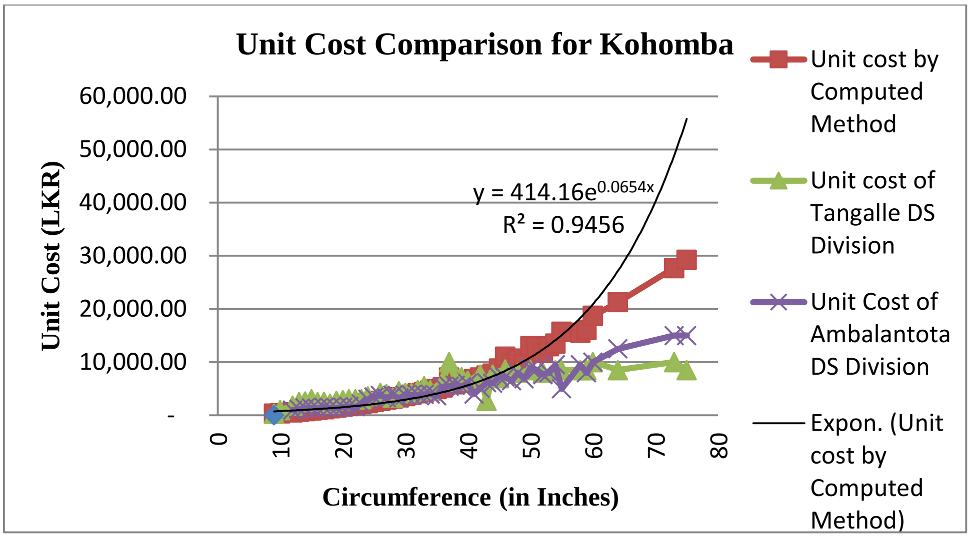

Figure 6.1: Unit cost comparison for Kohomba

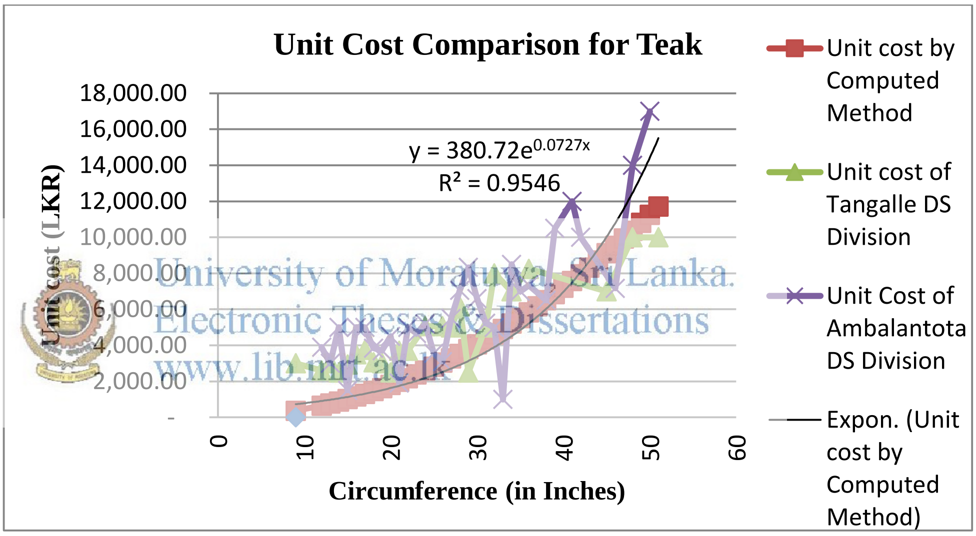

Figure 6.2: Unit cost comparison for Teak

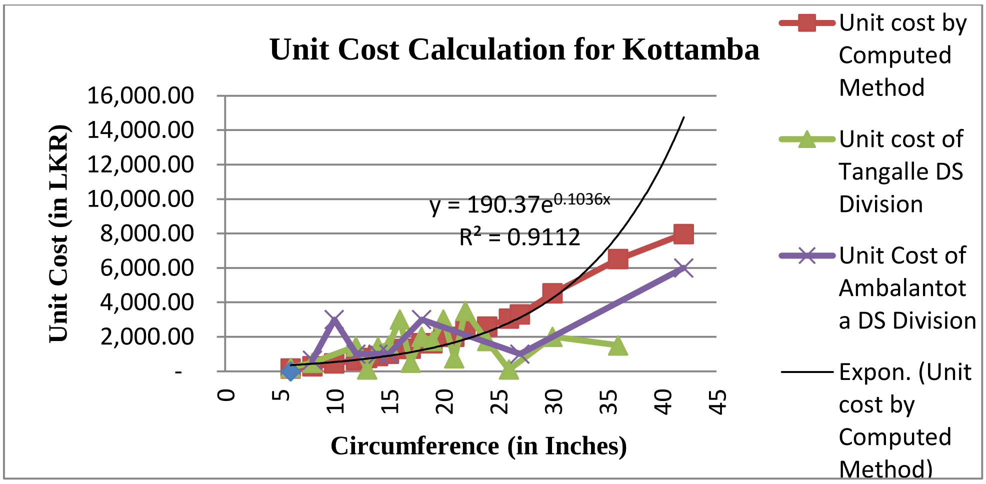

Figure 6.3: Unit cost comparison for Kottamba

6.1.2 Sensitivity analysis for species class rating

The species class rating has a considerable impact on the proposed tree valuation method and this rating was obtained by looking at the benefits and the characteristics of each tree species. Here, seven characteristics have been defined where each characteristic was assigned a value between 0 and 1.

Sensitivity analysis was done to see how the optimum values used for each tree characteristics would vary with the species class rating values. For this Kohomba tree was considered as an example as follows. Food and medicinal value of a tree can have either 1 or 0, while standard wood density is also a value defined by Forest Department. Therefore, values assigned for these 3 variables were remained changed while the assigned values for other variables indicating by * symbols were changed.

Table 6.1: Sensitivity analysis for Kohomba tree

Tree	Case	Food value	Medicinal Value	Standard wood density	Conservative value*	Timber value*	Aesthetic value*	Useful life expectancy value*	Species class rating
Kohomba	Base	1	1	0.8	0.20	0.10	1.00	0.90	**0.71**
	1	1	1	0.8	0.20	0.10	1.00	0.90	**0.71**
	2	1	1	0.8	0.26	0.13	0.96	0.93	**0.72**
	3	1	1	0.8	0.20	0.15	0.92	0.96	**0.72**
	4	1	1	0.8	0.20	0.18	0.88	0.87	**0.70**
	5	1	1	0.8	0.20	0.20	0.84	0.84	**0.70**
	6	1	1	0.8	0.20	0.23	0.80	0.81	**0.69**
	7	1	1	0.8	0.26	0.10	0.96	0.90	**0.71**
	8	1	1	0.8	0.32	0.10	0.92	0.93	**0.72**
	9	1	1	0.8	0.38	0.10	0.88	0.96	**0.72**
	10	1	1	0.8	0.14	0.10	0.84	0.87	**0.70**
	11	1	1	0.8	0.08	0.10	0.80	0.84	**0.68**
	12	1	1	0.8	0.02	0.10	0.76	0.81	**0.66**
	13	1	1	0.8	0.26	0.10	1.00	0.90	**0.72**
	14	1	1	0.8	0.32	0.13	1.00	0.93	**0.74**
	15	1	1	0.8	0.38	0.15	1.00	0.96	**0.76**
	16	1	1	0.8	0.14	0.18	1.00	0.87	**0.71**
	17	1	1	0.8	0.08	0.20	1.00	0.84	**0.70**
	18	1	1	0.8	0.02	0.23	1.00	0.81	**0.69**
	19	1	1	0.8	0.26	0.10	1.00	0.9	**0.72**
	20	1	1	0.8	0.32	0.13	0.96	0.9	**0.73**
	21	1	1	0.8	0.38	0.15	0.92	0.9	**0.74**
	22	1	1	0.8	0.14	0.18	0.88	0.9	**0.70**
	23	1	1	0.8	0.08	0.20	0.84	0.9	**0.69**

	24	1	1	0.8	0.02	0.23	0.80	0.9	**0.68**

Base : Actual values used in the tree valuation method

Case 1 – 24 : By changing the variables stated by symbol *

By changing four variables (conservative value, timber value, aesthetic value, useful life expectancy value), the above 24 possible options were obtained. According to the above, the species class value is deviated ± 7.04% from the base value. This results that, the base values assigned for calculating species class rating are more reliable to accept.

6.1.3 Regression Analysis for validating the computation method

The regression analysis was done for Kohomba tree (as an example) to further evaluate the effects of circumference on unit cost calculated by the computed method. QI Macros performed the regression analysis calculations and the following results were given.

Table 6.2: Summary output of Regression Analysis for Kohomba

SUMMARY OUTPUT Force Constant to Zero

FALSE

Regression Statistics		
Multiple R	0.949	
R Square	0.901	Goodness of Fit >= 0.80
Adjusted R Square	0.899	
Standard Error	2160.432	
Observations	52	

ANOVA

	df	*SS*	*MS*	*F*	*P-value*
Regression	1	2.11E+09	2114098127	452.94	0.000
Residual	50	2.33E+08	4667467.4		
Total	51	2.35E+09			

Confidence L

0.95

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 99%*	*U*
Intercept	-6796.95	724.8028	-9.3776468	0.000	-8252.754	-5341.1358	-8737.8173	-
Circumference (In)	388.0965	18.2355	21.2824648	0.000	351.46939	424.723565	339.265567	4

The value of R Square is 0.901 and it means that, 90.1% of the variation in unit cost can be explained by the circumference of the tree. The adjusted R Square of 0.899 means 89.9%. Since, the p value ($0 < 0.05$), there is a relation between the two variables.

Therefore, when analyzing the above graphs it can be seen that the computed method can be applied for tree valuation in Sri Lanka.

6.2 Program setup

Based on the formula of the proposed method, a user friendly program application was developed for tree valuation and it is named as "Tree Value Calculator".

This data processing program was developed as .net application using C#. The data required for the computation is obtained from the text files. Based on the data inputs, the application will calculate the result and the results of the computations are also viewed on the same excel worksheet. A report is also generated in Excel worksheet with all the required details and it can be produced as the tree valuation report.

The site ES prepares a report which consists of the name, the girth and the quantity of trees to be removed and produces a copy of this report to DS of the respective division. The valuator will then consider the details indicated in this report and at the valuation, the name and the address of the land owner can be entered in to the program. The valuator should properly study the location and the condition of the tree and need to select the most accurate value in order to get a precise valuation of the tree. If there is more than a tree at a land, the program provides that facility too. The base value was obtained from Forest Department of Sri Lanka.

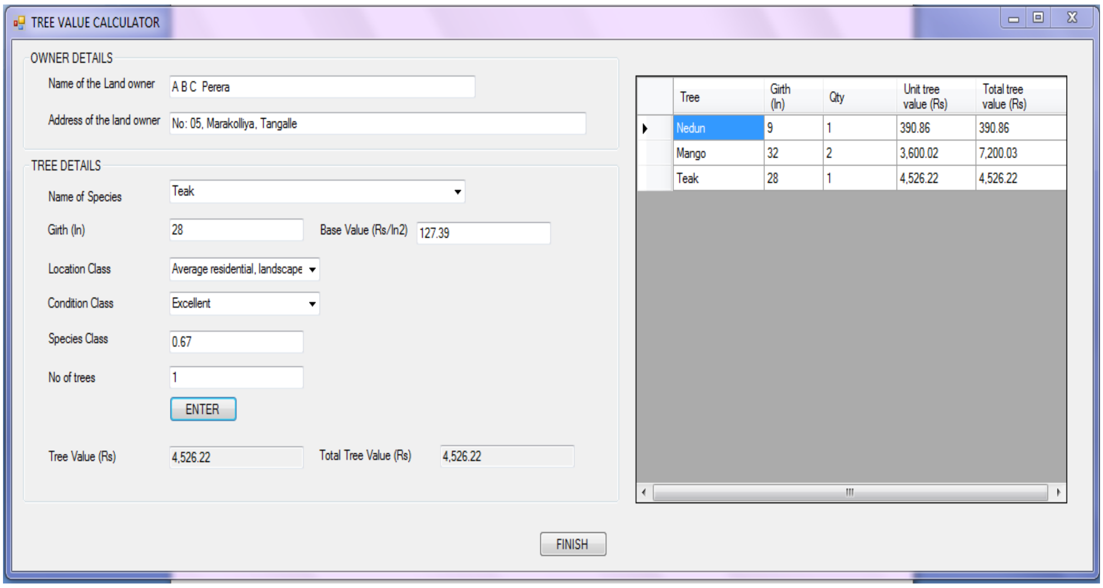

Figure: 6.4: Program Interface

This program was developed so that a report can also be generated for each land owner with the detailed breakup of the compensation to be made. Therefore, the valuation officer can easily calculate the compensation amount and the report can be produced to CEB in order to make payment.

	A	B	C	D	E
1	Owner :	A B C Perera			
2	Address :	No: 05	Marakolliya	Tangalle	
3					
4	Tree	Girth (In)	Qty	Unit tree value (Rs)	Total tree value (Rs)
5	Nedun	9	1	390.86	390.86
6	Mango	32	2	3,600.02	7,200.03
7	Teak	28	1	4,526.22	4,526.22
8					
9	Grand Total:	12,117.11			
10					
11					

Figure 6.5: Sample report

6.3 Calculation of the ROW width of 33kV transmission line

Minimum ROW widths are determined by the swing characteristics of the line plus minimum clearance specified. Also, ROW required will depend on the topography, structure type, span length, etc too.

Therefore, in this study, it is considered the maximum sag calculated at 75^{0}C with wind condition. The maximum swing angle is taken as 45^0[18] and T type tower structures are used. According to [19], the minimum electrical clearance to be maintained for tree falling towards 33kV line is 0.8m. The length of the insulator string is 0.75m.

The ROW of a transmission line can be graphically interpreted as follows.

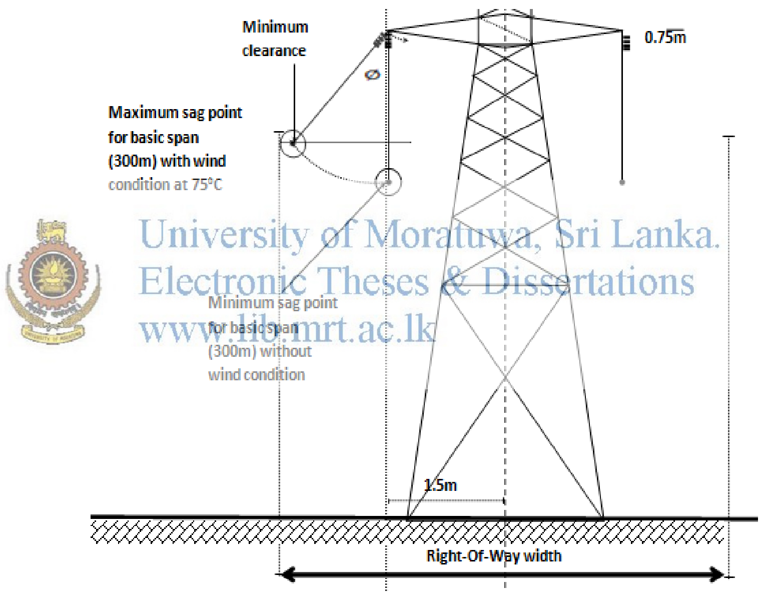

Figure 6.6: Right-Of-Way of a 33kV tower line

Swing angle can be expressed as,

$$\emptyset = \tan^{-1}(d * F/w)$$

Where,	D	= Diameter of the conductor
	F	= Wind Pressure
	W	= Weight of the conductor

The wind pressure can be calculated by,

$$F = \left(\frac{w}{d}\right) \tan \emptyset$$

The tower line is constructed using T type towers with basic span of 300m. From Table 6.2,

Maximum sag for basic span 300m without wind condition at 75^{0}C	= 7.56 m
Maximum sag for basic span 300m with wind condition at 75^{0}C	= 9.06 m
Width of the cross arm	= 3.00 m

The conductor used for the line is LYNX 30/7/2.79 and the properties of the conductor used for the calculations are mentioned below.

Diameter of the conductor	= 19.53 mm
Total cross sectional area	= 226.20 mm^2
Modulus of Elasticity	= 80.00 kN/mm^2
Linear coefficient of Expansion	= 0.0000178/^{0}C
Ultimate breaking strength	= 79.80 kN
Weight of the conductor	= 0.8424 kg/m

Calculations were done based on the following assumptions.

Maximum wind pressure	= 970 N/m^2
Minimum temperature of the conductor	= 7 ^{0}C
Maximum temperature of the conductor	= 75 ^{0}C
Minimum earth to phase clearance	= 0.80 m
Length of the insulator string	= 0.75 m

Therefore,

$$\text{The Right-Of-Way width} \qquad = 2\,(\,1.5 + (\,9.06 + 0.75)\sin 45 + 0.8)$$

$$= 18.50 \text{ m}$$

Accordingly, the ROW width of the 33kV transmission line with basic span of 300m is 18.50 m.

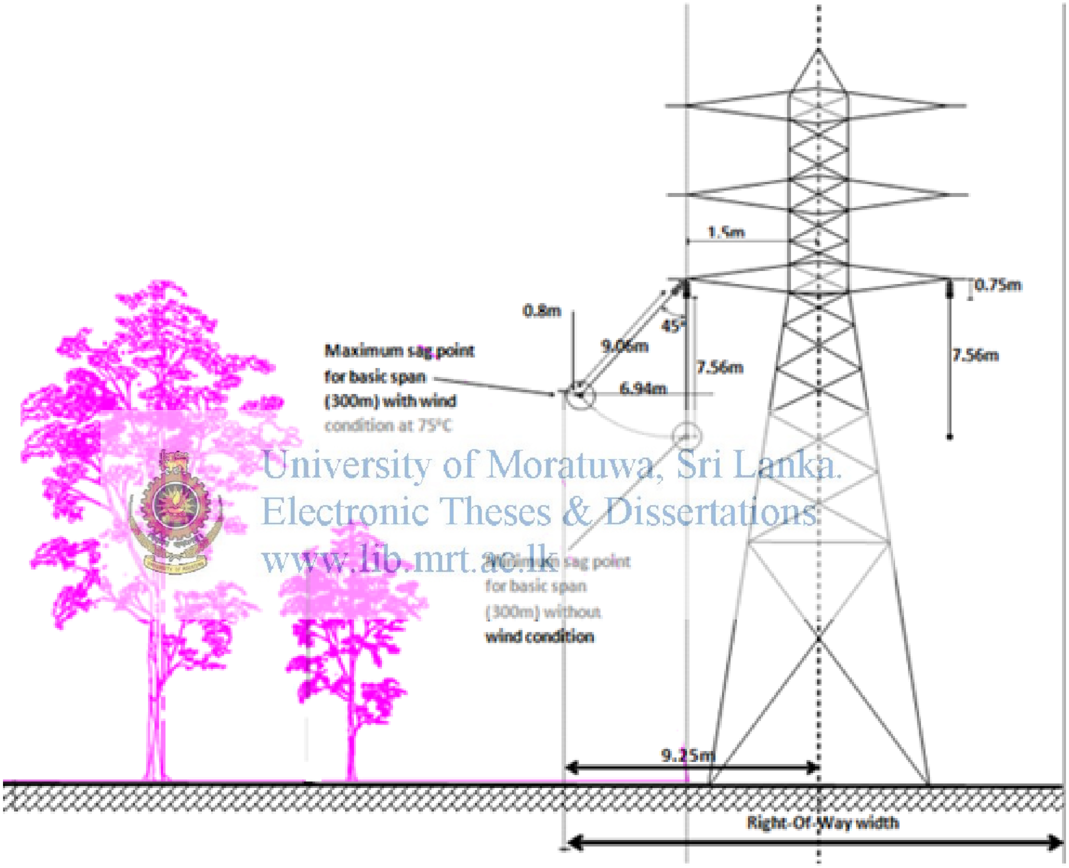

Figure 6.7: Calculated Right-Of-Way width of a 33kV tower line

Similarly, ROW width for 200m span of 33kV LYNX bare conductor line and CC line can also be calculated and the probable ranges of ROW clearance using T type steel lattice structures are shown below.

Table 6.3: Calculated Right-Of-Way widths

Line Description	**Equivalent Span (m)**	**ROW width (m)**
33kV LYNX Bare conductor line	300	18.50
33kV LYNX Bare conductor line	200	12.50
33kV LYNX Covered conductor line	200	14.20

According to the several research papers and practical experience of the countries that use CC technology, it has been proven that the ROW of CC line is narrower than the bare conductor line. Since, it has not yet been designed a structure considering the properties of the LYNX CC, in this study, it is assumed that, the same T type structure is used where ROW width has also been calculated by making the same assumption.

6.4 Vegetation saving by proper line designing

Currently used ROW clearance for 33kV tower line applications in DD4, CEB is 20m regardless of the equivalent span and the calculated value is less than this figure. Therefore, it is concluded that the payment for wayleave compensation can also be reduced, if the line is designed proper way. The total vegetation saving from proper line design can be calculated as follows.

Case 1: Same LYNX tower line with calculated ROW for 300m span

Conventional ROW width = 20.0m

Calculated ROW for 33kV tower line = 18.5m

ROW saving = 7.5 %

Vegetation saving = (20 – 18.5) x 1000 m^2

= 0.15 Hectares

Case I1: Same LYNX tower line with calculated ROW for 200m span

Conventional ROW width = 20.0m

Calculated ROW for 33kV tower line = 12.5m

ROW saving = 37.5 %

Vegetation saving = (20 – 12.5) x 1000 m^2

= 0.75 Hectares

Case III: Designed LYNX Covered Conductor Tower line with calculated ROW for 200m span

Conventional ROW width = 20.0m

Calculated ROW for 33kV tower line = 14.2m

ROW saving = 29 %

Vegetation saving = (20 – 14.2) x 1000 m^2

= 0.58 Hectares

6.5 Proposed vegetation management procedure

Properly maintained right-of-ways (ROW) are essential for the safety of the public and our workers. The long-term goal of our vegetation management program is to provide for public safety, worker safety, and environmental safety while providing for reliable service.

After calculating the exact ROW width, vegetation zones associated with 33kV transmission line can be defined as described in 4.10.4 to optimize the safe and reliable transmission of electricity. According to the calculated ROW width for LYNX bare conductor line with basic span of 300m,

Wire zone = 9.0m

Border zone = 4.75m from wire-zone in either side

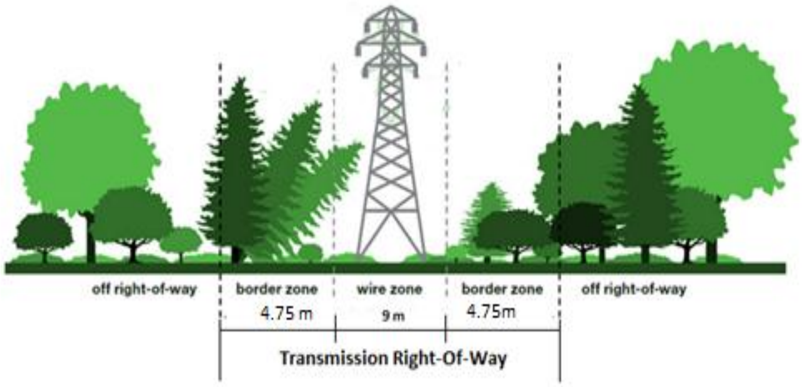

Figure 6.8: Calculated Wire-zone/Border-zone of 33kV tower line

Therefore, the vegetation around the tower line can be properly managed in cost effective and environmentally friendly manner. 33kV transmission line requires maintaining 6.1m ground clearance. Therefore, low-growing shrub and grass communities can be allowed to grow within the wire zone while taller shrubs, and brush plant community can be allowed to grow within broader zone. This is the transition zone between the low-growing vegetation and taller. Normal vegetation can be allowed to grow beyond the broader zone depending on the mature tree height as shown in the Annex VI.

Matured tree height of some trees in local community were obtained from the Forest Department of Sri Lanka and attached in Annex VII.

The same methodology can be applied for 132kV and 220kV transmission lines as well.

Chapter 7

Cost Estimation

7.1 Introduction

For analysis purpose, three separate line sections (T11- T14, T54- T58, T80-T84) of the existing tower line were considered and the average value is taken at each situation. Detail field information on vegetation distribution within these sections, line design by LYNX bare conductor and CC were considered for the cost estimation.

7.2 Calculating per km vegetation payment

Utility company spends considerable amount of money for vegetation management of the lines owned by them and at the line construction also they have to allocate significant budget for prospective wayleave compensation. It is very clear that, the wayleave compensation depends on the ROW width of the line, because number of trees to be removed is increased with the ROW width. As explained earlier, the total compensation for wayleave clearing of Tangalle – Nonagama line is LKR 22,882,985.00 and in order to check per km wayleave payment for this line, it was considered the actual payment made for the land owners along the line at three separate tower spans.

Table 7.1: Per km wayleave compensation

Tower span	Length of the span (m)	Total actual payment for wayleave (LKR)	Per km payment for wayleave (LKR)
11-14	914.01	415,550.00	454,644.92
54-58	1,052.03	1,162,150.00	1,093,798.53
80-84	1,092.37	1,146,000.00	1,049,095.09

Accordingly, the average per km wayleave compensation of the Tangalle – Nonagama line is LKR 865,846.18.

In addition, it was checked the position of the removed trees within the ROW (i.e. the distance to the removed trees from the center line) for further analysis of wayleave cost due to the variation of ROW width (Annex VIII).

If it is assumed that, the vegetation distribution along the line is uniform, the cost saving on vegetation can be calculated for each case as follows.

Case 1: Same LYNX tower line with calculated ROW for 300m span

Payment for trees/km (avg)	= Rs. 865,846.18
ROW width maintained along the line	= 20.0m
Calculated ROW for 33kV tower line	= 18.5m
ROW saving	= 7.5 %
Therefore, Cost saving on vegetation/km	= Rs. 64,938.46
Total cost saving on vegetation for total line	= Rs. 1,616,967.65

Case II: Designed LYNX Covered Conductor Tower line with calculated ROW for 200m span

Payment for trees/km (avg)	= Rs. 865,846.18
ROW width maintained along the line	= 20.0m
Calculated ROW for 33kV tower line	= 14.2m
ROW saving	= 29 %
Therefore, Cost saving on vegetation/km	= Rs. 251,095.39
Total cost saving on vegetation for total line	= Rs. 6,252,275.21

7.3 Cost of a transmission line

A transmission line consists of various components. Even though, the most important components are towers and conductors, there are some other smaller components such as insulators, overhead ground wire, etc which are necessary when electricity is transferred.

Therefore, the cost of a transmission line can mainly be classified in to following three parts [20].

1. Material cost – cost for towers/ conductors/ connectors/ other components
2. Installation cost – erection/stringing/installation cost of the above materials
3. Other costs
    - 3.1 Civil cost – wayleave clearing/ foundation
    - 3.2 Engineering cost – 10% of the total cost
    - 3.3 Commissioning cost – 1% of the total cost

CEB has standard price list for each and every item that are used for any CEB construction work [21] whereas there is another Price list for towers for the use of Projects and Heavy Maintenance Branches [21] for obtaining the cost of 33kV towers with accessories. Construction of foundations, erections of towers and stringing of conductors were done by contractors and LSHP has its own PPC approved rates for tower foundation, erection and stringing [22]. The following cost estimates were done using these documents.

7.3.1 Cost estimate of LYNX bare conductor line

Total cost for three sections of the selected tower line was calculated as below. The material cost includes all the material used for the line construction such as 70kN Suspension insulator sets, 120kN Tension insulator sets, armour rods, suspension clamps for earth wire, tension clamps for earth wire, vibration dampers, LYNX conductors, earth conductors and different types of T type towers according to the design. The cost of these materials was taken from [21].

Table 7.2: Calculated total cost of selected tower spans – Existing LYNX conductor line with ROW width of 20m

Description	**11-14**	**54 – 58**	**80 – 84**
Line length (m)	914.01	1,052.03	1,092.37
Material cost (Rs)	6,674,712.08	8,265,565.66	8,778,573.50
Installation cost (Rs)	847,433.02	1,074,409.06	1,085,019.74
Civil cost (Rs)	2,105,470.00	3,657,770.00	3,328,960.00
Total Cost (TC) (Rs)	9,627,615.10	12,997,744.66	13,192,553.24
Engineering cost (Rs)(10% of TC)	962,761.51	1,299,774.47	1,319,255.32
Commissioning cost (Rs)(1% of TC)	96,276.15	129,977.45	131,925.53
Grand Total (Rs)	10,686,652.76	14,427,496.58	14,643,734.09
Grand Total (Rs)/ km	**11,692,052.34**	**13,713,959.28**	**13,405,470.76**

Accordingly, the average per km cost of the existing transmission line is Rs. 12,937,160.79 using T type structures with LYNX conductors for 300m span (at conventional 20m ROW width).

7.3.2 Cost estimate of LYNX bare conductor line for calculated ROW

The calculated ROW width of MV transmission line with LYNX conductors for 300m span is 18.5m. Therefore, required wayleave clearance has become less and based on the distance to the removed trees along the corridor; per km cost of the line was calculated as follows. Materials used for the line construction are same as in the 7.3.1, the cost of the materials were taken using [21].

Table 7.3: Calculated total cost– LYNX conductor line for calculated ROW of 18.5m

Description	**11-14**	**54 – 58**	**80 – 84**
Line length (m)	914.01	1,052.03	1,092.37
Material cost (Rs)	6,674,712.08	8,265,565.66	8,778,573.50
Installation cost (Rs)	847,433.02	1,074,409.06	1,085,019.74
Civil cost (Rs)	1,969,770.00	3,348,770.00	3,008,360.00
Total Cost (TC) (Rs)	9,491,915.10	12,688,744.72	12,871,953.24
Engineering cost (Rs)(10% of TC)	949,191.51	1,268,874.47	1,287,195.32
Commissioning cost (Rs)(1% of TC)	94,919.15	126,887.45	128,719.53
Grand Total (Rs)	10,536,025.76	14,084,506.64	14,287,868.10
Grand Total (Rs)/ km	**11,527,254.36**	**13,387,932.51**	**13,079,696.53**

Accordingly, the average "per km cost" of the existing transmission line is Rs. 12,664,961.13 using T type, LYNX conductor for 300m span with 18.5m ROW.

7.3.3 Cost estimate of LYNX Covered Conductor line

Several assumptions were made while estimating the cost related to the CC line. It was assumed that, the towers to be used in this line design are similar to T type towers used for LYNX bare conductor line.

Due to the special construction of CC with insulation, the stringing work shall be done with some extra care so that, no damage is occurred for its insulation. Special attention must be paid to the grounding of the conductor before and during the stringing and specially when working in the vicinity of other energized lines. Since the covering prevents the conduction of induced voltages to ground, special care must be taken to keep the conductor free end on the reel constantly grounded and during stringing, to have the conductor ends always in contact with ground. Therefore, rate for the stringing was assumed as 20% more than that of a bare conductor. Lightning protection is essential for overhead CC lines and optimum lightning protection system indicated in some literatures is having Arc Protection Devices. The cost of an arc protection device was obtained from a manufacturer and the cost of the other materials was obtained from [21].

Table 7.4: Calculated total cost– Using CC for calculated ROW

Description	**11-14**	**54 – 58**	**80 – 84**
Line length (m)	914.01	1,052.03	1,092.37
Material cost (Rs)	7,656,709.12	9,518,332.35	9,917,274.26
Installation cost (Rs)	997,019.62	1,149,332.87	1,246,853.69
Civil cost (Rs)	2,107,960.00	3,094,850.00	3,012,700.00
Total Cost (TC) (Rs)	10,761,688.74	13,762,515.22	14,176,827.94
Engineering cost (Rs) (10% of TC)	1,076,168.87	1,376,251.52	1,417,682.79
Commissioning cost (Rs) (1% of TC)	107,616.89	137,625.15	141,768.28
Grand Total (Rs)	11,945,474.50	15,276,391.89	15,736,279.02
Grand Total (Rs)/ km	**13,069,303.95**	**14,520,870.97**	**14,405,630.89**

Accordingly, the average per km cost of the transmission line is Rs. 13,998,601.94using T type, LYNX covered conductor for 200m span with 14.2m ROW.

7.4 Cost comparison

The summary of per km cost of the transmission line is tabulated as follows.

Table 7.5: Cost comparison

Line description	**Per km cost (Rs)**
Existing LYNX conductor line with 20m ROW	12,937,160.79
Same LYNX conductor line for calculated ROW (18.5m)	12,664,961.13
Using CC for calculated ROW (14.2m)	13,998,601.94

Per km cost difference using CC against the existing line = Rs. 1,061,441.15

Percentage increase of per km cost = 8.2%

The CC technology provides several benefits as explained earlier in this report. The CC line reduces the required width of the ROW and it saves considerable amount of vegetation around the power line. As it is done on the bare conductor line, total tree removal is not required with CC line and pruning/ trimming can be done by considering the clearance requirement.

Trees provide many valuable ecosystem services as described: they reduce energy consumption, they trap and filter storm water, they help clean the air by intercepting air pollutants, and they help in the fight against global climate change by carbon sequestration. At the same time, they provide a wide array of aesthetic, social, economic and health benefits that are less tangible.

Therefore, the cost increment will be counter balanced by the long-term benefits provided by this eco-friendly line due to vegetation saving.

Chapter 8

Conclusion

8.1 Conclusions

When designing and constructing a power line, the utility company should consider the associated environmental issues adhering to technically advanced methods. Due to the urbanization, selecting a line route by minimizing objections from the land owners will be difficult in future. Currently, any compensation for the line corridor is not paid for the land owners but, CEB may have to think of it near future.

A novel tree evaluation method has been introduced in this study and, CEB can introduce this method to Divisional Secretariats for valuating compensation for trees along any line corridor. The following formula has been introduced for tree evaluation which has been derived from internationally accepted tree valuation formulae with effective modifications to suit Sri Lankan ecosystem.

Tree Value = Base Value x Cross Sectional Area x Species Class x Condition Class x Location Class

No species class ratings have been defined for species in Sri Lanka and therefore, a value is defined for each tree by considering tree based characteristics such as conservation value, medicinal usage, aesthetic value, food value, timber value, life expectancy and standard wood density. A value between 0 and 1 was assigned for each of the characteristic except for standard wood density. The defined species class values for trees which were along the Tangalle – Nonagama line is in Annex II. The sensitivity analysis revealed that the species class rating defined in this study are more reliable to accept.

A user-friendly software tool called “Tree Value Calculator” has also been developed using the above equation in order to make easier the responsible party for efficacious tree valuation. Accordingly, for instance, Teak tree in residential area having excellent condition with 28-in circumference costs LKR. 4,526.22 while a Nedun tree of 9-in circumference in the same area with good condition costs LKR 390.86.

A uniform figure for ROW width by considering the equivalent span can be used for 33kV transmission line construction in CEB instead of applying different values whereby minimizing the damage to the vegetation while saving a cost for CEB in terms of way leave compensation.

Therefore, in spite of the currently use ROW width of 20-30m in CEB for both 200m span and 300m span, this study has proposed figures of 18.5m ROW width for 300m span and 12.5m ROW width for 200m span in 33kV tower line applications. This shows that, the reduction of 7.5% and 37.5% ROW width could have been achieved with 0.15ha and 0.75ha of vegetation saving from a 33kV line of 300m span and 200m span respectively. This accounts for LKR 1,616,967.65 of cost saving on wayleave compensation from the Tangalle – Nanagama 33kV tower line.

Proper vegetation management procedure needs to be followed by the utility company at the construction and maintenance of an eco friendly transmission line. Internationally used vegetation management method called WZ/BZ method has been explained in this study, where CEB can also adopt this method. Since, the mature height of a tree is playing a vital role in vegetation management and growth of trees varying from area to area within the island is essential that the CEB should work in coordination with the Forest Department to obtain required information.

Accordingly, for the line with the proposed ROW width of 18.5m, the Wire Zone is 9m and the Border Zone is 4.75m from the WZ in either side. The allowable maximum height of trees is varying from different locations within the ROW. According to the Annex VI, the typical values for maximum height of trees can be specified and the vegetation management can be performed in proper manner.

Along with the technological advancement, the utility company may go for advanced techniques so that safe, reliable and environmentally friendly power can be supplied to the customers. As explained in the study, covered conductors offer several benefits to the utility company as well as the consumer. Both Finnish and Slovene experience show that, the covered conductors operate well in the network and reduce remarkably the number of outages [3].

The use of covered conductors is becoming more popular in the world and the application is being expanded to higher voltage levels too. Covered conductors are currently used by the CEB in the 33kV and 11kV distribution pole line applications. A covered conductor which has been developed for the construction of 33kV tower lines in Sri Lanka was used for the line design in this study.

It is obvious that, the explained covered conductor can be used by CEB for MV transmission line construction whereas the towers needs to be designed by structural engineers so as to comply with the wind span and weight span of the said conductor. The calculated ROW width of the LYNX equivalent CC line of 200m span is 14.2m where this can be further reduced by proper designing of line structure considering all design limits. According to [13], the line structure is compact when CC is used and ROW clearance will be narrower while providing many environmental and social benefits.

The per km cost of the proposed CC line is 8.2% higher than a bare conductor line. The prospective benefits received by this eco-friendly CC line will outweigh the effects of this additional cost increment due to the line.

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ANNEXES