ASSESSMENT OF EFFICIENCY AND CONDITION BASED OPTIMUM LOADING OF TRANSMISSION LINES

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Degree of Master of Science

by

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Abstract

Transmission lines in any transmission network is the critical part or the one of the major limiting factors for power transfer capability of the transmission network.

The thermal power transfer capability of Overhead Transmission lines is primarily a function of the height of the conductor above the ground. This height affects the safety of the public and is therefore clearly specified in legislation.

Different methods for determination of Power Transfer capability of transmission lines are available. These include deterministic and various probabilistic approaches. The latter include a model simulating condition that affect the safety of the transmission line relating specially to the conductor position from which a measure of safety is developed. This measure can be used by designers to optimally design the transmission line from current loading point of view.

The deterministic approach has been used by most utilities around the world, as it is quick and simple. That method assumes bad cooling conditions that will result in the line design temperature being achieved.
Probabilistic methods use actual weather data and conditions prevailing on the line to determine the likelihood or probability of a certain condition. In this project, condition was taken as the conductor temperature rising up to the design temperature, which is 75 degree Celsius.

Designing of transmission lines in Sri Lanka has been done considering average weather conditions through out the year. Whereas in the real situation, weather conditions are seasonally varying. Therefore, based on the seasonal variation of weather condition in Sri Lanka, existing transmission network can be optimally loaded delaying future construction of transmission lines.

DECLARATION

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

It has not already been accepted for any degree, and is also not being concurrently submitted in whole or part to any University or Institution for any other degree.

WDAJ Chandrakumara
29.11 . 2005

We / I endorse the declaration by the candidate

UOM Verified Signature

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Symbols	Description
I	Conductor current, A
q_c	Convected heat loss, W/ft
q_r	Radiated heat loss, W/ft
q_s	Heat gain from the sun, W/ft
t_a	Ambient temperature, ^{o}C
t_c	Average temperature of conductor, ^{o}C
t_f	Air film temperature, ^{o}C
R	AC resistance, Ω/ft
d	Conductor diameter, in
d_0	Conductor diameter, ft
ρ_f	Density of air, lb/ft^3
V	Velocity of air stream, ft/h
μ_f	Absolute viscosity of air, lb/h
k_f	Thermal conductivity of air at temperature t_f W/ft.
K_c	Temperature of conductor, K
K_a	Ambient temperature, K
e	Coefficient of emissivity, 0.23 to 0.91
a	Coefficient of solar absorption, 0.23 to 0.91
Q_s	Total solar and sky radiated heat, W/ft^2
A'	Projected area of conductor = d/12
θ	Effective angle of incidence of the sun's rays, degrees
H_c	Altitude of sun, degrees
Z_c	Azimuth of sun, degrees
Z_l	Azimuth of line, degrees
H_e	Elevation of conductor above sea level, ft
W_c	Conductor weight
W_w	Wind force on conductor
S	Catenary length along conductor
D	Sag
f	Stress or T/A
E	Young's modules
T	Tension of the conductor
a	Coefficient of linear expansion of conductor
L	Span

Chapter 1

Introduction

1.1 General background

Transmission lines are the most essential and more expensive part in any national grid. Since a transmission line need to travel across the country in different terrain having different weather conditions, designing and construction of such transmission line is extremely tedious and expensive.

Currently, transmission network of Sri Lanka is operating on two transmission Voltages namely, 132 kV and 220 kV. Presently most of the hydro generation is confined to the central hill region of the country, and requires to be transmitted to load centres where population density is high and industries are based.

The country is experiencing about 10% of Electricity Demand growth while 73 % of total houses have presently been electrified. Therefore in order to cater for future demand, generation and transmission capacities are required to be increased accordingly.

In order to increase the transmission capacities, it is required to construct new transmission lines. As we are aware that Sri Lanka is a small island and already considerable area has been utilized for existing Transmission Network. In future, construction of such transmission lines is much more difficult due to objections coming from environmentalists and the general public.

Therefore it is badly needed to find alternatives to increase the transmission capacities of the existing Transmission Network

This project deals with investigating the possibilities to asses the present operating efficiency or utilization factor of Transmission lines and to schedule a optimum loading pattern of the selected two transmission lines from the set of existing transmission lines.

The loading of a transmission line is governed by the Current carrying capacity of the conductor strung on the transmission line. In the transmission network of Sri Lanka, Aluminum Conductor Steel Reinforced (ACSR) has been used having different ratings. Those conductors are normally identified by the name of animals such as Zebra, Goat Lynx etc. (see table C1 in Appendix C)

There are two basic types of conductors available namely homogeneous & non-homogeneous conductors. Homogeneous conductors can be categorized further in to two types namely All Aluminum Conductors (AAC) and All Aluminum Alloy Conductor (AAAC). Non-homogeneous conductors can be categorized into two types namely Aluminum Conductor Steel Reinforced (ACSR) and Aluminum Conductor Alloy Reinforced (ACAR).

At present, National Grid of Sri Lanka is having two Transmission networks. One with 132 kV High Voltage lines and the other with 220 kV Extra High Voltage network. 132 kV Network is having nearly 42 transmission lines with a total of 1500 km length. The other network is having 8 transmission lines with total length of 350 km.
Most of the transmission lines in the 132 kV Transmission network is fairly old therefore those lines are now planned to be replaced by 220 kV Transmission lines. Therefore the investigating the possibilities for optimum loading of such transmission lines is not worth. Therefore the study was focused mainly on the 220 kV Transmission network. The case study in project has been confined to selected two transmission lines, one running from south to north and the other running from east to west to represent total 220 kV network. (See figure. 2.1)

1.2 Goals

The main objective of this study is to assess the present efficiency of the two selected transmission lines and prepare a schedule for optimum loading pattern for the selected transmission lines from the existing transmission network without exceeding designed criteria given below,

(a) Minimum Ground Clearance
(b) Maximum allowable conductor temperature
(c) Hardware properties

The design criteria (a) and (b) can not be violated due to the fact that the safety of the public is governed by the criteria given in Technical Specification for transmission lines [11].

1.3 Methodology used to accomplish goals

The following methodology was used to accomplish goals

a. Study of the transmission network
The operating criteria and variation of the demand through out day of the transmission network were studied. The most important transmission lines for the study were selected.

b. Study on literature on transmission lines
Study the past and present practice of designing of transmission lines in the Ceylon Electricity Board typical transmission line design, [7]. Similarly, other standard and available formal and informal methods of designing of transmission lines in other countries were also studied.

c. Study on loading parameters of transmission lines

The parameters of a transmission line, which govern the loading of a line, were studied [6]. The ways and means to control such parameters to improve the loading of a transmission lines were investigated.

d. Selection of sample lines.

Two transmission lines for a case study were selected in such a way that both transmission lines can reasonably represent total transmission network of Sri Lanka. The operating pattern of both transmission lines was studied.

e. Collection of data

The data which control the parameters of transmission line loading for the selected two transmission lines were collected on reasonable interval for reasonable period. Present operating data of selected two transmission lines were also collected.

f. Identification and developing of a model

A model was developed based on accepted design practices to calculate the current rating using data collected. A probabilistic approach was developed based on reasonable criteria to select optimum current ratings for a three-hour period of time.

g. Study on effects due to loading on calculated optimum ratings

The voltage regulation, power loss and variation of sag of the transmission lines were calculated for the estimated optimum current ratings to recommend exact optimum current rating.

Chapter 2

Operation of transmission network

2.1 Transmission network in Sri Lanka

The transmission network in Sri Lanka is operating in two Voltage levels 132 kV and 220 kV. Presently 132 kV Transmission network is being upgraded to 220 kV in order to improve the power transfer capability and to reduce the transmission losses. (Transmission network in Sri Lanka is shown in Figure 2.5)

2. 2 Arrangement of the transmission network in Sri Lanka

There are about 50 Transmission lines in commercial operation island wide. The length of the 220 kV Transmission Network is about 350 km and that of 132 kV systems is about 1500km. (List of the transmission lines is given in Table 2.1a and 2.1b).

2.3 Loading Pattern of selected transmission lines

At Present, almost all the transmission lines are utilized to their full capacity. Some of the transmission lines are operating at its maximum permitted Ampere rating during peak hours causing bottle necks to the system leading to system failures when one of the transmission lines fails. Therefore, any possibility to permit extra power flow through such transmission lines can eliminate bottlenecks and high stresses when operating the system at peak demand. Presently Sri Lanka transmission network experiences peak demands at daytime and nighttime. During daytime, system experiences two peak demands, first peak demand occurs between 05.30 hrs and 07.30 hrs. That is mainly due to morning activities in houses. The other daytime peak demand occurs between 9.30 hrs and 12.30 hrs due to commencement of office and other related activities. The highest peak demand in the system occurs in the night between 18.30 and 21.30 hrs. The night peak demand occurs mainly due to lighting load in the country (Daily Load Curve on 15.01.2004 is given in Figure 2.4 for reference). During peak demand in the system, whole transmission network is fully utilized. Therefore network is now being operated in full capacity.

The average loading pattern of selected two transmission lines, 220 kV Kotmale – Biyagama Transmission line and 220 kV Kotmale – Anuradapura Transmission line are shown in Figure 2.2 and Figure. 2.3 respectively. The loading patterns of both transmission lines follow the same pattern of Daily load curve. In addition, they experience seasonal variations of loading patterns.

Section	Voltage kV	Cond. Type	Length km
Kolonnawa - Kelanitissa	132	Zebra	2.2
Kolonnawa - Pannipitiya	132	Lynx	12.9
Kolonnawa - Kelaniya	132	Zebra	16.7
Kelaniya - Sapugaskanda	132	Zebra	4.6
Kelaniya - Kotugoda	132	Zebra	16.7
Kotugoda - Bolawatta	132	Zebra	21.0
Bolawatta - Puttlam	132	Lynx	84
Chilaw spur	132	Lynx	6.8
Kolonnawa - Athurugiriya	132	Lynx	14
Athurugiriya - Polpitiya	132	Lynx	64
Oruwal - Athurugiriya	132	Lynx	3.4
Thulhiriya spur	132	Lynx	23.9
Kolonnawa - Kosgama	132	Lynx	31.9
Kosgama - Polpitiya	132	Lynx	34.4
Pannipitiya - Ratmalana	132	Lynx	6.9
Pannipitiya - Mathugama	132	Goat	41.4
Panadura spur	132	Lynx	4.7
Polpitiya - Laxapana	132	Lynx	8.3
Laxapana - wps	132	Lynx	5.1
Laxapana - Canyon	132	Lynx	10
Polpitiya - Kothmale	132	Lynx	29.5
Kothmale -Kiribathkumbura	132	Lynx	22.5
Kiribathkumbura - Ukuwela	132	Lynx	7.3
Ukuwela - Habarana	132	Lynx	82.3
Habarana - Anuradhapura	132	Lynx	48.9
Ukuwela - Bowatanna	132	Lynx	30.0
Kiribathkubura - Kurunagala	132	Lynx	34.6
Habarana - Valachchanai	132	Lynx	99.7
Anuradapura - Trincomalee	132	Lynx	103.3
New Laxapana - Balangoda	132	Lynx	43.9
Balangoda - Samanalawewa	132	Zebra	19.0
Samanala - Embilipitiya	132	Lynx	38.0
Balangoda - Deniyaya	132	Tiger	44.2
Deniyaya - Galle	132	Tiger	57.3
Rantambe – Badulla old	132	Lynx	37
Rantambe – Badulla old	132	Lynx	37
Badulla - Inginiyagala	132	Oriole	79.9
Anuradhapura - Vavuniya	132	Lynx	86
Anuradapuara - Puttlam	132	Lynx	28
Balangoda - Rathnapura	132	Lynx	22
Horana spur	132	Lynx	12

Table 2.1a - Existing 132kV major transmission lines in Sri Lanka

Section	Voltage kV	Conductor Type	Length km
Biyagam – Kotugoda	220	Zebra	19.6
Biyagama – Kotmale	220	Zebra	70.5
Kotmale – Victoria	220	Zebra	30.1
Victoria – Randenigala	220	Zebra	16.4
Randenigal – Rantambe	220	Zebra	3.1
Biyagama – Pannipitiya	220	Zebra	15.5
Biyagama – Kelanitissa	220	Goat	12.5
Kotmale – Anuradhapura	220	Zebra	163

Table 2.1b - Existing 220 kV transmission line circuits in Sri Lanka

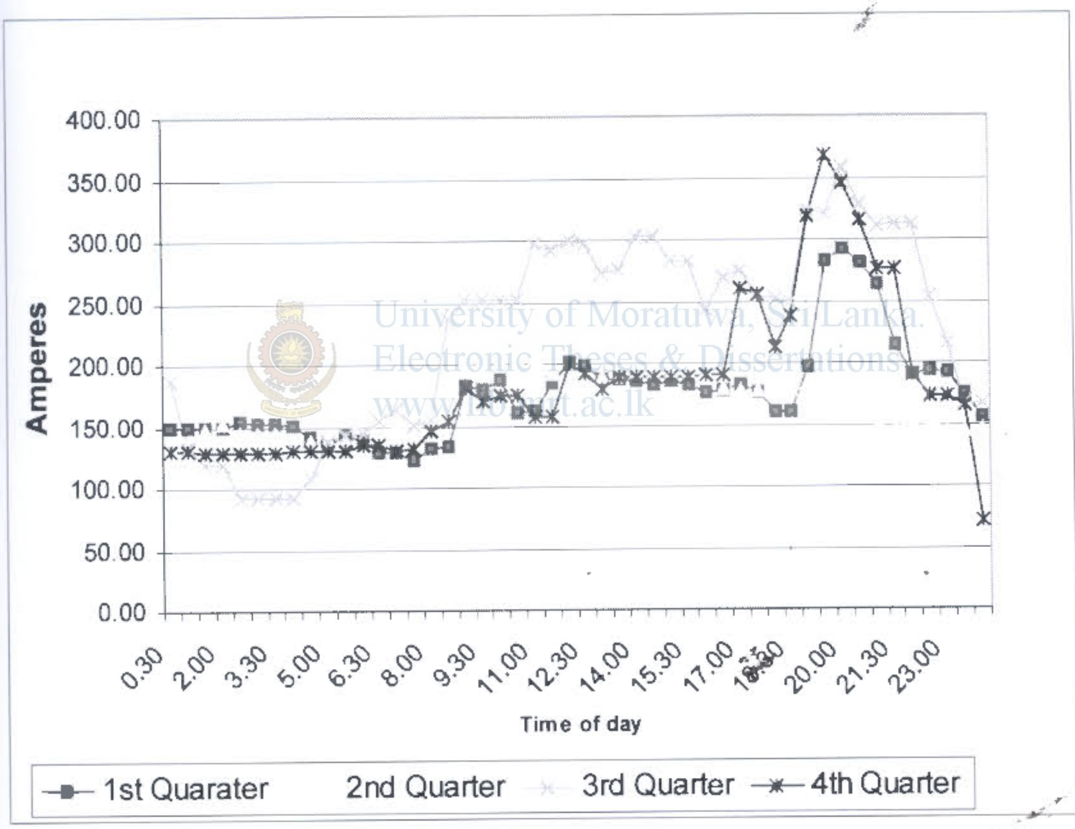


Figure 2.1 - Present Average Operating Pattern of 220 kV Kotmale – Biyagama Transmission Line (Year 2000-2005data)

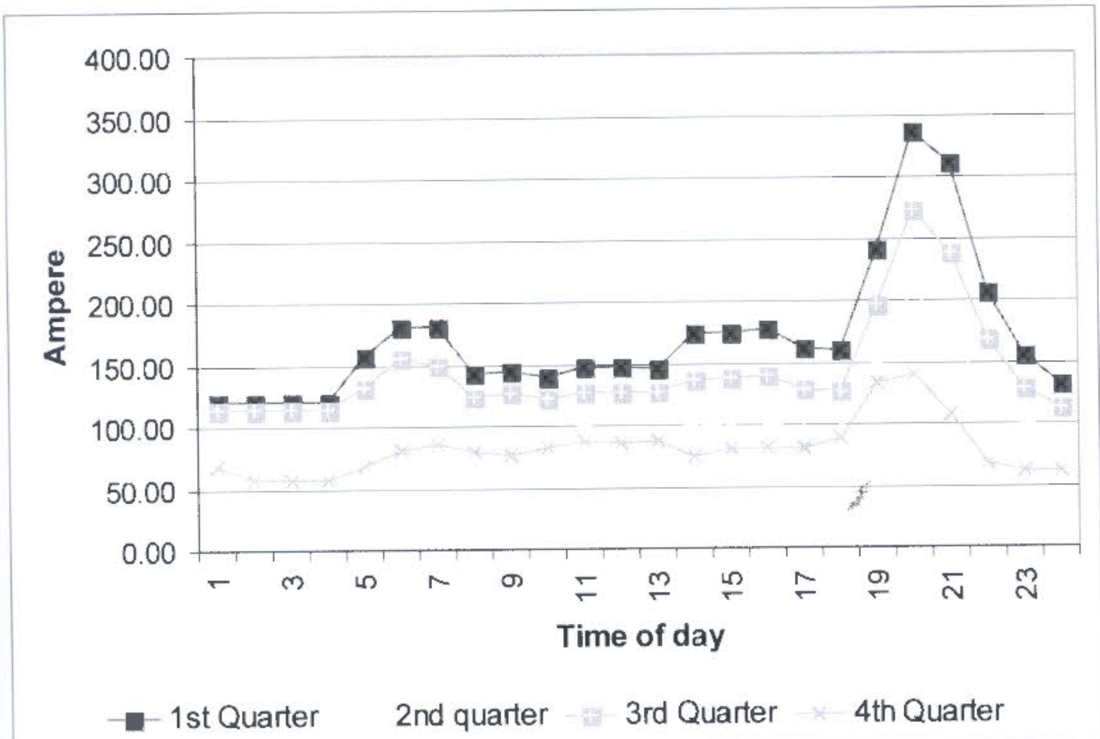


Figure 2.2 - Present Average Operating Pattern of 220 kV Kotmale – Anuradapura Transmission Line (Year 2000-2005 data)

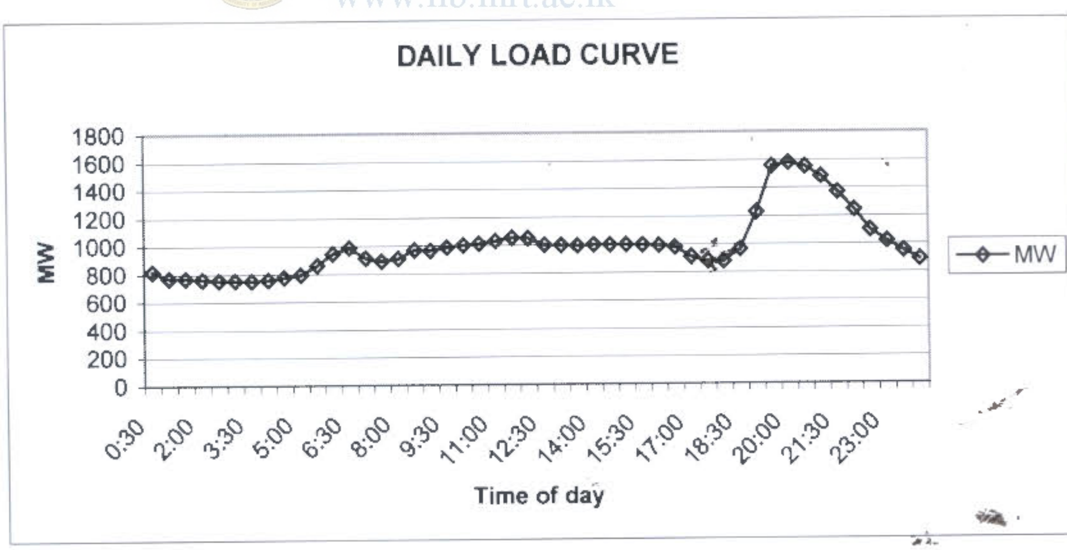


Figure 2.3 Daily Load Curve on 15th Jan. 2004

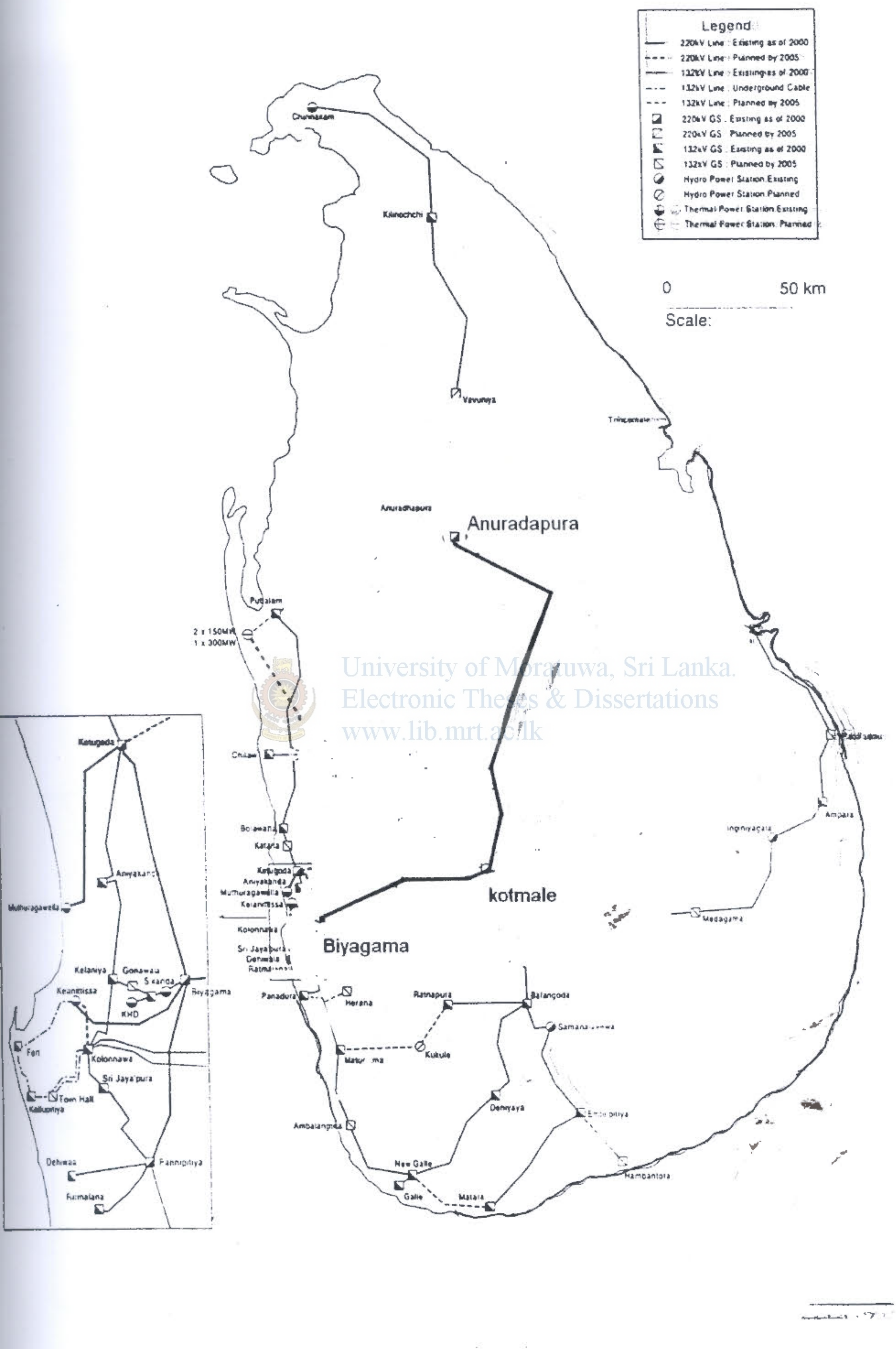


Figure 2.4 - Map of selected two transmission lines

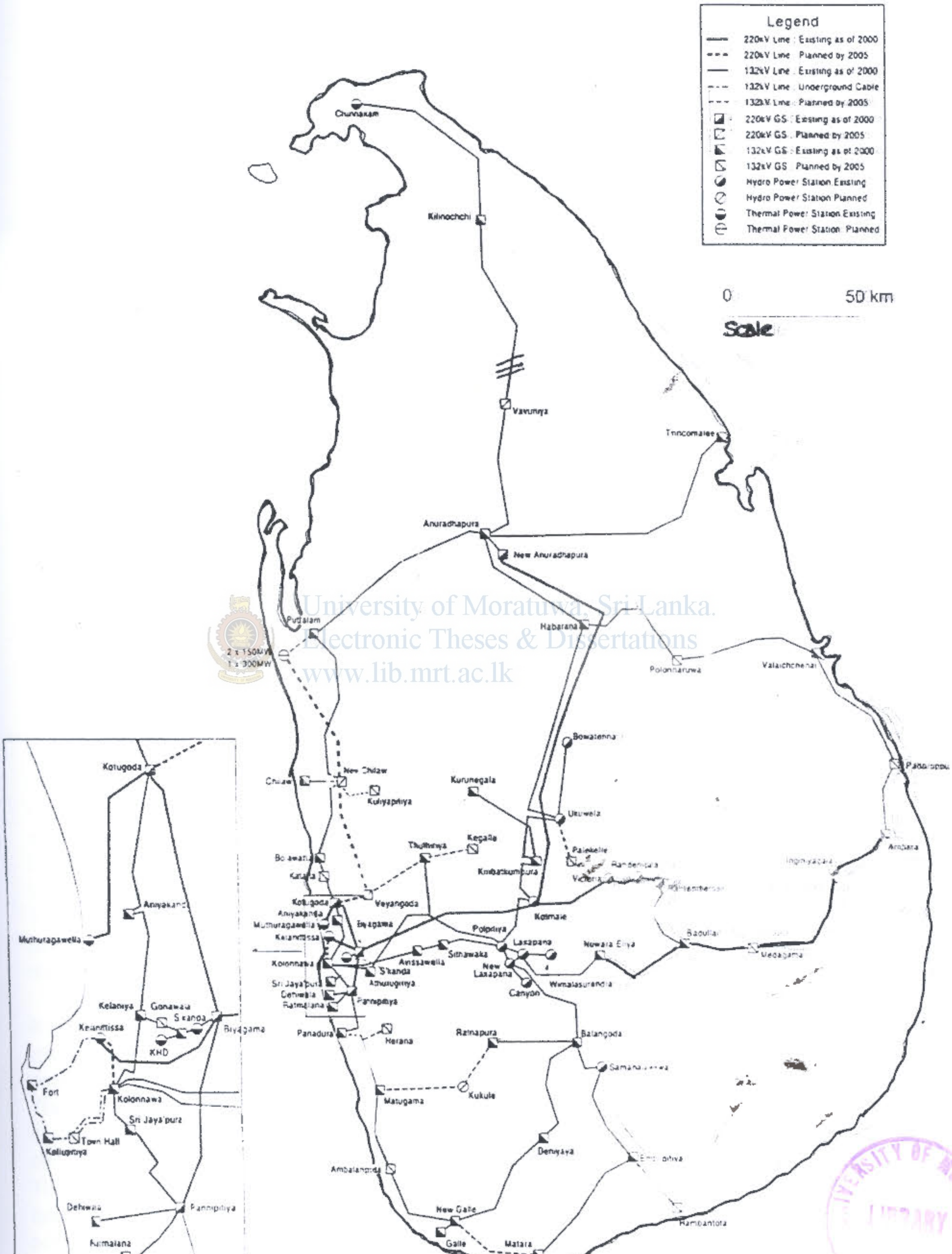


Figure 2.5 Sketch of transmission network of Sri Lanka in year 2005

Chapter 3

Methods used to determine transmission line Current ratings

The power transfer on transmission lines affects the sag of the conductors and hence the height of the conductor above the ground. This in turn affects the safety of the public. The determination of the allowable power transfer is thus not only a function of properties of the conductor but also of the public safety. It is thus essential that the designers are aware of the factors that affect the safety as well as the types of accidents or factors that are pertinent to the utility.

3.1 Methods for determination of conductor current rating

Basically following methods have been adopted by most of the utilities all over the world for determination of current carrying capacity of a transmission line conductor [2],[3].

a. Probabilistic approach
b. Deterministic approach

The deterministic approach assumes certain bad cooling conditions (low wind speed, high ambient temperature etc.) and calculates the current that would result in the line design temperature. The line temperature or design temperature is the temperature at which the height of the conductor above the ground is minimum permissible. The deterministic approach has been used by utilities for number of years. The draw back of the method is that it does not address the safety or the relationship between the safety and the power transfer capability.

Power utilities at present are designing and operating their lines and power systems based on inter alia, the allowable current (or ampacity) that can flow down the line. This current is usually calculated using deterministic approach assuming bad cooling conditions. It is assumed that by limiting the current the safety criteria will be met and the line will not contravene any regulations.

It is also known, however, that this condition may result at some stage in the conductor exceeding the line design temperature causing line to be under clearance. What is needed therefore is the quantification of the safety of the design.

The probabilistic approach uses the actual weather conditions and data prevailing on the line to determine the probability of a certain condition occurring. Such a condition could be for example, conductor temperature rising above the design temperature. These methods have been developed to include a measure of safety of the transmission line. This can be used as a means of comparison of practices between utilities in all countries.

3.1.1 Probabilistic Methods Available

There are three main probabilistic methods available at present.

Method 1

The first is a method whereby the probability of an accident occurring can be quantified. The benefits of this method are that an absolute measure of safety is achieved. The draw back is that the nature of the parameters is extremely difficult to determine. In addition correlation between the parameters need to be determined. This could vary form country to country, [2]-[5].

Method 2

The second method uses the existing weather data to determine the temperature of the line conductors for a given current flow. The amount of time that the temperature exceeds the line design temperature can be determined for each current level. The utility can then decide on the current level based on the percentage of excursion or "exceedence". The advantages of this method are that it is relatively easy to determine the percentages and decide on a level by which to operate. The disadvantage is that there is no way of determining the difference in safety.
An adaptation of above method is to simulate the weather data and the current flow to determine the cumulative distribution of the conductor temperature as a function of current. This curve could be used to determine the current and excursion level, [2]-[5].

Method 3

The third method is to simulate the safety of a transmission line by incorporating all the factors that affect the safety of the line. From this method a measure of safety can be developed whereby the practices in different countries can be compared objectively. The advantages of this method are that all factors are considered. The variation of occurrence of objects under the line can be related to the safety of the line, [2]-[5].

3.1.2 Deterministic Method

Thermal Rating Parameters

The temperature of an overhead conductor is primarily a function of current flow, ambient conditions (wind speed and direction, air temperature, and solar radiation), and the physical properties of the conductor (electrical resistivity, emissivity, absorptivity, and specific heat). Some of the important points that shall be considered when calculating thermal rating of conductors are as follows;

- Ohmic (I^2r) line loss, the main source of heat input to the conductor, is a function of electrical current and conductor resistance. Heat input from solar radiation is a much smaller source, even during daylight hours, and is impacted by the conductor's absorptivity.

- Heat is lost from the conductor primarily through convection and radiation. Air temperature and wind speed, and direction impact of convection loss, conductor emissivity controls radiation loss.
- The temperature of the conductor is an indirect measurement of the thermal energy (heat) stored within the conductor. As thermal energy is added, much of it is stored within the conductor, raising the conductor temperature. This thermal storage capacity depends on the specific heat of the conductor material.

The steady state current rating and short circuit capacity is calculated based on IEEE - 738 –1986, [6]. The equations stated in this standard are as follows;

Basic Heat balance equation

Heat generated due to resistance of the conductor = I^2r

Heat gained from sun = q_s
Heat loss due to convection = q_c
Heat loss due to radiation = q_r

Heat gained = Heat loss

$$I^2r + q_s = q_c + q_r \quad (3.1)$$

Therefore,

$$I = \sqrt{(q_c + q_r - q_s)/r} \quad (3.2)$$

Forced convected Heat Loss is given by following empirical formula

$$q_{c1} = \{1.01 + 0.371(d\rho_r V/\mu_f)^{0.52}\}k_f(t_c - t_a) \text{ W/ft} \quad (3.3)$$

$$q_{c2} = 0.1695(d\rho_r V/\mu_f)^{0.6}\}k_f(t_c - t_a) \text{ W/ft} \quad (3.4)$$

The maximum value of q_c obtained from Eq (3.3) or (3.4) is used.

Natural Convection Heat Loss at Sea Level is given by following empirical formula

$$q_c = 0.072.d^{0.75}(t_c - t_a)^{1.25} \text{ W/ft} \quad (3.5)$$

Radiated Heat Loss is given by following empirical formula

$$q_r = 0.138.d.e.\{(k_c/100)^4 - (k_a/100)^4\} \text{ W/ft} \quad (3.6)$$

Solar Heat Gain is given by

$$q_s = a.Q_s.(\sin\theta)A' \qquad (3.7)$$

$$\theta = \cos^{-1}\{(\cos H_c).\cos(Z_c - Z_l)\} \qquad (3.8)$$

Identification of Letter Symbols

I = Conductor current, A
q_c = Convected heat loss, W/ft
q_r = Radiated heat loss, W/ft
q_s = Heat gain from the sun, W/ft
t_a = Ambient temperature, ^oC
t_c = Average temperature of conductor, ^oC
t_f = Air film temperature, ^oC
r = AC resistance, Ω/ft
d = Conductor diameter, in
d_0 = Conductor diameter, ft
ρ_f = Density of air, lb/ft^3
V = Velocity of air stream, ft/h
μ_f = Absolute viscosity of air, lb/h
k_f = Thermal conductivity of air at temperature t_f W/ft.
K_c = Temperature of conductor, K
K_a = Ambient temperature, K
e = Coefficient of emissivity, 0.23 to 0.91
a = Coefficient of solar absorption, 0.23 to 0.91
Q_s = Total solar and sky radiated heat, W/ft^2
A' = Projected area of conductor = d/12
θ = Effective angle of incidence of the sun's rays, degrees
H_c = Altitude of sun, degrees
Z_c = Azimuth of sun, degrees
Z_l = Azimuth of line, degrees
H_e = Elevation of conductor above sea level, ft

Chapter 4

Assessment of efficiency of transmission lines

Transmission Network in Sri Lanka comprises around 50 different lines. Studying all these lines is beyond the scope of this project. As a case study, the following two transmission lines have been selected for the purpose of assessing the efficiency.

1. 220 kV Kotmale - Biyagama double circuit duplex conductor transmission line

2. 220 kV Kotmale - Anuradhapura Single circuit simplex conductor transmission Line

Since the designing of transmission lines in Sri Lanka has been carried out using deterministic model, current carrying capacity of Overhead Transmission lines have two different ratings based on day and evening time through out the year.

4.1 Designed values of current carrying capacity of selected Transmission lines

The present Daytime and Evening current ratings are given in table 4.1

Name of the Transmission line	Current carrying capacity (A)	
	Day time	Evening
220 kV Kotmale - Biyagama Transmission line	4*726	4*987
220 kV Kotmale – A' pura Transmission line	726	987

Table 4.1 - Design values of current carrying capacity of selected transmission lines

4.2 Utilization of the transmission lines.

The main purpose of a transmission line is to transfer bulk power from the point of generation to the point of delivery. It is required to transfer reactive and active power along the transmission lines. Therefore, in assessing the efficiency or utilization factor, it is more versatile to consider flow of current along the transmission line though it contributes to increase the transmission loss. Therefore, in assessing the efficiency, annual **efficiency** was calculated based on flow of charge (Ampere * time). (Please see table A1 and A2 in appendix A) respectively for calculation of hourly flow of actual charges.

4.3 Calculation of annual efficiency of transmission lines.

$$\text{Annual efficiency} = \frac{\text{Annual actual flow of charge} * 100}{\text{annual expected flow of charges}}$$

Annual actual flow of charge = $t_e*C*K*A_e + t_d*C*K*A_d$

Where

A_e = Evening rating of the conductor of the line

A_d = Day time rating of the conductor of the line

t_e = time duration for evening rating of the conductor

t_d = time duration for day time rating of the conductor

C = Number of circuits of the line

K = Number of conductors per phase

4.3.1 220 kV Kotmale - Biyagama Transmission line

Annual expected flow of charge = (18*2*726+6*2*987)*365 Ah
= 13862700 Ah

Annual average actual flow of charge = 1628861.4 Ah
(See table A1 in appendix A)

Annual efficiency (utilization factor) = 11.75 %

4.3.2 220 kV Kotmale – Anuradhapura Transmission line

Annual expected flow of charge = (18*726+6*987)*365 Ah
= 6931350 Ah

Annual average actual flow of charge = 1118148.8 Ah
(see table A2 in appendix A)

Annual efficiency (utilization factor) = 16.1 %

Chapter 5

Case Study

Case study was done on selected two transmission lines described in Chapter 2.

Since the designing of transmission lines in Sri Lanka have mainly been carried out by the Ceylon Electricity Board as per IEEE 738 -1993 model [9], the designed current ratings of two lines are as given below in table 5.1.

Transmission line	Area mm^2	Length km	Conductor type	Max. operat. Temperature ^oC	Current carrying capacity (A)	
					Day	evening
220 kV Kotmale - Biyagama Tr. line	2*400	72	Twin Zebra	75	4*726	4*987
220 kV Kotmale – A' pura Tr. line	400	163	Zebra	75	726	987

Table 5.1 - Designed Parameters of two selected Transmission lines

5.1 Collection of data

The Wind velocity and the ambient Temperature in three-hour intervals for the past 5 years were collected at following locations (i.e. nearly 25000 values per location).

220 kV Kotmale - Biyagama Double circuit Duplex conductor transmission line runs from Kotmale Grid Substation and terminates at Biyagama Grid Substation. Therefore ambient temperatures and Wind velocities were collected at sites located at Kandy (Kotmale) and Colombo (Biyagama). (See Appendix B).

220 kV Kotmale – Anuradhapura single circuit Simplex conductor transmission line runs from Kotmale Grid Substation via Maradankadawala area and terminates at Anuradhapura Grid Substation. Therefore ambient temperatures and wind velocities were collected at sites located in Kandy (Kotmale), Mahailukpallama and Anuradhapura. (See tables B1-B4 in Appendix B).

5.2 Analyzing Data

As per Chapter 3, the thermal rating of conductor is calculated as follows;
From the equation(3.2)

$$\mathbf{I = \sqrt{(q_c + q_r - q_s)/r}}$$

5.2.1.Sample Calculation

Sample calculations are presented for following data taken at Biyagama for 220 kV Kotmale – Biyagama Transmission Line.

Data

Time	= 15.00 hrs a.m. on 2000 (April - September)
Wind Speed	= 33150 ft/h
Ambient temperature	= 31.86 ^oC
Coefficient of emissivity[1]	= 0.5
Coefficient of solar absorption[1]	= 0.5
Conductor out side diameter	= 28.62 mm = 1.126 inch
Absolute viscosity of Air (μ_f)[2]	= 0.0478 lb/h
Density of Air (ρ_f) [2]	= 0.0672 lb/ft^3
Conductor AC resistance at 75 ^{0} C	= 2.5237x 10^{-5} Ω/ft
Thermal conductivity of Air	= 0.00864 W/ft

Calculation

Ambient air temperature in Kelvin (K_a) = 31.8 + 273
= **304.8** K

Air film temperature = [(75 + 26)/2] ^oC
= 50.5 ^oC

(a) Convection Heat loss

Since wind velocity is greater than zero the forced convection heat loss is given by the equation (3.3) and (3.4).

$$q_{c1} = \{1.01 + 0.371(d\rho_r V/\mu_f)^{0.52}\}k_f(t_c - t_a)$$
$$= \{1.01 + 0.371(1.1267x0.0672x33150/0.478)^{0.52}\}0.00864(43.2)$$
$$= 39.8 \text{ W/ft}$$

$$q_{c2} = 0.1695(d\rho_r V/\mu_f)^{0.6}\}k_f(t_c - t_a) \text{ W/ft}$$
$$= 0.1695(1.1267x0.0672x33150/0.0478)^{0.6}\}0.00864(43.2) \text{ W/ft}$$
$$= 42.98 \text{ W/ft}$$

Select the largest value,

Natural convection Heat loss = $0.072*(0.77)^{0.75}(75 - 31.8)^{1.25}$
= 6.55 W/ft

Therefore **q_c** = 49.53 W/ft

---

1 values accepted for Sri Lanka
2 from IEEE 738 table

(b) **Radiation Heat loss**

from equation (3.6)

$$q_r = 0.138.d.e.\{(k_c/100)^4 - (k_a/100)^4\} \text{ W/ft}$$
$$q_r = 0.138.x1.12677x0.5\{(348/100)^4 - (304.8/100)^4\} \text{ W/ft}$$
$$\mathbf{q_r} = 4.692 \text{ W/ft}$$

(c) **Solar Heat gain**

from equation (3.7)

$$q_s = a.Q_s.(\text{Sin}\theta)A'$$
$$\theta = \text{Cos}^{-1}\{(\text{Cos } H_c).\text{Cos } (Z_c - Z_1)\}$$

$A' = d/12 = 1.126/12 = 0.094 \text{ ft}^2$
$Q_s = 75.75 \text{ W/ ft}^2$

Local Sun Time	Altitude H_C	Azimuth Z_C
10. a.m.	62	98
Noon	81	180
Average	71.5	139

Z1 = 90 or 270
$\theta = \text{Cos}^{-1}\{(\text{Cos } 71.5).\text{Cos } (139 - 90)\}$
$= 78.62^{\circ}$

$q_s = 0.5*75.75(\text{Sin}78.62)*0.094$

$\mathbf{q_s} = 3.49$ W/ft (this value is taken as constant for all calculations)

Therefore, Steady State Current Rating

$$\mathbf{I = \sqrt{(q_c + q_r - q_s)/r}}$$
$$= \sqrt{(49.53 + 4.692 - 3.49)/ 2.5237\text{x } 10^{-5}}$$
$$= 1418 \text{ A}$$

5.3 Summary of Calculation

Summary of calculations for 220 kV Kotmale - Biyagama Double circuit Duplex conductor transmission line at Kotmale and Biyagama are given in Annex. B. The summary was prepared for three periods of the year, first period from January to March (first quarter), second period from April to September (second and Third quarter) and the last from October to December (fourth quarter) by considering the seasonal variations of the weatber.

Summary of calculations for 220 kV Kotmale – Anuradhapura Single circuit Simplex Conductor transmission line at Kotmale, Anuradhapura and Mahailukpallama are given in annex B. The summary was prepared for three periods of the year, first period from January to April., second period from May to September and the last from October to December by considering the seasonal variations of the weather.

5.4 Assessment of possible current rating of Transmission lines

5.4.1 220 kV Kotmale - Biyagama Double circuit Duplex conductor transmission line

The calculated average current ratings at Kotmale and Biyagama at every three-hour intervals are presented in Tables B1 and B2. For each and every three-hour interval, calculated average current ratings and the probability of their occurrence are shown in Appendix C.

5.4.2 220 kV Kotmale – Anuradhapura Single Circuit Simplex conductor Transmission line

Similarly, the calculated average current ratings at Kotmale, Anuradhapura and Mahailukpallama are presented in Tables B1, B3 and B4. For each and every three-hour intervals, calculated average current ratings and the probability of their occurrence are shown in Appendix C.

5.5 Criteria for selection of optimum Current rating

The optimum current ratings were decided based on following criteria, which was proposed by the author based on the distribution of the data collected.

(a) Expected current rating should have been possible at least for a minimum of 90 percent of total time of the period or
(b) Next highest current rating is selected which has less than 90 percent of Total time and greater than 80 percent provided next lower value of the Current rating is around 95 percent of total time.
(c) In addition to above, distribution pattern of calculated Ampere ratings throughout the period were also considered.

The above criteria was mainly developed based on the current rating corresponding to 100 percent probability and the proposed optimum current rating may create a temperature difference of less than one degree Celsius when operating in proposed optimum current rating which occur with a maximum of 10 % probability. One degree Celsius shall make no change to the sag of the conductor. (Calculated optimum current ratings are highlighted in Appendix C.)

Calculated Optimum loading Pattern of 220 kV Kotmale - Biyagama double circuit Duplex conductor transmission line for three periods of the year are given in figure 5.1, 5.2 and 5.3.

Calculated Optimum loading Pattern of 220 kV Kotmale – Anuradapura single circuit simplex conductor transmission line for three periods of the year are given in figure 5.4, 5.5 and 5.6.

5.6 Voltage Variation at the receiving end of the Transmission line

Due to operation of the transmission line on calculated optimum current rating which will be a higher Current rating than the designed rating, there will be a possibility of violating the standard voltage regulation in the receiving end grid substation.
Therefore it is necessary to calculate the Voltage drop along the transmission line when the line is operated on calculated optimum current rating.
Voltage drop along the transmission line is given by the following equation [10].

$V_d = I(R \cos\varphi + X \sin\varphi).L$

Where,

- V_d - Voltage drop (V)
- I - Maximum current (A)
- L - Line length (km)
- R - Resistance of conductor at maximum operating temperature (Ω/km)
- X - Reactance of conductor (Ω/km)
- Cosφ - Normal operating power factor

The Conductor used for both of the selected transmission lines is ZEBRA. The parameters for the 220 kV Kotmale – Biyagama Transmission line are given below.

X = 0.1021Ω/km, R = 0.0828Ω/km per conductor (at the operating conductor temperature of 75^{o}C)
L = 75 km, Cosφ = 0.9

For a sample calculation of the Voltage drop, take I = 1100 A (proposed optimum current rating from 15.00 hrs to 18.00 hrs from January to March for the above transmission line).

$V_d = 1100.(0.0828x0.9 + 0.1021x0.4359x0.5x75) = 40908.95V$

Voltage drop = 1.86 %

Voltage drop under above calculated optimum is less than 10 %. Therefore the proposed rating is not Violating the accepted Voltage regulation.
The Voltage drop corresponding to calculated optimum current ratings are given in Tables 5.9-5.14

5.7 Assessment of Power loss in the Transmission line

When operating the lines on higher current ratings than the designed current rating, the power loss along the transmission line increases due to increase in both Current flow and the Conductor temperature.

Therefore, it is important to assess the power loss along the transmission line. Following sample calculation is made assuming power loss along the transmission line occurs due to copper loss only.

The power loss of the conductor = $I^2 * r * L$

Where I = Current flow along the transmission line
r = AC resistance at 75 °C (Ω/km)
L = Length of the transmission line in meters

Sample calculation

For a sample calculation of the Power loss, take I = 1100 A (proposed optimum current rating from 15.00 hrs to 18.00 hrs from January to March for 220 kV Kotmale – Biyagama Transmission line).

Data

Sending end Voltage $V_L = 220$ kV
Sending end Current $I_L = 1100$ A

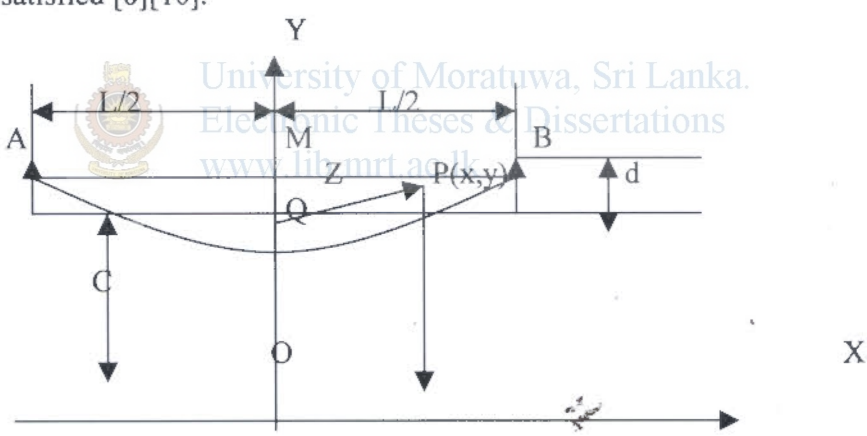
Sending Power = $2\sqrt{3}\ V_L I_L$ (for Twin conductor arrangement)
= $2\sqrt{3}\ 220*1100*10^{-3}$ MW
= 838.3 MW

Power loss along the line = $2*3(1100)^2\ (0.0828)*75$
= 45.08 MW
= **5.37 %**

The Power loss relevant to calculated optimum current ratings are given in Tables 5.9-5.14.

5.8 Effect on sag of the transmission line when operating on calculated Optimum Current rating

An overhead line shall be designed from the mechanical point of view to withstand the worst defined climatic conditions. In still air, the conductor will be acted on by its own weight only. The combination of still air with highest temperature given the maximum sag and minimum conductor tension. The combination of lowest temperature, highest cross wind yields the highest value of conductor tension. Maximum sag of lowest conductor plus statutory minimum ground clearance plus any allowance for conductor creep and survey error dictates the minimum required height of the support, considering the number of conductor levels and separation between these levels. The maximum conductor tensions determine maximum working loading on the supports. In practice, a line will be erected under a set of conditions based on statutory electricity regulations or other specified conditions as relevant. The problem is therefore to determine the sag under erection conditions which will ensure that specified factors of safety of conductors and clearances under the prescribed limits of temperature and/or wind conditions are satisfied [8][10].



Variation of Sag of the transmission line with the temperature and the wind

Consider the catenary formed by conductor AQB supported between supports A and B.
W = Weight per unit length
T = Tension at Q
C = T/W, where C is a constant
It can be proved that;
$Y = C.\text{Cosh}(x/C)$
$Z = C.\ \text{Sinh}(x/C)$

Expansion of above two equations give;

$$Y = C\{1 + x^2/2!C^2 + x^4/4!C^4 + \ldots\ldots\ldots\}$$

$Z = C\{x/C + x^3/3!C^3 + x^5/5!C^5 + \dots\dots\dots\}$

Unless the span length in any practical case is very long, it is permissible to neglect all but the first two terms in the expansion, and little error is introduced by writing;

$Z = C\{x/C + x^3/6.C^3\}$
$Y = C + x^2/2.C^2$
i.e. $y - C = x^2/2C$
So that the maximum sag d for A and B occurs when $x = L/2$
$(MO - QO) = (L/2)^2/2C = L^2/8.C$
If conductor length AQB along the conductor is denoted by S;
$S = 2.Z_{QB} = 2.MB\ \{1 + (MB)^2/6.C^2\}$
$S = 2(L/2)\{1 + (L/2)^2/6.C^2\}$
Elastic and Temperature relationship
Let,

- W = Loading per unit length of conductor
- W_c = Conductor weight
- W_w = Wind force on conductor
- S = Catenary length along conductor
- d = Sag
- t = Temperature
- A = Conductor cross sectional area
- f = Stress or T/A
- E = Young's modules
- T = Tension of the conductor
- a = Coefficient of linear expansion of conductor
- L = Span

Let suffix 1 and 2 represent status 1 and 2.
$S1 = L + (w_1^2.L^3)/24.T_1^2$
$S2 = L + (w_2^2.L^3)/24.T_2^2$

Due to change of temperature from t1 to t2, change in conductor length $= S1.a.(t2 - t1)$
Due to change of tension from T_1 to T_2, change in conductor length $= S1(T_2 - T_1)/A.E$
Therefore the final length;
$S2 = S1 + S1.a.(t2 - t1) + S1(T_2 - T_1)/A.E$
As a and 1/AE are small, S1 is approximately equal to L and hence by substituting S1 in the 2nd and 3rd terms of the above equation with L;
$S2 = S1 + L.a(t2 - t1) + L(T_2 - T_1)/A.E$
Substituting for S1 & S2 and rearranging we can obtain;
$T_2^2[T_2 - \{T_1 - A.E.w_1.L^2/24.\ T_1^2 - A.E.a(t2 - t1)\}] = A.E.w_2^2.L^2/24$

Further;
$f_2^2\ [f_2 - (f_1 - L^2.\delta^2.Q_1^2.E/24.f_1^2 - a.t.E] = L^2.\delta^2.Q_2^2.E/24$

Where,
t = Temperature difference =(t2 -t1)

δ = Weight of conductor with grease/m/cm^2
Q_1 = Loading factor at state1 = $(P^2 + w^2)^{1/2}/w$
P = Wind force on conductor per meter
w = Weight of the conductor per meter
Q_2 = Loading factor at state2

Properties of the conductor

Coefficient of Linear Expansion of galvanized steel = α_{st} = 0.0000115 per ^oC

Coefficient of Linear Expansion of Aluminium = α_{al} = 0.0000230 per ^oC

Modulus of Elasticity of galvanized steel = E_{st} = 200,000Mpa

Modulus of Elasticity of Aluminium = E_{al} = 69,000Mpa

Conductor - ZEBRA -54/7/3.18

Total area of Aluminium = $A_{al} = \pi.(3.18/2)^2.54 = 428.9$ mm^2

Total area of steel = $A_{st} = \pi.(3.18/2)^2.7 = 55.6$ mm^2

Total area = A_{tot} = 55.6+428.9 = 484.5 mm^2

Calculation of composite (ZEBRA) conductor properties

Modulus of Elasticity of composite conductor = $E_{as} = E_{al}(A_{al}/A_{tot}) + E_{st}(A_{st}/A_{tot})$ = 84 kN/mm^2

Coefficient of Linear Expansion of composite conductor = α_{as}

$\alpha_{as} = \alpha_{al}(E_{al}/E_{as})(A_{al}/A_{tot}) + \alpha_{st}(E_{st}/E_{as})(A_{st}/A_{tot})$ = 0.0000199 Per ^oC

Summary of properties

Conductor Material	ZEBRA	
Conductor Size	54/7/3.18	
Overall Diameter of the conductor	28.6	mm
Area of conductor (for all strands	484.5	mm^2
Weight of the conductor with grease	1.619	Kg/m
Ultimate breaking strength	133	kN
Coefficient of linear expansion	0.0000199	Per ^oC
Modulus of elasticity	84	KN/mm^2

Design data

Basic Span	300	m
Temperature Minimum Everyday Maximum	 7 32 75	 Deg. C Deg. C Deg. C
Maximum Wind Pressure	970	N/m^2
Minimum factor of safety for conductors & Earth wire based on UTS At maximum working tension Everyday Temperature, No load	 2.5 4.5	

Sample calculation

Wind force on conductor per meter run,

$P = 970328.630.001 = 27.742$ N/m

State1 - Minimum temperature (7^0C), with maximum wind (970N/m^2)

The corresponding FOS = 2.5

Loading factor at 7 ^oC ;

$$\text{With wind, } Q1 = (P^2 + w^2)^{1/2}/w \qquad (5.1)$$

$$Q1 = \{27.742/9.8067)^2 + 1.619^2\}^{1/2}/1.619 = 2.0132$$

Loading factor at given temperature - state2 (without wind)

$$Q2 = 1$$

Factor Of Safety for state1 = 2.5

Maximum allowable working tension under this condition = 133000/2.5 = 53200 N

Max. allowable working stress under this condition = f_1 = 53200/484.5 = 109.804 N

Weight of conductor with grease = δ = (1.619x9.806)/484.5 N/m/mm^2

= 0.03277 N/m/mm^2

Sag at 7^0C with wind load for equivalent span 300m

$f_2^2 [f_2 - (f_1 - L^2.\delta^2.Q_1^2.E/24.f_1^2 - a.t.E)] = L^2.\delta^2.Q_2^2.E/24$

$t = (7 - 32) = -25^0C$

$(f_1 - L^2.\delta^2.Q_1^2.E/24.f_1^2 - a.t.E) = F1$

$F1 = 178.991 - \{300^2x0.0785^2x1x176.4x10^3\}/(24x178.991^2) + 0.0000115x25x176.4x10^3$

F1 = 102.471

$L^2.\delta^2.Q_2^2.E/24 = F2$

$F2 = (300^2x0.0785^2x2.302^2x176.4x10^3)/24 = 21601295.63$

Therefore the equation,

$$f_2^3 - 102.471.f_2^2 = 21601295.63$$

Solving by iteration,

$f_2 = 317.205$ N/mm^2

$T_2 = f_2 \times 58.1$

$T_2 = 1879.3$ N

Sag = $(0.465x300^2)/8x1879.3 = 2.784$ m

Similarly sag and tension for other weather conditions can be calculated and are summarized as shown in the following table.

Temp. (^oC)	Wind (N/m^2)	Tension (kg)	Sag (m)
7	970	1879.3	2.784
32	0	1060.5	4.93
32	970	1758.9	2.97
75	**0**	**881.2**	**5.94**
7	0	1197.9	4.37

Table 5.2 - Sag corresponding to different temperatures

When designing the transmission lines, Maximum sag has been calculated when the temperature of the conductor is 75 ^{0}C without wind. Whereas When operating the transmission lines on proposed Optimum current ratings, the sag can change due to presence of wind. The presence of wind increase the stress on the conductor thus increasing the sag.
Therefore it necessary to asses the change in sag due to presence of wind while operating the transmission line in proposed optimum ratings.

Sample calculation

For a sample calculation for the Sag, take wind velocity (V_R) corresponds to I = 1100 A (calculated optimum current rating from 15.00 hrs to 18.00 hrs from January to March for 220 kV Kotmale – Biyagama Transmission line).

V_R = 7200 ft/h
= 0.615 mps

from IEC 826

wind force = $0.5\mu V_R^2$
wind force = $0.5*1.225*(0.615)^2$
= 0.231 N/m^2

Wind force on conductor per meter run,

P = 0.231x28.6x0.001 = 0.006 N/m

From equation 5.1

Without wind Q1 $= (P^2 + w^2)^{1/2}/w$
$= (0^2 + w^2)^{1/2}/w$
Q1 = 1

With wind, $Q2= (P^2 + w^2)^{1/2}/w$

$Q\,2 = \{0.006/9.8067)^2 + 1.619^2\}^{1/2}/1.619 \cong 1$

Since Q1 and Q2 are nearly equal, the change in sag due to presence of wind is negligible.

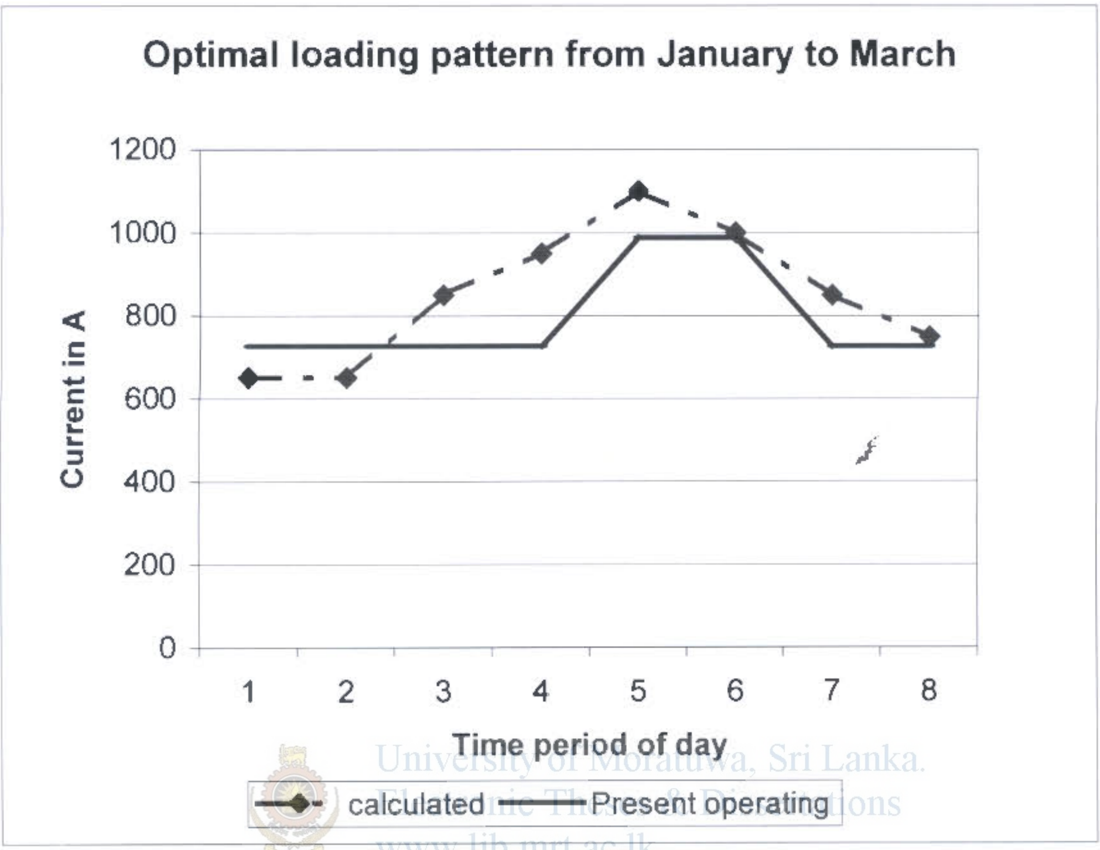


Figure. 5.1- Optimal loading pattern of 220 kV Kotmale –Biyagama Transmission line from January to March (first quarter)

Time period	Time	Calculated values Ampere	Present Values Ampere	Percentage change
1	3.00 - 6.00	650	726	-10.4
2	6.00 - 9.00	650	726	-10.4
3	9.00 - 12.00	850	726	17.1
4	12.00 - 15.00	950	726	30.8
5	15.00 - 18.00	1100	987	11.4
6	18.00 - 21.00	1000	987	1.3
7	21.00 - 24.00	850	726	17.1
8	24.00 - 3.00	750	726	3.3

Table 5.3 - calculated optimum ratings and corresponding designed ratings of 220 kV Kotmale –Biyagama Transmission line from January to March (first quarter)

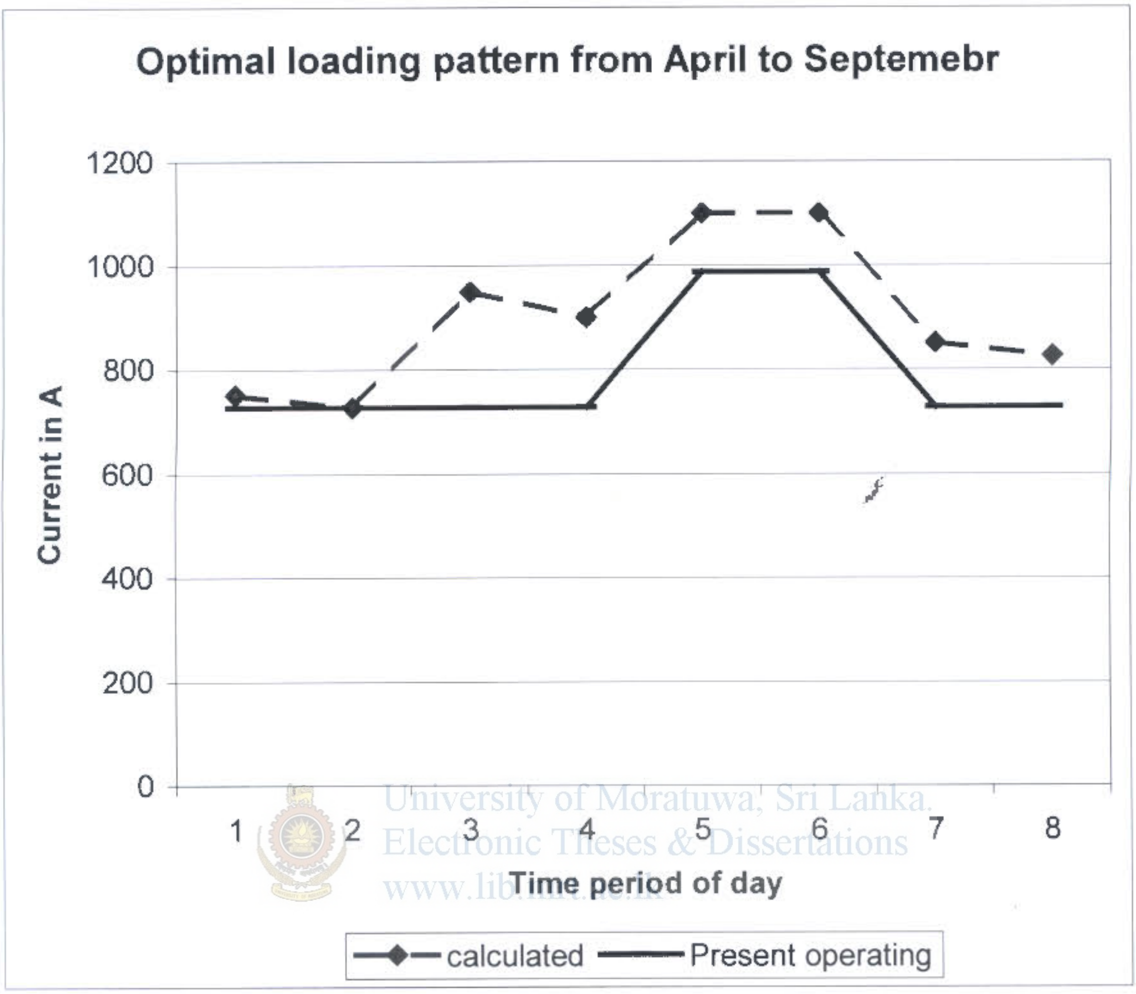


Figure. 5.2 – Optimal loading pattern of 220 kV Kotmale –Biyagama Transmission line from April to September (second & third quarters)

Time period	Time	Calculated values Ampere	Present Values Ampere	Percentage change
1	3.00 - 6.00	750	726	3.3
2	6.00 - 9.00	726	726	0
3	9.00 - 12.00	950	726	30.8
4	12.00 - 15.00	900	726	23.9
5	15.00 - 18.00	1100	987	11.4
6	18.00 - 21.00	1100	987	11.4
7	21.00 - 24.00	850	726	17.1
8	24.00 - 3.00	800	726	13.6

Table 5.4 . – Calculated optimum ratings and corresponding designed ratings of 220 kV Kotmale –Biyagama Transmission line from April to September (second & third quarters)

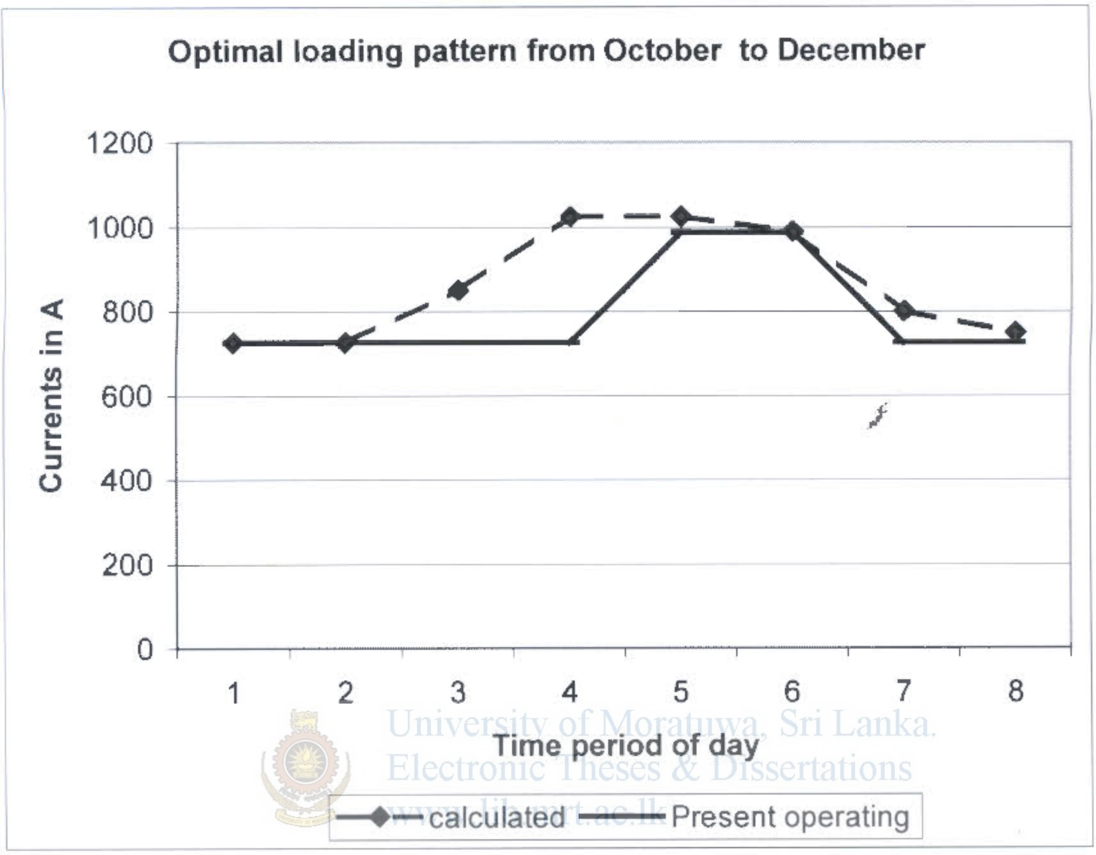


Figure 5.3 – Optimal loading pattern of 220 kV Kotmale –Biyagama Transmission line from October to December (fourth quarter)

Time period	Time	Calculated values Ampere	Present Values Ampere	Percentage change
1	3.00 - 6.00	650	726	-10.4
2	6.00 - 9.00	650	726	-10.4
3	9.00 - 12.00	850	726	17.0
4	12.00 - 15.00	1000	726	37.7
5	15.00 - 18.00	1000	987	1.3.
6	18.00 - 21.00	987	987	00
7	21.00 - 24.00	800	726	10.1
8	24.00 - 3.00	750	726	3.3

Table 5.5 – Calculated optimum ratings and corresponding designed ratings of 220 kV Kotmale –Biyagama Transmission line from October to December (fourth quarter)

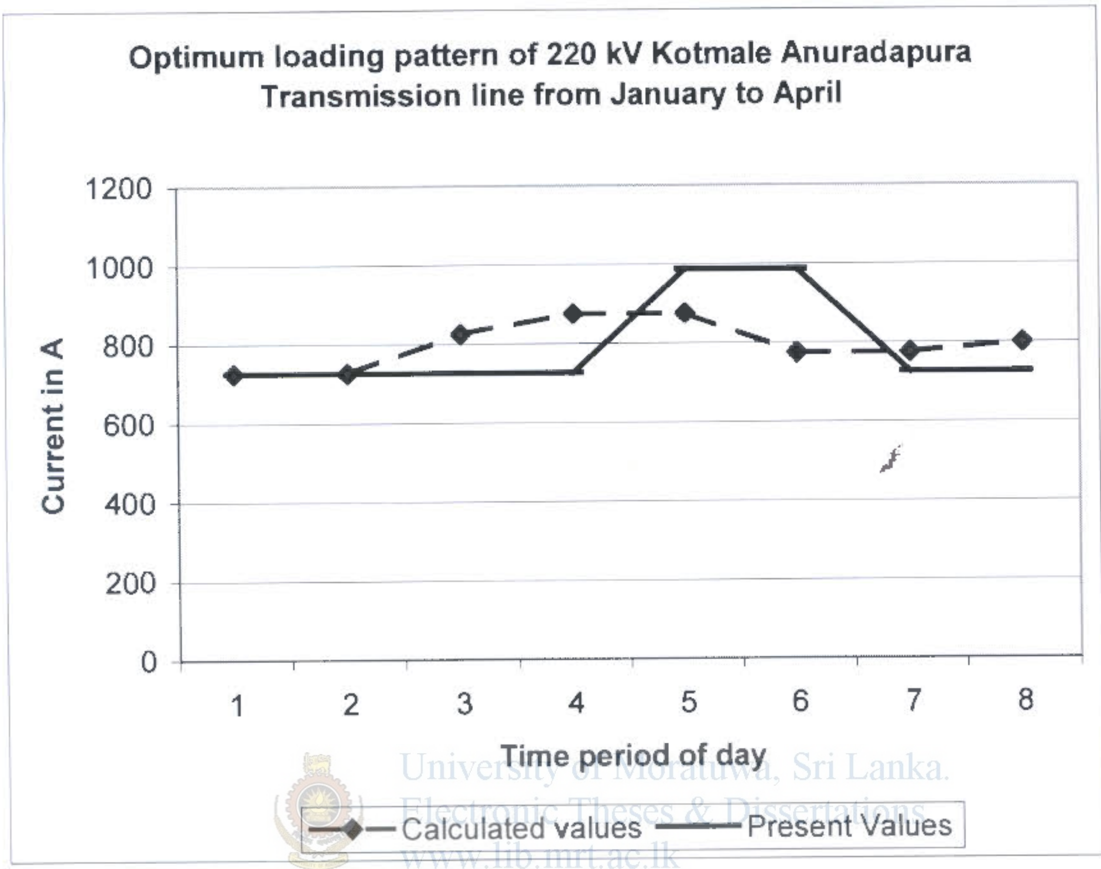


Figure. 5.4 – Optimal loading pattern of 220 kV Kotmale – Anuradhapura Transmission line from January to April

Time period	Time	Calculated values Ampere	Present Values Ampere	Percentage change
1	3.00 - 6.00	700	726	-3.5
2	6.00 - 9.00	700	726	-3.5
3	9.00 - 12.00	800	726	10.2
4	12.00 - 15.00	850	726	17.0
5	15.00 - 18.00	850	987	-13.8
6	18.00 - 21.00	750	987	-24.0
7	21.00 - 24.00	750	726	3.3
8	24.00 - 3.00	800	726	10.2

Table 5.6 - Calculated optimum values and corresponding present designed Values of 220 kV Kotmale – Anuradhapura Transmission line from January to April

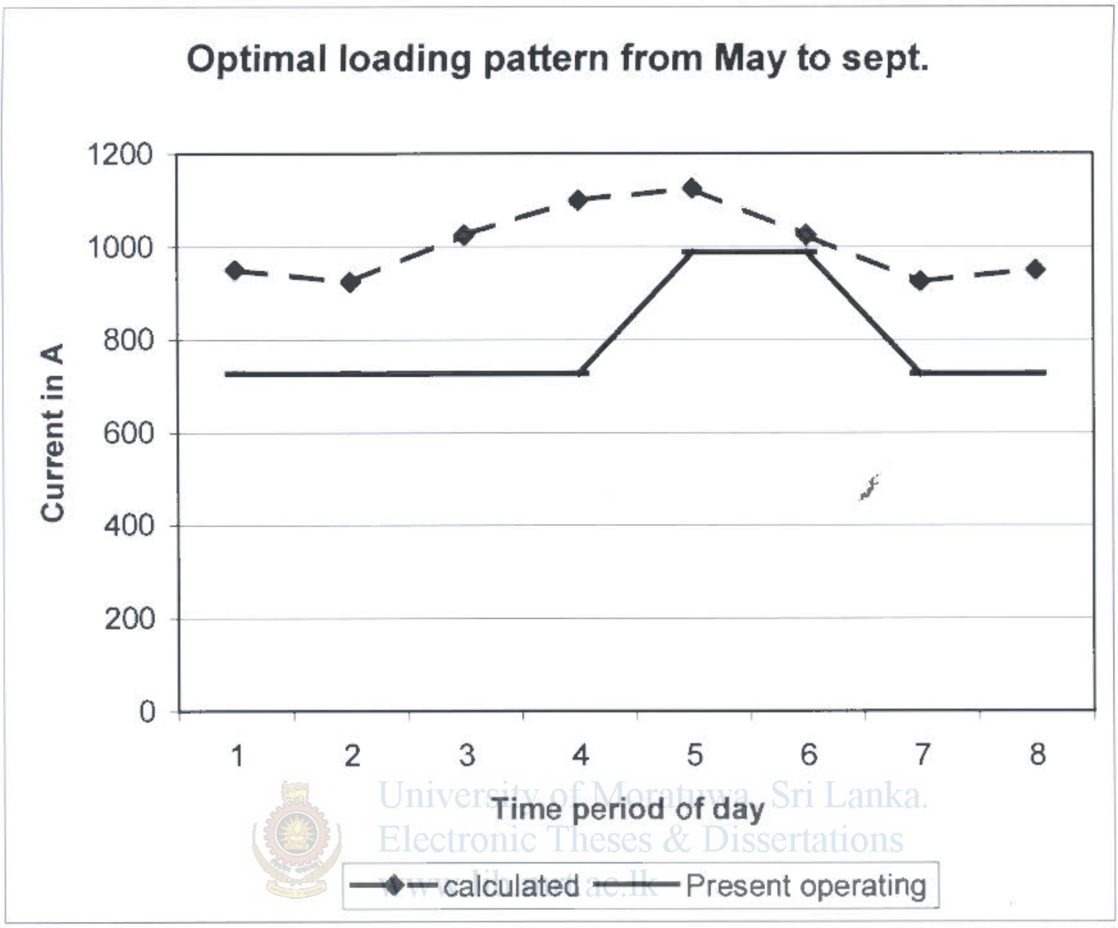


Figure 5.5 – Optimal loading pattern of 220 kV Kotmale – Anuradhapura Transmission line from May to September

Time period	Time	Calculated values Ampere	Present Values Ampere	Percentage change
1	3.00 - 6.00	950	726	30.8
2	6.00 - 9.00	900	726	27.4
3	9.00 - 12.00	1025	726	41.2
4	12.00 - 15.00	1100	726	51.5
5	15.00 - 18.00	1050	987	6.3
6	18.00 - 21.00	1000	987	1.3
7	21.00 - 24.00	900	726	23.9
8	24.00 - 3.00	950	726	30.8

Table 5.7 – Calculated optimum ratings corresponding to designed ratings of 220 kV Kotmale – Anuradhapura Transmission line from May to September

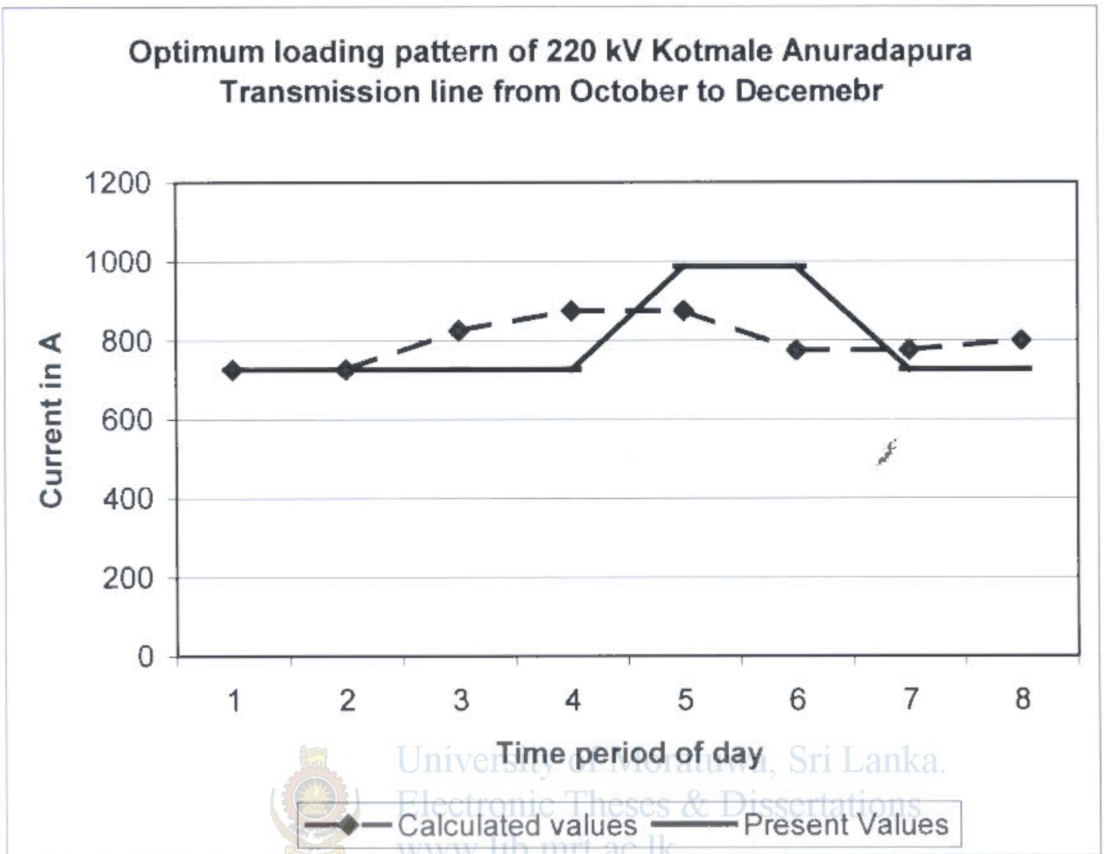


Figure 5.6 – Optimal loading pattern of 220 kV Kotmale – Anuradhapura Transmission line from October to December

Time period	Time	Calculated values Ampere	Present Values Ampere	Percentage change
1	3.00 - 6.00	700	726	-3.5
2	6.00 - 9.00	700	726	-3.5
3	9.00 - 12.00	800	726	10.2
4	12.00 - 15.00	850	726	17.0
5	15.00 - 18.00	850	987	-13.8
6	18.00 - 21.00	750	987	-24.0
7	21.00 - 24.00	750	726	3.3
8	24.00 - 3.00	800	726	10.2

Table 5.8 - Calculated optimum values and corresponding present designed Values of 220 kV Kotmale – Anuradhapura Transmission line from October to December

Time	Calculated ratings (A)	Voltage drop (%)	Power Loss (%)
3.00 - 6.00	650	1.32	3.2
6.00 - 9.00	650	1.32	3.2
9.00 - 12.00	850	1.72	4.2
12.00 - 15.00	950	1.93	4.6
15.00 - 18.00	1100	2.23	5.4
18.00 - 21.00	1000	2.03	4.9
21.00 - 24.00	850	1.72	4.2
24.00 - 3.00	750	1.52	3.7

Table 5.9 Calculated optimum current ratings and corresponding Voltage drop and power loss of 220kV Kotmale –Biyagama Transmission line from January to March (first quarter)

Time	Calculated ratings (A)	Voltage drop (%)	Power Loss (%)
3.00 - 6.00	750	1.42	3.7
6.00 - 9.00	726	1.47	3.5
9.00 - 12.00	950	1.93	4.6
12.00 - 15.00	900	1.83	4.4
15.00 - 18.00	1100	2.23	5.4
18.00 - 21.00	1100	2.23	5.4
21.00 - 24.00	850	1.72	4.2
24.00 - 3.00	800	1.62	3.9

Table 5.10 Calculated optimum current ratings and corresponding Voltage drop and power loss of 220kV Kotmale –Biyagama Transmission line from April to September (second and third quarters)

Time	Calculated ratings (A)	Voltage drop (%)	Power Loss (%)
3.00 - 6.00	650	1.32	3.2
6.00 - 9.00	650	1.32	3.2
9.00 - 12.00	850	1.72	4.2
12.00 - 15.00	1000	2.03	4.9
15.00 - 18.00	1000	2.03	4.9
18.00 - 21.00	987	2.00	4.8
21.00 - 24.00	800	1.62	3.9
24.00 - 3.00	750	1.52	3.7

Table 5.11 Calculated optimum current ratings and corresponding Voltage drop and power loss of 220 kV Kotmale –Biyagama Transmission line from October to December (forth quarter)

Time	Calculated ratings (A)	Voltage drop (%)	Power Loss (%)
3.00 - 6.00	700	6.17	7.4
6.00 - 9.00	700	6.17	7.4
9.00 - 12.00	800	7.05	8.5
12.00 - 15.00	850	7.50	9.0
15.00 - 18.00	850	7.50	9.0
18.00 - 21.00	750	6.61	8.0
21.00 - 24.00	750	6.61	8.0
24.00 - 3.00	800	7.05	8.5

Table 5.12 Calculated optimum current ratings and corresponding Voltage drop and power loss of 220kV Kotmale –Anuradapura Transmission line from January to April.

Time	Calculated ratings (A)	Voltage drop (%)	Power Loss (%)
3.00 - 6.00	950	8.38	10.1
6.00 - 9.00	900	7.94	9.6
9.00 - 12.00	1025	9.04	10.9
12.00 - 15.00	1100	9.07	11.7
15.00 - 18.00	1050	9.26	11.2
18.00 - 21.00	1000	8.82	10.6
21.00 - 24.00	900	7.94	9.6
24.00 - 3.00	950	8.38	10.1

Table 5.13 Calculated optimum current ratings and corresponding Voltage drop and power loss of 220kV Kotmale –Anuradapura Transmission line from May to September (second and third quarters)

Time	Calculated ratings (A)	Voltage drop (%)	Power Loss (%)
3.00 - 6.00	700	6.17	7.4
6.00 - 9.00	700	6.17	7.4
9.00 - 12.00	800	7.05	8.5
12.00 - 15.00	850	7.50	9.0
15.00 - 18.00	850	7.50	9.0
18.00 - 21.00	750	6.61	8.0
21.00 - 24.00	750	6.61	8.0
24.00 - 3.00	800	7.05	8.5

Table 5.14 Calculated optimum current ratings and corresponding Voltage drop and power loss of 220kV Kotmale –Anuradapura Transmission line from October to December.

Chapter 6

Conclusion & Recommendation

6.1 Conclusion

The calculated efficiency of both selected transmission lines are very low. Therefore the both transmission lines are being underutilized at the moment.
The study has revealed following facts related to optimum loading of the lines.

(a) 220 kV Kotmale – Biyagama Transmission line

(i.) Period from 3.00 hrs. to 9.00 hrs.
During first and fourth quarters of the year, the calculated Ampere rating of the transmission line is less than the designed values. In the second and third quarter of the year, the calculated Ampere rating is very close to the designed rating.

(ii) Period from 9.00hrs to 15.00 hrs.
Through out the year, the transmission line can be additionally loaded about 20 % more than the designed rating of the transmission line. This is an advantage as the daytime peak occurs in this time interval, which requires higher flow of current.

(iii) Period from 15.00hrs. to 21.00 hrs.
In the first and fourth quarter of the year, the transmission line needs to be operated marginally within the designed ratings. During second and third quarters of the year, the transmission line can be additionally loaded about 10 % more than the designed rating.

(iv) Period from 21.00 hrs. to 3.00 hrs.
During the first and fourth quarters of the year, the transmission line can be loaded marginally to its designed rating. From second quarter till the end of third quarter, transmission line can be additionally loaded by about 10 % more than the designed rating.

(a) 220 kV Kotmale – Anuradapura Transmission line

(i.) Period from 3.00 hrs. to 9.00 hrs.
During first and fourth quarters of the year, the calculated optimum current rating of the transmission line is 4 % less than the designed rating. In the second and third quarter of the year, the transmission line can be additionally loaded by about 25 % more than the designed rating.

(ii) Period from 9.00 hrs to 15.00 hrs.

In the first & fourth quarters and second & third quarter of the year, the transmission line can be additionally loaded about 10 % and 40 % more than the designed rating of the transmission line respectively. This is an advantage as the daytime peak occurs in this time interval, which requires higher flow of current.

(iii) Period from 15.00 hrs. to 21.00 hrs.

In the first and fourth quarters of the year, the transmission line need to be operated about 30% less than the designed rating. During second and third quarters of the year, the transmission line can be loaded to its designed rating.

(iv) Period from 21.00 hrs. to 3.00 hrs.

During the first and fourth quarters of the year, the transmission line can be additionally loaded by about 5 % more than its designed rating. From second quarter till the end of third quarter, transmission line can be additionally loaded by about 20 % more than the designed rating.

Time period	Designed Rating (Ampere)	Additional loading (%)			Total possible Ampere flow through the transmission line (Double circuit, duplex Conductor arrangement)		
		1st quarter	2nd 3rd quarter	4th quarter	1st Quarter	2nd 3rd quarter	4th quarter
3.00 – 9.00	4*726	-10	00	-10	- 290.4	00	- 290.4
9.00 – 15.00	4*726	20	20	20	580.8	580.8	580.8
15.00 – 21.00	4*987	00	10	00	00	394.8	00
21.00 – 3.00	4*726	00	10	00	00	290.4	00

Table 6.1 - Calculated optimum annual current rating of 220 kV Kotmale – Biyagama Transmission line

Time period	Designed Rating (Ampere)	Additional loading (%)			Total possible Ampere flow through the transmission line (Single circuit, Simplex Conductor arrangement)		
		1st Quarter	2nd 3rd quarter	4th quarter	1st Quarter	2nd 3rd quarter	4th quarter
3.00 – 9.00	1*726	- 4	35	- 4	-30	254.1	-30
9.00 – 15.00	1*726	10	40	10	72.6	290.4	72.6
15.00 – 21.00	1*987	- 30	00	-30	-296.1	0	-296.1
21.00 – 3.00	1*726	05	20	05	36.3	145	36.3

Table 6.2 - Calculated optimum annual current rating of 220 kV Kotmale – Anuradapura Transmission line

The voltage drop of both lines due to flow of calculated optimum current ratings are less than 10% (See table 5.15- 5.20). Therefore the calculated optimum current ratings are acceptable.

Power loss along 220 kV Kotmale – Biyagama Transmission line is less than 5.0% except during the period between 15.00hrs and 18.00hr in first, second and third quarters. The financial analysis reveals that loading of the transmission line over 2.50 % power loss is not economical. (Please see appendix E for the financial analysis. But due to unavailability of Right of Way, environmental issues, limited land resources, the operation of the line above 2.5 % power loss is justifiable. The allowable power loss along the line is required to be considered financially with other options available for transfer of power. In economic point of view, operating in the range of 5.0 % power loss is presently acceptable when compared with high cost under ground cable system, which is the only alternative due to mentioned above.

The power loss along the 220 kV Kotmale – Anuradapuara Transmission line when operating on optimum calculated ratings is always more than 7.0%. The financial analysis reveals that operating on more than 5.0 % power loss is not financially viable. Therefore, 220 kV Kotmale – Anuradapuara Transmission line is required to be operated on reduced current ratings than the calculated optimum current ratings. In order to operate the transmission line on calculated optimum ratings, it is recommended to financially analyze the options of redesigning the line for a higher voltage or replacing the conductors by low loss conductor to reduce the power loss to acceptable levels.

After considering both calculated optimum current ratings and Power loss along the transmission lines, following Optimum current ratings are recommended for the operation of two transmission lines. The same methodology proposed in the study can be extended to all the other lines to obtain the Optimum loading patterns.

Time	Recommended ratings (A)	Voltage drop (%)	Power Loss (%)
3.00 - 6.00	650	1.32	3.2
6.00 - 9.00	650	1.32	3.2
9.00 - 12.00	850	1.72	4.2
12.00 - 15.00	950	1.93	4.6
15.00 - 18.00	1000	2.03	4.9
18.00 - 21.00	1000	2.03	4.9
21.00 - 24.00	850	1.72	4.2
24.00 - 3.00	750	1.52	3.7

Table 6.3a Recommended optimum current ratings of 220kV Kotmale – Biyagama Transmission line from January to March (first quarter)

Time	Calculated ratings (A)	Voltage drop (%)	Power Loss (%)
3.00 - 6.00	750	1.42	3.7
6.00 - 9.00	726	1.47	3.5
9.00 - 12.00	950	1.93	4.6
12.00 - 15.00	900	1.83	4.4
15.00 - 18.00	1000	2.03	4.9
18.00 - 21.00	1000	2.03	4.9
21.00 - 24.00	850	1.72	4.2
24.00 - 3.00	800	1.62	3.9

Table 6.3b Recommended optimum current ratings of 220kV Kotmale – Biyagama Transmission line from April to September (second and third quarters)

Time	Calculated ratings (A)	Voltage drop (%)	Power Loss (%)
3.00 - 6.00	650	1.32	3.2
6.00 - 9.00	650	1.32	3.2
9.00 - 12.00	850	1.72	4.2
12.00 - 15.00	1000	2.03	4.9
15.00 - 18.00	1000	2.03	4.9
18.00 - 21.00	987	2.00	4.8
21.00 - 24.00	800	1.62	3.9
24.00 - 3.00	750	1.52	3.7

Table 6.3c Recommended optimum current ratings of 220 kV Kotmale – Biyagama Transmission line from October to December (fourth quarter)

Time	Recommended ratings (A)	Voltage drop (%)	Power Loss (%)
3.00 - 6.00	450	4.19	5.0
6.00 - 9.00	450	4.19	5.0
9.00 - 12.00	450	4.19	5.0
12.00 - 15.00	450	4.19	5.0
15.00 - 18.00	450	4.19	5.0
18.00 - 21.00	450	4.19	5.0
21.00 - 24.00	450	4.19	5.0
24.00 - 3.00	450	4.19	5.0

Table 6.3d Recommended optimum current ratings of 220kV Kotmale – Anuradapura Transmission line from January to Decemebr.

6.2 Discussion

Although the present practice of determination of current rating of transmission lines is easy and straightforward, it does not permit the optimum usage of the transmission lines. This problem has become worst, as there is no easy way of measuring the actual conductor operating temperature. Therefore, the transmission network is not optimally utilized most of the time leading to loss of profit to the utility by unnecessarily advancing new transmission projects. This study had revealed that the actual temperature of the conductors corresponding to the Ampere flow is significantly lower than the value calculated by the currently used model. Therefore, it is possible to allow much higher currents as recommended in tables 5.9 –5.14. Since this study was carried out for 220 kV system, measuring of the conductor temperature has to be carried out keeping considerable distance from the energized conductor using infrared camera. Therefore, it was difficult to collect the actual temperature readings during daytime.

Further, it was planned to measure the actual temperature of the conductor by allowing to flow high Ampere range along the transmission line. But due to insufficient generation and some other system constraints, this plan was abandoned.

The optimum current ratings have been recommended based on 5.0 % power loss along the transmission line. The recommended ratings can be modified depending on elaborate financial analysis on power loss along the line. The actual decision is required to be taken by the utility considering the power flow analysis on the transmission network.

The model, which was adopted for the study, was mainly based on the IEEE 738. Therefore, it is assumed that most of the formulas have been derived for American weather conditions. Validity of these equations for Sri Lankan weather condition is recommended to be studied separately.

6.3 Recommendations for Future Research

The present study was carried out for determination of current ratings of conductors, which reach the design maximum temperature, 75^0 C while exposing to the actual weather condition around the transmission line. This temperature value decides the maximum sag which determines the minimum ground clearance required for the safety of the general public. But in practice, during the construction of any transmission line, few feet more than the required ground clearance are maintained. Therefore in reality, it is possible to over load the conductor above the design maximum temperature until it reaches to actual minimum ground clearance of the constructed line. Therefore, in future, it is possible to make a study on preparing a guide line for electrical over loading of Transmission Lines which will further improve the optimum loading pattern of overhead transmission lines provided the power loss is within the acceptable limits.

While studying the design criteria adopted by the Ceylon Electricity Board, it is observed that worst temperature condition is assumed to be 7°C. This is the temperature for minimum sag and the maximum conductor tension which correspond to minimum factor of safety.

During data collection for ambient temperature around the transmission lines, it was found that only few places in Sri Lanka experience such a low temperature. In average lowest temperature in most of the areas other than central hill country is around 15°C. Therefore, the author is of the view that the above designing criteria requires reconsideration. If the designing minimum temperature can be increased to suit for the relevant area, depending on geographical zones, there is a possibility to increase the loading capacity of such transmission lines which corresponding to 75°C maximum temperature. The possibility for the above is required to be reviewed by separate study before implementation.

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APPENDIX - A : Calculation of Annual Average Charge flow

The Operation data of both 220 kV Kotmale – Biyagama and 220 kV Kotmale – Anuradhapra transmission lines were collected for the past four years. The average of current flow in four quarters were calculated to get annual charge flow along both transmission lines. The calculated values are given in Table A1 & A2.

	AMPERE X TIME				
Time	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter	Total
0.30	6686.5609	6103.5009	8419.6914	5838.6389	27048.3921
1.00	6686.5609	6217.7252	6003.0303	5851.5230	24758.8394
1.30	6686.5609	6657.9141	5376.7817	5812.5128	24533.7695
2.00	6686.5609	6821.6927	5376.7817	5812.5128	24697.5481
2.30	6949.7856	6490.4755	4165.7814	5786.6196	23392.6621
3.00	6830.3404	6490.4755	4165.7814	5786.6196	23273.2169
3.30	6830.3404	6490.4755	4165.7814	5799.7396	23286.3369
4.00	6770.7894	6191.0326	4160.3889	5826.3374	22948.5484
4.30	6352.4858	6191.0326	4846.6812	5826.3374	23216.5370
5.00	6092.4696	6269.6257	6186.8210	5826.3374	24375.2537
5.30	6432.1382	6269.6257	6397.7046	5852.5918	24952.0602
6.00	6218.1185	7151.2704	6481.6330	6095.7120	25946.7339
6.30	5768.6650	7151.2704	6896.3984	6095.7120	25912.0458
7.00	5778.4668	6850.5671	7377.8638	5866.1965	25873.0942
7.30	5505.6339	6570.7160	6789.7520	5919.6330	24785.7350
8.00	5959.3920	6968.9094	7018.3640	6559.9470	26506.6125
8.30	6010.3288	7173.4821	10647.1068	6921.9001	30752.8179
9.00	8201.2743	9249.7464	11371.0399	8139.4701	36961.5307
9.30	8041.4296	9249.7464	11371.0399	7636.4474	36298.6633
10.00	8460.5602	9173.0087	11371.0399	7880.8824	36885.4912
10.30	7221.9113	9191.9304	11371.0399	7880.8824	35665.7639
11.00	7315.3361	9191.9304	13365.3747	7055.3794	36928.0206
11.30	8259.6245	8650.1218	13169.4993	7055.3794	37134.6250
12.00	9066.0835	8391.1397	13484.4619	8972.7223	39914.4073
12.30	8899.5573	8391.1397	13384.7520	8613.6802	39289.1291
13.00	8456.6097	8535.3643	12306.3494	8068.0754	37366.3988
13.30	8456.6097	8535.3643	12406.0593	8505.4819	37903.5152
14.00	8372.5920	8715.3295	13645.3300	8505.4819	39238.7335
14.30	8227.0120	8738.3061	13645.3300	8505.4819	39116.1300
15.00	8350.7391	8738.3061	12739.7968	8479.2760	38308.1179
15.30	8242.7392	8738.3061	12739.7968	8479.2760	38200.4180
16.00	7917.5933	8738.3061	10959.1231	8552.4654	36167.4879
16.30	8025.5932	8070.5102	12150.3267	8552.4654	36798.8956
17.00	8213.2141	7985.9840	12323.4202	11686.3129	40208.9312
17.30	7931.5741	7966.2203	11411.9161	11476.3078	38786.0183
18.00	7179.7535	8032.4805	11358.6482	9550.5030	36121.3851
18.30	7179.7535	7971.4820	11241.5308	10720.2591	37113.0253
19.00	8881.0112	8049.6210	14540.2137	14322.0265	45792.8724
19.30	12690.7239	8820.3777	14404.1231	16591.1488	52506.3735

20.00	13147.9741	8325.4879	16132.9345	15575.7738	53182.1703
20.30	12669.9936	8325.4879	14816.9335	14180.0085	49992.4236
21.00	11846.7693	6709.9786	13998.1793	12410.2028	44965.1300
21.30	9640.2163	6600.2288	14072.4095	12410.2028	42723.0575
22.00	8596.9099	6851.5014	14072.4095	8597.1542	38117.9751
22.30	8727.1441	6836.3982	11427.2799	7759.9640	34750.7862
23.00	8652.1112	6510.0197	9743.6637	7774.4836	32680.2782
23.30	7833.9868	6510.0197	7471.7215	7427.2971	29243.0251
24.00	7034.6016	6540.0882	7471.7215	3194.3079	24240.7191
Total Sum					**1628861.4**

Table A1 – Average Annual charge flow of 220 kV Kotmale - Biyagama Transmission Line

time	**1st Quarter**	**2nd quarter**	**3rd Quarter**	**4th Quarter**	Total
1.00	120.62	108.20	114.4	67.85	37515.9
2.00	120.62	108.20	114.4	56.51	36484.0
3.00	120.62	108.20	114.4	56.51	36484.0
4.00	120.36	108.20	114.3	56.51	36448.8
5.00	156.61	107.36	132.0	68.92	42411.7
6.00	180.68	130.08	155.4	80.74	49896.4
7.00	181.16	116.93	149.0	86.17	48646.9
8.00	142.87	106.25	124.6	79.22	41319.7
9.00	145.08	107.69	126.4	76.64	41584.5
10.00	139.10	106.02	122.6	83.08	41124.5
11.00	147.94	104.94	126.4	86.78	42519.3
12.00	148.06	106.56	127.3	86.46	42729.3
13.00	146.27	106.56	126.4	86.68	42505.8
14.00	173.89	97.78	135.8	74.67	43975.4
15.00	173.89	101.83	137.9	81.31	45136.7
16.00	177.99	100.95	139.5	81.31	45576.2
17.00	161.33	95.53	128.4	81.74	42595.6
18.00	159.58	95.28	127.4	89.06	42989.4
19.00	241.96	152.03	197.0	133.74	66102.6
20.00	336.52	210.31	273.4	139.39	87537.2
21.00	311.86	164.31	238.1	108.43	75029.9
22.00	205.65	132.12	168.9	67.52	52382.0
23.00	154.86	101.77	128.3	62.43	40812.1
24.00	132.19	91.77	112.0	62.41	36341.0
					1148148.8

Table A2 – Average Annual charge Flow of 220 kV Kotmale -Anuradapura Transmission line

APPENDIX - B : Collected Data and Calculation of current rating

The wind velocity and the ambient temperature at Biyagama, Kotmale Mahaelukpallama and Anuradapura were collected for every three-hour interval for the past four years. The possible current ratings were calculated as described in sample calculation in Chapter 5.

Nearly 25000 dates per location were used for calculation of current rating. Only a sample page for each location is given below.

Date	Month Time	Ambient Temp. °C	Wind speed **ft/h**	Natural Convection (W/ft)	forced Conve.Heat loss Qc(W/ft)	Radiation heat loss Qr(W/ft)	Possible Current (A)
1	3.00	21.1	6500	8.64	20.17762408	5.585997	1107
	6.00	20.9	19500	8.68	39.15175906	5.601802	1407
	9.00	25	18200	7.8	34.71731138	5.271277	1326
	12.00	30	20800	6.90	33.85195557	4.849311	1292
	15.00	25.2	13650	7.83	29.0965958	5.254801	1238
	18.00	24.4	5200	7.99	16.56859837	5.320508	1023
	21.00	22.3	18850	8.40	37.37065204	5.490482	1376
	24.00	21.8	0	8.50	0	5.530422	646
2	3.00	20	0	8.86	0	5.67253	662
	6.00	20.3	14300	8.80	32.86413427	5.649026	1318
	9.00	23.5	16250	8.17	33.40815529	5.393797	1313
	12.00	28.6	16900	7.17	30.81649566	4.96959	1250
	15.00	30.5	15600	6.80	28.16877867	4.805948	1199
	18.00	25.8	12350	7.71	27.07064009	5.205173	1203
	21.00	23	16250	8.26	33.73250631	5.434225	1320
	24.00	21.1	14950	8.64	33.2588117	5.585997	1320
3	3.00	19.5	5200	8.97	18.17306738	5.711543	1079
	6.00	18.4	3250	9.19	13.97911557	5.796669	1005
	9.00	21.8	29900	8.50	49.75624444	5.530422	1546
	12.00	25.9	29250	7.69	45.32003764	5.196872	1472
	15.00	26.7	26650	7.54	42.15981595	5.130168	1426
	18.00	25.1	12350	7.85	27.45579147	5.263043	1212
	21.00	22.1	9100	8.44	24.23336674	5.506482	1172
	24.00	20.8	3250	8.70	13.38636155	5.609693	979
4	3.00	19.5	0	8.97	0	5.711543	666
	6.00	18	3250	9.27	14.0779079	5.827386	1009
	9.00	21.9	12350	8.48	29.21648351	5.52245	1255

Table B1 – Data collected and calculation of current ratings at Kotmale for January 2004 (sample sheet)

Date	Month Time	Ambient Temp. ^oC	wind speed **ft/h**	Natural convection (W/ft)	forced Convection Heat loss Qc(W/ft)	Radiation heat loss Qr(W/ft)	Possible Current (A)
1	3.00	26	7200	7.67	19.50	5.19	1070
	6.00	22.6	7200	8.34	20.86	5.47	1111
	9.00	24.8	7200	7.91	19.98	5.29	1085
	12.00	30.4	7200	6.82	17.75	4.81	1013
	15.00	31.5	19500	6.61	31.48	4.72	1248
	18.00	29.8	26000	6.94	38.87	4.87	1367
	21.00	27.2	40950	7.44	53.99	5.09	1580
	24.00	25	0	7.87	0.00	5.27	618
2	3.00	24.5	19500	7.97	36.55	5.31	1355
	6.00	24	13000	8.07	28.94	5.35	1241
	9.00	25.4	13000	7.79	28.14	5.24	1222
	12.00	30.2	13650	6.86	26.18	4.83	1167
	15.00	30.5	19500	6.80	32.20	4.81	1264
	18.00	27.7	29250	7.34	43.66	5.05	1443
	21.00	26.3	22100	7.61	37.99	5.16	1369
	24.00	25.1	23400	7.85	40.29	5.26	1406
3	3.00	24.6	13000	7.95	28.60	5.30	1233
	6.00	26.2	16250	7.63	31.66	5.17	1274
	9.00	25	0	7.87	0.00	5.27	618
	12.00	28	0	7.28	0.00	5.02	591
	15.00	28.5	13000	7.19	26.38	4.98	1179
	18.00	28	39650	7.28	52.07	5.02	1553
	21.00	25.4	16250	7.79	32.18	5.24	1286
	24.00	24	14950	8.07	31.47	5.35	1281
4	3.00	24.6	50700	7.95	64.71	5.30	1718
	6.00	24.2	0	8.03	0.00	5.34	625
	9.00	26.4	0	7.59	0.00	5.16	606
	12.00	29.4	29250	7.01	42.09	4.90	1415
	15.00	31	14950	6.71	27.15	4.76	1180
	18.00	24.9	29900	7.89	46.86	5.28	1497
	21.00	26.8	0	7.52	0.00	5.12	602
	24.00	25.6	0	7.75	0.00	5.22	613

Table B2 - Data collected and calculation of current ratings at Biyagama for March 2000 (sample sheet)

Date	Month Time	Ambient Temp. ^{o}C	wind speed **ft/h**	Natural convection (W/ft)	forced Convection Heat loss Qc(W/ft)	Radiation heat loss Qr(W/ft)	Possible Current (A)
1	3.00	21.9	0	8.48	0	5.5225	646
	6.00	21.6	3250	8.54	13.18877688	5.5463	971
	9.00	23.3	4550	8.20	15.62538146	5.4100	1010
	12.00	28	6500	7.28	17.59458872	5.0206	1023
	15.00	29	9750	7.09	21.9631106	4.9354	1099
	18.00	26.4	3250	7.59	12.00326884	5.1552	918
	21.00	23.8	0	8.11	0	5.3694	629
	24.00	22.6	0	8.34	0	5.4664	639
2	3.00	22	0	8.46	0	5.5145	645
	6.00	22	0	8.46	0	5.5145	645
	9.00	24.6	0	7.95	0	5.3041	622
	12.00	26.6	19500	7.56	35.02671236	5.1385	1324
	15.00	26	3250	7.67	12.10206118	5.1886	922
	18.00	24.2	0	8.03	0	5.3369	625
	21.00	23.6	0	8.15	0	5.3857	631
	24.00	23	0	8.26	0	5.4342	636
3	3.00	23.2	0	8.22	0	5.4181	634
	6.00	23.2	0	8.22	0	5.4181	634
	9.00	24.8	4550	7.91	15.17203384	5.2877	993
	12.00	24.6	3900	7.95	13.88681175	5.3041	968
	15.00	24	4550	8.07	15.41381924	5.3532	1002
	18.00	24	3900	8.07	14.05213093	5.3532	975
	21.00	23.4	0	8.18	0	5.4019	633
	24.00	23.2	0	8.22	0	5.4181	634
4	3.00	28.8	0	7.13	0	4.9525	583
	6.00	23.4	0	8.18	0	5.4019	633
	9.00	23.8	0	8.11	0	5.3694	629
	12.00	25.5	1950	7.77	8.998273996	5.2300	856
	15.00	26.7	8450	7.54	21.16383678	5.1302	1096
	18.00	24.9	3900	7.89	13.80415215	5.2795	965
	21.00	24.1	3250	8.05	12.57132478	5.3450	944
	24.00	23.8	0	8.11	0	5.3694	629

Table B3 Data collected and Calculation of current ratings at Anuradapura for January 2000 (smple sheet)

Date	Month Time	Ambient Temp. °C	wind speed **ft/h**	Natural Convection (W/ft)	forced Convection Heat loss Qc(W/ft)	Radiation heat loss Qr(W/ft)	Possible Current (A)
1	3.00	27	39000	7.48	52.6518	5.105016	1564
	6.00	29.4	45500	7.01	54.86621	4.901064	1584
	9.00	33.1	32500	6.31	41.19811	4.576983	1388
	12.00	34.2	26000	6.10	35.08952	4.478339	1293
	15.00	31.6	26000	6.59	37.32562	4.709793	1337
	18.00	28.2	13000	7.24	26.55493	5.003649	1183
	21.00		0	13.06	0	7.084013	812
	24.00		0	13.06	0	7.084013	812
2	3.00	26.5	32500	7.57	47.68755	5.146894	1502
	6.00	29.4	39000	7.01	50.01921	4.901064	1522
	9.00	33.2	19500	6.29	30.25034	4.568059	1221
	12.00	33.9	19500	6.16	29.74376	4.505347	1209
	15.00	32	13000	6.52	24.39876	4.674568	1128
	18.00	28.6	19500	7.17	33.57933	4.96959	1294
	21.00		0	13.06	0	7.084013	812
	24.00		0	13.06	0	7.084013	812
3	3.00	26.6	26000	7.56	41.6258	5.138535	1419
	6.00	29.4	39000	7.01	50.01921	4.901064	1522
	9.00	32	6500	6.52	16.09718	4.674568	971
	12.00	33.7	45500	6.20	49.69242	4.523309	1502
	15.00	31	32500	6.71	43.26293	4.762371	1425
	18.00	26.8	26000	7.52	41.45379	5.121792	1416
	21.00		0	13.06	0	7.084013	812
	24.00		0	13.06	0	7.084013	812
4	3.00	26.6	19500	7.56	35.02671	5.138535	1324
	6.00	29.2	13000	7.05	25.98751	4.918246	1169
	9.00	32.6	13000	6.40	24.05831	4.62147	1119
	12.00	34	32500	6.14	40.31319	4.496354	1371
	15.00	27.6	19500	7.36	34.30302	5.054484	1309
	18.00	26.6	13000	7.56	27.46279	5.138535	1205
	21.00		0	13.06	0	7.084013	812
	24.00		0	13.06	0	7.084013	812

Table B4 – Data collected and calculation of current ratings at Mahaelukpallama for May 2000 (sample sheet)

APPENDIX - C : Optimum current ratings

Calculated optimum current ratings based on criteria on paragraph 5.5 are given in Table C1 through C12.

	12.00 -15.00		
Range (A)	Freq.	Prob.	Cum. Prob.
Higher than 1300	0	0.00	0.00
1201 - 1300	6	0.19	0.19
1151 - 1200	7	0.22	0.41
1101 -1150	4	0.13	0.53
1051 - 1100	2	0.06	0.59
1001 - 1050	7	0.22	0.81
976- 1000	1	0.03	0.84
951 -975	1	0.03	0.88
901 -950	1	0.03	0.91
801 -900	2	0.06	0.97
700 - 800	0	0.00	0.97
700 - 800	0	0.00	0.97
Total events	31		

	15.00 18.00		
Range (A)	Freq.	Prob.	Cum. Prob.
1250 - 1300	15	0.5	0.50
1201 - 1250	7	0.23	0.73
1151 - 1200	4	0.13	0.87
1101 -1150	1	0.03	0.90
1051 - 1100	1	0.03	0.93
1001 - 1050	0	0.00	0.93
976- 1000	3	0.10	1.03
951 -975	0	0.00	1.03
901 -950	0	0.00	1.03
801 -900	0	0.00	1.03
700 - 800	0	0.00	1.03
700 - 800	0	0.00	1.03
Total events	31		

	18.00- 21.00		
Range (A)	Freq.	Prob.	Cum. Prob.
1250 - 1300	2	0.07	0.07
1201 - 1250	3	0.10	0.17
1151 - 1200	4	0.13	0.30
1101 -1150	6	0.20	0.50
1051 - 1100	8	0.27	0.77
1001 - 1050	0	0.00	0.77
976- 1000	4	0.13	0.90
951 -975	3	0.10	1.00
901 -950	1	0.03	1.04
801 -900	0	0.00	1.04
700 - 800	0	0.00	1.04
700 - 800	0	0.00	1.04
Total events	31		

	21.00 -24.00		
Range (A)	Freq.	Prob.	Cum. Prob.
1150	2	0.06	0.06
1101 - 1150	3	0.10	0.16
1051 - 1100	2	0.06	0.22
1001 - 1050	5	0.16	0.38
951 - 1000	8	0.26	0.64
901 - 950	1	0.03	0.67
851 - 900	3	0.10	0.77
801 - 850	4	0.13	0.90
751 - 800	3	0.10	1.00
701 - 750	0	0.00	1.00
651 - 700	0	0.00	1.00
600 - 650	0	0.00	1.00
Total events	31		

Table C1 - Probability Distribution of possible current ratings of 220 kV Kotmale - Biyagama Transmission Line from January to March on three hourly basis

	6.00 - 9.00		
Range (A)	Freq.	Prob.	Cum. Prob.
1200	0	0.00	0.00
1151 - 1200	0	0.00	0.00
1051 - 1100	0	0.00	0.00
1001 - 1050	0	0.00	0.00
951 - 1000	1	0.03	0.03
901 - 950	4	0.13	0.16
851 - 900	2	0.06	0.23
801 - 850	4	0.13	0.35
751 - 800	7	0.23	0.58
701 - 750	7	0.23	0.81
651 - 700	1	0.03	0.84
600 - 650	5	0.16	1.00
Total events	31		

	9.00 - 12.00		
Range (A)	Freq.	Prob.	Cum. Prob.
1151	2	0.06	0.06
1101 - 1150	3	0.10	0.16
1051 - 1100	3	0.10	0.25
1001 - 1050	3	0.10	0.35
951 - 1000	5	0.16	0.51
901 - 950	7	0.23	0.74
851 - 900	4	0.13	0.87
801 - 850	2	0.06	0.93
751 - 800	0	0.00	0.93
701 - 750	2	0.06	1.00
651 - 700	0	0.00	1.00
600 - 650	0	0.00	1.00
Total events	31		

	24.00 -3.00		
Range (A)	Freq.	Prob.	Cum. Prob.
1200	0	0.00	0.00
1101 - 1150	1	0.03	0.03
1051 - 1100	2	0.06	0.10
1001 - 1050	0	0.00	0.10
951 - 1000	4	0.13	0.23
901 - 950	5	0.16	0.39
851 - 900	3	0.10	0.48
801 - 850	7	0.23	0.71
751 - 800	4	0.13	0.84
701 - 750	3	0.10	0.94
651 - 700	0	0.00	0.94
600 - 650	2	0.06	1.00
Total events	31		

	3.00 - 6.00		
Range (A)	Freq.	Prob.	Cum. Prob.
1200	0	0.00	0.00
1151 - 1200	0	0.00	0.00
1051 - 1100	1	0.03	0.03
1001 - 1050	1	0.03	0.06
951 - 1000	1	0.03	0.10
901 - 950	2	0.06	0.16
851 - 900	7	0.23	0.39
801 - 850	4	0.13	0.52
751 - 800	4	0.13	0.65
701 - 750	3	0.10	0.74
651 - 700	1	0.03	0.77
600 - 650	7	0.23	1.00
Total events	31		

Table C2 - Probability Distribution of possible current ratings of 220 kV Kotmale - Biyagama Transmission Line from January to March on three hourly basis

	3.00 - 6.00		
Range (A)	Freq.	Prob.	Cum. Prob.
1200	0	0.00	0.00
1151 - 1200	0	0.00	0.00
1051 - 1100	0	0.00	0.00
1001 - 1050	1	0.03	0.03
951 - 1000	4	0.13	0.16
901 - 950	2	0.06	0.23
851 - 900	10	0.32	0.55
801 - 850	3	0.10	0.65
751 - 800	5	0.16	0.81
701 - 750	4	0.13	0.94
651 - 700	1	0.03	0.97
600 - 650	1	0.03	1.00
Total events	31		

	6.00 - 9.00		
Range (A)	Freq.	Prob.	Cum. Prob.
1200	0	0.00	0.00
1151 - 1200	0	0.00	0.00
1051 - 1100	0	0.00	0.00
1001 - 1050	2	0.06	0.06
951 - 1000	3	0.10	0.16
901 - 950	3	0.10	0.26
851 - 900	7	0.23	0.48
801 - 850	4	0.13	0.61
751 - 800	3	0.10	0.71
701 - 750	5	0.16	0.87
651 - 700	2	0.06	0.94
600 - 650	2	0.06	1.00
Total events	31		

	9.00 - 12.00		
Range (A)	Freq.	Prob.	Cum. Prob.
1200	0	0.00	0.00
1101 - 1150	2	0.06	0.06
1051 - 1100	10	0.32	0.39
1001 - 1050	7	0.23	0.61
951 - 1000	5	0.16	0.77
901 - 950	4	0.13	0.90
851 - 900	1	0.03	0.94
801 - 850	1	0.03	0.97
751 - 800	0	0.00	0.97
701 - 750	0	0.00	0.97
651 - 700	0	0.00	0.97
600 - 650	1	0.03	1.00
Total events	31		

	12.00 -15.00		
Range (A)	Freq.	Prob.	Cum. Prob.
1200	11	0.35	0.35
1101 - 1150	7	0.23	0.58
1051 - 1100	3	0.10	0.67
1001 - 1050	3	0.10	0.77
951 - 1000	2	0.06	0.83
901 - 950	1	0.03	0.87
851 - 900	2	0.06	0.93
801 - 850	1	0.03	0.96
751 - 800	0	0.00	0.96
701 - 750	0	0.00	0.96
651 - 700	0	0.00	0.96
600 - 650	1	0.03	1.00
Total events	31		

Table C3 - Probability Distribution of possible current ratings of 220 kV Kotmale – Biyagama Transmission Line from April to September on three hourly basis

	15.00 - 8.00		
Range (A)	Freq.	Prob.	Cum. Prob.
1250 -	11	0.35	0.35
1201 - 1250	6	0.19	0.54
1151 - 1200	3	0.10	0.64
1101 - 1150	4	0.13	0.77
1051 - 1100	4	0.13	0.90
1001 - 1050	0	0.00	0.90
951 - 1000	1	0.03	0.93
901 - 950	0	0.00	0.93
851 - 900	1	0.03	0.96
801 - 850	0	0.00	0.96
751 - 800	0	0.00	0.96
701 - 750	0	0.00	0.96
651 - 700	0	0.00	0.96
600 - 650	1	0.03	1.00
Total events	31		

	18.00 - 21.00		
Range (A)	Freq.	Prob.	Cum. Prob.
1250 -	1	0.03	0.35
1201 - 1250	0	0.00	0.35
1151 - 1200	3	0.10	0.45
1101 - 1150	8	0.26	0.70
1051 - 1100	7	0.23	0.93
1001 - 1050	1	0.03	0.96
951 - 1000	5	0.16	1.12
901 - 950	2	0.06	1.19
851 - 900	2	0.06	1.25
801 - 850	0	0.00	1.25
751 - 800	1	0.03	1.29
701 - 750	0	0.00	1.29
651 - 700	0	0.00	1.29
600 - 650	1	0.03	1.32
Total events	31		

	21.00 -24.00		
Range (A)	Freq.	Prob.	Cum. Prob.
1200	0	0.00	0.00
1101 - 1150	2	0.06	0.06
1051 - 1100	2	0.06	0.13
1001 - 1050	3	0.10	0.23
951 - 1000	9	0.29	0.52
901 - 950	5	0.16	0.68
851 - 900	4	0.13	0.81
801 - 850	3	0.10	0.90
751 - 800	0	0.00	0.90
701 - 750	0	0.00	0.90
651 - 700	2	0.06	0.97
600 - 650	1	0.03	1.00
Total events	31		

	24.00 -3.00		
Range (A)	Freq.	Prob.	Cum. Prob.
1150	0	0.00	0.06
1101 - 1150	0	0.00	0.06
1051 - 1100	2	0.06	0.12
1001 - 1050	5	0.16	0.29
951 - 1000	1	0.03	0.32
901 - 950	1	0.03	0.35
851 - 900	6	0.19	0.54
801 - 850	8	0.26	0.80
751 - 800	6	0.16	0.96
701 - 750	1	0.03	1.00
651 - 700	1	0.03	1.03
600 - 650	1	0.03	1.06
Total events	31		

Table C4 – Probability Distribution of possible current ratings of 220 kV Kotmale - Biyagama Transmission Line from April to September on three hourly basis

	3.00 - 6.00		
Range (A)	Freq.	Prob.	Cum. Prob.
1200	0	0.00	0.00
1151 - 1200	1	0.03	0.03
1051 - 1100	1	0.03	0.06
1001 - 1050	1	0.03	0.10
951 - 1000	2	0.06	0.16
901 - 950	6	0.19	0.35
851 - 900	0	0.00	0.35
801 - 850	6	0.19	0.55
751 - 800	5	0.16	0.71
701 - 750	2	0.06	0.77
651 - 700	0	0.00	0.77
600 - 650	7	0.23	1.00
Total events	31		

	6.00 - 9.00		
Range (A)	Freq.	Prob.	Cum. Prob.
1200	0	0.00	0.00
1151 - 1200	0	0.00	0.00
1051 - 1100	1	0.03	0.03
1001 - 1050	0	0.00	0.03
951 - 1000	1	0.03	0.06
901 - 950	6	0.19	0.26
851 - 900	0	0.00	0.26
801 - 850	3	0.10	0.35
751 - 800	7	0.23	0.58
701 - 750	7	0.23	0.81
651 - 700	1	0.03	0.84
600 - 650	5	0.16	1.00
Total events	31		

	900 - 12.00		
Range (A)	Freq.	Prob.	Cum. Prob.
1101 -1150	6	0.19	0.19
1051 - 1100	1	0.03	0.23
1001 - 1050	4	0.13	0.35
976- 1000	5	0.16	0.52
951 -975	3	0.10	0.61
901 -950	4	0.13	0.74
851 - 900	3	0.10	0.84
801 - 850	2	0.06	0.90
751 - 800	2	0.06	0.97
701 - 750	1	0.03	1.00
651 - 700	0	0.00	1.00
650	0	0.00	1.00
Total events	31		

	12.00 - 15.00		
Range (A)	Freq.	Prob.	Cum. Prob.
1351	0	0.00	0.00
1300 - 1350	0	0.00	0.00
1251 - 1300	2	0.06	0.06
1201 - 1251	3	0.10	0.16
1151 - 1200	7	0.23	0.39
1101 - 1150	7	0.23	0.61
1051 - 1100	3	0.10	0.71
1001 -1050	4	0.13	0.84
951 - 1000	4	0.13	0.97
901 -950	0	0.00	0.97
851 - 900	1	0.03	1.00
800 - 850	0	0.00	1.00
Total events	31		

Table C5 – Probability distribution of possible current ratings of 220 kV Kotmale - Biyagama Transmission Line from October to December on three hourly basis

	15.00 - 18.00		
Range (A)	Freq.	Prob.	Cum. Prob.
1351	2	0.06	0.06
1301 - 1350	6	0.19	0.25
1276 - 1300	1	0.03	0.29
1251 - 1275	6	0.19	0.48
1201 - 1250	4	0.13	0.61
1151 - 1200	3	0.10	0.71
1051 - 1150	3	0.10	0.80
1001 - 1050	2	0.06	0.87
951 - 1000	3	0.10	0.96
901 - 950	0	0.00	0.96
851 - 900	1	0.03	1.00
800 - 850	0	0.00	1.00
Total events	31		

	18.00 - 21.00		
Range (A)	Freq.	Prob.	Cum. Prob.
1351	0	0.00	0.06
1301 - 1350	1	0.03	0.09
1276 - 1300	0	0.00	0.09
1251 - 1275	2	0.06	0.16
1201 - 1250	1	0.03	0.19
1151 - 1200	2	0.06	0.25
1051 - 1150	9	0.29	0.54
1001 - 1050	3	0.10	0.64
951 - 1000	5	0.16	0.80
901 - 950	6	0.19	1.00
851 - 900	0	0.00	1.00
800 - 850	2	0.06	1.06
Total events	31		

	21.00 -24.00		
Range (A)	Freq.	Prob.	Cum. Prob.
1200	5	0.16	0.16
1101 - 1150	2	0.06	0.22
1051 - 1100	6	0.19	0.42
1001 - 1050	1	0.03	0.45
951 - 1000	3	0.10	0.55
901 - 950	2	0.06	0.61
851 - 900	2	0.06	0.68
801 - 850	3	0.10	0.77
751 - 800	7	0.23	1.00
701 - 750	0	0.00	1.00
651 - 700	0	0.00	1.00
600 - 650	0	0.00	1.00
Total events	31		

	24.00 -3.00		
Range (A)	Freq.	Prob.	Cum. Prob.
1150	1	0.03	0.03
1101 - 1150	2	0.06	0.09
1051 - 1100	3	0.10	0.19
1001 - 1050	1	0.03	0.22
951 - 1000	4	0.13	0.35
901 - 950	3	0.10	0.45
851 - 900	5	0.16	0.61
801 - 850	1	0.03	0.64
751 - 800	5	0.16	0.80
701 - 750	4	0.13	0.93
651 - 700	0	0.00	0.93
600 - 650	2	0.06	1.00
Total events	31		

Table C6 - Probability distribution of possible current ratings of 220 kV Kotmale - Biyagama Transmission Line from October to December on three hourly basis

Range (A)	3.00 - 6.00 Freq.	Prob.	Cum. Prob.
1200	0	0.00	0.00
1151 - 1200	0	0.00	0.00
1051 - 1100	0	0.00	0.00
1001 - 1050	0	0.00	0.00
951 - 1000	0	0.00	0.00
901 - 950	1	0.03	0.03
851 - 900	3	0.10	0.13
801 - 850	4	0.13	0.26
751 - 800	13	0.42	0.68
701 - 750	5	0.16	0.84
651 - 700	5	0.16	1.00
600 - 650	0	0.00	1.00
Total events	31		

Range (A)	6.00 - 9.00 Freq.	Prob.	Cum. Prob.
1200	0	0.00	0.00
1151 - 1200	0	0.00	0.00
1051 - 1100	0	0.00	0.00
1001 - 1050	0	0.00	0.00
951 - 1000	0	0.00	0.00
901 - 950	0	0.00	0.00
851 - 900	0	0.00	0.00
801 -900	5	0.16	0.16
751 - 800	11	0.35	0.52
701 - 750	8	0.26	0.77
651 - 700	7	0.23	1.00
600 - 650	0	0.00	1.00
Total events	31		

Range (A)	9.00 - 12.00 Freq.	Prob.	Cum. Prob.
1200	0	0.00	0.00
1101 - 1150	2	0.06	0.06
1051 - 1100	0	0.00	0.06
1001 - 1050	6	0.19	0.26
951 - 1000	2	0.06	0.32
901 - 950	5	0.16	0.48
851 - 900	8	0.26	0.74
801 - 850	4	0.13	0.87
751 - 800	3	0.10	0.97
701 - 750	1	0.03	1.00
651 - 700	0	0.00	1.00
600 - 650	0	0.00	1.00
Total events	31		

Range (A)	12.00 -15.00 Freq.	Prob.	Cum. Prob.
1201 -	1	0.03	0.03
1150 -1200	2	0.06	0.09
1101 - 1150	4	0.13	0.22
1051 - 1100	6	0.19	0.42
1001 - 1050	2	0.06	0.48
951 - 1000	5	0.16	0.64
901 - 950	3	0.10	0.74
851 - 900	4	0.13	0.87
801 - 850	3	0.10	0.97
751 - 800	1	0.03	1.00
701 - 750	0	0.00	1.00
651 - 700	0	0.00	1.00
600 - 650	0	0.00	1.00
Total events	30		

Table C7 – Probability distribution of possible current ratings of 220 kV Kotmale Anuradhapura Transmission Line from January to April on three hourly basis

	15.00 - 18.00		
Range (A)	Freq.	Prob.	Cum. Prob.
1250 -	1	0.03	0.03
1201 - 1250	0	0.00	0.03
1151 - 1200	1	0.03	0.06
1101 - 1150	2	0.06	0.13
1051 - 1100	4	0.13	0.26
1001 - 1050	9	0.29	0.55
951 - 1000	4	0.13	0.68
901 - 950	4	0.13	0.80
851 - 900	2	0.06	0.87
801 - 850	3	0.10	0.97
751 - 800	1	0.03	1.00
701 - 750	0	0.00	1.00
651 - 700	0	0.00	1.00
600 - 650	0	0.00	1.00
total events	31		

	18.00 - 21.00		
Range (A)	Freq.	Prob.	Cum. Prob.
1250 -	0	0.00	0
1201 - 1250	0	0.00	0.00
1151 - 1200	0	0.00	0.00
1101 - 1150	0	0.00	0.00
1051 - 1100	1	0.03	0.03
1001 - 1050	3	0.10	0.13
951 - 1000	6	0.19	0.32
901 - 950	5	0.16	0.48
851 - 900	6	0.19	0.68
801 - 850	4	0.13	0.81
751 - 800	2	0.06	0.87
701 - 750	1	0.03	0.90
651 - 700	2	0.06	0.97
600 - 650	1	0.03	1.00
Total events	31		

	21.00 -24.00		
Range (A)	Freq.	Prob.	Cum. Prob.
1200	0	0.00	0.00
1101 - 1150	0	0.00	0.00
1051 - 1100	1	0.03	0.03
1001 - 1050	1	0.03	0.06
951 - 1000	1	0.03	0.10
901 - 950	6	0.19	0.29
851 - 900	6	0.19	0.48
801 - 850	9	0.29	0.77
751 - 800	3	0.10	0.87
701 - 750	3	0.10	0.97
651 - 700	1	0.03	1.00
600 - 650	0	0.00	1.00
Total events	31		

	24.00 -3.00		
Range (A)	Freq.	Prob.	Cum. Prob.
1150	0	0.00	0.10
1101 - 1150	0	0.00	0.10
1051 - 1100	0	0.00	0.10
1001 - 1050	0	0.00	0.10
951 - 1000	0	0.00	0.10
901 - 950	3	0.10	0.20
851 - 900	6	0.19	0.39
801 - 850	7	0.23	0.62
751 - 800	10	0.32	0.94
701 - 750	3	0.10	1.04
651 - 700	2	0.06	1.10
600 - 650	0	0.00	1.10
Total events	31		

Table C8 – Probability distribution of possible current ratings of 220 kV Kotmale Anuradhapura Transmission Line from January to April on three hourly basis

Range (A)	3.00 - 6.00 Freq.	Prob.	Cum. Prob.
1200	0	0.00	0.00
1151 - 1200	5	0.16	0.16
1051 - 1100	6	0.19	0.35
1001 - 1050	4	0.13	0.48
951 - 1000	5	0.16	0.65
901 - 950	8	0.26	0.90
851 - 900	2	0.06	0.97
801 - 850	1	0.03	1.00
751 - 800	0	0.00	1.00
701 - 750	0	0.00	1.00
651 - 700	0	0.00	1.00
600 - 650	0	0.00	1.00
Total events	31		

Range (A)	6.00 - 9.00 Freq.	Prob.	Cum. Prob.
1200	0	0.00	0.00
1151 - 1200	1	0.03	0.03
1051 - 1100	8	0.26	0.29
1001 - 1050	4	0.13	0.42
951 - 1000	8	0.26	0.68
901 - 950	5	0.16	0.84
851 - 900	5	0.16	1.00
801 - 850	0	0.00	1.00
751 - 800	0	0.00	1.00
701 - 750	0	0.00	1.00
651 - 700	0	0.00	1.00
600 - 650	0	0.00	1.00
Total events	31		

Range (A)	9.00 - 12.00 Freq.	Prob.	Cum. Prob.
1200	7	0.23	0.23
1101 - 1150	10	0.32	0.55
1051 - 1100	7	0.23	0.78
1001 - 1050	4	0.13	0.91
951 - 1000	0	0.00	0.91
901 - 950	2	0.06	0.97
851 - 900	0	0.00	0.97
801 - 850	1	0.03	1.00
751 - 800	0	0.00	1.00
701 - 750	0	0.00	1.00
651 - 700	0	0.00	1.00
600 - 650	0	0.00	1.00
Total events	31		

Range (A)	12.00 -15.00 Freq.	Prob.	Cum. Prob.
1201 -	13	0.42	0.42
1150 -1200	7	0.23	0.65
1101 - 1150	4	0.13	0.77
1051 - 1100	4	0.13	0.90
1001 - 1050	1	0.03	0.94
951 - 1000	1	0.03	0.97
901 - 950	1	0.03	1.00
851 - 900	0	0.00	1.00
801 - 850	0	0.00	1.00
751 - 800	0	0.00	1.00
701 - 750	0	0.00	1.00
651 - 700	0	0.00	1.00
600 - 650	0	0.00	1.00

Table C9 – Probability distribution of possible current ratings of 220 kV Kotmale Anuradhapura Transmission Line from May to September on three hourly basis

Range (A)	15.00 - 18.00 Freq.	Prob.	Cum. Prob.
1250 -	5	0.16	0.16
1201 - 1250	10	0.32	0.48
1151 - 1200	8	0.26	0.74
1101 - 1150	4	0.13	0.87
1051 - 1100	0	0.00	0.87
1001 - 1050	3	0.10	0.97
951 - 1000	0	0.00	0.97
901 - 950	0	0.00	0.97
851 - 900	1	0.03	1.00
801 - 850	0	0.00	1.00
751 - 800	0	0.00	1.00
701 - 750	0	0.00	1.00
651 - 700	0	0.00	1.00
600 - 650	0	0.00	1.00
Total events	31		

Range (A)	18.00 - 21.00 Freq.	Prob.	Cum. Prob.
1250 -	3	0.10	0.1
1201 - 1250	3	0.10	0.20
1151 - 1200	8	0.26	0.45
1101 - 1150	3	0.10	0.55
1051 - 1100	2	0.06	0.62
1001 - 1050	5	0.16	0.78
951 - 1000	5	0.16	0.94
901 - 950	0	0.00	0.94
851 - 900	1	0.03	0.97
801 - 850	1	0.03	1.00
751 - 800	0	0.00	1.00
701 - 750	0	0.00	1.00
651 - 700	0	0.00	1.00
600 - 650	0	0.00	1.00
Total events	31		

Range (A)	21.00 - 24.00 Freq.	Prob.	Cum. Prob.
1200	5	0.16	0.16
1101 - 1150	1	0.03	0.19
1051 - 1100	4	0.13	0.32
1001 - 1050	4	0.13	0.45
951 - 1000	6	0.19	0.64
901 - 950	4	0.13	0.77
851 - 900	6	0.19	0.97
801 - 850	1	0.03	1.00
751 - 800	0	0.00	1.00
701 - 750	0	0.00	1.00
651 - 700	0	0.00	1.00
600 - 650	0	0.00	1.00
Total events	31		

Range (A)	24.00 -3.00 Freq.	Prob.	Cum. Prob.
1150	3	0.10	0.10
1101 - 1150	2	0.06	0.16
1051 - 1100	6	0.19	0.36
1001 - 1050	7	0.23	0.58
951 - 1000	5	0.16	0.75
901 - 950	5	0.16	0.91
851 - 900	3	0.10	1.00
801 - 850	0	0.00	1.00
751 - 800	0	0.00	1.00
701 - 750	0	0.00	1.00
651 - 700	0	0.00	1.00
600 - 650	0	0.00	1.00
Total events	31		

Table C10 – Probability distribution of possible current ratings of 220 kV Kotmale Anuradhapura Transmission Line from May to September on three hourly basis

	3.00 - 6.00		
Range (A)	Freq.	Prob.	Cum. Prob.
1200	0	0.00	0.00
1151 - 1200	0	0.00	0.00
1051 - 1100	0	0.00	0.00
1001 - 1050	0	0.00	0.00
951 - 1000	0	0.00	0.00
901 - 950	1	0.03	0.03
851 - 900	3	0.10	0.13
801 - 850	4	0.13	0.26
751 - 800	13	0.42	0.68
701 - 750	5	0.16	0.84
651 - 700	6	0.16	1.00
600 - 650	0	0.00	1.00
Total events	31		

	6.00 - 9.00		
Range (A)	Freq.	Prob.	Cum. Prob.
1200	0	0.00	0.00
1151 - 1200	0	0.00	0.00
1051 - 1100	0	0.00	0.00
1001 - 1050	0	0.00	0.00
951 - 1000	0	0.00	0.00
901 - 950	0	0.00	0.00
851 - 900	0	0.00	0.00
801 -900	5	0.16	0.16
751 - 800	11	0.35	0.52
701 - 750	8	0.26	0.77
651 - 700	7	0.23	1.00
600 - 650	0	0.00	1.00
Total events	31		

	9.00 - 12.00		
Range (A)	Freq.	Prob.	Cum. Prob.
1200	0	0.00	0.00
1101 - 1150	2	0.06	0.06
1051 - 1100	0	0.00	0.06
1001 - 1050	6	0.19	0.26
951 - 1000	2	0.06	0.32
901 - 950	5	0.16	0.48
851 - 900	8	0.26	0.74
801 - 850	4	0.13	0.87
751 - 800	3	0.10	0.97
701 - 750	1	0.03	1.00
651 - 700	0	0.00	1.00
600 - 650	0	0.00	1.00
total events	31		

	12.00 -15.00		
Range (A)	Freq.	Prob.	Cum. Prob.
1201 -	1	0.03	0.03
1150 -1200	2	0.06	0.09
1101 - 1150	4	0.13	0.22
1051 - 1100	6	0.19	0.42
1001 - 1050	2	0.06	0.48
951 - 1000	5	0.16	0.64
901 - 950	3	0.10	0.74
851 - 900	4	0.13	0.87
801 - 850	3	0.10	0.97
751 - 800	1	0.03	1.00
701 - 750	0	0.00	1.00
651 - 700	0	0.00	1.00
600 - 650	0	0.00	1.00
total events	30		

Table C11 – Probability distribution of possible current ratings of 220 kV Kotmale Anuradhapura Transmission Line from October to December on three hourly basis

	15.00 - 18.00		
Range (A)	Freq.	Prob.	Cum. Prob.
1250 -	1	0.03	0.03
1201 - 1250	0	0.00	0.03
1151 - 1200	1	0.03	0.06
1101 - 1150	2	0.06	0.13
1051 - 1100	4	0.13	0.26
1001 - 1050	9	0.29	0.55
951 - 1000	4	0.13	0.68
901 - 950	4	0.13	0.80
851 - 900	2	0.06	0.87
801 - 850	3	0.10	0.97
751 - 800	1	0.03	1.00
701 - 750	0	0.00	1.00
651 - 700	0	0.00	1.00
600 - 650	0	0.00	1.00
Total events	31		

	18.00 - 21.00		
Range (A)	Freq.	Prob.	Cum. Prob.
1250 -	0	0.00	0
1201 - 1250	0	0.00	0.00
1151 - 1200	0	0.00	0.00
1101 - 1150	0	0.00	0.00
1051 - 1100	1	0.03	0.03
1001 - 1050	3	0.10	0.13
951 - 1000	6	0.19	0.32
901 - 950	5	0.16	0.48
851 - 900	6	0.19	0.68
801 - 850	4	0.13	0.81
751 - 800	2	0.06	0.87
701 - 750	1	0.03	0.90
651 - 700	2	0.06	0.97
600 - 650	1	0.03	1.00
Total events	31		

	21.00 - 24.00		
Range (A)	Freq.	Prob.	Cum. Prob.
1200	0	0.00	0.00
1101 - 1150	0	0.00	0.00
1051 - 1100	1	0.03	0.03
1001 - 1050	1	0.03	0.06
951 - 1000	1	0.03	0.10
901 - 950	6	0.19	0.29
851 - 900	6	0.19	0.48
801 - 850	9	0.29	0.77
751 - 800	3	0.10	0.87
701 - 750	3	0.10	0.97
651 - 700	1	0.03	1.00
600 - 650	0	0.00	1.00
Total events	31		

	24.00 -3.00		
Range (A)	Freq.	Prob.	Cum. Prob.
1150	0	0.00	0.10
1101 - 1150	0	0.00	0.10
1051 - 1100	0	0.00	0.10
1001 - 1050	0	0.00	0.10
951 - 1000	0	0.00	0.10
901 - 950	3	0.10	0.20
851 - 900	6	0.19	0.39
801 - 850	7	0.23	0.62
751 - 800	10	0.32	0.94
701 - 750	3	0.10	1.04
651 - 700	2	0.06	1.10
600 - 650	0	0.00	1.10
Total events	31		

Table C12 – Probability distribution of possible current ratings of 220 kV Kotmale Anuradhapura Transmission Line from October to December on three hourly basis

APPENDIX - D : Daily operating currents of selected two transmission lines

The operating currents of both 220 kV Kotmale – Biyagama and 220 kV Kotmale – Anuradhapura transmission lines were collected hourly for the year 2004. Average currents of each transmission line are tabulated below.

time	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter
	Current (A)	Current (A)	Current (A)	Current (A)
1.00	148.59	138.17	133.40	130.03
2.00	148.59	151.59	119.48	129.17
3.00	151.79	144.23	92.57	128.59
4.00	150.46	137.58	92.45	129.47
5.00	135.39	139.33	137.48	129.47
6.00	138.18	158.92	144.04	135.46
7.00	128.41	152.23	163.95	130.36
8.00	132.43	154.86	155.96	145.78
9.00	182.25	205.55	252.69	180.88
10.00	188.01	203.84	252.69	175.13
10.30	160.49	204.27	252.69	175.13
11.00	162.56	204.27	297.01	156.79
11.30	183.55	192.22	292.66	156.79
12.00	201.47	186.47	299.65	199.39
12.30	197.77	186.47	297.44	191.42
13.00	187.92	189.67	273.47	179.29
13.30	187.92	189.67	275.69	189.01
14.00	186.06	193.67	303.23	189.01
14.30	182.82	194.18	303.23	189.01
15.00	185.57	194.18	283.11	188.43
15.30	183.17	194.18	283.11	188.43
16.00	175.95	194.18	243.54	190.05
16.30	178.35	179.34	270.01	190.05
17.00	182.52	177.47	273.85	259.70
17.30	176.26	177.03	253.60	255.03
18.00	159.55	178.50	252.41	212.23
18.30	159.55	177.14	249.81	238.23
19.00	197.36	178.88	323.12	318.27
20.00	292.18	185.01	358.51	346.13
21.00	263.26	149.11	311.07	275.78
22.00	191.04	152.26	312.72	191.05
23.00	192.27	144.67	216.53	172.77
24.00	156.32	145.34	166.04	70.98

Table D1 - Average operating data of 220 kV Kotmale - Biyagama transmission Line

	1st Quarter	2nd quarter	3rd Quarter	4th Quarter
time	Current (A)	Current (A)	Current (A)	Current (A)
1.00	120.62	108.20	114.4	67.85
2.00	120.62	108.20	114.4	56.51
3.00	120.62	108.20	114.4	56.51
4.00	120.36	108.20	114.3	56.51
5.00	156.61	107.36	132.0	68.92
6.00	180.68	130.08	155.4	80.74
7.00	181.16	116.93	149.0	86.17
8.00	142.87	106.25	124.6	79.22
9.00	145.08	107.69	126.4	76.64
10.00	139.10	106.02	122.6	83.08
11.00	147.94	104.94	126.4	86.78
12.00	148.06	106.56	127.3	86.46
13.00	146.27	106.56	126.4	86.68
14.00	173.89	97.78	135.8	74.67
15.00	173.89	101.83	137.9	81.31
16.00	177.99	100.95	139.5	81.31
17.00	161.33	95.53	128.4	81.74
18.00	159.58	95.28	127.4	89.06
19.00	241.96	152.03	197.0	133.74
20.00	336.52	210.31	273.4	139.39
21.00	311.86	164.31	238.1	108.43
22.00	205.65	132.12	168.9	67.52
23.00	154.86	101.77	128.3	62.43
24.00	132.19	91.77	112.0	62.41

Table D2 - Average operating data of 220 kV Kotmale -Anuradapura transmission line

APPENDIX - E : Financial Analysis

E.1 Financial Analysis on Power Loss of a transmission Line

Energy losses in transmission lines may result either from thermal effect (I^2r) or from corona losses. Usually corona loss is considered to be negligible compared to the thermal losses thus the corona loss has not been taken in to consideration in the loss calculation

The cost of losses produced by heating current can be influenced by different factors, listed below.

a. factors depending on the manner of transporting energy during the period
   i. line loading
   ii. utilization pattern
   iii. power factor
b. factors of circuit lay out
   i. resistance of the circuit
   ii. parallel connection of circuits
c. Energy cost
   i. Cost of energy

Both types of above losses have two components:

(a) Demand (capacity) Loss
(b) Energy loss

Annual cost of demand losses in year n (ADC_n) and the annual cost of energy loss in year n (AEC_n) can be determined from the following equations.

$$ADC_n = DL*DC*IDC*AFC*(1+RES)*(1+ESC)^n$$

$$AEC_n = 8760*DL*LSF*EC*(1+ESC)^n$$

Present value of cost in year n is given by,

$$PV(ADC_n) = (ADC_n)/(1+R)^n$$

$$PV(AEC_n) = (AEC_n)/(1+R)^n$$

DL = Demand Loss = $I^2R/1000$ kW
DC = Demand Charge Rs. per kW
IDC=Incremental Demand Charge
AFC=Annual Fixed Charge

RES= Generating Capacity Reserved
LSF=Loss factor
EC= Energy Charge   Rs. per kWh
ESC=Energy Inflation Rate
R= time value of money per time period

Annual demand cost is not considered for the calculation.

For the sample calculation, select 220 kV Kotmale – Biyagama transmission line.

Approximate cost of construction of similar transmission line = Rs.2160 (million) .

Normal life span of a transmission line is taken as 20 years

Current (A)	Power MW	Power loss MW	Power loss %	Annual Energy Cost Rs. Million	Annual energy cost saving due to new line	PV of cost saving
300.00	228.62	3.35	1.5	251.90	125.95	721.69
400.00	304.83	5.96	2.0	447.82	223.91	1283.00
500.00	381.04	9.32	2.4	699.71	349.86	2004.68
600.00	457.25	13.41	2.9	1007.59	503.79	2886.74
700.00	533.46	18.26	3.4	1371.44	685.72	3929.18
800.00	609.66	23.85	3.9	1791.27	895.64	5131.99
900.00	685.87	30.18	4.4	2267.08	1133.54	6495.17
1000.00	762.08	37.26	4.9	2798.86	1399.43	8018.73
1100.00	838.29	45.08	5.4	3386.62	1693.31	9702.67

Table E - Financial calculation

The above analysis shows that present value of cost saved is equal to cost of construction when operating the line with approximately 2.5 % power loss

2.5 % Power Loss is acceptable.

E.2 The other factors which are inestimable for a new construction

1. Loss of land, which is a limited resource.
2. Effect on the aesthetic beauty of the area
3. Electromagnetic effects
4. Cost of environmental clearances

E.3 Other options available to avoid above factors

Underground transmission lines can avoid some of above effects. However, the cost of construction of such transmission lines are nearly four to five times higher than that of the overhead transmission lines. In addition, it requires at least 4-year to construct the line. Therefore, when we consider the cost of construction of underground transmission lines, the above financial analysis shows that 5.0 % power loss is acceptable, for cases where the only alternative is an underground line.

APPENDIX - F : Different conductor types used in The Transmission Network of Sri Lanka

Code Name	Tiger	Coyote	Oriole	Lynx	Goat	Zebra
Steel Stranding	7/2.36	7/1.91	7/2.69	7/2.79	7/3.71	7/3.18
Steel Area (mm2)	30.59	20.09	39.78	42.77	75.67	55.59
Steel core Diameter (mm)	7.08	5.73	8.07	8.37	11.13	9.54
Aluminum Stranding	30/2.36	26/2.54	30/2.69	30/2.79	30/3.71	54/3.18
Aluminum Area (mm2)	131.1	132.1	170.5	183.4	324.3	428.9
Total Area (mm^2)	161.7	152.2	210.3	226.2	400.0	484.5
Overall Diameter (mm)	16.52	15.89	18.83	19.53	25.97	28.62
Greased Weight (kg/m)	0.602	0.522	0.782	0.842	1.489	1.621
Ultimate Tensile Strength (kg)	5914	4732	7730	8137	13838	13450
Modulus of Elasticity (kg/mm2)	8200	7700	8200	8200	8200	7000
Temperature Coefficient (per deg C)	17.8x10-6	18.8x10-6	17.8x10-6	17.8x10-6	17.8x10-6	19.8x10-6
DC Resistance (ohms/km)	0.2204	0.2187	0.1694	0.1576	0.0891	0.0674`
Current Rating at 54 °C Day (A) Evening (A)	178 365	180 361	199 432	204 453	244 658	253 750
Current Rating at 75 °C Day (A) Evening (A)	379 487	377 483	444 578	464 607	656 882	726 987
Current Rating at 90° Emergency (A)	554	550	658	690	1005	1112
Fault Current 1 Sec. (kA)`	12.7	11.9	16.5	17.8	31.5	34.3

Table F – ACSR Conductor types