Conceptual Design of EHV and UHV Transmission Line

Major Project Report

Submitted in Partial Fulfillment of the Requirements for the *Degree of*

MASTER OF TECHNOLOGY

IN

ELECTRICAL ENGINEERING
(Electrical Power Systems)

By

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May 2014

Undertaking For Originality of the Work

I, **Mr. Sudip S. Godbole**, (**Roll No:12MEEE15**), give undertaking that the Major Project entitled **"Conceptual Design of EHV and UHV Transmission Line"** submitted by me, towards the partial fulfillment of the requirement for the degree of Master of Technology in **Electrical Power Systems**, **Electrical Engineering**,under Institute of Technology, Nirma University, Ahmedabad is the original work carried out by me and I give assurance that no attempt of Plagiarism has been made. I understand that in the event of any similarity found subsequently with any published work or any dissertation work elsewhere; it will result in severe disciplinary action.

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Certificate

This is to certify that the Major Project Report (Part-II) entitled **"Conceptual Design and Protection of EHV and UHV Transmission Line"** submitted by **Mr.Sudip S. Godbole (12MEEE15)**, towards the partial fulfillment of the requirements for Semester-IV of **Master of Technology (Electrical Engineering)** in the field of **(Electrical Power System)** of Nirma University is the record of work carried out by him under our supervision and guidance. The work submitted has reached a level required for being accepted for examination. The results embodied in this major project, to the best of my knowledge, have not been submitted to any other University or Institution for award of any degree or diploma.

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Acknowledgements

Success of any work depends upon the dedication, sincerity and hard work. It also requires some ingredients such as motivation, guidance, encouragement and time. I am very thankful to all those who are behind the successful completion of the dissertation work.

It is a matter of extreme honor and privilege for me to offer my grateful acknowledgement to my industrial guide **Er. S.M.Takalkar, Director, TPEC** for permitting me to carry out design work. I would also like to thank **Er. Alpesh Mohite** for providing me a chance to work under his guidance and supervision.

I am highly obliged to my revered project guide and Co-guide **Prof.C.R.Mehta and Prof. S.Godwal (EPS), Institute of Technology, Nirma University, Ahmedabad** for his valuable, inspiring and excellent guidance. I express my sincere appreciation and thanks to **C.R.Mehta** for constant encouragement and help during various stages of work. I would also like to thank **Dr. K.Kotecha, Director, Institute of Technology, Nirma University** for allowing me to carry out my project work in industry. My sincere thanks and gratitude to **Head Of the Department** for encouragement and support. I am thankful to Nirma University for providing all kind of required resources.

I express my thanks to all the staff members of TPEC, specially,Er Alpesh Mohite,Er. Kishor Gsikwad,Er. Parth Desai, Er. Sumit Lingarchani,Er.Swati Pimplekar, Er. Keval Velani, Er. Ms. Heena Darji for their time to time support during my entire study. I would also like to thank my friend Er.Parth for his kind support and help. I extent my heartfelt thanks to my parents and younger sister for their motivation, moral support and encouragement throughout my dissertation work. And above all, I pay my regards to the Almighty for his love and blessing.

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Abstract

Power system comprises of three main parts namely: Generation, Transmission and Distribution. Generating voltage adopted worldwide are 11 kV and 13.8 kV. Transmission voltage is again classified in five different forms such as LV (Low voltage), MV (Medium Voltage), HV (High Voltage), EHV (Extra High Voltage) and UHV (Ultra High Voltage).

In the earlier days, transmission of power was carried out at HV and EHV level as power demand was less. Due to industrialization and rapid growth in population, demand of power consumption has also been increased. Moreover, transmitting the power requires a dedicated power corridor and Right of Way (R.O.W). Right of Way (R.O.W) is the biggest concern for the utility and the private players of power industry due to reluctance from the local people to give away their piece of cultivated land for erection of lattice towers for transmitting the power. Thus the utility and private players has shifted from the conventional way of transmitting power to different new concepts and modern trends such as Uprating, Upgrading, use of higher system voltages (EHV and UHV) for transferring large blocks of power using same R.O.W, use of Multi Circuit towers in replacement of Single Circuit towers.

The report provides detailed design of 400 kV transmission line Quard Configuration double Circuit and comparitive study of different 400 kV double circuit tower configuration.Comparitive study involve power flow, electromagnetic and electrostatic effect, corona loss and Radio and audio noise.This also includes 765 kV tower electrostatic and environment effect.

Contents

List of Tables

List of Figures

Abbreviations

AAAC .... All Aluminium Alloy Conductor
AAC .... All Aluminium conductor
ACAR .... Aluminium Conductor-Aluminium-Alloy Reinforced
ACCC .... Aluminium Conductor Composite Core
ACSR .... Aluminium Conductor Steel Reinforced
AN .... Audible Noise
CCC .... Current Carrying Capacity
EHV .... Extra High Voltage
FOS .... Factor of Safety
LTWP .... Lake Turkana Wind Power
GMD .... Geometric Mean Distance
GMR .... Geometric Mean Radius
RI .... Radio Interference
ROW .... Right of Way
STACIR .... Super Thermal Resistance Aluminium Alloy conductor
TVI .... Television interference
UHV .... Ultra High Voltage
UTS .... Ultimate Tensile strength
VR .... Voltage Regulation

Nomenclature

α .... Constant of mass temperature coecient of resistance of conductor per 0C
C .... Capacitance
D .... Diameter of conductor
f .... Frequency
G_m .... Equivalent Mutual GMD
G_s .... Equivalent GMR
I .... Current in Ampere
K_e .... Emissivity co-efficient in respect to black body
L .... Inductance
N_u .... Nusselt number
P_j .... Heat generated by joule effect
P_{sol} .... Solar heat gain by conductor surface
P_{rad} .... Heat loss by radiation of the conductor
P_{con} .... Convection heat loss
R_{ac} .... AC resistance of conductor at final equilibrium temperature
R_e .... Reynold's number
S .... Stefan-Boltzman constant
S_i .... Intensity of solar radiation
V .... Wind velocity
$|V_r|noload$ .... Magnitude of receiving end voltage at no load
$|V_r|fullload$ .... Magnitude of receiving end voltage at full load
Y .... Admittance
Z .... Impedance

Chapter 1

Introduction

An electrical power system, at transmission level, consists of synchronous generators for generating electrical energy, transformer for stepping up and down voltage, high voltage transmission line for transferring bulk power, compensating devices, and loads. Generating power stations are mostly far away from load centre. Power generated in power station is at rated voltage (11kV/13.6kV/15kV). This voltage is further stepped up by transformer to transmit power at longer distance. Existing transmission voltage levels are (33kV/66kV/132kV/220kV/400kV/765kV/1200kV).
Rapid growth in power sector in the country requires matching extra high voltage and ultra high voltage transmission line. Such transmission line mostly connect mega power station and load centre. EHV and UHV lines should therefore have a very high reliability. This is obvious as any tripping or outage on this line will have very big impact on the system connected on both ends by this line.
So for newly erected lines we have to provide optimised solution for maximum power transfer. Right of way (R.O.W) has become very serious issue day by day and therefore caring of large block of power through a small corridor is the order of the day.
Advantages carrying of EHV-AC Transmission Line are as Follows:

a. Power transfer capability of circuit increases.

b. Number of circuits and land requirement for transmission are reduced for definite MW power transfer.

c. At high voltage level, transmitted current in the line reduces thereby reduces the line losses per unit MW power transfer.

d. For reduced transmission current, size of conductor reduces for a given quantum of power which decreases the volume of conductor and cost per MW transfer.

e. Increase in transmission efficiency

f. Due to reduction in Current, the Voltage drop(IR) reduces and therefore the voltage regulation improve.

1.1 RECENT TRENDS

The power sector in India is undergoing a drastic change. It has been widely accepted by one and all that out of various infra structure development, power is the most essential infrastructure. Till the year 2000, the business of power generation, transmission and distribution was the monopoly of state and centre owned utilities. Cost of construction and maintenance depended upon the standards set out by the Central Electricity Authority.
In pre-independece India, the generation of electrical power was mainly undertaken by private sector and was limited to urban areas. The development of power sector commenced with the commissioning of 130-kW hydro generator, in 1897.Post-independence.the Government of India (GOI) took upon itself the task of developing power sector in a rationalized manner.
Starting with an installed capacity of 1,713 MW at the end of 1950, installed capacity has been continually enhanced to meet the growing demand for power. As per the Central Electricity Authority General Review 2005, the total installed generation capacity, constituted of hydro, thermal(including steam, gas, diesel and wind), and nuclear, at the end of five year plan (31 March 2002) stood at 1,05,046 MW and it is envisaged to increase generation by 41,110 MW at the end of the tenth plan as shown in figure1.1. As increasing generation capacity to transmit power to load station we required to installed transmission lines. At the end of the second year of the five year plan, that is 31 March 2004, the total length of transmission and distribution lines stood at 63, 44,858 circuit kilometres (circuit Km).Recent and expected increase in

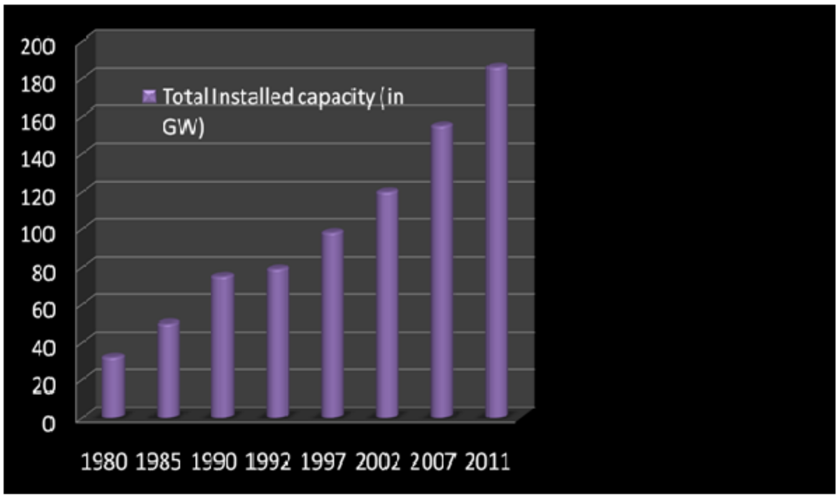


Figure 1.1: Total installed Capacity in India

Table I: Transmission Line at the End of 11-12 Plan

Tr line, Voltage level	End of 11th plan(ckm)	End of 12th plan(ckm)
765 kV	7,612	25,000-30,000
HCDC, Bi-Pole	11,078	4,000-6,000
400 kV	1,25,000	50,000
200 kV	1,50,000	40,000
Total, Tr line	2,93,852	1,19,000-1,26,000

line length are mention in tableI.

1.2 PROJECT OBJECTIVE

Design of EHV and UHV transmission line has become essential for today's transmission engineer. Demand of power has rises to a great deal and to transmit large block of power to a long distance, high voltage transmission lines are required. Optimized design of these transmission lines does not have any unique process or standard procedure, though there are certain elements that are universal to all designs procedures. Depending on the design parameter given by the client or purchaser, there are several possible solutions to send the designated power to a distant place. Out of various possible solutions, Final selection of any design is chosen according to the practical constraints such as allowable ROW, route of transmission line, height of tower, environmental conditions etc. This is called a design basis report.

1.3 PROBLEM IDENTIFICATION AND PROJECT PLANNING

1.3.1 PROBLEM IDENTIFICATION

a. Voltage level selection is the one of the most important factor to be considered. Power transfer capacity is approximately proportional to the square of the voltage. Hence higher voltage is required to transmit more power. If higher voltage is selected, then with increase in voltage level, cost of insulation along with height and weight of tower increases, resulting into overall cost escalation of the transmission line. Therefore the voltage level must be judiciously selected.

b. Choice of conductor according to its current carrying capacity, and choice of number of circuit i.e. single circuit, double circuit or multi circuit.

c. Choice of number of bundles in a conductor. As number of bundle in conductor increases, GMR increases resulting into reduced inductance of the line and consequently reduced losses. With increase in bundle, mechanical design of tower changes and hardware assembly becomes complicated and expensive.

d. Appropriate conductor configuration must be selected, so as to minimize the inductive losses, corona loss, AN, TVI, RI, ROW, etc, while maintaining the suitable electrical clearances.

e. R.O.W is biggest hurdle in construction of long line. Selection of route decide as to give optimise solution in cost of line.

f. Optimise line design which can transmit maximum power for rated voltage level.

g. Provide line protection for long transmission line reliable operation.

Chapter 2

Literature Review

Reference [1] is responsible for preparation of perspective generation and transmission plans and for coordinating the activities of planning agencies as provided under Section 73(a) of the Electricity Act 2003. The Central Transmission Utility (CTU) is responsible for development of an efficient and coordinated inter-state transmission system (ISTS). Similarly, the State Transmission Utility (STU) is responsible for development of an efficient and coordinated intra-state transmission system (Intra-STS). The ISTS and Intra-STS are interconnected and together constitute the electricity grid. It is therefore imperative that there should be a uniform approach to transmission planning for developing a reliable transmission system. The planning criteria detailed herein are primarily meant for planning of Inter-State Transmission System (ISTS) down to 132kV level and Intra-State Transmission System (Intra-STS) down to 66kV level, including the dedicated transmission lines. The manual covers the planning philosophy, the information required from various entities, permissible limits, reliability criteria, broad scope of system studies, modeling and analysis, and gives guidelines for transmission planning.

Reference [2] provide electrical clearance to br maintain for different voltage level under various environment condition (such as crossing river, communication line, railway line, other power line etc.) along with type, shape and geometry of tower. Electrical climatic and geological considerations which influence the design of transmission lines are also included. Sag and tension calculation procedure for any conductor, under different terrain region, temperature and wind speed are considered in detail. Sag and tension are inversely proportional to each other. If working tension is less than sag will be more and to maintain minimum clearance between lowest conductor and ground, height of tower had to be increased which ultimately incur more cost. Similarly if the tension of conductor is higher, the tower will be heavy and foundation will also be heavy. Thus optimum value of tension, sag, and factor of safety can be obtained for particular span.

Reference [3] gives the idea about different components of EHV lines, the different types of tower, the different types of conductors that are used on the transmission line depending upon the voltage class and amount of current to be handled, the current loading limit and power transfer capability of various transmission lines, sag and tension calculations.

Reference [4] provides an overview on the generation demand scenario, transmission and distribution. It provides the power intensity in MW/m at different voltage level which shows that with increasing voltage, power intensity can be increased and transmission voltage up to 765 kV already operating. Towards the development of high intensity transmission corridor, there is plan to develop 800 kV, 6000 MW HVDC system as part of evacuation of bulk power from North Eastern Region (NER) to Northern Region (NR) over a distance of around 2000 kms. In addition, increasing the AC voltage level at 1200 kV level has been planned. It is to mention that we are aiming towards use of 1100 kV equipments for 1200 kV operation by optimizing their protective level with help of high energy level surge arrester so as to achieve economy in respect of 1200 kV UHV system development. Research work for 1000 kV HVDC system has been commenced.

Paper [5] provides calculation for bare conductor temperature and Ampacity under steady state condition. This calculation is based on Heat Balanced Theory. In normal condition bare conductor heat absorption is equal to heat loss at steady state. It also includes constants as intensity of solar radiation, Emissivity with respect to black body, solar absorption co-efficient, Thermal conductivity. We can find ampacity for specified bare conductor using equation for ambient and maximum temperature.

Reference [6] provides the specification of Aluminium conductor reinforced galvanized steel conductor for extra high voltage above 400 kV. The standard size (Nominal sizes and tolerance on nominal sizes), property, number of strands in conductor, electrical resistance, sectional area, approximate overall diameter of ACSR conductor are provided. Brief detail of tests (Surface condition test, Resistance test, Corona test, RI test) and rejection and retests are available. Reference

Chapter 3

Current Carrying Capacity (CCC) for bare conductor

These calculations are necessary to find out the capacity of the conductor to transfer the power at the rated voltage without any material damage to the conductor (deformation).The purpose of this standard is to present a method of calculating the current-temperature relationship of bare overhead conductors. Conductor surface temperatures are a function of

(1) Conductor material properties

(2) Conductor diameter

(3) Conductor surface conditions

(4) Ambient weather conditions

(5) Conductor electrical current

The rst two of these properties are specic chemical and physical properties. The third may vary with time, and that variation is dependent upon ambient atmospheric conditions other than weather. The fourth, weather, varies greatly with the hour and season. The fth, conductor electrical current, may be constant or may vary with power system loading, generation dispatch, and other factors.

The equations relating electrical current to conductor temperature may be used in either of the following two ways:

(1) To calculate the conductor temperature when the electrical current is known

(2) To calculate the current that yields a given maximum allowable conductor temperature

This standard includes mathematical methods and indicates sources of the values to be used in the calculation of conductor temperatures and conductor thermal ratings. However, because there is a great diversity of weather conditions and operating circumstances for which conductor temperatures and/or thermal ratings must be calculated, the standard does not undertake to list actual temperature-current relationships for speci c conductors or weather conditions. Each user must make their own assessment of which weather data and conductor characteristics best pertain to their area or particular transmission line.

3.1 CCC calculation

Here one sample calculation are shown for ACSR moose conductor to find its ampacity for given ambient temperature Weather Condition and COnductor detail are shown in table I.

Ampere Capacity of conductor $I = \sqrt{\frac{Q_c+Q_r+Q_s}{R_{ac}}}$
Where,
Q_c=Heat dissipated by convection
Q_r=Heat dissipated by Radiation
Q_s=Heat gained by conductor due to solar radiation
Now,

D.C Resistance at Temperature t_c : $R_{dc} = R_{t1}(1 + \alpha(t_c - t_1))$

Table I: AMPACITY calculation for ACSR moose conductor

Input Parameters	Symbole	unit	
Coefficient of Emissivity	ϵ		0.45
Temperature t_1	t_1	^0C	20
D.C Resistance at Temperaturet_1	R_{t1}	ohm/km	0.05595
Diameter of Conductor	D	mm	31.77
Wind Velocity	V	m/hr	2000
Average ambient temperature	t_a	^0C	40
Average conductor temperature	t_c	^0C	75
Solar Rediation	S	Wt/Sq.m	1045
Temperature Rise	δt	^0C	35
Average ambient temperature in kelvin	K_a	^0K	313
Average conductor temperature in kelvin	K_c	^0K	348
Solar absorption co-efficient	a		0.8
Constant of mass temp co-efficient	α	ohm/ ^0C	0.004
Frequency	f	cy/sec	50
Permeability(non-mag mat)	μ		1

= 0.05595(1+0.004(75-20))

= 0.0683 ohm/km

$X = 0.063598\sqrt{\frac{\mu_f}{R_{dc}}}$

$= 0.063598\sqrt{\frac{50*1}{0.0683}}$

=1.3608

Corresponding to obtained value of X, value of K=1.017195

A.C Resistance at temp t_c : $R_{ac} = K * R_{dc}$

=1.017195*0.0683

=0.0695

Absolute viscosity of air μ_f= 0.0715805 kg/m.hr

Air density at sea level P_f= 1.0676 kg/cum

Thermal conductivity of air K_f= 0.0285265 Wt/Sq.m

Heat gained by conductor due to solar radiation$Q_s = S * a * \frac{D}{1000}$

$= 0.8 * 1164 * \frac{31.77}{1000}$

=29.5842 Wt/m

Heat dissipated by Radiation$Q_r = 0.17838 * 10^{-6} * \epsilon * \frac{D}{1000} * (K_c^4 - K_a^4)$

$= 0.45 * \frac{31.77}{1000} * (348^4 - 313^4)$

=12.9069 Wt/m

Heat dissipated by convection :

$Q_{c1} = (1.00531 + (1.35088 * \frac{\frac{D}{1000} * P_f * V}{\mu_f})^{0.52}) * K_f * (t_c - t_a)$

$= (1.00531 + (1.35088 * \frac{\frac{31.77}{1000} * 1.08525 * 2000}{0.070762})^{0.52}) * 0.0281495 * (75 - 40)$

=42.2231

$Q_{c2} = 0.75398 * (\frac{\frac{D}{1000} * P_f * V}{\mu_f})^{0.6} * K_f * (t_c - t_a)$

$= 0.75398 * (\frac{\frac{31.77}{1000} * 1.08525 * 2000}{0.070762})^{0.6} * 0.0281495 * (75 - 40)$

=45.9910

Whichever Value is higher of above two Q_c is to be considered.

so, here Q_c= 65.4390

Now, Current Carring Capacity can be determine as,

$I = \sqrt{\frac{65.4390 + 12.9069 - 29.5842}{0.0695 * 10^{-3}}}$

=649.6007

3.2 CCC Program Results

In long transmission line over 132 kv voltage level mostly ACSR moose conductors are used.Here different conductor of Zebra type and moose type equivalent Resistance are given, for different temperature.At 400 kV, 765 kV and above ACSR Zebra and ACSR Moose are used as per required configuration of line. For voltage above 765 kV now a days new generation conductors i.e Bersimis, HTLS conductors are used. Some conductors Ampacity rating for different Am-

Table II: Resistance data for Zebra equivalent Conductors

Conductor	20_{dc}	20	75	85	95	120	150	175	200
ACSR	0.068	0.068	0.084	0.087	NA	NA	NA	NA	NA
AAAC	0.069	0.070	0.085	0.088	0.090	NA	NA	NA	NA
TACSR	0.075	0.076	0.093	0.096	0.099	0.106	0.115	NA	NA
AL59	0.078	0.079	0.096	0.099	0.102	NA	NA	NA	NA
ACSS	0.084	0.085	0.103	0.107	0.110	0.118	0.128	0.137	0.145
STACIR	0.080	0.081	0.098	0.101	0.104	0.112	0.122	0.130	0.138
ACCC	0.055	0.056	0.068	0.070	0.072	0.078	0.084	0.090	NA

Table III: Resistance data for Moose equivalent Conductors

Conductor	20_{dc}	20	75	85	95	120	150	175	200
ACSR	0.055	0.056	0.069	0.071	NA	NA	NA	NA	NA
AAAC	0.059	0.061	0.074	0.076	0.078	NA	NA	NA	NA
TACSR	0.054	0.056	0.068	0.070	0.072	0.077	0.083	NA	NA
AL59	0.050	0.052	0.063	0.065	0.067	NA	NA	NA	NA
ACSS	0.052	0.053	0.065	0.066	0.068	0.074	0.080	0.085	0.090
STACIR	0.068	0.069	0.084	0.086	0.089	0.096	0.104	0.111	0.118
ACCC	0.043	0.045	0.055	0.056	0.057	0.062	0.067	0.071	NA
ACSR Bersimis	0.041	0.043	0.052	0.054	NA	NA	NA	NA	NA
AAACBersimis	0.049	0.051	0.061	0.063	0.065	NA	NA	NA	NA
ACSRLapwing	0.038	0.040	0.048	0.049	NA	NA	NA	NA	NA
ACSRLapwing	0.038	0.040	0.048	0.049	NA	NA	NA	NA	NA

bient temperature are given as belove.

Table IV: ACSR Zebra (28.62 mm) AMPACITY for Maximum Conductor Temp

Ambient Temp	65	75	85	95	120	150
40	425.4	603.6	735.07	NA	NA	NA
45	297	524	673.3	NA	NA	NA
48	179.3	469.45	633	NA	NA	NA
50	113.2	429	604.6	NA	NA	NA

Table V: AAAC Zebra (28.42 mm) AMPACITY for Maximum Conductor Temp

Ambient Temp	65	75	85	90	95	120
40	423.6	600.5	731	786.5	837	NA
45	296.3	521.4	669.6	730.7	786.7	NA
48	180	467.2	629.6	694.8	753.2	NA
50	101.3	427.1	601.4	669.7	730.5	NA

Table VI: ACSR Moose (31.77 mm) AMPACITY for Maximum Conductor Temp

Ambient Temp	65	75	85	95	120	150
40	473.6	682.2	834.8	NA	NA	NA
45	320.6	589.8	763.5	NA	NA	NA
48	245.5	526.1	717	NA	NA	NA
50	82	478.7	684.1	NA	NA	NA

Table VII: AAAC Moose (31.07 mm) AMPACITY for Maximum Conductor Temp

Ambient Temp	65	75	85	90	95	120
40	458.7	658.5	804.9	867.2	924.2	NA
45	312.8	569.8	736.4	805	867	NA
48	172.7	508.8	691.7	764.9	830.5	NA
50	96	463.4	660.1	736.9	805.2	NA

Table VIII: ACSR Snowbird (30.57 mm) AMPACITY for Maximum Conductor Temp

Ambient Temp	65	75	85	95	120	150
40	476.2	682.2	833.3	NA	NA	NA
45	326.3	590.7	762.6	NA	NA	NA
48	183.8	527.8	716.4	NA	NA	NA
50	110	481	683.8	NA	NA	NA

Table IX: ACSR Bersimis (35.04 mm) AMPACITY for Maximum Conductor Temp

Ambient Temp	65	75	85	95	120	150
40	546.3	799.8	983.7	NA	NA	NA
45	357.1	688.5	898.3	NA	NA	NA
48	155.4	611.4	842.5	NA	NA	NA
50		553.8	802.9	NA	NA	NA

Table X: AAAC Bersimis (36 mm) AMPACITY for Maximum Conductor Temp

Ambient Temp	65	75	85	90	95	120
40	505.7	743.8	915.9	989.2	1056	NA
45	327	639.4	836.1	916.8	989.6	NA
48	129.8	567.1	783.8	870.2	947.2	NA
50		513	746.8	837.5	917.7	NA

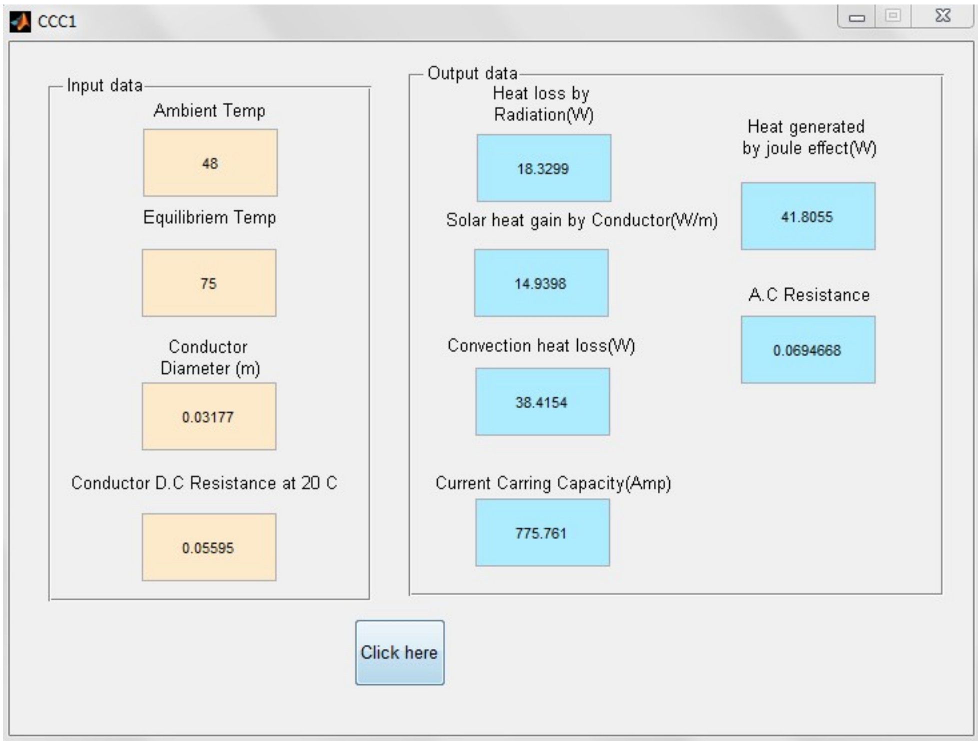
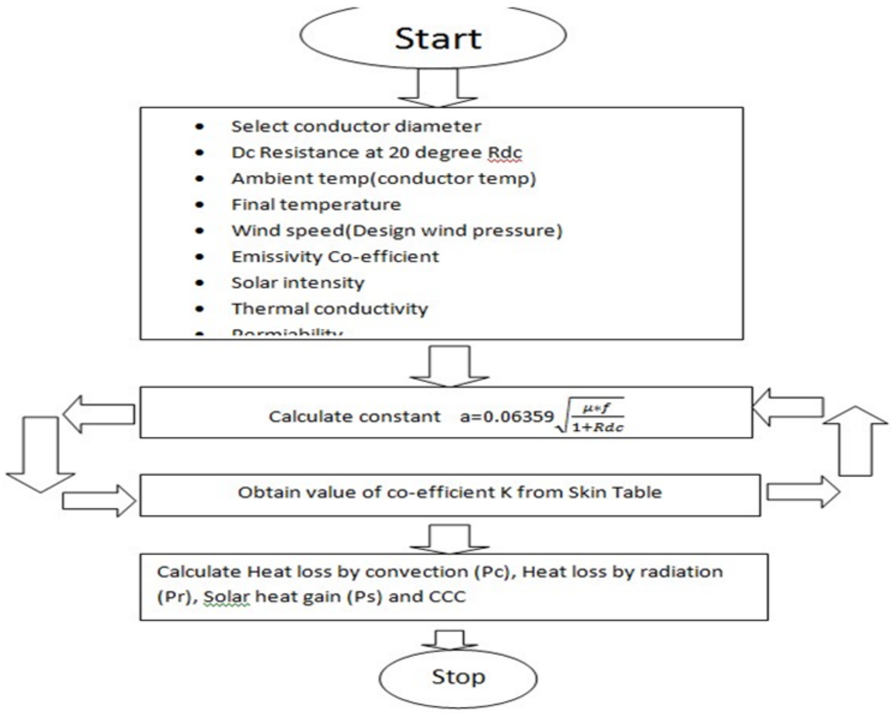


Figure 3.1: Current Carring Capacity Calculation

Here, CCC calculation and flow chart is shown in figure2.1,



Chapter 4

Case study

LAKE TURKANA WIND POWER (LTWP) is a company incorporated in Kenya (East Africa) to develop energy sources from wind. Fig5.1 shows the location of Lake Turkana in kenya and Fig5.2 shows map of kenya.

The Lake Turkana which is approximately 600 km away in the North-West direc- tion of capital city of Nairobi, is found to be most opportune for the purpose. Unique to the site are Mt. Kulal to the North and Mt. Nyiru to the South that act to produce a venturi effect further accelerating the winds across the proposed location where the multiple wind turbines are located.

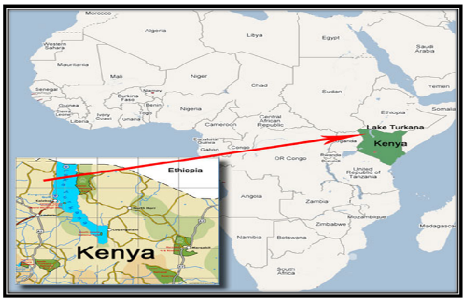


Figure 4.1: Location of Lake Tukana

Figure 4.2: Map of kenya

4.1 Environment condition

After a lot of studies, field investigations and visibility examination, the company has been in a position to identify an area having potential source of wind in Kenya. Over- all the site is characterized by extremely low rainfall that sustains sparse vegetation on a barren rocky volcanic soil. Indigenous nomadic populations utilize the area and the impact of the project on them is addressed in the project's environmental impact assessment (EIA) Layout 360 wind turbine generators are installed in LTWP, each one having an installed capacity of 890 KW. The generated power is evacuated at 33 KV and then stepped up in two stages of 132 KV and 400 KV. There is a 400 KV substation at Lake Turkana. Further the power is transmitted at 400 KV level via Double circuit line having an approximate length of 428 Km. The line is terminate at 400 KV substation planned near the town of Suswa, around 70 km North-West of Nairobi. The power received at 400 KV at Suswa is transformed to 220 KV / 132 KV and released in the Extra High Voltage (EHV) network of Kenya Power and Lighting Company (KPLC).

Chapter 5

Methodology

5.1 ELECTRIC TRANSMISSION LINE PARAMETERS

The power transmission line is one of the major components of an electric power system. Its major function is to transport electric energy, with minimal losses, from the power sources to the load centers, usually separated by long distances. The design of a transmission line depends on four electrical parameters:

(1) Series resistance

(2) Series inductance

(3) Shunt capacitance

(4) Shunt conductance

The series resistance relies basically on the physical composition of the conductor at a given temperature. The series inductance and shunt capacitance are produced by the presence of magnetic and electric fields around the conductors, and depend on their geometrical arrangement. The shunt conductance is due to leakage currents flowing across insulators and air. As leakage current is considerably small compared to nominal current, it is usually neglected, and therefore, shunt conductance is normally not considered for the transmission line modeling.

5.2 Series Resistence

The AC resistance of a conductor in a transmission line is based on the calculation of its DC resistance. If DC current is flowing along a round cylindrical conductor, the current is uniformly distributed over its cross-section area and its DC resistance is evaluated by:

$$R_{dc} = \frac{\rho * l}{A}(ohm) \tag{5.1}$$

where:
ρ is the resistivity of conductor
l is the length
A is the cross-sectional area
If AC current is flowing, rather than DC current, the following factors need to be considered:

(1) Frequency or skin effect

(2) Temperature

(3) Spiraling of stranded conductors

(4) Bundle conductors arrangement

(5) Proximity effect

(6) Also the resistance of magnetic conductors varies with current magnitude

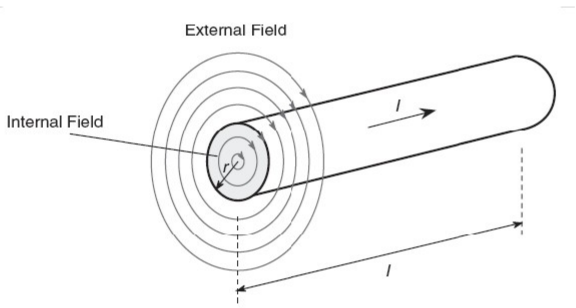


Figure 5.1: Flux linkage of long conductor

5.3 Line Inductance

The inductive reactance is by far the most dominating impedance element. A current-carrying conductor produces a magnetic field around the conductor. The magnetic flux lines are concentric closed circles with direction given by the right hand rule. With the thumb pointing in the direction of the current, the fingers of the right hand encircled the wire point in the direction of the magnetic field. When the current changes, the flux changes and a voltage is induced in the circuit. By definition, for nonmagnetic material, the inductance L is the ratio of its total magnetic flux linkage to the current I, given by:

$$L = \frac{\lambda}{I} \tag{5.2}$$

Consider H_x external to the conductor at radius$x > r$ as shown in Figure4.1. Since the circle at radius x encloses the entire current $I_x = I$ and in I_x is replaced by I and the flux density at radius x.

Internal flux Linkage is given by,

$$L_{int} = \frac{\mu * I}{2 * \pi * x} \tag{5.3}$$

Consider H_x external to the conductor at radius $x > r$ as shown in Figure 5. Since the circle at radius x encloses the entire current $I_x = I$ and in I_x is replaced by I and the flux density at radius x
External flux Linkage is given by:

$$L_{ext} = 2 * 10^{-7} ln \frac{D_2}{D_1} \tag{5.4}$$

5.4 Inductance of three phase transmission lines -symmetrical spacing

Consider one meter length of a three phase line with three conductors, each with radius r, symmetrically spaced in a triangular configuration as shown in Figure,
Assuming balanced three phase currents we have

$$I_a + I_b + I_c = 0 \tag{5.5}$$

so,

$$\lambda_a = 2 * 10^{-7} I_a ln \frac{1}{r'} + I_b ln \frac{1}{D} + I_c ln \frac{1}{D} \tag{5.6}$$

Substituting, $-I_a = I_b + I_c$
$\lambda_a = 2 * 10^{-7} I_a ln \frac{1}{r'} - I_a ln \frac{1}{D}$
Because of symmetry, $\lambda_a = \lambda_b = \lambda_c$, and the three inductance are identical. Therefore, the indactance per phase per kilometer length is

$L = 0.2 * ln \frac{D}{D_s}$

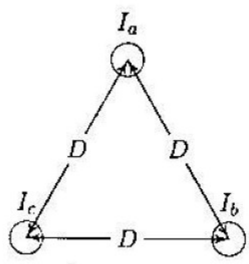


Figure 5.2: Three phase line with symmetrical spacing

5.5 Inductance of three phase transmission lines asymmetrical spacing

Practical transmission lines cannot maintain symmetrical spacing of conductors because of construction considerations. With asymmetrical spacing, even with balanced currents, the voltage drop due to the line inductance will be unbalanced.

Consider one meter length of a three phase line with three conductors, each with radius r. the conductors are asymmetrically spaced with distances shown in Figure4.2

The application will result in the following flux linkages

$$\lambda_a = 2*10^{-7} I_a ln\frac{1}{r'} + I_b ln\frac{1}{D_{12}} + I_c ln\frac{1}{D_{13}} \tag{5.7}$$

$$\lambda_b = 2*10^{-7} I_a ln\frac{1}{D_{12}} + I_b ln\frac{1}{r'} + I_c ln\frac{1}{D_{23}} \tag{5.8}$$

$$\lambda_c = 2*10^{-7} I_a ln\frac{1}{D_{13}} + I_b ln\frac{1}{D_{23}} + I_c ln\frac{1}{r'} \tag{5.9}$$

For balanced three phase currents with I_a as reference, we have

$$I_b = I_a \angle 240 = a^2 I_a \tag{5.10}$$

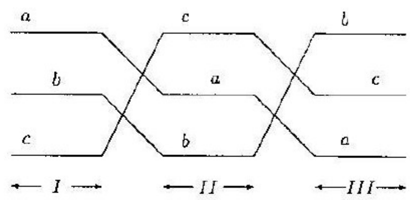


Figure 5.3: A Transposed three phase line

$$I_c = I_a \angle 120 = aI_a \tag{5.11}$$

$$\lambda_a = 2 * 10^{-7} I_a ln\frac{1}{r'} + a^2 I_b ln\frac{1}{D_{12}} + aI_c ln\frac{1}{D_{13}} \tag{5.12}$$

$$\lambda_b = 2 * 10^{-7} aI_a ln\frac{1}{D_{12}} + I_b ln\frac{1}{r'} + a^2 I_c ln\frac{1}{D_{23}} \tag{5.13}$$

$$\lambda_c = 2 * 10^{-7} a^2 I_a ln\frac{1}{D_{13}} + aI_b ln\frac{1}{D_{23}} + I_c ln\frac{1}{r'} \tag{5.14}$$

5.6 Transpose Line

The equilateral triangular spacing configuration is not the only configuration commonly used in practice. Thus the need exists for equalizing the mutual inductances. One means for doing this is to construct transpositions or rotations of overhead line wires. A transposition is a physical rotation of the conductors, arranged so that each conductor is moved to occupy the next physical position in a regular sequence such as a-b-c, b-c-a, c-a-b, etc. Such a transposition arrangement is shown in Figure4.3. If a section of line is divided into three segments of equal length separated by rotations, we say that the line is completely transposed.

Since a transposed line each takes all three positions, the inductance per phase can be obtained by finding the average value of

$$L = \frac{L_a + L_b + L_c}{3} \tag{5.15}$$

Noting that $a + a^2 = -1$

$L = \frac{2*10^{-7}}{3} 3ln\frac{1}{r'} - ln\frac{1}{D_{12}} - ln\frac{1}{D_{23}} - ln\frac{1}{D_{13}}$

$L = 2 * 10^{-7} ln\frac{1}{r'} - ln\frac{1}{(D_{12}*D_{23}*D_{13})^{\frac{1}{3}}}$
$= 2 * 10^{-7} ln\frac{(D_{12}*D_{23}*D_{13})^{\frac{1}{3}}}{r'}$

$L = 0.2ln\frac{GMD}{D_s}$

This again is of the same form as the expression for the inductance of one phase a single-phase line. GMD (geometric mean distance) is the equivalent conductor spacing. For the above three phase line is the cube root of the product of the tree phase spacings. D_s is the geometric mean radius, GMR. For stranded conductor D_s is obtained from the manufactures data. For solid conductor.
In modern transmission lines, transposition is not generally used. However, for the purpose of modeling, it is most practical to treat the circuit as transposed.

5.7 LINE CAPACITANCE

Transmission line conductors exhibit capacitance with respect to each other due to the potential difference between them. The amount of capacitance between conductors is a function of conductor size, spacing, and height above ground. By definition, the capacitance C is the ratio of charge q to the voltage v, given by
$C = \frac{q}{V}$
Consider a long round conductor with radius r, carrying a charge of q coulombs

per meter length as shown in Figure
The charge on the conductor gives rise to an electric field with radial flux lines. The total electric flux is numerically equal to the value of charge on the conductor. The intensity of the field at any point defined as the force per unit charge and is termed electric field intensity designated as E. Concentric cylinders surrounding the conductor are equipentential surfaces and have the same electric flux density. From Gausss law for one meter length of the conductor, the electric flux density at a cylinder of a radius x is given by
$D = \frac{q}{A} = \frac{q}{2*\pi*x*l}$
The electric field intensity E may be found from the relation
$E = \frac{D}{\epsilon}$
$E = \frac{q}{2*\pi*\epsilon*x}$
The potential difference between cylinders from position $D_1$to D_2 is defined as the work done in moving a unit charge of one coulomb from $D_2$to D_1 through the electric field produced by the charge on the conductor. This is given by

$$V_{12} = \frac{q}{2*\pi*\epsilon*x} ln \frac{D_2}{D_1} \tag{5.16}$$

5.7.1 CAPACITANCE OF THREE PHASE LINES

Consider one meter length of a three phase line with three long conductors, each with radius r, with conductor spacing as shown in
Since we have a balanced three phase system:

$$q_a + q_b + q_c = 0 \tag{5.17}$$

We shall neglect the effect of ground and the shield wires. Assume that the lines is transposed as shown in figure4.4. We proceed with the calculation of the potential difference between a and b for each section of transposition. Applying to the first section of the transposition,

$$V_{ab}(1) = \frac{1}{2*\pi*\epsilon} q_a ln \frac{D_{12}}{r} + q_b ln \frac{r}{D_{12}} + q_c ln \frac{D_{23}}{D_{13}} \tag{5.18}$$

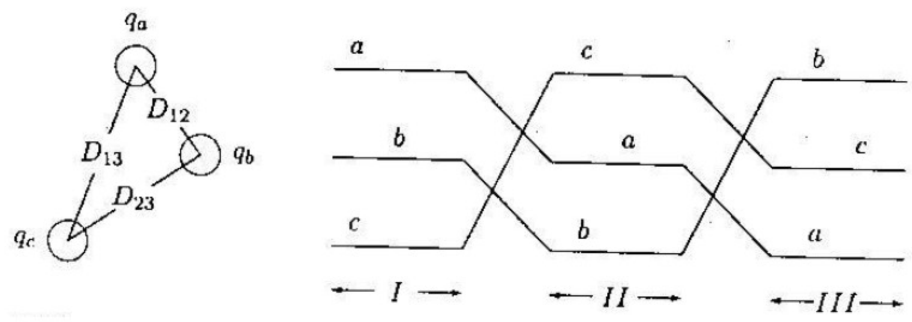


Figure 5.4: three phase transmission line

Similarly, for the second section of the transposition, we have

$$V_{ab}(2) = \frac{1}{2*\pi*\epsilon} q_a ln \frac{D_{23}}{r} + q_b ln \frac{r}{D_{13}} + q_c ln \frac{D_{13}}{D_{12}} \tag{5.19}$$

And for the last section

$$V_{ab}(3) = \frac{1}{2*\pi*\epsilon} q_a ln \frac{D_{13}}{r} + q_b ln \frac{r}{D_{13}} + q_c ln \frac{D_{12}}{D_{23}} \tag{5.20}$$

The average value of V_{ab} is

$V_{ab} = \frac{1}{3*2*\pi*\epsilon} q_a ln \frac{D_{12}*D_{23}*D_{13}}{r^3} + q_b ln \frac{r^3}{D_{12}*D_{23}*D_{13}} + q_c ln \frac{D_{12}*D_{23}*D_{13}}{D_{12}*D_{23}*D_{13}}$

$V_{ab} = \frac{1}{2*\pi*\epsilon} q_a ln (D_{12}*D_{23}*D_{13})^{\frac{1}{3}} r + q_b ln \frac{r}{(D_{12}*D_{23}*D_{13})^{\frac{1}{3}}}$

Note that the GMD of the conductor appears in the logarithm arguments and is given by,

$$GMD = 3\sqrt{D_{12}*D_{23}*D_{13}} \tag{5.21}$$

Therefore, V_{ab} is,

$$V_{ab} = \frac{1}{2*\pi*\epsilon} q_a ln \frac{GMD}{r} + q_b ln \frac{r}{GMD} \tag{5.22}$$

Similarly, we find the average voltage V_{ac} as

$$V_{ac} = \frac{1}{2 * \pi * \epsilon} q_a ln \frac{GMR}{r} + q_b ln \frac{r}{GMR} \tag{5.23}$$

Substituting for $q_b + q_c = -q_a$, we have

$$V_{ab} + V_{ac} = \frac{1}{2 * \pi * \epsilon} 2 q_a ln \frac{GMD}{r} - q_a ln \frac{r}{GMD} = \frac{3 * q_a}{2 * \pi * \epsilon} ln \frac{GMD}{r} \tag{5.24}$$

For balanced three phase voltage,

$V_{ab} = V_{an} \angle 0 - V_{an} \angle - 120$

$V_{ac} = V_{an} \angle 0 - V_{an} \angle - 240$

Therefore,

$$C = \frac{0.0556}{ln \frac{GMD}{r}} \tag{5.25}$$

This is the same form as the expression the capacitance of one phase of a single phase line. GMD (geometric mean distance) is the equivalent conductor spacing. For the above three phase line is the cube root of the product of three phase spacings.

5.8 GMD

GMD is the Geometrical mean of distances between conductors of any one phase with respect to other. It represents equivalent geometrical spacing. Calculation of GMD for inductance and capacitance is same.

Single Circuit

$$G_m = 3\sqrt{D_{ab} * D_{bc} * D_{ca}} \tag{5.26}$$

Double Circuit

$$G_m = 3\sqrt{D_{ab} * D_{bc} * D_{ca}} \tag{5.27}$$

$$D_{ab} = 4\sqrt{D_{ab} * D_{a'b} * D_{ab'} * D_{a'b'}} \tag{5.28}$$

$$D_{bc} = 4\sqrt{D_{bc} * D_{b'c} * D_{bc'} * D_{b'c'}} \tag{5.29}$$

$$D_{ca} = 4\sqrt{D_{ca} * D_{c'a} * D_{ca'} * D_{c'a'}} \tag{5.30}$$

5.9 GMR

Self GMD of a conductor is known as GMR. GMR of single conductor, for inductance calculation is r' whereas GMR for capacitance calculation is conductor's radius (r) itself

Single Conductor Configuration

GMR= 0.7788*r =r'

Twin Conductor Configuration

Twin conductor is a basic bundle conductor, having two subconductor. To calcu- late GMR of bundled conductor, consider each sub conductor along with the spacing between considered sub conductor and all other sub conductors present in the bundle.

$GMR = 4\sqrt{(0.7788 * r)(0.7788 * r)}$
$= 4\sqrt{(0.7788 * r)^2}$
$GMR = \sqrt{r' * d}$

Triple Conductor Configuration

$GMR = 9\sqrt{(r' * d * d)(r' * d * d)(r' * d * d)}$

$GMR = 9\sqrt{r' * d^2}$ **Quad Conductor Configuration**

$GMR = 16\sqrt{(r' * d^2 * d')^4}$

Here,

$d' = \sqrt{d^2 + d^2}$
$= \sqrt{2}d$

$GMR = 1.09 * 4\sqrt{r' * d^3}$

Hexa Conductor Configuration

$GMR = 36\sqrt{(r' * d^2 * d_1 * d_2 * d_3)^6}$

Here, $d_1 = d_3 = 2 * cos(30) * d = 1.732d$

$d_2 = \sqrt{d_1^2 + d^2} = 2d$

$GMR = 6\sqrt{r' * d^2 * d_1^2 * d_2}$

$GMR = 1.348 * 6\sqrt{r' * d^5}$

Octa Conductor Configuration

$GMR = 64\sqrt{(r' * d^2 * d_1^2 * d_2^2 * d_3)^8}$

Here,

$d_1 = 2 * cos(22.5) * d = 1.84776d$

$d_2 = (tan22.5)^{-1} * d = 2.4142d$

$d_3 = \sqrt{d_2^2 + d^2} = 2.6131d$

$GMR = 1.638 * 8\sqrt{r' * d^7}$

Similarly GMR of other bundled conductors can be obtained. As bundling of conductor is increased, its self GMR will increases resulting in reduced inductance and hence reduced losses. So now-a-days for EHV transmission bundled conductors are preferred. GMR calculation for capacitance is same as inductance calculation, where instead of r', only r is considered.

Inductance of the transmission line is obtained in (H/phase/m). If length of transmis- sion line is known, then inductance of complete line can be obtained. Inductance of the line varies as per its configuration and most economical configuration is opted.Usually in single circuit, horizontal configuration is chosen as it eliminates the need of trans- position and in Double circuit, vertical configuration is chosen as it reduces the ROW and cost associated to it.

5.10 Impedance and Admittance of Conductor

5.10.1 Impedance

$$Z = R + jX \tag{5.31}$$

$$R = R_t l \tag{5.32}$$

$$X = 2 * \pi * f * L \tag{5.33}$$

Z: Impedance of line (ohm)

R: AC resistance of line (ohm)

X: Reactance of line (ohm)

Rt: AC Resistance of line at t2 $^0C(ohm/Km)$

l: Transmission line length (Km)

f: frequency of system (Hz)

L: Inductance of line (H/Phase)

5.10.2 Admittance

$$Y = 2 * \pi * f * C \tag{5.34}$$

Y: Admittance of line (℧)

f: frequency of system (Hz)

C: Capacitance of line ($\mu F/phase$)

5.11 Voltage regulation

Voltage regulation is measure of ability to hold constant voltage, despite of load condition. Voltage regulation of transmission line is:

V.R = $V_s - V_r \frac{}{V_r * 100 (5.35)}$

$$V_s = A * V_r + B * I_r(V) \tag{5.36}$$

$$I_s = c * V_r + A * I_r(A) \tag{5.37}$$

$$V_r = D * V_s - B * I_s(V) \tag{5.38}$$

$$I_r = -C * V_s + A * I_s(A) \tag{5.39}$$

Here V_r is obtained using ABCD constant. Parameters A, B, C, D, varies according to the length of the transmission line. To calculate ABCD parameters, values of impedance and admittance of transmission line are required. Transmission line can be designated to be either short, medium or long as per requirement and analysis procedure.

Transmission line having length more than 250 Km is considered to be long transmission line. Here line parameters are distributed uniformly over the entire length.

5.12 Surface Voltage gradient of Conductor

The surface voltage gradient on conductors in a bundle governs generation of corona on the line which have serious consequences causing audible noise and radio interference. They also affect carrier communication and signalling on the line and cause interference to television reception. The designer of a line must eliminate these nuisances or reduce them to tolerable limits specified by standards, if any exist. These limits will be discussed at appropriate places where AN, RI and other interferring fields are discussed in the next two chapters. Since corona generation depends on the voltage gradient on conductor surfaces, this will be taken up now for e.h.v. conductors with number of sub-conductors in a bundle ranging from 1 to N. The maximum value of N is 8 at present but a general derivation is not difficult.

To find Surface Gradient different methods are used are as following:

- Maxwell Potential Coefficient Method
- IMarkt and Mengele's Method

5.12.1 Maxwell Potential Coefficient Method

An exact analytical solution exists for the case of a single conductor above ground. By imaging in the ground plane, the problem is transformed into that of solving the electric field of two parallel cylindrical conductors in infinite space with equal and opposite voltages applied to them. The analysis shows that the charge distribution on each conductor is represented exactly by means of a line charge located at a small distance away from the centre of the conductor. The distance of the line charge location from the centre of the conductor is a direct function of H/r, where H is the height of the conductor above ground and r is the conductor radius. For large values of H/r (¿100), as in the case of practical transmission line configurations, the line charge is located very nearly at the centre of the conductor. This basic principle has been extended to determine the electric field of multiconductor configurations where the heights of the conductors above ground as well as the distances between the individual conductors are very large compared to the radii of the conductors. The charge on each conductor is then represented by a line charge located at its centre. This gives rise to the well-known Maxwell potential coefficient method3 of calculating the charges and electric fields on the conductors of A-multi-conductor system.

The representation of a conductor charge by means of a single line charge at its centre automatically implies a uniform charge and electric field distribution around the conductor surface. Such an assumption becomes inadequate in the case of transmission lines using bundle conductors since the subconductor spacing in a bundle is only of the order of 10-40 times the subconductor radius. The charge on the individual subconductors is therefore nonuniformly distributed and cannot be represented by a single line charge at its centre.

5.12.2 Mangoldt (Markt-Mengele) Formula

In the case of a 3-phase ac line with horizontal configuration of phases, a convenient formula due to Mangoldt can be derived. This is also known as the Markt-Mengele Formula by some others,To find voltage gradient we assume image of conductor as shown in figure4.5
The Maxwell's Potential coefficients are

$$P_{11} = P_{22} = P_{33} = ln(\frac{2H}{r_{eq}}) Where, r_{eq} = R(\frac{Nr}{R})^{1/N} \tag{5.40}$$

$$P_{12} = P_{21} = P_{23} = P_{32} = ln(\frac{\sqrt{4H^2+S^2}}{S}) = ln(\sqrt{1+(\frac{2H}{S})^2}) \tag{5.41}$$

$$P_{13} = P_{31} = ln(\frac{\sqrt{4H^2+S^2}}{2S}) = ln(\sqrt{1+(\frac{H}{S})^2}) \tag{5.42}$$

$$The voltage - charge relations are$$

V$_1 = P_{11}.\frac{Q_1}{2\pi e_o} + P_{12}.\frac{Q_2}{2\pi e_o} + P_{13}.\frac{Q_3}{2\pi e_o}$(5.44)

$$V_2 = P_{21}.\frac{Q_1}{2\pi e_o} + P_{22}.\frac{Q_2}{2\pi e_o} + P_{23}.\frac{Q_3}{2\pi e_o} \tag{5.45}$$

$$V_3 = P_{31}.\frac{Q_1}{2\pi e_o} + P_{32}.\frac{Q_2}{2\pi e_o} + P_{33}.\frac{Q_3}{2\pi e_o} \tag{5.46}$$

Both the voltages and the charges are sinusoidally varying at power frequency and at every instant of time,$V_1 + V_2 + V_3 = 0$ and $Q_1 + Q_2 + Q_3 = 0$. When the charge of any phase is passing through its peak value, the charges of the remaining two phases are negative but of magnitude 0.5 peak. From symmetry, the peak values of charges on the two outer phases will be equal. If we assume the peak values of Q_1, Q_2, Q_3 to be approximately equal,Combining this equation we get voltage gradient for outer phase and inner phase as,

For Outer phase,

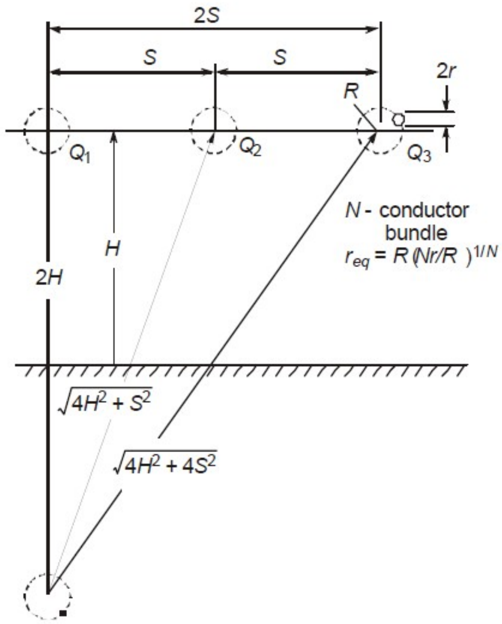


Figure 5.5: 3-phase horizontal configuration of line for derivation of Mangoldt Formula

$$E_{om} = \frac{1 + \frac{(N-1)r}{R}}{Nrln\frac{2H}{r_{eq}}\frac{1}{[(1+(\frac{2H}{S})^2)(1+(\frac{H}{S})^2)]^{1/4}}} \tag{5.47}$$

Same as For inner phase,

$$E_{cm} = \frac{1 + \frac{(N-1)r}{R}}{Nrln\frac{2H}{r_{eq}}\frac{1}{[1+\frac{2H}{S}]^{1/2}}} \tag{5.48}$$

Equations are known as Mangoldt or Markt-Mengele Formulas. They were first derived only for the centre phase which gives a higher maximum voltage gradient than the outer phases. With corona assuming lot more importance since this formula was derived, we have extended their thinking to the outer phases also.

5.13 Corona loss

when the alternating potential between two parallel conductors increase beyond a certain limits, a point is reached when a pale violet glow appears on the conductor surface, and accompanied by hissing sound. This phenomenon is known as corona. The atmosphere contains some charged particles or ions and the flow of current through a conductor causes such particles to move, Which collied in their transit with the uncharged particles in air. When the potential gradient is sufficient high, these particles will discharge due to violent collision of electron and thus ionise uncharged particles.The effect continues as a chain reaction. The minimum potential difference required between the conductors, to start ionisation is termed as the disruptive critical voltage for corona formation. When the line-to-line voltage is above the disruptive critical voltage, the corona occurs but there is no visual glow. For visual glow, a higher voltage is necessary and this is termed as visual critical voltage.

In EHV transmission line corona loss is of main consideration due to its higher voltage level. As voltage level is increased, there is considerable increase in corona losses. Corona phenomena are drastically affected by the weather. Foul weather conditions have the greatest effect on corona generation. Here both fair weather condition and foul weather condition are considered.
EPRI(Electrical Power Research Institute) Red Book has several methods for calculating corona losses under various weather conditions. Most of these methods were developed many years ago, and unlike radio noise and audible noise, a comparison of all of these methods with corona loss measurements has never been conducted. However, it is the opinion of the authors that until further studies are conducted, any one of the methods suggested in EPRI Red Book can be used for compact lines. However, one needs to be alert to the fact that many of these methods do not take altitude into consideration and were developed from measurements on conductors that for the most part carried no load current (unheated conductors). High altitude seems to be a situation where corona loss may play a role in conductor selection for overhead transmission

lines (Burns et al. 1985). The corona loss applet in (EPRI 2005) calculates corona loss using the following six methods:

(1) Petersons Formula Applies only to single conductors

(2) EDF Method Developed for any type of line

(3) BPA Method Developed for any type of line

(4) IREQ Method Developed for any type of line

(5) EPRI Red Book, Second Edition Developed for any type of line

(6) Project EHV Method Developed for lines with voltages between 345 and 800 kV

1)Fair weather Condition

As per peterson's formula:

$$P_c = \frac{21 * 10^{-6} * f * V_s^2 * F}{(log\frac{GMD}{GMR})^2} \tag{5.49}$$

Here F factor depend on V/Vd ratio.

$$V_d = \frac{3 * 10^6}{\sqrt{2}} * r * \delta * \mu * ln(\frac{GMD}{GMR}) \tag{5.50}$$

and $\delta = \frac{3.86*p}{273+t}$

Here,

f=frequency (Hz)

V_s = Sending end Voltage (KV)

GMD= Geometric mean distance (m)

μ = Surface factor (0 to 1, according to surface of conductor)

p=barometric pressure (cm)

r= radius of conducto (m)

t =temperature (^oC)

2)Foul weather Condition

An equation for corona loss in rain giving the excess loss above the fair weather loss is

$P_c = P_{FW} + [\frac{V}{\sqrt{3}} * J * r^2 * ln(1 + K * \rho)] * \sum_{i=2} 3N$ (KW/3phase/Km)

Here,

$P_FW = Total3phasefairweathercoronaloss$

V= Conductor Voltage (Kv) Line-Line

J=Loss current constant=$4.37 * 10^{-10} for400kvline$

r=Conductor radius (Cm)

K= Wetting Co-efficient(=10,for RR in mm/hr)

RR = rain rate in (mm/hr)

N= number of conductor in bundle of each phase

$E_i = Surfacevoltagegradient(KV/cm)$

5.14 Audible Noise

Audible noise is undesired sound that is produced by EHV transmission line (usu- ally corona loss is accompanied by hissing sound i.e. AN).To calculate the corona generated sound pressure in the vicinity of a power transmission line, essentially two factors must be considered. The generated sound pressure of the line and the prop- agation effects on the sound as it travels away from the line. The combination of the propagation equation with the generation equation gives the heavy-rain sound pressure in dB.

5.14.1 Heavy Rain

Heavy rain Audible noise is calculated using following empirical formula

$$AN(i) = 120log_{10}E(i)+55log_{10}d-11.4log_{10}D(i)+26.4log_{10}N-128.4dBifN > 3 \quad (5.51)$$

Where,

$E(i) = AverageMaximumsurfacegradient$

d=Diameter of sub-conductor

N= Number of sub-conductor

D(i)=Aerial distance from phase(i) to location of microphone

$$AN(i) = 120log_{10}E(i) + 55log_{10}d - 11.4log_{10}D(i) - 115.4dBifN < 3 \quad (5.52)$$

After calculating the sound from each phase of a multi-phase line by above equation, the resultant noise due to all the phases is calculated by above by summation of the sound from individual phases as follows

$$P_{Total} = 10log(\sum_{i=1}^{n} 10^{(AN(i)/10)} \quad (5.53)$$

5.15 Radio Interference

Radio interference is degradation of the reception of a wanted signal caused by RF disturbance. The RI (dB) level from conductor i at an aerial distance D from conductor to any point along the ground is calculated by following empirical formula

$$RI(dB) = 3.5g_m + 6d - 33log(D_i/22) - 30 \quad (5.54)$$

On a double circuit line, there are two phase conductors belonging to each phase. the resulting RI value due to the two circuits are

$$RI_A = 20log\sqrt{10^(RI_{a1}^2) + 10^(RI_{a2}^2)} \quad (5.55)$$

$$RI_B = 20log\sqrt{10^(RI_{b1}^2) + 10^(RI_{b2}^2)} \quad (5.56)$$

$$RI_C = 20log\sqrt{10^(RI_{c1}^2) + 10^(RI_{c2}^2)} \tag{5.57}$$

The quantities $RI_A, RI_B, andRI_C$, are treated as the contributions from the three phases.

$RI(dB) = (Averageoftwoheighest + 1.5)$

5.16 Sag Tension Calculation

5.16.1 Introduction to Sag

The difference in level between points of supports the lowest point on the conductor is called sag.It is very important that conductors are under safe tension.In order to permit safe tension in conductors they are not fully stretched but are allowed to have sag.

The regulations require that sag must be calculated for worst probable conditions and the minimum ground clearance should be maintained for these conditions. Moreover, the maximum tension in the conductor should not exceed half the breaking load (so as to allow a factor of safety of two).In practice the ambient conditions, when the line is erected, are very different from the worst probable conditions.

Factor Affecting Sag

(1) Weight of Conductor:: Sag is directly proportional to weight per unit length of conductor. Ice and Wind loads also increase the sag.

(2) Span: A longer span causes more sag. Since sag is proportional to square of span, an increase of 25

(3) Conductor Tension: Sag is inversely proportional to conductor tension. However, an increase in conductor tension causes more stresses in the conductor and more load on insulation and towers.

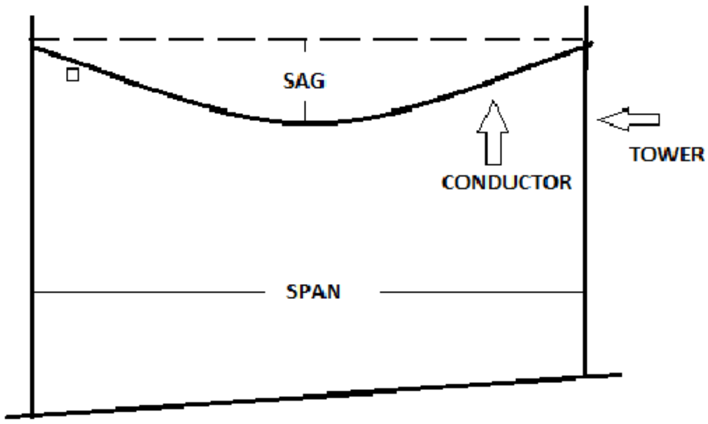


Figure 5.6: Sag

Table I: Span As Per kV

VOLTAGE IN kV	SPAN (m)
11	50
66	200
110	250-300
132	300
230	335-375
400	400

(4) Ground Clearance: Electricity rules specify minimum clearance between the ground and conductor. To maintain this clearance, it may be necessary to increase the height of the towers if higher value of sag is desired.

(5) Temperature: A decrease in temperature reduces the sag. However, when a decrease in temperature is accompanied by snow and wind, the sag may increase. Generally heavy snow and high wind pressure create worst condition for the line.

When a conductor is strung between two support points, then it forms catenary and follow a parabolic curve. This shape of conductor is due to its weight, however conductor in its lifetime also elongate with time, temperature, tension, weight (due to ice and wind loading) thereby it increases the sag and hence decrease the clearance above the ground. Tension of conductor depend on temperature and wind velocity, and Sag-Tension are inversely proportional to each other. Thus prior calculation of sag and tension for any conductor is essential. Conductor sag is the vertical distance between point of fixity on tower to the null point (lowest point on catenary). Sag in a conductor is obtained using following equation (considering both tower are on same level).

$S = \frac{WL^2}{8T}$ (m)

$T = f * A$

Where,

S=sag at mid span,in meter

W=Weight of conductor(N/m)

L=Length of span i.e.Horizontal distance between supports.

T= Conductor Tension in Newton

L= Span between two tower (m)

f= Stress on conductor (Kg/m2)

Basic equations required for sag tension calculations:

Reference wind speed: $VR = \frac{Vb}{K0}$(m/s)

Design wind speed:$Vd = VR * K1 * K2$ (m/s)

Design wind pressure:$Pd = 0.6 * (Vd)^2$ (N/m2)

Wind on conductor: $P = \frac{Pd*Gc}{9:81}(Kg/m2)$

$Density of conductor : \delta = \frac{w}{A}(Kg/m/m2)$

Tension:$T = \frac{U}{F:O:S}(Kg)$

Resultant load: $q = \sqrt{1 + (\frac{P*P_i*D}{w})^2}$

Variable operator: $G = \frac{L^2*\delta^2*q^2*E}{24}$

Also $G = f^2 * (f - (k - \alpha * t * E))$

here constant$k = f - \frac{G}{f^2} + \alpha * t * E$

Now as value of constant k term is obtained, then value of f is calculated, by equating both G equation (eliminating G), by trial and error method. And after obtaining value of f, sag and tension calculation are obtained for different wind conditions and temperature.

V_b: Wind speed (m/s)

K_0: is a factor to convert 3second gust speed into average speed of wind during 10 minutes period. (constant value K0=1.375 should be taken)

K_1: Risk Co-efficient

K_2: Terrain Roughness Coefficient

G_c: Gust Response Factor.

w: Weight of conductor per meter (Kg/m)

A: Area of conductor (m2)

P_i: Different wind condition

U: Ultimate tensile strength (Kg)

F.O.S.: Factor of Safety $=\frac{S}{T}$

L: $Span of conductor (m)$

$\alpha : Co-efficient of linear expansion$

t: Temperature (0C)

E: Modulus of elasticity (Kg/m2)

5.16.2 SAG-TENSION CALCULATION FOR ACSR MOOSE CONDUCTOR OF UNIT

ACSR conductor detail are as follow:

Ultimate Strength- 16,438 (kg)

Overall dia.-3.177 cm

Total Section area-5.970 cm^2

Unit Weight-2.004 kg/m

Co-efficient of Linear Expansion-$19.30 * 10^{-6}$

Modulus of Elasticity-$0.704 * 10^{10}$

Reference wind speed: $V_R = \frac{V_b}{K_0} = \frac{47}{1.375} = 34.18$ m/s

Design wind speed: $V_d = VR * K1 * K2 = 34.18 * 1 * 1 = 34.18$ m/s

Design wind pressure:$P_d = 0 : 6 * (V_d)^2 = 0 : 6 * (34 : 18)^2 = 701.04 N/m^2$

Wind on conductor: $P = \frac{P_d * Gc}{9:81} = \frac{701.04*1.798}{9.81} = 128.49 Kg/m^2$

Density of conductor:$\delta = \frac{w}{A} = \frac{2.004}{5.97*10^{-4}} = 3356.7839 Kg/m/m^2$

Wind force:$p = P * D = 128 : 49 * 3.177 * 10^{-2} = 4.08$ Kg

For different wind conditions, values of q can be obtained as:

$q = \sqrt{1} + (\frac{P*D*P_i}{w})^2 (Resultantload)$

$q_1^2 = 1 + (\frac{128.49*3.177*10^{-2}*1}{2.004})^2 = 5.149 (UnderfullWind)$

$q_2^2 = 1 + (\frac{128.49*3.177*10^{-2}*0.36}{2.004})^2 = 1.5377 (Under36offullWind)$

$q_3^2 = 1 + (\frac{128.49*3.177*10^{-2}*0}{2.004})^2 = 1 (UndernowindCondition)$

Now for different wind condition, value of variable operator are:

$G = \frac{L^2 * \delta^2 * q_i^2 * E}{24}$

$G_1 = \frac{400^2 * 3356.7839^2 * 5.149 * 7.04 * 10^9}{24} = 2.723 * 10^{21}$(Under full Wind)

$G_2 = \frac{400^2 * 3356.7839^2 * 1.5377 * 7.04 * 10^9}{24} = 8.132 * 10^{20}$ (Under 36 of Wind)

$G_3 = \frac{400^2 * 3356.7839^2 * 1 * 7.04 * 10^9}{24} = 5.288 * 10^{20}$(Under no wind Condition)

Values of stress and working tension both are calculated as follows, if either of conditions (F.O.S.,tension or sag) are known or considered for boundary limits.

(1) Calculation for given value of F.O.S.

Tension:$T = \frac{U}{F:O:S} = \frac{16432}{4.5454} = 3615.04 Kg$

Now,$f = \frac{T}{A} = \frac{3615.4015}{5.97*10^{-4}} = 6.055 * 10^6 Kg/m^2$

Now consider case 1, where F.O.S. is taken as 4.545 (ratio of $100strengthand22G$ as $G3$, under no wind condition)

Also $G = f^2 * (f - (k - \alpha * t * E))$

$\therefore k = f - \frac{G}{f^2} + \alpha * t * E$

$= 6.055 * 10^6 - \frac{5.288*10^{20}}{(6.055*10^6)^2} + (19.3 * 10^{-6} * 32 * 7.04 * 10^9)$

$\therefore k = -4.02 * 10^6$

This k is constant for specific span and is independent of temperature and wind pressure variation. Similarly value of k can be found out for case 2 and 3 where value of sag and tension are given.

Now following unknown are found out as follows:

(1) Under full wind condition consider $G = G_1 = f^2 * (f - (k - \alpha * t * E))$

i. Sag and Tension at 0 Degree (Minimum Temperature) and full wind.
$2.723 * 10^{21} = f^2 * (f - (-4.02 * 10^6 - (19.3 * 10^{-6} * 0 * 7.04 * 10^9)))$
$f = 1.27 * 10^7$ (Trial and error method)
Working tension: $T = f * A = 1.27 * 10^7 * 5.97 * 10^{-4} = 7611.21kg$
$Sag = \frac{W*L^2}{8*T} = \frac{2.004*400^2}{8*7611.21} = 5.27m$

ii. Sag and Tension at 32 Degree (Every day temperature) and full Wind.
$2.723 * 10^{21} = f^2 * (f - (-4.02 * 10^6 - (19.3 * 10^{-6} * 32 * 7.04 * 10^9)))$
$f = 1.17 * 10^7$ (Trial and error method)
Working tension: $T = f * A = 1.17 * 10^7 * 5.97 * 10^{-4} = 6963.65kg$
$Sag = \frac{W*L^2}{8*T} = \frac{2.004*400^2}{8*6963.65} = 5.76m$

iii. Sag and Tension at 85 Degree (Every day temperature) and full Wind.
$2.723 * 10^{21} = f^2 * (f - (-4.02 * 10^6 - (19.3 * 10^{-6} * 85 * 7.04 * 10^9)))$
$f = 1.2 * 10^7$ (Trial and error method)
Working tension: $T = f * A = 1.2 * 10^7 * 5.97 * 10^{-4} = 6089.4kg$
$Sag = \frac{W*L^2}{8*T} = \frac{2.004*400^2}{8*6089.4} = 6.58m$

(2) Under 36 wind condition consider $G = G_2 = f^2 * (f - (k - \alpha * t * E))$

i. Sag and Tension at 0 Degree (Minimum Temperature) and 36 wind.

$8.132 * 10^{20} = f^2 * (f - (-4.02 * 10^6 - (19.3 * 10^{-6} * 0 * 7.04 * 10^9)))$

$f = 8.17 * 10^6$ (Trial and error method)

Working tension: $T = f * A = 8.17 * 10^6 * 5.97 * 10^{-4} = 4877.73kg$

$Sag = \frac{W*L^2}{8*T} = \frac{2.004*400^2}{8*4877.73} = 8.22m$

ii. Sag and Tension at 32 Degree (Minimum Temperature) and 36 wind.

$8.132 * 10^{20} = f^2 * (f - (-4.02 * 10^6 - (19.3 * 10^{-6} * 32 * 7.04 * 10^9)))$

$f = 7.22 * 10^6$ (Trial and error method)

Working tension: $T = f * A = 7.22 * 10^6 * 5.97 * 10^{-4} = 4312.79kg$

$Sag = \frac{W*L^2}{8*T} = \frac{2.004*400^2}{8*4312.79} = 9.29m$

iii. Sag and Tension at 85 Degree (Minimum Temperature) and 36 wind.

$8.132 * 10^{20} = f^2 * (f - (-4.02 * 10^6 - (19.3 * 10^{-6} * 85 * 7.04 * 10^9)))$

$f = 6.52 * 10^6$ (Trial and error method)

Working tension: $T = f * A = 6.52 * 10^6 * 5.97 * 10^{-4} = 3892.44kg$

$Sag = \frac{W*L^2}{8*T} = \frac{2.004*400^2}{8*3892.44} = 10.29m$

(3) Under no wind condition consider $G = G_3 = f^2 * (f - (k - \alpha * t * E))$

i. Sag and Tension at 0 Degree (Minimum Temperature) and no wind.

$5.288 * 10^{20} = f^2 * (f - (-4.02 * 10^6 - (19.3 * 10^{-6} * 0 * 7.04 * 10^9)))$

$f = 6.94 * 10^6$ (Trial and error method)

Working tension: $T = f * A = 6.94 * 10^6 * 5.97 * 10^{-4} = 4145.63kg$

$Sag = \frac{W*L^2}{8*T} = \frac{2.004*400^2}{8*4145.63} = 9.67m$

ii. Sag and Tension at 32 Degree (Minimum Temperature) and no wind.

$5.288 * 10^{20} = f^2 * (f - (-4.02 * 10^6 - (19.3 * 10^{-6} * 32 * 7.04 * 10^9)))$

$f = 6.05 * 10^6$ (Trial and error method)

Working tension: $T = f * A = 6.05 * 10^6 * 5.97 * 10^{-4} = 3614.48kg$

$Sag = \frac{W*L^2}{8*T} = \frac{2.004*400^2}{8*3614.48} = 11.09m$

iii. Sag and Tension at 85 Degree (Minimum Temperature) and no wind.

$5.288 * 10^{20} = f^2 * (f - (-4.02 * 10^6 - (19.3 * 10^{-6} * 85 * 7.04 * 10^9)))$

$f = 5.5 * 10^6$ (Trial and error method)

Working tension: $T = f * A = 5.376 * 10^6 * 5.97 * 10^{-4} = 3283.5kg$

$Sag = \frac{W*L^2}{8*T} = \frac{2.004*400^2}{8*3283.5} = 12.2m$

5.17 Sag Templates

A sag template is a very convenient way of locating the towers in the field. This template is prepared on celluloid or tracing cloth and the curves are drawn to same horizontal and vertical scales as the profile of the line.

The upper curve represents conductor. The middle curve is below the upper curve by a uniform vertical distance equal to the desired minimum vertical clearance to ground. The lower curve is below the upper one by a uniform vertical distance equal to height of standard tower measured to the point of support of the conductor.

If the left tower in has been located, then the position of the right hand tower is found by adjusting the sag template so that the line passes through the point of support on the left hand tower and the clearance line is tangent to ground and never dips below. The tower footing line indicates the actual position of tower on ground.Sag-tension Curve is as shown in figure4.7

5.17.1 Tower Spotting

Since each tower is designed to withstand a definite load only, in each of transverse, vertical and longitudinal directions, the surveyor must know these limitations for the various types of towers available for use on line so than he can spot an appropriate type of tower structures along the route. These limits are given in a chart form called Structure Limitation Chart or Tower Spotting Data which is prepared by the design department of the utility /contractor. These charts define the limits for permissible ruling span, weight span, wind span, individual span and the degree of the deviation allowed on each of the standard towers. These charts are made for normal towers only.

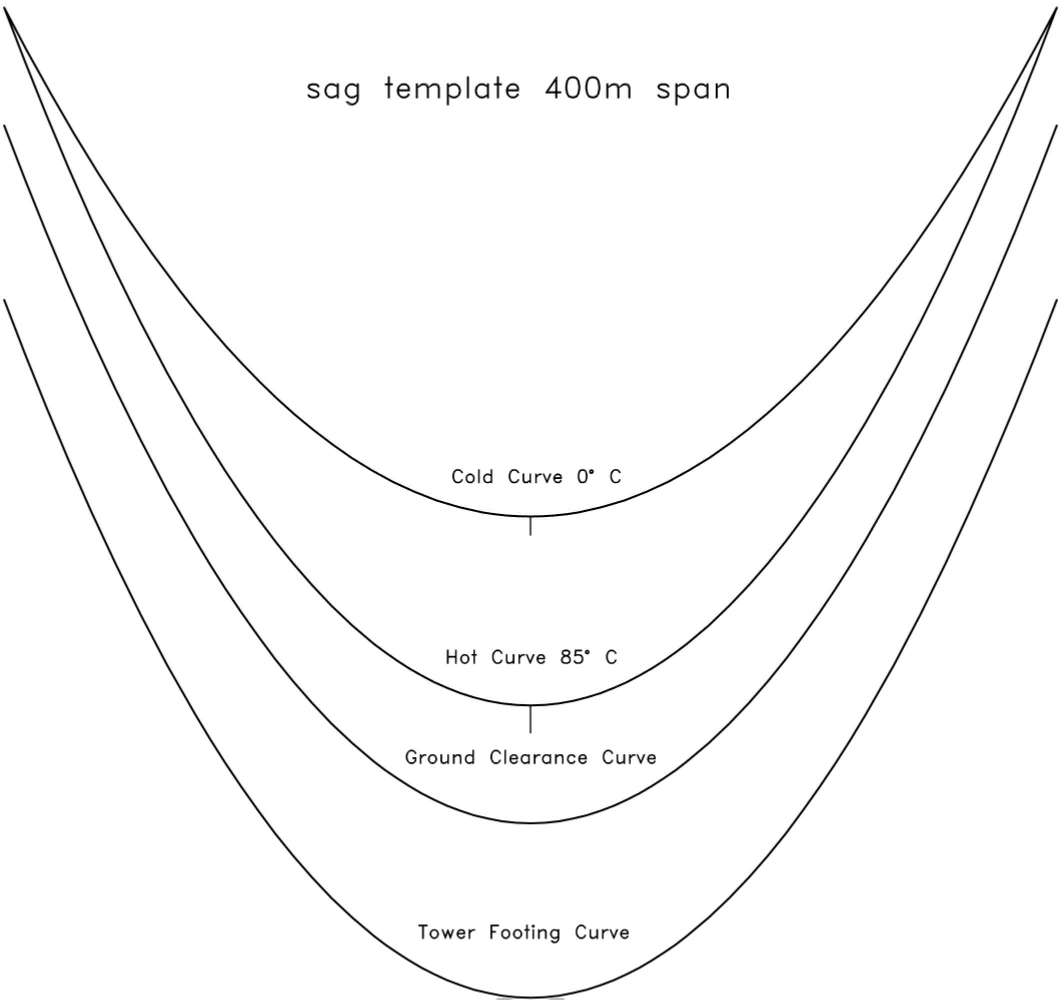


Figure 5.7: Sag-Tension Curve

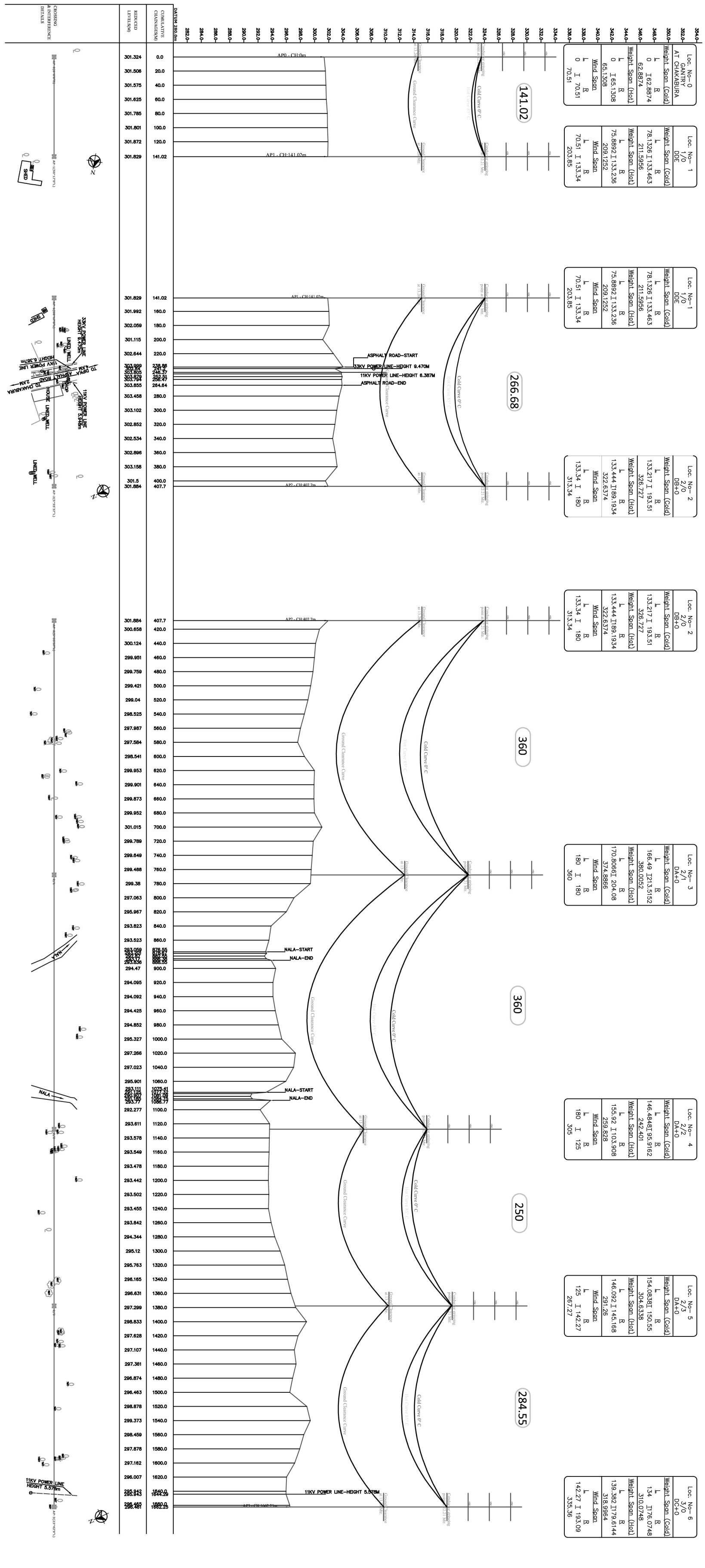


Figure 5.8: Transmission line Profile

Chapter 6

Line calculation

6.1 Inductance Calculation

Spacine considered between Conductor and subconductor are shown in figure5.1

Distance of Phase A from center of Tower D_{ha} = 6540 mm

Distance of Phase B from center of Tower D_{hb} = 7120 mm

Distance of Phase C from center of Tower D_{hc} = 8230 mm

Vertical Separation between Conductor D_v = 8000 mm

(1) GMD

i. D_{AB}

Distance between $D_{ab} = D_{a'b'} = \sqrt{D_v^2 + (D_{hb} - D_{ha})^2} = \sqrt{8000^2 + (7120 - 6540)^2}$

=8020.997 mm

Distance between $D_{ab'} = D_{a'b} = \sqrt{D_v^2 + (D_{hb} - D_{ha})^2} = \sqrt{8000^2 + (7120 + 6540)^2}$

=15830.212 mm

$D_{AB} = 4\sqrt{(D_{ab} * D_{a'b'} * D_{a'b} * D_{ab'})}$

$D_{AB} = 4\sqrt{(8020.997 * 8020.997 * 15830.212 * 15830.212)}$

$D_{AB} = 11268.278mm$

ii. D_{BC} Distance between $D_{bc} = D_{b'c''} = \sqrt{D_v^2 + (D_{hc} - D_{hb})^2} = \sqrt{8000^2 + (8230 - 7$

=8076.639 mm

Distance between $D_{ab'} = D_{a'b} = \sqrt{D_v^2 + (D_{hb} - D_{ha})^2} = \sqrt{8000^2 + (8230 + 7120)^2$

=17309.607 mm

$D_{BC} = 4\sqrt{(D_{bc} * D_{b'c'} * D_{b'c} * D_{bc'})}$

$D_{BC} = 4\sqrt{(8076.639 * 8076.693 * 17309.607 * 17309.607)}$

$D_{BC} = 11823.851mm$

iii. D_{CA} Distance between $D_{cz} = D_{c'a'} = \sqrt{D_v^2 + (D_{hc} - D_{ha})^2} = \sqrt{8000^2 + (8230 - 6$

=16089.006 mm

Distance between $D_{ca'} = D_{c'a} = \sqrt{D_v^2 + (D_{hc} - D_{ha})^2} = \sqrt{8000^2 + (8230 + 6540)^2$

=21775.052 mm

$D_{CA} = 4\sqrt{(D_{ca} * D_{c'a'} * D_{c'a} * D_{ca'})}$

$D_{CA} = 4\sqrt{(16089.006 * 16089.006 * 21775.052 * 21775.052)}$

$D_{CA} = 18717.343mm$

Now,

$GMD = 3\sqrt{(D_{AB} * D_{BC} * D_{CA})} = 3\sqrt{(11268.278 * 11823.851 * 18717.343)}$

$GMD = 13560.85mm$

(2) GMR

i. D_{SA}

$D_{SA} = \sqrt{D_{aa} * D_{aa'}}$

$D_{aa} = 1.09 * 4\sqrt{0.7788 * 15.89 * 450^3} = 199.7281$ mm

$D_{aa'} = 6540 * 2 = 13080$ mm

$D_{SA} = \sqrt{199.7281 * 13080}$

=1616.3 mm

ii. D_{SB}

$D_{SB} = \sqrt{D_{bb} * D_{bb'}}$

$D_{bb} = 1.09 * 4\sqrt{0.7788 * 15.89 * 450^3} = 199.7281$ mm

$D_{bb'} = 7120 * 2 = 14240$ mm

$D_{SB} = \sqrt{199.7281 * 14240}$

=1686.5 mm

iii. D_{SC} $D_{SC} = \sqrt{D_{cc} * D_{cc'}}$

$D_{cc} = 1.09 * 4\sqrt{0.7788 * 15.89 * 450^3} = 199.7281$ mm

$D_{cc'} = 8230 * 2 = 16460$ mm

$D_{SC} = \sqrt{199.7281 * 16460}$

=1813.2 mm

Now,

$GMR = 3\sqrt{1616.3 * 1686.5 * 1813.2}$

$GMR = 1703.4$

$InductanceL = 2 * 10^{-7} ln\frac{GMR}{GMD}(H/Phase/m)$

$= 2 * 10^{-7} ln\frac{13560.85}{1703.4}$

$\therefore Inductance = 4.14 * 10^{-7}(H/phase/m)$

Inductance $= 0.000414(H/Phase/Km)$

6.2 Capacitance Calculation

(1) GMD for inductance and capacitance calculation are same.

$\therefore GMD = 13560.85$

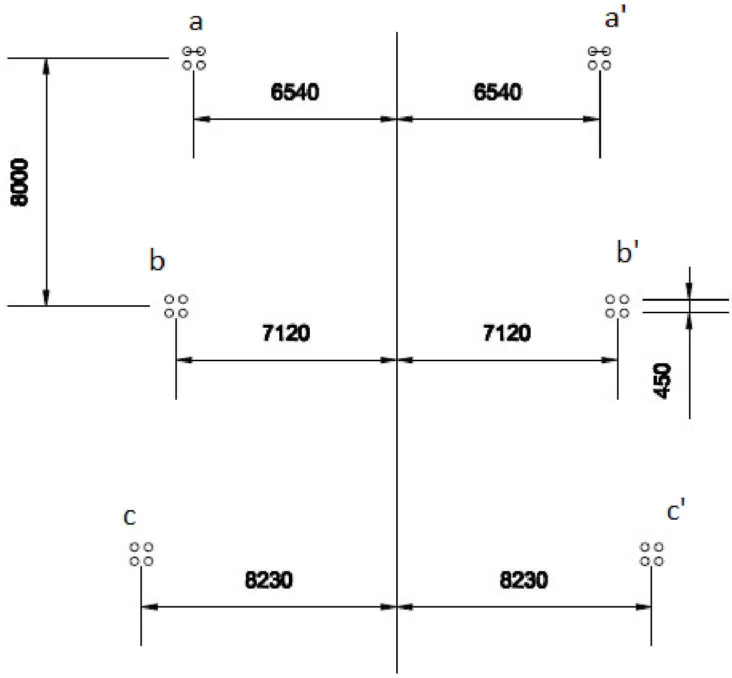


Figure 6.1: Spacing between Conductor and subconductor

(2) GMR

i. D_{SA}

$D_{SA} = \sqrt{D_{aa} * D_{aa'}}$

$D_{aa} = 1.09 * 4\sqrt{15.89 * 450^3} = 212.6095$ mm

$D_{aa'} = 6540 * 2 = 13080$ mm

$D_{SA} = \sqrt{212.6095 * 13080}$

=1667.6 mm

ii. D_{SB}

$D_{SB} = \sqrt{D_{bb} * D_{bb'}}$

$D_{bb} = 1.09 * 4\sqrt{15.89 * 450^3} = 212.6095$ mm

$D_{bb'} = 7120 * 2 = 14240$ mm

$D_{SB} = \sqrt{212.6095 * 14240}$

$= 1740$ mm

iii. D_{SC} $D_{SC} = \sqrt{D_{cc} * D_{cc'}}$

$D_{cc} = 1.09 * 4\sqrt{15.89 * 450^3} = 212.6095$ mm

$D_{cc'} = 8230 * 2 = 16460$ mm

$D_{SC} = \sqrt{212.6095 * 16460}$

=1813.2 mm

Now,

$GMR = 3\sqrt{1667.6 * 1740 * 1813.2}$

$GMR = 1757.4$

$CapacitanceC = \frac{0.05560618997}{ln\frac{GMR}{GMD}}$

$= \frac{0.05560618997}{ln\frac{13560.85}{1757.4}}$

$Capacitance = 0.0272(\mu F/phase/m)$

6.3 Resistance, Impedance and Admittance

(1) Resisitance of whole line for one Phase is given by

$R = \frac{(R_{ac}*300)}{4}$

$= 5.2$ ohm

(2) $ReactanceTotalReactanceofline = 2 * /pi * f * L$

$= 2 * \pi * 50 * L$

$X = 39.1048ohm$

(3) Impedance of line$Z = R + jX$

$\therefore Z = 5.2 + j39.10$

(4) Admittance of line $Y = 2 * \pi * f * C * 10^{-6}\mho$

$= 2 * \pi * 50 * 2.22 * 10^{-6}$

$\therefore 0.0026i\mho$

6.4 Voltage Regulation

(1) ABCD Parameter

i. A and D parameter

$A = cosh(al + bl) = cosh(\sqrt{ZY})$

$= cosh(\sqrt{(5.2 + j39.10)(0.0026j)})$

$\therefore A = D = 0.9503 + 0.0066j$

ii. B parameter

$B = Z_c * sinh(al + bl) = \sqrt{\frac{Z}{Y}} * sinh * (\sqrt{ZY})$

$B = 5.0371 + 38.4658j$

iii. C Parameter

$C = \frac{1}{Z_c} * sinh(al + bl) = \frac{1}{Z_c} * sinh * (\sqrt{ZY})$

$C = -0.000 + 0.0025j$

(2) Voltage Regulation

$V_s = A * V_r + B * I_r$

Assume that Receiving end power factor will be 0.8. $I_r = \frac{P}{\sqrt{3} * V_r * p_f}$

Table I: Voltage regulation at different power factor

Power(MW)	P_f(Receiving end)	V_R	length
600	0.8	8.52	300
700	0.8	10.9	300
800	0.85	10.8	300
900	0.9	10.2	300
1000	0.95	8.54	300
1100	0.95	10.13	300

For different receiving end power factor power trasfer at permissible voltage regulation can be determine by given tableI

6.5 Voltage gradient for vertical configuration

6.5.1 Voltage Gradient Calculation by Markt and Mengele's Method

- Maximum C phase surface voltage gradient:

$$E_c = \frac{1 + \frac{(N-1)r}{R}}{Nrln\frac{2H}{r_{eq}} * \frac{1}{X_{c1} * X_{c2}}} = 16.5601 \tag{6.1}$$

$X_{c1} = \frac{\sqrt{(2H+S)^2+(DisC-DisB)^2}}{DisBC}$

$= 4.2119$

$X_{c2} = \frac{\sqrt{(2H+2S)^2+(DisC-DisA)^2}}{DisAC}$

$= 2.6126$

- Maximum B phase surface voltage gradient:

$$E_b = \frac{1 + \frac{(N-1)r}{R}}{Nrln\frac{2H+2S}{r_{eq}} * \frac{1}{X_{b1} * X_{b2}}} = 19.5925 \tag{6.2}$$

$X_{b1} = \frac{\sqrt{(2H+S)^2+(DisC-DisB)^2}}{DisBC}$

$= 4.2119$

$X_{b2} = \frac{\sqrt{(2H+3S)^2+(DisB-DisA)^2}}{DisAB}$

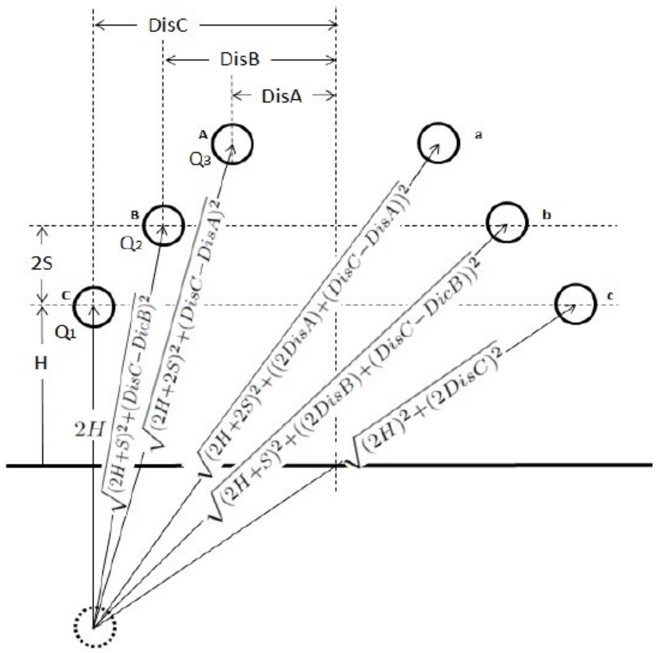


Figure 6.2: Voltage Gradient for Double circuit

= 6.2341

- Maximum C phase surface voltage gradient:

$$E_a = \frac{1 + \frac{(N-1)r}{R}}{Nrln\frac{2H+4S}{r_{eq}} * \frac{1}{X_{c1} * X_{c2}}} = 14.2422 \tag{6.3}$$

$X_{a1} = \frac{\sqrt{(2H+3S)^2+(DisB-DisA)^2}}{DisBA}$

= 6.2341

$X_{a2} = \frac{\sqrt{(2H+2S)^2+(DisC-DisA)^2}}{DisCA}$

=2.6126

Where,

$R : B/(2 * Sin\pi * N)(m)$

$GMR : R_{eq} = (n * r * R^(n-1))^(\frac{1}{n})$

B: Bundle spacing (m)

N: Number of sub conductor in bundle.

r: radius of sub conductor in bundle (m).

H: Height of conductor from ground (m).

S: Spacing between conductor (m).

DisA: Distance between mid of tower to conductor of phaseA (m).

DisB: Distance between mid of tower to conductor of phaseB (m).

DisC: Distance between mid of tower to conductor of phaseC (m).

Disxy: Distance between conductor of phase x to phase y (m).(x=A,B,C y=a,b,c)

6.6 Novel Method to Find Surface Voltage Gradient

Certain basic assumptions are involved in all the existing methods for calculating the electric field in the vicinity of transmission line conductor

- The ground is assumed to be an infinite horizontal conducting plane surface
- The conductor are assumed to be smooth infinitely long circular cylinders parallel to each other and to the ground plane
- The conductor are assumed to be equipotential surface, with known potential applied to them, the ground plane is assumed to be at zero potential

In addition to the above, it is also assumed that the horizontal spacing between the conductors remains constant as specified value and that the height above ground of each conductor is an average value equal to H-2/3S where H is the height above ground at support point and S is the estimated mean annual conductor temperature.

The Finite Element Method can analyze geometries with irregular shapes coupled with different field. However it is limited by the scale of geometries it can simulate. The largest number of mesh elements an 8 gigabyte PC can sustain is approximately one million. Taking the proposed transmission line parameters as an example, simulation for whole span of overhead line will result less than two elements over a 1 cm length on the conductor surface. This number can be increased by using a finer mesh size in vicinity of conductor surface. However

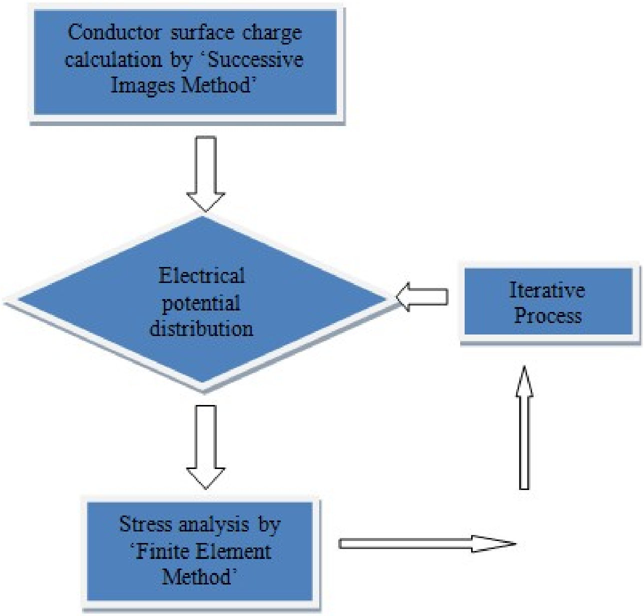


Figure 6.3: Novel Method Flow Chart

this demonstrates the limitation of FEM in modeling the large scale transmission line environment. On the other hand, the successive images Method can only simulate regular cylindrical conductor with smooth surface profile, but it can do so for a relatively large scale for two dimensions.

These characteristics make it possible to combine the two methods together as shown in figure5.3 to analyze the surface stranding effect within the whole scale of transmission line environment.The flow chart in fig combines the two methods in analyzing the surface field distribution. The Successive Images Method is employed to calculate the electric charge on conductor surface. Within large scale, surface profile and protrusions are negligible, so the calculation results obtained are within tolerable distortion. As long as large scale results are obtained, a micro-scale domain is extracted as boundary conditions for FEM process.

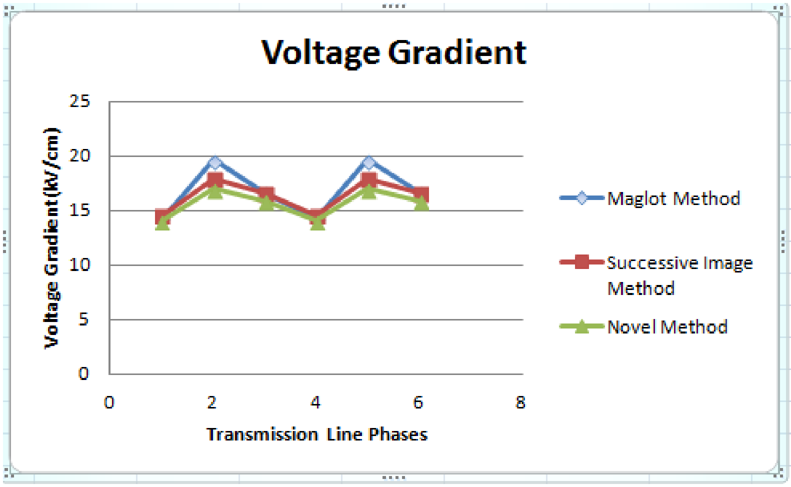


Figure 6.4: Comparison among different Methods

Table II: Surface Gradient Result for analytical methods

Gradient	Markte-Maglot Method			Successive Image Method		
	R	Y	B	R	Y	B
A	14.24	19.59	16.56	14.49	17.93	16.56
AM		16.79			16.32	
MB		19.59			17.93	

6.6.1 Result analysis

As present in fig, two numerical methods have been studied and Maximum Surface Gradient (rms) for each is compared. It is found that phase 2 and 4 sustain higher surface stresses while phase 1, 3, 4 and 6 create lower stress (see fig.1). When comparing the different methods, Successive Images Methods give accurate value and Maglot give higher value due to non-uniform charge density.

The simulation results shown in figure5.4 are produced from the novel method as previously introduced. TableII compares the results between the simplified calculation and novel method. Traditional empirical equations for noise level evaluation employ the maximum gradient on a smooth cylinder as an intermediate variable. However, the acoustic power depends upon the surface area of emission. So the percentage of surface area having surface stress above a certain level is more important than single maximum value overall. Where,

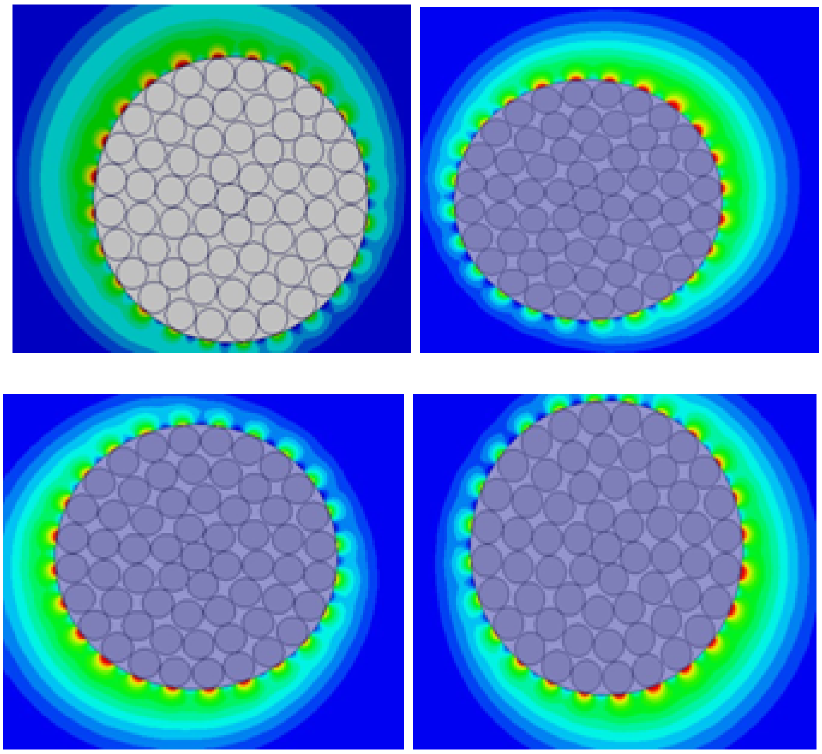


Figure 6.5: Result of Novel method for one phase

A: Average bundle gradient

AM: Average maximum bundle gradient

MB: Maximum bundle gradient

Table III: Novel method results

Phase	Emax(kV/cm)	Eavg(kV/cm)
R phase	21.30	13.01
Y phase	22	14.01
B phase	20.56	13.94
R' phase	21.30	13.01
Y' phase	22	14.01
B' phase	20.56	13.94

6.7 Audio Noise

Audio noise in Transmission Line can be derive by following equation for heavy rain condition:

$$AN(i) = 120log_{10}E(i)+55log_{10}d-11.4log_{10}D(i)+26.4log_{10}N-128.4dBifN > 3 \tag{6.4}$$

- $AN(1) = 120log_{10}(17.74)+55log_{10}(3.177)-11.4log_{10}(19.84)+26.4log_{10}(4)-128.4dBifN > 3$
  = 149.87+27.61-14.79+15.89-128.4
  =50.18 (dB)

- $AN(2) = 120log_{10}(19.42)+55log_{10}(3.177)-11.4log_{10}(26.46)+26.4log_{10}(4)-128.4dBifN > 3$
  = 154.58+27.61-16.21+15.89-128.4
  =53.47(dB)

- $AN(3) = 120log_{10}(15.21)+55log_{10}(3.177)-11.4log_{10}(33.41)+26.4log_{10}(4)-128.4dBifN > 3$
  = 141.85+27.61-17.37+15.89-128.4
  = 39.58 (dB)

- $AN(4) = 120log_{10}(17.74)+55log_{10}(3.177)-11.4log_{10}(34.04)+26.4log_{10}(4)-128.4dBifN > 3$
  = 149.87+27.61-17.46+15.89-128.4
  = 47.51 (dB)

- $AN(5) = 120log_{10}(19.42)+55log_{10}(3.177)-11.4log_{10}(36.89)+26.4log_{10}(4)-128.4dBifN > 3$
  = 154.58+27.61-17.86+15.89-128.4

= 51.82 (dB)

- $AN(6) = 120log_{10}(15.21)+55log_{10}(3.177)-11.4log_{10}(41.55)+26.4log_{10}(4)-128.4dB if N > 3$
  = 141.85+27.61-18.45+15.89-128.4
  = 38.5 (dB)
- Total AN
  $= 10 * log[10^{5.018} + 10^{5.347} + 10^{3.958} + 10^{4.751} + 10^{5.182} + 10^{3.85}]$
  = 57.41 dB

Which is in permissible limit according to perry criterion which is 52.5 dB to 59 dB.

6.8 Radio Interference

Radio Interference on transmission line can be find by following equation when other communication line passing near by,

$$RI(dB) = 3.5g_m + 6d - 33log(D_i/22) - 30 \tag{6.5}$$

- $RI(1) = 3.5 * (17.74) + 6(3.177) - 33log(20/22) - 30$
  = 62.09+19.062+1.36-30
  = 52.512 dB

- $RI(2) = 3.5 * (19.42) + 6(3.177) - 33log(26.46/22) - 30$
  = 67.97+19.062-2.64-30
  = 54.392 dB

- $RI(3) = 3.5 * (15.21) + 6(3.177) - 33log(33.41/22) - 30$
  = 53.235+19.062-5.98-30

= 36.317 dB

- $RI(4) = 3.5 * (17.74) + 6(3.177) - 33log(34.04/22) - 30$

  = 62.09+19.062-6.25-30

  = 44.902 dB

- $RI(5) = 3.5 * (19.42) + 6(3.177) - 33log(36.89/22) - 30$

  = 67.97+19.062-7.4-30

  = 49.63 dB

- $RI(1) = 3.5 * (15.21) + 6(3.177) - 33log(41.55/22) - 30$

  = 53.235+19.062-9.11-30

  = 33.187

- Total RI:

  - $RI_c = 20 * log\sqrt{(10^{(\frac{52.512}{20})})^2 + (10^{(\frac{44.902}{20})})^2}$

    $= 20 * log\sqrt{178319.97 + 30917.18}$

    $= 53.20$ dB

  - $RI_b = 20 * log\sqrt{(10^{(\frac{54.392}{20})})^2 + (10^{(\frac{49.43}{20})})^2}$

    $= 20 * log\sqrt{274915.98 + 91833.25}$

    $= 55.64$ dB

  - $RI_a = 20 * log\sqrt{(10^{(\frac{36.317}{20})})^2 + (10^{(\frac{33.187}{20})})^2}$

    $= 20 * log\sqrt{4282.52 + 2083.05}$

    $= 38.03$ dB

- In common practise we take average of largest two phase radio interferenc.

  $= \frac{53.20+55.64}{2} + 1.5$

= 55.92 dB.

6.9 Electrostatic Fields of EHV Lines

Electrostatic effects from overhead e.h.v. lines are caused by the extremely high voltage while electromagnetic effects are due to line loading current and short-circuit currents. Hazards exist due to both causes of various degree. These are, for example, potential drop in the earth's surface due to high fault currents, direct flashover from line conductors to human beings or animals. Shock currents can be classified as follows:

- Primary Shock Currents

  These cause direct physiological harm when the current exceeds about 6-10 mA. The normal resistance of the human body is about 2-3 kilohms so that about 25 volts may be necessary to produce primary shock currents. The danger here arises due to ventricular fibrillation which affects the main pumping chambers of the heart. This results in immediate arrest of blood circulation. Loss of life may be due to:

  - arrest of blood circulation when current flows through the heart
  - permanent respiratory arrest when current flows in the brain
  - asphyxia due to flow of current across the chest preventing muscle contraction

- Secondary Shock Currents

  These cannot cause direct physiological harm but may produce adverse reactions. They can be steady state 50 Hz or its harmonics or transient in nature. The latter occur when a human being comes into contact with a capacitively charged body such as a parked vehicle under a line. Steady state currents up to 1 mA cause a slight tingle on the fingers. Currents from 1 to 6 mA are classed as, 'let go' currents. At this level, a human being has control of muscles to let the conductor go as soon as a tingling sensation occurs. For a 50 probability that the let-to current may increase to primary shock current, the limit for men is 16 mA and for women 10 mA. At 0.5 percentage probability, the currents are 9 mA for men, 6 mA for women, and 4.5 mA for children.

6.9.1 CALCULATION OF ELECTROSTATIC FIELD OF A.C. LINES

6.9.2 Electrostatic Field of Single-Circuit 3-Phase Line

Let us consider first a 3-phase line with 3 bundles on a tower and excited by the voltages

$V = V_m(sin(wt) * sin(wt - 120) * sin(wt - 240))$

Select an origin O for a coordinate system at any convenient location. In general, this may be located on ground under the middle phase in a symmetrical arrangement. The coordinates of the line conductors are (X_i, Y_i). A point A(x, y) is shown where the horizontal, vertical, and total e.s. field components are required to be evaluated, as shown in Figure5.6. The field vector at A due to the charge of the aerial conductor

$D_i = (x - x_i)^2 + (y - y_i)^2$

$E_c = (q_i/2 * \pi * e_o) * (1/D_i)$

Its horizontal and vertical components are:

$E_h = (q_i/2 * \pi * e_o) * (x - x_i)/D_i^2$

$E_v = (q_i/2 * \pi * e_o) * (y - y_i)/D_i^2$

Similarly, due to image charge of conductor

$E'_c = (q_i/2 * \pi * e_o) * (1/D'_i)$

Where, $D_i'^2 = (x - x_i)^2 + (y + y_i)^2$

$E'_h = (q_i/2 * \pi * e_o) * (x - x_i)/D_i'^2$

$E'_v = (q_i/2 * \pi * e_o) * (y + y_i)/D_i^2$

We observe that the field components of Ec and Ec' are in opposite directions. Therefore, the total horizontal and vertical components at A due to both charges are

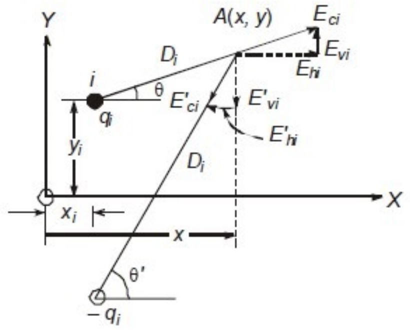


Figure 6.6: Calculation of e.s. field components near the line

$E_{hi} = (q_i/2 * \pi * e_o) * (x - x_i)[1/D_i^2 - 1/D_i'^2]$

$E_{vi} = (q_i/2 * \pi * e_o) * (y - y_i)[1/D_i^2 - 1/D_i'^2]$

The total electric field at A is

$E_{in} = \sqrt{(E_{hn}^2 + E_{vn}^2)}$

Bundle charge calculated from equation as

$E_{h1} = (q_i/2 * \pi * e_o) * J_1$

$= V_m * J_1 * [M_{11} * sin(wt) + M_{12} * sin(wt - 120) + M_{13} * sin(wt - 240)]$

$E_{h2} = V_m * J_2 * [M_{21} * sin(wt) + M_{22} * sin(wt - 120) + M_{23} * sin(wt - 240)]$

$E_{h3} = V_m * J_3 * [M_{31} * sin(wt) + M_{32} * sin(wt - 120) + M_{33} * sin(wt - 240)]$

The total horizontal component is, adding vertically

$E_{hn} = V_m[(J_1 * M_{11} + J_2 * M_{21} + J_3 * M_{31}) * sin(wt) + (J_1 * M_{12} + J_2 * M_{22} + J_3 * M_{32}) * sin(wt - 120) + (J_1 * M_{13} + J_2 * M_{23} + J_3 * M_{33}) * sin(wt - 240)]$

This is a simple addition of three phasors of amplitudes J_1, J_2, J_3 inclined at 120 to each other. Resolving them into horizontal and vertical components (real and j parts with j = 0), we obtain

$Realpart = J_{h1} - 0.5 * J_{h2} - 0.5 * J_{h3}$

$Imaginarypart = 0 - 0.866 * J_{h2} - 0.866 * J_{h3}$

Consequently, the amplitude of electric field is

$$E_{hn} = \sqrt{J_{h1}^2 + J_{h2}^2 + J_{h3}^2 - J_{h1} * J_{h2} - J_{h2} * J_{h3} - J_{h1} * J_{h3}} * V_m$$

In a similar manner, the r.m.s. value of toal vertical component of field at

A due to all 3 phases is

$$E_{vn} = \sqrt{(K_{v1}^2 + K_{v2}^2 + K_{v3}^2 - K_{v1} * K_{v2} - K_{v2} * K_{v3} - K_{v1} * K_{v3})} * V_m$$
$$K_{v1} = K_1 * M_{11} + K_2 * M_{21} + K_3 * M_{31}$$
$$K_{v2} = K_1 * M_{12} + K_2 * M_{22} + K_3 * M_{32}$$
$$K_{v3} = K_1 * M_{13} + K_2 * M_{23} + K_3 * M_{33}$$

6.10 Electrostatic Field of Double-Circuit 3-phase A.C. Line

On a D/C line there are 6 conductors on a tower, neglecting ground wires above the line conductors. [Some proposals for using shielding wires under the line conductors are made]. The e.s. field will depend on the phase configuration of the two circuits and for illustrating the procedure, the arrangement shown in Figure5.7 will be used. The positions occupied by the phases are numbered 1 to 6 and it is evident that (a) conductors 1 and 4 have the voltage $Vmsin(wt+\phi)$, (b) conductors 2 and 5 have voltages $Vmsin(wt+\phi-120)$ and (c) conductors 3 and 6 have voltages $Vmsin(wt+\phi+120)$.

Same as single circuit we can find e.s field for double circuit transmission line as, the total e.s field at every point A(x,y) will be
$E_t = \sqrt{E_{ht}^2 + E_{vt}^2}$
Similarly, the total vertical component of e.s. field can be obtained by using equation
$E_{vt} = k_v * V$
Where, $K_v = \sqrt{K_{v1}^2 + K_{v2}^2 + K_{v3}^2 - K_{v1} * K_{v2} - K_{v2} * K_{v3} - K_{v1} * K_{v3}}$
with,

$$K_{v1} = K_1(M_{11} + M_{14}) + K_2(M_{21} + M_24) + K_3(M_{31} + M_{34}) + K_4(M_{41} + M_{44}) +$$

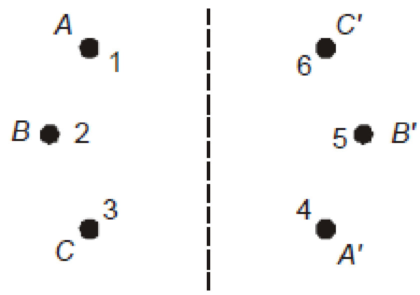


Figure 6.7: Configuration of double ciruit line

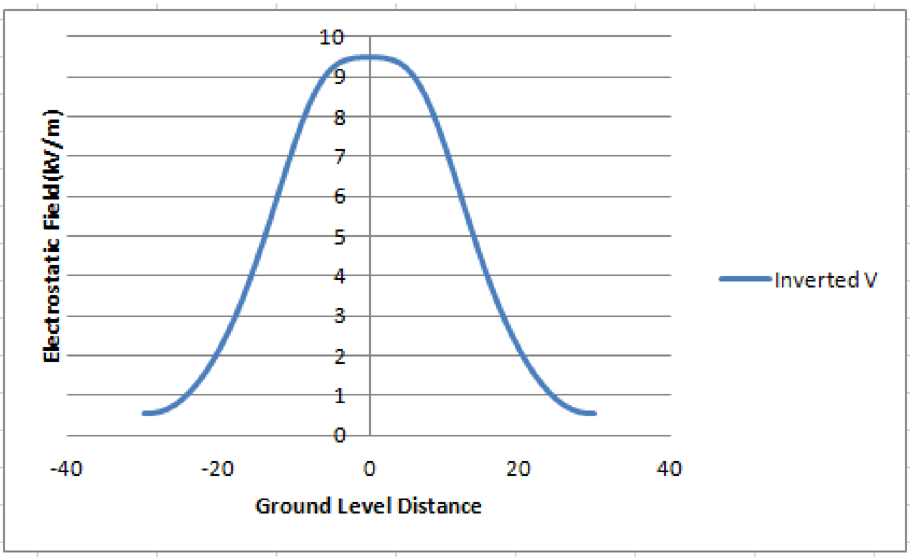


Figure 6.8: Electrostatic field double circuit line

$K_5(M_{51} + M_{54}) + K_6(M_{61} + M_{64})$

.

.

.

The total e.s field at every point A(x,y) will be

$E_t = \sqrt{E_{ht}^2 + E_{vt}^2}$

For double Circuit 400kV transmission line, electrostatic field for ground level is plotted which shown in figure5.8, as we can see that at ground level maximum stress will be 9.5 kV/cm which is in the limit decided by standareds.

6.11 Corona Loss

6.11.1 Corona loss For Fair weather Condition

Corona loss of in bundle conductor at fair weather Condition can be find by Peterson's Formula as:

$$P_c = \frac{21 * 10^{-6} * f * V_s^2 * F}{(log\frac{GMD}{GMR})^2} \tag{6.6}$$

$$Ed = 21.1 * m * r * \delta * ln\frac{GMD}{r_{eq}} \tag{6.7}$$

$= 21.1 * 4 * 0.85 * 0.84 * 1.59 * ln\frac{12.69}{0.199}$

=370.54

Here to find Factor F,

$\frac{E}{E_d} = \frac{230.94}{370.54} = 0.623$

From Table E/Ed ratio gives Value of Constant F, Pc=0.28 Kw/phase/km Total Corona Loss = 0.28*3*300 = 252 kw

6.11.2 Corona loss at Foul weather Condition

At rainy season Corona loss on Transmission line will be maximum to find Corona loss at Foul weather condition we can not use Peterson's Formula. EPRI(Electrical Power research institute) Transmission Line reference book suggested Corona loss equation for Foul weather Condition as,

$$P(dB) = 14.2 + 65log(\frac{E_m}{18.8}) + 40log(\frac{d}{3.51}) + K_1log(\frac{n}{4}) + K_2 + \frac{Alt}{300} \tag{6.8}$$

Where,

n is number of subconductors.

d is diameter of subconductor, cm.

Em is the average maximum bundle gradient.

$K_1 = 13forn4$

$= 19 for n > 4$

K_2 is a term that adjusts corona loss for rain rate RR, and is given as

$K_2 = 10log(\frac{RR}{1.676}) For RR < 3.6mm/hr$

$= 3.3 + 3.5log(\frac{RR}{1.676}) For RR > 3.6mm/hr$

$P(dB) = 14.2 + 65log(\frac{19.59}{18.8}) + 40log(\frac{3.177}{3.51}) + 13log(\frac{4}{4}) + 2.52 + \frac{100}{300}$

= 18.65 dB

So, Pc= 73.6 Kw/km For three Phase,

Total Corona Loss = 73.6*300 = 22002 kw

6.12 SCF

In this section SCF calculation carried out to calculate maximum force in sub-conductor during short circuit.The following applies to regular bundle configurations, where the midpoints of the subconductors are located on a circle with equal distances between adjacent sub-conductors.

For regular bundle configurations up to four subconductors, the tensile force is calculated by

$F_p i = 1.1 F_t$

Sub-conductors are considered to clash effectively if the clearance as between the midpoints of adjacent sub-conductors, as well as the distance ls between two adjacent spacers fulfil either Equations as following:

$a_s/d < 2 and l_s > 50a_s$

$a_s/d < 2.5 and l_s > 70a_s$

If the regular bundle configuration does not fulfil the conditions stated above, the following equations apply to calculating F_{pi}.

The short circuit force is given by:

$$F_v = (n-1) * \frac{\mu}{2*\pi} * \frac{I_k}{n}^2 * \frac{l_s}{a_s} * \frac{v_2}{v_3}$$

Here, I_k is maximum short circuit current for transmission line maximum short circuit current will be three-phase initial short circuit current,

$$v_1 = f * \frac{1}{sin\frac{180}{n}} \sqrt{\frac{(a_s-d)*m_S}{\frac{\mu}{2*\pi}*\frac{I_k}{n}^2*\frac{n-1}{a_s}}}$$

The factor v_2 is given by:

$$v_2 = 1 - a_1 + a_2 - a_3 * [a_4 + a_5]$$

Where,
$a_1 = \frac{sin(4*\pi*f*T_{pi}-2*\gamma)}{4*\pi*f*T_{pi}}$
$a_2 = \frac{f*\tau}{f*T_{pi}} * (1 - e^{\frac{-2*f*T_{pi}}{f*\tau}}) * sin^2\gamma$
$a_3 = \frac{8*\pi*f*\tau*sin\gamma}{1+(2*\pi*f*\tau)^2}$
$a_4 = (2\pi * f * \tau * \frac{cos(2*\pi*f*T_{pi}-\gamma)}{2*\pi*f*T_{pi}} * \frac{sin(2*\pi*f*T_{pi}-\gamma)}{2*\pi*f*T_{pi}}) * e^{\frac{-2*f*T_{pi}}{f*\tau}}$
$a_5 = \frac{sin\gamma-2*\pi*f*\tau*cos\gamma}{2*\pi*f*T_{pi}}$
where is the time constant of the network and can be calculated according to

$\frac{1}{\tau} = \frac{-2*\pi*f}{3} * ln\frac{k-1.02}{0.98}$
if $k < 1.1 then k = 1.1 shall be used.$
$fT_{pi} is solution of the equation:$
$v_1 = f * T_{pi} * \sqrt{v_2}$
this solution of equation give value of v_2

$The factor v_3 given by:$

$v_3 = \frac{d/a_s}{sin\frac{180}{n}} * \frac{sqrt(a_s/d)-1}{arctan\sqrt{(a_S/d)-1}}$

The strain factors characterizing the contraction of the bundle shall be calculated from

$\varepsilon_{st} = \frac{1.5*F_{st}*l_s^2*N}{(a_S-d)^2} * (sin\frac{180}{n})^2$

$\varepsilon_{pi} = \frac{0.375*F_v*l_s^3*N}{(a_S-d)^3} * (sin\frac{180}{n})^3$

$j = \sqrt{\frac{\varepsilon_{pi}}{1+\varepsilon_{st}}}$

determines the bundle configuration during short-circuit current flow as follows:

$j > 1$,The subconductor clash. The tensile force$F_{pi} is calculated,$

$j < 1$,The subconductor reduce their distance but do not clash.

6.13 Case study

400 kV transmission line has following parameters as:

$F_{st} = Static Tensile force in flexible conductor per phase = 66375.096$

$I_k = Three phase Initial symmetrical short - circuit(r.m.s) = 5 * 10^3$

n=No. of sub-conductor of a main conductor = 4

$m_s = Subconductor mass per unit length = 2$

$d_s = Diameter of flexible conductor = 0.03177m$

$A_s = Cross Section of one subconductor = 5.97 * 10^{-4}$

$l_s = spacer span = 40$

$m_c = Additional Concerated mass(other than spacer) = 0$

$n_c = Nos. of Trapzee Connection of pentagraph isolator in one span = 0$

$n_s = No. of spacers in span = 9$

$m_{sc} = Resulting Mass Per Unit length of one subconductor$

l = Span length = 400

$d_{cl} = TotalconsolidatedlengthofdiskInsulatorHardwareinonesideofSpan = 0.9$

$a_s = EffectivedistancebetweenSub - conductor = 0.3$

$l_c = Lengthofconductorcarryingshortcircuitcurrent = 392$

S = Resultant Spring constant of both support of one Span N/m = 100000

E = Young's modulus = 6.86*10^{10}

$T_k = Duration of the first short circuit current flow = 1$

$g_n = GravitationalConstant = 9.81$

f = frequency = 50 hz

short circuit current is very important parameter for calculating maximum pinch force in subconductor. In this case for 400 kV transmission line we select maximum short circuit current is 5 kA.As we know 3-phase to ground fault will be most sevier fault on line but if fault occurs on bus in substation that fault current will be feed by respected line. there fore to find maximum fault current flow from line we have to take one system. Practically 400 kV line maximum loaded with 700 MW power rating.

Here we take bidhanbag 14 bus system is taken for analysis pupose as shown in figure5.9. now at 400 kV bus we are take short circuit data for each effected line.In analysis we can see that when we take short circuit test on 400 kV bus none of line exceeds fault current above 5 kA

In this case

$a_s d_s = \frac{0.3}{0.03177} = 9.44$

neither equation is satisfied so we can say that in this case sub-conductor are not effectively clashing,so now we can find pinch force between sub-conductor as:

$$v_1 = f * 1sin180n\sqrt{\frac{(a_s - d) * m_S}{\frac{\mu}{2*\pi} * \frac{I_k}{n}^2 * \frac{n-1}{a_s}}}$$

$v_1 = 20.79$

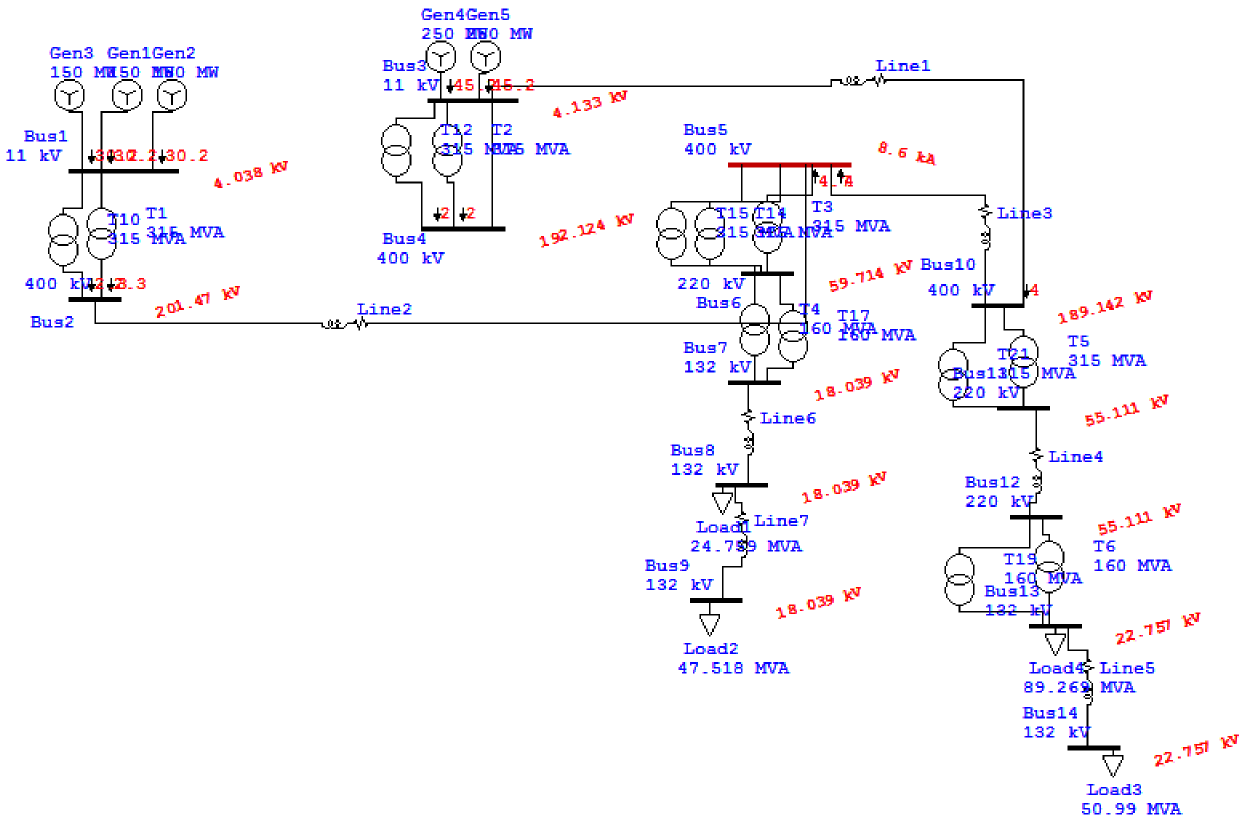


Figure 6.9: bithanbag system short circuit analysis

From v1 we can find v2 by solving equation

$v_2 = 1.5$

$v_3 = \frac{d/a_s}{sin\frac{180}{n}} * \frac{sqrt(a_s/d)-1}{arctan\sqrt{(a_S/d)-1}}$

$v_3 = 0.3511$

The strain factors characterizing the contraction of the bundle shall be calculated

$\varepsilon_{st} = 35.755$

$\varepsilon_{pi} = 30.3327$

Now,

$j = 0.908$

factor j is less than 1 it determines that sub-conductor is not clashing for 0.3 m distance,so 0.3 is safe limit in this case.

6.14 Efficiency

- Transmission Line Efficiency at Fair Weather Condition

$$Efficiency = \frac{ReceivingendPower}{ReceivingendPower + TotalCoronaloss + Totallineloss} \tag{6.9}$$

$= \frac{785000}{785000+252+27773} * 100$

$= 96.56$

- Transmission line efficiency at Foul weather Condition

$= \frac{785000}{785000+220002+27773} * 100$

=94

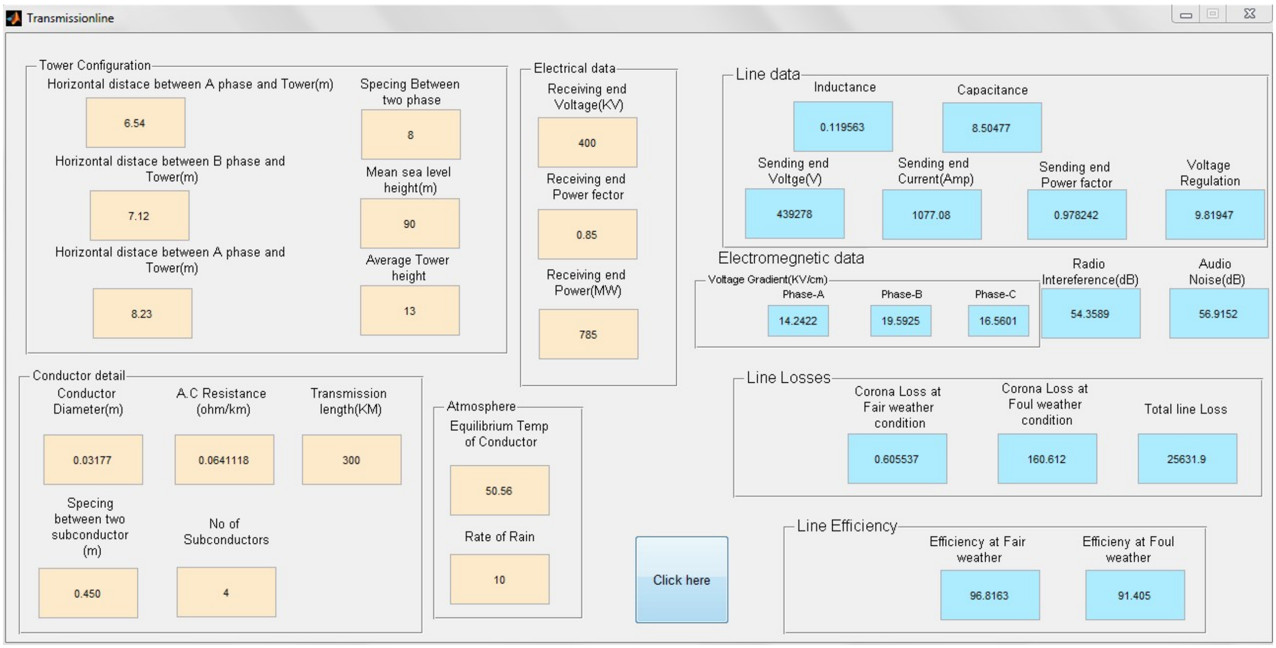


Figure 6.10: GUI Model for Double-Circuit Line

As shown above we can design transmission line and its different parameters.From this calculation transmission line model generate in MATLAB as GUI as shown in figure5.10. Now with help of computer programming we can calculate transmission line parameters for any tower configuration and different conductors.

6.15 Transmission Line Tower Design

The design of transmission line tower is a precise job. The structural engineering practice adapted in design is different from those adapted from other mechanical structures. Since the tower has a different geometry and the stringing of conductor and earth wire has to be done on the tower there are dynamic loads due to conductor tension and wind.

Calculation of tower loading is the first step towards tower design. The loading have to be worked out precisely depending upon the design parameters. In the load calculation the wind plays a vital role. The correct assessment of wind as per the wind zone will lead to proper load assessment and reliable design of tower structure. The Transmission line tower is subjected to the loads in three directions, viz. Transverse, Longitudinal Vertical. These loads depend upon the wind velocity and line material specifications. The loadings have to be worked out for Normal condition broken wire condition. The I.S. 802]1995 covers various combinations of broken wire conditions. Thus, there will be different sets of loadings and the loading trees.

6.16 Nature of Loads

6.16.1 Transverse Load

Wind load acting perpendicular on tower structure, conductor, ground-wire and insulator strings Horizontal components of mechanical tension of conductor and ground-wire.

6.16.2 Vertical Load

Loads due to weight of each conductor, ground wire based on appropriate weight span, weight of insulator strings and fittings. Self-]weight of structure.Loads during construction and maintenance.

6.16.3 Longitudinal Load

Unbalanced Horizontal loads in longitudinal direction due to linear component of Mechanical tension of conductor and/or ground wire during broken Wire condition (The dead end towers are designed for full longitudinal tension of all the conductors during Normal condition.)

6.17 Case study 400kv Double-Circuit Line(LT IDPL CHENNAI)

6.17.1 General notes

- All Loads are worked out with reference to IS - 802 (Part - 1 / Sec - 1) 1995
- All steel shall conform to IS - 2062 with Yield stress $F_y = 2550 fracKgcm^2$ for Mild steel $F_y = 3550 fracKgcm^2$ for High Tensile steel.
- All bolts shall be of property class 5.6 as specified in IS:12427 -1998 and Nuts shall be of property class 5 as specified in IS:1367 (Patr-6) :1980
- All spring washers shall conform to type B of IS:3063:1972.
- Shearing and bearing stress on bolt is considered as follows, conforming to IS : 802 (Part-1 / Sec-2):1992
  - Shearing stress = 3160 $\frac{Kg}{cm^2}$
  - Bearing stress = 6320 $\frac{Kg}{cm^2}$
- Sag Tension Calculations are worked out conforming to IS - 802 (Part - 1 / Sec - 1) 1995
- All members are designed for compression and tension as per formula given in IS - 802 (Part -1 /Section - 2) : 1992
- All members shall be galvanized as per IS - 4759 : 1984.
  - 5 mm thick and over : 86 microns (610 g / sq.m.)
  - 5 mm thick and over : 86 microns (610 g / sq.m.)
- Minimum Thickness is considered as follows conforming to IS - 802 (Part - 1 / Sec - 2) : 1992
  - For Leg Members : 5 mm
  - All other members : 4 mm
- Limiting values of KL/r are considered as follows conforming to IS - 802 (Part - 1 / Sec - 2) : 1992

- * Leg Members, G.W.Peak LM of Cross Arms : 120
- * Other load bearing compression members : 200
- * Secondary Bracings : 250
- * Tension Members : 400

– Factor of Safety Required : 1.02 (This F.O.S is considered above the Ultimate Load) conforming to IS - 802 (Part - 1 / Sec - 1) 1995

6.17.2 Conductor Detail

Table IV: Conductor detail

CHARACTRISTICS OF WIRES	**UNITS**	**CONDUCTOR**	**GROUND WIRE**
NAME		ACSR MOOSE	7/3.66
STRANDS IN ALUMINIUM		54/3.53	
STRANDS IN STEEL		7/3.53	7/3.66
SPAN	m	400	400
DIAMETER	m	3.18E-02	1.10E-02
CROSS SECTIONAL AREA	m	5.97E-04	7.36E-05
UNIT WEIGHT	Kg/m	2.004	0.575
MODULAS OF ELASTICITY	kg/m2	7.00E+09	1.93E+10
COEEF. OF LINEAR EXPANSION	degree	1.93E-05	1.15E-05
ULTIMATE TENSILE STRENGTH	kg	16438	6972
WIND PRESSURE DETAILS	**UNITS**	**CONDUCTOR**	**GROUND WIRE**
BASIC WIND SPEED	m/s	33	33
WIIND ZONE		1	1
RELIABILITY LEVEL		1	1
TERRAIN CATEGARY		2	2
MAX. HEIGHT ABOVE GROUND	m	33.11	42.69
GUST RESPONSE FACTOR		2.11	2.22
DRAG CO-EFFICIENT		1	1.2
DESIGN WIND PRESSURE	kg/m2	35.23	35.23
WIND ON WIRE	kg/m2	74.47	93.97

6.17.3 Sag Tension data

– Conductor sag tension data:

– Ground wire Sag Tension data:

Table V: Conductor Sag Tension data

SR.NO	TEMP	WIND FACT	WIND PRES	SAG M	TENSION KG	FOS
1	0	0	0.00	9.66	4147.73	3.96
2	0	100	74.47	6.97	5748.66	2.86
3	0	36	26.81	9.08	4416.48	3.72
4	32	0	0.00	11.08	3616.72	4.55
5	32	75	55.85	8.75	4579.79	3.59
6	32	100	74.47	7.78	5152.33	3.19
7	85	0	0.00	13.25	3023.97	5.44

Table VI: Ground wire Sag Tension data

SR.NO	TEMP	WIND FACT	WIND PRES	SAG M	TENSION KG	FOS
1	0	0	0.00	8.70	1322.33	5.27
2	0	100	74.47	5.18	2218.44	3.14
3	0	36	26.81	7.66	1501.21	4.64
4	32	0	0.00	9.61	1196.33	5.86
5	32	75	55.85	6.45	1781.97	3.91
6	32	100	74.47	5.54	2076.12	3.36
7	85	0	0.00	10.20	1127.67	6.18

6.17.4 List of Assumption and Method for Tower Design

Various assumptions on which transmission line tower design is done are as follows:

- All members of a bolted type tower frame work are pin-connected in such a manner that the members carry axial loads only.
- Thee bolt slippages throughout the structures are such as to allow the use of the same modulus of elasticity for the entire structure, thus permitting the use of the principle of super-position for stress analysis.

6.18 Loading Calculations of tower at different Wind Temp Condition

LOADING CALCULATIONS FOR 2° DEVIATION (32°C & FULL WIND)																
DESIGN DATA :																
DEVIATION ANGLE	2	°														
	N.C. (RELIABILITY)															
WIND SPAN	400	X	1	=	400	m										
WEIGHT SPAN (MAX)	400	X	1.5	=	600	m										
WEIGHT SPAN (MIN)	400	X	0.5	=	200	m										
CASE DESCRIPTION	**LOADING CASE :- RELIABILITY CONDITION : 32°C & FULL WIND**															
												N.C.		**B.W.C**		
1. GROUND WIRE :	TENSION @ 32°C & FULL WIND						=		2076.12	Kg		**RELIABILITY**		**SECURITY**		
A. TRANSVERSE LOAD																
1. WIND ON WIRE (Pd x Cdc x L x d x Gc)	1.0	X	35.23	X	1.2	X	400	X	0.01098	X	2.22	413		0		
2. DEVIATION LOAD (2T x Sin ɵ/2)	1	X	2	X	2076	X	Sin		1.0			72		0		
											TOTAL	**485**		**0**		
B. VERTICAL LOADS												**MAX**	**MIN**	**MAX**	**MIN**	
1. WEIGHT OF WIRE (Wt Span x Unit Wt)	1	X	600	X	0.575							345	115	0	0	
2. WEIGHT OF CLAMP	1	X	50									50	50	0	0	
3. WT. OF MAN WITH TOOLS												0	0	0	0	
											TOTAL	**395**	**165**	**0**	**0**	
C. LONGITUDINAL LOADS																
1. WIRE TENSION												0		0		
											TOTAL	**0**		**0**		
2. CONDUCTOR :	Tension @ 32°C & FULL WIND						=		5152.33	Kg						
A. TRANSVERSE LOADS																
1. WIND ON INSULATOR (No. of Insu. x Pd x Cdi x(Ai x d x L) x Gi)	2	X	35.23	X	1.20	X 0.5 X	0.255	X	4.55	X	2.47	121		0		
2. WIND ON COND. (No. of Cond. x Pd x Cdc x L x d x Gc)	4	X	35.23	X	1	X	400	X	0.0318	X	2.11	3785		0		
3. DEVIATION LOAD (No. of Cond. x 2T x Sin ɵ/2)	4	X	2	X	5152	X	Sin		1			719		0		
											TOTAL	**4626**		**0**		
B. VERTICAL LOADS												**MAX**	**MIN**	**MAX**	**MIN**	
1. WEIGHT OF COND. (No. of Cond. x Wt Span x Unit Wt)	4	X	600	X	2.004							4810	1603	0	0	
2. WT. OF INSULATOR (No. of String x WT of Insu.String) + H.W.	2	X	250	+	50							550	550	0	0	
3. WT.OF MAN WITH TOOLS												0	0	0	0	
											TOTAL	**5360**	**2153**	**0**	**0**	
C. LONGITUDINAL LOADS																
1. CONDUCTOR TENSION												0		0		
											TOTAL	**0**		**0**		
FACTOR OF SAFETY	1.02															
ALL LOADS ARE ULTIMATE LOADS IN Kg																

LOADING CALCULATIONS FOR 2° DEVIATION (32 °C & 0.75-FULL WIND)															
DESIGN DATA :															
DEVIATION ANGLE	2 °														
	INTACT WIRE						**B.W.C. (SECURITY)**								
WIND SPAN	400	X	1	=	400	m	400	X	0.6	=	240 m				
WEIGHT SPAN (MAX)	400	X	1.5	=	600	m	600	X	0.6	=	360 m				
WEIGHT SPAN (MIN)	400	X	0.5	=	200	m	200	X	0.5	=	100 m				
CASE DESCRIPTION	**LOADING CASE :- SECURITY CONDITION : 32°C & 0.75-FULL WIND**														
												INTACT WIRE		**B.W.C SECURITY**	
1. GROUND WIRE :	TENSION @ 32°C & 0.75-FULL WIND						=	1781.97		Kg					
A. TRANSVERSE LOAD															
1. WIND ON WIRE (Pd x Cdc x L x d x Gc)	1	X	26.42	X	1.2	X	400	X	0.01098	X	2.22	310		186	
2. DEVIATION LOAD (2T x Sin ϴ/2)	1	X	2	X	1782	X	Sin		1.0			62		31	
											TOTAL	**372**		**217**	
B. VERTICAL LOADS												**MAX**	**MIN**	**MAX**	**MIN**
1. WEIGHT OF WIRE (Wt Span x Unit Wt)	1	X	600	X	0.575							345	115	207	58
2. WEIGHT OF CLAMP	1	X	50									50	50	50	50
3. WT. OF MAN WITH TOOLS												0	0	0	0
											TOTAL	**395**	**165**	**257**	**108**
C. LONGITUDINAL LOADS															
1. WIRE TENSION	B.W.C =		1782	X	Cos		1					0		1782	
											TOTAL	**0**		**1782**	
2. CONDUCTOR :	Tension @ 32°C & 0.75-FULL WIND						=	4579.79		Kg		**INTACT WIRE**		**B.W.C SECURITY**	
A. TRANSVERSE LOADS															
1. WIND ON INSULATOR (No. of Insu. x Pd x Cdi x(Ai x d x L) x Gi)	2	X	26.42	X	1.20	X 0.5 X	0.255	X	4.55	X	2.47	91		91	
2. WIND ON COND. (No. of Cond. x Pd x Cdc x L x d x Gc)	4	X	26.42	X	1	X	400	X	0.0318	X	2.11	2839		1703	
3. DEVIATION LOAD (No. of Cond. x 2T x Sin ϴ/2)	4	X	2	X	4580	X	Sin		1			639		160	
											TOTAL	**3569**		**1954**	
B. VERTICAL LOADS												**MAX**	**MIN**	**MAX**	**MIN**
1. WEIGHT OF COND. (No. of Cond. x Wt Span x Unit Wt)	4	X	600	X	2.004							4810	1603	2886	802
2. WT. OF INSULATOR (No. of String x WT of Insu. String) + H.W.	2	X	250	+	50							550	550	550	550
3. WT.OF MAN WITH TOOLS												0	0	0	0
											TOTAL	**5360**	**2153**	**3436**	**1352**
C. LONGITUDINAL LOADS															
1. CONDUCTOR TENSION	B.W.C =		4	X	4580	X	0.5	X	COS	1		0		9158	
											TOTAL	**0**		**9158**	
FACTOR OF SAFETY	1.02														
ALL LOADS ARE ULTIMATE LOADS IN Kg															

LOADING CALCULATIONS FOR 2° DEVIATION (0 °C & 0.36-FULL WIND)

DESIGN DATA :															
DEVIATION ANGLE	2	°													
	N.C. (RELIABILITY)						**B.W.C. (SECURITY)**								
WIND SPAN	400	X	1	=	400	m	400	X	0.6	=	240	m			
WEIGHT SPAN (MAX)	400	X	1.5	=	600	m	600	X	0.6	=	360	m			
WEIGHT SPAN (MIN)	400	X	0.5	=	200	m	200	X	0.5	=	100	m			
CASE DESCRIPTION	**LOADING CASE :- NORMAL & RELIABILITY CONDITION : 0°C & 0.36-FULL WIND**														
												N.C.		**B.W.C**	
1. GROUND WIRE :	TENSION @ 0°C & 0.36-FULL WIND						=		1501.21	Kg		**RELIABILITY**		**SECURITY**	
A. TRANSVERSE LOAD															
1. WIND ON WIRE (Pd x Cdc x L x d x Gc)	1	X	12.68	X	1.2	X	400	X	0.01098	X	2.22	149		89	
2. DEVIATION LOAD (2T x Sin ɵ/2)	1	X	2	X	1501	X	Sin		1.0			52		26	
											TOTAL	**201**		**115**	
B. VERTICAL LOADS												**MAX**	**MIN**	**MAX**	**MIN**
1. WEIGHT OF WIRE (Wt Span x Unit Wt)	1	X	600	X	0.575							345	115	207	58
2. WEIGHT OF CLAMP	1	X	50									50	50	50	50
3. WT. OF MAN WITH TOOLS												0	0	0	0
											TOTAL	**395**	**165**	**257**	**108**
C. LONGITUDINAL LOADS															
1. WIRE TENSION	B.W.C =		1501	X	Cos	1						0		1501	
											TOTAL	**0**		**1501**	
2. CONDUCTOR :	Tension @ 0°C & 0.36-FULL WIND						=		4416.48	Kg					
A. TRANSVERSE LOADS															
1. WIND ON INSULATOR (No. of Insu. x Pd x Cdi x(Ai x d x L) x Gi)	2	X	12.68	X	1.20	X 0.5 X	0.255	X	4.55	X	2.47	44		44	
2. WIND ON COND. (No. of Cond. x Pd x Cdc x L x d x Gc)	4	X	12.68	X	1	X	400	X	0.0318	X	2.11	1363		818	
3. DEVIATION LOAD (No. of Cond. x 2T x Sin ɵ/2)	4	X	2	X	4416	X	Sin		1			617		154	
											TOTAL	**2023**		**1015**	
B. VERTICAL LOADS												**MAX**	**MIN**	**MAX**	**MIN**
1. WEIGHT OF COND. (No. of Cond. x Wt Span x Unit Wt)	4	X	600	X	2.004							4810	1603	2886	802
2. WT. OF INSULATOR (No. of String x WT of Insu. String) + H.W.	2	X	250	+	50							550	550	550	550
3. WT.OF MAN WITH TOOLS												0	0	0	0
											TOTAL	**5360**	**2153**	**3436**	**1352**
C. LONGITUDINAL LOADS															
1. CONDUCTOR TENSION	B.W.C =		4	X	4416	X	0.5	X	COS	1		0		8832	
										TOTAL		**0**		**8832**	
FACTOR OF SAFETY	1.02														
ALL LOADS ARE ULTIMATE LOADS IN Kg															

LOADING CALCULATIONS FOR 2° DEVIATION (32 °C & NO WIND)

DESIGN DATA :															
DEVIATION ANGLE	2	°													
	SAFETY (STRUNG)						SAFETY (STRINGING)								
WIND SPAN	400	X	1	=	400	m	400	X	0.6	=	240	m			
WEIGHT SPAN (MAX)	400	X	1.5	=	600	m	600	X	0.6	=	360	m			
WEIGHT SPAN (MIN)	400	X	0.5	=	200	m	200	X	0.5	=	100	m			
CASE DESCRIPTION	**LOADING CASE :- SAFETY CONDITION : 32°C & NO WIND**														
												N.C.		**B.W.C**	
1. GROUND WIRE :	TENSION @ 32°C & NO WIND						=		1196.33	Kg		**STRUNG**		**STRINGING**	
A. TRANSVERSE LOAD															
1. WIND ON WIRE (Pd x Cdc x L x d x Gc)	1	X	0.00	X	1.2	X	400	X	0.01098	X	2.22	0		0	
2. DEVIATION LOAD (2T x Sin ө/2)	1	X	2	X	1196	X	Sin		1.0			42		42	
											TOTAL	**42**		**42**	
B. VERTICAL LOADS												**MAX**	**MIN**	**MAX**	**MIN**
1. WEIGHT OF WIRE (Wt Span x Unit Wt)	600	X	0.575									345	115	207	58
2. WT. OF INSULATOR (No. of Insu. x WT of Insu.)	2	X	250									500	500	500	500
3. WT. OF MAN WITH TOOLS	1500 N / 9.81 = 152.91 Kg.											153	153	153	153
											TOTAL	**998**	**768**	**860**	**710**
C. LONGITUDINAL LOADS															
1. WIRE TENSION	B.W.C. 5000 N / 9.81 = 510 Kg.											0		510	
											TOTAL	**0**		**510**	
2. CONDUCTOR :	Tension @ 32°C & NO WIND						=		3616.72	Kg					
A. TRANSVERSE LOADS												**STRUNG**		**STRINGING**	
1. WIND ON INSULATOR (No. of Insu. x Pd x Cdi x(Ai x d x L) x Gi)	2	X	0.00	X	1.20	X 0.5 X	0.255	X	4.55	X	2.47	0		0	
2. WIND ON COND. (No. of Cond. x Pd x Cdc x L x d x Gc)	4	X	0.00	X	1	X	400	X	0.0318	X	2.11	0		0	
3. DEVIATION LOAD (No. of Cond. x 2T x Sin ө/2)	4	X	2	X	3617	X	Sin		1			505		252	
											TOTAL	**505**		**252**	
B. VERTICAL LOADS												**MAX**	**MIN**	**MAX**	**MIN**
1. WEIGHT OF COND. (No. of Cond. x Wt Span x Unit Wt)	4	X	600	X	2.004							4810	1603	2886	802
2. WT. OF INSULATOR (No. of String x WT of Insu.String) + H.W.	2	X	250	+	50							550	550	550	550
3. WT.OF MAN WITH TOOLS	1500 N / 9.81 = 152.91 Kg.											153	153	153	153
4. EXTRA LOAD ON TIP OF CROSS ARM	20000 N / 9.81 = 2039 Kg.											2039	2039	2039	2039
											TOTAL	**7551**	**4345**	**5627**	**3543**
C. LONGITUDINAL LOADS															
1. CONDUCTOR TENSION	B.W.C. 10000 N / 9.81 = 1019 Kg.											0		1019	
											TOTAL	**0**		**1019**	
FACTOR OF SAFETY	1.02														
ALL LOADS ARE ULTIMATE LOADS IN Kg															

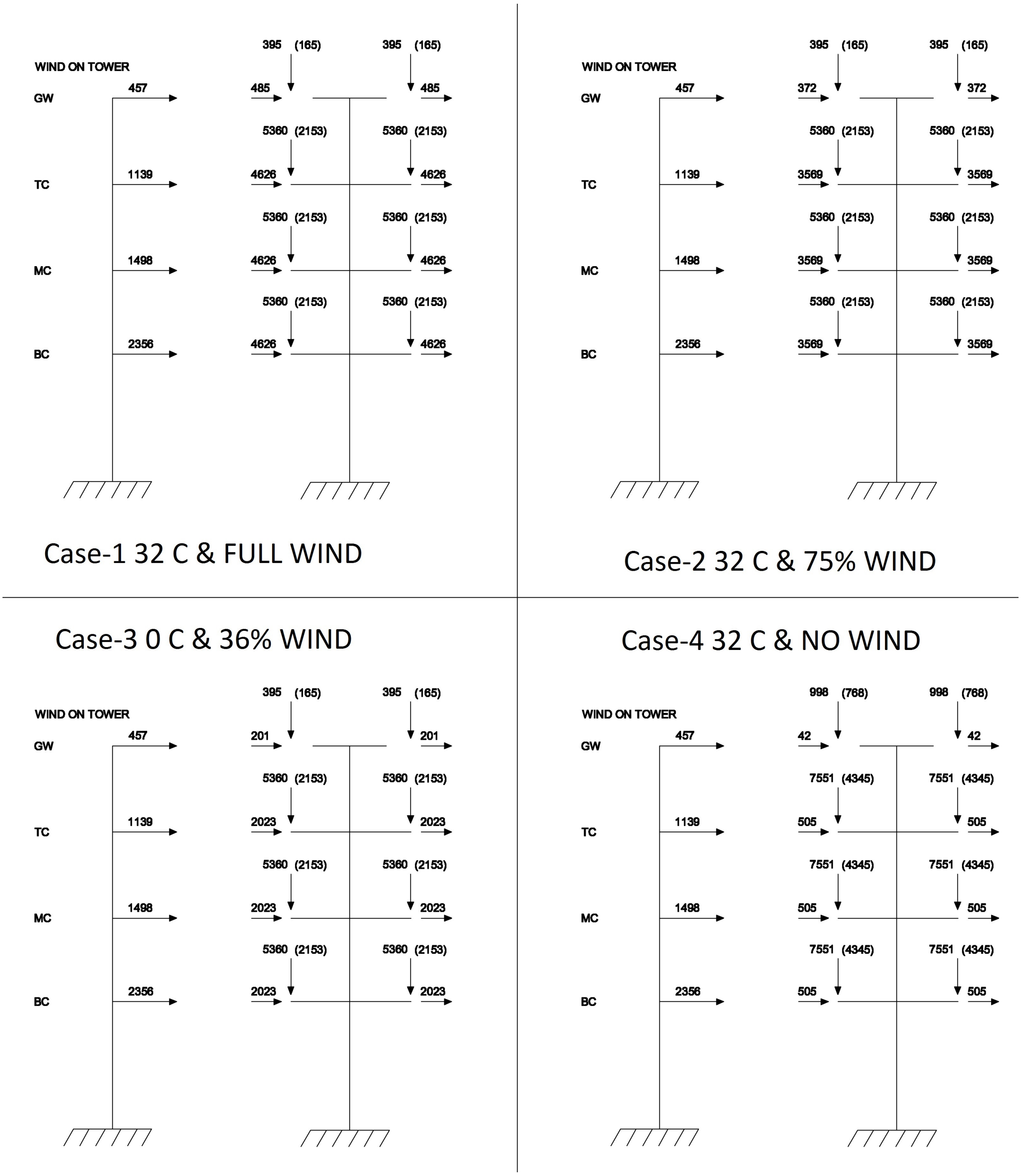


Figure 6.11: Loading Tree Diagram

6.18.1 Tower Lag design

For study purpose here, we are calculating lag member design for pannel-7.This pannel can be seen in graphical Tower design,

- GW= Total load * lever arm length=1427*19.371=27642.417
- TC= 10391*14.981 = 155667.571
- MC = 10750*6.409= 68896.75
- $\sum M$ Total = 252206.738
- $S_{TL} = \frac{\sum M}{2*W*cos^2\alpha} = \frac{252206.738}{2*3.346*0.998794}$
  =37733.303
- $S_{V(max)} = \frac{TotalmaxVerticalload}{4*cos^2\alpha}$
  $= \frac{38488}{3.995176}$
  =9633.6181
- $S_{V(min)} = \frac{TotalminVerticalload}{4*cos^2\alpha}$
  $= \frac{18789}{3.995176}$
  =4702.9217
- Compresion stress = $S_{TL} + S_{V(max)}$
  =37733.303+9633.6181
  =47366.9
- Tension stress = $S_{TL} + S_{V(min)}$
  =37733.303-4702.9217
  =33030.38
- Now we have to select suitable lag member, L/r ratio of member is very important to select lag member.
  suppose that we select lag member as 150*150*10
- Detail of section 150*150*10 as following:
  * $GrossArea = 29.2cm^2$
  * Unsupported length = 176.41 km
  * Radius of Gyr = 2.98 m
  * $\frac{L}{r} = 59$

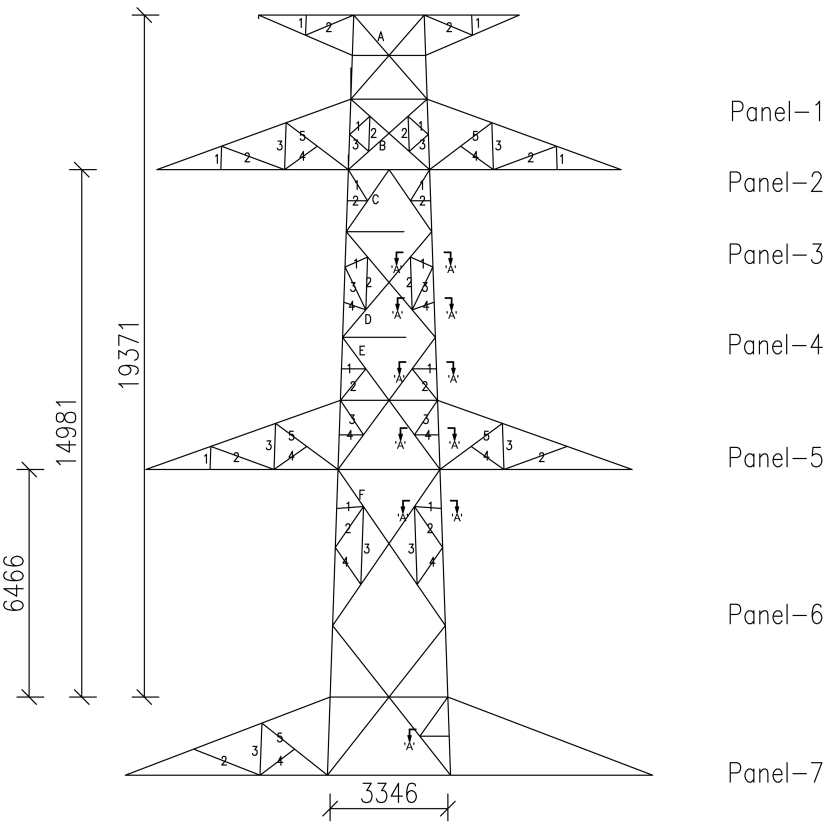


Figure 6.12: Tower Pannel Design

* $Comperationload = 69192 N/m^2$
* Comp F.O.S = 1.16
* $Tensionload = 53368 N/m^2$
* Ten F.O.S = 1.72

6.18.2 Latties design

here we design latties member at pannel 4,design of latties member first we have to calculate streeses working on it, Calculation of stresses at pannel 4 for latties member are as following:

- GW: load * effective length
  = 1427 * 2
- TC: load * effective length
  = 10391 * 2.305
- Total Monent $\sum M$ = Monent GW + Monent TC

= 26805.25 Stree act on latties can be find by following equation:

$$Stress = \frac{\sum M}{4 * W * cos\alpha} \quad (6.10)$$

$= \frac{26805.25}{4*2.525*cos49.8374}$

= 4111

The design of transmission line tower is a precise job. The structural engineering practice adapted in design is different from those adapted from other mechanical structures. Since the tower has a different geometry and the stringing of conductor and earth wire has to be done on the tower there are dynamic loads due to conductor tension and wind.

N.C. @ 32°C & FW (2° DEVIATION)															
CASE : 1		TOWER LOADINGS									SELF WEIGHT	STRESSES			
		TRANSVERSE			VERTICAL				LONGITUDINAL			LEG MEMBER		LATTICE	
		LEFT	RIGHT	WL	LEFT		RIGHT		LEFT	RIGHT					
PANEL NO.					MAX	MIN	MAX	MIN				COMP.	TENSION	TRANS.	LONG.
PANEL-1	GW	485	485	457	395	165	395	165	0	0	450	705	199	522	0
PANEL-2	TC	4626	4626	1139	5360	2153	5360	2153	0	0	1000	4318	-449	429	0
PANEL-3											226	4661	-219	5131	0
PANEL-4											386	12136	7062	4111	0
PANEL-5	MC	4626	4626	1498	5360	2153	5360	2153	0	0	1241	21570	12115	4089	0
PANEL-6											719	31975	22159	8399	0
PANEL-7	BC	4626	4626	2355	5360	2153	5360	2153	0	0	1519	47463	33126	6990	0
PANEL-8											980	57263	42215	4150	0
PANEL-9											1550	63335	47498	3051	0
PANEL-10	BASIC TOWER			2645							2027	67869	51003	2121	0
PANEL-11	NT			878							1967	69975	52110	2892	0
PANEL-12	+1M EXT.			227							556	72356	54208	2071	0
PANEL-13															
PANEL-14															
PANEL-15															
PANEL-16											#REF!				
PANEL-17											#REF!				
PANEL-18											#REF!				
PANEL-19											#REF!				
PANEL-20											#REF!				

DESIGN OF LEG MEMBER

			DESIGN FOR COMPRESSION										DESIGN FOR TENSION				DESIGN FOR BOLTS					
PART NO.	STEEL TYPE	Section	Gross Area	USL	Rmin/ Rmed	Radius of Gyr.	L/r	Curve No.	KL/r	Comp. Load	UCS	Comp . FOS	Tension Load	Net Area	UTS	Tens FOS	Bolt Size	Nos	SS/ DS	Shearing Strength	Bearing Strengt	Bolt FOS
			cm^2	cm		cm				kg	kg		kg	cm^2	kg		M16			kg	kg	
	MS	100x100x6	11.7	124.33	MIN.	1.95	64	1	64	1246	24653	19.79	620	9.60	24472	39.49	M16	6	DS	76243	36403.2	29.22
PART-1	MS	100x100x6	11.7	100.06	MIN.	1.95	51	1	51	10650	25881	2.43	3664	9.60	24472	6.68	M16	6	DS	76243	36403.2	3.42
	MS	100x100x6	11.7	88.33	MIN.	1.95	45	1	45	10464	26379	2.52	3462	9.60	24472	7.07	M16	8	DS	101657	48537.6	4.64
PART-2	MS	100x100x6	11.7	100.06	MIN.	1.95	51	1	51	16917	25881	1.53	11061	9.60	24472	2.21	M16	8	DS	101657	48537.6	2.87
PART-3	HT	100x100x7	13.7	98.22	MIN.	1.97	50	1	50	28826	42443	1.47	18710	11.25	40150	2.15	M16	10	SS	63536	70784	2.20
PART-4	HT	110x110x8	17.1	110.94	MIN.	2.18	51	1	51	40865	52910	1.29	30515	14.30	51035	1.67	M16	12	DS	152485	97075.2	2.38
PART-5	HT	110x110x10	21.1	111.00	MIN.	2.16	51	1	51	57016	66363	1.16	42255	17.60	62812	1.49	M16	20	SS	127071	202240	2.23
PART-6	HT	130x130x10	25.1	127.27	MIN.	2.57	50	1	50	65747	79703	1.21	50460	21.60	77088	1.53	M16	24	SS	152485	242688	2.32
PART-7	HT	150x150x10	29.2	176.41	MIN.	2.98	59	1	59	69192	80453	1.16	53368	25.70	91720	1.72	M16	16	DS	203314	161792	2.34
PART-8	HT	150x150x10	29.2	142.72	MIN.	2.98	48	1	48	71867	85043	1.18	55191	25.70	91720	1.66	M16	16	DS	203314	161792	2.25
PART-9	HT	150x150x10	29.2	120.89	MIN.	2.98	41	1	41	73230	87499	1.19	55626	25.70	91720	1.65	M16	16	DS	203314	161792	2.21

DESIGN OF LATTICE MEMBER

			DESIGN FOR COMPRESSION										DESIGN FOR TENSION				DESIGN FOR BOLTS					
NAME OF LATTICE	STEEL TYPE	Section	Gross Area	USL	Rmin/ Rmed	Radius of Gyr.	L/r	Curve No.	KL/r	Comp. Load	UCS	Comp. FOS	Tension Load	Net Area	UTS	Tens FOS	Bolt	Nos	SS/ DS	Shearing Strength	Bearing Strength	Bolt FOS
			cm²	cm		cm				kg	kg		kg	cm²	kg		M16			kg	kg	
A-Trans.L1	MS	55x55x4	4.26	164.83	MIN.	1.06	156	4	155.50	1675	3546	2.12	1675	2.93	7468	4.46	M16	2	SS	12707	8089.6	4.83
A-Long.L1	MS	55x55x4	4.26	164.83	MIN.	1.06	156	4	155.50	1858	3546	1.91	1858	2.93	7468	4.02	M16	2	SS	12707	8089.6	4.35
B-Trans.L1	MS	55x55x4	4.26	154.64	MED.	1.68	92	3	106.02	5425	6917	1.28	5425	2.93	7468	1.38	M16	4	SS	25414	16179.2	2.98
B-Long.L1	MS	45x45x4	3.47	154.64	MED.	1.37	113	3	116.44	1525	4972	3.26	1525	2.24	5698	3.74	M16	2	SS	12707	8089.6	5.30
C-Trans.L1	HT	80x80x6	9.29	214.21	MED.	2.46	87	3	103.54	14955	17174	1.15	14955	7.00	24966	1.67	M16	4	SS	25414	24268.8	1.62
C-Long.L1	HT	90x90x6	10.5	214.21	MED.	2.77	77	3	98.67	15597	20538	1.32	15597	8.06	28764	1.84	M16	4	SS	25414	24268.8	1.56
BELT-3 Trans.	HT	90x90x6	10.5	115.25	MIN.	1.75	66	3	92.93	14955	22081	1.48	14955	8.06	28764	1.92	M16	4	SS	25414	24268.8	1.62
BELT-3 Long.	HT	80x80x6	9.29	115.25	MIN.	1.56	74	3	96.94	15597	19147	1.23	15597	7.00	24966	1.60	M16	4	SS	25414	24268.8	1.56
D-Trans.L1	HT	70x70x5	6.77	102.18	MIN.	1.36	75	3	97.56	11982	13717	1.14	11982	4.95	17668	1.47	M16	4	SS	25414	20224	1.69
D-Long.L1	HT	75x75x5	7.27	102.18	MIN.	1.46	70	3	94.99	12496	14905	1.19	12496	5.39	19235	1.54	M16	4	SS	25414	20224	1.62
E-Trans.L1	HT	75x75x5	7.27	121.98	MIN.	1.46	84	3	101.77	11920	13611	1.14	11920	5.39	19235	1.61	M16	4	SS	25414	20224	1.70
E-Long.L1	HT	70x70x6	8.06	121.98	MIN.	1.36	90	3	104.85	12432	14548	1.17	12432	5.91	21076	1.70	M16	4	SS	25414	24268.8	1.95
F-Trans.L1	HT	90x90x6	10.5	141.37	MIN.	1.75	81	3	100.39	15076	20056	1.33	15076	8.06	28764	1.91	M16	4	SS	25414	24268.8	1.61
F-Long.L1	HT	75x75x6	8.66	141.37	MIN.	1.46	97	3	108.41	13011	14830	1.14	13011	6.43	22955	1.76	M16	4	SS	25414	24268.8	1.87
G-Trans.L1	HT	75x75x6	8.66	141.29	MIN.	1.46	97	3	108.39	12546	14838	1.18	12546	6.43	22955	1.83	M16	4	SS	25414	24268.8	1.93
G-Long.L1	HT	75x75x5	7.27	141.29	MIN.	1.46	97	3	108.39	10828	12264	1.13	10828	5.39	19235	1.78	M16	4	SS	25414	20224	1.87
H-Trans.L1	MS	80x80x6	9.29	188.59	MIN.	1.56	121	4	120.89	9681	12504	1.29	9681	7.00	17833	1.84	M16	3	SS	19061	18201.6	1.88
H-Long.L1	MS	80x80x6	9.29	188.59	MIN.	1.56	121	4	120.89	9815	12504	1.27	9815	7.00	17833	1.82	M16	3	SS	19061	18201.6	1.85
K-Trans.L1	MS	70x70x6	8.06	189.94	MIN.	1.36	140	4	139.66	7121	8318	1.17	7121	5.91	15054	2.11	M16	3	SS	19061	18201.6	2.56
K-Trans.L2	MS	90x90x6	10.5	260.60	MIN.	1.75	149	4	148.91	7121	9530	1.34	7121	8.06	20546	2.89	M16	3	SS	19061	18201.6	2.56
K-Long.L1	MS	70x70x6	8.06	189.94	MIN.	1.36	140	4	139.66	7220	8318	1.15	7220	5.91	15054	2.09	M16	2	SS	12707	12134.4	1.68
K-Long.L2	MS	90x90x6	10.5	260.60	MIN.	1.75	149	4	148.91	7220	9530	1.32	7220	8.06	20546	2.85	M16	2	SS	12707	12134.4	1.68
L-Trans.L1	MS	70x70x5	6.77	327.19	MED.	2.15	152	4	152.18	4953	5884	1.19	4953	4.95	12620	2.55	M16	2	SS	12707	10112	2.04
L-Trans.L2	MS	75x75x5	7.27	217.46	MIN.	1.46	149	4	148.94	4953	6596	1.33	4953	5.39	13739	2.77	M16	2	SS	12707	10112	2.04
L-Long.L1	MS	70x70x5	6.77	327.19	MED.	2.15	152	4	152.18	5022	5884	1.17	5022	4.95	12620	2.51	M16	2	SS	12707	10112	2.01
L-Long.L2	MS	75x75x5	7.27	217.46	MIN.	1.46	149	4	148.94	5022	6596	1.31	5022	5.39	13739	2.74	M16	2	SS	12707	10112	2.01
M-Trans.L1	MS	60x60x5	5.75	157.82	MIN.	1.16	136	4	136.05	5141	6252	1.22	5141	4.05	10315	2.01	M16	3	SS	19061	12480	2.43
M-Long.L1	MS	60x60x4	4.71	157.82	MIN.	1.18	134	4	133.75	4439	5300	1.19	4439	3.35	8528	1.92	M16	3	SS	19061	9984	2.25
BELT-11 Trans.	MS	75x75x6	8.66	218.11	MIN.	1.46	149	4	149.39	5141	7810	1.52	5141	6.43	16397	3.19	M16	2	SS	12707	9984	1.94

WIND LOAD DISTRIBUTION

Level	Width (m)	Height (m)	Gross Area (m^2)	Net Area - Ae (m^2)	Solidity Ratio	Drag Coeffi. - Cdt	Ht above GL from CG (m)	Gust Response Factor-Gt	Basic Pr. - Pd (Kg/m^2)	Wind load (Pd.Cdt.Ae .Gt) (Kg)	Distribution (Kg)	Wind Level	Level
GW	2.00										456.9	456.9	GW
		4.39	9.449	5.422	0.574	2.000	46.243	2.450	35.229	936.0	479.0		
TC	2.31										659.9	1138.9	TC
		8.52	22.146	6.375	0.288	2.549	39.681	2.397	35.229	1371.8	711.9		
MC	2.90										786.0	1497.9	MC
		8.69	27.777	7.689	0.277	2.593	31.106	2.311	35.229	1623.1	837.1		
BC	3.50										1518.3	2355.4	BC
		20.55	125.608	14.685	0.117	3.315	15.161	2.065	35.229	3541.1	2022.8		
BASIC TOWER	8.72										622.3	2645.1	BASIC TOWER
		6.00	56.924	5.544	0.097	3.410	3.270	1.920	35.229	1278.9	656.6		
NT	10.25										221.7	878.3	NT

Chapter 7

Comparison of different Tower Configuration

7.1 400 kV transmission line tower Configurations:-

Here 400 kV Double Circuit different Five configurations are compared. simple vertical, Hexa and Inverted V, Compact and Delta configuration. All input considered here are same except the distance of conductor from mid of the tower.TableI and tableII compair power flow and voltage regulation for different Five Configuration.

Table I: Output Results For Hexa, V and vertical Configuration

Description	Inverted V	Hexa	Vertical
Inductance L(H/phase/km)	0.03985	0.03948	0.03971
Capacitance C(uF/phase/km)	2.83	2.86	2.844
Receiving end voltage (kV)	400	400	400
Receiving end voltage Angle	-2.96	-2.97	-2.96
Receiving end Power(MW)	750	750	750
Voltage Regulation	8.03	7.91	7.98
Sending end Voltage	432.129	431.67	431.95

Table II: Output Results For Compact and Delta Configuration

Description	Compact	Delta
Inductance L(H/phase/km)	0.0472	0.041
Capacitance C(uF/phase/km)	2.30	2.56
Receiving end voltage (kV)	400	400
Receiving end voltage Angle	-4.01	-2.97
Receiving end Power(MW)	750	750
Voltage Regulation	11.8	9.51
Sending end Voltage	442.18	436.1

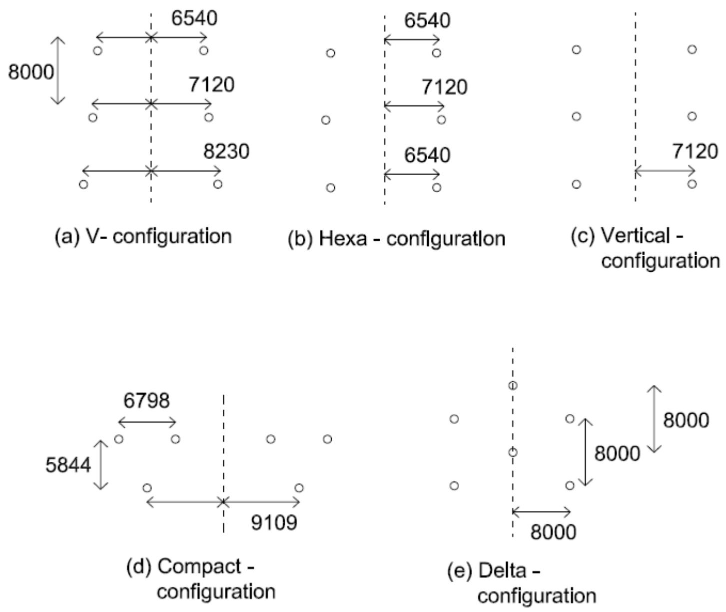


Figure 7.1: Different 400 kV Transmission line Tower Configuration

7.2 Surface Voltage Gradient

Successive images method is a good method to calculate the transmission line conductor surface voltage gradient. The number of images is decided by the ratio of the minimum distance between subconductors and the subconductor radius; the bigger the ratio, the fewer the number of images needed. When the ratio is bigger than 10, the calculation error is less than 0.2Here Novel method is use to calculate Surface Voltage Gradient as shown in figure6.2, In this method Successive image Method and Finite element method are combine.This method gives comparitively accurate result with respect to other method.

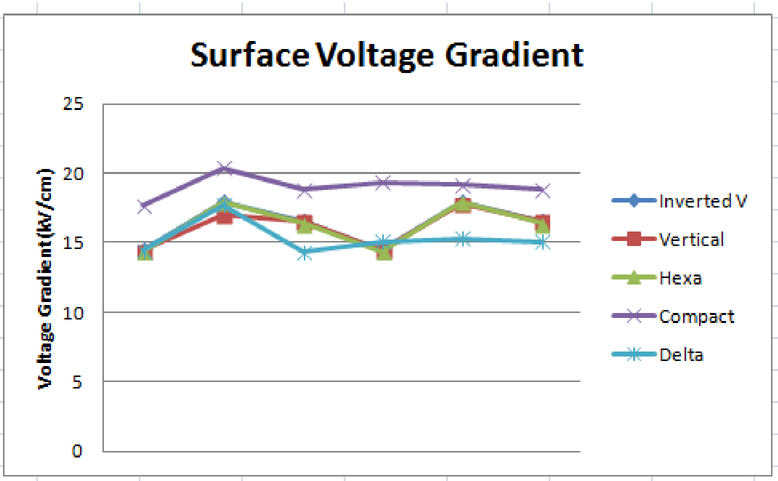


Figure 7.2: Surface Voltage Gradient

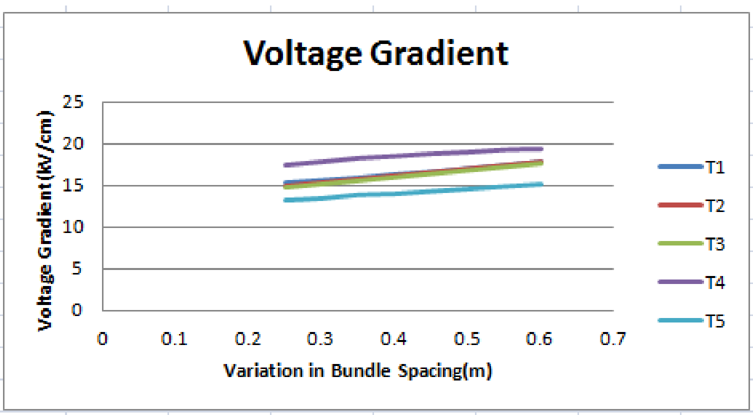


Figure 7.3: Surface Gradient with change in Sub conductor Spacing

Table III: PHASE CONDUCTOR AVERAGE MAXIMUM BUNDLE GRADIENTS AND AVERAGE BUNDLE GRADIENTS (KV RMS/CM)

Phase	T1	T2	T3	T4	T5
Phase R	14.49	14.5	14.4	17.72	14.45
Phase Y	17.93	17	17.9	20.4	17.72
Phase B	16.56	16.6	16.4	18.8	14.34
Phase R’	14.49	14.5	14.4	19.35	15.06
Phase Y’	17.73	17.8	17.9	19.15	15.322
Phase B’	16.66	16.6	16.4	18.88	15.092

Surface Voltage Gradient are also affected by change in Sub-conductor Spacing , Here the comparision of surface Voltage Gradient with variation in subconductor spacing are shown in figure6.3. Here in this image for different five configuration caparision are shown,

7.3 Corona loss

Corona loss is most important parameter in transmission line design.To calculate accurate Corona loss in EHV transmission line so many equations are there. In india weather conditions are different from other country. Weather Condition is also main factor which effect to calculate corona loss as Surface Voltage gradient.

To calculate corona loss equation is for foul weather condition,

$$P(db) = 14.2+65log(\frac{Emax}{18.8})+40log(\frac{d}{3.51})+13log(\frac{n}{4})+10log(\frac{RR}{1.676})+\frac{H}{300} \tag{7.1}$$

Where,

Emax = Maximum Average surface Voltage Gradient

d= Conductor diameter in cm

n= No of sub conductors

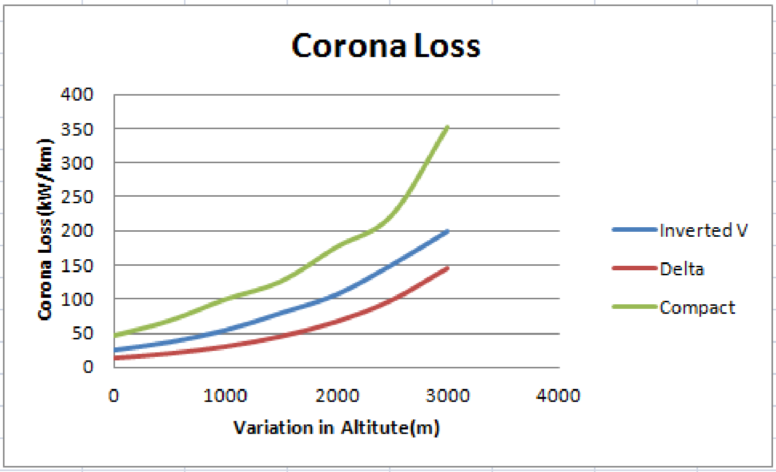


Figure 7.4: Corona Loss at Various Mean Sea Level

RR = Rate of rain

H = Height of tower from mean sea level

Table IV: Corona loss at different mean sea level

Alttitude	T1	T4	T5
0	25.12	47.15	14.52
500	36.90	69.34	21.33
1000	54.07	100.23	31.26
1500	79.52	126.19	45.96
2000	106.71	176.40	67.45
2500	150.75	222.7	99.021
3000	200	350.9	145.35

As Corona loss has direct effect of voltage gradient, as voltage gradient or surface stress will be more corona will increase and decrease as stress decrease as we can see in figure6.4. As change in conductor spacing also change corona loss, for various sub conductor spacing corona loss are calculated as shown in figure6.5.

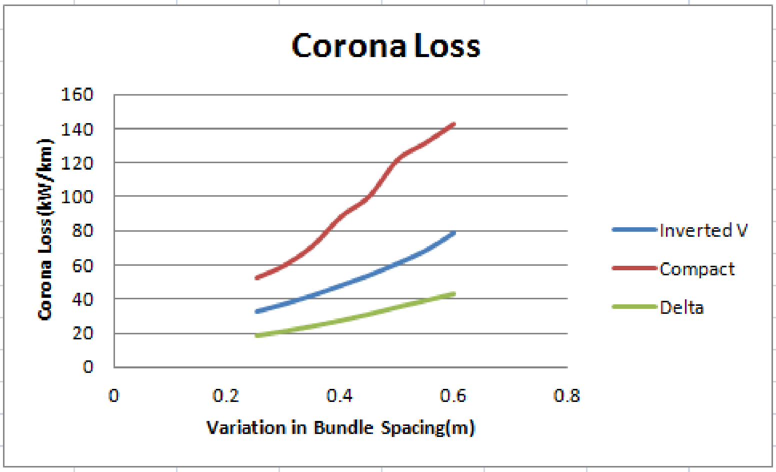


Figure 7.5: Corona Loss For Various Sub-Conductor Spacing at mean height 1000 m

7.4 Radio Interference Audio noise

Radio Interference can be found by:

$RI(db) = 3.5Gm + 6d - 33log(\frac{Di}{22}) - 30$

Where,

Gm = Voltage Gradient at respected phase

d= Conductor diameter

Di = Acrial distance from phase to location of microscope meter

Audio interference can be found by

$AN = 102logEm + 55logd - 11.4logDi + 26.4logN - 128.4$

Where,

Em = Voltage Gradient at respected phase

d= Conductor diameter

Di = Acrial distance from phase to location of microscope meter

N = no of sub conductor

Table V: Radio Audio Interference

	T1	T4	T5
RI(db)	51.44	59.087	44.51
AN(db)	53.86	60.48	49.90

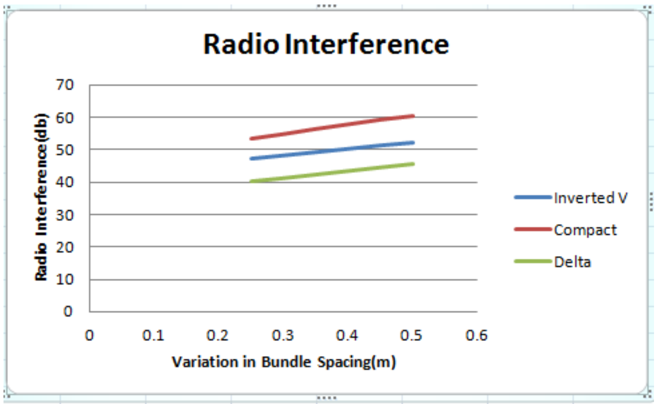


Figure 7.6: RI at various sub-conductor spacing

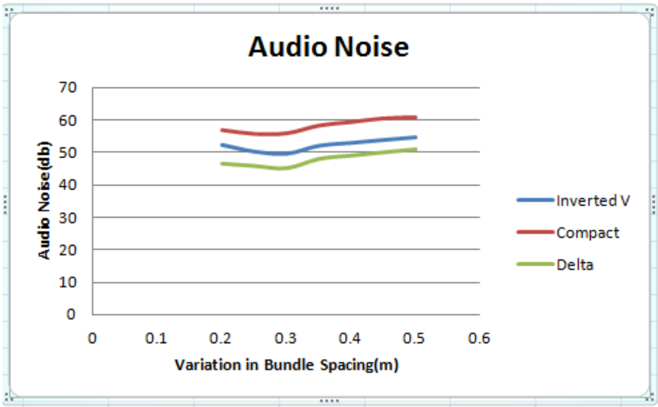


Figure 7.7: AN at various sub-conductor spacing

7.5 Electrosatatic Effect

Electrostatic effects from overhead e.h.v. lines are caused by the extremely high voltage while electromagnetic effects are due to line loading current and short-circuit currents. Hazards exist due to both causes of various degree. These are, for example, potential drop in the earth's surface due to high fault currents, direct flashover from line conductors to human beings or animals. Electrostatic fields cause damage to human life, plants, animals, and metallic objects such as fences and buried pipe lines. Under certain adverse circumstances these give rise to shock currents of various intensities.For given various Configuration Electrostatic field are ploted as shown in figure6.8,figure6.9 and figure6.10

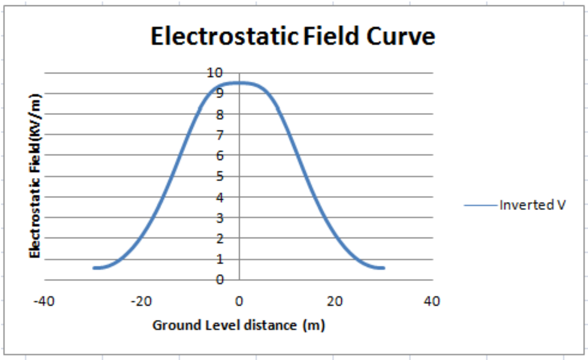


Figure 7.8: Electrostatic field of Inverted-V Configuration

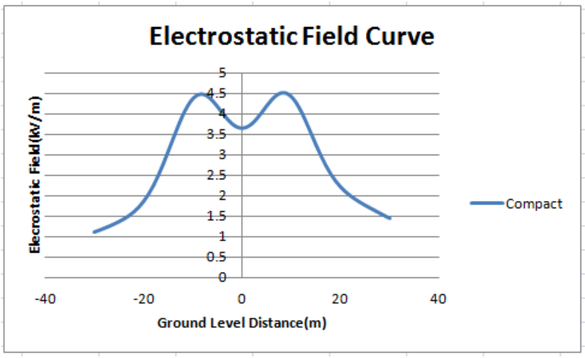


Figure 7.9: Electrostatic field of Compact Configuration

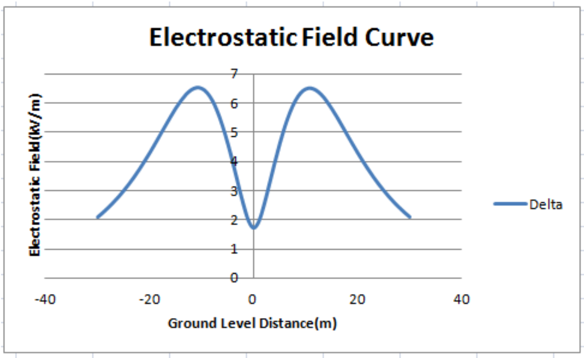


Figure 7.10: Electrostatic field of Delta Configuration

7.6 765 kV transmission line Tower Configuration:-

Here in this Comparitive study two 765 kV transmission line tower are compaired. Two different configuration of tower are mainly is Inverted-V and Hexa configuration. Inverted-V tower Configuration tower is errected by Lt IDPL chennai.Distance of phase A, B, C from mid of tower for Hexa configuration are 10917, 13090 and 12090 mm respectively. And distance of phase A, B, C from mid of tower for Inverted V configuration are 10917, 12090 and 14078 mm respectively.

7.6.1 Surface Voltage Gradient

Successive images method is a good method to calculate the transmission line conductor surface voltage gradient. The number of images is decided by the ratio of the minimum distance between subconductors and the subconductor radius; the bigger the ratio, the fewer the number of images needed. When the ratio is bigger than, the calculation error is less than 0.2Here to calculate Surface Voltage Gradient Novel method is used, For to different Configuration voltage gradient are shown in tableVI
Points are selected around each subconductor periphery 6 apart. The voltage gradients of each point Ep (root mean square-rms) are compared, and the biggest one is the maximum voltage gradient Esm (rms) of this subconductor. The average value of all the subconductor Esm values of one phase is the average maximum bundle gradient Em (rms) of this phase. The average value of all the subconductor Ep (rms) values of one phase is the average bundle gradient Epa of this phase. Em and Epa of the three double-circuit tower transmission lines are given in TableVI.

Table VI: PHASE CONDUCTOR AVERAGE MAXIMUM BUNDLE GRADIENTS AND AVERAGE BUNDLE GRADIENTS

Phase	T1		T2	
	Em	Epa	Em	Epa
A1	15.40	12.55	15.24	12.42
B1	15.57	12.68	15.18	12.37
C1	15.32	12.48	15.10	12.30
A2	15.32	12.48	15.10	12.30
B2	15.57	12.68	15.18	12.37
C2	15.40	12.55	15.24	12.42

7.7 Corona Loss

Each phase annual average CL per kilometer at fine, snow, rain, and rime weather conditions can be estimated by the following empirical formula:

$$Pcor = \frac{n^2 * r^2}{8760}[T1 \sum f1(\frac{Emi}{(2/3)Emo}) + \sum Tj \sum fj \frac{Emp}{Emo}] \tag{7.2}$$

Where Pcor is the annual average CL per kilometer of the line, kW/km; n is the number of subconductors in a phase; r is the radius of the subconductor, cm; m is the number of phases; T1, T2, T3, T4 are the annual calculation hours for fine, snow, rain, and rime weather conditions respectively, h; Empa is the maximum average bundle gradient of each phase (maximum value, 2 times of Epa), kV/cm; Em0 is the corona onset field intensity of conductor, kV/cm; f1, f2, f3, f4 are the dependence of Pj/n2r2 on Empa/Em0 for four weather conditions respectively j is the weather condition index Pj is the an hour average CL per kilometer line at j weather condition i is the phase index and a is the relative air density for fine weather.

Here for calculation weather condition are taken as shown in tableVII:

Correction of conductor working current is not made here, and the correction is needed in engineering according to a practical situation

Table VII: WEATHER CONDITIONS AND CALCULATION HOURS PER YEAR

weather	Fine	Snow	Rain	Rime
Calaulation Hour	5580		2800	

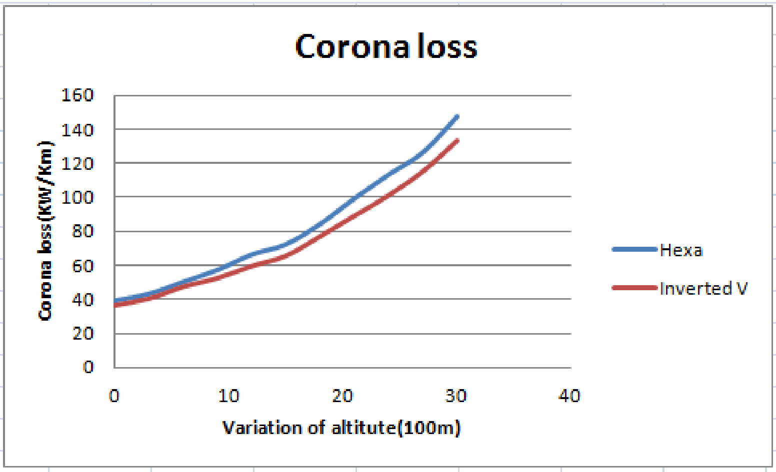


Figure 7.11: Corona loss variation with altitudes

$$Emo = 30.3m\delta(1 + \frac{0.3}{\sqrt{r}}) \quad (7.3)$$

Where m is the conductor surface factor, 0.82 for stranded conductors in general; δ is the relative air density; r is the radius of subconductor, cm

Table VIII: CORONA LOSS AT TYPICAL ALTITUDES FOR DIFFERENT TOWERS

Ha	0	500	1000	1500	2000	2500	3000
T1	38.5	47.4	59.7	72.7	92.8	116.4	145.8
T2	33.6	43.0	53.6	66.4	82.1	105.1	131.2

It can be seen from Figure6.12 that corona loss increases almost linearly with the increase of bundle spacing. This mean that the Epa also increases almost linearly with the increase of bundle spacing; and the calculated results of Epa validate this relationship.

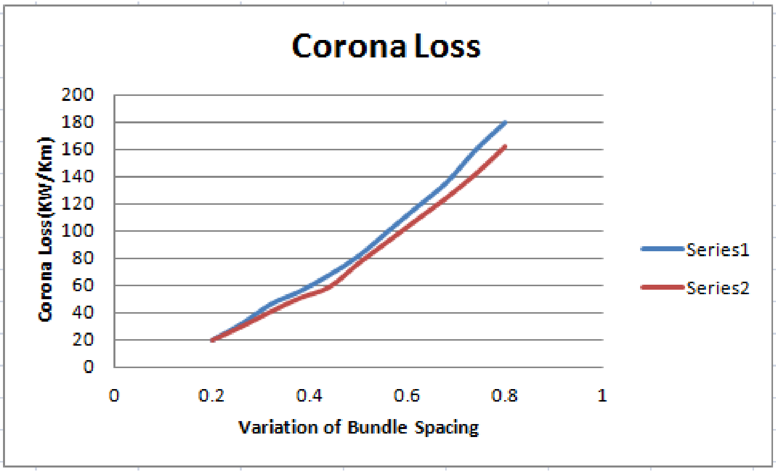


Figure 7.12: Corona loss variation with bundle spacing

7.8 Radio Intereference

The Westinghouse Electric Corporation of the USA summarized a empirical formula for calculating fine weather RI level of 700-775 kV AC transmission lines, which was summarized from the research on some operating high voltage lines, measured data of some test lines, and laboratory research. For heavy rain, a correction of 24 dB must be added.

$$Eri = Erid + 3.5(Em - Em1) + 30log(d/3.51) + 20log(30.7 + \frac{1}{D^2}) + 10(1 - f) + 40(1 - \frac{\delta}{\delta o}) \quad (7.4)$$

Erid and Em1 are constants and come from long term radio interference measurements and statistical analysis. Erid is 48 and Em1 is 17.5 for the 750 kV levels, f is 0.5 MHz in this calculation.

$$Eri = 20log[(10^{Eri/20})^2 + (10^{Erj/2})^2]^{1/2} \quad (7.5)$$

The RI level variation with Ha calculated by the Westinghouse method

Table IX: RADIO INTERFERENCE LEVEL AT TYPICAL ALTITUDE HEIGHT

Ha	0	500	1000	1500	2000	2500	3000
T1	42.8	44.8	46.7	48.6	50.3	52	53.7
T2	41.6	43.6	45.5	47.4	49.1	50.8	52.5

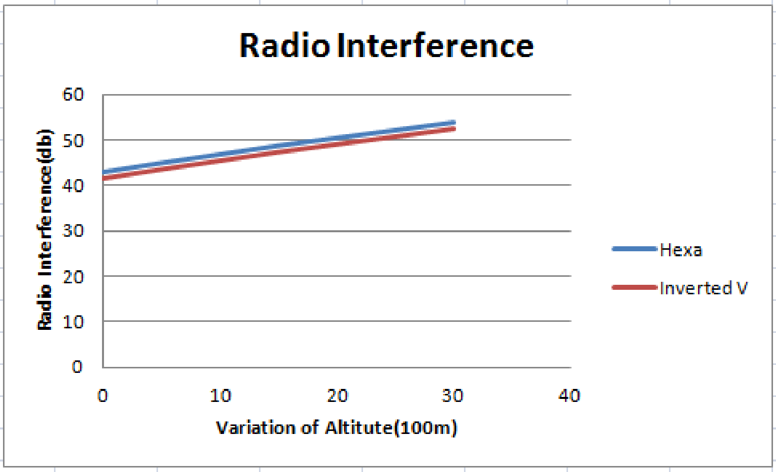


Figure 7.13: Radio interference level variation with altitudes

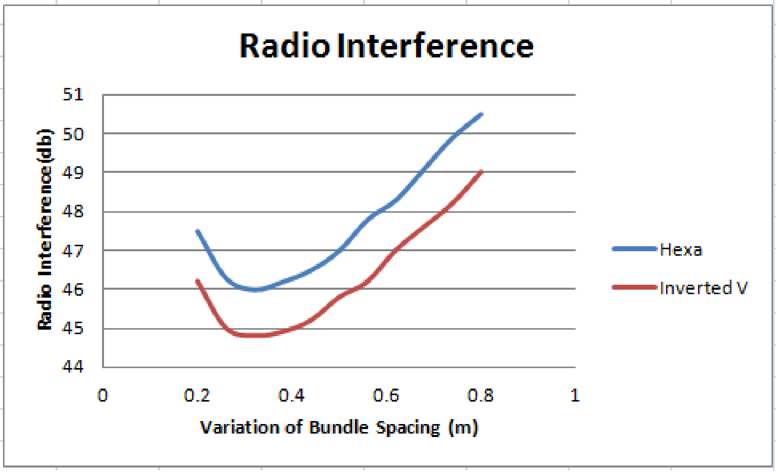


Figure 7.14: RI level variation with bundle spacing

curves of three typical tower lines is given in Figure, It can be seen from Figure that RI level first lowers and then increases with the increase of bundle spacing, and the turning point is at the place where the bundle spacing is 0.33 m,

7.9 Audio Noise

Audible noise is also an important electromagnetic environment parameter of UHV AC transmission lines. AN is the sound pressure at the reference

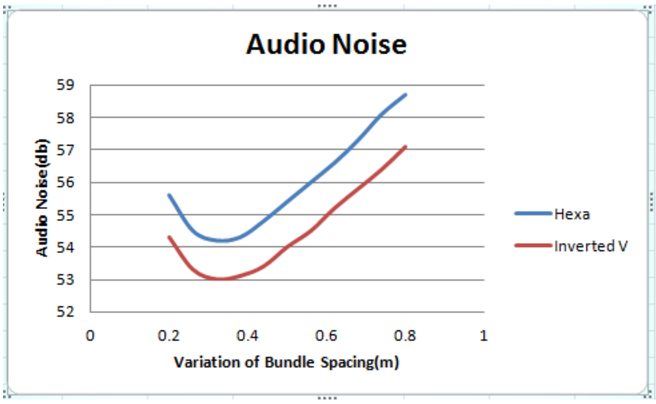


Figure 7.15: AN level variation with bundle spacing

point.

AN is estimated by using the BPA method, which is summarized from the long term measured data of some operating and test high voltage lines by BPA of the USA.

$$AN = 10log \sum log[(PWL(i) - 11.41logRi - 5.8)/10] \quad (7.6)$$

Where SLA is the A weighted sound power level i is the phase index z is the number of phase; PWL(i) is the sound power level of phase i Ri is the radial distance between reference point and phase i, m.

$$PWL = -164.4 + 120logEm + 55logdeq \quad (7.7)$$

It can be seen from Fig. 8 that AN first lowers and then increases with the increase of bundle spacing, and the turning point is at the place where the bundle spacing is 0.33 m.

Chapter 8

Conclusion and Future work

8.1 General

Conclusions are derived from the results obtained by alternatives, in which the power transfer, losses (line loss and corona loss) and effect of corona loss are the major factors. Based on these conclusions, recommendations are made and future scope of work is outlined in this chapter.

8.2 Conclusion

As Comparitive study we take five 400 kV tower configuration(Inverter-V, Hexa, Vertical, Compact, Delta) and two 765 kV tower configuration. Conclusion for 400 kV line can be drawn as:

- Inverted configuration has minimum inductance induced per phase,where othe hexa and vertical has nearly same value.Cpmpact and delta have 18.4 amd 2.8 percent higher inductance per phase than Inverted configuration.
- Distance between phases have direct impact on voltage gradient. Compact configuration conductor has maximum stress on conductor. Av-

erage maximum voltage gradient on inverted, compact ane delta are respectively 16.32 kV/cm, 18 and 15.1 kV/cm.

- With increase in sub-conductor spacing conductor voltage gradient also decrease.
- RI and AN are in safe limit at inverted and delta configuration even at 3000 mean height
- Inverted and delta both satisfy electrostatic and electromagnetic limits, but delta shows good result as environmental aspects

Conclusion for 765 kV line configuration can be drawn as:

- Induced inductance and capacitance are nearly same for both configuration
- Hexa has 2.5 percent more stress then inverted on conductor as increase mean height this percent are also increase
- Function f1, f2, f3, f4 in empirical formula are directly relevent to weather condition. Its also can consider in detail the influence of altitute to RI. The empirical formula can be good reference to calculation od UHV AC line.
- RI and AN gain minimum value at nearly 0.33 m sub-conductor spacing.
- Inverted satisfies all condition even in heigher mean height. Its gain good results at respected Indian weather Conditions.

8.3 Future Work

- Calculation and analys 1200 kV transmission line for single and double Circuit line
- Generalize GUI transmission line program for single, double and multicircuits
- Develop novel method to calculate voltage gradient which also includes factors like line sag, ground levels, conductor surface factor

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Appendix A

List of Publication

Paper title ”Novel Technique for calculating Surface Potential Gradient of Overhead Line Conductors” will be publiced at IJACR (International Journal of Advanced Computer Research).
ISSN: (Print):2249-7277
ISSN: (Online):22777970