"COMPUTER AIDED DESIGN, ANALYSIS AND COMPARISON OF VARIOUS CONFIGURATIONS OF E.H.V. 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

ANJU J. VERMA
(10MEEE17)

Department of Electrical Engineering
INSTITUTE OF TECHNOLOGY
NIRMA UNIVERSITY
AHMEDABAD-382481

MAY 2012

Undertaking for Originality of the Work

I **Anju J Verma**, Roll No. **10MEEE17**, give undertaking that the Major Project entitled **"Computer Aided Design Analysis and Comparison of Various Configurations of E.H.V. Transmission Line"** submitted by me, towards the partial fulfillment of the requirements for the degree of Master of Technology in **Electrical Power Systems, Electrical Engineering**, under Institute of Technology of 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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Signature of student

Date: May 2, 2012

Place:Ahmedabad

Endorsed by:

Mr. Alpesh Mohite
Mr. Kishor Gaikwad
(Industry Guide)
DGM, TPEC
Vadodara.

Prof. C.R.Mehta
(Institute Guide)
Asst. Professor
Department of Electrical Engineering
Institute of Technology
Nirma University, Ahmedabad.

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CERTIFICATE

This is to certify that **Miss. Anju J. Verma (10MEEE17)** from Institute of Technology, Nirma University, Ahmedabad has been under our training for the project titled **"COMPUTER AIDED DESIGN, ANALYSIS AND COMPARISON OF VARIOUS CONFIGURATIONS OF E.H.V. TRANSMISSION LINE"**. The training period was from May 2011 to June 2011. Thereafter she has been doing dissertation work in our company under our supervision till date. According to our assessment she has put in good amount of working days and has completed her work to our satisfaction. We understand that this work is towards the partial fulfillment of the syllabus for Master Degree in Electrical Engineering (Electrical Power Systems) of the university.

We wish her all the best for her all future assignments.

Date: 25th April 2012

SM TAKALKAR
Managing Director, TPEC, Vadodara

Alpesh Mohite
DGM ,TPEC, Vadodara

Kishor Gaikwad
DGM, TPEC, Vadodara

197- Vishwamitri Township, Opp. Gujarat Tractors, Vadodara–390 011. Tele Fax: 0265-235 6291, Tel: 234 3001 Mobile: 09879599402 /09925233951, Email: smtakalkarpca@gmail.com, Website: www.tpec.in

Certificate

This is to certify that the Major Project Report entitled **"Computer aided Design, Analysis and Comparison of Various Configurations of EHV Transmission Line"** submitted by Ms. **Anju J. Verma (10MEEE17)**, towards the partial fulfillment of the requirements for the award of degree in **Master of Technology (Electrical Engineering)** in the field of **Electrical Power Systems** of Nirma University is the record of work carried out by her under our supervision and guidance. The work submitted has in our opinion reached a level required for being accepted for examination. The results embodied in this major project work to the best of our knowledge have not been submitted to any other University or Institution for award of any degree or diploma.

Date: 25^{th} April 2012

Mr. Alpesh Mohite
Mr. Kishor Gaikwad
(Industry Guide)
DGM, TPEC
Vadodara.

Prof. C. R. Mehta
(Institute Guide)
Asst. Professor
Department of Electrical Engineering
Institute of Technology
Nirma University, Ahmedabad.

Head of Department
Department of Electrical Engineering
Institute of Technology
Nirma University
Ahmedabad

Director
Institute of Technology
Nirma University
Ahmedabad

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- Anju J. Verma
10MEEE17

Abstract

Power demand had a drastic raise in past few decades. To fulfil the power demand, transmission line become an vital part of power system. As power generating units are at a far distant from user, transmission of power to consumer is only possible via transmission and distribution lines. Optimum design of transmission line is essential and it requires proper selection of voltage level, number of circuit required, type of conductor, number of sub-conductor in a bundle, spacing between adjacent sub-conductor, clearances etc.

The manual method of transmission line design involves tedious calculation and rely on the knowledge and experience of designer. Computational design of transmission line gives faster result and wide vision of the probable solutions. According to the existing constraint variable, design parameters and solution varies. For EHV transmission line design, certain areas are given more importance, such as corona loss, electric and magnetic fields.Transmission line designing is done in such a way that conductor has low losses, high efficiency, good voltage regulation, less RI, TVI and AN. By using high order bundled conductor, corona loss, AN, RI are reduced. As these loss increases with the raise in voltage level, so in case of EHV and UHV transmission level bundled conductor are used.

This report provided an insight into design of transmission line. Almost all the electrical calculation are discussed which are required for EHV transmission line design. These calculations are required for selection of appropriate conductor for power transmission, at extra high voltage level. A *C#* based software is developed so as to calculate all electrical parameter required for transmission line design. Programme is developed for single and double circuit transmission line, including upto eight sub-conductor in a bundle. By employing this user friendly software, a range of options can be obtained.

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Abbreviation

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 / Invar Reinforced
TVI .... Television interference
UHV .... Ultra High Voltage
UTS .... Ultimate Tensile strength
VR .... Voltage Regulation

Nomenclature

α .... Constant of mass temperature coefficient of resistance of conductor per ^{0}C
γ .... Solar radiation absorption coefficient
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_{conc} .... 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

Contents

Chapter 1

Introduction

Power is generated in power station at rated voltage (usually $11KV/13.6KV/15KV$) which is stepped up by step up transformers and transmitted through transmission line to substations, where it is further stepped down and distributed to the consumers. Fig1.1 shows the basic arrangement of power generation, transmission and distribution. Overhead lines are essential to transmit power from one place to other and also for interconnection purposes. Interconnected lines are used to transfer power in case of emergency. In order to match the mechanical and electrical characteristics of the overhead conductors to the environmental conditions, climatic details must be first collected and analyzed. For economic design of transmission lines, electrical calculations are completed and subsequently type of conductors are selected. According to the electrical calculation, soil property, atmospheric condition etc. tower configuration and design are primed.

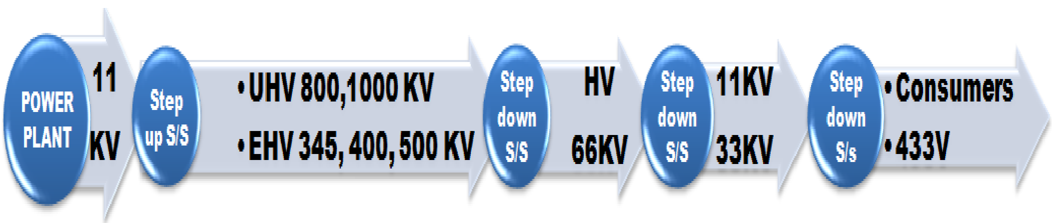


Figure 1.1: Basic arrangement of power generation, transmission and distribution

- Advantages of EHV-AC Transmission Line
  - Power transfer capability of circuit increases.
  - Number of circuits and land requirement for transmission are reduced for a definite MW power transfer.
  - At high voltage level, transmitted current in the line reduces thereby reduces the line losses per unit MW power transfer.
  - For reduced transmission current, size of conductor required reduces which decreases the volume of conductor and cost per MW transfer.
  - Increase in transmission efficiency.
- Disadvantages of EHV-AC Transmission Line
  - Necessitate high insulation level and the cost of insulation increases.
  - Large clearance are required between conductor to ground, phase to phase.
  - Corona loss and its effects RI, AN.
  - Cost of tower support and foundations is enormous.
  - Cost of switchgear equipments, protective equipment and transformer increases.
  - Right of way problem is predominant.
  - Ferranti effect comes into picture.
  - EHV is dangerous for all forms of life.

1.1 Objective of project

Design of EHV and UHV transmission line has become essential for today's transmission engineer. Demand of power has risen 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.
In this project, a programme will be developed using C # (C sharp), that will enable the designer to obtain the most economical and reliable design without rigorous manual calculations. Designer will have flexibility to find the optimum solution, depending upon the specification and site conditions.

1.2 Problem Identification & Project Planning

1.2.1 Problem Identification

- 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.

- Selection of the shortest route must be considered along with the cost required to acquire the land, for ROW.

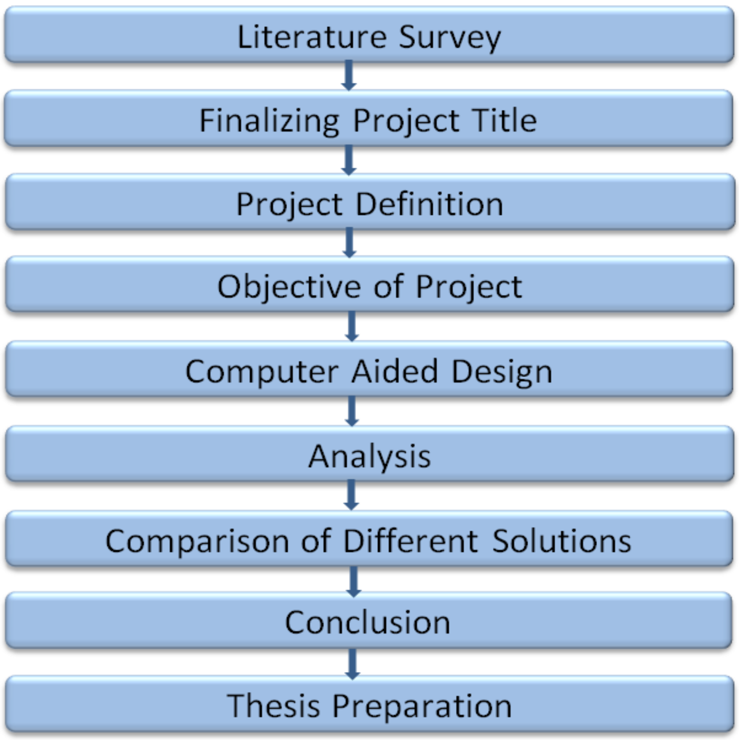
- Choice of conductor according to its current carrying capacity, and choice of number of circuit i.e. single circuit, double circuit or multicircuit.

- 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.

- 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.

- According to the atmospheric condition, calculate corona loss of selected conductor for normal weather condition and critical weather condition. Corona calculation changes as per the number of bundle in a conductor and atmospheric conditions of the line. Conductors with large GMD or diameter have low corona losses but at the same time with increase in diameter, weight of line increases resulting into high cost of tower and foundation.

1.2.2 Project Planning



1.3 Thesis Organization

Chapter 1 is introduction to the basic transmission line design along with the problem identification and project planning so as to complete work.

Chapter 2 shows various papers and standard referred to understand the basics of designing and develop an application using the idea of the earlier research done in transmission line design area.

Chapter 3 deals with study area which is considered here for EHV transmission line design. It also includes environmental condition of area and its layout.

Chapter 4 includes brief description of all electrical calculation that are essential for transmission line design, such as CCC, Voltage gradient, Corona Loss, RI, AN etc..

Chapter 5 deals with C# which is employed for development of software and it also give brief introduction to the software developed for CCC calculation and for all other electrical calculation for single circuit or double circuit transmission line in conjunction with flowchart associated with same.

Chapter 6 shows the input parameter used for calculations and calculation procedures employed here. It also includes result and analysis of different conductors and different possible combination and configuration of transmission line.

Chapter 7 includes conclusion and future scope of EHV transmission line design in the field of electrical power system.

Chapter 2

Literature Review

2.1 General

This chapter briefly discusses the literature review carried out for present study. Transmission line transmits the power from transmission station to receiving station. Design of transmission line is utterly dependent on the selection of correct data's. Selected design parameter should be acceptable to ensure reliability, stability and security of transmission line along with the higher efficiency as well as desired power transfer capability.

2.2 Factor affecting Transmission Line design

2.2.1 Transmission Voltage Level

This is one of the most important parameter. All the parameter such as air gap clearance, phase to phase clearance, ground clearance etc. are entirely dependent on the voltage level. Following are the transmission voltages:

$66KV, 110KV, 132KV, 220KV, 345KV, 400KV, 500KV, 765KV, 1000KV, 1200KV$

2.2.2 Conductor Type & Size

A good conductor must possess good mechanical strength and less resistance. Optimum selection of conductor type and size, require understanding of characteristics of all available conductor type.

- Stranded Conductor: In EHV transmission, stranded conductors are always used, standard conductors affords reduction in skin effect to a considerably low value. Some of the commonly used conductors are ACSR (Aluminium Conductor Steel Reinforced), ACCC (Aluminium Conductor Composite core), ACAR (Aluminium conductor-Aluminium-Alloy Reinforced), AAAC (All Aluminium Alloy Conductor), and AAC (All Aluminium conductor), AACSR (Aluminium Alloy Conductor Steel reinforced), ACSS (Aluminium Conductor Steel Supported). Various combinations and modifications of these conductor types provide a wide variety of possible conductor designs.

- Bundle Conductor : Bundled conductors are combination of more than one conductor per phase in parallel suitably spaced from each other, used in overhead transmission line. Corona loss decreases with increase in number of subconductors in a bundle. Mostly twin, quad, hexa and octa bundle conductors are used in EHV lines. However there are lines which deploy triple bundle.

2.2.3 Number of Circuit

Transmission line can be mainly divided into three categories:

- Single circuit : Single circuit carry only one circuit on a tower. For three-phase system, each tower supports three conductors or three bundles of conductors.

- Double circuit: Double circuit carry two circuit on a tower. For three-phase system, each tower supports six conductors or six bundles of conductors.

- Multi circuit: Multi circuit carry more than two circuits on a tower. For three-phase system, each tower supports more than six conductors.

2.2.4 Line regulation and Voltage Control

Transmission line must have better voltage regulation so that voltage is maintained at desired value for suitable operation of line.

2.2.5 Corona

A luminous discharge due to ionization of the air surrounding an electrode caused by a voltage gradient exceeding a certain critical value is corona. Occurrence of corona gives rise to audible noise and radio interference. There are two principle mode of corona, glow mode and streamer mode. Power is lost during corona process.
Problem arising due to corona in EHV lines are

- Radio Interference (RI): Degradation of the reception of a wanted signal caused by RF disturbance.
- Audible noise (AN): Any undesired sound.
- Television interference (TVI): A radio interference occurring in the frequency range of television signals.
- Electromagnetic interference: Degradation of the performance of a device, a piece of equipment, or a system caused by an electromagnetic disturbance.

2.2.6 Conductor Spacing

Line design is greatly affected by spacing, between phase-phase vertical and horizontal power conductor of same circuit or different circuit, conductor clearance to ground, clearance with other power or communication line, clearance above river, etc.

2.2.7 Sag Tension calculation

Maximum sag, Maximum tension and minimum sag, all these parameters must be known so as to maintain clearance to the ground and conductor, proper structure to withstand tension, and to control structure uplift problem.

2.2.8 Environmental condition

Reliability of a transmission system depends on the accuracy of the parameter related to environment conditions considered for design e.g. Temperature, Wind Velocity, Solar radiation, rainfall, snow, lightning etc.

Special consideration of EHVAC transmission line are Corona loss, Radio Interference, Television interference, Bundle conductor, Lightning protection, Line charging current, Clearances Constructional aspect, Switching over-voltages, Electrostatic field at ground level.

Standard [1] provides the specification of Aluminium conductor reinforced galvanized steel conductor for extra high voltage above 400KV. The standard size (Nominal sizes and tolerance on nominal sizes), property, number of strands in the conductor, electrical resistance, sectional area, Approx 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.

Standard [2] provides calculation method for current carrying capacity of conductor under any particular environmental conditions and to obtain heat balance equation such that heat gained by the conductor must be equal to the heat lost by the conductor. These calculation includes calculation of power loss due to joule effect, Radiated heat loss, Convection heat loss, Solar heat gain. It also provide CCC of recommended conductor which are as per IEC 1089 under certain atmospheric conditions and with change in certain condition like wind speed and ambient temperature, CCC of conductor changes and it can be recalculated according to the equations available in this standard.

Standard [3] provides basic equations and parameters required for calculation of sag and tension of a conductor. Reliability considerations, effect of wind on conductor, risk coefficient for different reliability level and wind zones, terrain roughness coefficient, terrain category, wind load on conductor and many other parameter are categorized and calculated such that all the required possibilities are covered for calculations. Computation of transverse load, vertical load and longitudinal loads for all conditions (Reliability, Security and safety conditions) are provided here.

Paper [4] presents computational method to calculate electric and magnetic field in the vicinity of transmission line. The electric field initiate corona resulting in corona loss with associated interference nuisances like RI, AN etc. Calculation procedure for conductor surface gradient, corona loss, AN and RI are given here along with certain rules that are applied in case of three phase single circuit and double circuit line. All calculations are carried out using program, which is developed in C language. This paper shows that the results obtained by software are comparable with the results published in various journals and transactions.

Paper [5] presents procedure for calculating Radio Interference of 500KV double circuit transmission line in Sanaxia Power Station. It was successfully proven that, the result found using metrical data and calculated values were nearly same and was within standard limits. Thus same calculation procedure can be employed for any double circuit EHV transmission line.

Paper [6] presents corona power loss measurement for 2, 4, 8 conductor bundles using Moose and Bersimis sub conductors for system voltage level from 420 KV to 1200 KV i.e. for EHV and UHV voltage level. Theoretical calculation procedure for surface gradient of conductor is briefed here and results are verified with the software. It is proved that for same voltage gradient, as number of sub-conductors are increased corona loss is reduced. This paper also shows that the number of sub conductors have a more impact than the sub conductor spacing on corona loss, and corona loss increase rapidly with increase in surface voltage gradient but reaches a steady value above about 22KV/cm.

Paper [7] presents a range of line optimization techniques which can be applied to decide whether standard or optimized line designs are appropriate. It is found that even simple methods of optimization can help the designer keep his costs to a minimum. There are several design factors which can be modified to minimize cost (such as choice of conductor diameter, number of subconductor) but some design factor are not in control of designer (such as restricted ROW because of land cost). All such conditions must be taken care by the designer. Potential source of saving can be made by choosing appropriate conductor size, conductor type, span, structure height, maximum allowable temperature etc.

Reference [8] provides data for the electric design of EHV and UHV transmission lines up to 1500 KV. Corona performance, electric and magnetic field, insulation design and circuit performance including conductor characteristics are the four major design area discussed. Design chart and equations as well as their underlying technology are developed for both single circuit as well as double circuit. Also present Electric field at ground level, effect of electric field on objects in ROW and effect of magnetic fields.

Reference [9] provides electrical clearance to be maintained for different voltage level under various environmental conditions (such as crossing of 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 the 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 [10] provides the calculation procedure for line parameter, voltage gradient on conductor, Corona loss, Effect of corona (RI and AN values)and design of EHV lines based upon steady state limit. The electrostatic fields in line vicinity, corona effects, losses, AN, RI, and TVI were recognized as steady state problems governing the line design and designing here are based on these limits.

Reference [11] provides the procedure to calculate line inductance and capacitance for single circuit line as well as double circuit line and for bundle conductors. ABCD parameter of line and voltage regulation of line is presented for short, medium and long transmission line.

Chapter 3

Study area

3.1 General

LAKE TURKANA WIND POWER (LTWP) is a company incorporated in Kenya (East Africa) to develop energy sources from wind. Fig3.1 shows the location of Lake Turkana in kenya and Fig3.2 shows map of kenya.

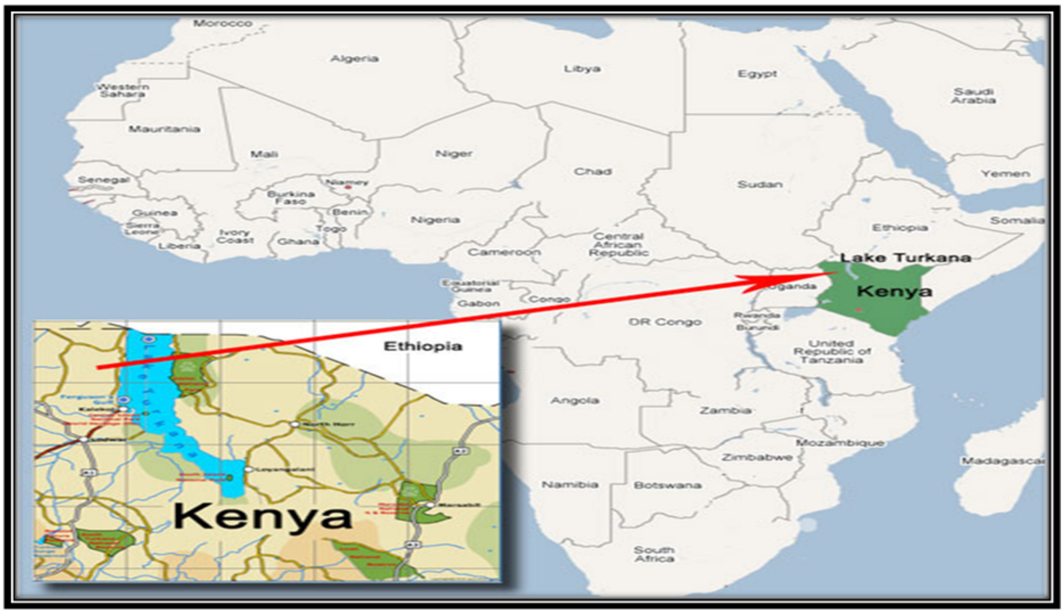


Figure 3.1: Location of lake turkana

The Lake Turkana which is approximately 600 km away in the North-West direction 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 3.2: Map of kenya

3.2 Environmental 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. Overall 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)

3.3 Layout

Fig3.3 shows the layout of the project LTWP. 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).

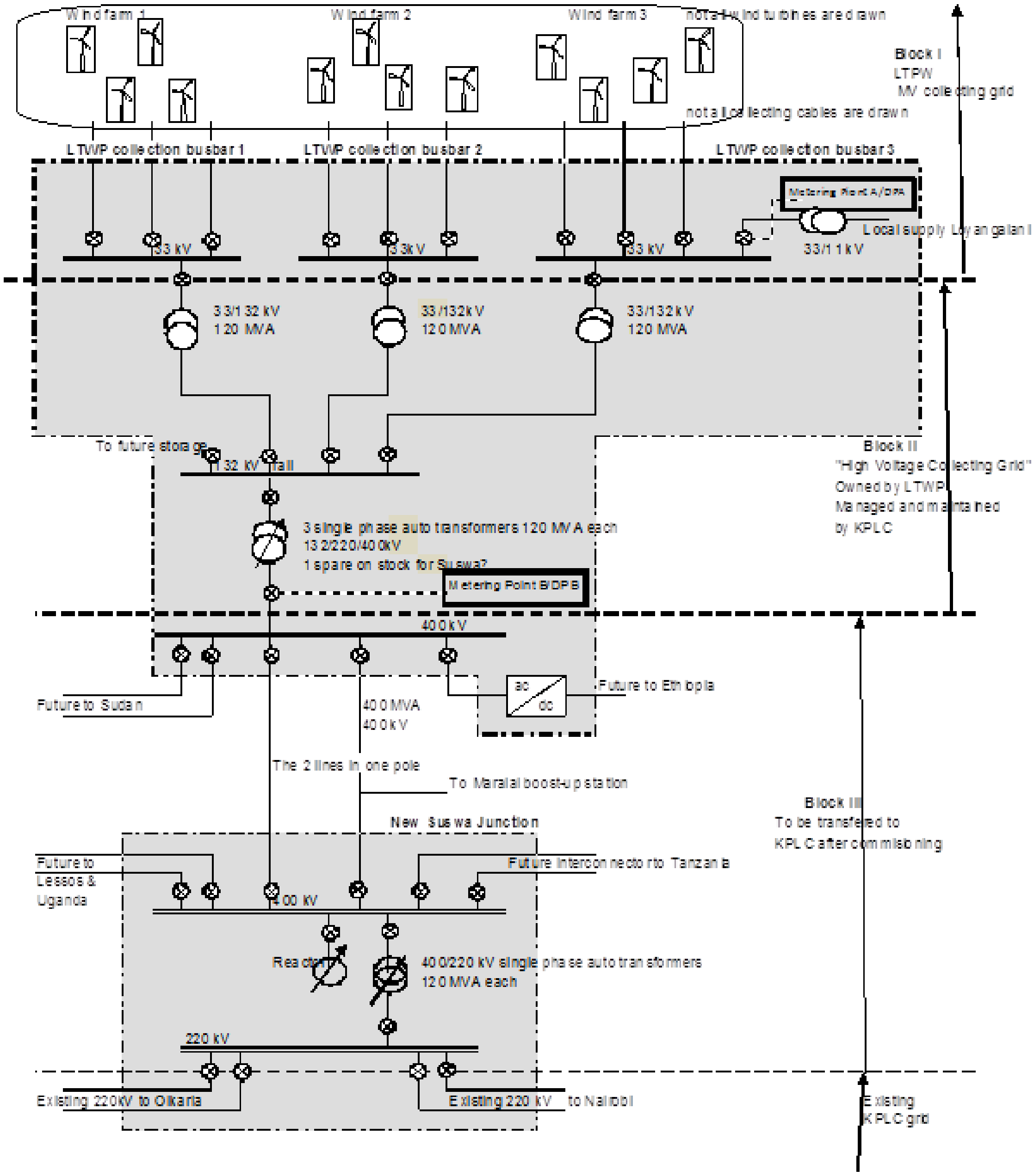


Figure 3.3: General layout of LTWP

Chapter 4

Methodology

4.1 General

This chapter deals with the methodology adopted for the study to satisfy our objectives.

4.2 CCC or Ampacity of Conductor

Current carrying capacity (CCC) of any conductor is the ampere it can carry before damaging the conductor. Amount of current that can be carried by a conductor is determined by the temperature withstand capacity of the conductor. Ampacity of a conductor must be more than the normal rated current to be transmitted, so as to carry the overload current without any damage.
CCC of a conductor depends on following factor

- Type of conductor
- Electrical resistance of the conductor
- Maximum allowable temperature rise
- Ambient weather conditions

Conductor carrying current cause I^2R loss that contributes in the increased temperature of conductor. Solar radiation is the other factor that raises the temperature of the conductor. Steady state temperature rise of a conductor is attained whenever the heat gained by the conductor from various sources is equal to heat losses.This is express by heat balance equation as [2]:

$$P_j + P_{sol} = P_{rad} + P_{conv} \tag{4.1}$$

P_j: Heat generated by joule effect (W)
P_{sol}: Solar heat gain by conductor surface(W)
P_{rad}: Heat loss by radiation of the conductor(W)
P_{conv}: Convection heat loss(W)

4.2.1 Heat generated by joule effect

Every conductor has some resistance value, when current flows through these conductors, I^2R loss occur. Power loss due to joule effect is [2]:

$$Pj = I^2 R_{ac} \tag{4.2}$$

I: Current through conductor (A)
R_{ac}: AC resistance of conductor at final equilibrium temperature. (Ω/m)
DC resistance of conductor at 20^0C is provided by the supplier. From this DC resistance at equilibrium temperature is obtained and thus AC resistance at equilibrium temperature. Following calculation are done to obtain R_{ac}

$$R_{ac} = K * R_{dc}$$

$$R_{dc} = R_{dc(t1)}(1 + \alpha(T_2 - t_1))$$
$$\check{a} = 0.063598 * \sqrt{\frac{\mu * f}{1.6 * R_{dc}}}$$

K is factor to be considered for skin effect

R_{dc}:DC resistance of conductor at final equilibrium temperature (Ω/m)

$R_{dc(t1)}$:DC resistance of conductor at 20^0C temperature (Ω/m)

α:Constant of mass temperature coefficient of resistance of conductor per^0C

t1: 20^0C

T_2:Final equilibrium temperature (^0C)

f: frequency of system (Hz)

μ: Permeability of non-magnetic materials

$\check{a}$: numerals whose corresponding value of K is used for calculation purposes.

4.2.2 Solar heat gain

Overhead transmission line are exposed to sunlight. According to the intensity of solar radiation in that region and solar radiation absorption coefficient of the conductor, solar heat is gained by the conductor [2].

$$P_{sol} = D * \gamma * S_i \tag{4.3}$$

D: Diameter of conductor (m)

γ: Solar radiation absorption coefficient

S_i: Intensity of solar radiation (W/m^2)

4.2.3 Radiated heat loss

Heat gained by the conductor is lost due to radiation. This radiation loss is given by Stefan-Boltzman law [2].

$$P_{rad} = \Pi * S * D * K_e * (T_2^4 - T_1^4) \tag{4.4}$$

S: Stefan-Boltzman constant ($W * m^{-2} * K^{-4}$)

D: Diameter of conductor (m)

K_e: Emissivity co-efficient in respect to black body

T_2: Final equilibrium temperature (K)

T_1: Ambient temperature (K)

4.2.4 Convection heat loss

Heat of the conductor is lost by convection to air. This loss greatly depends on atmospheric condition i.e. wind velocity, ambient temperature etc [2].

$$P_{con} = \Pi * \lambda * N_u * (T_2 - T_1) \tag{4.5}$$

Here N_u is Nesselt's number and can be obtained using Reynold's number (R_e) as shown below.

$$N_u = 0.65 * R_e^{0.2} + 0.23 * R_e^{0.61}$$
$$R_e = 1.64 * 10^9 * V * D * (T_1 + (0.5 * (T_2 - T_1)))$$

λ: Thermal conductivity of air film in contact with conductor ($'W * m^{-1} * K^{-1}$)

V: Velocity of wind (m/s)

D: Diameter of conductor (m)

T_2: Final equilibrium temperature (K)

T_1: Ambient temperature (K)

Now, CCC of any conductor can be obtained using above equation:

$$CCC = \sqrt{\frac{P_{rad} + P_{con} - P_{sol}}{Rac}} \tag{4.6}$$

Conductor is chosen as per CCC of the conductor (in Amp), for transmitting power at different voltage levels.

4.3 Inductance and Capacitance

Inductance of transmission line is the flux linkage per ampere and its calculation varies as per different conductor configuration. Capacitance of a transmission line is the result of the potential difference between the conductors, it causes them to be charged in the same manner as the plates of a capacitor when there is a potential difference between them. The capacitance between conductors is the charge per unit of potential difference.

Inductance and capacitance of an overhead transmission line can be determined by following equations.

$$L = 2 * 10^{-7} ln \frac{G_m}{G_s} \quad (H/Phase/m) \tag{4.7}$$

$$C = \frac{0.0556}{ln \frac{G_m}{G_s}} \quad (\mu F/Phase/Km) \tag{4.8}$$

G_m: Geometric Mean Distance (GMD)

G_s: Geometric Mean Radius (GMR) or Self GMD

4.3.1 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

$$G_m = \sqrt[3]{D_{ab} D_{bc} D_{ca}}$$

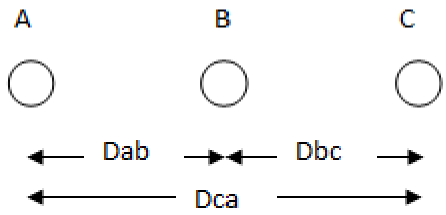


Figure 4.1: Single circuit horizontal configuration

Double circuit

$$G_m = \sqrt[3]{D_{ab} D_{bc} D_{ca}}$$

$$D_{ab} = \sqrt[4]{D_{ab} D_{a'b} D_{ab'} D_{a'b'}}$$
$$D_{bc} = \sqrt[4]{D_{bc} D_{b'c} D_{bc'} D_{b'c'}}$$
$$D_{ca} = \sqrt[4]{D_{ca} D_{c'a} D_{ca'} D_{c'a'}}$$

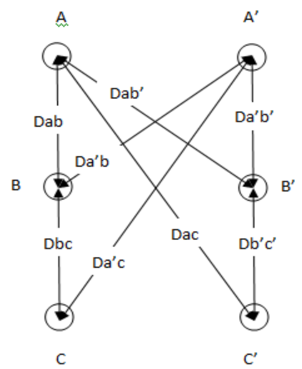


Figure 4.2: Double Circuit vertical configuration

4.3.2 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 [11].

Single conductor configuration

$GMR = 0.7788 * r = r'$

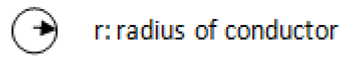


Figure 4.3: GMR of single conductor configuration

Twin conductor configuration

Twin conductor is a basic bundle conductor, having two subconductor. To calculate 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.

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

Similarly for other bundled conductor, GMR can be calculated as follows:

Figure 4.4: GMR of twin conductor configuration

Triple conductor configuration

$$GMR = \sqrt[9]{(r' * d * d)(r' * d * d)(r' * d * d)}$$
$$= \sqrt[9]{(r' * d^2)^3}$$
$$GMR = \sqrt[3]{r' * d^2}$$

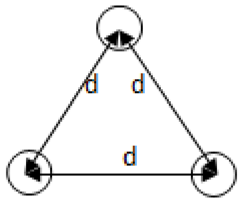


Figure 4.5: GMR of triple conductor configuration

Quad conductor configuration

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

Here,

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

$\quad = \sqrt{2}d$

$GMR = \sqrt[4]{r' * d^2 * \sqrt{2} * d}$

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

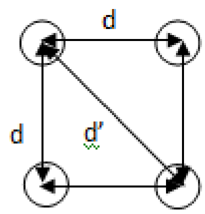


Figure 4.6: GMR of quad conductor configuration

Hexa conductor configuration

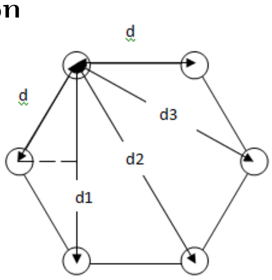


Figure 4.7: GMR of hexa conductor configuration

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

Here,

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

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

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

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

Octa conductor configuration

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

Here,

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

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

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

$GMR = \sqrt[8]{r' * d^2 * d_1^2 * d_2^2 * d_3}$

$= \sqrt[8]{52 * r' * d^7}$

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

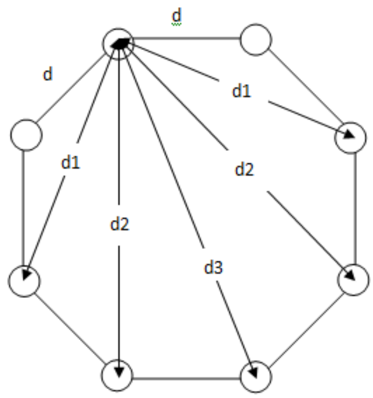


Figure 4.8: GMR of octa conductor configuration

Similarly GMR of other bundled conductors can be obtained. As bundling of con-

ductor 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 transmission 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 transposition and in Double circuit, vertical configuration is chosen as it reduces the ROW and cost associated to it.

4.4 Impedance and Admittance of conductor

Total impedance is calculated using reactance and resistance value of the transmission line.

4.4.1 Impedance

$$Z = R + jX \tag{4.9}$$

$$R = R_t I$$
$$X = 2\pi f L$$

Z: Impedance of line (Ω)

R: AC resistance of line (Ω)

X: Reactance of line (Ω)

R_t: AC Resistance of line at t2 ^{0}C (Ω/Km)

l: Transmission line length (Km)

f: frequency of system (Hz)

L: Inductance of line (H/Phase)

4.4.2 Admittance

$$Y = 2\Pi f C \tag{4.10}$$

Y: Admittance of line (℧)

f: frequency of system (Hz)

C: Capacitance of line (μF/phase)

4.5 Voltage Regulation

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

$$V.R.\% = \frac{|V_r|_{noload} - |V_r|_{fullload}}{|V_r|_{fullload}} * 100 \tag{4.11}$$

$$V_s = A * V_r + B * I_r \quad \text{(V)}$$
$$I_s = C * V_r + A * I_r \quad \text{(A)}$$
$$V_r = D * V_s - B * I_s \quad \text{(V)}$$
$$I_r = -C * V_s + A * I_s \quad \text{(A)}$$

$|V_r|_{noload}$: Magnitude of receiving end voltage at no load

$|V_r|_{fullload}$: Magnitude of receiving end voltage at full load

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.

A,B,C,D Parameter

$$A = \left(1 + \frac{ZY}{2!} + \frac{(ZY)^2}{4!} + \frac{(ZY)^3}{6!}\right) = cosh(\gamma l) = D.$$

$$B = Z\left(1 + \frac{ZY}{3!} + \frac{(ZY)^2}{5!} + \frac{(ZY)^3}{7!}\right) = Zc * sinh(\gamma l)$$

$$C = Y\left(1 + \frac{ZY}{3!} + \frac{(ZY)^2}{5!} + \frac{(ZY)^3}{7!}\right).\frac{1}{Zc} * sinh(\gamma l)$$

Voltage regulation

$$V.R.\% = \frac{|V_r|_{noload} - |V_r|_{fullload}}{|V_r|_{fullload}} * 100$$
$$V_{rnoload} = \frac{|V_s|}{|A|} = \frac{|V_s|}{cosh\gamma l}; \qquad where\gamma = \sqrt{ZY}$$
$$V_{rfullload} = D * V_s - B * I_s$$

4.6 Voltage Gradient

Voltage gradient on conductors governs generation of corona on the line which have significant effect on AN and RI. A convenient formula known as Markt-Mengele formula can be derived for horizontal and vertical configurations. Voltage charge relations are given by [10]:

$V_1 = P_{11} * \frac{Q_1}{2*\Pi*e_0} + P_{12} * \frac{Q_2}{2*\Pi*e_0} + P_{13} * \frac{Q_3}{2*\Pi*e_0}$

$V_2 = P_{21} * \frac{Q_1}{2*\Pi*e_0} + P_{22} * \frac{Q_2}{2*\Pi*e_0} + P_{23} * \frac{Q_3}{2*\Pi*e_0}$

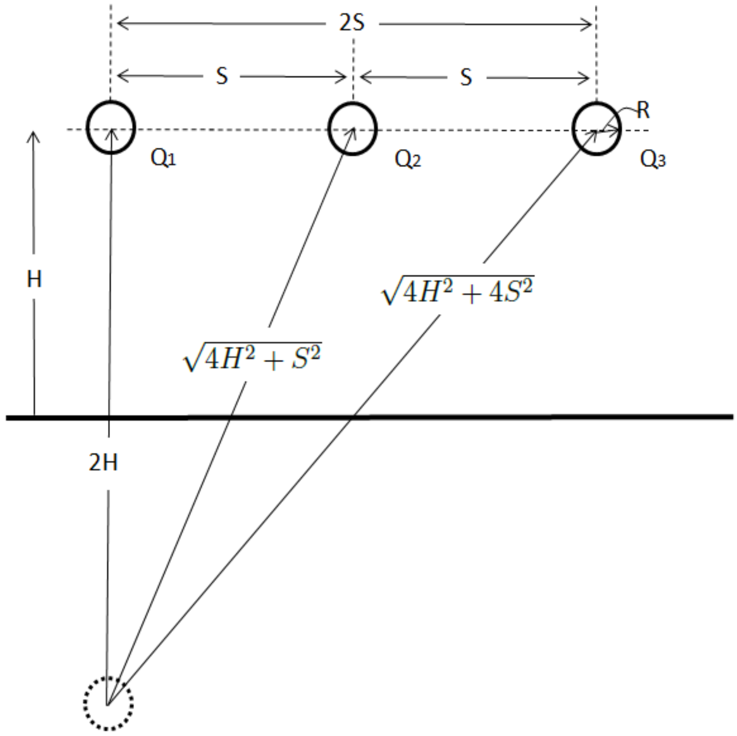
$V_3 = P_{31} * \frac{Q_1}{2*\Pi*e_0} + P_{32} * \frac{Q_2}{2*\Pi*e_0} + P_{33} * \frac{Q_3}{2*\Pi*e_0}$

Here,

P_{ij}: Maxwell's Potential coefficients. (i=1,2,3 & j=1,2,3)

Q_k: Instantaneous charges on the bundles. (k=1,2,3)

(1) Voltage gradient for horizontal configuration



$P_{11} = P_{22} = P_{33} = ln(\frac{2H}{r_{eq}})$
$P_{12} = P_{21} = P_{23} = P_{32} = ln(\frac{\sqrt{4H^2+S^2}}{S}) = ln(\sqrt{1+(\frac{2H}{S})^2})$
$P_{13} = P_{31} = ln(\frac{\sqrt{4H^2+4S^2}}{2S}) = ln(\sqrt{1+(\frac{H}{S})^2})$
Both the voltages and the charges are sinusoidally varying at power frequency. At every instant of time, $V_1+V_2+V_3 = 0$ and $Q_1+Q_2+Q_3 = 0$. When the charge on any one phase is at its peak, then the charges on the other two remaining phases are negative in direction and half in magnitude. Assume peak value of instantaneous charges on the bundle, $Q_1 = Q_2 = Q_3$. Combining equations of V_i and P_{ij}, we obtain:
$V_1 = \frac{Q_1}{2*\Pi*e_0} * (P_{11} - 0.5P_{12} - 0.5P_{13})$
$V_1 = \frac{Q_1}{2*\Pi*e_0} ln(e^{P_{11}} * \frac{1}{e^{P_{12}^{(0.5)}} * e^{P_{13}^{(0.5)}}})$
Similarly V_2 and V_3 can be obtained.Now maximum surface voltage gradient:

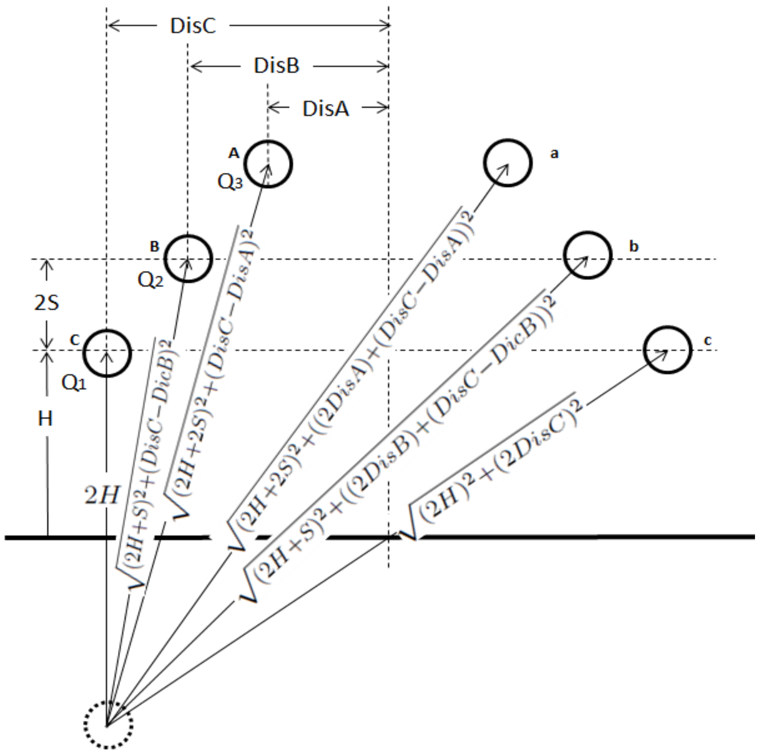
(i) Maximum outer surface voltage gradient

$$E_{om} = \frac{1 + (N-1) * \frac{r}{R}}{N * r * ln(\frac{2H}{GMR} * (\frac{1}{(1+(2H/S)^2)*(1+(H/S)^2)^{1/4}}))} * V \tag{4.12}$$

(ii) Maximum center surface voltage gradient

$$E_{cm} = \frac{1 + (N-1) * \frac{r}{R}}{N * r * ln(\frac{2H}{GMR} * (\frac{1}{(1+(2H/S)^2)^{1/2}}))} * V \tag{4.13}$$

(2) Voltage gradient for vertical configuration



$P_{11} = ln(\frac{2H}{r_{eq}})$

$P_{12} = ln(\frac{\sqrt{(2H+S)^2+(DisC-DicB)^2}}{DisBC})$

$P_{13} = ln(\frac{\sqrt{(2H+2S)^2+(DisC-DisA)^2}}{DisAC})$

$P_{11'} = ln(\frac{\sqrt{(2H)^2+(2DisC)^2}}{DisCc})$

$P_{12'} = ln(\frac{\sqrt{(2H+S)^2+((2DisB)+(DisC-DicB))^2}}{DisCb})$

$P_{13'} = ln(\frac{\sqrt{(2H+2S)^2+((2DisA)+(DisC-DisA))^2}}{DisCa})$

Similarly $P_{21}, P_{22}, P_{23}, P_{21'}, P_{22'}, P_{23'}, P_{31}, P_{32}, P_{33}, P_{31'}, P_{32'}, P_{33'}$ can be obtained. At every instant of time, $V_1 + V_2 + V_3 = 0$ and $Q_1 + Q_2 + Q_3 = 0$. Assume peak value of instantaneous charges on the bundle, $Q_1 = Q_2 = Q_3$. Combining equations of V_i and P_{ij}, we obtain:
$V_1 = \frac{Q_1}{2*\Pi*e_0} * (P_{11} - 0.5P_{12} - 0.5P_{13} + P_{11'} - 0.5P_{12'} - 0.5P_{13'})$
Similarly V_2 and V_3 can be obtained. Now maximum surface voltage gradient are:

(i) Maximum A phase surface voltage gradient

$$E_A = \frac{1 + (N-1) * \frac{r}{R}}{N * r * ln((\frac{2H+4S}{r_{eq}}) * (\frac{\sqrt{(2H+4S)^2+(2DisA)^2}}{DisAa}) * (\frac{1}{X_{a1}*X_{a2}*X_{a3}*X_{a4}{}^{1/2}}))} * V \quad (4.14)$$

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

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

$X_{a3} = \frac{\sqrt{(2H+3S)^2+((2DisA)+(DisB-DicA))^2}}{DisCb}$

$X_{a4} = \frac{\sqrt{(2H+2S)^2+((2DisA)+(DisC-DisA))^2}}{DisAc}$

(ii) Maximum B phase surface voltage gradient

$$E_B = \frac{1 + (N-1) * \frac{r}{R}}{N * r * ln((\frac{2H+2S}{r_{eq}}) * (\frac{\sqrt{(2H+2S)^2+(2DisB)^2}}{DisBb}) * (\frac{1}{X_{b1}*X_{b2}*X_{b3}*X_{b4}{}^{1/2}}))} * V \quad (4.15)$$

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

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

$X_{b3} = \frac{\sqrt{(2H+S)^2+((2DisB)+(DisC-DicB))^2}}{DisBc}$

$X_{b4} = \frac{\sqrt{(2H+3S)^2+((2DisA)+(DisB-DisA))^2}}{DisBa}$

(iii) Maximum C phase surface voltage gradient

$$E_C = \frac{1+(N-1)*\frac{r}{R}}{N*r*ln((\frac{2H}{r_{eq}})*(\frac{\sqrt{(2H)^2+(2DisC)^2}}{DisCc})*(\frac{1}{X_{c1}*X_{c2}*X_{c3}*X_{c4}{}^{1/2}}))} * V \tag{4.16}$$

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

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

$X_{c3} = \frac{\sqrt{(2H+S)^2+((2DisB)+(DisC-DicB))^2}}{DisCb}$

$X_{c4} = \frac{\sqrt{(2H+2S)^2+((2DisA)+(DisC-DisA))^2}}{DisCa}$

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

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

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)

4.7 Corona loss

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.

(1) Fair weather condition

As per peterson's formula:

$$P_c = \frac{21 * 10^{-6} * f * V_s^2 * F}{(log\frac{GMD}{GMR})^2}(kW/phase/km) \tag{4.17}$$

Here F factor depend on $\frac{V}{V_d}$ ratio.

$V_d = \frac{3*10^6}{\sqrt{2}} * r * \delta * m_0 * ln(\frac{GMD}{GMR})$ (Volts)

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

here,

f: frequency (Hz).

V_s: Sending end voltage per phase (KV).

GMD: Geometric mean distance between conductor (m).

r: radius of conductor (m).

m_0: surface factor. (0 to 1, according to surface of conductor)

p: barometric pressure (cm)

t: Temperature (^0C).

(2) Foul weather condition

An equation for corona loss in rain giving the excess loss above the fair weather loss is [8],[12],[14]

$$P_c = P_{FW} + [\frac{V}{\sqrt{3}} * J * r^2 * ln(1 + K * \rho)] * (\sum_{i=1}^{3N} E_i{}^5)(KW/3phaseKm) \quad (4.18)$$

here,

P_{FW}: Total 3 phase fair weather corona loss (KW/3phase Km)

$= 1to5$ KW/Km for 500KV and $= 3to20$ KW/Km for 700 KV.

V: Conductor voltage (KV), line-line rms.

J: Loss current constant

$= 3.32 * 10^{-10}$ for 500 to 700 KV; and $4.37 * 10^{-10}$ for 400 KV line

r: conductor radius (cm).

K: Wetting coefficient (=10, for ρ in mm/hr)

ρ= rain rate in (mm/hour).

N: number of conductors in bundle of each phase.

E_i: Surface voltage gradient, (KV/cm).

4.8 Audible Noise

Audible noise is undesired sound that is produced by EHV transmission line (usually 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 propagation 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.

4.8.1 Heavy Rain AN

Heavy rain Audible noise is calculated using following empirical formula [4]:

$$P(dB) = 20logn + 44logd - \frac{665}{E} + Kn + 75.2 - 10logR - 0.02Rforn < 3 \quad (4.19)$$

$$P(dB) = 20logn + 44logd - \frac{665}{E} + (22.9(n-1) * (\frac{d}{D})) + 67.9 - 10logR - 0.02Rforn \geq 3 \quad (4.20)$$

where,

Kn=7.5 if n=1;

Kn=2.6 if n=2;

Kn=0.0 if n=> 3;

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 [4]:

$$P_{Total} = 10log(\sum_{i=1}^{n} 10^{(\frac{P_i}{10})}) \quad (4.21)$$

4.9 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 [4] ,[5] :

$$RI(dB) = 3.5g_m + 6d - 30 - 33log(\frac{D}{20}) \quad (4.22)$$

On a double circuit line, there are two phase conductors belonging to each phase. the resulting RI value due to the two circuits are [5]:

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

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

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

The quantities RI_A, RI_B, and RI_C, are treated as the contributions from the three phases.

4.9.1 Rules for addition of RI level

After calculating the RI level due to each phase at the point under consideration, the total RI level of a 3-phase line is evaluated as follows [4], [5]:

- If one of the RI levels is atleast 3 dB higher than the rest, then this is the RI level of the line.
- If only one of the three Rl levels is atleast 3 dB lower than the rest, then the RI level of the line is:

$$RI(dB) = (averageofthetwohighest + 1.5) \quad (4.23)$$

4.10 Sag Tension Calculation

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 flexibility and 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) [3] [9]:

$$S = \frac{W * L^2}{8 * T} \quad (m) \tag{4.24}$$

$$T = f * A \quad (Kg) \tag{4.25}$$

where,
S: Sag in conductor (m)
T: Tension of conductor (Kg)
W: weight of conductor (Kg/m)
L: Span between two tower (m)
f: Stress on conductor (Kg/m^2)

Basic equations required for sag tension calculations:
Reference wind speed: $V_R = \frac{V_b}{K_0}$ (m/s)
Design wind speed: $V_d = V_R * K_1 * K_2$ (m/s)
Design wind pressure: $P_d = 0.6 * (V_d)^2$ (N/m^2)
Wind on conductor: $P = \frac{P_d * G_c}{9.81}$ (Kg/m^2)
Density of conductor: $\delta = \frac{w}{A}$ (Kg/m/m^2)

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.

Here,

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 K_0=1.375 should be taken)

K_1: Risk Coefficient

K_2: Terrain Roughness Coefficient

G_c: Gust Response Factor. For any specific terrain category, height of lowest-crossarm above the ground and span, this factor value can be interpolated from the table 7 of [3].

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

A: Area of conductor (m^2)

P_i: Different wind condition

D: Overall diameter of conductor (m)

U: Ultimate tensile strength (Kg)

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

L: Span of conductor (m)

α: Coefficient of linear expansion ($/^0C$)

t: Temperature (^0C)

E: Modulus of elasticity (Kg/m^2)

Chapter 5

Software

5.1 General

This chapter deals with the software developed for EHV transmission line design.

5.2 C

In modern engineering work, computer programming is used for developing software. Some of the software languages are C, C++, C #, Visual Basic, MATLAB. C# is an object oriented and component oriented programming. For electrical calculation of EHV transmission line, C# with dot net framework 2.0 (Visual Studio 2005)is chosen to develop program. Program is an user friendly tool and it represents result and data in graphical form, which enables easy understanding to an individual.

5.3 Main screen

Main screen of program provides various calculation option. It shows option for Current capacity calculation, Electrical calculation for Double circuit vertical configuration, Single circuit vertical configuration and Single circuit horizontal configuration.

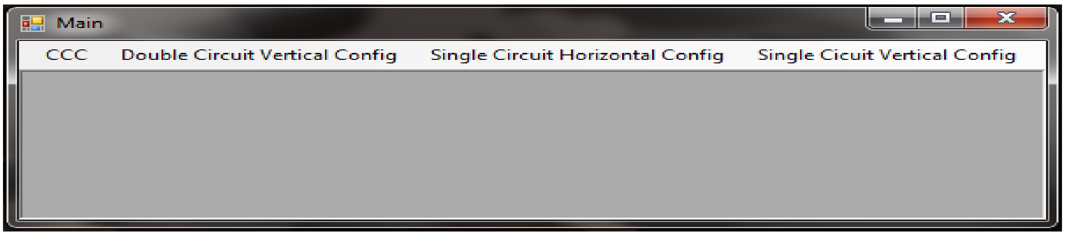


Figure 5.1: Main screen of software

5.4 Ampacity

Ampacity calculations are done as per [2]. A typical screen of program is shown in Fig5.2 . Program used for calculation is given in Appendix [A]

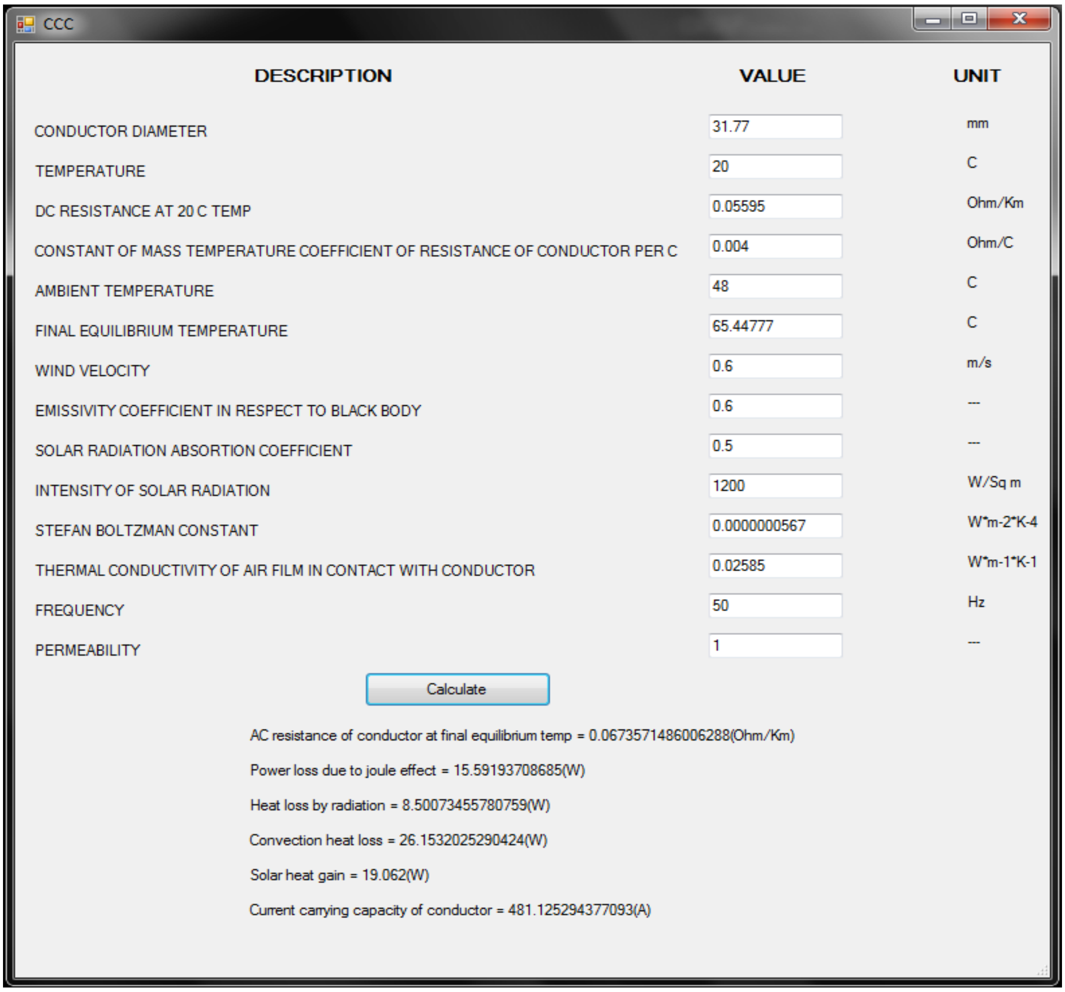


Figure 5.2: Screen for Ampacity calculation

5.4.1 Flowchart for Ampacity calculation

Flowchart for Ampacity calculation of a conductor is shown in in Fig5.3 . Program for the same is given in Appendix[A]

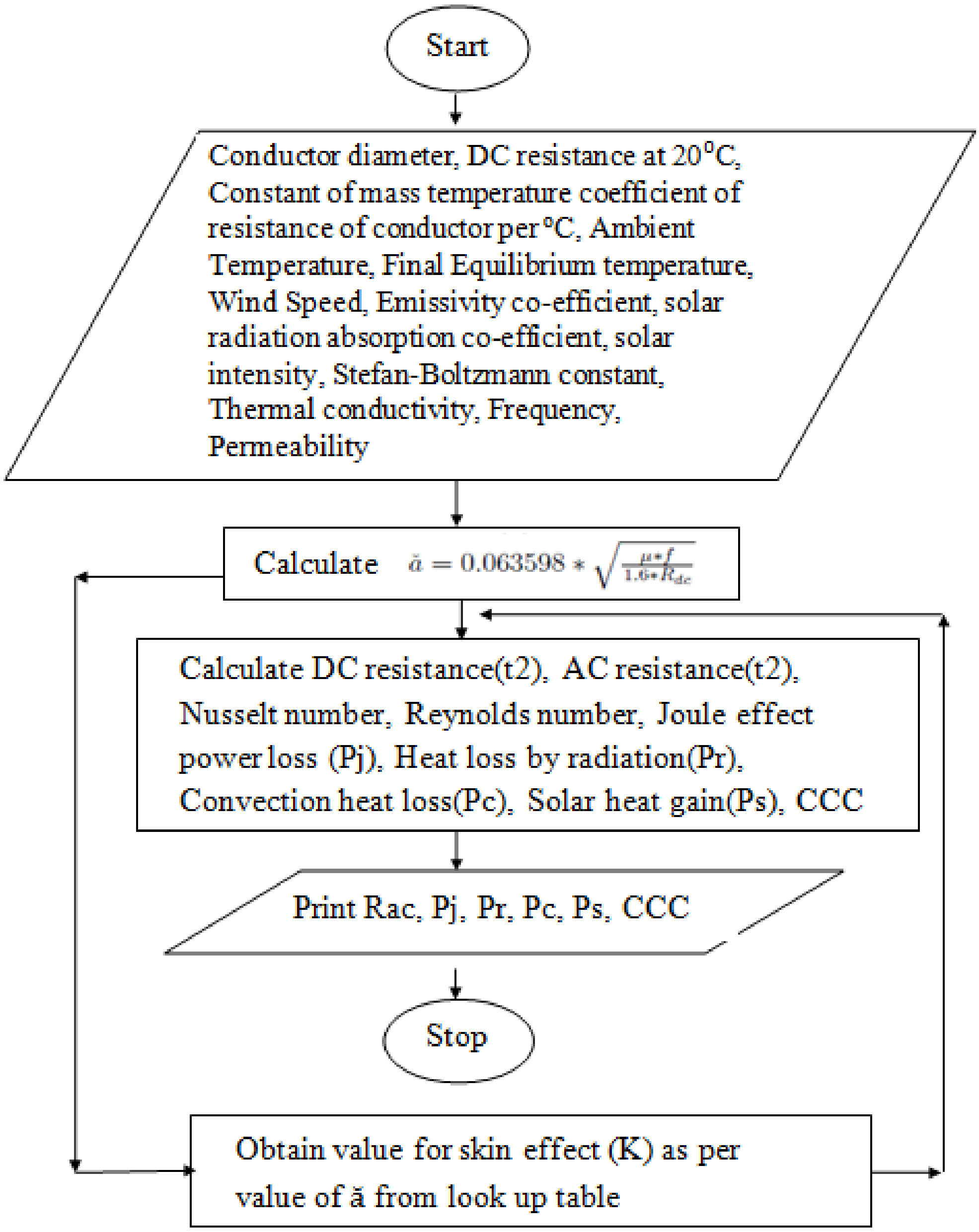


Figure 5.3: Flowchart for Ampacity calculation

5.5 Inductance and capacitance

A typical screen for inductance and capacitance calculation is shown in Fig5.4 . For

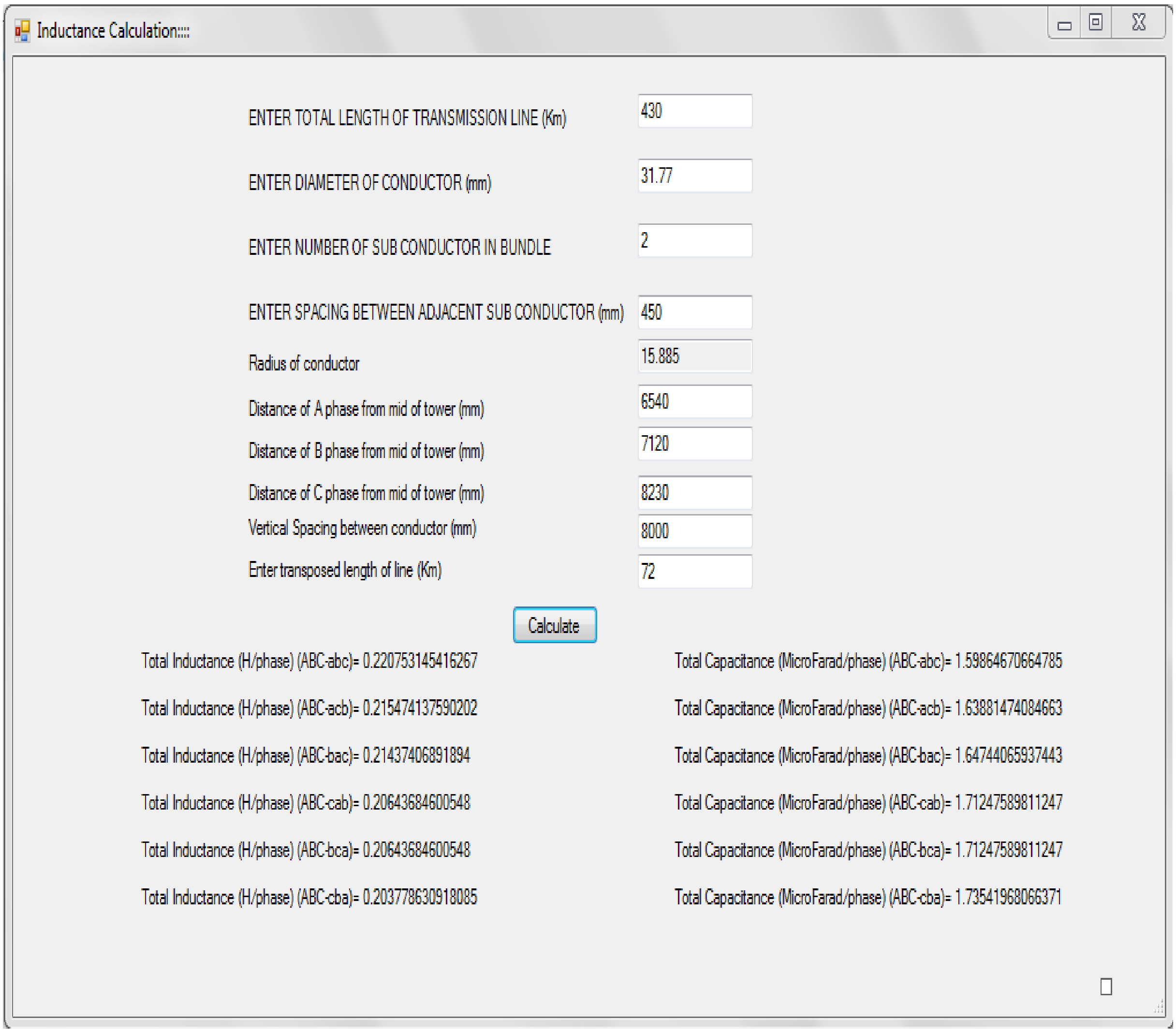


Figure 5.4: Screen for Inductance and capacitance configuration

all six possible combinations, Inductance and Capacitance of various configuration of double circuit is calculated by this program. Different combination and configuration of D/C vertical configuration is shown in Fig 5.5 and 5.6 .

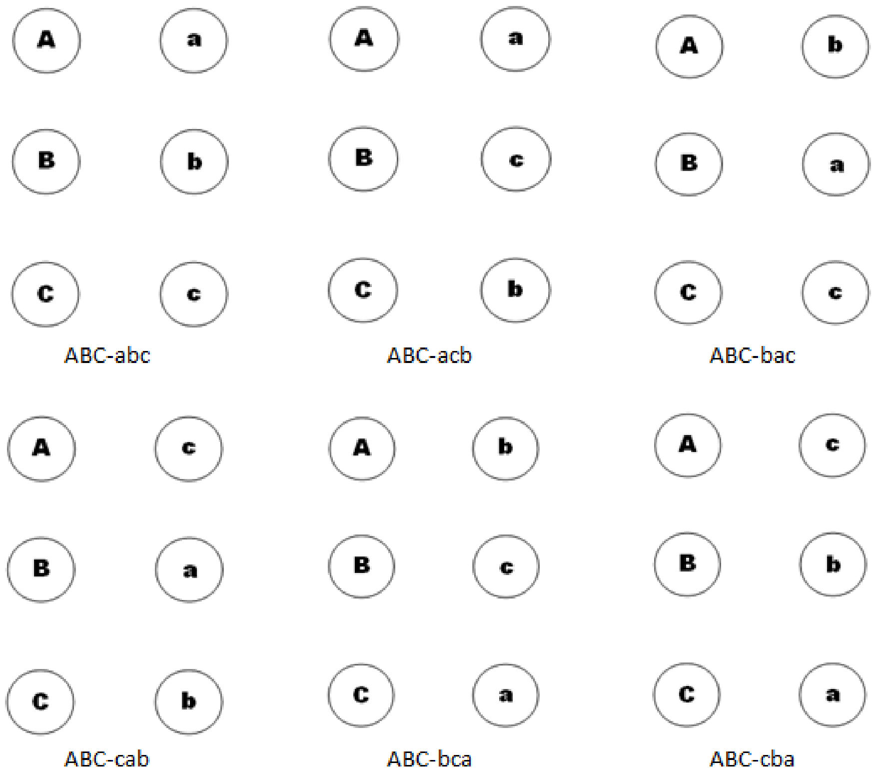


Figure 5.5: Different combination of double circuit vertical configuration

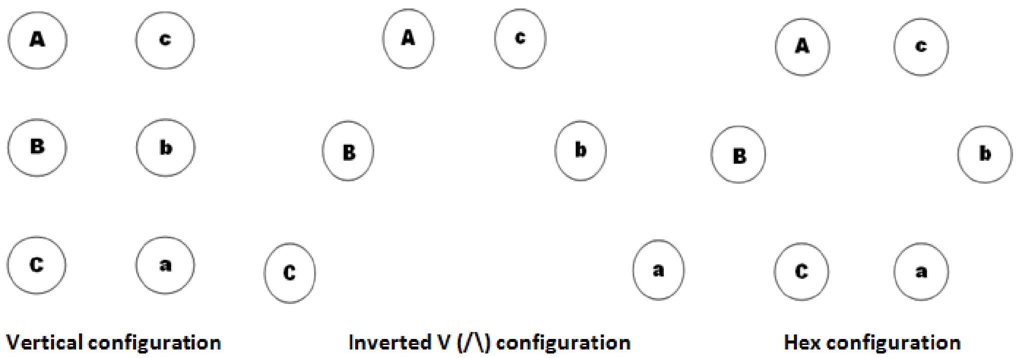


Figure 5.6: Various conductor configuration

5.6 Electrical calculation for double circuit configuration

A typical screen for transmission line design of double circuit is shown in fig 5.7.

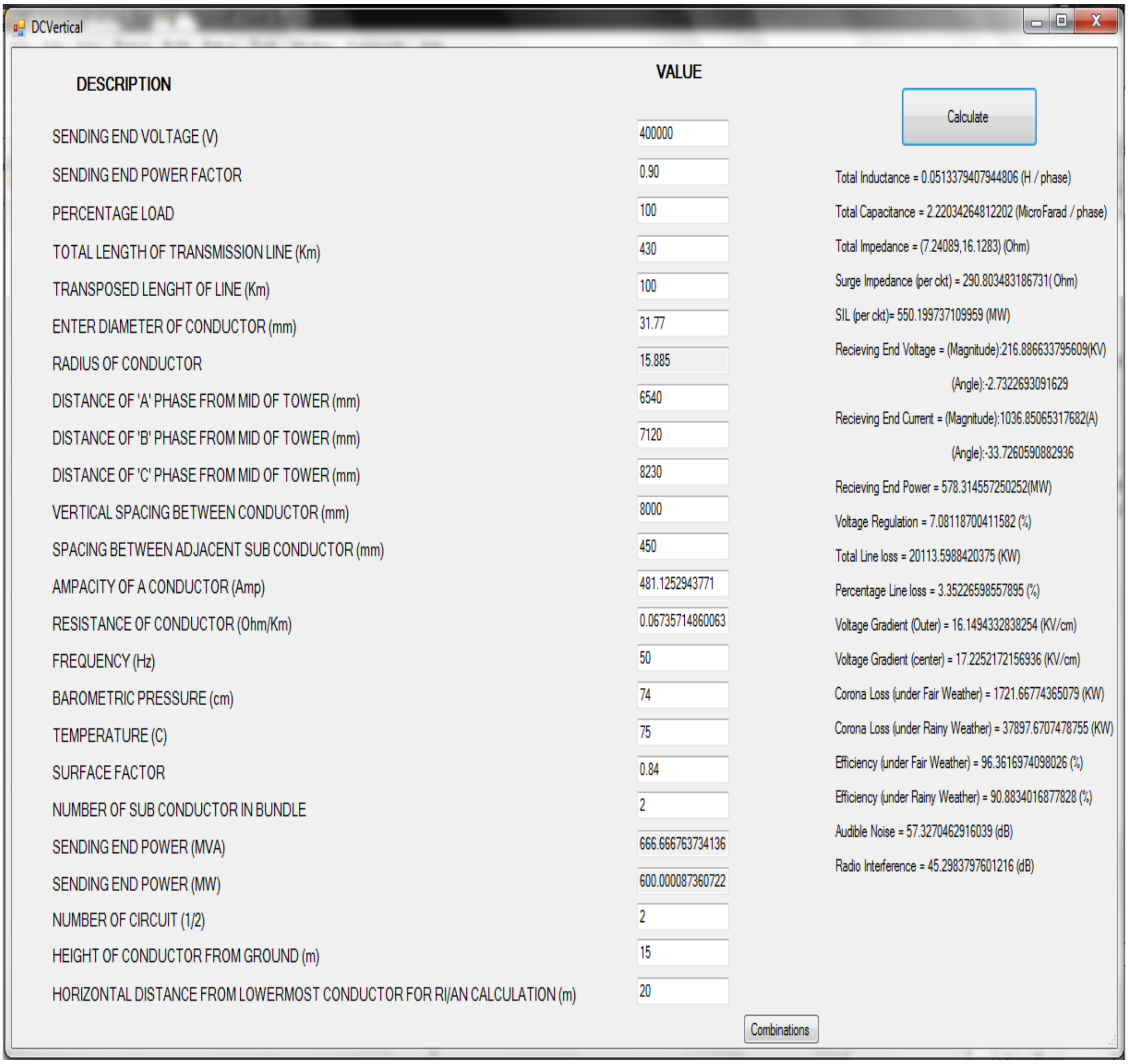
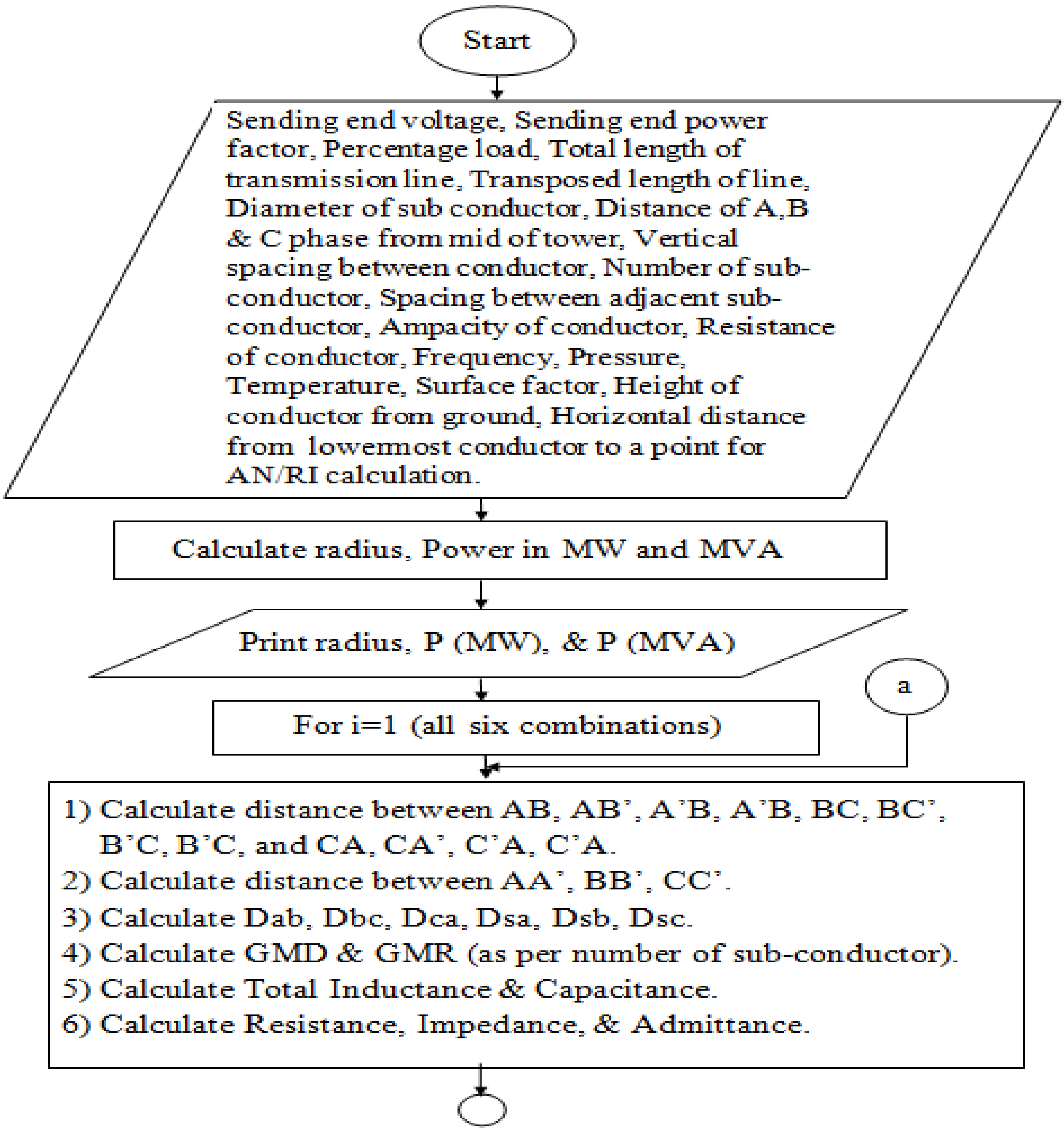


Figure 5.7: Screen for Electrical calculation for double circuit configuration

5.6.1 Flowchart

Flowchart for Ampacity calculation of a conductor is shown in in fig 5.8. Program for the same is given in Appendix[B]



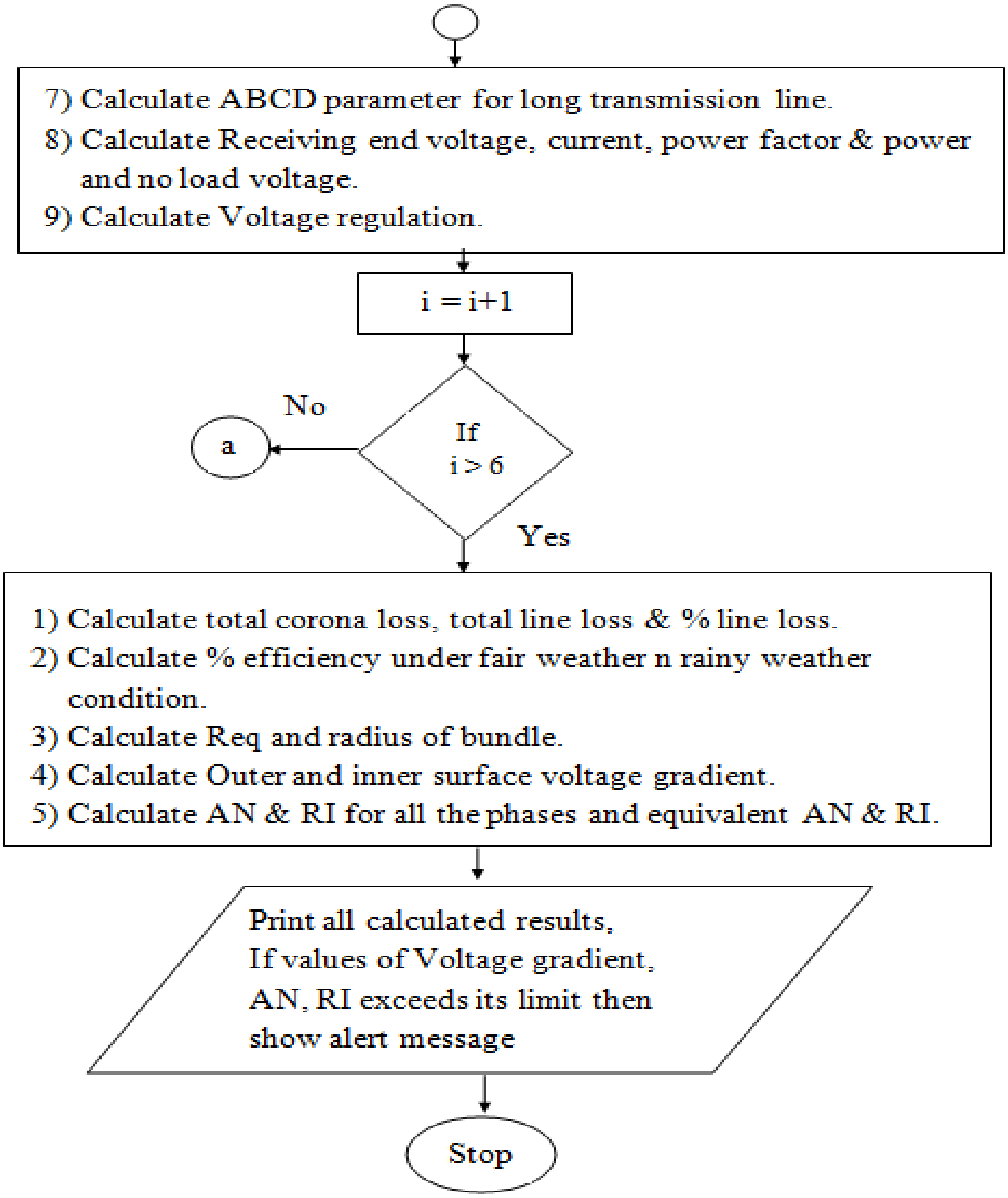


Figure 5.8: Flowchart for Electrical calculation for double circuit configuration

Chapter 6

Results and Analysis

6.1 General

This chapter deals with the results and analysis carried out with reference to the results obtained after designing and computation for all the alternatives.

6.2 Input Parameters

Description	Unit	ACSR Moose
Conductor Diameter	mm	31.77
Temperature	^0C	20
DC resistance at 20^0C temperature	Ω/Km	0.05595
Constant of mass temperature coefficient of resistance per ^0C	$\Omega/^0C$	0.004
Ambient Temperature	^0C	48
Final Equilibrium Temperature	^0C	65.45
Wind velocity	m/s	0.6
Emissivity co-efficient in respect to black body	$--$	0.6
Solar radiation absorption co-efficient	$--$	0.5
Intensity of solar radiation	W/m^2	1200
Stefan-Boltzmann constant	$W/(m^2 * K^4)$	$5.67 * 10^{-8}$
Thermal conductivity of air film in contact with conductor	$W/(m * K$	0.02585
Frequency	Hz	50
Permeability		1

Table 6.1: Input data for calculating ampacity of ACSR moose conductor

Description	Unit	Value
Sending end voltage	V	400000
Sending end power factor	−−	0.90
Percentage load	%	100
Total length of transmission line	Km	430
Transposed length of line	Km	100
Sending end power	MW	600
Conductor diameter	mm	31.77
Distance of A phase from center of tower	mm	6540
Distance of B phase from center of tower	mm	7120
Distance of C phase from center of tower	mm	8230
Vertical separation	mm	8000
Distance between adjacent sub conductor	mm	450
Number of sub conductor	−−	2
Ampacity at t2^{0}C temp per phase	Amp	481.13
Resistance of conductor at t2^{0}C temp	Ω/Km	0.0674
Frequency	Hz	50
Barometric pressure	cm	74
Temperature	^{0}C	75
Surface factor	−−	0.84

Table 6.2: Input data for electrical calculation of ACSR moose conductor

Table 6.1 and 6.2 6.3 shows input data that are considered for electrical design of EHV transmission line. [1] , [9], [18], [19] .

Description	Unit	ACSR Moose
Span	m	400
Cross section area of conductor	m^2	$5.97 * 10^{-4}$
UTS	Kg	16432
Weight of conductor	Kg/m	2.004
Modulus of Elasticity	Kg/m^2	$7.04 * 10^9$
Coefficient of linear Expansion	$/^0C$	$19.3 * 10^{-6}$
Wind pressure	Kg/m^2	128.49
Overall diameter	m	0.03177

Table 6.3: Input data for Sag and Tension Calculation of ACSR moose conductor

6.3 Current carrying capacity

a. Heat loss by radiation

$P_{rad} = \Pi * S * D * K_e * (T_2^4 - T_1^4)$

$= \Pi * 5.67 * 10^{-8} * \frac{31.77}{1000} * 0.6 * (273 + 65.45)^4 - (273 + 48)^4$

$= 8.50 \quad \text{W}$

b. Convection heat loss

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

$R_e = 1.64 * 10^9 * V * D * (T_1 + (0.5 * (T_2 - T_1)))$

$= 1.64 * 10^9 * 0.6 * \frac{31.77}{1000} * ((273 + 48) + (0.5 * ((273 + 65.45) - (273 + 48))))$

$= 1032.20$

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

$= 0.65 * 1032.20^{0.2} + 0.23 * 1032.20^{0.61}$

$= 18.46$

$P_{conv} = \Pi * 0.02585 * 18.46 * ((273 + 65.45) - (273 + 48))$

$= 26.15 \quad \text{W}$

c. Solar heat gain

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

$= \frac{31.77}{1000} * 0.5 * 1200$

$= 19.06 \quad \text{W}$

d. Heat generated by joule effect

$Pj = I^2 R_{ac}$

$R_{dc} = R_{dc(t1)}(1 + \alpha(T_2 - t_1))$

$R_{dc} = 0.05595(1 + 0.004(65.45 - 20))$

$= 0.06612 \quad \Omega/Km$

$\breve{a} = 0.063598 * \sqrt{\frac{\mu * f}{1.6 * R_{dc}}}$

$= 0.063598 * \sqrt{\frac{1*50}{1.6*0.06612}}$

$= 1.3826$

For $\breve{a} = 1.3826; K = 1.01869$

$R_{ac} = K * R_{dc}$

$R_{ac} = 1.01869 * 0.06612$

$= 0.067357 \quad \Omega/Km$

$CCC = \sqrt{\frac{P_{rad}+P_{conv}-P_{sol}}{Rac}}$

$= \sqrt{\frac{8.50+26.15-19.06}{\frac{0.067357}{1000}}}$

$= 481.125 \quad A$

Similarly calculation are done for other conductors.

6.4 Inductance calculation

Spacing considered between conductor and subconductor are shown in fig.

Distance of phase A from center of tower $D_{ha} = 6540 \quad mm$

Distance of phase B from center of tower $D_{hb} = 7120 \quad mm$

Distance of phase C from center of tower $D_{hc} = 8230 \quad mm$

Vertical Separation between conductor $D_v = 8000 \quad mm$

(1) GMD

(i) D_{AB}

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

$= \sqrt{8000^2 + (7120 - 6540)^2}$

$= 8020.997 \quad mm$

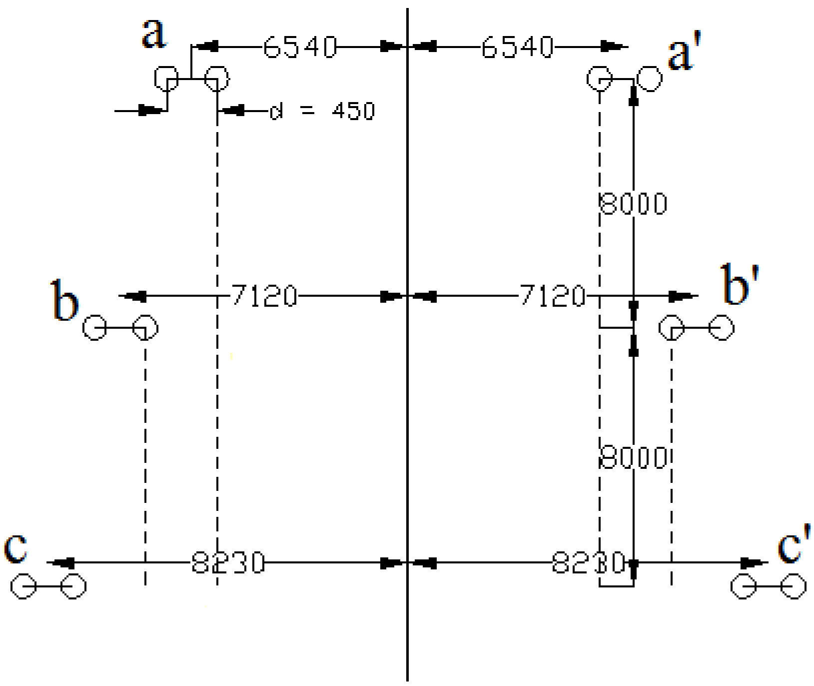


Figure 6.1: Spacing Between conductor and subconductor

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

$= \sqrt{8000^2 + (7120 + 6540)^2}$

$= 15830.212 \quad mm$

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

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

$D_{AB} = 11268.278 \quad mm$

(ii) D_{BC}

Distance between $D_{bc} = D_{b'c'} = \sqrt{{D_v}^2 + (D_{hc} - D_{hb})^2}$

$= \sqrt{8000^2 + (8230 - 7120)^2}$

$= 8076.639 \quad mm$

Distance between $D_{ab'} = D_{a'b} = \sqrt{{D_v}^2 + (D_{hc} + D_{hb})^2}$

$= \sqrt{8000^2 + (8230 + 7120)^2}$
$= 17309.607 \quad mm$

$D_{BC} = \sqrt[4]{(D_{bc} * D_{b'c'} * D_{b'c} * D_{bc'})}$
$D_{BC} = \sqrt[4]{(8076.639 * 8076.639 * 17309.607 * 17309.607)}$
$D_{BC} = 11823.851 \quad mm$

(iii) D_{CA}

Distance between $D_{ca} = D_{c'a'} = \sqrt{{D_v}^2 + (D_{hc} - D_{ha})^2}$
$= \sqrt{8000^2 + (8230 - 6540)^2}$
$= 16089.006 \quad mm$
Distance between $D_{ca'} = D_{c'a} = \sqrt{{D_v}^2 + (D_{hc} + D_{ha})^2}$
$= \sqrt{8000^2 + (8230 + 6540)^2}$
$= 21775.052 \quad mm$

$D_{CA} = \sqrt[4]{(D_{ca} * D_{c'a'} * D_{c'a} * D_{ca'})}$
$D_{CA} = \sqrt[4]{(16089.006 * 16089.006 * 21775.052 * 21775.052)}$
$D_{CA} = 18717.343 \quad mm$

Now,

$GMD = \sqrt[3]{(D_{AB} * D_{BC} * D_{CA})}$
$= \sqrt[3]{(11268.278 * 11823.851 * 18717.343)}$
$GMD = 13560.85 \quad mm$

(2) GMR

(i) D_{SA}

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

$D_{aa} = \sqrt{0.7788 * 15.89 * 450}$

$= 74.613 \quad mm$

$D_{aa'} = 6540 * 2$

$= 13080 \quad mm$

$D_{SA} = \sqrt{74.613 * 13080} = 987.89 \quad mm$

(ii) D_{SB}

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

$D_{bb} = \sqrt{0.7788 * 15.89 * 450}$

$= 74.613 \quad mm$

$D_{bb'} = 7120 * 2$

$= 14240 \quad mm$

$D_{SB} = \sqrt{74.613 * 14240} = 1030.77 \quad mm$

(iii) D_{SC}

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

$D_{cc} = \sqrt{0.7788 * 15.89 * 450}$

$= 74.613 \quad mm$

$D_{cc'} = 8230 * 2$

$= 16460 \quad mm$

$D_{SC} = \sqrt{74.613 * 16460} = 1108.21 \quad mm$

Now,

$GMR = \sqrt[3]{(D_{SA} * D_{SB} * D_{SC})}$

$GMR = \sqrt[3]{(987.89 * 1030.77 * 1108.21)}$

$GMR = 1041.11 \quad mm$

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

$= 2 * 10^{-7} ln(\frac{13560.85}{1041.11})$

$\therefore Inductance = 5.13 * 10^{-7}(H/phase/m)$

Inductance $= 0.000513$ **(H/phase/Km)**

$\therefore$ Total Inductance of line $= 0.000513 * 100$

Total Line Inductance is 0.0513 H/phase

6.5 Capacitance calculation

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

$\therefore GMD = 13560.85 \quad mm$

(2) GMR

(i) D_{SA}

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

$D_{aa} = \sqrt{15.89 * 450}$

$= 84.547 \quad mm$

$D_{aa'} = 6540 * 2$

$= 13080 \quad mm$

$D_{SA} = \sqrt{84.547 * 13080} = 1051.61 \quad mm$

(ii) D_{SB}

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

$D_{bb} = \sqrt{15.89 * 450}$

$= 84.547 \quad mm$

$D_{bb'} = 7120 * 2$

$= 14240 \quad mm$

$D_{SB} = \sqrt{84.547 * 14240} = 1097.25 \quad mm$

(iii) D_{SC}

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

$D_{cc} = \sqrt{15.89 * 450}$

$= 84.547 \quad mm$

$D_{cc'} = 8230 * 2$

$= 16460 \quad mm$

$D_{SC} = \sqrt{84.547 * 16460} = 1179.68 \quad mm$

Now,

$GMR = \sqrt[3]{(D_{SA} * D_{SB} * D_{SC})}$

$GMR = \sqrt[3]{(1051.61 * 1097.25 * 1179.68)}$

$GMR = 1108.26 \quad mm$

Capacitance C $= \dfrac{0.05560618997}{ln(\frac{GMD}{GMR})}$

$= \dfrac{0.05560618997}{ln(\frac{13560.85}{1108.26})}$

$\therefore$ **Capacitance** $= 0.0222$ **(μ F/phase/Km)**

$\therefore$ Total Capacitance of line $= 0.0222 * 100$

Total Line Capacitance is 2.22 μF/phase

6.6 Inductance of various combinations and configurations

Inductance of line for all the possible combination can be done similarly. Results obtained for the same are given in table 6.4

Combination	Total Inductance(H/phase)
ABC-abc	0.220753145
ABC-acb	0.215474138
ABC-bac	0.214374069
ABC-cab	0.206436846
ABC-bca	0.206436846
ABC-cba	0.203778631

Table 6.4: Inductance of various combination

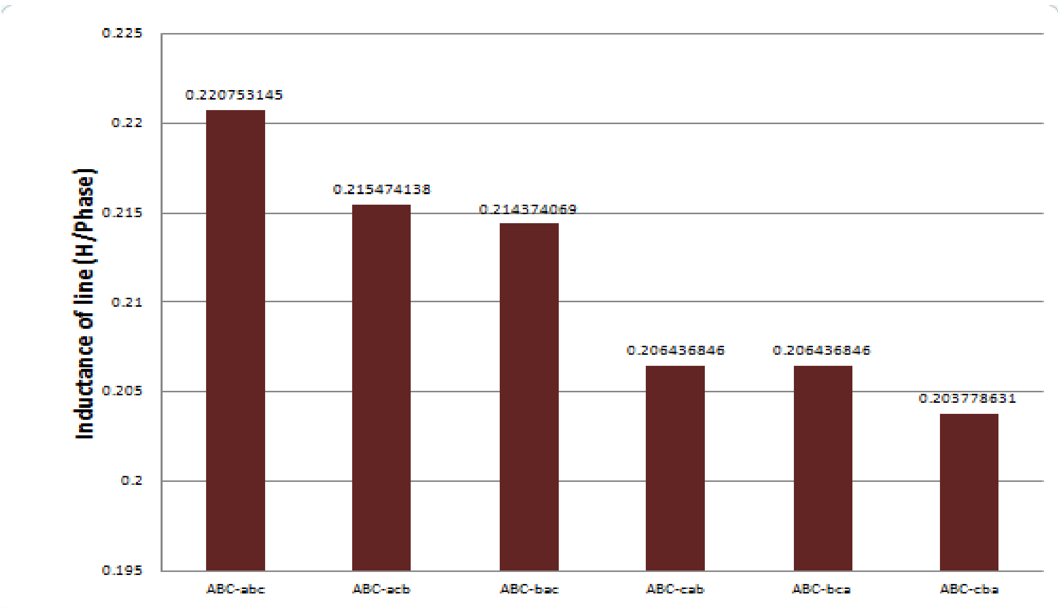


Figure 6.2: Graphical representation of Inductance for various configuration

Above analysis indicate that ABC-cba combination provide minimum line inductance.

Now for different configuration let us consider some data's as shown in the table 6.5. Datas are considered for 400KV line. Inductance obtained after calculation are given in table 6.6

From table 6.6 it can be conclude that Hex configuration with ABC-cba combination provide least inductance.

Total length of transmission line (Km)			300
Diameter of conductor (mm)			31.77
Number of sub conductor in a bundle			1
configuration	Vertical	Hex	Inverted V
Distance of phase A from mid of tower (mm)	6380	6380	6380
Distance of phase B from mid of tower (mm)	6380	6880	6880
Distance of phase C from mid of tower (mm)	6380	6380	7380
Vertical seperation (mm)	7800	7800	7800

Table 6.5: Input data for Inductance calculation of different configuration

Configuration	Vertical (H/phase)	Hex (H/phase)	Inverted V (H/phase)
ABC-abc	0.208072271602887	0.207924176390229	0.2073548817245
ABC-acb	0.203309985275847	0.203445543671235	0.203410289646973
ABC-bac	0.203309985275847	0.203445543671235	0.202876249005505
ABC-cab	0.196453785676769	0.196589344072157	0.196904746799551
ABC-bca	0.196453785676769	0.196589344072157	0.196904746799551
ABC-cba	0.19435987240473	0.194211777192072	0.194877836671123

Table 6.6: Inductance calculation for different configuration and combination

6.7 Resistance, Impedance and Admittance

(1) Resistance Resistance of single conductor as obtained above is $0.067136\Omega/Km$.

Thus resistance of whole line for one phase is 7.47 Ω.

$R = \frac{(0.067357*430)}{4} = 7.241 \quad \Omega$

(2) Reactance Total reactance of line $= 2*\pi*f*L \quad \Omega$

$= 2*\pi*50*0.0513$

$\therefore X = 16.13 \quad \Omega$

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

$\therefore$ **Z=7.241+16.13i** Ω

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

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

$\therefore$ **0.000698i** mho

6.8 Voltage regulation

(1) ABCD Parameter

(i) A and D Parameter

$$A = cosh(\gamma l) = cosh(al + jbl) = cosh(\sqrt{ZY})$$

$$= cosh(\sqrt{(7.241 + 16.13i)(0 + 0.000698i)})$$

$$\therefore A = D = 0.994379136422617 + 0.00252067809358973i$$

(ii) B parameter

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

$$= \sqrt{\frac{7.241+16.13i}{0+0.000698i}} * sinh * (\sqrt{(7.241 + 16.13i)(0 + 0.000698i)})$$

$$\therefore B = 7.21376113498054 + 16.1041509626235i$$

(iii) C parameter

$$C = \frac{1}{Z_c} * sinh(\gamma l) = \frac{1}{Z_c} * sinh(al + jbl) = \frac{1}{\sqrt{\frac{Z}{Y}}} * sinh * (\sqrt{ZY})$$

$$= \frac{1}{\sqrt{\frac{7.241+16.13i}{0+0.000698i}}} * sinh * (\sqrt{(7.241 + 16.13i)(0 + 0.000698i)})$$

$$\therefore C = -5.86532357074016E - 07 + 0.000696233895668444i$$

(2) Voltage regulation

(i) No load receiving end voltage

$|V_r|_{noload} = \frac{|V_s|}{|A|}$

$= \frac{230940.1077}{0.994382331} \quad V$

$\because |V_s| = \frac{400000}{\sqrt{3}} = 230940.1077 \quad V$

$\therefore |V_r|_{noload} = 232244.7819 \quad V$

(ii) Full load receiving end voltage

$V_{r\,fullload} = \frac{D*V_s - B*I_s}{AD-BC} = A*V_s - B*I_s$

$\because A = D$ and $AD - BC = 1$

$= (0.994379136422617 + 0.00252067809358973i)*(230940.1077)-$

$(7.21376113498054 + 16.1041509626235i)*(866.026 - 419.436i)$

$= 216640.059472216 - 10338.7766557955i \quad V$

$\because I_s = P_s V_s * \sqrt{3}$

here P_s is Sending end power in VA and V_s is sending end voltage in volts.

$\therefore |V_r|_{fullload} = 216886.62 \quad V$

Now, $V.R.\% = \frac{|V_r|_{noload} - |V_r|_{fullload}}{|V_r|_{fullload}} * 100 \quad \%$

$= \frac{232244.78 - 216886.62}{216886.62} * 100$

$\therefore$ **V.R.%=7.08119** $\approx 7.09\%$

6.9 Line losses and receiving end power

(1) Line loss

Line loss per phase $= I^2 * R$

$= (481.125*2)^2 * 7.241 * 10^{-3} = 6704.53 \quad$ (KW/phase)

Total line loss $= 3 * 6704.53 = 20113.60 \quad KW$

Percentage line loss $= \frac{Totallineloss}{Sendingendpower} * 100$ %

$= \frac{20113.60}{600*1000} * 100$ % $= 3.35$ %

(2) Receiving end power

Receiving end power $P_r = 3 * |V_r| * |I_r| * Cos\phi_r * 10^-6 \quad$ (MW)

(i) Receiving end voltage

$V_r = D * V_s - B * I_s \quad$ (V)

$= ((0.994379136422617 + 0.00252067809358973i) * 230940.1077) -$

$((7.21376113498054 + 16.1041509626235i) * 866.026 - 419.436i)$

$V_r = 216640.059472216 - 10338.7766557955i \quad$ V

$|V_r| = 216886.6194 \quad$ V

(ii) Receiving end current

$I_r = -C * V_s + A * I_s \quad$ (A)

$I_r = (-(-5.86532357074016E - 07 + 0.000696233895668444i) * 230940.1077) +$

$((7.21376113498054 + 16.1041509626235i) * 866.026 - 419.436i)$

$I_r = 862.350902982108 - 575.683765531158i \quad$ A

$|I_r| = 1036.85 \quad$ A

(iii) Receiving end power factor

$Cos\phi_r = cos(\angle V_r - \angle I_r) = 0.857$

$\therefore P_r = 3 * 216886.6194 * 1036.85 * 0.857 * 10^{-6}$

$P_r = 578.31485 \approx 578 \quad$ MW

6.10 Voltage gradient

(i) Maximum outer surface voltage gradient

$$E_{om} = \frac{1+(N-1)*\frac{r}{R}}{N*r*ln(\frac{2H}{GMR}*(\frac{1}{(1+(2H/S)^2)*(1+(H/S)^2)^{1/4}}))}*\text{V}$$

$$= \frac{1+(2-1)*\frac{0.015885}{0.225}}{2*0.015885*ln(\frac{(2*15)}{0.0845}*(\frac{1}{(1+((2*15)/8)^2)*(1+(15/8)^2)^{1/4}}))} * 230.94$$

$= 16.14943328 \quad$ KV/cm

$\therefore E_{om} \approx 16 \quad$ KV/cm

(ii) Maximum center surface voltage gradient

$$E_{cm} = \frac{1+(N-1)*\frac{r}{R}}{N*r*ln(\frac{2H}{GMR}*(\frac{1}{(1+(2H/S)^2)^{1/2}}))}*\text{V}$$

$$= \frac{1+(2-1)*\frac{0.015885}{0.225}}{2*0.015885*ln(\frac{(2*15)}{0.0845}*(\frac{1}{(1+((2*15)/8)^2)^{1/2}}))} * 230.94$$

$= 17.22521722 \quad$ KV/cm

$\therefore E_{cm} \approx 17 \quad$ KV/cm

Here value of E_{om} and E_{cm} are below 21 KV/cm (air breakdown strength). Thus values obtained are within safe limits.

6.11 Corona loss

(1) Fair weather corona loss

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

$\delta = \frac{3.86*74}{273+64.3} \approx 0.85$

$V_d = \frac{3*10^6}{\sqrt{2}} * n * r * \delta * m_0 * ln(\frac{GMD}{GMR}) \quad$ (Volts)

$= \frac{3*10^6}{\sqrt{2}} * 2 * 15.885 * 10^{-3} * 0.85 * 0.84 * ln(\frac{10.139}{0.0845})$

$\therefore V_d = 229461.9973 \quad V$

Now $\frac{V}{V_d} = \frac{230.94}{229.46} \approx 1$

for $\frac{V}{V_d} = 1; F = 0.0515$

$P_c = \frac{21*10^{-6}*f*V_s^2*F}{(log(GMD/GMR))^2} \quad (kW/phase/km)$

$= \frac{21*10^{-6}*50*230.94^2*0.0515}{(log(10.139/0.0845))^2}$

$= 0.667$ kW/phase/km

$\therefore$ Total corona loss per circuit $= 3 * 0.667 * 430 = 860.83$ KW

(2) Foul weather corona loss

$P_c = P_{FW} + [\frac{V}{\sqrt{3}} * J * r^2 * ln(1 + K * \rho)] * (\sum_{i=1}^{3N} E_i{}^5)$ (KW/3phase Km)

$= (0.667 * 3) + [\frac{400}{\sqrt{3}} * 4.37 * 10^{-10} * 1.589^2 * ln(1 + 10 * 5)] * 2 * (\sqrt{(}2) * 16.15)^5$

$+(\sqrt{(}2) * 17.22)^5 + (\sqrt{(}2) * 16.15)^5$

$P_c = 44.07$ KW/3phase Km

$\therefore$ Total corona loss per circuit $= 44.07 * 430 = 18948.84$ KW ≈ 19 MW

6.12 Efficiency

(1) Fair weather efficiency

Efficiency of line in fair weather condition

$= \frac{Receivingendpower}{Receivingendpower+(coronalosspercircuit*Numberofcircuit)+Totallineloss} * 100$ %

$= \frac{578.31*1000}{(578.31*1000)+(860.83*2)+20113.60} * 100$ %

$\eta = 96.36$ %

(2) Foul weather efficiency

Efficiency of line in foul weather condition

$$= \frac{Receivingendpower}{Receivingendpower+(coronalosspercircuitunderfoulweather*Numberofcircuit)+Totallineloss} * 100\%$$

$$= \frac{578.31*1000}{(578.31*1000)+(18948*2)+20113.60} * 100\ \%$$

$$\eta_f = 90.88\ \%$$

6.13 Audible Noise

$$P(dB) = 20logn + 44logd - \frac{665}{E} + Kn + 75.2 - 10logR - 0.02Rforn < 3$$

Figure below shows the corresponding distance of all the phases from considered point.

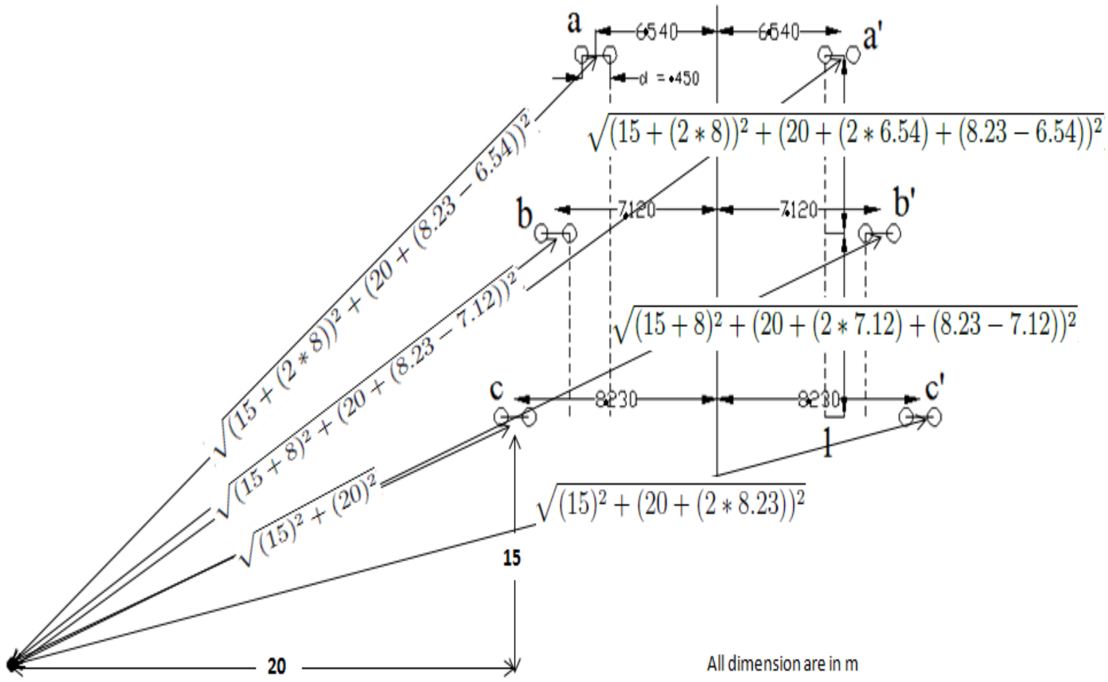


Figure 6.3: Corresponding distance of all the phases from considered point

(1) Circuit I

(i) Phase A

$AN_{(ia)} = 20log(2) + 44log(3.177) - \frac{665}{16.15} + 2.6 + 75.2-$

$10log(\sqrt{(15 + (2 * 8))^2 + (20 + (8.23 - 6.54))^2})-$

$0.02(\sqrt{(15 + (2 * 8))^2 + (20 + (8.23 - 6.54))^2})$

$AN_{(ia)} = 48.2 \quad dB$

(ii) Phase B

$AN_{(ib)} = 20log(2) + 44log(3.177) - \frac{665}{17.22} + 2.6 + 75.2-$

$10log(\sqrt{(15 + 8)^2 + (20 + (8.23 - 7.12))^2})-$

$0.02(\sqrt{(15 + 8)^2 + (20 + (8.23 - 7.12))^2})$

$AN_{(ib)} = 51.73 \quad dB$

(iii) Phase C

$AN_{(ic)} = 20log(2) + 44log(3.177) - \frac{665}{16.15} + 2.6 + 75.2-$

$10log(\sqrt{((15)^2 + (20)^2)}) - 0.02(\sqrt{(15)^2 + (20)^2})$

$AN_{(ic)} = 50.25 \quad dB$

(2) Circuit II

(i) Phase A

$AN_{(ia')} = 20log(2) + 44log(3.177) - \frac{665}{16.15} + 2.6 + 75.2-$

$10log(\sqrt{(15 + (2 * 8))^2 + (20 + (2 * 6.54) + (8.23 - 6.54))^2})-$

$0.02(\sqrt{(15 + (2 * 8))^2 + (20 + (2 * 6.54) + (8.23 - 6.54))^2})$

$AN_{(ia')} = 47.11 \quad dB$

(ii) Phase B

$AN_{(ib')} = 20log(2) + 44log(3.177) - \frac{665}{17.22} + 2.6 + 75.2-$

$10log(\sqrt{(15 + 8)^2 + (20 + (2 * 7.12) + (8.23 - 7.12))^2})-$

$0.02(\sqrt{(15 + 8)^2 + (20 + (2 * 7.12) + (8.23 - 7.12))^2})$

$AN_{(ib')} = 50.21 \quad dB$

(iii) Phase C

$AN_{(ic')} = 20log(2) + 44log(3.177) - \frac{665}{16.15} + 2.6 + 75.2 -$

$10log(\sqrt{(15)^2 + (20 + (2 * 8.23))^2}) - 0.02(\sqrt{(15)^2 + (20 + (2 * 8.23))^2})$

$AN_{(ic')} = 47.99 \quad dB$

Now Total AN of line is $P_{Total} = 10log(\sum_{i=1}^{n} 10^{(\frac{P_i}{10})})$

$= 10log(\sum_{i=1}^{6} 10^{(\frac{AN_i}{10})})$

$= 10 * log(10^{(0.1*48.2)}) + (10^{(0.1*51.73)}) + (10^{(0.1*50.25)}) + (10^{(0.1*47.11)}) +$

$(10^{(0.1*50.21)}) + (10^{(0.1*47.99)})$

$P_{Total} = 57.33 \quad dB$

6.14 Radio Interference

$RI(dB) = 3.5g_m + 6d - 30 - 33log(\frac{D}{20})$

(1) Circuit I

(i) Phase A

$RI_{(ia)} = 3.5(16.15) + 6(3.177) - 30 - 33log(\frac{\sqrt{(15+(2*8))^2+(20+(8.23-6.54))^2}}{20})$

$RI_{(ia)} = 36.45 \quad dB$

(ii) Phase B

$RI_{(ib)} = 3.5(17.22) + 6(3.177) - 30 - 33log(\frac{\sqrt{(15+8)^2+(20+(8.23-7.12))^2}}{20})$

$RI_{(ib)} = 42.97 \quad dB$

(iii) Phase C

$RI_{(ic)} = 3.5(16.15) + 6(3.177) - 30 - 33log(\frac{\sqrt{(15)^2+(20)^2}}{20})$

$RI_{(ic)} = 42.39 \quad dB$

(2) Circuit II

(i) Phase A

$RI_{(ia')} = 3.5(16.15) + 6(3.177) - 30 - 33og(\frac{\sqrt{(15+(2*8))^2+(20+(2*6.54)+(8.23-6.54))^2}}{20})$

$RI_{(ia')} = 33.47 \quad dB$

(ii) Phase B

$RI_{(ib')} = 3.5(17.22) + 6(3.177) - 30 - 33log(\frac{\sqrt{(15+8)^2+(20+(2*7.12)+(8.23-7.12))^2}}{20})$

$RI_{(ib')} = 38.66 \quad dB$

(iii) Phase C

$RI_{(ic')} = 3.5(16.15) + 6(3.177) - 30 - 33log(\frac{\sqrt{(15)^2+(20+(2*8.23))^2}}{20})$

$RI_{(ic')} = 35.86 \quad dB$

For double circuit line

$RI_A = 20 * log\sqrt{(10^{(RI_{ia}/20)})^2 + (10^{(RI_{ia'}/20)})^2}$

$= 20 * log\sqrt{(10^{(36.45/20)})^2 + (10^{(33.47/20)})^2}$

$RI_A = 38.22 \quad dB$

$RI_B = 20 * log\sqrt{(10^{(RI_{ib}/20)})^2 + (10^{(RI_{ib'}/20)})^2}$

$= 20 * log\sqrt{(10^{(42.97/20)})^2 + (10^{(38.66/20)})^2}$

$RI_B = 44.34 \quad dB$

$RI_C = 20 * log\sqrt{(10^{(RI_{ic}/20)})^2 + (10^{(RI_{ic'}/20)})^2}$

$= 20 * log\sqrt{(10^{(42.39/20)})^2 + (10^{(35.85/20)})^2}$

$RI_C = 43.26 \quad dB$

Now Total RI of line is $\frac{44.34+43.26}{2} + 1.5 = 45.3 \quad dB$

6.15 Sag-Tension

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

Design wind speed: $V_d = V_R * K_1 * K_2 = 34.18 * 1 * 1 = 34.18$ 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: $P = \frac{P_d * G_c}{9.81} = \frac{701.04*1.798}{9.81} = 128.49$ 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:

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

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

$q_2{}^2 = 1 + (\frac{128.49*3.177*10^{-2}*0.36}{2.004})^2 = 1.5377$; (Under 36% of full wind)

$q_3{}^2 = 1 + (\frac{128.49*3.177*10^{-2}*0}{2.004})^2 = 1$; (Under no wind condition)

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 full 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

(2) Calculation for given value of Tension

Tension value is provided in this case, let consider 700 Kg.

Now, f = $\frac{T}{A} = \frac{700}{5.97*10^{-4}}$ = 1.725*10^6 Kg/m^2

(3) Calculation for given value of Sag

S= $\frac{W*L^2}{8*T}$ ∴ T= $\frac{W*L^2}{8*S}$ T= $\frac{2.004*400^2}{8*6}$ = 6680 Kg

Now, f = $\frac{T}{A} = \frac{6680}{5.97*10^{-4}}$ = 1.119*10^7 Kg/m^2

Now consider case 1, where F.O.S. is taken as 4.545 (ratio of 100% Ultimate tensile strength and 22% safety factor), substituting value of f in following equation (consider G as G_3, 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 0^0C (Minimum Temperature) and full wind.

$2.723 * 10^{21} = f^2 * (f - (-4.02 * 10^6 - (19.3 * 10^{-6} * 0 * 7.04 * 10^9))$

$\therefore f = 1.27 * 10^7$ (Trial and error method)

Working tension: T = f * A = $1.27 * 10^7 * 5.97 * 10^{-4} = 7611.21$ Kg

Sag: S = = $\frac{W*L^2}{8*T} = \frac{2.004*400^2}{8*7611.21} = 5.27$ m

(ii) Sag and Tension at 32^0C (Every day temperature) and full wind.

$2.723 * 10^{21} = f^2 * (f - (-4.02 * 10^6 - (19.3 * 10^{-6} * 32 * 7.04 * 10^9))$

$\therefore f = 1.17 * 10^7$ (Trial and error method)

Working tension: T = f * A $= 1.17 * 10^7 * 5.97 * 10^{-4} = 6963.65$ Kg

Sag: S $= = \frac{W*L^2}{8*T} = \frac{2.004*400^2}{8*6963.65} = 5.76$ m

(iii) Sag and Tension at 64^0C (Operating temperature) and full wind.

$2.723 * 10^{21} = f^2 * (f - (-4.02 * 10^6 - (19.3 * 10^{-6} * 65.45 * 7.04 * 10^9))$

$\therefore f = 1.07 * 10^7$ (Trial and error method)

Working tension: T = f * A $= 1.07 * 10^7 * 5.97 * 10^{-4} = 6409.09$ Kg

Sag: S $= = \frac{W*L^2}{8*T} = \frac{2.004*400^2}{8*6425.93} = 6.25$ m

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

(i) Sag and Tension at 0^0C (Minimum Temperature) and 36% wind.

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

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

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

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

(ii) Sag and Tension at 32^0C (Every day temperature) and 36% wind.

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

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

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

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

(iii) Sag and Tension at 64^0C (Operating temperature) and 36% wind.

$8.132 * 10^{20} = f^2 * (f - (-4.02 * 10^6 - (19.3 * 10^{-6} * 65.45 * 7.04 * 10^9))$

$\therefore f = 6.478 * 10^6$ (Trial and error method)

Working tension: T = f * A $= 6.478 * 10^6 * 5.97 * 10^{-4} = 3867.25$ Kg

Sag: S = = $\frac{W*L^2}{8*T}$ = $\frac{2.004*400^2}{8*3880.32}$ = 10.36 m

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

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

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

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

Working tension: T = f * A = $6.97 * 10^6 * 5.97 * 10^{-4}$ = 4145.63 Kg

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

(ii) Sag and Tension at 32^0C (Every day temperature) and no wind.

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

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

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

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

(iii) Sag and Tension at 64^0C (Operating temperature) and no wind.

$5.288 * 10^{20} = f^2 * (f - (-4.02 * 10^6 - (19.3 * 10^{-6} * 65.45 * 7.04 * 10^9))$

$\therefore f = 5.376 * 10^6$ (Trial and error method)

Working tension: T = f * A = $5.376 * 10^7 * 5.97 * 10^{-4}$ = 3209.59 Kg

Sag: S = = $\frac{W*L^2}{8*T}$ = $\frac{2.004*400^2}{8*3221.29}$ = 12.49 m

Similarly, Sag and tension of a conductor under any temperature and wind condition can be calculated.

6.16 Result table

Table 6.7 shows the result for twin conductor, double circuit ACSR moose conductor. Results are considered for power transfer of 600MW at 400KV voltage and for transmission length of 430 Km.

Description	Unit	Value
Total Inductance	H/phase	0.05134
Total Capacitance	$\mu/phase$	2.220
Impedance	Ω	7.24+16.13i
Receiving End Voltage (Magnitude & Angle)	KV	216.89, -2.73
Receiving End Current (Magnitude & Angle)	A	1036.85, -33.73
Receiving End Power	MW	578
Voltage regulation	%	7.08
Total Line loss	KW	20113.60
Percentage Line loss	%	3.35
Max. outer surface Voltage gradient	KV	16.15
Max. center surface Voltage gradient	KV	17.23
Fair weather corona loss per circuit	KW	861
Foul weather corona loss per circuit	MW	19
Efficiency under fair weather	%	96.36
Efficiency under foul weather	%	90.88
Audible Noise	dB	57.33
Radio Interference	dB	45.3
Sag at operating temperature & no wind	m	12.49
Sag at operating temperature & 0.36 full wind	m	10.36
Sag at operating temperature & full wind	m	6.25
Tension at operating temperature & no wind	Kg	3210
Tension at operating temperature & 0.36 full wind	Kg	3867
Tension at operating temperature & full wind	Kg	6409

Table 6.7: Calculation result for ACSR moose conductor

6.17 Comparison of different conductors

Here two conductors: Twin ACSR Moose conductor and twin ACCC Delhi are considered for 600MW power transfer at 400KV. Calculation procedure is same as above.

Description	**ACSR Moose**	**ACCC Delhi**
Sending End Voltage (V)	400000	400000
Sending End Power Factor	0.90	0.90
Percentage load (%)	100	100
Total length of Transmission Line (Km)	430	430
Transposed Length of line (Km)	100	100
Diameter of conductor (mm)	31.77	31.40
Distance of top conductor from mid of tower (mm)	6540	6540
Distance of mid conductor from mid of tower (mm)	7120	7120
Distance of bottom conductor from mid of tower (mm)	8230	8230
Vertical Spacing between conductor (mm)	8000	8000
Spacing between adjacent sub-conductor (mm)	450	450
Ampacity of conductor per phase per ckt (A)	962.25	962.25
Resistance of conductor at operating temp(Ω/Km)	0.06736	0.050317
Frequency (Hz)	50	50
Barometric Pressure (cm)	74	74
Temperature (^0C)	65.45	63.47
Surface Factor	0.84	0.84
Number of sub-conductor in bundle	2	2
Sending End Power (MVA)	667	667
Sending End Power (MW)	600	600
Height of conductor from ground (m)	15	15
Horizontal distance from bottom conductor (m)	20	20
Span between adjacent tower (m)	400	400
Cross section area of conductor (m^2)	$5.97 * 10^{-4}$	$7.38 * 10^{-4}$
UTS (Kg)	16432	17166.6
Weight of conductor (Kg/m)	2.004	1.996
Modulus of Elasticity (Kg/m^2)	$7.04 * 10^9$	$1.18 * 10^{10}$
Coefficient of linear Expansion ($/^0C$)	$19.3 * 10^{-6}$	$1.61 * 10^{-6}$
Wind pressure (Kg/m^2)	128.49	128.49

Table 6.8: Input data for ACSR moose and ACCC Delhi conductor

Description	**ACSR Moose**	**ACCC Delhi**
Total Inductance (H/phase)	0.05134	0.0514
Total Capacitance ($\mu/phase$)	2.22	2.218
Impedance (Ω)	7.24+16.13i	5.41+16.15i
Receiving End Voltage-Magnitude (KV)	216.89	218.50
Receiving End Voltage-Angle	-2.73	-2.96
Receiving End Current-Magnitude (A)	1036.85	1036.80
Receiving End Current-Angle	-33.73	-33.75
Receiving End Power (MW)	578.31	583.80
Voltage regulation (%)	7.08	6.29
Total Line loss (KW)	20113.60	15025.27
Percentage Line loss (%)	3.35	2.50
Max. outer surface Voltage gradient (KV)	16.15	16.31
Max. center surface Voltage gradient (KV)	17.23	17.39
Fair weather corona loss (KW)	1721.67	1717.46
Foul weather corona loss (MW)	37.90	38.81
Efficiency under fair weather (%)	96.36	97.21
Efficiency under foul weather (%)	90.88	91.56
Audible Noise (dB)	57.33	57.49
Radio Interference (dB)	45.30	45.65
Sag at operating temperature & no wind (m)	12.49	10.7
Sag at operating temperature & 0.36 full wind (m)	10.36	8.85
Sag at operating temperature & full wind (m)	6.25	5.27
Tension at operating temperature & no wind (Kg)	3210	3730
Tension at operating temperature & 0.36 full wind (Kg)	3867	4510
Tension at operating temperature & full wind (Kg)	6409	7579

Table 6.9: Output result for ACSR moose and ACCC Delhi conductor

Description	ACSR Moose	ACCC Delhi
Cross Sectional Area (mm^2)	597	738.4
Conductor Diameter (mm)	31.77	31.40
Modulus of elasticity (Kg/cm^2)	704000	1182400
Coefficient of linear Expansion (per ^{0}C)	$19.3*10^{-6}$	$1.45*10^{-6}$
Weight (Kg/Km)	2004	1996
UTS (Kgf)	16432	17166
DC Resistance at 20^0C (Ω /Km)	0.05595	0.04145
Emergency Temperature (^0C)	105	200
Maximum Operating Temperature (^0C)	75	175
Line length (Km)	430	430
Calculation are carried out at temp (^0C)	65.45	63.47
Current to be maintained per phase (A)	962	962
Resistance of conductor (Ω/Km)	0.067357	0.050317
I^2R losses (KW/double ckt)	20114	15025
Total Fair weather losses (KW/double ckt)	21835	16743
Total Foul weather losses (KW/double ckt)	58011	53837
Power transferred in Fair weather (MW/double ckt)	578	584
Power transferred in Foul weather (MW/double ckt)	542	546
Cost of conductor per km	1250000	5625000
Cost of losses in INR2.5 per double ckt in 1 yr	1,21,68,51,898	1,00,04,09,614
Cost of power transferred in INR2.5 per double ckt in 1 yr	25,06,86,42,382	25,29,95,52,830
Revenue generated in INR per double ckt in 1 yr	23,85,17,90,484	24,29,91,43,216
Saving per year		44,73,52,732.72
Pay back period (year)		4

Table 6.10: Technical comparison ACSR moose and ACCC Delhi conductor

From above comparison its clear that installation cost of ACSR conductor is low but the running cost of ACCC Delhi conductor is low.

6.18 Comparison of different configuration of ACCC Delhi conductor

Here three different configurations are compared Fig 5.5,5.6i.e. simple vertical, Hexa and Inverted V configuration. All input considered here are same except the distance of conductor from mid of the tower.

Distance of phase A, B, C from mid of tower for Vertical configuration are 7120 mm Distance of phase A, B, C from mid of tower for Hexa configuration are 6540, 7120 and 6540 mm respectively. And distance of phase A, B, C from mid of tower for Inverted V configuration are 6540, 7120 and 8230 mm respectively.

Description	**Vertical**	**Hexa**	**Inv.V**
Total Inductance (H/phase)	0.05139	0.05165	0.051397
Total Capacitance ($\mu/phase$)	2.21790	2.20663	2.21775
Impedance (Ω)	5.41+16.1456i	5.41+16.2260i	5.41+16.1467i
Receiving End Voltage-Magnitude (KV)	218505	218475	218505
Receiving End Voltage-Angle	-2.96	-2.97	-2.96
Receiving End Current-Magnitude (A)	1036.81	1036.36	1036.80
Receiving End Current-Angle	-33.75	-33.72	-33.75
Receiving End Power (MW)	583.8026	583.8095	583.8027
Voltage regulation (%)	**6.288**	**6.303**	**6.288**
Total Line loss (KW)	15025	15025	15025
Percentage Line loss (%)	2.50	2.50	2.50
Max. outer surface Voltage gradient (KV)	**16.315**	**16.307**	**16.307**
Max. center surface Voltage gradient (KV)	**17.42**	**17.39**	**17.39**
Fair weather corona loss (KW)	1771.85	1770.55	1717.46
Foul weather corona loss (MW)	38.958	38.865	38.812
Efficiency under fair weather (%)	**97.203**	**97.204**	**97.212**
Efficiency under foul weather (%)	**91.54**	**91.55**	**91.56**
Audible Noise (dB)	**57.62**	**57.65**	**57.49**
Radio Interference (dB)	**45.92**	**46.02**	**45.65**

Table 6.11: Output result for different configuration of ACCC Delhi conductor

Chapter 7

Conclusion and Future work

7.1 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.

7.2 Conclusion

In this report all the necessary calculation for transmission line design is shown and two conductor viz: ACSR Moose and ACCC Delhi are compared. Program is developed for easy calculation of current carrying capacity of conductor, for electrical calculation of Double circuit transmission line, Single circuit transmission line for both vertical and horizontal orientation. In this program nearly all the configurations can be considered.

- ACSR Moose conductor is a standard conductor which is used for 400 KV transmission line. This conductor can be considered where operating temperature doesn't exceed beyond 75^0C and where initial cost has to be kept minimum.

- ACCC Delhi conductor has less line losses, have more capacity build towards future demand and are ideal for reconductoring. Maximum operating temperature of ACCC conductor is 180^0C which is much higher as compared to ACSR Moose. Cost of this conductor is 4 to 5 times higher then ACSR conductors.

- Out of three considered configurations, inverted V configuration is chosen as it gives higher efficiency and low AN and RI.

7.3 Recommendations

Based on the above conclusions following recommendations are suggested:

- ACSR Moose conductor is recommended when:
  - Length of transmission line is small so that line losses are less.
  - Transmission line are not near coastal areas, as ACSR conductors get corroded and hence reduces its life.
  - Where initial cost is to be kept minimum.
  - Operating temperature is less than 75^0C.
  - Future demand are not very high.

- ACCC Delhi conductor is recommended when:
  - Transmission line is long as its line losses are less.
  - These conductor can meet high power demand as they can be operated at high temperature while improving line clearances and losses.
  - As conductor have high UTS, it can be used in windy region and because of absence of steel, chances of corrosion reduces and hence can also be used near coastal region.

7.4 Future work

This work can be extended in future for:

- Calculation and analysis for UHV-AC transmission line with single or double circuit.
- Extend program for multi circuit transmission lines.
- Develop program for transmission line design while considering ground wires and consider other geometry for sub-conductor in a bundle (except circular geometry).
- Optimizing the solution of EHV transmission line design using boundary conditions and closed loop in programming.

Publication

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References

[1] IS 398 (Part 5)(1992): Aluminium conductor for overhead transmission purposes-Specification

[2] IEC 1597 (1995): overhead electrical conductors-Calculation methods for stranded bare conductors.

[3] IS 802 (Part 1 / Sec 1)(1995): Use of structural steel in overhead transmission line towers - code of practice.

[4] M. Kanya Kumari, Rajesh Kumar, P.V.V. Nambudiri, K.N. Srinivasan, "Computation of Electrical environment effects of transmission lines", High Voltage Engineering Symposium, 22-27 August 1999, Conference Publication No. 467, pp 2.160- 2.163.

[5] Liu Dichen, Li Zhi, Qian Wei, Wan Baoquan, "A study on Radio Intereference of 500KV double circuit transmission lines in the Sanxia Power Station", Asia Pacific Conference on Environmental Electromagnetics, CEEM 2003, 4-7 November 2003, Hangzhuo, China, pp 190-193.

[6] B.Gunasekaran, A.Yellaiah, "Corona loss measurement in corona cage on UHV Bundle conductor", 16th National power systems conference, 15-17 December 2010, pp 558-561.

[7] Richard E. Kenon, "EHV Transmission line design opportunities for cost reduction", IEEE Transactions on Power Delivery, Vol. 5, No.2, April 1990.

[8] "Transmission line Reference book for 345KV and above". 2^{nd} ed. California: Electric Power Research Institute (EPRI), 1982.

[9] "Transmission line manual", Central Board of Irrigation and Power (CBIP), New Delhi, Publication No. 268 Chapters 3,4,5.

[10] Rakosh Das Begamudre, "Extra High Voltage AC Transmission Engineering", 3^{rd} edition. New Delhi, New age International Publisher, 2006, pp22-167.

[11] John J. Grainger, Wiiliam D. Stevenson,Jr., "Power System Analysis", Singapore, McGraw-Hill, 1994, pp 141-230.

[12] S. Rao, "EHV-AC and HVDC transmission practice", Khanna Publishers, pp 824-883.

[13] J. Reichman, "Bundled conductor voltage gradient calculations", IEEE Transaction, August 1959

[14] J. G. Anderson, fellow, IEEE, M. Baretsky, Jr. member, IEEE, and D. D. MacCarthy, fellow, IEEE, "Corona-Loss Characteristics of EHV Transmission Lines Based on Project EHV Research", IEEE transsactions on power apparatus and systems, VOL. PAS-85, NO. 12,December, 1966.

[15] P.S. Maruvada, Chairman, R.J. Bacha, A.C. Baker, W.E. Blair, M.E. Bulawka, V.L. Chartier, R. Cortina, L.B. Craine, G.R. Elder, C. Gary, J.F. hIall, W. Janischewskyj, N. Kolcio, T.J. McDermott, R.M. M4orris, R.J. Nigbor, W.E. Pakala, A. Paldi, M.D. Perkins, J, Reichman, J.P. Reilly, R.J. Richeda, W.R. Schlinger, S.A. Sebo, P.D. Tuttle, F.W. Warburton, B.F. Whitney and P.S. Wong., "A survey of methods for calculating transmission line conductor surface voltage gradients", IEEE Transactions on Power Apparatus and Systems, Vol. PAS-98, No.6 Nov./Dec. 1979.

[16] IEEE Std 738(1993): IEEE Standard for calculating Temperature relationship of bare overhead conductors.

[17] DICABS conductors, technical catalogue, diamond cables Ltd.

[18] Sterlite conductors, technical catalogue, Sterlite technology Ltd.

[19] TPEC (Takalkar Power Engineers And Consultants Pvt. Ltd. (India)), Lake Turkana Spec/Part1 Gen.spec.1.

[20] S.M. Takalkar, "Basic about power transmission system and bare conductor", Chapter 1.

Appendix A

Program for calculating Ampacity of conductor

```
using System;
using System.Collections.Generic;
using System.ComponentModel;
using System.Data;
using System.Drawing;
using System.Text;
using System.Windows.Forms;
using KarlsTools;
using System.Data.OleDb;
namespace Project
{
public partial class CCC : Form
{
public CCC()
{
InitializeComponent();
```

```
}

    private void btnCalculate_Click(object sender, EventArgs e)
{

/*Current carrying capacity calculation*/
/*common*/
double Dia = Convert.ToDouble(txtconddia.Text);
double Temp = Convert.ToDouble(txttemp.Text);
double Rdc20 = Convert.ToDouble(txtdcres.Text);
double masstempcoef = Convert.ToDouble(txtmasstempcoef.Text);
double Tamb = Convert.ToDouble(txtambtemp.Text);
double Tfeq = Convert.ToDouble(txtfineqtemp.Text);
double Ws = Convert.ToDouble(txtwindspeed.Text);
double Ke = Convert.ToDouble(txtemisscoef.Text);
double Ksol = Convert.ToDouble(txtsolarradabs.Text);
double Si = Convert.ToDouble(txtintsolarrad.Text);
double Ksb = Convert.ToDouble(txtstefbolzconst.Text);
double lambda = Convert.ToDouble(txtthermalcond.Text);
double freq = Convert.ToDouble(txtfreq.Text);
double perm = Convert.ToDouble(txtpermeability.Text);
double X = 0;
double K = 0;
double Rdceqt = 0;
double Raceqt = 0;
double Tambk = 0;
double Tfeqk = 0;
double Nuss = 0;
double Rey = 0;
```

```
double Pj = 0;
double Prad = 0;
double Pconv = 0;
double Psol = 0;
double CCC = 0;
double heatbalance = 1;
Rdceqt = Rdc20 * (1 + masstempcoef * (Tfeq - Temp));
X = Math.Round ( 0.063598 * (Math.Sqrt(perm * freq / (1.6 * Rdceqt))),2);
K = GetKsValueFromX(X);// 1;/*lookup table*/
Raceqt = Rdceqt * K;
Tambk = 273 + Tamb;
Tfeqk = 273 + Tfeq;
Rey = (1.644 * (Math.Pow(10, 9)) * Ws * (Dia / 1000)) * (Math.Pow((Tambk + (0.5
* (Tfeqk - Tambk))), -1.78));
Nuss = (0.65 * Math.Pow(Rey, 0.2)) + (0.23 * Math.Pow(Rey, 0.61));
Prad = Ksb * (Math.PI) * (Dia / 1000) * Ke * ((Math.Pow(Tfeqk, 4)) - (Math.Pow(Tambk,
4)));
Pconv = lambda * Nuss * (Math.PI) * (Tfeqk - Tambk);
Psol = Ksol * (Dia / 1000) * Si;
CCC = Math.Sqrt((Prad + Pconv - Psol) / (Raceqt / 1000));
Pj = Math.Pow(CCC, 2) * (Raceqt / 1000);
heatbalance = Pj + Psol - Prad - Pconv;
lblRac.Text = "AC resistance of conductor at final equilibrium temp = " + (Raceqt).ToString()+
"(Ohm/Km)";
lblPj.Text = "Power loss due to joule effect = " + (Pj).ToString()+ "(W)";
lblprad.Text = "Heat loss by radiation = " + (Prad).ToString() + "(W)";
lblpconv.Text = "Convection heat loss = " + (Pconv).ToString() + "(W)";
lblpsol.Text = "Solar heat gain = " + (Psol).ToString() + "(W)";
lblccc.Text = "Current carrying capacity of conductor = " + CCC.ToString() +
```

```
"(A)";
lblhbeq.Text = "Heat balance (Zero value indicate balanced equation) " + heatbal-
ance.ToString();
}
private double GetKsValueFromX(double X)
{
double rtnValue = 0;
OleDbConnection con = new OleDbConnection ( "Provider=Microsoft.Jet.OLEDB.4.0;Data
Source=C : /CCC.xls;Extended Properties=Excel 8.0");

OleDbDataAdapter da = new OleDbDataAdapter( "select [Skin Effect Table] AS
[Key] ,F2 AS [Value] from ['Skin Effect Table$'] WHERE [Skin Effect Table] = " +
X.ToString() + "", con);
DataTable dt = new DataTable();
da.Fill(dt);
rtnValue = Convert.ToDouble(dt.Rows[0][1].ToString());
return rtnValue;
}
}
}
```

Appendix B

Program for Double circuit vertical configuration

```
using System;
using System.Collections.Generic;
using System.ComponentModel;
using System.Data;
using System.Drawing;
using System.Text;
using System.Windows.Forms;
using KarlsTools;
namespace Project
{
public partial class frmInductanceCal : Form
{
DataSet dsSource = new DataSet("dsSource");
DataTable dt = new DataTable("Data");
DataTable dtLnc = new DataTable();
string strTotalInductance1;
```

```
string strTotalInductance2;
string strTotalInductance3;
string strTotalInductance4;
string strTotalInductance5;
string strTotalInductance6;
string strTotalCap1;
string strTotalCap2;
string strTotalCap3;
string strTotalCap4;
string strTotalCap5;
string strTotalCap6;
StringBuilder sbNotification = new StringBuilder(string.Empty);
public frmInductanceCal()
{
InitializeComponent();
dt.Columns.Add("Name", typeof(string));
dt.Columns.Add("Value", typeof(double));
dsSource.Tables.Add(dt);
dtLnc.Columns.Add();
dtLnc.Columns.Add();
dtLnc.Columns.Add();
dtLnc.Columns.Add();
dtLnc.Columns.Add();
dtLnc.Columns.Add();
dtLnc.Columns.Add();
dtLnc.Columns.Add();
dtLnc.Columns.Add();
dtLnc.Columns.Add();
dtLnc.Columns.Add();
```

```
dtLnc.Columns.Add();
dtLnc.Rows.Add();
dtLnc.Rows.Add();
dtLnc.Rows.Add();
dtLnc.Rows.Add();
dtLnc.Rows.Add();
dtLnc.Rows.Add();
dtLnc.Rows.Add();
}
private void txtDiameter_Leave(object sender, EventArgs e)
{
if (txtDiameter.Text != string.Empty)
{
txtRadius.Text = Convert.ToString((Convert.ToDouble(txtDiameter.Text) / 2));
}
}
private void btnCalculate_Click(object sender, EventArgs e)
{
/*GMD Calculation*/
/*Common*/
double disA = Convert.ToDouble(txtDisBetA.Text);
double disB = Convert.ToDouble(txtDisBetB.Text);
double disC = Convert.ToDouble(txtDisBetC.Text);
double verDis = Convert.ToDouble(txtVerSpace.Text);
double Totallength = Convert.ToDouble(txtTotalLength.Text);
double Transpose = Convert.ToDouble(txttanspos.Text);
double radius = Convert.ToDouble(txtRadius.Text);
double bundlespace = Convert.ToDouble(txtBundlespace.Text);
int bundlenum = Convert.ToInt32(txtBundle.Text);
```

```
double value1 = 0.0;
double value2 = 0.0;
double GMD1 = 0;
double GMR1 = 0;
double GMD2 = 0;
double GMR2 = 0;
double GMD3 = 0;
double GMR3 = 0;
double GMD4 = 0;
double GMR4 = 0;
double GMD5 = 0;
double GMR5 = 0;
double GMD6 = 0;
double GMR6 = 0;
double CGMR1 = 0;
double CGMR2 = 0;
double CGMR3 = 0;
double CGMR4 = 0;
double CGMR5 = 0;
double CGMR6 = 0;
double varL1 = 0;
double varL2 = 0;
double varL3 = 0;
double varL4 = 0;
double varL6 = 0;
double varL8 = 0;
double varC1 = 0;
double varC2 = 0;
double varC3 = 0;
```

```
double varC4 = 0;
double varC6 = 0;
double varC8 = 0;
/*for look up*/
varL1 = 0.7788 * radius;
varL2 = Math.Sqrt(bundlespace * 0.7788 * radius);
varL3 = Math.Pow((0.7788 * radius * Math.Pow(bundlespace, 2)), (1 / 3));
varL4 = 1.09 * Math.Pow((0.7788 * radius * Math.Pow(bundlespace, 3)), (1 / 4));
varL6 = 1.348 * Math.Pow((0.7788 * radius * Math.Pow(bundlespace, 5)), (1 / 6));
varL8 = 1.638 * Math.Pow((0.7788 * radius * Math.Pow(bundlespace, 7)), (1 / 8));
varC1 = radius;
varC2 = Math.Sqrt(bundlespace * radius);
varC3 = Math.Pow((radius * Math.Pow(bundlespace, 2)), (1 / 3));
varC4 = 1.09 * Math.Pow((radius * Math.Pow(bundlespace, 3)), (1 / 4));
varC6 = 1.348 * Math.Pow((radius * Math.Pow(bundlespace, 5)), (1 / 6));
varC8 = 1.638 * Math.Pow((radius * Math.Pow(bundlespace, 7)), (1 / 8));
if (bundlenum == 1)
{
value1 = varL1;
value2 = varC1;
}
else if (bundlenum == 2)
{
value1 = varL2;
value2 = varC2;
}
else if (bundlenum == 3)
{
value1 = varL3;
```

```
value2 = varC3;
}
else if (bundlenum == 4)
{
value1 = varL4;
value2 = varC4;
}
else if (bundlenum == 6)
{
value1 = varL6;
value2 = varC6;
}
else if (bundlenum == 8)
{
value1 = varL8;
value2 = varC8;
}
/*Step 1*/
double disBetAB = 0;
double disBetABdes = 0;
double disBetAdesBdes = 0;
double disBetAdesB = 0;
double disBetABGMD = 0;
disBetAB = Math.Sqrt((Math.Pow(verDis, 2)) + Math.Pow((disA - disB), 2));
disBetABdes = Math.Sqrt((Math.Pow(verDis, 2)) + Math.Pow((disA + disB), 2));
disBetAdesB = Math.Sqrt((Math.Pow(verDis, 2)) + Math.Pow((disA + disB), 2));
disBetAdesBdes = Math.Sqrt((Math.Pow(verDis, 2)) + Math.Pow((disA - disB), 2));
disBetABGMD = Math.Pow(disBetAB * disBetAdesB * disBetABdes * disBetAdes-
Bdes, .25);
```

```
/*Step 2*/
double disBetBC = 0;
double disBetBCdes = 0;
double disBetBdesCdes = 0;
double disBetBdesC = 0;
double disBetBCGMD = 0;
disBetBC = Math.Sqrt((Math.Pow(verDis, 2)) + Math.Pow((disB - disC), 2));
disBetBCdes = Math.Sqrt((Math.Pow(verDis, 2)) + Math.Pow((disB + disC), 2));
disBetBdesC = Math.Sqrt((Math.Pow(verDis, 2)) + Math.Pow((disB + disC), 2));
disBetBdesCdes = Math.Sqrt((Math.Pow(verDis, 2)) + Math.Pow((disB - disC), 2));
disBetBCGMD = Math.Pow(disBetBC * disBetBdesC * disBetBCdes * disBetBde-
sCdes, .25);
/*Step 3*/
double disBetCA = 0;
double disBetCAdes = 0;
double disBetCdesAdes = 0;
double disBetCdesA = 0;
double disBetCAGMD = 0;
disBetCA = Math.Sqrt((Math.Pow(verDis * 2, 2)) + Math.Pow((disC - disA), 2));
disBetCAdes = Math.Sqrt((Math.Pow(verDis * 2, 2)) + Math.Pow((disC + disA),
2));
disBetCdesA = Math.Sqrt((Math.Pow(verDis * 2, 2)) + Math.Pow((disC + disA),
2));
disBetCdesAdes = Math.Sqrt((Math.Pow(verDis * 2, 2)) + Math.Pow((disC - disA),
2));
disBetCAGMD = Math.Pow(disBetCA * disBetCdesA * disBetCAdes * disBetCde-
sAdes, .25);
/*GMD final*/
GMD1 = Math.Pow((disBetABGMD * disBetBCGMD * disBetCAGMD), (1 / 3.0));
```

```
/* GMR Calculation*/
/*STEP 4*/
double disBetAA = 0;
double disBetAAdes = 0;
double disBetAAGMD = 0;
disBetAA = value1;
disBetAAdes = disA * 2;
disBetAAGMD = Math.Sqrt(disBetAA * disBetAAdes);
/*STEP 5*/
double disBetBB = 0;
double disBetBBdes = 0;
double disBetBBGMD = 0;
disBetBB = value1;
disBetBBdes = disB * 2;
disBetBBGMD = Math.Sqrt(disBetBB * disBetBBdes);
/*STEP 6*/
double disBetCC = 0;
double disBetCCdes = 0;
double disBetCCGMD = 0;
disBetCC = value1;
disBetCCdes = disC * 2;
disBetCCGMD = Math.Sqrt(disBetCC * disBetCCdes);
GMR1 = Math.Pow((disBetAAGMD * disBetBBGMD * disBetCCGMD), (1 / 3.0));
CGMR1 = Math.Pow(((Math.Sqrt(value2 * disBetAAdes)) * (Math.Sqrt(value2 *
disBetBBdes)) * (Math.Sqrt(value2 * disBetCCdes))), (1 / 3.0));
/* INDUCTANCE and CAPACITANCE*/
double inductance1 = 0;
inductance1 = 2000 * (Math.Pow(10, -7)) * (Math.Log(GMD1 / GMR1, Math.E));
double capacitance1 = 0;
```

```
capacitance1 = 0.05560618997 / (Math.Log(GMD1 / CGMR1, Math.E));
/*Add row to Datatable*/
dt.Rows.Add("ABC-abc", inductance1 * (Convert.ToDouble(txtTotalLength.Text)));
/*Step 1*/
double disBetA2B2 = 0;
double disBetA2B2des = 0;
double disBetA2desB2des = 0;
double disBetA2desB2 = 0;
double disBetA2B2GMD = 0;
disBetA2B2 = Math.Sqrt((Math.Pow(verDis, 2)) + Math.Pow((disA - disB), 2));
disBetA2B2des = Math.Sqrt((Math.Pow((verDis * 2), 2)) + Math.Pow((disA + disC),
2));
disBetA2desB2 = Math.Sqrt((Math.Pow(verDis, 2)) + Math.Pow((disA + disB), 2));
disBetA2desB2des = Math.Sqrt((Math.Pow((verDis * 2), 2)) + Math.Pow((disA -
disC), 2));
disBetA2B2GMD = Math.Pow(disBetA2B2 * disBetA2desB2 * disBetA2B2des * dis-
BetA2desB2des, .25);
/*Step 2*/
double disBetB2C2 = 0;
double disBetB2C2des = 0;
double disBetB2desC2des = 0;
double disBetB2desC2 = 0;
double disBetB2C2GMD = 0;
disBetB2C2 = Math.Sqrt((Math.Pow(verDis, 2)) + Math.Pow((disB - disC), 2));
disBetB2C2des = Math.Sqrt(Math.Pow((disB + disB), 2));
disBetB2desC2 = Math.Sqrt(Math.Pow((disC + disC), 2));
disBetB2desC2des = Math.Sqrt((Math.Pow(verDis, 2)) + Math.Pow((disB - disC),
2));
disBetB2C2GMD = Math.Pow(disBetB2C2 * disBetB2desC2 * disBetB2C2des * dis-
```

```
BetB2desC2des, .25);
/*Step 3*/
double disBetC2A2 = 0;
double disBetC2A2des = 0;
double disBetC2desA2des = 0;
double disBetC2desA2 = 0;
double disBetC2A2GMD = 0;
disBetC2A2 = Math.Sqrt((Math.Pow(verDis * 2, 2)) + Math.Pow((disC - disA), 2));
disBetC2A2des = Math.Sqrt((Math.Pow(verDis * 2, 2)) + Math.Pow((disC + disA),
2));
disBetC2desA2 = Math.Sqrt((Math.Pow(verDis, 2)) + Math.Pow((disB + disA), 2));
disBetC2desA2des = Math.Sqrt((Math.Pow(verDis, 2)) + Math.Pow((disB - disA),
2));
disBetC2A2GMD = Math.Pow(disBetC2A2 * disBetC2desA2 * disBetC2A2des * dis-
BetC2desA2des, .25);
/*GMD final*/
GMD2 = Math.Pow((disBetA2B2GMD * disBetB2C2GMD * disBetC2A2GMD), (1
/ 3.0));
/* GMR Calculation*/
/*STEP 4*/
double disBetA2A2 = 0;
double disBetA2A2des = 0;
double disBetA2A2GMD = 0;
disBetA2A2 = value1;
disBetA2A2des = disA * 2;
disBetA2A2GMD = Math.Sqrt(disBetA2A2 * disBetA2A2des);
/*STEP 5*/
double disBetB2B2 = 0;
double disBetB2B2des = 0;
```

```
double disBetB2B2GMD = 0;
disBetB2B2 = value1;
disBetB2B2des = Math.Sqrt(Math.Pow(verDis, 2) + Math.Pow((disB + disC), 2));
disBetB2B2GMD = Math.Sqrt(disBetB2B2 * disBetB2B2des);
/*STEP 6*/
double disBetC2C2 = 0;
double disBetC2C2des = 0;
double disBetC2C2GMD = 0;
disBetC2C2 = value1;
disBetC2C2des = Math.Sqrt(Math.Pow(verDis, 2) + Math.Pow((disB + disC), 2));
disBetC2C2GMD = Math.Sqrt(disBetC2C2 * disBetC2C2des);
GMR2 = Math.Pow((disBetA2A2GMD * disBetB2B2GMD * disBetC2C2GMD), (1
/ 3.0));
CGMR2 = Math.Pow(((Math.Sqrt(value2 * disBetA2A2des)) * (Math.Sqrt(value2 *
disBetB2B2des)) * (Math.Sqrt(value2 * disBetC2C2des))), (1 / 3.0));
/* INDUCTANCE and CAPACITANCE */
double inductance2 = 0;
inductance2 = 2000 * (Math.Pow(10, -7)) * (Math.Log(GMD2 / GMR2, Math.E));
double capacitance2 = 0;
capacitance2 = 0.05560618997 / (Math.Log(GMD2 / CGMR2, Math.E));
/*Add row to Datatable*/
dt.Rows.Add(“ABC-acb”, inductance2 * (Convert.ToDouble(txtTotalLength.Text)));
/*Step 1*/
double disBetA3B3 = 0;
double disBetA3B3des = 0;
double disBetA3desB3des = 0;
double disBetA3desB3 = 0;
double disBetA3B3GMD = 0;
disBetA3B3 = Math.Sqrt((Math.Pow(verDis, 2)) + Math.Pow((disA - disB), 2));
```

```
disBetA3B3des = Math.Sqrt(Math.Pow((disA + disA), 2));
disBetA3desB3 = Math.Sqrt(Math.Pow((disB + disB), 2));
disBetA3desB3des = Math.Sqrt((Math.Pow((verDis), 2)) + Math.Pow((disA - disB),
2));
disBetA3B3GMD = Math.Pow(disBetA3B3 * disBetA3desB3 * disBetA3B3des * dis-
BetA3desB3des, .25);
/*Step 2*/
double disBetB3C3 = 0;
double disBetB3C3des = 0;
double disBetB3desC3des = 0;
double disBetB3desC3 = 0;
double disBetB3C3GMD = 0;
disBetB3C3 = Math.Sqrt((Math.Pow(verDis, 2)) + Math.Pow((disB - disC), 2));
disBetB3C3des = Math.Sqrt((Math.Pow(verDis, 2)) + Math.Pow((disB + disC), 2));
disBetB3desC3 = Math.Sqrt((Math.Pow((verDis * 2), 2)) + Math.Pow((disA + disC),
2));
disBetB3desC3des = Math.Sqrt((Math.Pow((verDis * 2), 2)) + Math.Pow((disA -
disC), 2));
disBetB3C3GMD = Math.Pow(disBetB3C3 * disBetB3desC3 * disBetB3C3des * dis-
BetB3desC3des, .25);
/*Step 3*/
double disBetC3A3 = 0;
double disBetC3A3des = 0;
double disBetC3desA3des = 0;
double disBetC3desA3 = 0;
double disBetC3A3GMD = 0;
disBetC3A3 = Math.Sqrt((Math.Pow(verDis * 2, 2)) + Math.Pow((disC - disA), 2));
disBetC3A3des = Math.Sqrt((Math.Pow(verDis, 2)) + Math.Pow((disB + disC), 2));
disBetC3desA3 = Math.Sqrt((Math.Pow(verDis * 2, 2)) + Math.Pow((disA + disC),
```

```
2));
disBetC3desA3des = Math.Sqrt((Math.Pow(verDis, 2)) + Math.Pow((disC - disB),
2));
disBetC3A3GMD = Math.Pow(disBetC3A3 * disBetC3desA3 * disBetC3A3des * dis-
BetC3desA3des, .25);
/*GMD final*/
GMD3 = Math.Pow((disBetA3B3GMD * disBetB3C3GMD * disBetC3A3GMD), (1
/ 3.0));
/* GMR Calculation*/
/*STEP 4*/
double disBetA3A3 = 0;
double disBetA3A3des = 0;
double disBetA3A3GMD = 0;
disBetA3A3 = value1;
disBetA3A3des = Math.Sqrt(Math.Pow(verDis, 2) + Math.Pow((disA + disB), 2));
disBetA3A3GMD = Math.Sqrt(disBetA3A3 * disBetA3A3des);
/*STEP 5*/
double disBetB3B3 = 0;
double disBetB3B3des = 0;
double disBetB3B3GMD = 0;
disBetB3B3 = value1;
disBetB3B3des = Math.Sqrt(Math.Pow(verDis, 2) + Math.Pow((disA + disB), 2));
disBetB3B3GMD = Math.Sqrt(disBetB3B3 * disBetB3B3des);
/*STEP 6*/
double disBetC3C3 = 0;
double disBetC3C3des = 0;
double disBetC3C3GMD = 0;
disBetC3C3 = value1;
disBetC3C3des = Math.Sqrt(Math.Pow((disC + disC), 2));
```

```
disBetC3C3GMD = Math.Sqrt(disBetC3C3 * disBetC3C3des);
GMR3 = Math.Pow((disBetA3A3GMD * disBetB3B3GMD * disBetC3C3GMD), (1 / 3.0));
CGMR3 = Math.Pow(((Math.Sqrt(value2 * disBetA3A3des)) * (Math.Sqrt(value2 * disBetB3B3des)) * (Math.Sqrt(value2 * disBetC3C3des))), (1 / 3.0));
/* INDUCTANCE and CAPACITANCE */
double inductance3 = 0;
inductance3 = 2000 * (Math.Pow(10, -7)) * (Math.Log(GMD3 / GMR3, Math.E));
double capacitance3 = 0;
capacitance3 = 0.05560618997 / (Math.Log(GMD3 / CGMR3, Math.E));
/*Add row to Datatable*/
dt.Rows.Add(“ABC-bac”, inductance3 * (Convert.ToDouble(txtTotalLength.Text)));
/*Step 1*/
double disBetA4B4 = 0;
double disBetA4B4des = 0;
double disBetA4desB4des = 0;
double disBetA4desB4 = 0;
double disBetA4B4GMD = 0;
disBetA4B4 = Math.Sqrt((Math.Pow(verDis, 2)) + Math.Pow((disA - disB), 2));
disBetA4B4des = Math.Sqrt((Math.Pow(verDis * 2, 2)) + Math.Pow((disA + disC), 2));
disBetA4desB4 = Math.Sqrt(Math.Pow((disB + disB), 2));
disBetA4desB4des = Math.Sqrt((Math.Pow((verDis), 2)) + Math.Pow((disB - disC), 2));
disBetA4B4GMD = Math.Pow(disBetA4B4 * disBetA4desB4 * disBetA4B4des * disBetA4desB4des, .25);
/*Step 2*/
double disBetB4C4 = 0;
double disBetB4C4des = 0;
```

```
double disBetB4desC4des = 0;
double disBetB4desC4 = 0;
double disBetB4C4GMD = 0;
disBetB4C4 = Math.Sqrt((Math.Pow(verDis, 2)) + Math.Pow((disB - disC), 2));
disBetB4C4des = Math.Sqrt((Math.Pow(verDis, 2)) + Math.Pow((disA + disB), 2));
disBetB4desC4 = Math.Sqrt(Math.Pow((disC + disC), 2));
disBetB4desC4des = Math.Sqrt((Math.Pow((verDis * 2), 2)) + Math.Pow((disA -
disC), 2));
disBetB4C4GMD = Math.Pow(disBetB4C4 * disBetB4desC4 * disBetB4C4des * dis-
BetB4desC4des, .25);
/*Step 3*/
double disBetC4A4 = 0;
double disBetC4A4des = 0;
double disBetC4desA4des = 0;
double disBetC4desA4 = 0;
double disBetC4A4GMD = 0;
disBetC4A4 = Math.Sqrt((Math.Pow(verDis * 2, 2)) + Math.Pow((disC - disA), 2));
disBetC4A4des = Math.Sqrt((Math.Pow(verDis, 2)) + Math.Pow((disB + disC), 2));
disBetC4desA4 = Math.Sqrt(Math.Pow((disA + disA), 2));
disBetC4desA4des = Math.Sqrt((Math.Pow(verDis, 2)) + Math.Pow((disA - disB),
2));
disBetC4A4GMD = Math.Pow(disBetC4A4 * disBetC4desA4 * disBetC4A4des * dis-
BetC4desA4des, .25);
/*GMD final*/
GMD4 = Math.Pow((disBetA4B4GMD * disBetB4C4GMD * disBetC4A4GMD), (1
/ 3.0));
/* GMR Calculation*/
/*STEP 4*/
double disBetA4A4 = 0;
```

```
double disBetA4A4des = 0;
double disBetA4A4GMD = 0;
disBetA4A4 = value1;
disBetA4A4des = Math.Sqrt(Math.Pow(verDis, 2) + Math.Pow((disA + disB), 2));
disBetA4A4GMD = Math.Sqrt(disBetA4A4 * disBetA4A4des);
/*STEP 5*/
double disBetB4B4 = 0;
double disBetB4B4des = 0;
double disBetB4B4GMD = 0;
disBetB4B4 = value1;
disBetB4B4des = Math.Sqrt(Math.Pow(verDis, 2) + Math.Pow((disB + disC), 2));
disBetB4B4GMD = Math.Sqrt(disBetB4B4 * disBetB4B4des);
/*STEP 6*/
double disBetC4C4 = 0;
double disBetC4C4des = 0;
double disBetC4C4GMD = 0;
disBetC4C4 = value1;
disBetC4C4des = Math.Sqrt(Math.Pow(verDis * 2, 2) + Math.Pow((disA + disC),
2));
disBetC4C4GMD = Math.Sqrt(disBetC4C4 * disBetC4C4des);
GMR4 = Math.Pow((disBetA4A4GMD * disBetB4B4GMD * disBetC4C4GMD), (1
/ 3.0));
CGMR4 = Math.Pow(((Math.Sqrt(value2 * disBetA4A4des)) * (Math.Sqrt(value2 *
disBetB4B4des)) * (Math.Sqrt(value2 * disBetC4C4des))), (1 / 3.0));
/* INDUCTANCE and CAPACITANCE*/
double inductance4 = 0;
inductance4 = 2000 * (Math.Pow(10, -7)) * (Math.Log(GMD4 / GMR4, Math.E));
double capacitance4 = 0;
capacitance4 = 0.05560618997 / (Math.Log(GMD4 / CGMR4, Math.E));
```

/*Add row to Datatable*/

dt.Rows.Add("ABC-cab", inductance4 * (Convert.ToDouble(txtTotalLength.Text)));

/*Step 1*/

double disBetA5B5 = 0;

double disBetA5B5des = 0;

double disBetA5desB5des = 0;

double disBetA5desB5 = 0;

double disBetA5B5GMD = 0;

disBetA5B5 = Math.Sqrt((Math.Pow(verDis, 2)) + Math.Pow((disA - disB), 2));

disBetA5B5des = Math.Sqrt(Math.Pow((disA + disA), 2));

disBetA5desB5 = Math.Sqrt((Math.Pow(verDis, 2)) + Math.Pow((disB + disC), 2));

disBetA5desB5des = Math.Sqrt((Math.Pow((verDis * 2), 2)) + Math.Pow((disA - disC), 2));

disBetA5B5GMD = Math.Pow(disBetA5B5 * disBetA5desB5 * disBetA5B5des * disBetA5desB5des, .25);

/*Step 2*/

double disBetB5C5 = 0;

double disBetB5C5des = 0;

double disBetB5desC5des = 0;

double disBetB5desC5 = 0;

double disBetB5C5GMD = 0;

disBetB5C5 = Math.Sqrt((Math.Pow(verDis, 2)) + Math.Pow((disB - disC), 2));

disBetB5C5des = Math.Sqrt(Math.Pow((disB + disB), 2));

disBetB5desC5 = Math.Sqrt((Math.Pow((verDis * 2), 2)) + Math.Pow((disA + disC), 2));

disBetB5desC5des = Math.Sqrt((Math.Pow(verDis, 2)) + Math.Pow((disA - disB), 2));

disBetB5C5GMD = Math.Pow(disBetB5C5 * disBetB5desC5 * disBetB5C5des * disBetB5desC5des, .25);

```
/*Step 3*/
double disBetC5A5 = 0;
double disBetC5A5des = 0;
double disBetC5desA5des = 0;
double disBetC5desA5 = 0;
double disBetC5A5GMD = 0;
disBetC5A5 = Math.Sqrt((Math.Pow(verDis * 2, 2)) + Math.Pow((disC - disA), 2));
disBetC5A5des = Math.Sqrt(Math.Pow((disC + disC), 2));
disBetC5desA5 = Math.Sqrt((Math.Pow(verDis, 2)) + Math.Pow((disA + disB), 2));
disBetC5desA5des = Math.Sqrt((Math.Pow(verDis, 2)) + Math.Pow((disB - disC),
2));
disBetC5A5GMD = Math.Pow(disBetC5A5 * disBetC5desA5 * disBetC5A5des * dis-
BetC5desA5des, .25);
/*GMD final*/
GMD5 = Math.Pow((disBetA5B5GMD * disBetB5C5GMD * disBetC5A5GMD), (1
/ 3.0));
/* GMR Calculation*/
/*STEP 4*/
double disBetA5A5 = 0;
double disBetA5A5des = 0;
double disBetA5A5GMD = 0;
disBetA5A5 = value1;
disBetA5A5des = Math.Sqrt(Math.Pow(verDis * 2, 2) + Math.Pow((disA + disC),
2));
disBetA5A5GMD = Math.Sqrt(disBetA5A5 * disBetA5A5des);
/*STEP 5*/
double disBetB5B5 = 0;
double disBetB5B5des = 0;
double disBetB5B5GMD = 0;
```

```
disBetB5B5 = value1;
disBetB5B5des = Math.Sqrt(Math.Pow(verDis, 2) + Math.Pow((disA + disB), 2));
disBetB5B5GMD = Math.Sqrt(disBetB5B5 * disBetB5B5des);
/*STEP 6*/
double disBetC5C5 = 0;
double disBetC5C5des = 0;
double disBetC5C5GMD = 0;
disBetC5C5 = value1;
disBetC5C5des = Math.Sqrt(Math.Pow(verDis, 2) + Math.Pow((disB + disC), 2));
disBetC5C5GMD = Math.Sqrt(disBetC5C5 * disBetC5C5des);
GMR5 = Math.Pow((disBetA5A5GMD * disBetB5B5GMD * disBetC5C5GMD), (1
/ 3.0));
CGMR5 = Math.Pow(((Math.Sqrt(value2 * disBetA5A5des)) * (Math.Sqrt(value2 *
disBetB5B5des)) * (Math.Sqrt(value2 * disBetC5C5des))), (1 / 3.0));
/* INDUCTANCE and CAPACITANCE*/
double inductance5 = 0;
inductance5 = 2000 * (Math.Pow(10, -7)) * (Math.Log(GMD5 / GMR5, Math.E));
double capacitance5 = 0;
capacitance5 = 0.05560618997 / (Math.Log(GMD5 / CGMR5, Math.E));
/*Add row to Datatable*/
dt.Rows.Add("ABC-bca", inductance5 * (Convert.ToDouble(txtTotalLength.Text)));
/*Step 1*/
double disBetA6B6 = 0;
double disBetA6B6des = 0;
double disBetA6desB6des = 0;
double disBetA6desB6 = 0;
double disBetA6B6GMD = 0;
disBetA6B6 = Math.Sqrt((Math.Pow(verDis, 2)) + Math.Pow((disA - disB), 2));
disBetA6B6des = Math.Sqrt((Math.Pow(verDis, 2)) + Math.Pow((disA + disB), 2));
```

disBetA6desB6 = Math.Sqrt((Math.Pow(verDis, 2)) + Math.Pow((disB + disC), 2));
disBetA6desB6des = Math.Sqrt((Math.Pow(verDis, 2)) + Math.Pow((disB - disC), 2));
disBetA6B6GMD = Math.Pow(disBetA6B6 * disBetA6desB6 * disBetA6B6des * disBetA6desB6des, .25);
/*Step 2*/
double disBetB6C6 = 0;
double disBetB6C6des = 0;
double disBetB6desC6des = 0;
double disBetB6desC6 = 0;
double disBetB6C6GMD = 0;
disBetB6C6 = Math.Sqrt((Math.Pow(verDis, 2)) + Math.Pow((disB - disC), 2));
disBetB6C6des = Math.Sqrt((Math.Pow(verDis, 2)) + Math.Pow((disA + disB), 2));
disBetB6desC6 = Math.Sqrt((Math.Pow(verDis, 2)) + Math.Pow((disB + disC), 2));
disBetB6desC6des = Math.Sqrt((Math.Pow(verDis, 2)) + Math.Pow((disA - disB), 2));
disBetB6C6GMD = Math.Pow(disBetB6C6 * disBetB6desC6 * disBetB6C6des * disBetB6desC6des, .25);
/*Step 3*/
double disBetC6A6 = 0;
double disBetC6A6des = 0;
double disBetC6desA6des = 0;
double disBetC6desA6 = 0;
double disBetC6A6GMD = 0;
disBetC6A6 = Math.Sqrt((Math.Pow(verDis * 2, 2)) + Math.Pow((disC - disA), 2));
disBetC6A6des = Math.Sqrt(Math.Pow((disC + disC), 2));
disBetC6desA6 = Math.Sqrt(Math.Pow((disA + disA), 2));
disBetC6desA6des = Math.Sqrt((Math.Pow(verDis * 2, 2)) + Math.Pow((disA - disC), 2));

```
disBetC6A6GMD = Math.Pow(disBetC6A6 * disBetC6desA6 * disBetC6A6des * disBetC6desA6des, .25);
/*GMD final*/
GMD6 = Math.Pow((disBetA6B6GMD * disBetB6C6GMD * disBetC6A6GMD), (1 / 3.0));
/* GMR Calculation*/
/*STEP 4*/
double disBetA6A6 = 0;
double disBetA6A6des = 0;
double disBetA6A6GMD = 0;
disBetA6A6 = value1;
disBetA6A6des = Math.Sqrt(Math.Pow(verDis * 2, 2) + Math.Pow((disA + disC), 2));
disBetA6A6GMD = Math.Sqrt(disBetA6A6 * disBetA6A6des);
/*STEP 5*/
double disBetB6B6 = 0;
double disBetB6B6des = 0;
double disBetB6B6GMD = 0;
disBetB6B6 = value1;
disBetB6B6des = Math.Sqrt(Math.Pow((disB + disB), 2));
disBetB6B6GMD = Math.Sqrt(disBetB6B6 * disBetB6B6des);
/*STEP 6*/
double disBetC6C6 = 0;
double disBetC6C6des = 0;
double disBetC6C6GMD = 0;
disBetC6C6 = value1;
disBetC6C6des = Math.Sqrt(Math.Pow(verDis * 2, 2) + Math.Pow((disA + disC), 2));
disBetC6C6GMD = Math.Sqrt(disBetC6C6 * disBetC6C6des);
```

```
GMR6 = Math.Pow((disBetA6A6GMD * disBetB6B6GMD * disBetC6C6GMD), (1
/ 3.0));
CGMR6 = Math.Pow(((Math.Sqrt(value2 * disBetA6A6des)) * (Math.Sqrt(value2 *
disBetB6B6des)) * (Math.Sqrt(value2 * disBetC6C6des))), (1 / 3.0));
/* INDUCTANCE and CAPACITANCE */
double inductance6 = 0;
inductance6 = 2000 * (Math.Pow(10, -7)) * (Math.Log(GMD6 / GMR6, Math.E));
double capacitance6 = 0;
capacitance6 = 0.05560618997 / (Math.Log(GMD6 / CGMR6, Math.E));
/*Add row to Datatable*/
dt.Rows.Add("ABC-cba", inductance6 * (Convert.ToDouble(txtTotalLength.Text)));
reportViewer1.LocalReport.DataSources.Add(new Microsoft.Reporting.WinForms.ReportDataSo
dsSource.Tables[ "Data"]));
reportViewer1.RefreshReport();
double lengthmul = 0;
if (Transpose == 0)
{
lengthmul = Totallength;
}
else
{
lengthmul = Transpose;
}
strTotalInducatnce1 = "Total Inductance (H/phase) (ABC-abc)= " + (inductance1
* Totallength).ToString();
strTotalInducatnce2 = "Total Inductance (H/phase) (ABC-acb)= " + (inductance2
* Totallength).ToString();
strTotalInducatnce3 = "Total Inductance (H/phase) (ABC-bac)= " + (inductance3
* Totallength).ToString();
```

strTotalInducatnce4 = “Total Inductance (H/phase) (ABC-cab)= ” + (inductance4 * Totallength).ToString();

strTotalInducatnce5 = “Total Inductance (H/phase) (ABC-bca)= ” + (inductance5 * Totallength).ToString();

strTotalInducatnce6 = “Total Inductance (H/phase) (ABC-cba)= ” + (inductance6 * Totallength).ToString();

strTotalCap1 = “Total Capacitance (MicroFarad/phase) (ABC-abc)= ” + (capacitance1 * lengthmul).ToString();

strTotalCap2 = “Total Capacitance (MicroFarad/phase) (ABC-acb)= ” + (capacitance2 * lengthmul).ToString();

strTotalCap3 = “Total Capacitance (MicroFarad/phase) (ABC-bac)= ” + (capacitance3 * lengthmul).ToString();

strTotalCap4 = “Total Capacitance (MicroFarad/phase) (ABC-cab)= ” + (capacitance4 * lengthmul).ToString();

strTotalCap5 = “Total Capacitance (MicroFarad/phase) (ABC-bca)= ” + (capacitance5 * lengthmul).ToString();

strTotalCap6 = “Total Capacitance (MicroFarad/phase) (ABC-cba)= ” + (capacitance6 * lengthmul).ToString();

//start loop here...

for (int strLoop = 6; strLoop >= 1; strLoop- -)

{

//Based on loop value set double inductanceToUse = 0;

double capacitanceToUse = 0;

if (strLoop == 6)

{

inductanceToUse = inductance6;

capacitanceToUse = capacitance6;

}

else if (strLoop == 5)

```
{
inductanceToUse = inductance5;
capacitanceToUse = capacitance5;
}
else if (strLoop == 4)
{
inductanceToUse = inductance4;
capacitanceToUse = capacitance4;
}
else if (strLoop == 3)
{
inductanceToUse = inductance3;
capacitanceToUse = capacitance3;
}
else if (strLoop == 2)
{
inductanceToUse = inductance2;
capacitanceToUse = capacitance2;
}
else if (strLoop == 1)
{
inductanceToUse = inductance1;
capacitanceToUse = capacitance1;
}
//Reset notification
lblNotification.Text = “”;
sbNotification = new StringBuilder(string.Empty);
lblinductance.Text = “Total Inductance = ” + (inductanceToUse * lengthmul).ToString()
+ “(H / phase)”;
```

```
dtLnc.Rows[strLoop][1] = lblinductance.Text;
lblcapacitance.Text = "Total Capacitance = " + (capacitanceToUse * lengthmul).ToString()
+ "(MicroFarad / phase)";
dtLnc.Rows[strLoop][2] = lblcapacitance.Text;
double GMDsc = 0; // Single ckt GMD for CL
double GMRCsc = 0; //Single ckt GMR for capacitance (SIL)
double GMRLsc = 0; //Single ckt GMR for inductance (SIL)
double L = 0;
double Cap = 0;
double SurgeImpedance = 0;
double SIL = 0;
double resistance = Convert.ToDouble(txtResistance.Text);
double numofsubcond = Convert.ToDouble(txtBundle.Text);
double Ampacity = Convert.ToDouble(txtAmpacity.Text) * numofsubcond ;
double Freq = Convert.ToDouble(txtFreq.Text);
double Circuitnum = Convert.ToDouble(txtckt.Text);
double Vs = Convert.ToDouble(txtVolt.Text);
double Pf = Convert.ToDouble(txtPf.Text); double Psmw = Convert.ToDouble((((Math.Sqrt(3))
* Ampacity * Vs * Pf * Convert.ToDouble(txtPercentageload.Text)) / 100000000));
double Psmva = Psmw / Pf;
double Totalresistance = 0;
double Totalreactance = 0;
double Admittance = 0;
double Vse = 0; // Sending end voltage
double Ise = 0; // Sending end current
double Isemag = 0; // Sending end current magnitude
double Iseang = 0; // Sending end current angle
double Isereal = 0; // Sending end current real part
double Iseimg = 0; // Sending end current imaginary part
```

```
double Vremag = 0; // Voltage magnitude (Receiving end)
double Vreang = 0; // Voltage angle(Receiving end)
double V0 = 0; // Noload Voltage
double Iremag = 0; // Current magnitude(Receiving end)
double Ireang = 0; // Current angle(Receiving end)
double PFre = 0; // Power Factor (Receiving end)
double Pre = 0; // Power (Receiving end)
double VoltageReg = 0; // Voltage regulation
Totalresistance = (resistance * Totallength / (numofsubcond * Circuitnum));
Totalreactance = (2 * Math.PI * Freq * inductanceToUse * lengthmul);
Complex Z = new Complex(Totalresistance, Totalreactance); //Impedance
lblimpedance.Text="Total Impedance = " + (Z).ToString() + "(Ohm)";
dtLnc.Rows[strLoop][3] = lblimpedance.Text;
GMDsc = Math.Pow(disBetAB * disBetBC * disBetCA, (1 / 3.0)); //change as per
combination
GMRLsc = value1;
GMRCsc = value2;
L = 2000 * (Math.Pow(10, -7)) * (Math.Log(GMDsc / GMRLsc, Math.E))*Totallength;
Cap = 0.05560618997 / (Math.Log(GMDsc / GMRCsc, Math.E)) * Totallength ;
SurgeImpedance = Math.Sqrt(L / (Cap*(Math.Pow(10,(-6)))));
lblsurgeImpedance.Text = "Surge Impedance = " + (SurgeImpedance).ToString() +
"( Ohm)";
dtLnc.Rows[strLoop][4] = lblsurgeImpedance.Text;
SIL = Math.Pow((Vs/1000),2) / SurgeImpedance;
lblSIL.Text = "SIL = " + (SIL).ToString() + "(MW)";
dtLnc.Rows[strLoop][5] = lblSIL.Text;
Admittance = (2 * Math.PI * Freq * capacitanceToUse * lengthmul * Math.Pow(10,
(-6)));
Complex Y = new Complex(0, Admittance);
```

```
Complex Z_c = Complex.Sqrt(Z / Y);
Complex invZ_c = Complex.Divide(1, Z_c);
Complex ZY = Complex.Multiply(Z, Y);
Complex rl = Complex.Sqrt(ZY);
Complex A = Complex.Cosh(rl);
Complex B = Complex.Multiply(Z_c, (Complex.Sinh(rl)));
Complex C = Complex.Multiply(invZ_c, (Complex.Sinh(rl)));
Vse = Vs / (Math.Sqrt(3));
Ise = (Psmva * 1000000) / (Vs * Math.Sqrt(3));
Isemag = Ise;
Iseang = -1 * Math.Acos(Pf) * (180 / Math.PI);
Isereal = Isemag * (Math.Cos(Iseang * Math.PI / 180));
Iseimg = Isemag * (Math.Sin(Iseang * Math.PI / 180));
Complex Iserect = new Complex(Isereal, Iseimg);
Complex Vre = Complex.Divide((Complex.Subtract((Complex.Multiply((A), (Vse))),
(Complex.Multiply((B), (Iserect))))), (Complex.Subtract((Complex.Multiply((A), (A))),
(Complex.Multiply((B), (C))))));
Vremag = Complex.Abs(Vre);
Vreang = Complex.Arg(Vre) * (180 / Math.PI);
lblVre.Text = “Recieving End Voltage = (Magnitude):” + (Vremag).ToString() +
“(V)”;
dtLnc.Rows[strLoop][6] = lblVre.Text;
lblvoltang.Text= “(Angle):” + (Vreang).ToString();
dtLnc.Rows[strLoop][7] = lblvoltang.Text;
V0 = Vse / Complex.Abs(A);
Complex Ire = Complex.Divide((Complex.Subtract((Vse), (Complex.Multiply((A),
(Vre))))), (B));
Iremag = Complex.Abs(Ire);
Ireang = Complex.Arg(Ire) * (180 / Math.PI);
```

```
lblIre.Text = "Recieving End Current = (Magnitude):" + (Iremag).ToString() +
"(A)";
dtLnc.Rows[strLoop][8] = lblIre.Text;
lblcurrentangle.Text = "(Angle):" + (Ireang).ToString();
dtLnc.Rows[strLoop][9] = lblcurrentangle.Text;
PFre = Math.Cos((Vreang - Ireang) * (Math.PI / 180));
Pre = (3 * Vremag * Iremag * PFre) / 1000000;
lblPre.Text = "Recieving End Power = " + (Pre).ToString() + "(MW)";
dtLnc.Rows[strLoop][10] = lblPre.Text;
VoltageReg = ((V0 - Vremag) / Vremag) * 100;
lblvoltagereg.Text = "Voltage Regulation = " + (VoltageReg).ToString() + "(%)";
dtLnc.Rows[strLoop][11] = lblvoltagereg.Text;
// end —loop here...
/* Corona Loss calculation */
double delta = 0;
double V_d = 0;
double ratioVV_d = 0;
double F = 0; // Lookup table
double Pcl = 0; // Power loss due to corona
double TotFWCL = 0; // Total Fair weather coronal loss
double PclRW = 0; // Power loss due to corona
double Rainrate = 5; // Rain rate in mm/hr
double J = 0;
double WettingCoeff = 10; // Wetting coefficient=10 if rain rate is in mm/hr
double TotRWCL = 0; // Total rainy weather corona loss
double TotLineloss = 0; //Total I2R loss
double PerLineloss = 0; //Percentage line loss
double EfficFW = 0; //Efficiency of transmission
double EfficRW = 0; //Efficiency under heavy rain
```

```
//Audible noise
double wholeCondRad = 0;
double Req = 0;
double height = Convert.ToDouble(txtHeight.Text);
double horzDist = Convert.ToDouble(txtHordist.Text);
double diameter = Convert.ToDouble(txtDiameter.Text);
double spacing = 0;
double Eom = 0;
double Ecm = 0;
wholeCondRad = (bundlespace * 0.001) / (2 * Math.Sin((Math.PI) / numofsub-
cond));
Req = Math.Pow(numofsubcond * radius * 0.001 * Math.Pow( wholeCondRad , (nu-
mofsubcond - 1)) , (1 / numofsubcond));
//spacing = minimun value(disBetAB, disBetBC, disBetCA);
double minDis = 0;
if (disBetAB < disBetBC)
{
if (disBetAB < disBetCA)
{
minDis = disBetAB;
}
else
{
minDis = disBetCA;
}
}
else
{
if (disBetBC < disBetCA)
```

```
{
minDis = disBetBC;
}
else
{
minDis = disBetCA;
}
}
spacing = minDis * 0.001;
Eom = ((1 + (numofsubcond - 1) * (radius * 0.001 / wholeCondRad)) / (numofsub-
cond * (radius * 0.001) * Math.Log(((2 * height) / (Req)) * (1 / (Math.Pow(((1 +
Math.Pow((2 * height / spacing), 2)) * (1 + Math.Pow((height / spacing), 2))), (1 /
4.0)))), Math.E))) * (Vs / (Math.Sqrt(3) * 1000)) * 0.01;
Ecm = ((1 + (numofsubcond - 1) * (radius * 0.001 / wholeCondRad)) / (numofsub-
cond * (radius * 0.001) * Math.Log(((2 * height) / (Req)) * (1 / (Math.Pow((1 +
Math.Pow((2 * height / spacing), 2)), (1 / 2.0)))), Math.E))) * (Vs / (Math.Sqrt(3)
* 1000)) * 0.01;
lblvgradientout.Text = "Voltage Gradient (Outer) = " + (Eom).ToString() + "(KV/cm)";
//Change Color
if (Eom > 20)
{
this.lblvgradientout.ForeColor = System.Drawing.Color.Red;
//Add notification here
sbNotification.AppendLine("Voltage Gradient (Outer) should be less than 20(KV/cm)");
}
else
{
this.lblvgradientout.ForeColor = System.Drawing.Color.Black;
}
```

```
lblvgradientcenter.Text = "Voltage Gradient (center) = " + (Ecm).ToString() +
"(KV/cm)";
//Change Color
if (Ecm > 20)
{
this.lblvgradientcenter.ForeColor = System.Drawing.Color.Red;
sbNotification.AppendLine("Voltage Gradient (center) should be less than 20(KV/cm)");
}
else
{
this.lblvgradientcenter.ForeColor = System.Drawing.Color.Black;
}

    delta = (3.86 * (Convert.ToDouble(txtPressure.Text))) / (273 + (Convert.ToDouble(txtTemp.
V_d = ((3 * 1000000) / (Math.Sqrt(2))) * ((numofsubcond * radius * 0.001) * delta *
(Convert.ToDouble(txtSurfaceFactor.Text)) * Math.Log(((GMDsc) / (value2)), Math.E));
ratioVV_d = Vse / V_d; F = 0.0515; // lookup table
Pcl = (21 * (Math.Pow(10, -6)) * Freq * Math.Pow((Vse * 0.001), 2) * F) / (Math.Pow(Math.Log1
/ value2), 2));
TotFWCL = 3 * Pcl * Totallength;
lblFWCL.Text = "Corona Loss (under Fair Weather) = " + (TotFWCL).ToString()
+ "(KW)";
if (Vs < 499000)
{
J = 4.37 * Math.Pow(10, (-10));
}
else
{
J = 3.32 * Math.Pow(10, (-10));
```

```
}
PclRW = (3 * Pcl) + (Vse * 0.001 * J * Math.Pow((radius * 0.1), 2) * Math.Log((1 +
WettingCoeff * (Rainrate)), Math.E)) * numofsubcond * (Math.Pow((Eom * Math.Sqrt(2)),
5) + Math.Pow((Math.Sqrt(2) * Ecm), 5) + Math.Pow((Math.Sqrt(2) * Eom), 5));
TotRWCL = PclRW * Totallength;
lblRWCL.Text = "Corona Loss (under Rainy Weather) = " + (TotRWCL).ToString()
+ "(KW)";
TotLineloss = (3 * Math.Pow((Ampacity / (numofsubcond * 2)), 2) * (resistance *
Totallength) * (numofsubcond * 2) * 0.001);
lbllineloss.Text="Total Line loss = " + (TotLineloss).ToString() + "(KW)";
PerLineloss = (TotLineloss / (Psmw * 1000)) * 100;
lblpercentagelineloss.Text= "Percentage Line loss = " + ( PerLineloss ).ToString()
+ "(%)";
EfficFW = (Pre * 1000) / ((Pre * 1000) + (TotFWCL * 2) + TotLineloss) * 100;
lblefficiencyFW.Text="Efficiency (under Fair Weather) = " + (EfficFW).ToString()
+ "(%)";
EfficRW = (Pre * 1000) / ((Pre * 1000) + (TotRWCL * 2) + TotLineloss) * 100;
lblefficiencyRW.Text="Efficiency (under Rainy Weather) = " + (EfficRW).ToString()
+ "(%)";
/*Audible Noise*/
double Kn = 0;
double ANofA = 0;
double ANofB = 0;
double ANofC = 0;
double ANofa = 0;
double ANofb = 0;
double ANofc = 0;
double AudNoise = 0;
/*Kn= (If numofsubcond =1;7.5 or numofsubcond =2;2.6 else n=>3;0)*/
```

```
if (numofsubcond < 3)
{
if (numofsubcond == 1)
{
Kn = 7.5;
}
else
{
Kn = 2.6;
}
}
else
{
Kn = 0;
}
if (numofsubcond < 3)
{
ANofA = 20 * Math.Log10(numofsubcond) + 44 * Math.Log10(diameter * 0.1) - (665 / Eom) + Kn + 75.2 - 10 * Math.Log10(Math.Sqrt(Math.Pow((height + (2 * verDis * 0.001)), 2) + Math.Pow((horzDist + ((disC - disA) * 0.001)), 2))) - 0.02 * (Math.Sqrt(Math.Pow((height + (2 * verDis * 0.001)), 2) + Math.Pow((horzDist + ((disC - disA) * 0.001)), 2)));
ANofB = 20 * Math.Log10(numofsubcond) + 44 * Math.Log10(diameter * 0.1) - (665 / Ecm) + Kn + 75.2 - 10 * Math.Log10(Math.Sqrt(Math.Pow((height + (verDis * 0.001)), 2) + Math.Pow((horzDist + ((disC - disB) * 0.001)), 2))) - 0.02 * (Math.Sqrt(Math.Pow((height + (verDis * 0.001)), 2) + Math.Pow((horzDist + ((disC - disB) * 0.001)), 2)));
ANofC = 20 * Math.Log10(numofsubcond) + 44 * Math.Log10(diameter * 0.1) - (665 / Eom) + Kn + 75.2 - 10 * Math.Log10(Math.Sqrt(Math.Pow(height, 2) +
```

Math.Pow(horzDist, 2))) - 0.02 * (Math.Sqrt(Math.Pow(height, 2) + Math.Pow(horzDist, 2)));

ANofa = 20 * Math.Log10(numofsubcond) + 44 * Math.Log10(diameter * 0.1) - (665 / Eom) + Kn + 75.2 - 10 * Math.Log10(Math.Sqrt(Math.Pow((height + (2 * verDis * 0.001)), 2) + Math.Pow((horzDist + (2 * disA * 0.001) + ((disC - disA) * 0.001)), 2))) - 0.02 * (Math.Sqrt(Math.Pow((height + (2 * verDis * 0.001)), 2) + Math.Pow((horzDist + (2 * disA * 0.001) + ((disC - disA) * 0.001)), 2)));

ANofb = 20 * Math.Log10(numofsubcond) + 44 * Math.Log10(diameter * 0.1) - (665 / Ecm) + Kn + 75.2 - 10 * Math.Log10(Math.Sqrt(Math.Pow((height + (verDis * 0.001)), 2) + Math.Pow((horzDist + (2 * disB * 0.001) + ((disC - disB) * 0.001)), 2))) - 0.02 * (Math.Sqrt(Math.Pow((height + (verDis * 0.001)), 2) + Math.Pow((horzDist + (2 * disB * 0.001) + ((disC - disB) * 0.001)), 2)));

ANofc = 20 * Math.Log10(numofsubcond) + 44 * Math.Log10(diameter * 0.1) - (665 / Eom) + Kn + 75.2 - 10 * Math.Log10(Math.Sqrt(Math.Pow(height, 2) + Math.Pow((horzDist + (2 * disC * 0.001)), 2))) - 0.02 * (Math.Sqrt(Math.Pow(height, 2) + Math.Pow((horzDist + (2 * disC * 0.001)), 2)));

}

else

{

ANofA = 20 * Math.Log10(numofsubcond) + 44 * Math.Log10(diameter * 0.1) - (665 / Eom) + (22.9 * (numofsubcond - 1) * ((diameter * 0.1) / (wholeCondRad * 2 * 100))) + 67.9 - 10 * Math.Log10(Math.Sqrt(Math.Pow((height + (2 * verDis * 0.001)), 2) + Math.Pow((horzDist + ((disC - disA) * 0.001)), 2))) - 0.02 * (Math.Sqrt(Math.Pow((height + (2 * verDis * 0.001)), 2) + Math.Pow((horzDist + ((disC - disA) * 0.001)), 2)));

ANofB = 20 * Math.Log10(numofsubcond) + 44 * Math.Log10(diameter * 0.1) - (665 / Ecm) + (22.9 * (numofsubcond - 1) * ((diameter * 0.1) / (wholeCondRad * 2 * 100))) + 67.9 - 10 * Math.Log10(Math.Sqrt(Math.Pow((height + (verDis * 0.001)), 2) + Math.Pow((horzDist + ((disC - disB) * 0.001)), 2))) - 0.02 * (Math.Sqrt(Math.Pow((height

```
+ (verDis * 0.001)), 2) + Math.Pow((horzDist + ((disC - disB) * 0.001)), 2)));
ANofC = 20 * Math.Log10(numofsubcond) + 44 * Math.Log10(diameter * 0.1)
- (665 / Eom) + (22.9 * (numofsubcond - 1) * ((diameter * 0.1) / (wholeCon-
dRad * 2 * 100))) + 67.9 - 10 * Math.Log10(Math.Sqrt(Math.Pow(height, 2) +
Math.Pow(horzDist, 2))) - 0.02 * (Math.Sqrt(Math.Pow(height, 2) + Math.Pow(horzDist,
2)));
ANofa = 20 * Math.Log10(numofsubcond) + 44 * Math.Log10(diameter * 0.1) -
(665 / Eom) + (22.9 * (numofsubcond - 1) * ((diameter * 0.1) / (wholeCondRad *
2 * 100))) + 67.9 - 10 * Math.Log10(Math.Sqrt(Math.Pow((height + (2 * verDis *
0.001)), 2) + Math.Pow((horzDist + (2 * disA * 0.001) + ((disC - disA) * 0.001)), 2)))
- 0.02 * (Math.Sqrt(Math.Pow((height + (2 * verDis * 0.001)), 2) + Math.Pow((horzDist
+ (2 * disA * 0.001) + ((disC - disA) * 0.001)), 2)));
ANofb = 20 * Math.Log10(numofsubcond) + 44 * Math.Log10(diameter * 0.1) - (665
/ Ecm) + (22.9 * (numofsubcond - 1) * ((diameter * 0.1) / (wholeCondRad * 2 *
100))) + 67.9 - 10 * Math.Log10(Math.Sqrt(Math.Pow((height + (verDis * 0.001)),
2) + Math.Pow((horzDist + (2 * disB * 0.001) + ((disC - disB) * 0.001)), 2))) - 0.02
* (Math.Sqrt(Math.Pow((height + (verDis * 0.001)), 2) + Math.Pow((horzDist + (2
* disB * 0.001) + ((disC - disB) * 0.001)), 2)));
ANofc = 20 * Math.Log10(numofsubcond) + 44 * Math.Log10(diameter * 0.1) - (665
/ Eom) + (22.9 * (numofsubcond - 1) * ((diameter * 0.1) / (wholeCondRad * 2 *
100))) + 67.9 - 10 * Math.Log10(Math.Sqrt(Math.Pow(height, 2) + Math.Pow((horzDist
+ (2 * disC * 0.001)), 2))) - 0.02 * (Math.Sqrt(Math.Pow(height, 2) + Math.Pow((horzDist
+ (2 * disC * 0.001)), 2)));
}
AudNoise = 10 * Math.Log10(Math.Pow(10, (0.1 * ANofA)) + Math.Pow(10, (0.1
* ANofB)) + Math.Pow(10, (0.1 * ANofC)) + Math.Pow(10, (0.1 * ANofa)) +
Math.Pow(10, (0.1 * ANofb)) + Math.Pow(10, (0.1 * ANofc)));
lblan.Text= “Audible Noise = ” + (AudNoise).ToString() + “(dB)”;
//Change Color
```

```
if (AudNoise > 60)
{
this.lblan.ForeColor = System.Drawing.Color.Red;
sbNotification.AppendLine("Audible Noise should be less than 60(dB)");
}
else
{
this.lblan.ForeColor = System.Drawing.Color.Black;
}
/*Radio Interference*/
double RIofA = 0;
double RIofB = 0;
double RIofC = 0;
double RIofa = 0;
double RIofb = 0;
double RIofc = 0;
double RIAphase = 0;
double RIBphase = 0;
double RICphase = 0;
double high = 0;
double higher = 0;
double highest = 0;
double RadioInterference = 0;
RIofA = 3.5 * (Eom) + 6 * (diameter * 0.1) - 33 * Math.Log10(Math.Sqrt(Math.Pow((height
+ (2 * verDis * 0.001)), 2) + Math.Pow((horzDist + ((disC - disA) * 0.001)), 2)) /
20) - 30;
RIofB = 3.5 * (Ecm) + 6 * (diameter * 0.1) - 33 * Math.Log10(Math.Sqrt(Math.Pow((height
+ (verDis * 0.001)), 2) + Math.Pow((horzDist + ((disC - disB) * 0.001)), 2)) / 20)
- 30;
```

```
RIofC = 3.5 * (Eom) + 6 * (diameter * 0.1) - 33 * Math.Log10(Math.Sqrt(Math.Pow(height,
2) + Math.Pow(horzDist, 2)) / 20) - 30;
RIofa = 3.5 * (Eom) + 6 * (diameter * 0.1) - 33 * Math.Log10(Math.Sqrt(Math.Pow((height
+ (2 * verDis * 0.001)), 2) + Math.Pow((horzDist + (2 * disA * 0.001) + ((disC -
disA) * 0.001)), 2)) / 20) - 30;
RIofb = 3.5 * (Ecm) + 6 * (diameter * 0.1) - 33 * Math.Log10(Math.Sqrt(Math.Pow((height
+ (verDis * 0.001)), 2) + Math.Pow((horzDist + (2 * disB * 0.001) + ((disC - disB)
* 0.001)), 2)) / 20) - 30;
RIofc = 3.5 * (Eom) + 6 * (diameter * 0.1) - 33 * Math.Log10(Math.Sqrt(Math.Pow(height,
2) + Math.Pow((horzDist + (2 * disC * 0.001)), 2)) / 20) - 30;
RIAphase = 20 * Math.Log10(Math.Sqrt(Math.Pow((Math.Pow(10, (RIofA / 20))),
2) + Math.Pow((Math.Pow(10, (RIofa / 20))), 2)));
RIBphase = 20 * Math.Log10(Math.Sqrt(Math.Pow((Math.Pow(10, (RIofB / 20))),
2) + Math.Pow((Math.Pow(10, (RIofb / 20))), 2)));
RICphase = 20 * Math.Log10(Math.Sqrt(Math.Pow((Math.Pow(10, (RIofC / 20))),
2) + Math.Pow((Math.Pow(10, (RIofc / 20))), 2)));
/* find the difference between RIAphase RIBphase and RICphase; if any1 phase is
>3 as compared to other two phases then cosider the highest value else tak avg of
two highest value n add 1.5 */
if ((RIAphase > RIBphase) && (RIBphase > RICphase))
{
highest = RIAphase;
higher = RIBphase;
high = RICphase;
}
else if ((RIAphase > RICphase) && (RICphase > RIBphase))
{
highest = RIAphase;
higher = RICphase;
```

```
high = RIBphase;
}
else if ((RIBphase > RIAphase) && (RIAphase > RICphase))
{
highest = RIBphase;
higher = RIAphase;
high = RICphase;
}
else if ((RIBphase > RICphase) && (RICphase > RIAphase))
{
highest = RIBphase;
higher = RICphase;
high = RIAphase;
}
else if ((RICphase > RIAphase) && (RIAphase > RIBphase))
{
highest = RICphase;
higher = RIAphase;
high = RIBphase;
}
else if ((RICphase > RIBphase) && (RIBphase > RIAphase))
{
highest = RICphase;
higher = RIBphase;
high = RIAphase;
}
if (highest > (3 + higher))
{
RadioInterference = highest;
```

```
}
else
{
RadioInterference = (highest + higher) / 2 + 1.5;
}
lblri.Text= “Radio Interference = ” + (RadioInterference).ToString() + “(dB)”;
//Change Color
if (RadioInterference ¿ 50)
{
this.lblri.ForeColor = System.Drawing.Color.Red;
sbNotification.AppendLine(“Radio Interference should be less than 50(dB)”);
}
else
{
this.lblri.ForeColor = System.Drawing.Color.Black;
}
lblNotification.Text = sbNotification.ToString(); }
}
private void frmInductanceCal_Load(object sender, EventArgs e)
{
lblNotification.Text = ””;
if (txtDiameter.Text != string.Empty)
{ txtRadius.Text = Convert.ToString((Convert.ToDouble(txtDiameter.Text) / 2));
}
reportViewer1.LocalReport.ReportEmbeddedResource = ”Project.Graph.rdlc”;
this.reportViewer1.RefreshReport();
}
private void txtAmpacity_Leave_1(object sender, EventArgs e)
{
```

```
if (txtAmpacity.Text != string.Empty)
{
Double powermw = Convert.ToDouble((((Math.Sqrt(3)) * Convert.ToDouble(txtAmpacity.Text)
* Convert.ToDouble(txtVolt.Text) * Convert.ToDouble(txtPf.Text) * Convert.ToDouble(txtBund
* Convert.ToDouble (txtPercentageload.Text)) / 100000000));
txtPowermw.Text = Convert.ToString(powermw);
if (txtPowermw.Text != string.Empty)
{
txtPowermva.Text = Convert.ToString((Convert.ToDouble(txtPowermw.Text)) / (Con-
vert.ToDouble(txtPf.Text)));
}
}
}
private void button1_Click(object sender, EventArgs e)
{
frmLnC fromObj = new frmLnC(ref dtLnC );
fromObj.ShowDialog();
}
}
}
```

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