# "Computer Aided Design, Analysis and Comparison of Various Configurations of U.H.V. Transmission Line"

Major Project Report

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

## MASTER OF TECHNOLOGY

**IN**

## ELECTRICAL ENGINEERING

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**By**


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# CERTIFICATE

This is to certify that the Major Project Report entitled "Computer Aided Design, Analysis and Comparison of Various Configurations of U.H.V. Transmission Line" submitted by Mr. Snehalkumar Rajendrakumar Patel (11MEEE51) 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 him/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.

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## Annexure VI
## Undertaking for Originality of the Work

I am Snehalkumar Rajendrakumar Patel, Roll No 11MEEE51, give undertaking that the Major Project entitled "Computer Aided Design, Analysis and Comparison of Various Configurations of U.H.V. Transmission Line" submitted by me, towards the partial fulfillment of the requirements for the degree of Master of Technology in (Electrical Engineering) in the field of Electrical Power Systems 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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# ABSTRACT

The manual method of transmission line design involves tedious calculation and relies 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 UHV 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. The system should have high efficiency, good voltage regulation, less Radio interference, Television interference and Audible noise. By using high order bundled conductor, the corona loss, Audible noise, Radio interference is reduced.

This Project will provide an insight into design of UHV transmission line. Almost all the electrical calculation will discuss which will require for UHV transmission line design. These calculations will require for selection of appropriate conductor for power transmission, at ultra-high voltage level. A VB+ based software will be developed so as to calculate all electrical parameter required for transmission line design by providing required parameters. Programming will be developed for single circuit transmission line, including up to eight sub-conductor in a bundle.

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# Chapter 1

## 1.1 Introduction

Power is generated in power station at rated voltage (usually 11K V /13.6K V /15K V ) 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 arrangements of power generation, transmission and distribution**

Advantages of UHV-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 UHV-AC Transmission Line

- Necessitate high insulation level and the cost of insulation increases.
- Large clearance is required between conductors to ground, phase to phase.
- Corona loss and its effects RI, AN.
- Cost of tower support and foundations is enormous.
- Cost of switchgear equipment, protective equipment and transformer increases.
- Right of way problem is predominant.
- Ferranti effect comes into picture.
- UHV is dangerous for all forms of life.

## 1.2 Objective of project

Design of 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 program will be developed using Vb+, that will en- able the designer to obtain the most economical and reliable design without rigorous manual calculations. Designer will have flexibility to find the optimum solution, de- pending upon the specification and site conditions.

## 1.3 Problem Identification & Project Planning

### 1.3.1 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 multi-circuit.

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 reduce 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.

### 1.3.2 Project Planning

# 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:

66K V, 110K V, 132K V, 220K V, 345K V, 400K V, 500K V, 765K V, 1000K V, 1200K V

### 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 UHV 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 Conduc- tor 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 Sup- ported). 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 over- head transmission line. Corona loss decreases with increase in number of sub- conductors in a bundle. Mostly twin, quad, hexa and octa bundle conductors are used in UHV 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 UHV 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 UHVAC 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 resistances, 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. This calculation includes calculation of power loss due to joule effect, Radiated heat loss, Convection heat loss, and 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 parameters 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 were within standard limits. Thus same calculation procedure can be employed for any double circuit UHV 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 sub conductor) 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

1000kV Jindongnan-Nanyang-Jingmen UHV AC Pilot Project starts at Changzhi substation in southeastern Shanxi province, passes through Nanyang switching station in Henan province and ends at Jingmen substation in Hubei province. The single circuit stretches 640 kilometers, crossing Yellow River and the Han River. It has transforming capacity of 6000MVA, with a nominal voltage of 1000kV and the highest operation voltage of 1100 kV.

The Project was approved by the National Development and Reform Commission in August 2006 and started construction by the end of the same year. It was completed in November 2008, put into trial operation after tested on November 30th and was put into operation after 168 hours of trial run at 10 pm, January 6st, 2009. The Project is in stable operation currently.

The Project was completed according to schedule and achieved all its prospective goals, without any incident during the construction, which was environmental-friendly. Built within a reasonable budget, the Project made many technological innovations and has a guaranteed quality. It marked a breakthrough in domestic equipment research and production.

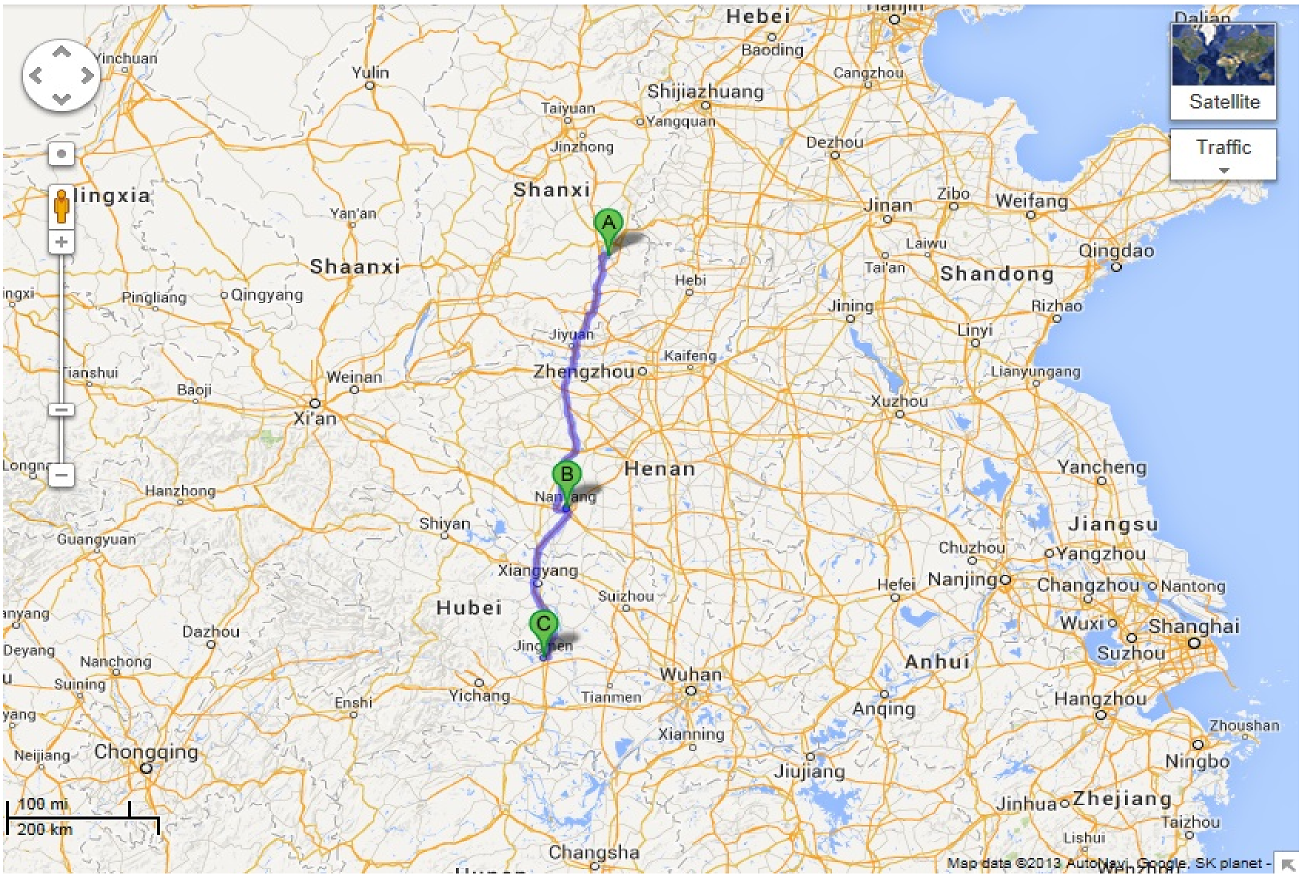



**Figure 2 Jindongnan-Nanyang-Jingmen UHV AC**

Since its preparation at the end of 2004, it only took four years to build this project which is currently the highest voltage and the most advanced technological level in operation in the world, with fully independent intellectual property rights owned by China. It represents a major breakthrough in China's long-distance, large-capacity, low-cost UHV power transmission core technology and the domestic production of power transmission equipments. It is a world-class accomplishment in the field of energy research and construction and a milestone in the world's history of electricity development. The successful completion of the Project has a significance meaning to the nation's energy safety and reliable power supply.

Through the project's practice, China has established a first-class UHV research system, mastered the core technology and formed a set of standards on UHV AC power transmission. The Project has also upgraded the manufacture industry of power facilities, trained and nurtured a team of technological and managing experts and validated the technical feasibility, equipment reliability, system safety and environmental friendliness in the UHV AC transmission. China is ready for the mass application of UHV AC power transmission.

# 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. ($\Omega$/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 ($\Omega$/m)

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

$\alpha$: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)

$\mu$: 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)

$\gamma$: 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.

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

$\lambda$: 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**

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

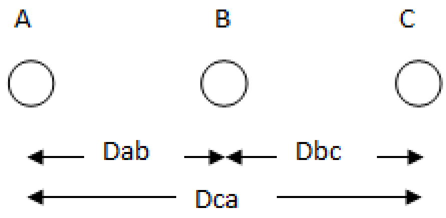



Figure 4.1: Single circuit horizontal configuration

**Double circuit**

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

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

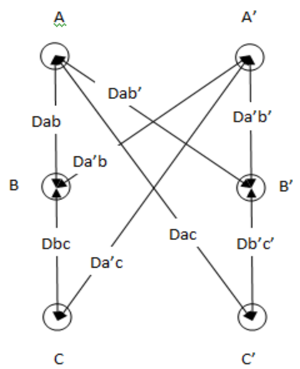



Figure 4.2: Double Circuit vertical configuration

### 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**

$GMR = 0.7788 * r = r'$

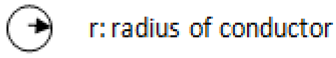



Figure 4.3: GMR of single conductor configuration

**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**

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

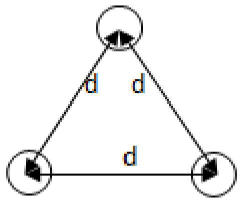



Figure 4.5: GMR of triple conductor configuration

### Quad conductor configuration

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

Here,

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

$\quad = \sqrt{2}d$

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

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

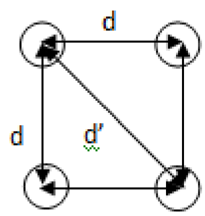



Figure 4.6: GMR of quad conductor configuration

### Hexa conductor configuration

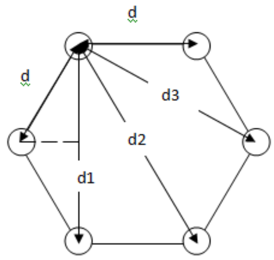



Figure 4.7: GMR of hexa conductor configuration

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

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,

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

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

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

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

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

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

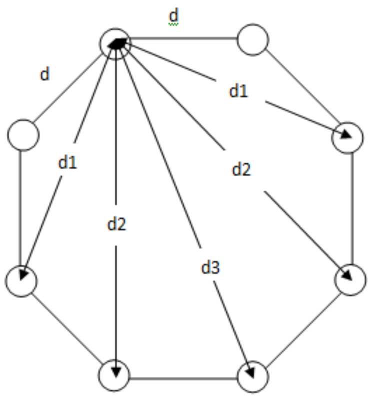



Figure 4.8: GMR of octa conductor configuration

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 ($\Omega$)
R: AC resistance of line ($\Omega$)
X: Reactance of line ($\Omega$)
$R_t$: AC Resistance of line at t2 $^0$C ($\Omega/Km$)
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 ($\mu$F/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:

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

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

$|V_r|_{noload}$: 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]:

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

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

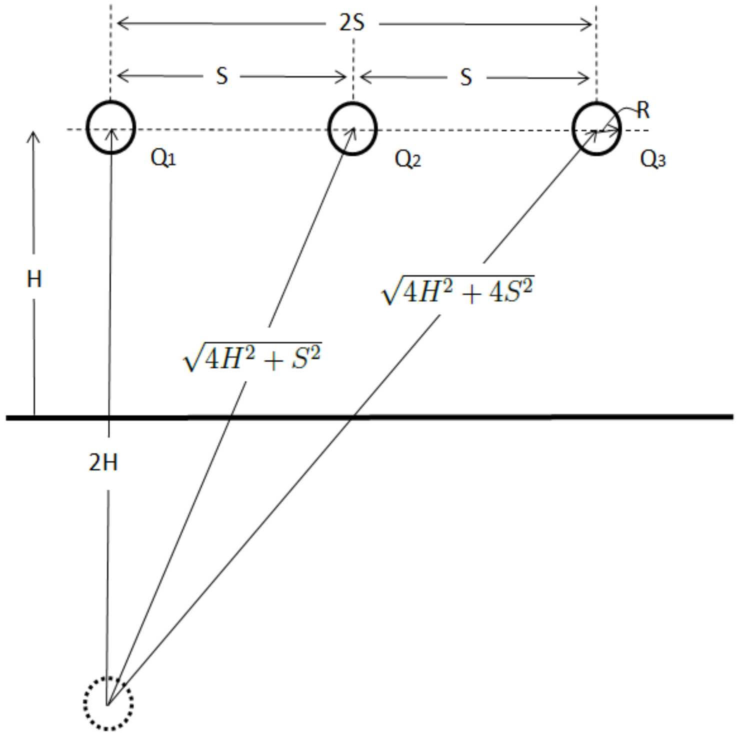
$V_3 = P_{31} * \frac{Q_1}{2*\Pi*e_0} + P_{32} * \frac{Q_2}{2*\Pi*e_0} + P_{33} * \frac{Q_3}{2*\Pi*e_0}$

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:

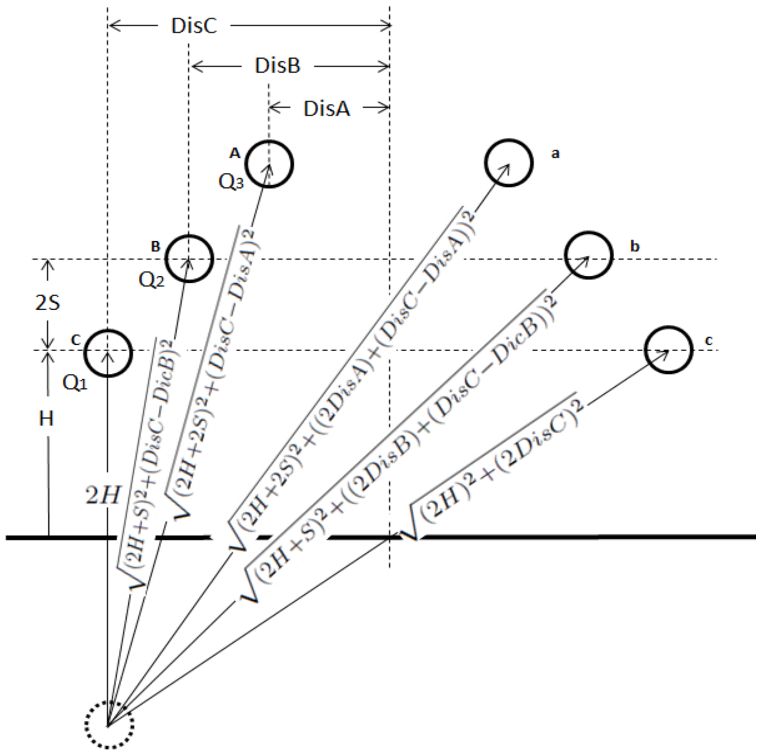
**(i)** Maximum outer surface voltage gradient

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

**(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

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

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

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

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

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

**(ii)** Maximum B phase surface voltage gradient

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

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

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

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

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

**(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 $\rho$ in mm/hr)

$\rho$= 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]:

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

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

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] :

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

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:

$$RI(dB) = (averageofthetwohighest + 1.5) \tag{4.23}$$

## 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)

$\alpha$: 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 UHV transmission line design.

### 5.2 VB+

In modern engineering work, computer programming is used for developing software. Some of the software languages are C, C++, C#, Visual Basic, MATLAB. VB+ is an object oriented and component oriented programming. For electrical calculation of UHV transmission line, UHV with dot net framework 4.5.1 (Visual Studio 2012) is chosen to develop program. Program is a 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 options. It shows option for Current capacity calculation, Indictor and Capacitor calculation and Single circuit horizontal configuration.

## 5.4 Ampacity Calculation

Ampacity calculations are done by given blow Sun-screen. A typical screen of program is shown in Fig 5.2.

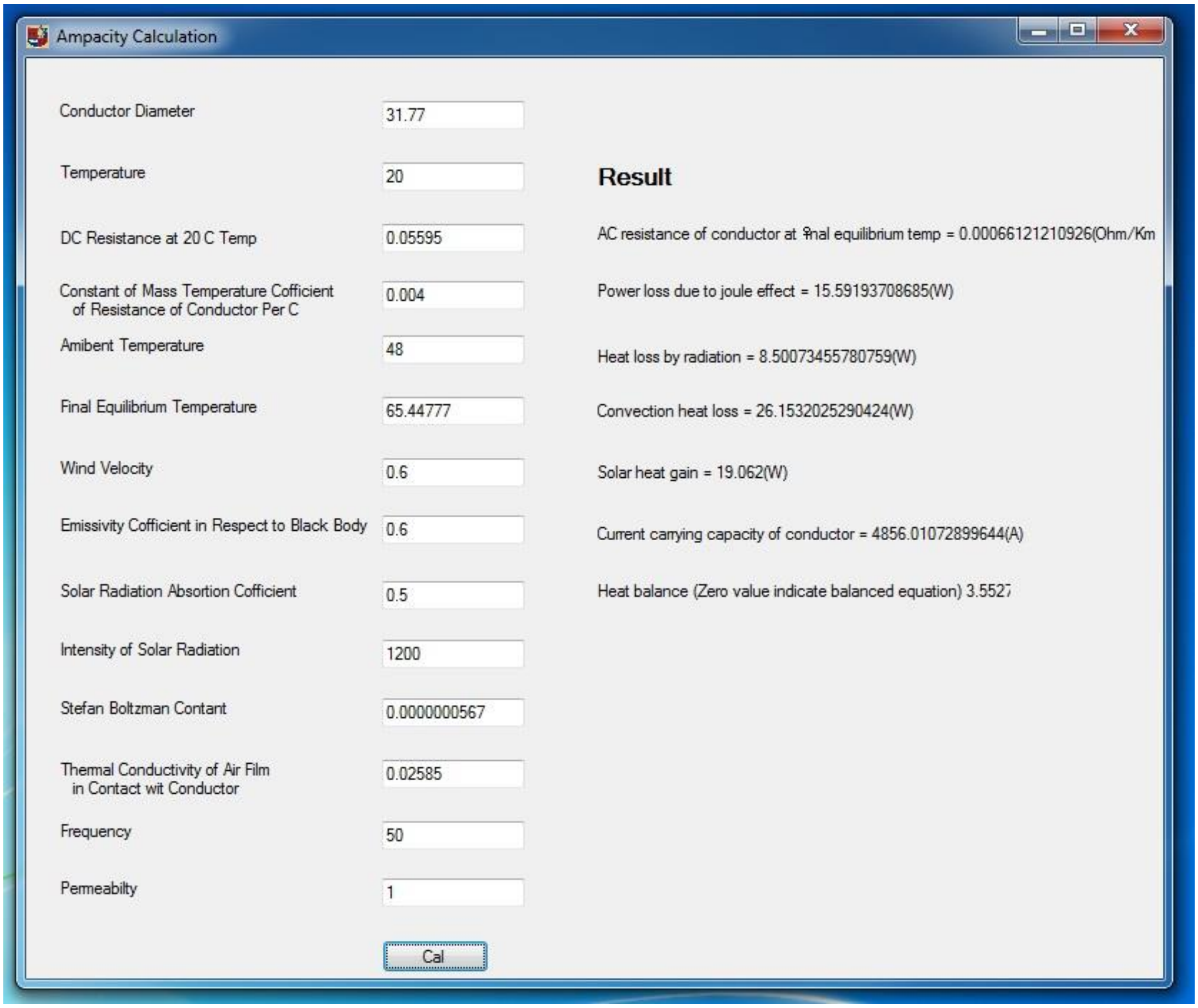



**Figure 3 Screen for Ampacity calculation**

### 5.4.1 Flowchart for Ampacity calculation

Flowchart for Ampacity calculation of a conductor is shown in in Fig5.3.

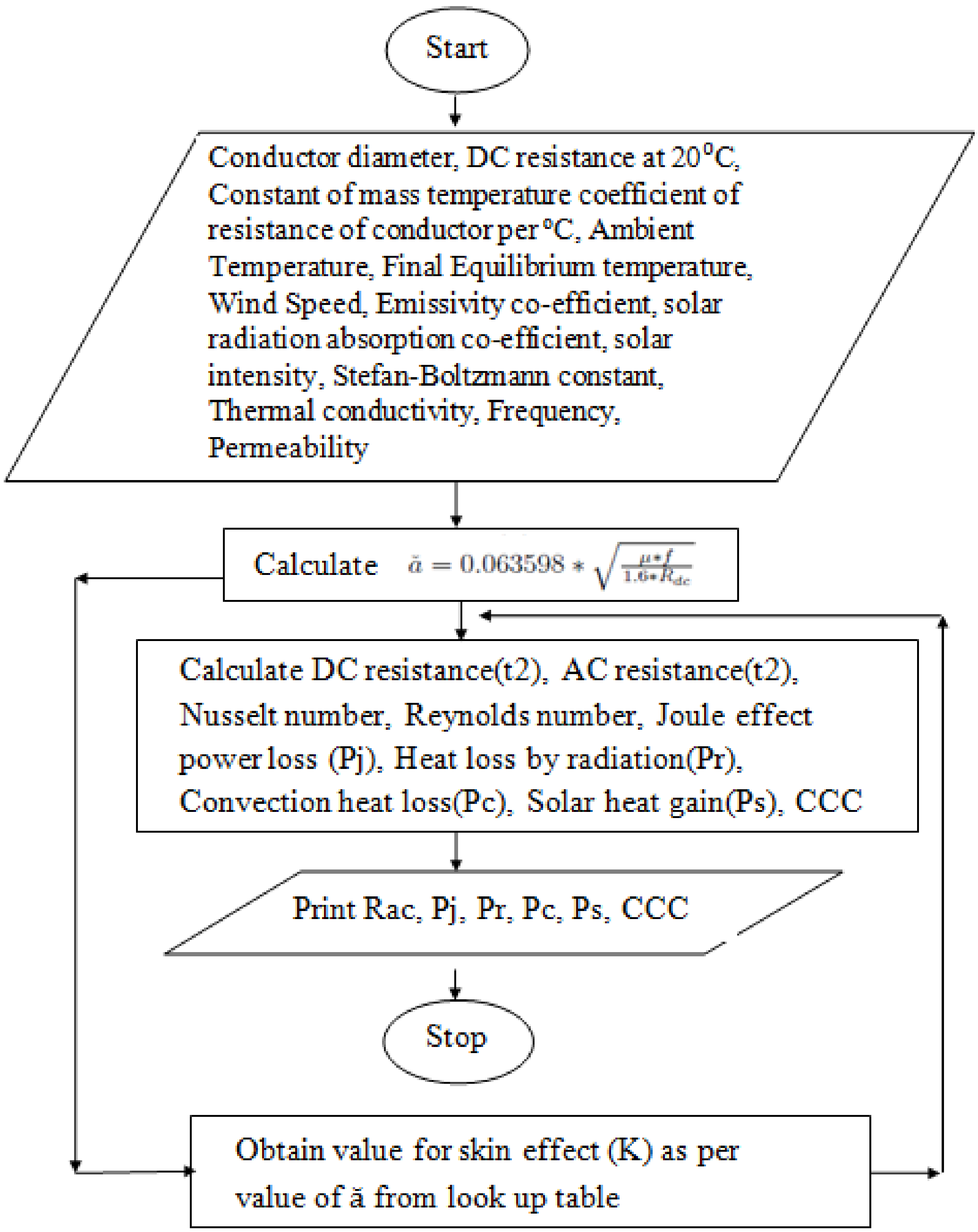



Figure 4 Flowchart for Ampacity calculation

## 5.5 Inductance and capacitance

A typical screen for inductance and capacitance calculation is shown in Fig 5.

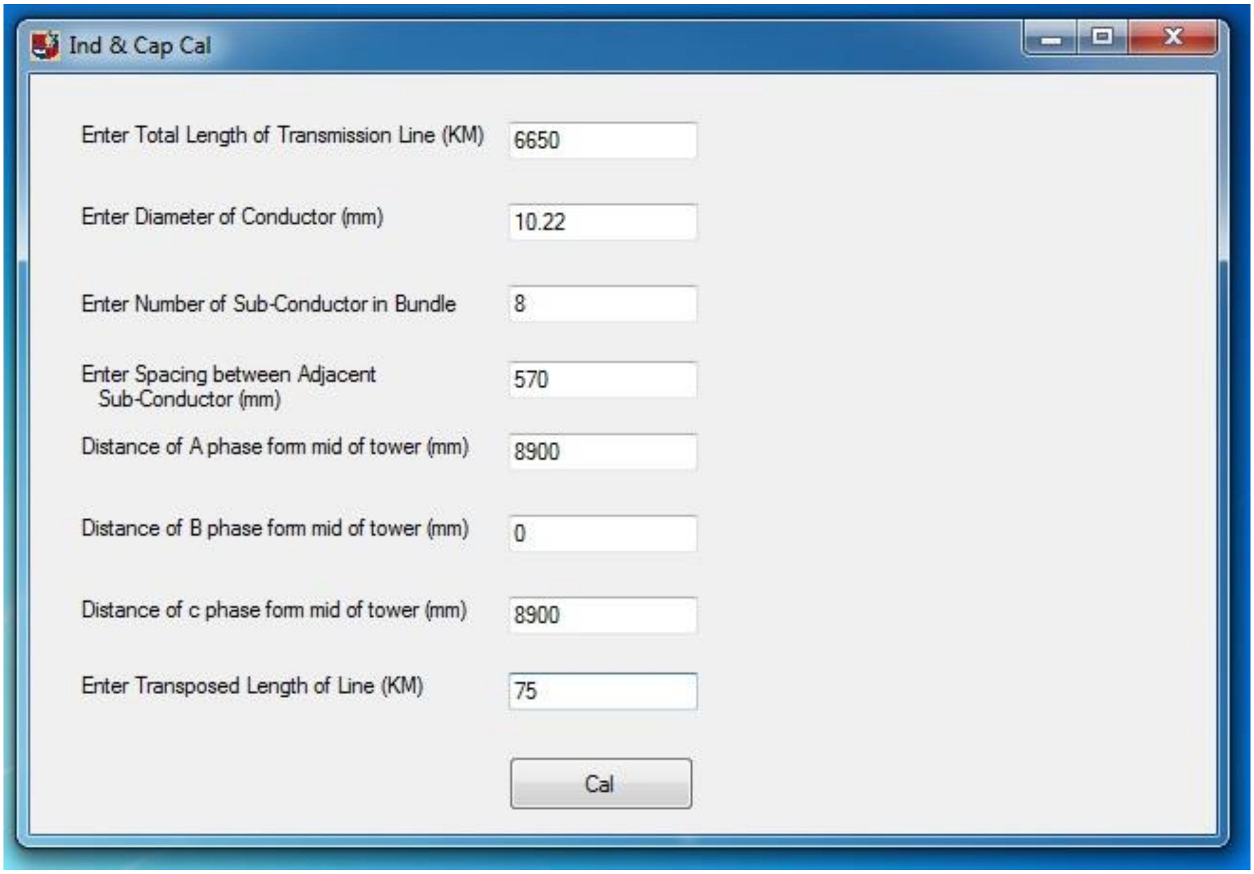



**Figure 5 Screen for Inductance and capacitance configuration**

### 5.6 Calculation for Signal Circuit Configuration

By this sub-program can calculation the below parameter of UHV Transmission line.

Total Inductance

Total Capacitance

Total Impedance

Surge Impedance

SIL

Receiving end Voltage

Receiving end Voltage Angle

Receiving end Current

Receiving end Current Angle

Receiving end Power

Voltage Regulation

Total line loss

Voltage Gradient ( outer )

Voltage Gradient ( Centre )

Corona Loss ( Fair Weather )

Corona Loss ( Rainy Weather )

Audible Noise

Radio Interference

### 5.6.1 Flow chart

Flowchart for Calculation for Signal Circuit Configuration is shown in below.

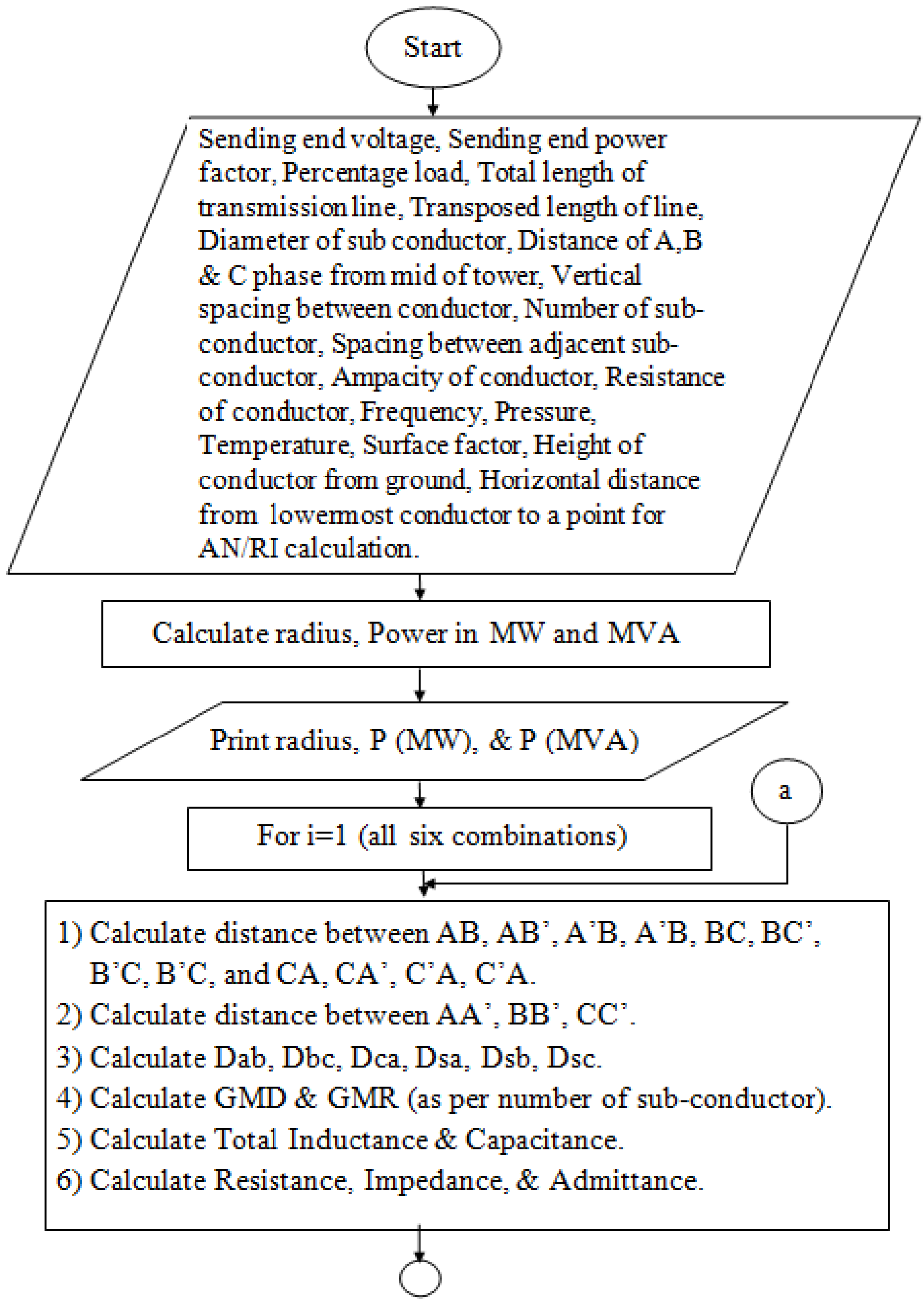
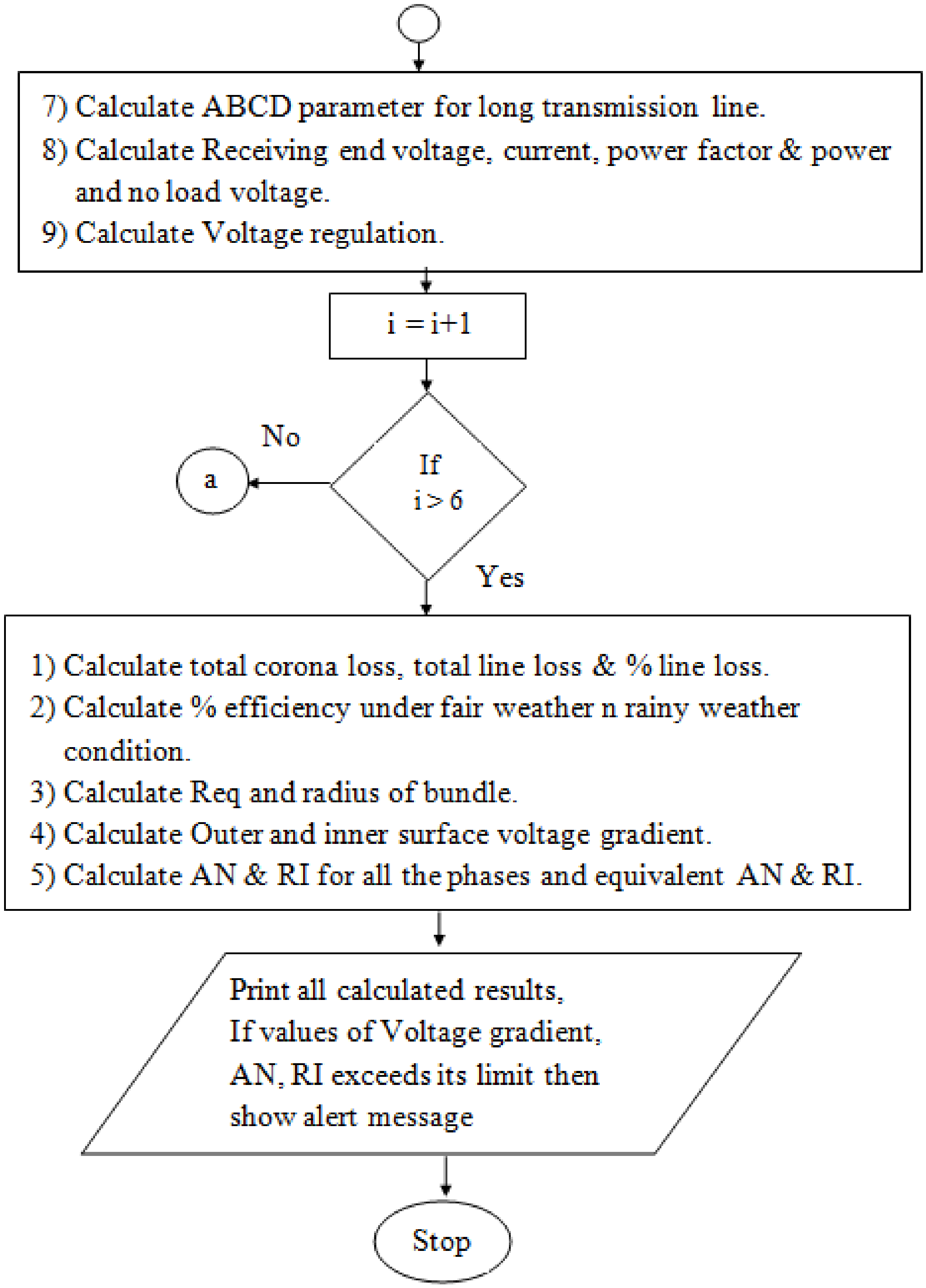



**Figure 6 Flowchart for Calculation for Signal Circuit Configuration**


7) Calculate ABCD parameter for long transmission line.
8) Calculate Receiving end voltage, current, power factor & power and no load voltage.
9) Calculate Voltage regulation.
i = i+1
No
a
If i > 6
Yes
1) Calculate total corona loss, total line loss & % line loss.
2) Calculate % efficiency under fair weather n rainy weather condition.
3) Calculate Req and radius of bundle.
4) Calculate Outer and inner surface voltage gradient.
5) Calculate AN & RI for all the phases and equivalent AN & RI.
Print all calculated results,
If values of Voltage gradient,
AN, RI exceeds its limit then
show alert message
Stop

# Chapter 6

## Conclusion and Future work

### 6.1 General

Conclusions are derived from the result so 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.

### 6.2 Conclusion

In this report all the necessary calculation for transmission line design is shown and two conductors. Program is developed for easy calculation of current carrying capacity of conductor, for electrical calculation of Single circuit transmission line for both vertical and horizontal orientation. In this program nearly all the congurations can be considered.

6.3 Future work

This work can be extended in future for:

- Calculation and analysis for UHV-AC transmission line with double circuit.
- Develop program for transmission line design while considering ground wires and consider other geometry for sub-conductor in a bundle (except circular geometry).

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