Design, Development and Simulation of Power Evacuation Schemes In EHV and UHV Network

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AHMEDABAD - 382481

May 2013

Design, Development and Simulation of Power Evacuation Schemes In EHV and UHV Network

Major Project Report

Submitted in Partial Fulfillment of the Requirements of

Master of Technology

In

Electrical Engineering
(Electrical Power System)

By

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May 2013

Certificate

This is to certify that the Major Project Report entitled **"Design, Development and Simulation of Power Evacuation Schemes In EHV and UHV Network "** submitted by **Ms . Chauhan Sweta (11MEEE23)**, towards the partial fulfillment of the requirements for Semester-IV of **Master of Technology (Electrical Engineering)** in the field of (**Electrical Power System)** of Nirma University is the record of work carried out by her under our supervision and guidance. The work submitted has reached a level required for being accepted for examination. The results embodied in this major project, to the best of my knowledge, have not been submitted to any other University or Institution for award of any degree or diploma.

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Undertaking For Originality of the Work

I, **Ms. Chauhan Sweta**, (**Roll No: 11MEEE23**), give undertaking that the Major Project entitled **"Design, Development and Simulation of Power Evacuation Schemes in EHV and UHV network"** submitted by me, towards the partial fulfillment of the requirement for the degree of Master of Technology in **Electrical Power Systems**, **Electrical Engineering**, under Institute of Technology, Nirma University, Ahmedabad is the original work carried out by me and I give assurance that no attempt of Plagiarism has been made. I understand that in the event of any similarity found subsequently with any published work or any dissertation work elsewhere; it will result in severe disciplinary action.

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Acknowledgements

It is a matter of extreme honour and privilege for me to offer my grateful acknowledgement to my supervisor Mr. Alpesh Mohite for providing me a chance to work under their guidance and supervision. I would also like to thank Mr. S.M.Takalkar, Director, TPEC for permitting me to carry out design work.

I am profound obliged to my revered project guide Mr. S.N. Jani, Asst. Professor, Nirma University, Institute of Engineering and Technology, Ahmedabad for his valuable, inspiring and excellent guidance. I express my sin- cere appreciation and thanks to Dr. S.C. Vora for constant encouragement and needful help during various stages of work. I would also like to thank Dr. K. Kotecha, Director, Institute of Technology, Nirma University for allowing me to carry out my project work in industry. I am thankful to Nirma University for providing all kind of required resources.

I express my thanks to Anoop Verma, Apoorv Talati, Jatin Mistry, Namita Tiwari, Pankita Tailor, Rohit Shah and Sumit Lingarchani for their time to time support during my entire study. I would also like to thank all the staff members of TPEC and my friends for help. I extent my heartfelt thanks to my parents for their motivation, moral support and encouragement through out my dissertation work. And above all, I pay my regards to the Almighty for his love and blessing.

- Chauhan Sweta

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Abstract

Increase in power demand in this country and in the entire world is resulting in to an expansion of transmission line network.EHV and UHV lines are being constructed all over the world for enblock transfer of power and higher reliability.In India 765 kV lines have come up and preparation for 1200 kV lines is in full swing. The transmission of bulk power to the tune of 1000 MW or 1500 MW per circuit over a long distance need very broad base towers with long cross arms. This means bigger Right of Way (ROW) corridor.

With the ambitious plan of GoI to add more than 1,20,000 MW during 12th five year plan, there is a big rush to construct UHV lines. Due to open access in power sector, private and corporate players have also found the business of power transmission very lucrative. Over last few years EPC (Engineering Procurement and Construction) contracts are being awarded on BOOT (Built own operate and transfer) and BOOM (Built own operate and maintenance) format. This is bound to increase the EHV/UHV network very fast. They can be called as a transmission Highway (THW) as each circuit will evacuate large chunk of power. This will certainly have an impact on the ROW. The compact line is therefore a theme which is talked about these days in developed and developing countries. Till the power reforms came in to existence in this country, the compaction had only one meaning and that is reducing the width of supports (Towers, Poles etc.). With the power reforms in vogue, the equations have changed now. Constructing over head transmission lines have started becoming difficult day by day. Increase in population,rapid urbanization and race for industrialization has added fuel to the fire. Focus is therefore on the transfer of maximum power through a minimum available corridor (ROW). Thus, compaction now necessarily means that optimization of power transfer capability of a transmission line from a given corridor(ROW). Compaction means physical (mechanical) compaction and the electrical compaction. The physical compaction relates to the use of narrow base towers, multi circuit towers, multi voltage towers, monopoles and trestle.The compaction can also be of electrical nature. Bundle configuration of conductor,electrical spacing of phases and circuit, insulation co-ordination optimization of electrical de-

sign of transmission line, are some of the important parameters for compaction of line. Guyed towers are also deployed for compaction of lines.Use of high Ampacity and high temperature conductors is a unique way to make the transmission line electrically compact.

Project will include all the necessary design calculations with simulation in MATLAB Software, AUTOCAD and programming will be there in MATLAB itself.

Abbreviations

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

Nomenclature

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

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_{conv} .... 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

Y .... Admittance

Z .... Impedance

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Chapter 1

INTRODUCTION

The Power Sector in India is undergoing a drastic change. It has been widely accepted by one and all that out of various infra structure developments, power is the most essential infrastructure. Till the year 2000, the business of power generation, transmission and distribution was the monopoly of state and centre owned utilities. Cost of construction and maintenance depended upon the standards set out by the Central Electricity Authority. The focus of the state and central governments was on the faster rural and urban electrification for accelerated industrial and agricultural development.

With the electricity act 2003 coming inforce, the scenario is changing fast.Element of competitive business in generation and transmission is introduced. Unfortunately, there are not many private takers for distribution net work, save giants like Reliance, Tata, BSES etc. The reason is obvious. With private sector ventures in to generation and transmission going in a big way, the sensitive issues like cost effective construction and trouble free service for a long run have assumed significance. Many National and International funding agencies now lay emphasis on the BOOM, BOOT and other formats for power sector infra structure development.

When we think of cost effectiveness we tend to consider immediate gains.This may not be always true. Initially expensive looking item of supply or erection can be cost effective in terms of maintenance. Reliability of innovative technology is most important. Reliability can be judged by rigorous testing and sometimes by past experience. Cost effectiveness of a power transmission system may definitely mean reducing the cost of Right of Way and minimizing use of land.Availability of land is becoming scarce.

The compaction of line is yet another way to reduce the cost. The compaction can be Mechanical or Electrical. Mechanical compaction relates to reduction in tower base width and use of multi circuit lines or multi voltage lines. Electrical compaction means use of new generation conductors having high Ampacity at high temperature. Such conductors afford large power transfer at unit ROW cost.

1.1 Objective of project

EHV transmission lines of 66 kV and above has a lion's share in total economies of the transmission system, the per km cost may range from Rs.15 lakhs to 200 lakhs depending upon the voltage class and number of circuits on a single tower/support. Larger the voltage, bigger is the tower and larger the cost of ROW. Route optimization can reduce the number of tower/line supports on the entire line. It is important to note that reduction in one tower location means reduction in the cost of tower material, line material (insulators, hardware, conductor/earthwire accessories etc.), the foundations and ROW.

In this project, a programme will be developed using MATLAB, 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 and 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.

1.2.2 Project Planning

Figure 1.1: Level Shifter Circuit

Chapter 2

Literature Review

Paper[1] 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[2] 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[3] provides the procedure to calculate line inductance and capacitance for single circuit line as well as double circuit line and for bundle conductors.

Reference[4] demonstrates the impact of three phase fault on power evacuation from wind turbines. It is found that the problems associated with power evacuation from wind farms entirely depends on the network topology. When the capacity of the Wind farm is doubled, system events results in unstable operation of the network. Instability can be seen from the changed operation condition after the fault is cleared at 100ms. The impact is minimized by increasing the capacity of the grid to 50MVA The oscillation in frequency is not acceptable where deviation is more than 5 Hz. Maximum oscillation is observed when the wind farm capacity is observed when the wind farm capacity is 4.5MW.

Reference[5] gives the idea about different components of EHV line, the different types of towers, the different types of conductors that are used on the transmission line depending upon the voltage class and the amount of current to be handled,the current loading limit and power transfer capability of various transmission lines, sag and tension calculations.

Reference[6] provides an overview on the generation demand scenario, transmission and distribution. It provides the power intensity in MW/m at different voltage level which shows that with the increasing voltage, power intensity can be increased and transmission voltage upto 765 kV already operating. Towards the development of high intensity transmission corridor, there is a plan to develop 800 kV, 6000 MW HVDC system as a part of evacuation of bulk power from North Eastern Region (NER) to Northern Region (NR) over a distance of around 2000 kms. In addition, increasing the AC voltage level at 1200kV level has been planned. It is to mention that we are aiming towards use of 1100kV equipments for 1200kV operation by optimizing their protective level with the help of high energy level Surge arrester so as to achieve economy in respect of 1200kV UHV system development. Research work for 1000kV HVDC system has also been commenced.

Reference[7] suggests that Compaction of transmission line is now a prime requirement in India and elsewhere due to ROW constraint. Compaction can be Physical or Electrical. New generation of conductors can be useful in bringing electrical compaction. Electrical parameters govern the compaction of line. It also suggests that an interesting case study of "chicken neck". We have lot of hydro power potential in the north eastern region including power generation in Bhutan. However, Bangladesh is geographically located in the center and Nepal on the West. Thus, the entire hydro power generation in the states of Bhutan, Sikkim, Assam, Arunachal and Meghalaya etc. can be brought to the load centers of Eastern Regional Grid (West Bengal, Bihar, Jharkhand, Chhattisgarh, Orissa etc.) only by constructing the transmission lines through the "Chicken Neck" between the strip of West Bengal, Bangladesh and Nepal. Bulk power to the tune of 1,00,000 MW or more can be transmitted by constructing transmission highways (i.e. lines of 400 kV and above). Mechanical and Electrical compaction will be a must in this situation. The lines of 765 kV and 1200 kV may be preferred for this Chicken Neck. The cost of ROW in India is estimated at Rs.2.0 Lac to Rs. 5.0 Lac per km. for an ROW of 30 M depending upon the region taking an average of 3.0 Lacs, the per sq. M cost of ROW comes to Rs.10. Thus, saving of ROW by 1 M means saving of Rs.10000 per km. This is substantial.

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.

Standard[9] 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[10] 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[11] 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.

Chapter 3

Study Area

It was planned to construct the 60MW (2 X30MW) Hydro Power Plant and evacuate the generated power in the State Grid (either in Himachal Pradesh or in Uttarakhand) or in the Grid of Power Grid Corporation of India Ltd.(PGCIL).A feasibility report and preliminary route survey through access roads for construction of transmission line including all materials for evacuation of 60 MW power from Hanol-Tiuni to Uttarakhand Jal Vidyut Nigam Ltd.(UJVNL) substation at Khodri and PGCIL's proposed substation at Selaqui near Dehradun in Uttarakhand.

3.1 Methodology of selection of route for transmission lines:

In consideration of the requirements of environmental parameters, construction methodology to be adopted for different terrain encountered en-route, design and engineering factors, availability of logistic support during construction, operation and maintenance of Transmission Lines and specific geographical condition to construct the lines along most feasible routes are identified based on the detailed desktop study of relevant topographic map and as per the guidelines to follow the route as inspected by the personal relevant topographic map along the various transmission line route were identified. After conducting a detailed desktop study of the proposed alternative routes, proposed line are marked on the topographic sheets. This was subsequently supplemented with preliminary route survey to access roads and data collection along the feasible route for arriving at the optimum route. While identifying alternatives for the selection of optimum route, following factors were considered:

- Compliances with environmental regulation.
- Shortest possible length as far as possible.
- Favourable ground profile for transmission lines.
- Accessibility to lines route during construction, maintenance and operation as far as possible.
- Location of various facilities and access thereto.
- Avoidance of Mining areas protected and reserved forest, archeological and other sensitive areas. Minimum damages to Flora and Fauna as far as possible.
- Avoidance of unstable ground feature as far as possible.
- Avoidance of Land Slide Zones and water flow areas, as far as possible.
- Minimizing road, canal, and river and flood prone zones area, as far as possible.
- Avoidance of Hard Rock stretches as far as possible.
- Avoidance of Areas reserved for planned and future development by Govt. and private agencies (which are notified), as far as possible.
- Flexibility for future expansion.

3.1.1 Proposal I: Open Access to Himachal Pradesh

A) Option-I - 220kV Double Circuit Transmission line From Hanol-Tiuni To Hatkoti using Single ACSR Zebra Conductor.

B) Option-II -66kV Double Circuit Transmission line From Hanol-Tiuni To Hatkoti using Twin ACSR Panther Conductor.

C) Option-III -66kV Double Circuit Transmission line From Hanol-Tiuni To Hatkoti using Single ACSR Zebra Conductor.

3.1.2 Proposal II: Open Access to PGCIL's Grid/Uttarnchal

A) Option-I - 220kV Double Circuit Transmission line From Hanol-Tiuni To Selaqui using Single ACSR Zebra Conductor for route I.

B) Option-II - 220kV Double Circuit Transmission line From Hanol-Tiuni To Selaqui using Single ACSR Panther Conductor for route I.

C) Option-III -132kV Double Circuit Transmission line From Hanol-Tiuni To Selaqui using Single ACSR Panther Conductor for Route I.

D) Option-IV -220kV Double Circuit Transmission line From Hanol-Tiuni To Selaqui using Single ACSR Zebra Conductor for route II.

E) Option-V -220kV Double Circuit Transmission line From Hanol-Tiuni To Selaqui using Single ACSR Panther Conductor for route II.

F) Option-VI -132kV Double Circuit Transmission line From Hanol-Tiuni To Selaqui using Single ACSR Panther Conductor for Route II.

For proposal I route length comes to 27kM from Hanol Tinui to Hatkoti, considering 10percent Extra route length to accommodate the Hilly terrain. For proposal II route length for route I and route II is 114kM and 118.15kM respectively from Hanol-Tiuni to Selaqui (PGCIL's Proposed Switchyard tentative location), considering 15percent extra route length to accommodate the hilly terrains.

Chapter 4

Methodology

4.1 General

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

4.1.1 Ampacity Calculation for conductor

These calculations are necessary to find out the capacity of the conductor to transfer the power at the rated voltage without any material damage to the conductor (deformation).

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

=0.06869(1+0.004(75-20))

=0.0838018 ohm/km

X=0.063598$\sqrt{\frac{\mu f}{R_{dc}}}$

=0.063598*$\sqrt{\frac{50*1}{0.0838018}}$

=1.5534

Corresponding to obtained value of X,value of K=1.029525

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

=1.029525*0.0838018

Table I: AMPACITY calculation for single ACSR Zebra conductor @ 75^0C

Input Parameters	symbol	unit	
Coefficient of Emissivity	ε		0.45
Temperature t_1	t_1	^0C	20
D.C Resistance at Temperature t_1	R_{t1}	ohm/km	0.06869
Diameter of Conductor	D	mm	28.62
Wind Velocity	V	m/hr	3600
Average ambient temperature	t_a	^0C	40
Average conductor temperature	t_c	^0C	75
Solar Radiation	S	Wt/Sq.m	1164
Temperature Rise	Δt	^0C	35
Average ambient temperature in kelvin	K_a	^0K	313
Average conductor temperature in kelvin	K_c	^0K	348
Solar absorption co-efficient	a		0.8
Constant of mass temp coefficient	α	ohm/^0C	0.004
Frequency	f	cy/sec	50
Permeability(non-mag mat)	μ		1
Total length of line	l	Km	27

=0.086276048 ohm/km

Total Resistance of line R=R_{ac}* l

=0.086276048*27

=2.3294533 ohm

Avg air film temp t_f=$\frac{t_c+t_a}{2}$

=$\frac{75+40}{2}$

= 57.5 ^0C

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

Air density at sea level P_f=1.0676 kg./cum

Thermal conductivity of air K_f=0.0285265 Wt/Sq.m^0C

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

=0.8*1164($\frac{28.62}{1000}$)

=26.65 Wt/m

Heat dissipated by Radiation Q_r=0.17838*10^{-6}*ε*(D/1000)*(K_c^4 - K_a^4)

=0.45*(28.62/1000)*(348^4 - 313^4)

=11.64358 Wt/m

Heat dissipated by convection :

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

=(1.00531 + (1.35088 * $\frac{((28.62/1000)*1.08525*3600)}{0.070762})^{0.52}$) * 0.0281495 * (75-40)

=54.00203

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

=0.75398 * ($\frac{((28.62/1000)*1.08525*3600)}{0.070762})^{0.6}$) * 0.0281495 * (75-40)

=61.465

whichever value is higher of above two Q_c is to be considered.

so here Q_c =61.465

Ampere Capacity of Conductor I=$\sqrt{\frac{Q_c+Q_r-Q_s}{R_{ac}}}$

=$\sqrt{\frac{61.465+11.6435-26.65}{0.086276048*10^{-3}}}$

=733.8097607

4.1.2 Inductance and Capacitance Calculation

These calculations are required to quantify the behavior of the transmission line with reference to the tower configuration and the conductor material. They also help in deciding the efficiency of the transmission line.

Table II: Ampacity and Resistance of 220kv D/C line with single acsr zebra conductor

Temp	R_{dc}	R_{ac}	R	Ampacity
65	0.0810542	0.08362751	2.25794274	550.444453
70	0.082428	0.08498384	2.29456381	649.992775
75	0.0838018	0.086276048	2.3294533	733.8097607
80	0.085176	0.087627	2.365937	806.8731
85	0.08655	0.08898	2.40237	872.933
90	0.0879232	0.09032368	2.43873934	932.971424

Table III: Inductance and Capacitance of single ACSR zebra conductor

Parameter	Unit	Value
Total length of transmission line	km	27
Transposed length of the line	km	0
Diameter of conductor	mm	28.62
Radius of conductor	mm	14.31
Spacing between conductors		
Horizontal separation		
Tower center to top conductor (A-Ph)	mm	1750
Tower center to middle conductor (B-Ph)	mm	1750
Tower center to bottom conductor (C-Ph)	mm	1750
Vertical separation	mm	2000
Distance between two subconductors	mm	0
Resistance of the line @ 75^0C	ohm/km	0.08628
Barometric pressure(p)	cm	74
Temperature (θ)	^{0}C	75
Surface factor(m_0)		0.84

Calculation of Mutual GMD:

D_{ab}=$\sqrt{Verticalseparation^2 + ((B - Ph) - (A - Ph))^2}$

=$\sqrt{2000^2 + (1750 - 1750)^2}$

=2000 mm

$D_{ab'}$=$\sqrt{Verticalseparation^2 + ((B - Ph) + (A - Ph))^2}$

$=\sqrt{2000^2 + (1750 + 1750)^2}$

$=4031.128874$ mm

$D_{ba}=D_{ab}$

$=2000$ mm

$D_{ba'}=D_{ab'}$

$=4031.128874$ mm

$D_{AB}=\sqrt{D_{ab} * D_{ab'}}$

$=\sqrt{2000 * 4031.128874}$

$=2839.411514$ mm

$D_{bc}=\sqrt{Verticalseparation^2 + ((C - Ph) - (B - Ph))^2}$

$=\sqrt{2000^2 + (1750 - 1750)^2}$

$=2000$ mm

$D_{bc'}=\sqrt{Verticalseparation^2 + ((C - Ph) + (B - Ph))^2}$

$=\sqrt{2000^2 + (1750 + 1750)^2}$

$=4031.128874$ mm

$D_{cb}=D_{bc}$

$=2000$ mm

$D_{cb'}=D_{bc'}$

$=4031.128874$ mm

$D_{BC}=\sqrt{D_{bc'} * D_{bc}}$

$=\sqrt{2000 * 4031.128874}$

$=2839.411514$ mm

D_{ca}=$\sqrt{(Verticalseparation*2)^2+((C-Ph)-(A-Ph))^2}$

=$\sqrt{(2000*2)^2+(1750-1750)^2}$

=4000 mm

$D_{ca'}$=$\sqrt{(Verticalseparation*2)^2+((C-Ph)+(A-Ph))^2}$

=$\sqrt{(2000*2)^2+(1750+1750)^2}$

=5315.072906 mm

D_{ac}=D_{ca}

=4000 mm

$D_{ac'}$=$D_{ca'}$

=5315.072906 mm

D_{CA}=$\sqrt{D_{ca}*D_{ca'}}$

=$\sqrt{4000*5315.072906}$

=4610.888377 mm

Equivalent Mutual GMD D_{eq}=$\sqrt[3]{D_{AB}*D_{BC}*D_{CA}}$

=$\sqrt[3]{2839.411514*2839.411514*4610.888377}$

=3337.442271 mm

Calculation of Mutual GMR: D_{aa}=0.7788 x Radius of conductor

=0.7788 x 14.31

=11.144628 mm

$D_{a'a'}$=D_{aa}

=11.144628 mm

$D_{aa'}$=2 x (A-Ph)

=2 x 1750

=3500 mm

$D_{a'a}$=$D_{aa'}$

=3500 mm

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

=$\sqrt{11.144628 * 3500}$

=197.4998684 mm

D_{bb}=D_{aa}

=11.144628 mm

$D_{b'b'}$=D_{aa}

=11.144628 mm

$D_{bb'}$=2 x (B-Ph)

=2 x 1750

=3500 mm

$D_{b'b}$=$D_{bb'}$

=3500 mm

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

=$\sqrt{11.144628 * 3500}$

=197.4998684 mm

D_{cc}=D_{aa}

=11.144628 mm

$D_{c'c'}$=D_{aa}

=11.144628 mm

$D_{cc'}$=2 x (C-Ph)

=2 x 1750

=3500 mm

$D_{c'c}$=$D_{cc'}$

=3500 mm

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

=$\sqrt{11.144628 * 3500}$

=197.4998684 mm

Equivalent GMR or self GMD = $\sqrt[3]{D_{SA} * D_{SB} * D_{SC}}$

=$\sqrt[3]{197.4998684 * 197.4998684 * 197.4998684}$

=197.4998684 mm

INDUCTANCE L=2x10^{-7}ln(D_{eq}/GMR)

=2x10^{-7}ln(3337.442271/197.4998684)

=5.65444x10^{-7} H/phase/m

=0.000565444 H/phase/km

Calculation of Capacitance:

Equivalent mutual GMD will be the same only GMR will change.

Calculation of mutual GMR:

D_{aa}=Radius of conductor

=14.31 mm

$D_{a'a'}$=D_{aa}

=14.31 mm

$D_{aa'}$=3500 mm

$D_{a'a}$=3500 mm

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

$=\sqrt{14.31 * 3500}$

=223.7967828 mm

$D_{bb}=D_{aa}$

=14.31 mm

$D_{b'b'}=D_{aa}$

=14.31 mm

$D_{bb'}$=3500 mm

$D_{b'b}$=3500 mm

$D_{SA}=\sqrt{D_{bb}D_{b'b}}$

$=\sqrt{14.31 * 3500}$

=223.7967828 mm

$D_{cc}=D_{aa}$

=14.31 mm

$D_{c'c'}=D_{aa}$

=14.31 mm

$D_{cc'}$=3500 mm

$D_{c'c}$=3500 mm

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

$=\sqrt{14.31 * 3500}$

=223.7967828 mm

Equivalent GMR or self GMD=$\sqrt[3]{D_{SA} * D_{SB} * D_{SC}}$

$=\sqrt[3]{223.7967828 * 223.7967828 * 223.7967828}$

=223.7967828 mm

CAPACITANCE C=0.02412/$ln(D_{eq}/GMR)$

=0.02412/ln(3337.442271/223.7967828)

=0.020552849 μ_f/phase/km

The Total Inductance of the line = 0.015266999 H/phase

The Total Capacitance of the line = 0.554926925 μ_f/phase

Table IV: Inductance and Capacitance of 220kv D/C line with single ACSR zebra conductor

Conductor type	SINGLE ACSR ZEBRA
Conductor Diameter D (mm)	28.62
Inductance L (H/phase/km)	0.000565444
Capacitance C_N (μ_f/phase/km)	0.020552849
Total Inductance L (H/phase)	0.015267
Total Capacitance C_N (μ_f/phase)	0.554926925

The total resistance of the line=Resistance of the line @ 75^0C x length of the line

=0.08628 x 27

=2.33 ohms

The total Reactance of the line X=2ΠfL

=2xΠx50x0.015266999

=4.8 ohms

Impedance Z=R+iX

=2.33 + i4.8

Magnitude=5.34 ohm

Angle=64.11

Admittance Y=2ΠfC

=0.000175i

Magnitude=0.000175 mho

Angle=90

Table V: Impedence and Admitttance of 220kv D/C line with single ACSR zebra conductor

Temp	Impedence Z(ohms)	$\|Z(ohms)\|$	Admittance Y(mho)
65	2.26+4.8i	5.305431	0.000175i
70	2.3+4.8i	5.322593	0.000175i
75	2.33+4.8i	5.335626	0.000175i
80	2.37+4.8i	5.353214	0.000175i
85	2.41+4.8i	5.371043	0.000175i
90	2.44+4.8i	5.384571	0.000175i

4.1.3 Calculation for Voltage Regulation

These calculations are required to quantify the behavior of the transmission line with reference to the tower configuration and the conductor material. They also help in deciding the efficiency of the transmission line.

(ZY)=-0.00084 + 0.00040775i

magnitude=0.000933734

angle=154.1072909

(ZY)/2=-0.00042 + 0.000203875i

magnitude=0.000466867

angle=154.1072909

(ZY)/6=-0.00014028 + 0.00006809425i

magnitude=0.000155934

angle=154.1072909

(Z^2Y^2)=0.0000005393399375-0.00000068502i

magnitude=8.7186E-07

angle=-51.78541821

(Z^2Y^2)/120=4.47652148125E-09-0.000000005685666i

magnitude=7.23644E-09

angle=-51.78541821

Parameter A=D=(1 + $\frac{ZY}{2!}$)=0.99958 + 0.000203875i

magnitude=0.999580021

angle=0.011686085

Parameter B=Z(1 + $\frac{ZY}{3!}$)=2.32934633292149+4.7994853238422i

magnitude=5.334877104

angle=64.11119263

Parameter C=Y(1 + $\frac{ZY}{3!}$)=-1.191549875845E-08+0.000174975451783391i

magnitude=0.000174975

angle=90.00390173

Sending End Voltage V_s=$\frac{220000}{\sqrt{3}}$

=127017.059221718 volts

magnitude=127017.0592 volts

angle=0

Sending End Current I_s=$\frac{Sendingendpower*10^6}{\sqrt{3}*220000}$

=$\frac{75*10^6}{\sqrt{3}*220000}$

=196.8239554 amps

magnitude=196.8239554 amps

angle=-36.86989765

Sending End Power=Sending end power in MVA * p.f

=75*0.8=60.0 MW

Receiving End Voltage V_r=D*V_s -B*I_s

=126030.143646558-454.754469082993i volts

magnitude=126030.9641 volts

angle=-0.206739419

Receiving End Current I_r=-C*V_s + A*I_s

=157.419455955749-140.238180668953i amps

magnitude=210.8260715 amps

angle=-41.69646152

Receiving End Power factor($\cos\phi_r$)=cos($angleofI_r \sim angleofV_r$)

=0.749074572

Receiving End Power=$\frac{3*|V_r|*|I_r|*\cos\phi_r}{10^6}$

=$\frac{3*126030.9641*210.8260715*0.749074572}{10^6}$=59.71011176 MW

Voltage Regulation=$\frac{|V_s|-|V_r|}{|V_r|}$*100

=$\frac{127017.0592-126030.9641}{126030.9641}$*100

=0.79

Table VI: Voltage Regulation at different load and different p.f of 220kv D/C line with single ACSR zebra conductor

Percentage load	50	100
MVA at load	37.50	75.00
Voltage Regulation at 0.8 p.f	0.42	0.79
Voltage Regulation at 0.85 p.f	0.38	0.71
Voltage Regulation at 0.9 p.f	0.34	0.63
Voltage Regulation at 0.95 p.f	0.29	0.53
Voltage Regulation at 1 p.f	0.19	0.34

4.1.4 Calculation for Corona Loss

The corona losses are the part of total losses of the transmission line. They are inversely proportional to the diameter of the conductor. The effect of corona are surface damage, hissing noise and emission of ozone. The corona losses are dependent upon voltage.

Air density factor: $\delta = \frac{3.86 * Barometricpressure(p)}{273 + Temperature(\theta)}$

$= \frac{3.86*74}{273+75}$

=0.820804598

Critical Disruptive Voltage: $V_d = \frac{3*10^6}{\sqrt{2}}$ * r * δ * m_0 * $\ln GMD/GMR$ (volts)

$= \frac{3*10^6}{\sqrt{2}}$ * 14.31*10^{-3} * 0.820804598 * 0.84 * $\ln 3337.442271/14.31$

=114109.2673 volts

V_s/V_d=127017.059221718/114109.2673

=1.1

For this value of V_s/V_d value of F which is the factor varies with ratio V_s/V_d is 0.065

Therefore F=0.065

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

$= \frac{21*10^{-6}*50*(127017.059221718*10^{-3})^2*0.065}{\log(3337.442271*10^{-3}/14.31*10^{-3})^2}$

=0.1964 (KW/phase/km)

Total Corona loss of the line=3x$P_c$xlength of the line

=3x0.1964x27

=15.91 KW

For D/C total Corona Losses=2xTotal Corona loss of the line

=2x15.91

=31.82

Table VII: Corona loss of 220kv D/C line with single ACSR zebra conductor

Corona loss: P_c	KW/phase/km	0.1964
Total Corona loss of the line	KW	15.91
For D/C total Corona Losses	KW	31.82

4.1.5 Line Losses

The losses due to resistance and inductance of the conductor are required to be calculated at different loads on the conductor. The losses are then capitalized for the purpose of comparison of various conductors and find out the break-even point.

Table VIII: Line Losses for Single ACSR Zebra Conductor

Description	Unit	Value
percent load		100
Sending End Power	MVA	75
Voltage Rating of the line	KV	220
Total length of transmission line	km	27
Resistance of the line @ 75^0C	ohm/km	0.08628
Power factor		0.8
The total resistance of the line	ohm	2.33
Sending End power	MW	60

Calculation For Line Losses for 100 percent load

At full load sending end power=75 MVA

Current for circuit per phase=$\frac{SendingEndPower*1000}{\sqrt{3}*VoltageRatingoftheline}$

Line Losses for single conductor per conductor=Current for circuit per $phase^2$ x The total resistance of the line

=196.8239554^2 x 2.33 x 10^{-3}

=90.26 KW

Total Line Losses For D/C = Line Losses for single conductor per conductor x 6

=90.26x6

=541.58 KW

Percentage line losses = $\frac{TotalLineLossesForD/C}{Fullloadsendingendpower*p.f*1000}$ x 100

=$\frac{541.58}{75*0.8*1000}$x100

=0.90

Table IX: Line Losses At Different Load of 220kV D/C line with Single ACSR Zebra Conductor

Percentage load	50	100
Total Current I (Amp)	98.41	196.82
Losses for single cond (KW)	22.57	90.26
Total line losses(KW)	135.40	541.58

Percentage Efficiency =$\frac{ReceivingEndPower}{SendingEndPower+TotalCoronaLosses+TotalLineLossesforFullLoad}$*100

=$\frac{59.71011176*1000}{60*1000+31.82+541.58}$*100

=98.57 percent

Total Line Loss(kwh)= 541.58*365*24

=4744246kwh

Total Corona Loss(kwh)= 31.82*120*24

Table X: Effiiciency At Different Load of 220kV D/C line with Single ACSR Zebra Conductor

Percentage load	50	100
Total Corona Loss (KW)	31.82	31.82
Total line losses(KW)	135.40	541.58
Sending End Power (KW)	30000	60000
Receiving End Power (KW)	29855.06	59710.11
Percentage η with corona loss	98.95	98.57
Percentage η without corona loss	99.07	98.63

=91633kwh

Total Power Loss/annum (kwh)=Total Line Loss + Total Corona Loss

=4744246 + 91633

=4835879

Total Economic Loss (INR)=Total Power Loss/annum * 5

=4835879*5

=24179396

Cost of ACSR Zebra conductor per KM=2,10,000 INR/Km

Total Cost=2,10,000*27*12*1.1

=7,48,44,000

Table XI: Total Capitalization of losses for 10 years span of Single ACSR Zebra conductor

Year	Total Economic loss(INR)	Interest	Total capitalization of losses(INR)
Year 1	2,41,79,396	0	2,41,79,396
Year 2	4,83,58,793	16,92,558	5,00,51,350
Year 3	7,25,38,189	33,85,115	7,59,23,304
Year 4	9,67,17,585	50,77,673	10,17,95,258
Year 5	12,08,96,981	67,70,231	12,76,67,212
Year 6	14,50,76,378	84,62,789	15,35,39,166
Year 7	16,92,55,774	1,01,55,346	17,94,11,120
Year 8	19,34,35,170	1,18,47,904	20,52,83,074
Year 9	21,76,14,566	1,35,40,462	23,11,55,028
Year 10	24,17,93,963	1,52,33,020	25,70,26,982
Total			1,406,031,892

Chapter 5

Software

5.1 General

This chapter deals with the software developed for carrying out the various calculations.Program is an user friendly tool and it represents result and data in graphical form, which enables easy understanding to an individual.

5.2 Main Screen

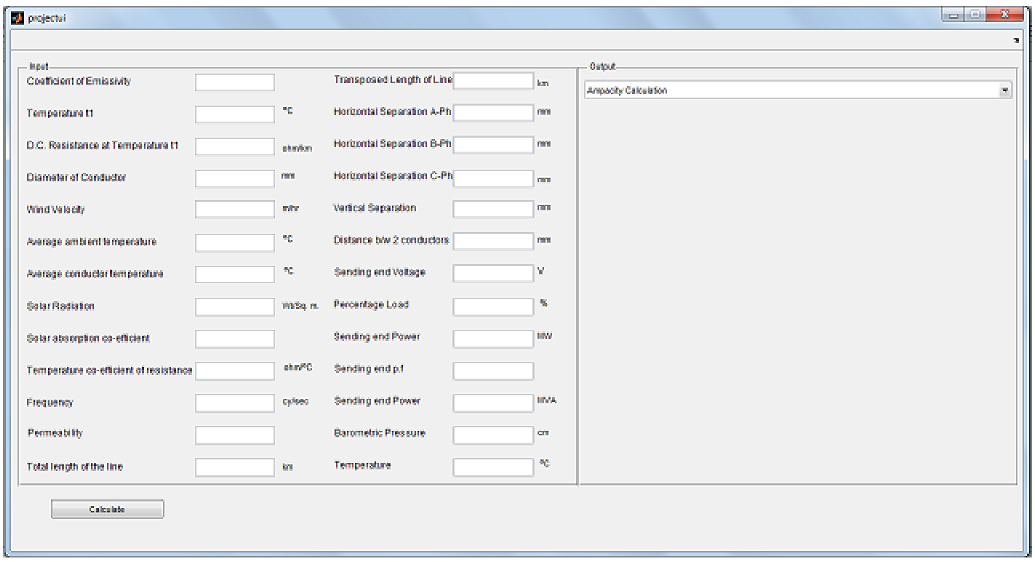


Figure 5.1: Main Screen

The main screen shows the various input parameters of the line which are to be fed by the user.

5.3 Ampacity calculation

A typical screen of program is shown in Fig5.2 . Program used for calculation is given in Appendix [A]

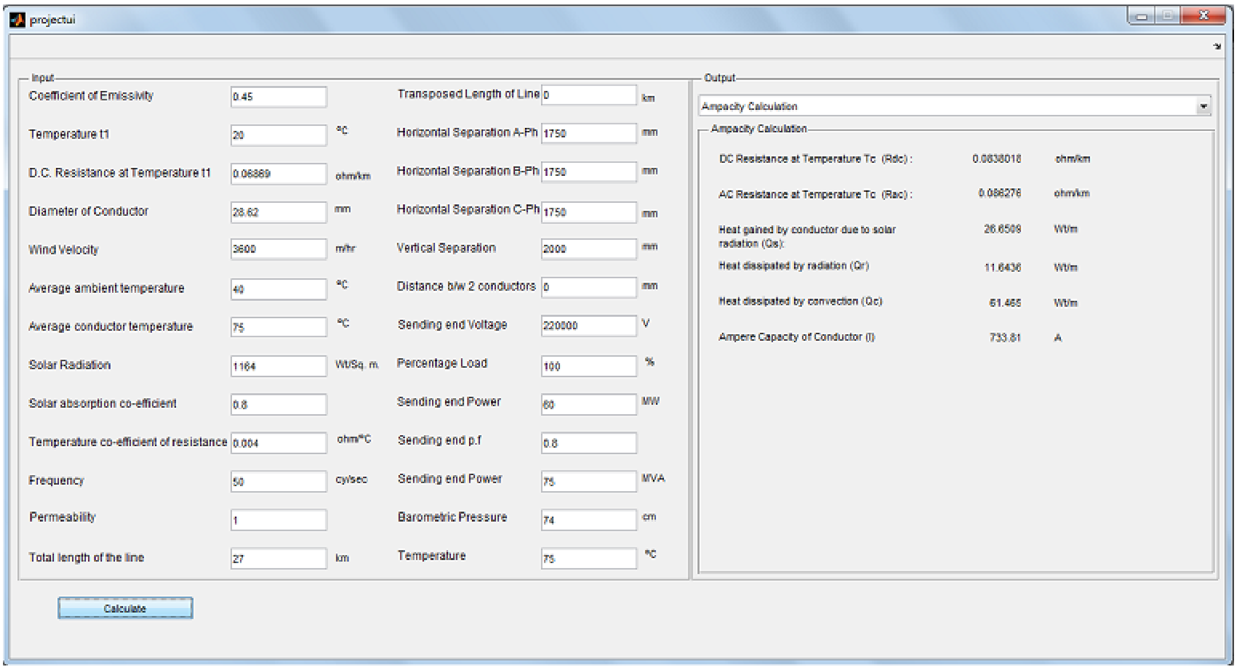


Figure 5.2: Screen for Ampacity Calculation

5.3.1 Flowchart for Ampacity calculation

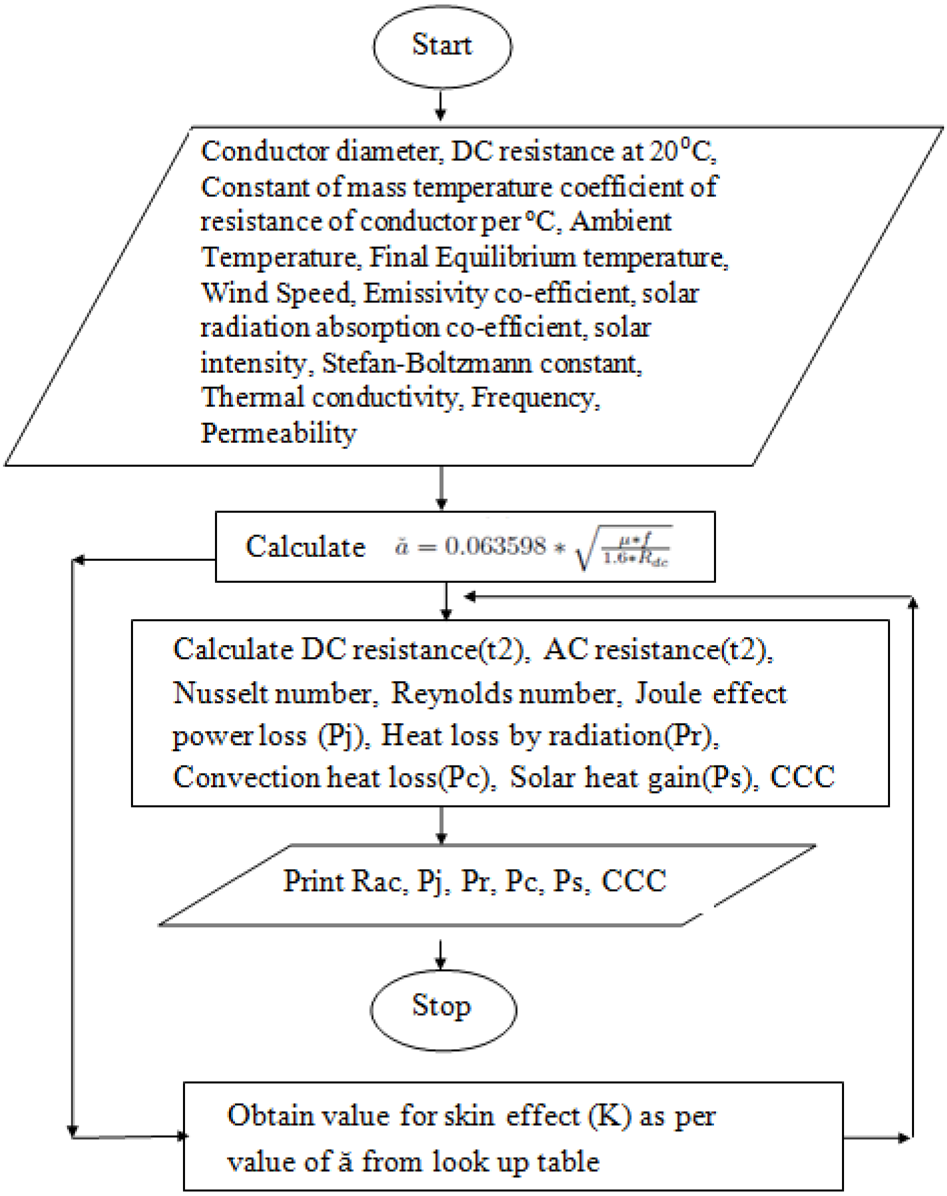


Figure 5.3: Flowchart for Ampacity Calculation

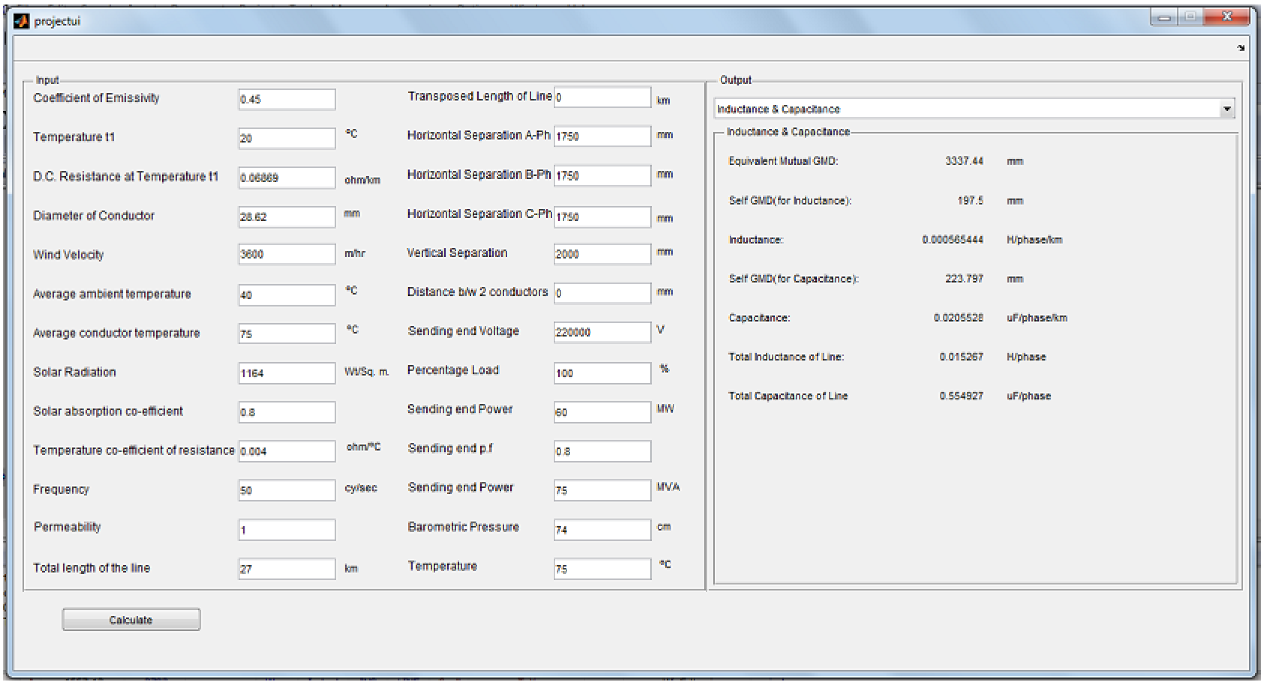


Figure 5.4: Screen for Inductance and Capacitance Calculation

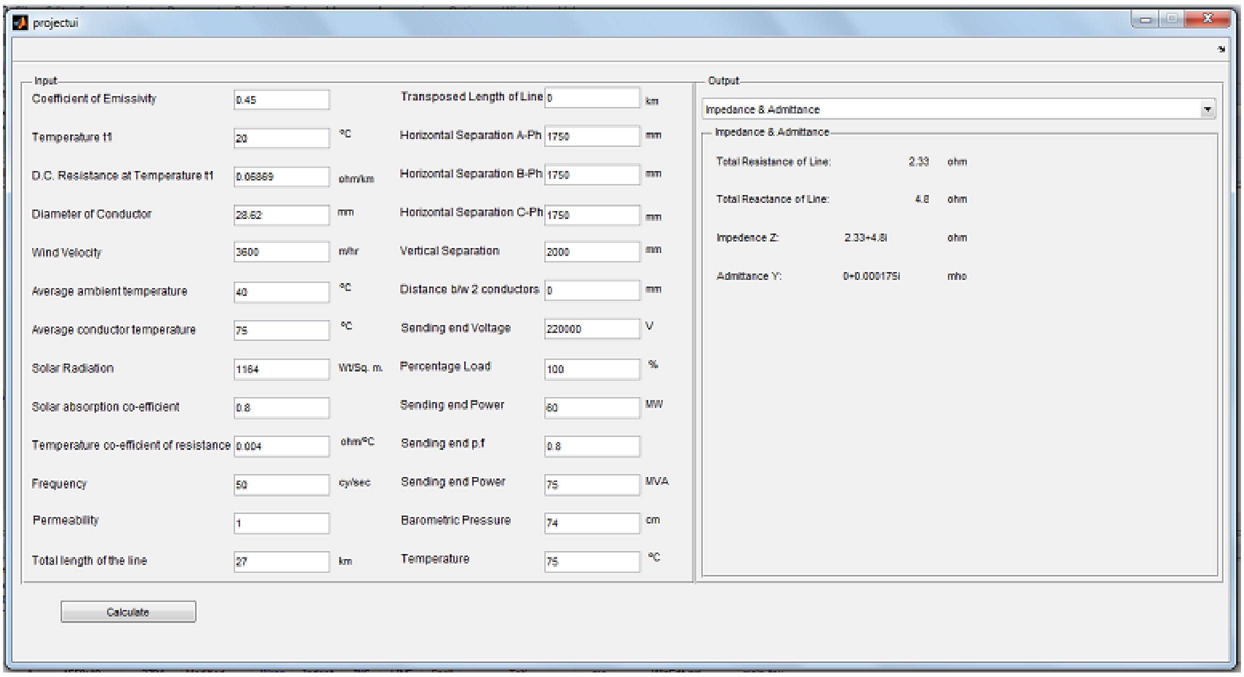


Figure 5.5: Screen for Impedance and Admittance Calculation

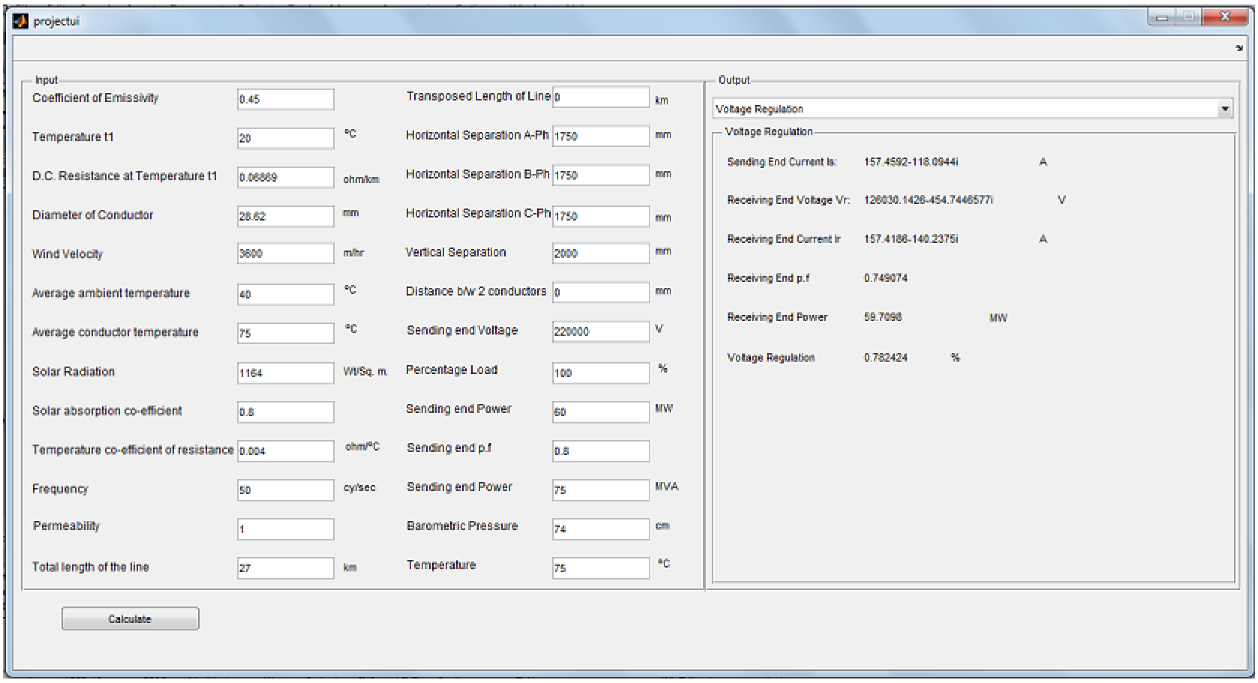


Figure 5.6: Screen for Voltage Regulation Calculation

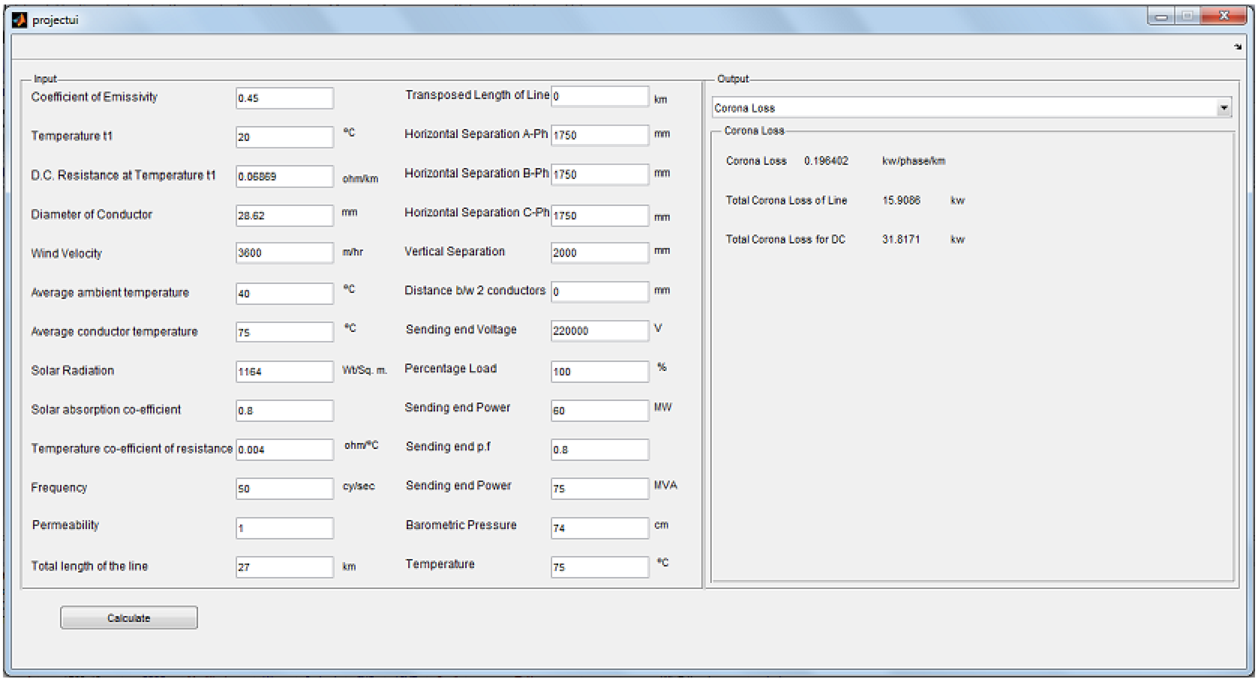


Figure 5.7: Screen for Corona Loss Calculation

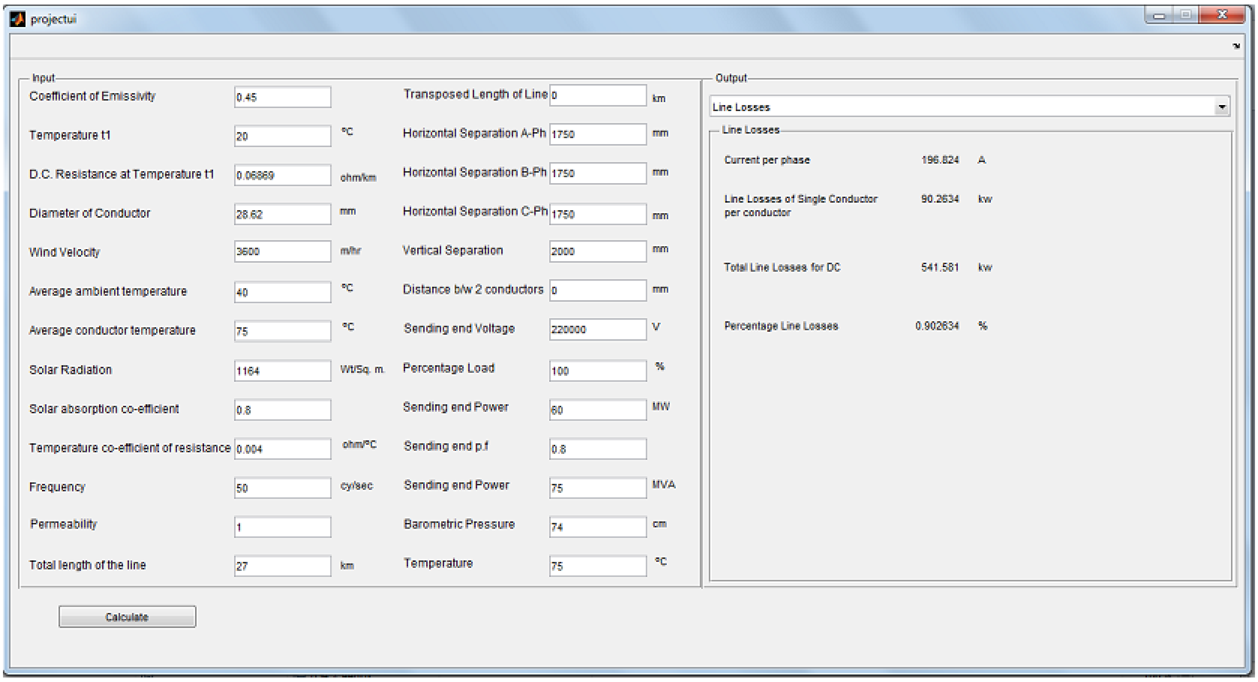


Figure 5.8: Screen for Line Losses Calculation

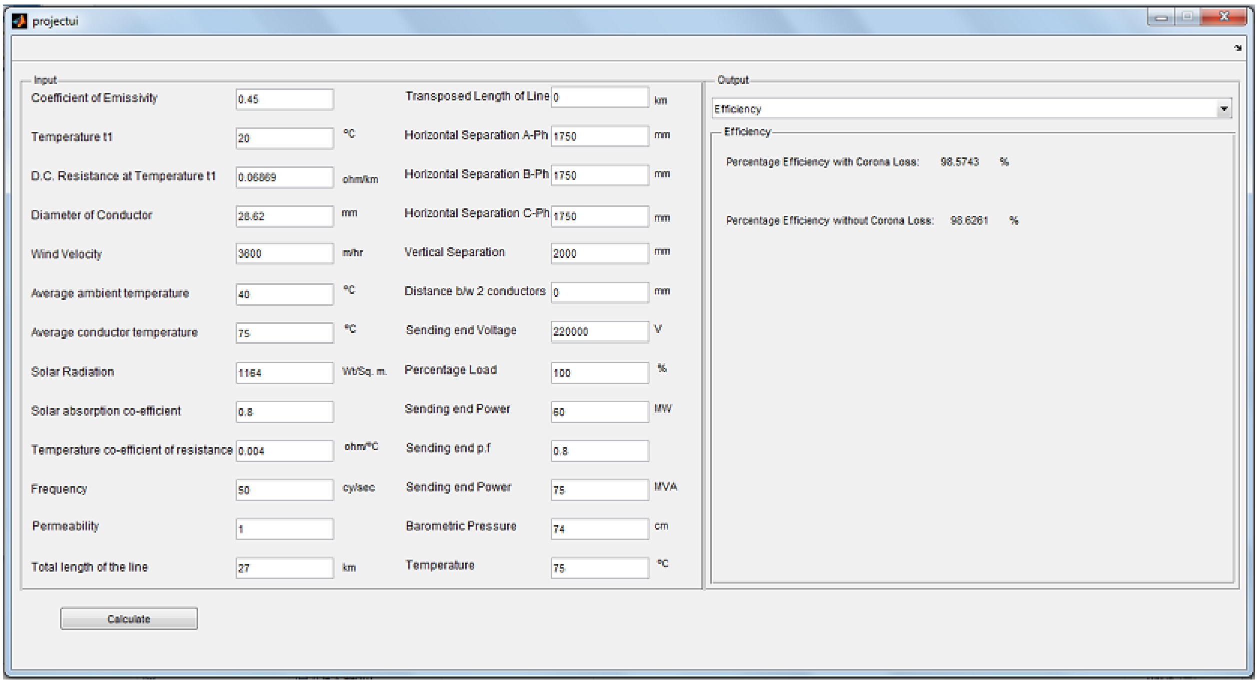


Figure 5.9: Screen for Efficiency Calculation

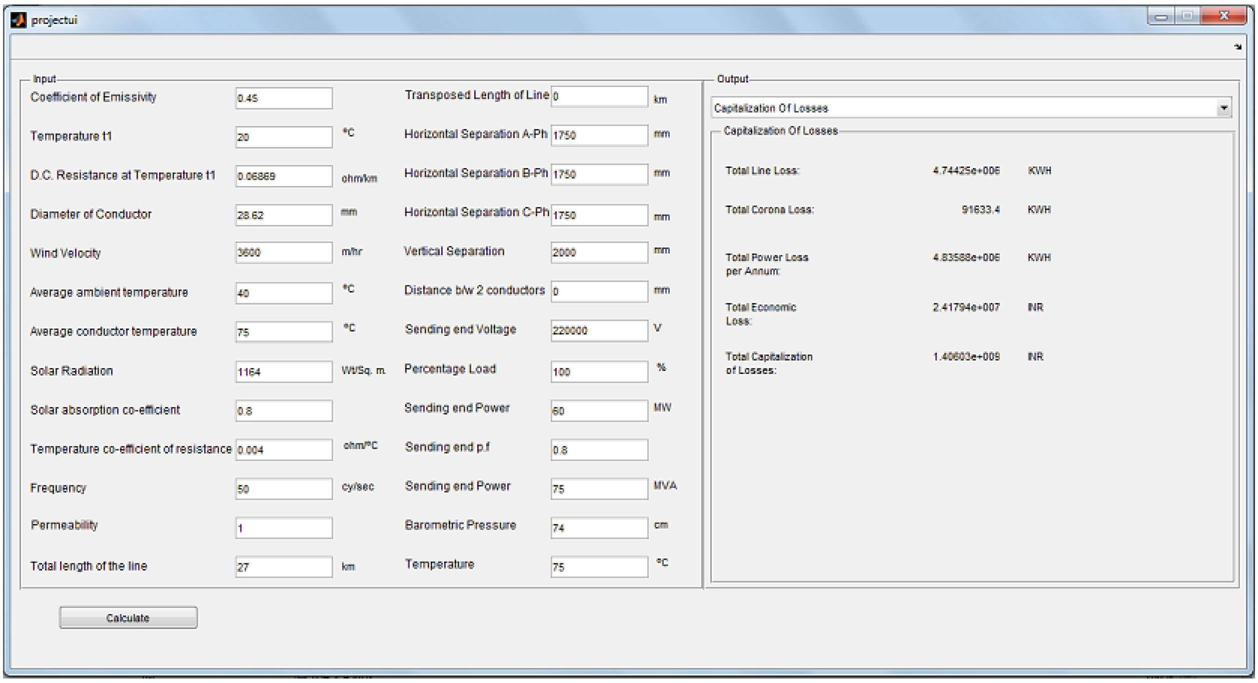
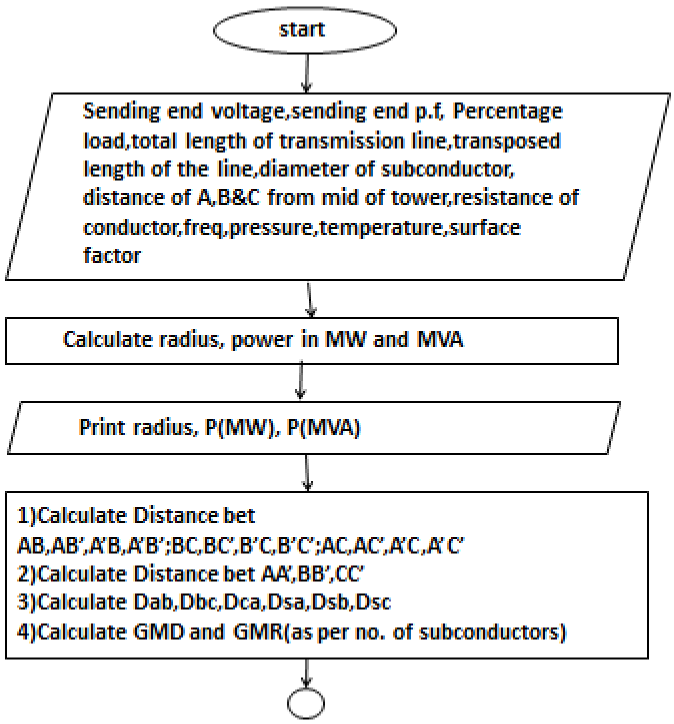


Figure 5.10: Screen for Capitalization of Losses



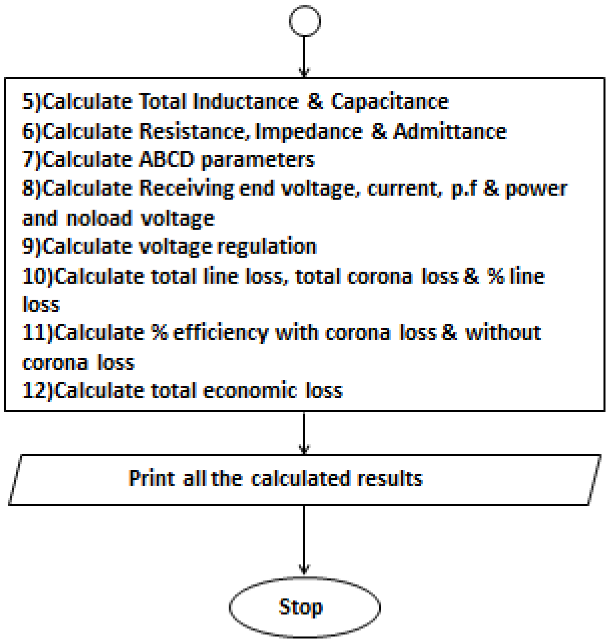


Figure 5.11: Flowchart for the program

Chapter 6

Final Techno-Commercial Comparison

FINAL TECHNICAL COMPARISION FOR DIFFERENT OPTIONS UNDER PROPOSAL - I AND PROPOSAL - II CONSIDERING 0.85pf AND 75^{0}C TEMPERATURE						
DESCRIPTION		AC RESISTANCE IN (Ω)	AMPACITY IN (AMP)	VOLTAGE REGULATION IN (%)	TOTAL LOSS IN (kW)	EFFICIENCY IN (%)
PROPOSAL I						
Option I :	220kV Double Circuit Transmission line From Hanol-Tiuni To Hatkoti using Single ACSR Zebra Conductor	2.329	733.810	0.710	573.398	98.575
Option II :	66kV Double Circuit Transmission line From Hanol-Tiuni To Hatkoti using Twin ACSR Panther Conductor	4.612	484.103	11.730	5965.100	85.734

Figure 6.1: Technical Comparison For Different Options Under Proposal I

Various proposals have been evaluated in terms of Indian Rs. from commercial point of view and tabulated in the table as Final cost and comparison for different options under proposal-I and proposal-II. The summary of the cost comparison for various options with cost capitalization are shown in table.

Option I	: 220kV Double Circuit Transmission line From Hanol-Tiuni To Selaqui using Single ACSR Zebra Conductor for route	9.835	733.810	3.630	2421.529	93.643
Option II	: 220kV Double Circuit Transmission line From Hanol-Tiuni To Selaqui using Single ACSR Panther Conductor for	19.474	484.103	5.030	5083.078	87.565
Option III	: 132kV Double Circuit Transmission line From Hanol-Tiuni To Selaqui using Single ACSR Panther Conductor for	19.474	484.103	13.560	12600.797	73.115
Option IV	: 220kV Double Circuit Transmission line From Hanol-Tiuni To Selaqui using Single ACSR Zebra Conductor for route	10.008	733.810	3.710	2463.400	93.524
Option V	: 220kV Double Circuit Transmission line From Hanol-Tiuni To Selaqui using Single ACSR Panther Conductor for	19.816	484.103	5.140	5171.847	87.340
Option VI	: 132kV Double Circuit Transmission line From Hanol-Tiuni To Selaqui using Single ACSR Panther Conductor for	19.816	484.103	13.850	12820.731	72.712

Figure 6.2: Technical Comparison For Different Options Under Proposal II

FINAL COST COMPARISON FOR DIFFERENT OPTIONS UNDER PROPOSAL - I AND PROPOSAL - II

DESCRIPTION		1	2	3	4	5	6	7	8	9
		COST OF LINE MATERIAL INCLUDING TOWER IN MILLION (INR)	ERECTION COST IN MILLION (INR)	COST OF S/S AT BOTH ENDS IN MILLION (INR)	TOTAL COST (1+2+3) IN MILLION (INR)	SIMPLE INTEREST ON CAPITAL @ 12% FOR 10 YEARS	TOTAL COST (4+5)	TOTAL CAPITALIZATION OF LOSSES DURING 10 YEARS SPAN IN MILLION (INR)	FINAL COST INCLUDING CAPATILIZATION (6+7)	RANKING
PROPOSAL I										
Option I	: 220kV Double Circuit Transmission line From Hanol-Tiuni To Hatkoti using Single ACSR Zebra Conductor	153	43	180	376	45	421	1406	1827	1
Option II	: 66kV Double Circuit Transmission line From Hanol-Tiuni To Hatkoti using Twin ACSR Panther Conductor	143	22	205	370	44	414	15197	15612	2
Option III	: 66kV Double Circuit Transmission line From Hanol-Tiuni To Hatkoti using Single ACSR Zebra Conductor	105	21	205	331	40	371	15327	15698	3

Figure 6.3: Final Cost Comparison For Different Options Under Proposal I

In Proposal no I three options have been considered.

The capitalization of losses for 10 years as well as the interest on the total capital cost (Column no 4) over a period of 10 years has been added to the total cost. The rankings have been given in the last column. Accordingly in Proposal no. I option no. I i.e 220kV D/C Transmission line from Hanol -Tiuni to Hatkoti using Single ACSR Zebra Conductor is ranking first at Rs 1827 Million. The other two options have a very high price tag. This is basically due to the capitalization of losses. It may be interesting to note that the installed capacity (2 X 30MW) being common for all the options, the current in 220kV will be reduced by 3.33 times. The losses will reduce by a proportion of $3.33^2 = 11.089$. The exact calculation comes to 10.4

PROPOSAL II										
Option I	:	220kV Double Circuit Transmission line From Hanol-Tiuni To Selaqui using Single ACSR Zebra Conductor for route I	594	181	180	955	115	1070	5938	7007	1
Option II	:	220kV Double Circuit Transmission line From Hanol-Tiuni To Selaqui using Single ACSR Panther Conductor for route I	477	155	180	812	97	909	11997	12907	3
Option III	:	132kV Double Circuit Transmission line From Hanol-Tiuni To Selaqui using Single ACSR Panther Conductor for Route I	409	134	246	789	95	884	32054	32938	5
Option IV	:	220kV Double Circuit Transmission line From Hanol-Tiuni To Selaqui using Single ACSR Zebra Conductor for route II	609	203	180	992	119	1111	6041	7152	2
Option V	:	220kV Double Circuit Transmission line From Hanol-Tiuni To Selaqui using Single ACSR Panther Conductor for route II	489	158	180	827	99	926	12207	13133	4
Option VI	:	132kV Double Circuit Transmission line From Hanol-Tiuni To Selaqui using Single ACSR Panther Conductor for Route II	419	138	246	803	96	899	32613	33513	6

Figure 6.4: Final Cost Comparison For Different Options Under Proposal II

and 10.49 respectively for option II and III. This is quite in order.

If the metering is to be done at Hanol Tiuni end, the capitalization of losses will not come into picture and therefore the option no III will be the cheapest option.

From the land consideration, option no II and III do not merit consideration. This is owing to the fact that in the region there is a dearth of leveled land. The construction of 66kV incoming line bays followed by Transformer and extension of 220kV bays will be very difficult for the utility to accept. In any case a 220kV substation proposed by the utility at Hatkoti will need about 25 acres of land. Perhaps this is the holding point in deciding the site by the utility for 220kV substation. Under the circumstances utility may not accept option II and option III. The distinct advantage of option II and III is less ROW and less construction work.**Taking an overall view it is recommended to go in for option I.**

In Proposal no II six options have been considered. Three with each optional route length.

The capitalization of losses for 10 years as well as the interest on the total capital cost (Column no 4) over a period of 10 years has been added to the total cost. The rankings have been given in the last column. Accordingly in Proposal no. II option no. I i.e 220kV D/C Transmission line from Hanol -Tiuni to Selaqui (Sherpur) using Single ACSR Zebra Conductor with alternate route no I which is ranks 1st position with Rs7007 Million, followed by option IV with alternate route no II which is ranking at no 2 at Rs 7152 Million . The other four options have a very high price tag. This is basically due to the capitalization of losses. It may be interesting to note that the installed capacity (2 X 30MW) being common for all the options, the current in 220kV will be reduced by 1.67 times. The losses will reduce by a proportion. Since panther is used as an alternate to Zebra, there will be an increase in resistance. Thus the losses with 132kV option are bound to be more.

If the metering is to be done at Hanol Tiuni end, the capitalization of losses will not come into picture and therefore the option no III of alternate route I followed by option VI of alternate route II will be the cheapest option.

From the land consideration, option no III and VI do not merit consideration. This is owing to the fact that in the region there is a dearth of land (as the proposed substations of PGCIL and UJVNL are on the either banks of the river and also surrounded by populated area) . The construction of 132kV incoming line bays followed by Transformer and extension of 220kV bays will be very difficult for the utility to accept. In any case a 220kV substation proposed by the utility at Selaqui (PGCIL) will need about 35 acres of land. Perhaps this is the holding point in deciding the site by the utility for 220kV substation. Under the circumstances utility may not accept option III and option VI. The distinct advantage of option III and VI is less ROW and less construction work. It may be pertinent to note that 220kV line with panther conductor will cost less compare to Zebra if metering point is at Hanol-Tiuni, otherwise it is much expensive. The utilities may entertain the use standard conductors at 220kV (viz. ACSR Zebra/ Moose)**Taking an overall view it is recommended to go in for option I or option IV.**

Similarly various proposals have been evaluated from technical point of view i.e electrical calculation such as Ampacity, Voltage regulation, Total electrical losses and Efficiency of the conductor. Among the above, efficiency is the important factor while deciding the final option.

In Proposal no I three options have been considered.The voltage regulation is best

in option I and efficiency is also very good compared to option II and III.**Therefore the option I Merits consideration.**
In Proposal no II Six options have been considered.The option I and option no IV gives the best voltage regulation of good efficiency and **therefore the option I with alternate route no I and Option no IV with alternate route no II Merits consideration.**

Recommendations:

A PROPOSAL I-

a. FROM COMMERCIAL POINT OF VIEW-It can be seen that for proposal I option I (i.e. 220kV D/C Transmission line from Hanol-Tiuni to Hatkoti using ACSR Zebra Conductor) is most economical option.
b. FROM TECHNICAL POINT OF VIEW-It can be seen from the above comparative statement the for proposal I, option I (i.e 220kV D/C Transmission line from Hanol-Tiuni to Hatkoti using ACSR Zebra Condcutor) is technically most efficient option.
c. CONCLUSION-It can be clearly seen that from techno-commercial point of view,proposal-I, option-I is the most feasible option and hence recommended.

B PROPOSAL II-

a. FROM COMMERCIAL POINT OF VIEW-It can be seen that for proposal II option I (i.e 220kV D/C Transmission line from Hanol-Tiuni to Selaqui using ACSR Zebra Conductor) is most economical option.
b. FROM TECHNICAL POINT OF VIEW-It can be seen from the above comparative statement the for proposal II, option I (i.e 220kV D/C Trans-

mission line from Hanol Tiuni to Selaqui using ACSR Zebra Condcutor) is technically most efficient option.

c. CONCLUSION-It can be clearly seen that from techno-commercial point of view,proposal-II, option-I and option-IV is the most feasible option and hence recommended.

Chapter 7

UHV NETWORK

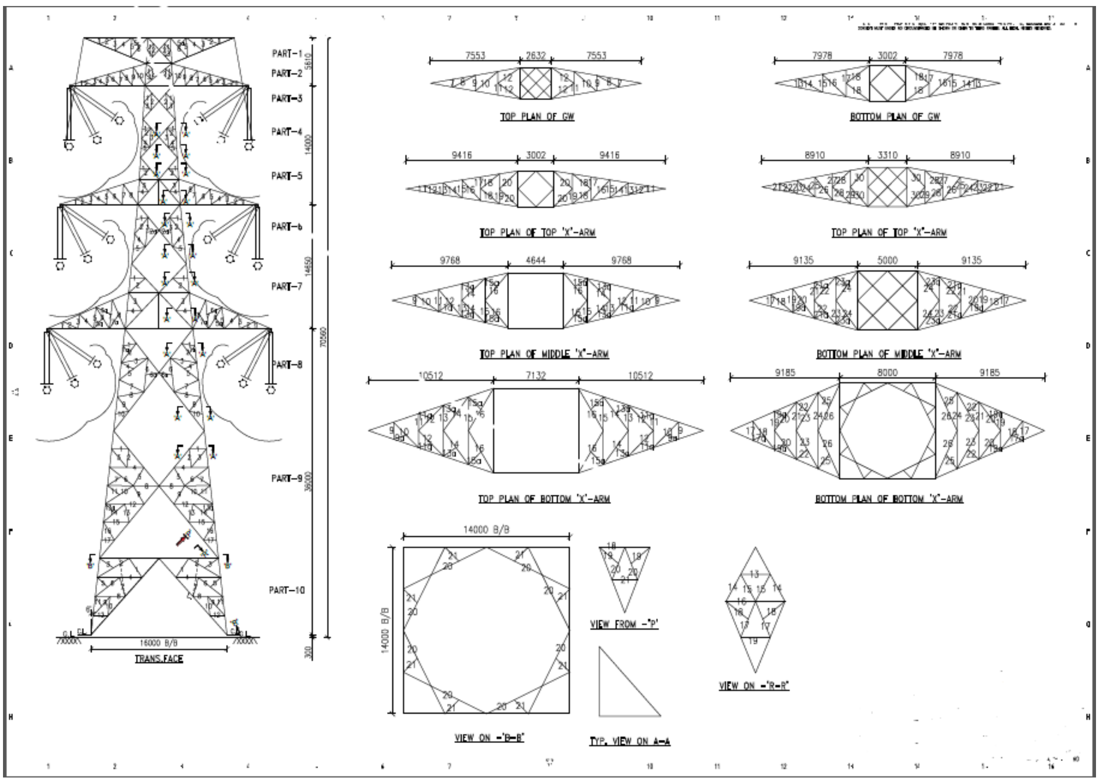


Figure 7.1: Line Dia 765kV Hexa-DC

7.1 Inductance and Capacitance calculation:

Considering the case of a 765kV line using HEXA-ACSR zebra conductor for a line of length 100 kM and capacity of 800MW of power to be transferred.

Table I: Inductance and Capacitance

Parameter	Unit	Value
Total length of transmission line	km	100
Transposed length of the line	km	0
Diameter of conductor	mm	28.62
Radius of conductor	mm	14.31
Spacing between conductors		
Horizontal separation		
Tower center to top conductor (A-Ph)	mm	10917
Tower center to middle conductor (B-Ph)	mm	12090
Tower center to bottom conductor (C-Ph)	mm	14078
Vertical separation	mm	28650
Distance between two subconductors	mm	0
Resistance of the line @ 75^0C	ohm/km	0.08628
Barometric pressure(p)	cm	74
Temperature (θ)	^{0}C	75
Surface factor(m_0)		0.84
Inductance L	(H/phase/km)	0.0008681617
Capacitance C_N	(μ_f/phase/km)	0.013173833
Total Inductance L	(H/phase)	0.08681617
Total Capacitance C_N	(μ_f/phase)	1.3173832

7.2 Voltage Regulation calculation:

Sending End Voltage $V_s = \frac{7650000}{\sqrt{3}}$

=441672.955 volts

magnitude=441672.955 volts

angle=0

Sending End Current $I_s = \frac{Sendingendpower*10^6}{\sqrt{3}*765000}$

$= \frac{1000*10^6}{\sqrt{3}*765000}$

=754.706 amps

magnitude=754.706 amps

angle=-36.86989765

Sending End Power=Sending end power in MVA * p.f

=1000*0.8=800.0 MW

Receiving End Voltage V_r=D*V_s -B*I_s

=421665.2954-11757.5393i volts

magnitude=421829.1848 volts

angle=-1.59

Receiving End Current I_r=-C*V_s + A*I_s

=601.27-631.70i amps

magnitude=872.11 amps

angle=-46.41

Receiving End Power factor($\cos\phi_r$)=cos($angleofI_r \sim angleofV_r$)

=0.7093

Receiving End Power=$\frac{3*|V_r|*|I_r|*\cos\phi_r}{10^6}$

=$\frac{3*421829.1848*872.11*0.7093}{10^6}$=782.89 MW

Voltage Regulation=$\frac{|V_s|-|V_r|}{|V_r|}$*100

=$\frac{441672.955-782.89}{782.89}$*100

=4.71

7.3 Corona loss calculation:

Air density factor: $\delta = \frac{3.86*Barometricpressure(p)}{273+Temperature(\theta)}$

$= \frac{3.86*74}{273+75}$

=0.820804598

Critical Disruptive Voltage: $V_d = \frac{3*10^6}{\sqrt{2}}$ * r * δ * m_0 * $\ln GMD/GMR$ (volts)

$= \frac{3*10^6}{\sqrt{2}}$ * 14.31*10^{-3} * 0.820804598 * 0.84 * $\ln 40186.68275/14.31$

=166189.5217 volts

V_s/V_d=441672.955/166189.5217

=2.7

For this value of V_s/V_d value of F which is the factor varies with ratio V_s/V_d is 0.065

Therefore F=0.065

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

$= \frac{21*10^{-6}*50*(441672.955*10^{-3})^2*0.065}{\log(40186.68275*10^{-3}/14.31*10^{-3})^2}$

=1.1196 (KW/phase/km)

Total Corona loss of the line=3x$P_c$xlength of the line

=3x1.1196x100

=335.88 KW

For D/C total Corona Losses=2xTotal Corona loss of the line

=2x335.88

=671.75

Table II: Corona loss

Corona loss: P_c	KW/phase/km	1.1196
Total Corona loss of the line	KW	335.88
For D/C total Corona Losses	KW	671.75

7.3.1 Line Losses

The losses due to resistance and inductance of the conductor are required to be calculated at different loads on the conductor. The losses are then capitalized for the purpose of comparison of various conductors and find out the break-even point.

Table III: Line Losses

Description	Unit	Value
percent load		100
Sending End Power	MVA	1000
Voltage Rating of the line	KV	765
Total length of transmission line	km	100
Resistance of the line @ 75^0C	ohm/km	0.08628
Power factor		0.8
The total resistance of the line	ohm	2.33
Sending End power	MW	800

Calculation For Line Losses for 100 percent load

At full load sending end power=1000 MVA

Current for circuit per phase=$\frac{SendingEndPower*1000}{\sqrt{3}*VoltageRatingoftheline*6}$

=125.78 A

Line Losses for single conductor per conductor=Current for circuit per $phase^2$ x The total resistance of the line

=125.78^2 x 2.33 x 10^{-3}

=136.54 KW

Total Line Losses For D/C = Line Losses for single conductor per conductor x 6

=136.54x6

=819.25 KW

Percentage line losses = $\frac{TotalLineLossesForD/C}{Fullloadsendingendpower*p.f*1000}$ x 100

=$\frac{819.25}{800*0.8*1000}$x100

=0.10 percent

Percentage Efficiency $=\frac{ReceivingEndPower}{SendingEndPower+TotalCoronaLosses+TotalLineLossesforFullLoad}$*100

$=\frac{782.89*1000}{800*1000+671.75+819.25}$*100

=97.68 percent

Total Line Loss(KWH)= 819.25*365*24

=7176613 KWH

Total Corona Loss(KWH)= 671.75*120*24

=1934648 KWH

Total Power Loss/annum (KWH)=Total Line Loss + Total Corona Loss

=7176613 + 1934648

=9111261 KWH

Total Economic Loss (INR)=Total Power Loss/annum * 5

=9111261*5

=45556306

Table IV: Total Capitalization of losses for 10 years span

Year	Total Economic loss(INR)	Interest	Total capitalization of losses(INR)
Year 1	4,55,56,306	0	4,55,56,306
Year 2	9,11,12,613	31,88,941	9,43,01,554
Year 3	13,66,68,919	63,77,883	14,30,46,802
Year 4	18,22,25,226	95,66,824	19,17,92,050
Year 5	22,77,81,532	1,27,55,766	24,05,37,298
Year 6	27,33,37,838	1,59,44,707	28,92,82,546
Year 7	31,88,94,145	1,91,33,649	33,80,27,794
Year 8	36,44,50,451	2,23,22,590	38,67,73,041
Year 9	41,00,06,758	2,55,11,532	43,55,18,289
Year 10	45,55,63,064	2,87,00,473	48,42,63,537
Total			48,42,63,537

Chapter 8

New Generation Conductors

8.1 Low Resistant Conductors-AL59 Alloy Conductrs

AL-59 alloy conductors are manufactured from Al-Mg-Si (aluminum-magnesium-silica) silicon rods. The conductor comprises an inner core and concentrically arranged strands forming the inner and outer layers of the conductor.

Figure 8.1: AL59 Alloy Conductor

Merits of these conductors are as follows[16]:

- 26 percent to 31 percent more current carrying capacity as compared to ACSR of the same size, while maximum sag remains the same and working tension is lesser than that of ACSR.

- Resistivity is substantially lesser than that of ACSR/AAAC conductors, resulting in lower I^2R losses for the same quantum of power transfer.
- Higher corrosion resistance compared to 6201 alloy series (AAAC) conductors.
- They can be manufactured to maintain dimensions of ACSR/AAAC and ACSR.

If we compare AL 59 conductors with conventional AAAC, ACSR following will be revealed:

- Even though the ultimate tensile strength of the Al59 conductor is less compared to conventional AAAC and ACSR, it can be strung at the same tension like conventional AAAC and ACSR conductors.
- If the same span and the working tension is maintained, the sag of AL 59 conductor will be lower compared to ACSR and AAAC. Thus this conductor can be used for up rating of existing lines as well as for new lines.
- If these conductors are operated at high temperature there will be a quantum jump in Ampacity compared to ACSR/AAAC.

Following numerical data in tabular format shows enhanced option of using Al59 conductor for Re-conductoring in place of existing ACSR conductor:

Table I: Technical Comparison-ACSR Dog and AL59(19/2.84)

Properties	ACSR Dog	AL59(19/2.84)
Conductor Diameter(mm)	14.15	14.20
Weight(Kg/Km)	394.00	330.00
DC Resistance @ 20^0C Temp (ohms/Km)	0.28100	0.24570
Voltage level(KV)	66	66
Line Length(Km)	1	1
Span (meters)	250	250
Maintaining Ampacity equivalent to ACSR in Al59 Conductor		
Temp	75	71.75
Current	280	280
AC Resistance	0.3431	0.2956
Line Losses (KW/circuit)	81	70
Ampacity at maximum operating temp in both conductors		
Temp	75	75
Current	280	397
AC Resistance	0.3431	0.3197
Line Losses (KW/circuit)	81	151
Power Factor	0.9	0.9
Power Transferred in MW/circuit	28	40
sag(Above temp and 0percent wind)	5.25	5.04
Tension(32^0C and 100percent wind)	2033.40	2014.02

The following points can be inferred from the above table:

- Weight of Al59 conductor (kg/km) is 16 percent less as compared to ACSR.
- DC Resistance at 20^0C of Al59 conductor is 13 percent lower as compared to ACSR thus boosting up ampacity and simultaneously decreasing losses.
- Maintaining Ampacity equivalent to ACSR, line losses of AL59 conductor is 14 percent less.

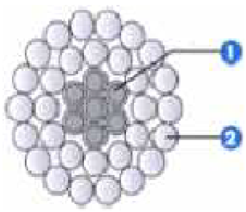


Figure 8.2: 1- Aluminum clad steel, 2-Thermal resistant Aluminum alloy conductor

- Al59 conductor can operate at its maximum temperature of 95^0C as compared to that of ACSR at 75^0C thus boosting up the current by 42 percent as compared to conventional ACSR conductors.
- Power Transferred (MW) of Al59 conductor at its maximum operating temperature is 43 percent higher as compared to that of ACSR.
- Maintaining tension of ACSR at 32^0C and full wind as starting condition in AL59 conductor as in the case of Re-conductoring, we obtain reduction of 4 percent in the values of sag at maximum operating temperature as compared to conventional ACSR conductor.

8.2 HTLS CONDUCTORS-TACSR

TACSR Conductors are high ampacity conductors, wherein the inner core is made of Galvanized Steel and surrounded by heat-resistant aluminum twist-paired with thermal resistant aluminum alloy stranded conductors (surrounded by 1/2/3 layers of thermal resistant aluminum alloy wires).

Different types of aluminum alloy conductor used for the formation of TACSR conductor. The Properties of these alloys are tabulated below:[13]

Table II: Different types of aluminum alloy conductor

Aluminium Alloys	conductivity	Tensile Strength	Temp	CCC
EC 1350	61percent	160Mpa	80^0C	100percent
TAL	60percent	160Mpa	150^0	160percent

These conductors find utility for the following:

- Used in lines where allowable current levels are 1.5-1.6 times higher than conventional ACSR conductors.
- Appropriate for overhead transmission lines in areas where corrosion arising from contact between two different metals may occur.
- Ideal for overhead transmission lines in areas where low-sag limitations are not a problem.
- If the amount of power to be transmitted is fixed, there is a reduction in cost of line components (towers, foundation etc).
- The continuous operating temperature of conductor is 150^0C.
- The conductors with cross section area of 240-1440 mm^2 are widely used in bus bars of switchyard.
- TACSR conductors are used to enhance the capacity of the existing transmission line by simply replacing the existing conductor without any modifications to the tower or foundations.

Following numerical data in tabular format shows enhanced option of using TACSR conductor for Re-conductoring in place of existing ACSR conductor:

Table III: Technical Comparison-ACSR Panther and TACSR Conductor

Properties	ACSR Panther	TACSR Panther
Cross-sectional area (mm^2)	262.00	262.00
Conductor Diameter(mm)	21.00	21.00
Weight(Kg/Km)	974.00	937.00
DC Resistance @ 20^0C Temp (ohms/Km)	0.13900	0.14130
Max operating temp (^{0}C)	75	150
Voltage level(KV)	132	132
Line Length(Km)	1	1
Span (meters)	325	325
Maintaining same Ampacity in TACSR Conductor		
Temp	75	75.34
Current	408	408
AC Resistance	0.1701	0.1731
Line Losses (KW/circuit)	85	86
Power Transferred in MW/circuit	81	81
Ampacity at maximum operating temp in TACSR conductor		
Temp	75	150
Current	408	818
AC Resistance	0.1701	0.2152
Line Losses (KW/circuit)	85	432
Power Factor	0.9	0.9
Power Transferred in MW/circuit	81	163
sag(Above temp and 0percent wind)	7.44	8.68
Tension(32^0C and 100percent wind)	4182.41	4183.04

The following points can be inferred from the above table:

- TACSR conductor can operate at its maximum temperature of 150^0C as compared to that of ACSR at 75^0C, thus boosting up the current by 100 percent as compared to conventional ACSR conductors.
- Power Transferred (MW) of TACSR conductor at its maximum operating temperature is 101 percent higher as compared to that of ACSR.

- If the tension of ACSR conductor is 32^0C and 100 percent wind is maintained, the sag of TACSR conductor is slightly higher but the existing tower structure/design can be utilized by slight reduction in span or by providing extensions.

8.3 HTLS-ACSS

ACSS conductors are manufactured from Annealed Aluminum 1350 wires and an inner high tensile strength core of Galfan (Zn 5 percent Al Mischmetal) coated steel wires or Aluminum Clad steel.

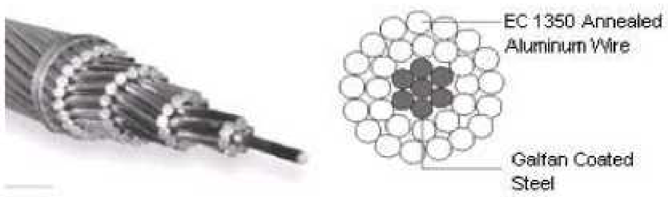


Figure 8.3: ACSS-Aluminium Conductor Steel Supported

Properties of Annealed Aluminum 1350 wires are as follows:

- Annealed Aluminum wire can operate continuously up to 250^0C without any loss in strength (As already Annealed, further strength drop is nil).
- When the complete conductor is stressed, Aluminum elongates and transfers the entire load to steel core.
- Lower compressive forces between annealed Aluminum and Steel Core enables higher self damping capacity because of this increased elongation in annealed Aluminum.

Properties of Mischmetal steel wires are as follows:

Table IV: Comparison between Hard drawn 1350 Al and Annealed Aluminium 1350

Properties	Hard drawn 1350 Al	Annealed Aluminium 1350
Tensile Strength (Mpa)	160	60
Conductivity (percentage IACS)	61.2	63
percentage Elongation	1.2-2	20-30

Table V: Comparison between Galvanized steel and Galfan steel

Properties	Galvanized steel	Galfan steel
Tensile Strength (Mpa)	1410	1410
percentage Elongation	4	4
continuous temp coating can withstand	150/200	250

- Mechanical and physical properties of Mischmetal steel wire are similar to that of the galvanized steel wires.
- Corrosion resistance of Mischmetal steel wires is better than that of galvanized steel wires.

ACSS is a composite concentric-lay stranded conductor. Steel strands form the central core of the conductor with one or more layers of aluminum 1350-0 wire stranded around it. The steel core carries most of all the mechanical load of the conductor due to the (fully annealed or soft) temper aluminum. Steel core wires are protected from corrosion by galvanizing, aluminizing, or mischmetal alloy coating. Corrosion protection can be selected to suit the environment to which the conductor will be exposed during service span.

ACSS conductors are manufactured in accordance with the requirements of the latest applicable ASTM specification B856. The O tempers of the aluminum, a fully annealed or soft temper and causes most or the mechanical load on ACSS to be carried by the steel.

The steel core may consist of 7, 19, 37 or more wires. Class A zinc coating is usually adequate for ordinary environments.

These conductors find the following applications:

- With the same tower loadings an ACSS conductor can carry up to double the current of a ACSR conductor with the same diameter.

- They are especially useful in re-conductoring applications requiring increased current without any change in existing support structures/foundation.

- If used for new lines there can be reduction in the cost of line components (towers, foundations etc) due to reduction in sag for same quantum of power transfer.

- New line constructed using this conductor can take higher emergency load (for short duration).

These conductors have following benefits:

- ACSS can operate continuously at high temperatures (200^0C) without damage; it sags less under emergency electrical loadings than ACSR.

- Self-damping if pre stretched during installation and its final sags are not affected by long time creep of the aluminum.

- High resistance to Aeolian vibration.

- Higher conductivity of the annealed aluminum (63 percent IACS).

Following numerical data in tabular format shows option of using ACSS conductor for Re-conductoring over existing ACSR conductor:

Table VI: Technical Comparison-ACSR Panther and ACSS Lark Conductor

Properties	ACSR Panther	ACSS Lark
Conductor Diameter(mm)	21.00	20.93
Weight(Kg/Km)	974.00	967.00
DC Resistance @ 20^0C Temp (ohms/Km)	0.13900	0.13290
Max operating temp (^{0}C)	75	210
Voltage level(KV)	132	132
Line Length(Km)	1	1
Span (meters)	325	325
Maintaining same Ampacity in ACSS Conductor		
Temp	75	74.17
Current	408	408
AC Resistance	0.1701	0.1622
Line Losses (KW/circuit)	85	81
Power Transferred in MW/circuit	81	81
Ampacity at maximum operating temp in ACSS conductor		
Temp	75	210
Current	408	1023
AC Resistance	0.1701	0.2343
Line Losses (KW/circuit)	85	736
Power Factor	0.9	0.9
Power Transferred in MW/circuit	81	204
sag(Above temp and 0percent wind)	7.44	9.88
Tension(32^0C and 100percent wind)	4182.41	4181.40

The following points can be inferred from the above table:

- DC Resistance at 20^0C of ACSS conductor is 4 percent lower as compared to ACSR thus boosting up ampacity and simultaneously reducing losses.

- Maintaining Ampacity equivalent to ACSR, line losses of ACSS conductor is less by 5 percent.

- ACSS conductor can operate at its maximum temperature of 200/210 ^{0}C as compared to that of ACSR at 75^0C thus boosting up the current carrying capacity by 150 percent as compared to conventional ACSR conductors.

- Power Transferred (MW) of ACSS conductor at its maximum operating temperature is 151 percent higher as compared to that of ACSR.
- If the tension of ACSR conductor is 32^0C and 100 percent wind is maintained, the sag of ACSS conductor is slightly higher but the existing tower structure/design can be utilized by slight reduction in span or by providing extensions.

8.4 HTLS-ACSS(TW)

ACSS/TW (Trapezoidal ACSS) is an enhancement of the original product where the aluminum strands are pre-shaped into wedge-like shapes to fit tightly together and reduce empty spaces between strands.
ACSS-TW (Shaped Wire Compact Concentric-Lay-Stranded Aluminum Conductor Steel Supported) is a concentrically stranded conductor with one or more layers of trapezoidal shaped hard drawn and annealed 1350-0 aluminum wires on a central core of steel.

Figure 8.4: ACSS(TW)-(Trapezoidal ACSS)

Importance of Annealed Aluminum strands:

Both ACSR and ACSS conductors are made from two different metals-aluminum and steel. Consequently, the composite conductor behavior is determined by the combined electrical and mechanical properties of the two materials that make up the conductor. Although ACSR and ACSS are made with 1350 alloy aluminum, their electrical and mechanical properties are very different.

Electrically, the conductivity of hard drawn aluminum in ACSR is 61.2 percent; whereas, soft aluminum has a conductivity of 63 percent relative to copper (100 percent). This means that the soft aluminum in ACSS is more efficient at transmitting power.

Mechanically, the tensile strength (resistance to breaking) of hard drawn aluminum in ACSR is approximately three times that of soft aluminum. This means that the aluminum in ACSS conductor contributes much less to the overall strength, and the composite conductor behaves more like steel.

The TW enhancement to ACSS was transferred from existing technology developed for ACSR (Aluminum Conductor Steel Reinforced) and AAC (All Aluminum Conductor) TW conductors.

ACSS/TW is typically manufactured to meet the aluminum cross-sectional area of a standard round conductor, but allows the overall diameter to be reduced by approximately 10 percent. ACSS/TW can also be manufactured to meet the existing diameter of a standard conductor, incorporating 20 percent to 25 percent more aluminum cross-sectional area.

Difference between ACSS and ACSS-TW is as follows:

- If we consider the same area, a minimum of 10 percent reduction in diameter is observed in ACSS-TW, If we consider the same diameter the aluminum content in ACSS-TW is higher by 20 to 25 percent.

- From the outside ACSS and ACSS/TW conductors look like traditional ACSR. All are manufactured with steel cores and aluminum outer strands.The key difference is that the ACSR aluminum is made from hard drawn aluminum, while ACSS uses soft aluminum (i.e. annealed or "O" temper). In the ACSS/TW trapezoidal conductor, the aluminum strands are not round but trapezoidal shaped.

- When ACSR conductors are operated at temperatures in excess of approximately 93 C, the aluminum starts to anneal. The annealing weakens the conductor and can potentially cause the conductor to break under high wind or ice conditions. To prevent this from happening, utilities generally limit conductor temperatures to 75 C for an ACSR conductor.ACSS/TW and ACSS conductors are manufactured using soft (annealed) aluminum, where operation at higher temperatures has no further effect on the aluminum's tensile strength. Operation of the ACSS product at higher temperature (e.g. 250 C) warrants the use of an enhanced type of galvanizing, which provides more durable high temperature endurance performance (Mischmetal-zinc/aluminum alloy coating). Another option for high temperatures is aluminum clad steel.

Pros and Cons of operating ACSS and ACSS-TW up to 250^0c are as under:

- The higher the current, the hotter the conductor and the greater the power losses. Ideally, lines are designed to minimize these power losses and keep normal day-to-day power loads well below the 200 C operating temperature limits.
- The hotter the conductor, the more it will sag and to compensate, the use of larger and/or stronger structures would be required.
- Electrical current also passes through the conductor joints (splices) and end fittings (dead ends), forming "weak links" that can mechanically and electrically fail because of overheating and Conductor supports and insulators also become more susceptible to failure.

Following are the important features of the conductor:

- ACSS/TW can either be designed to have an equal aluminum cross sectional area as that of a standard ACSS which results in a smaller conductor diameter maintaining the same ampacity level but reduced wind loading parameters or with diameter equal to that of a standard ACSS which results in a significantly higher aluminum area, lower conductor resistance and increased current rating.
- ACSS/TW is designed to operate continuously at elevated temperatures, it sags less under emergency electrical loadings compared to ACSR.
- Excellent self-damping properties.
- Final sags are not affected by long-term creep of aluminum.
- ACSS/TW also provides many design option in new line construction: i.e., reduced tower foundation cost, decreased sag, increased self-damping properties, increased operating temperature and improved corrosion resistance.

Following are the important applications of these conductors:[15]

- The ACSS/TW conductor could enable a tremendous emergency load carrying capability that the utility could call upon when needed.
- Cyclic Loads and Peak Demand can be accommodated using ACSS/TW because it can operate at temperatures higher than ACSR.
- ACSS/TW enables utilities to plan for future situations of increased power requirements because ACSS/TW has power carrying capacity already built into the system.
- Utilities can also turn to ACSS products in situations where they need additional power capacity along existing right-of-ways, but are facing the environmental challenges of building new lines. The ACSS/TW re-conductoring option may be the only solution available to upgrade lines with minimal changes along existing routes

Following numerical data in tabular format shows option of using ACSS-TW conductor for Re-conductoring over existing ACSR conductor:

Table VII: Technical Comparison-ACSR Zebra and ACSS-TW

Properties	ACSR Zebra	ACSS-TW
Conductor Diameter(mm)	28.62	28.62
DC Resistance @ 20^0C Temp (ohms/Km)	0.06868	0.0514
Max operating temp (^{0}C)	75	210
Voltage level(KV)	220	220
Line Length(Km)	1	1
Span (meters)	350	350
Maintaining same Ampacity in ACSS-TW Conductor		
Temp	75	70.48
Current	623	623
AC Resistance	0.0848	0.0631
Line Losses (KW/circuit)	99	73
Power Transferred in MW/circuit	207	207
Ampacity at maximum operating temp in ACSS-TW conductor		
Temp	75	210
Current	623	1829
AC Resistance	0.0848	0.0914
Line Losses (KW/circuit)	99	918
Power Factor	0.9	0.9
Power Transferred in MW/circuit	207	609
sag(Above temp and 0percent wind)	9.26	12.49
Tension(32^0C and 100percent wind)	6007.99	6001.97

The following points can be inferred from the above table:

- DC Resistance at 20^0c of ACSS-TW conductor is 25 percent lower as compared to ACSR, thus boosting up ampacity and simultaneously reducing losses.
- Maintaining Ampacity equivalent to ACSR, line losses of ACSS-TW conductor are 26 percent less.
- ACSS-TW conductor can operate at maximum temperature of $200/210^0$c as compared to that of ACSR at 75^0c, thus boosting up the current by 193 percent (nearly 2 times) as compared to conventional ACSR conductors.

- Power Transferred (MW) of ACSS-TW conductor at its maximum operating temperature is 194 percent higher as compared to that of ACSR.
- If the tension of ACSR conductor is 32^0c and 100 percent wind is maintained, the sag of ACSS-TW conductor is slightly higher but the existing tower structure/design can be utilized by slight reduction in span or by providing extensions.

8.5 HTLS-STACIR

Super Thermal Resistant Aluminum Alloy conductor, INVAR reinforced conductor is manufactured from Super Thermal Aluminum (STAL) alloy wires and the inner core is composed of aluminum clad INVAR (Metal alloy with 36 percent Ni in Steel) wires.

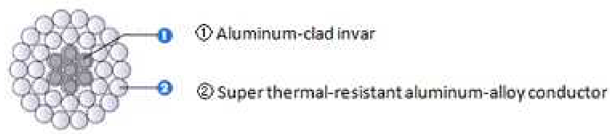


Figure 8.5: STACIR Conductor

This conductor find following applications:
Replacing the installed ACSR/AAAC conductor by STACIR equivalent conductor. STACIR is a solution to up rate existing transmission lines in a short time frame. Modification or reinforcement of the towers is not required.
Following are the properties of INVAR:

- Less Coefficient of linear Expansion-$3.7*10^{-6}$ $/^0$c.
- It is aluminum claded so 14 percent more conductivity.

Following are the benefits of these conductors:

- Possibility to increase the capacity of existing lines by 100percent as compared to ACSR conductors.
- Excellent Sag properties due to INVAR core.
- Modification or reinforcement of the existing towers is very limited or not required.
- With the same tower loadings, STACIR conductor can carry up to two times the current of a conductor with the same diameter.

Following numerical data in tabular format shows option of using STACIR conductor for Re-conductoring over existing ACSR conductor:

Table VIII: Technical Comparison-ACSR Moose and STACIR Conductor

Properties	ACSR Moose	STACIR
Conductor Diameter(mm)	31.77	31.77
Weight(Kg/Km)	2004	1956
DC Resistance @ 20^0C Temp (ohms/Km)	0.05595	0.05409
Max operating temp (^{0}C)	75	210
Voltage level(KV)	400	400
Line Length(Km)	1	1
Span (meters)	400	400
Maintaining same Ampacity in STACIR Conductor		
Temp	75	74.44
Current	706	706
AC Resistance	0.0695	0.0671
Line Losses (KW/circuit)	208	201
Power Transferred in MW/circuit	854	854
Ampacity at maximum operating temp in STACIR conductor		
Temp	75	210
Current	706	2160
AC Resistance	0.0695	0.0758
Line Losses (KW/circuit)	208	2123
Power Factor	0.9	0.9
Power Transferred in MW/circuit	854	2613
sag(Above temp and 0percent wind)	12.87	12.35
Tension(32^0C and 100percent wind)	6601.75	6602.58

The following points can be inferred from the above table:

- DC Resistance at 20^0c of STACIR conductor is 3 percent lower as compared to ACSR thus increasing ampacity and simultaneously reducing losses (since INVAR 14 percent conductivity and Al alloy with 60 percent conductivity).
- Maintaining Ampacity equivalent to ACSR, line losses of STACIR conductor is 3 percent less.
- STACIR conductor can operate at its maximum temperature of 210^0c as com-

pared to that of ACSR at 75^0c thus boosting up the current by 205 percent (nearly 2 times) as compared to conventional ACSR conductors.

- Power Transferred (MW) of STACIR conductor at its maximum operating temperature is 205 percent higher as compared to that of ACSR.
- If the tension of ACSR conductor is 32^0c and 100 percent wind is maintained, the sag of STACIR conductor is slightly higher but the existing tower structure/design can be utilized by slight reduction in span or by providing extensions.

8.6 HTLS-ACCC

Aluminum conductor composite core consists of hybrid carbon and glass fiber core which is wrapped with trapezoidal shaped aluminum strands. The high strength structural core carries most of the conductors mechanical loads, while the fully annealed aluminum strands carries all of the conductors electrical current. ACCC conductor composite core is much lighter and stronger than conventional or high strength steel core.

Figure 8.6: ACCC Conductor

The composite core is 30 percent lighter than aluminum, stronger than steel, and expands at less than 15 percent of steel. This results in savings on tower steel, foundation and losses. (Very less Coefficient of Thermal Expansion=$1.6*10^{-6}/^0$c) ACCC conductors will carry about 28 percent more annealed aluminum in a trapezoidal configuration giving greatly increased conductivity, greater ampacity, reduces line losses and less temperature, without any increase in the conductors overall diameter or weight. The carbon core provides increased strength and dimensional stability which affords fewer or lighter structures on new lines. Lower coefficient of thermal expansion virtually eliminates high temperature sag allowing more efficient operation at up to 175^0c. The carbon fiber core is having strength around 2150 N/mm^2 compare to normal steel 1340 N/mm^2.

ACCC conductor utilizes a high-strength, light-weight and dimensionally stable, single strand, composite core that is wrapped with trapezoidal shaped aluminum strands. Hybrid composite core resists degradation from vibration, corrosion, ultraviolet radiation, corona, chemical and thermal oxidation and most importantly, cyclic load fatigue.

Following are the important features and applications of these conductors:

- Mitigate Thermal Sag - ACCC conductors carbon composite core has a much lower coefficient of thermal expansion compared to steel, aluminum, or other core materials.

- Reduce Line Losses - Under equivalent load conditions, ACCC conductor reduces line losses by 30percent to 40percent compared to other conductors of the same diameter and weight. This is because of lower resistance.

- ACCC conductors additional aluminum content improves conductivity and reduces line losses, which can increase overall system efficiency

- ACCC conductor can reduce the cost of upgrading existing lines or new corridors due to its greater strength, reduced sag, and increased capacity.

- ACCC conductors ability to reduce line losses can provide significant reductions in fuel consumption and their associated emissions from fossil fuel sources or improve the overall efficiency and economic performance of renewable resources. Increased power delivery can also reduce the demand for new sources of energy.

- This conductor does not rust, corrode or cause electrolysis with aluminum conductor or components. This makes this conductor suitable for polluted and oceanic zones.

Following are the applications of these conductors:

1 Reduced line losses in new line:

- Under equal loading conditions reduces line losses by 30 to 40of same diameter and weight.
- 100percent more capacity built towards future demand.

2 Ideal for Re-conductoring on existing lines and for up gradation of existing lines:

- Increases capacity by improving line clearance.
- Reduces strain on structures thus increasing life.

Following numerical data in tabular format shows option of using ACCC conductor for Re-conductoring over existing ACSR conductor:

Table IX: Technical Comparison-ACSR Panther and ACCC Conductors

Properties	ACSR Panther	ACCC Casablanca
Conductor Diameter(mm)	21.00	20.50
Weight(Kg/Km)	974.00	840.00
DC Resistance @ 20^0C Temp (ohms/Km)	0.13900	0.10330
Max operating temp (^{0}C)	75	175
Voltage level(KV)	132	132
Line Length(Km)	1	1
Span (meters)	325	325
Maintaining same Ampacity in ACCC Conductor		
Temp	75	70.15
Current	408	408
AC Resistance	0.1701	0.1247
Line Losses (KW/circuit)	85	62
Power Transferred in MW/circuit	81	81
Ampacity at maximum operating temp in ACCC conductor		
Temp	75	175
Current	408	1041
AC Resistance	0.1701	0.1679
Line Losses (KW/circuit)	85	546
Power Factor	0.9	0.9
Power Transferred in MW/circuit	81	208
sag(Above temp and 0percent wind)	7.44	6.88
Tension(32^0C and 100percent wind)	4182.41	4182.14

The following points can be inferred from the above table:

- DC Resistance at 20^0c of ACCC conductor is 27percent lower as compared to ACSR thus increasing ampacity and simultaneously reducing losses.
- Maintaining Ampacity equivalent to ACSR, line losses of ACCC conductor is 27percent less.
- ACCC conductor can operate at its maximum temperature of 175^0c as compared to that of ACSR at 75^0c thus boosting up the current by 155percent (nearly 2

times) as compared to conventional ACSR conductors.

- Power Transferred (MW) of ACCC conductor at its maximum operating temperature is 157percent higher as compared to that of ACSR.
- If the tension of ACSR conductor is 32^0c and 100percent wind is maintained, the sag of ACCC conductor is slightly higher but the existing tower structure/design can be utilized by slight reduction in span or by providing extensions.

8.7 HTLS-GZTACSR

GTACSR/ GZTACSR (GAP TYPE THERMAL RESISTANT ALUMINUM ALLOY CONDUCTOR) have a unique construction featuring a small gap between the steel core and (super) thermal-resistant aluminum alloy layer.

Figure 8.7: GZTACSR Conductor

The Gap conductor consists of a core of high strength steel, surrounded by a small gap filled with temperature resistant grease and, stacked around this gap, circular layers of trapezoidal (1^{st} layer is Trapezoidal and next layers may be either round or Trapezoidal) aluminum alloy wires. The filling factor of the AlZr (Aluminum Zirconium Alloy) layers can reach 98.5 percent giving the possibility to make optimal use of the maximum acceptable outer diameter of the conductor. (The steel can move freely inside the conductor)

Thermal-resistant aluminum alloy (TAI) and Super thermal-resistant aluminum al-

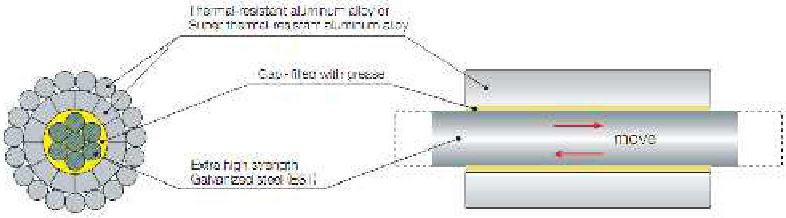


Figure 8.8: GZTACSR Conductor

loy (ZTAI) improve its thermal-resistant characteristics by adding zirconium. ZTAI and TAI can keep its tensile strength in high temperature condition.

TAI can withstand up to 150 deg C and can carry 1.6 times current of hard drawn aluminum (1350).

ZTAI can withstand up to 210 deg C and can carry 2.0 times current of hard drawn aluminum (1350).

Both TAL and ZTAL maintain nearly the same Mechanical and Electrical characteristic as hard drawn aluminum (1350).

Mechanical and Electrical Characteristic of Aluminum Alloy conductor is as follows:

The aluminum alloys used are aluminum zirconium (AlZr). This can be either TAL or ZTAL depending on the current carrying capacity increase required. For both TAL and ZTAL the strength characteristics are not reduced by thermal cycles up to the maximum temperature given in the table below.

Above the stringing temperature the thermal expansion characteristic of the gap

	Continuous	Peak
GTACSR	150	180
GZTACSR	210	240

conductor is that of the steel core, which allows small sag at high operating temperatures. Below the stringing temperature the characteristics are the same as for a mechanically equivalent ACSR conductor. In heavy load conditions (low temperatures, heavy wins, ice) the aluminum is contributing to the strength of the gap conductor.

The important features of these conductors are as follows:

- Extra and Ultra High Strength steel core with adequately tested galvanization and temperature resistance up to 250^0C.
- High temperature grease developed to allow the aluminum to move freely over the steel core while protecting the core from long term corrosion, resistant to temperatures up to 300^0C.
- The first layer consisting of Trapezoidal over which either Trapezoidal or round wire.
- Environmentally friendly surface finish for an emissivity higher than 0.6 from day one.

Facts and Figures of Alloys used in GAP Conductor are as under:

Series of aluminum-zirconium alloys that resisted the annealing effects of high temperatures. These alloys can retain their strength at temperatures $180/230^0$c with respect to TAL/ZTAL wires. T-aluminum conductor INVAR reinforced (GTACSR) is capable of operation up to 150^0c (302^0F), with ZTACSR capable of 210^0c (410^0F). The thermal expansion coefficients of all the conventional steel-cored conductors are governed by both materials together, resulting in a value between that of the steel and that of the aluminum. This behavior relies on the fact that both components are carrying mechanical stress.

However, because the expansion coefficient of aluminum is twice that of steel, stress will be increasingly transferred to the steel core as the conductor's temperature rises. Eventually the core bears all the stress in the conductor. From this point on, the conductor as a whole essentially takes on the expansion coefficient of the core. For a typical 54/7 ACSR (54 aluminum strands, 7 steel) this transition point (also known as the knee-point) occurs around 100^0c (212^0F).

If a conductor could be designed with a core that exhibited a lower expansion coefficient than steel or that exhibited a lower knee-point temperature, more advantage could be taken of the high-temperature alloys. A conductor that exhibits both of

these properties uses Invar, an alloy of iron and nickel. Invar has an expansion coefficient about one-third of steel (2.8 micro strain per Kelvin up to 100^0c, and 3.6 over 100^0c, as opposed to 11.5 for steel).
The principle of the Gap-type conductor is that it can be tensioned on the steel core alone during erection. A small annular Gap exists between a high-strength steel core and the first layer of trapezoidal-shaped aluminum strands, which allows this to be achieved. The result is a conductor with a knee-point at the erection temperature. Above this, thermal expansion is that of steel (11.5 micro strain per Kelvin), while below it is that of a comparable ACSR (approximately 18). This construction allows for low-sag properties above the erection temperature and good strength below it as the aluminum alloy can take up significant load.

Following are the disadvantages of these conductors:

- Generally, Invar is not required in GAP Conductor. If Invar core used, we prefer STACIR and not GAP.
- Gap-type conductor is its complex installation procedure, which requires destranding the aluminum alloy to properly install on the joints. There is also the need for semi-strain assemblies for long line sections (typically every five spans). Gap-type conductor requires about 25 percent more time to install than an ACSR.

Small sag in GAP Conductor is due to the following facts:
At the time of sagging, all tension is applied to the steel core by a special stringing method. As a result, the thermal expansion characteristics of GTACSR/GZTACSR become that of steel core. The thermal expansion coefficient of steel core is 11.5 $X10^{-6}(/^0C)$ and it is approximately half of normal ACSR (around 20 $X10^{-6}(/^0C)$).
GTACSR/GZTACSR has better thermal expansion characteristics than conventional ACSR. So GTACSR/GZTACSR can maintain small sag in high temperature condition.
The following needs to be noted for the accessories used in GAP Conductor:

- The size of dead-end clamp for GTACSR/GZTACSR is slightly larger than conventional ACSR allowing it to carry large current. Other accessories are same as conventional ACSR.
- In case of replacing an existing transmission line, only compression type dead-end clamp should be changed. Other Accessories can be reused.

Benefits of using GAP Conductor are as under:

- Augmentation of line capacity, supporting the emergency loading currents and permanent increment of electric load, maintaining adequate electrical clearances.
- No modification or reinforcement required for existing towers and foundation.
- Low cost and short construction period of lines.

The following points can be inferred from the below table:

- GAP conductor can operate at its maximum temperature of 210^0c as compared to that of ACSR at 75^0c thus boosting up the current by 155 percent (nearly 1.5 times) as compared to conventional ACSR conductors.
- Power Transferred (MW) of GAP conductor at its maximum operating temperature is 156 percent higher as compared to that of ACSR.

Following numerical data in tabular format shows option of using GAP conductor for Re-conductoring over existing ACSR conductor:

Table X: Technical Comparison-ACSR Zebra and GAP Conductor

Properties	ACSR Zebra	GZTACSR 440 SQMM
Conductor Diameter(mm)	28.62	28.5
DC Resistance @ 20^0C Temp (ohms/Km)	0.06868	0.0686
Max operating temp (^{0}C)	75	210
Voltage level(KV)	220	220
Line Length(Km)	1	1
Span (meters)	350	350
Maintaining same Ampacity in GAP Conductor		
Temp	75	75.029
Current	623	623
AC Resistance	0.0848	0.0847
Line Losses (KW/circuit)	99	99
Power Transferred in MW/circuit	207	207
Ampacity at maximum operating temp in GAP conductor		
Temp	75	210
Current	623	1589
AC Resistance	0.0848	0.1214
Line Losses (KW/circuit)	99	920
Power Factor	0.9	0.9
Power Transferred in MW/circuit	207	529

8.8 Parameters for selection of new generation conductors

While selecting a conductor for Re-conductoring applications, following need to be attended to:

- The continuous maximum operating current rating of the existing conductor should be reviewed keeping in view the maximum surface temperature (Ambient

+Heat due to passage of current) of the conductor. This shall not exceed the limit prescribed by the manufacturer (from the deformation point of view).

- The proposed increment in the power flow and resultant increment in the current shall be worked out.
- The Re-survey of the existing line shall be carried out to establish the existing span between the towers and the angle of deviation on each angle tower.
- The stringing chart shall be prepared for this line for existing conductor.
- New Generation conductors will be selected in such a way that mechanical loadings on the tower due to the new conductor shall not exceed the design limits of existing tower.
- If the designs of the existing towers are not available they will be randomly Re-designed with existing conductor and with existing line profile (span and angle of deviation).
- Calculations shall be done to establish the value of the temperature at which the selected new generation conductor satisfies the required current capacity (worked out from the proposed augmentation of power transfer capability).
- Stringing charts shall be prepared for the line once again with the maximum temperature worked out as mentioned in (7) above.
- It shall be ensured that in any of the span the sag do not increase beyond the value worked out for the existing conductor as indicated in (1) and (4) above.
- If the maximum sag in any one of the span in the line is more than that of existing conductor under maximum temperature condition, the selected conductor shall be considered as un suitable.
- Another conductor then shall be selected and the complete procedure as above shall be repeated.The exercise shall continue till desired results are achieved.

- Re conductoring may also include up gradation of lines (increasing the voltage level). The exercise as above. The tower structure may need modification to afford electrical clearances.

- Normally the standard clamp and connectors suitable for ACSR and AAAC conductors can be used for Re-conductoring applications if the New Generation conductor is not likely to attain a maximum temperature of more than 150^0c with augmented power transfer capability. Failing this, clamp and connectors shall be Re-designed to withstand elevated temperature.

While selecting a conductor for application of New Transmission line following need to be attended to:

- The details of maximum power flow expected and the voltage level shall be obtained from the utility/client. Simultaneously the climatic conditions prevailing in the region through which the line is expected to pass shall be obtained.

- It is preferable to carry out Walk over survey along the proposed route of the new transmission line. This is necessary to establish the angle points, power line crossing, railway crossing, river crossing and other obstructions.

- A new generation conductor shall be selected in such a way that it satisfies the desired power transfer capability. The exact surface temperature of the conductor (Ambient +Heat due to passage of current) for the desired power transfer capability shall then be worked out.

- The sag and Tension calculations shall be done for the selected conductor to find out if it can be preferably laid on the type tested towers with /without extensions. The mechanical strength of the existing type tested tower and minimum ground clearance for the voltage rating of the proposed transmission line shall be the criteria.

- If the selected conductor tails to meet the requirement of power flow and or mechanical strength of the existing tower, the exercise as in (4) above shall be repeated.

- If the proposed transmission line with proposed deployment of new generation conductors is very long (say more than 100 km) and the time available for construction is more than 18 months, the utility/client concerned can decide up on whether to opt for tested tower design or to develop tailor made designs and resort to the proto model tower testing.
- The clamp and connectors shall be designed to suite to the proposed new generation conductor.

Chapter 9

Results

Table I: Technical Comparison-ACSR Dog and its equivalent Conductors

Properties	ACSR Dog	TACSR	STACIR	ACCC Helsinki	AL-59 (19/2.84)	AAAC (19/2.89)
Cross-sectional area (mm^2)	118.50	118.50	118.50	181.70	120.00	124.6
Conductor Diameter(mm)	14.15	14.15	14.16	15.65	14.20	14.45
Modulus of Elasticity (kg/cm^2)	775000	775000	674100	655453.61	693407.00	693407.00
Co-efficient of Linear Expansion (/0C)	$19.8 * 10^{-6}$	$11.5 * 10^{-6}$	$3.7 * 10^{-6}$	$1.61 * 10^{-6}$	$23 * 10^{-6}$	$23 * 10^{-6}$
Weight (Kg/Km)	394.00	394.00	394.00	479.70	330.00	342
UTS (kgf)	3309.00	3785.00	3309.00	7034.00	3072.00	3736.00
DC Resistance @ 20^0C Temp (ohms/Km)	0.28100	0.27805	0.28100	0.18610	0.24789	0.26540

Max operating temp (^{0}C)	85	150	210	175	95	95
Voltage level(kV)	66	66	66	66	66	66
No. of cond/ph	1	1	1	1	1	1
No. of ckts	1	1	1	1	1	1
Line Length(Km)	1	1	1	1	1	1
Span (meters)	250	250	250	250	250	250
Case 1: Maintaining same current as that of ACSR Dog at its maximum operating temp						
Temp	85	84.63	85.05	70.54	80.23	82.35
Current	386	386	386	386	386	386
AC Resistance (ohms/km)	0.3543	0.3502	0.3544	0.2241	0.3079	0.3318
Line Losses (KW/circuit)	158	157	158	100	138	148
Power Factor	0.85	0.85	0.85	0.85	0.85	0.85
Power Transferred in MW/circuit	36	36	36	36	36	36
sag(Above temp and 0percent wind)	5.60	4.82	4.24	5.48	5.20	5.55
Tension(32^{0}C and 100percent wind)	2015.47	2015.13	2015.99	2017.22	2015.496	2015.42
Case 2: Maintaining same sag as that of ACSR Dog at its maximum operating temp						
Temp	85	123.5	NA	113	90.23	83.50
Current	386	524	NA	622	436	392
AC Resistance (ohms/km)	0.3543	0.3934	NA	0.2556	0.317794	0.3331

Line Losses (KW/circuit)	158	324	NA	296	181	153
Power Factor	0.85	0.85	NA	0.85	0.85	0.85
Power Transferred in MW/circuit	36	49	NA	59	41	37
sag(Above temp and 0percent wind)	5.60	5.60	NA	5.60	5.60	5.60
Tension(32^0C and 100percent wind)	2015.47	2015.13	NA	2017.22	2015.496	2015.42
Case 3: Current in Amp at maximum continuous operating temp						
Temp	85	150	210	175	95	95
Current	386	588	689	803	457	443
AC Resistance (ohms/km)	0.3543	0.4228	0.4947	0.3018	0.3225	0.3453
Line Losses (KW/circuit)	158	439	705	584	202	203
Power Factor	0.85	0.85	0.85	0.85	0.85	0.85
Power Transferred in MW/circuit	36	36	36	36	36	36
sag(Above temp and 0percent wind)	5.60	4.82	4.24	5.48	5.20	5.55
Tension(32^0C and 100percent wind)	2015.47	2015.13	2015.99	2017.22	2015.496	2015.42

Table II: Saving per single circuit

Saving per single circuit as in case1						
Cost of Conductor per km in INR	55,000	74,250	330,000	247,500	66000	77,000
Cost of power loss in INR 4/- per kW	5536320	5501280	5536320	3504000	4835520	5185920
Cost of power tranferred w/o losses in INR 4/- per kW	1261440000	1261440000	1261440000	1261440000	1261440000	1261440000
Revenue generated in INR 4/-	1255903680	1255938720	1255903680	1257936000	1256604480	1256254080
Additional Revenue generated as compared to ACSR in INR	—	35040	0	2032320	700800	350400
Saving per single circuit as in case2						
Cost of power loss in INR 4/- per kW	5536320	11352960	NA	10371840	6342240	5361120
Cost of power tranferred w/o losses in INR 4/- per kW	1261440000	1716960000	NA	2067360000	1436640000	1296480000
Revenue generated in INR 4/-	1255903680	1705607040	NA	2056988160	1430297760	1291118880
Additional Revenue generated as compared to ACSR in INR	—	449703360	NA	801084480	174394080	35215200

Saving per single circuit as in case3						
Cost of power loss in INR 4/- per kW	5536320	15382560	24703200	20463360	7078080	7113120
Cost of power tranferred w/o losses in INR 4/- per kW	1261440000	1927200000	2277600000	2663040000	1506720000	1471680000
Revenue generated in INR 4/-	1255903680	1911817440	2252896800	2642576640	1499641920	1464566880
Additional Revenue generated as compared to ACSR in INR	—	655913760	996993120	1386672960	243738240	208663200

We can see that when Acsr dog is compared with its equivalent new generation conductors, ACCC Helsinki is the best conductor as the line losses are minimum, sag is within limit, maximum power transfer capability is double. When the sag is maintained same as in ACSR Dog then the power transferred is more.
Similarlty we find that at 132kV ACCC Lisbon conductor is best and at 220kV ACCC Kolkata is best.

Chapter 10

Conclusion and Future Scope

10.1 Conclusion

With the increase in the pace of the development of power infrastructure, large no. of transmission lines having voltage class of 66kv, 132kv, 220kv, 400kv and 765kv are required to be constructed all over the country.

Before the electricity Act 2003 came in to existence, the power generation, transmission and distribution was the sole domain of state utility Boards. But now large no. of private players have entered in to the development of transmission sector. Thus, the element of competition is added in the power business. It has therefore become necessary to evaluate the construction of transmission line from no. of technical and commercial angles. Use of optimized designs of transmission line, deployment of new type of line materials, use of new generation conductors etc. has become very much important. It is concluded that proper attention to each and every aspect of design and engineering of transmission line matters much.

10.2 Recommendations

The selection of voltage level will depend up on the system to which the new transmission line is to be connected. If the new line is part of a standalone system, the voltage level can be selected depending up on the generator voltage, transformation ratio and voltage level of actual power consumption.

The cost of ROW along the route of the transmission line shall be one of the main criteria for selection of new generation conductor for the selected voltage level. Therefore, it is necessary to work out cost economics while deploying new generation conductors. For longer lines losses are important and therefore while selecting the conductor for new long transmission line the loss factor shall also be tower in to account.

10.3 Future Scope

This work can be extended in future for:

- 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).

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Appendix A

Appendix: Program

```
function varargout = projectui(varargin)
gui_Singleton = 1;
gui_State = struct('gui_Name',       mfilename, ...
                   'gui_Singleton',  gui_Singleton, ...
                   'gui_OpeningFcn', @projectui_OpeningFcn, ...
                   'gui_OutputFcn',  @projectui_OutputFcn, ...
                   'gui_LayoutFcn',  [] , ...
                   'gui_Callback',   []);
if nargin && ischar(varargin{1})
    gui_State.gui_Callback = str2func(varargin{1});
end

if nargout
    [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
else
    gui_mainfcn(gui_State, varargin{:});
end

function projectui_OpeningFcn(hObject, eventdata, handles, varargin)
set(handles.ACPanel,'Visible','Off')
set(handles.IACPanel,'Visible','Off')
set(handles.IAAPanel,'Visible','Off')
set(handles.LLPanel,'Visible','Off')
set(handles.VRPanel,'Visible','Off')
set(handles.EPanel,'Visible','Off')
set(handles.CLPanel,'Visible','Off')
set(handles.COLPanel,'Visible','Off')
guidata(hObject, handles);

function varargout = projectui_OutputFcn(hObject, eventdata, handles)
function COE_Callback(hObject, eventdata, handles)
function COE_CreateFcn(hObject, eventdata, handles)

if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end


function T1_Callback(hObject, eventdata, handles)
handles.temperatureT1 = str2double(get(hObject,'String'));
guidata(hObject, handles)

function T1_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
```

```
function DCRt_Callback(hObject, eventdata, handles)
handles.DCResisAtT1 = str2double(get(hObject,'String'));
guidata(hObject, handles)

function DCRt_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function D_Callback(hObject, eventdata, handles)
handles.DiameterOfConductor = str2double(get(hObject,'String'));
guidata(hObject, handles)

function D_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function WV_Callback(hObject, eventdata, handles)
handles.WindVelocity = str2double(get(hObject,'String'));
```

```
guidata(hObject, handles)
function WV_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function Ta_Callback(hObject, eventdata, handles)
handles.AvgAmbientTemperature = str2double(get(hObject,'String'));
guidata(hObject, handles)

function Ta_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end



function Tc_Callback(hObject, eventdata, handles)
handles.AvgConductorTemperature = str2double(get(hObject,'String'));
guidata(hObject, handles)

function Tc_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
```

```
function SR_Callback(hObject, eventdata, handles)
handles.SolarRadiation = str2double(get(hObject,'String'));
guidata(hObject, handles)
```

```
function SR_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function SA_Callback(hObject, eventdata, handles)
handles.SolarAbsorpCoeff = str2double(get(hObject,'String'));
guidata(hObject, handles)


function SA_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function TCR_Callback(hObject, eventdata, handles)
handles.TemperatCoeffOfResis = str2double(get(hObject,'String'));
guidata(hObject, handles)

function TCR_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function F_Callback(hObject, eventdata, handles)
handles.Freq = str2double(get(hObject,'String'));
guidata(hObject, handles)

function F_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function L_Callback(hObject, eventdata, handles)
handles.PermeabilityVal = str2double(get(hObject,'String'));
guidata(hObject, handles)
```

```
function L_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function P_Callback(hObject, eventdata, handles)
handles.LenOfLine = str2double(get(hObject,'String'));
guidata(hObject, handles)
```

```
function P_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
```

```
function Untitled_1_Callback(hObject, eventdata, handles)

function Calculate_Callback(hObject, eventdata, handles)
skinEffectTbl=[0,1;0.01,1;0.02,1;0.03,1;0.04,1;0.05,1;0.06,1;0.07,1;0.08,1;0.09,1;0.1,1;0.11,1.00
0001;0.12,1.000002;0.13,1.000003;0.14,1.000004;0.15,1.000005;0.16,1.000006;0.17,1.000007;0.18,1.0
00008;0.19,1.000009;0.2,1.00001;0.21,1.000013;0.22,1.000016;0.23,1.000019;0.24,1.000022;0.25,1.00
0025;0.26,1.000028;0.27,1.000031;0.28,1.000034;0.29,1.000037;0.3,1.00004;0.31,1.000049;0.32,1.000
058;0.33,1.000067;0.34,1.000076;0.35,1.000085;0.36,1.000094;0.37,1.000103;0.38,1.000112;0.39,1.00
0121;0.4,1.00013;0.41,1.000149;0.42,1.000168;0.43,1.000187;0.44,1.000206;0.45,1.000225;0.46,1.000
244;0.47,1.000263;0.48,1.000282;0.49,1.000301;0.5,1.00032;0.51,1.000355;0.52,1.00039;0.53,1.00042
5;0.54,1.00046;0.55,1.000495;0.56,1.00053;0.57,1.000565;0.58,1.0006;0.59,1.000635;0.6,1.00067;0.6
1,1.000727;0.62,1.000784;0.63,1.000841;0.64,1.000898;0.65,1.000955;0.66,1.001012;0.67,1.001069;0.
68,1.001126;0.69,1.001183;0.7,1.00124;0.71,1.001328;0.72,1.001416;0.73,1.001504;0.74,1.001592;0.7
5,1.00168;0.76,1.001768;0.77,1.001856;0.78,1.001944;0.79,1.002032;0.8,1.00212;0.81,1.002248;0.82,
1.002376;0.83,1.002504;0.84,1.002632;0.85,1.00276;0.86,1.002888;0.87,1.003016;0.88,1.003144;0.89,
1.003272;0.9,1.0034;0.91,1.003579;0.92,1.003758;0.93,1.003937;0.94,1.004116;0.95,1.004295;0.96,1.
004474;0.97,1.004653;0.98,1.004832;0.99,1.005011;1,1.00519;1.01,1.005429;1.02,1.005668;1.03,1.005
907;1.04,1.006146;1.05,1.006385;1.06,1.006624;1.07,1.006863;1.08,1.007102;1.09,1.007341;1.1,1.007
58;1.11,1.007893;1.12,1.0082146;1.13,1.00854394;1.14,1.008880246;1.15,1.009222821;1.16,1.00957103
9;1.17,1.009924335;1.18,1.010282202;1.19,1.010644182;1.2,1.01071;1.21,1.011109;1.22,1.011508;1.23
,1.011907;1.24,1.012306;1.25,1.012705;1.26,1.013104;1.27,1.013503;1.28,1.013902;1.29,1.014301;1.3
,1.0147;1.31,1.015199;1.32,1.015698;1.33,1.016197;1.34,1.016696;1.35,1.017195;1.36,1.017694;1.37,
1.018193;1.38,1.018692;1.39,1.019191;1.4,1.01969;1.41,1.020303;1.42,1.020916;1.43,1.021529;1.44,1
.022142;1.45,1.022755;1.46,1.023368;1.47,1.023981;1.48,1.024594;1.49,1.025207;1.5,1.02582;1.51,1.
026561;1.52,1.027302;1.53,1.028043;1.54,1.028784;1.55,1.029525;1.56,1.030266;1.57,1.031007;1.58,1
.031748;1.59,1.032489;1.6,1.03323;1.61,1.034112;1.62,1.034994;1.63,1.035876;1.64,1.036758;1.65,1.
03764;1.66,1.038522;1.67,1.039404;1.68,1.040286;1.69,1.041168;1.7,1.04205;1.71,1.043085;1.72,1.04
412;1.73,1.045155;1.74,1.04619;1.75,1.047225;1.76,1.04826;1.77,1.049295;1.78,1.05033;1.79,1.05136
5;1.8,1.0524;1.81,1.0536;1.82,1.0548;1.83,1.056;1.84,1.0572;1.85,1.0584;1.86,1.0596;1.87,1.0608;1
.88,1.062;1.89,1.0632;1.9,1.0644;1.91,1.065776;1.92,1.067152;1.93,1.068528;1.94,1.069904;1.95,1.0
7128;1.96,1.072656;1.97,1.074032;1.98,1.075408;1.99,1.076784;2,1.07816;2.01,1.079719;2.02,1.08127
8;2.03,1.082837;2.04,1.084396;2.05,1.085955;2.06,1.087514;2.07,1.089073;2.08,1.090632;2.09,1.0921
91;2.1,1.09375;2.11,1.095501;2.12,1.097252;2.13,1.099003;2.14,1.100754;2.15,1.102505;2.16,1.10425
6;2.17,1.106007;2.18,1.107758;2.19,1.109509;2.2,1.11126;2.21,1.113203;2.22,1.115146;2.23,1.117089
;2.24,1.119032;2.25,1.120975;2.26,1.122918;2.27,1.124861;2.28,1.126804;2.29,1.128747;2.3,1.13069;
2.31,1.132828;2.32,1.134966;2.33,1.137104;2.34,1.139242;2.35,1.14138;2.36,1.143518;2.37,1.145656;
2.38,1.147794;2.39,1.149932;2.4,1.15207;2.41,1.154401;2.42,1.156732;2.43,1.159063;2.44,1.161394;2
.45,1.163725;2.46,1.166056;2.47,1.168387;2.48,1.170718;2.49,1.173049;2.5,1.17538;2.51,1.177898;2.
52,1.180416;2.53,1.182934;2.54,1.185452;2.55,1.18797;2.56,1.190488;2.57,1.193006;2.58,1.195524;2.
59,1.198042;2.6,1.20056;2.61,1.203257;2.62,1.205954;2.63,1.208651;2.64,1.211348;2.65,1.214045;2.6
6,1.216742;2.67,1.219439;2.68,1.222136;2.69,1.224833;2.7,1.22753;2.71,1.230397;2.72,1.233264;2.73
,1.236131;2.74,1.238998;2.75,1.241865;2.76,1.244732;2.77,1.247599;2.78,1.250466;2.79,1.253333;2.8
,1.2562;2.81,1.259224;2.82,1.262248;2.83,1.265272;2.84,1.268296;2.85,1.27132;2.86,1.274344;2.87,1
.277368;2.88,1.280392;2.89,1.283416;2.9,1.28644;2.91,1.289605;2.92,1.29277;2.93,1.295935;2.94,1.2
991;2.95,1.302265;2.96,1.30543;2.97,1.308595;2.98,1.31176;2.99,1.314925;3,1.31809;3.01,1.321383;3
.02,1.324676;3.03,1.327969;3.04,1.331262;3.05,1.334555;3.06,1.337848;3.07,1.341141;3.08,1.344434;
3.09,1.347727;3.1,1.35102;3.11,1.354422;3.12,1.3578333;3.13,1.36125297;3.14,1.364680173;3.15,1.36
8114156;3.16,1.37155424;3.17,1.374999816;3.18,1.378450335;3.19,1.381905301;3.2,1.38504;3.21,1.388
535;3.22,1.39203;3.23,1.395525;3.24,1.39902;3.25,1.402515;3.26,1.40601;3.27,1.409505;3.28,1.413;3
.29,1.416495;3.3,1.41999;3.31,1.423561;3.32,1.427132;3.33,1.430703;3.34,1.434274;3.35,1.437845;3.
```

```
36,1.441416;3.37,1.444987;3.38,1.448558;3.39,1.452129;3.4,1.4557;3.41,1.459332;3.42,1.462964;3.43
,1.466596;3.44,1.470228;3.45,1.47386;3.46,1.477492;3.47,1.481124;3.48,1.484756;3.49,1.488388;3.5,
1.49202;3.51,1.495697;3.52,1.499374;3.53,1.503051;3.54,1.506728;3.55,1.510405;3.56,1.514082;3.57,
1.517759;3.58,1.521436;3.59,1.525113;3.6,1.52879;3.61,1.532498;3.62,1.536206;3.63,1.539914;3.64,1
```

```
.543622;3.65,1.54733;3.66,1.551038;3.67,1.554746;3.68,1.558454;3.69,1.562162;3.7,1.56587;3.71,1.5
69597;3.72,1.573324;3.73,1.577051;3.74,1.580778;3.75,1.584505;3.76,1.588232;3.77,1.591959;3.78,1.
595686;3.79,1.599413;3.8,1.60314;3.81,1.606877;3.82,1.610614;3.83,1.614351;3.84,1.618088;3.85,1.6
21825;3.86,1.625562;3.87,1.629299;3.88,1.633036;3.89,1.636773;3.9,1.64051];

temperaturePropertiesTbl=[0,0.061759,1.2927,0.024245;5,0.06265,1.2703,0.024606;10,0.063545,1.2478
,0.025;15,0.064438,1.2254,0.025361;20,0.06533,1.2046,0.025722;25,0.066074,1.1854,0.026083;30,0.06
6967,1.1661,0.026476;35,0.06786,1.1469,0.026837;40,0.068604,1.1277,0.027231;45,0.069497,1.1101,0.
027592;50,0.07039,1.0941,0.027953;55,0.071134,1.0764,0.028346;60,0.072027,1.0588,0.028707;65,0.07
2771,1.0444,0.029068;70,0.073515,1.03,0.029462;75,0.074408,1.0156,0.029823;80,0.075152,1.0044,0.0
30217;85,0.075896,0.098674,0.030577;90,0.07664,0.97393,0.030938;95,0.077533,0.95951,0.031234;100,
0.078277,0.94669,0.031693];

epsilon=str2double(get(handles.COE,'String'));
t1=str2double(get(handles.T1,'string'));
Rt1=str2double(get(handles.DCRt,'string'));
D=str2double(get(handles.D,'string'));
v=str2double(get(handles.WV,'string'));
ta=str2double(get(handles.Ta,'string'));
tc=str2double(get(handles.Tc,'string'));
S=str2double(get(handles.SR,'string'));
a=str2double(get(handles.SA,'string'));
alpha=str2double(get(handles.TCR,'string'));
f=str2double(get(handles.F,'string'));
mu=str2double(get(handles.P,'string'));
l=str2double(get(handles.L,'string'));
lt=str2double(get(handles.TL,'string'));
Aph=str2double(get(handles.APH,'string'));
Bph=str2double(get(handles.BPH,'string'));
Cph=str2double(get(handles.CPH,'string'));
Vseparation=str2double(get(handles.VS,'string'));
DistBW2Conductors=str2double(get(handles.DBC,'string'));
SendingEndVoltage_V=str2double(get(handles.SEV,'string'));
PercentageLoad=str2double(get(handles.PL,'string'));
SendingEndPower_MW=str2double(get(handles.SEPMW,'string'));
SendingEndPF=str2double(get(handles.SEPF,'string'));
SendingEndPower_MVA=str2double(get(handles.SEPMVA,'string'));
BarometricPressure=str2double(get(handles.BP,'string'));
Temperature=str2double(get(handles.T,'string'));
radius = D/2;
delta_t=tc-ta;
Ka=ta+273;
Kc=tc+273;




%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%AMPACITY
Rdc=Rt1*(1+alpha*(tc-t1));
X = 0.063598*(sqrt(f*mu/Rdc));
```

```
Xrounded = round(X*100)/100;
K=skinEffectTbl(skinEffectTbl(:,1)==Xrounded,2);

Rac = K*Rdc;

R=Rac*l;

tf=(tc+ta)/2;
if rem(tf,5)==0
    muf=temperaturePropertiesTbl(temperaturePropertiesTbl(:,1)==tf,2);
    Pf=temperaturePropertiesTbl(temperaturePropertiesTbl(:,1)==tf,3);
    Kf=temperaturePropertiesTbl(temperaturePropertiesTbl(:,1)==tf,4);
else
    tf_ceil = ceil(tf/5)*5;
    tf_floor = floor(tf/5)*5;

    muf_ceil = temperaturePropertiesTbl(temperaturePropertiesTbl(:,1)==tf_ceil,2);
    muf_floor = temperaturePropertiesTbl(temperaturePropertiesTbl(:,1)==tf_floor,2);
    muf = muf_floor + rem(tf,5)*((muf_ceil-muf_floor)/(tf_ceil-tf_floor));

    Pf_ceil = temperaturePropertiesTbl(temperaturePropertiesTbl(:,1)==tf_ceil,3);
    Pf_floor = temperaturePropertiesTbl(temperaturePropertiesTbl(:,1)==tf_floor,3);
    Pf = Pf_floor + rem(tf,5)*((Pf_ceil-Pf_floor)/(tf_ceil-tf_floor));

    Kf_ceil = temperaturePropertiesTbl(temperaturePropertiesTbl(:,1)==tf_ceil,4);
    Kf_floor = temperaturePropertiesTbl(temperaturePropertiesTbl(:,1)==tf_floor,4);
    Kf = Kf_floor + rem(tf,5)*((Kf_ceil-Kf_floor)/(tf_ceil-tf_floor));
end

Qs=a*S*D/1000;
Qr=(0.17838e-6)*epsilon*(D/1000)*(Kc^4-Ka^4);
Qc1=(1.00531+((1.35088*((D/1000)*Pf*v)/muf)^0.52))*Kf*(tc-ta);
Qc2=(0.75398*((((D/1000)*Pf*v)/muf)^0.6))*Kf*(tc-ta);
if Qc1>Qc2
    Qc=Qc1;
else
    Qc=Qc2;
end
I=sqrt((Qc+Qr-Qs)/(Rac*(10^-3)))

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%INDUCTANCE andCAPACITANCE

r=D/2;%radius of conductor
%/////////////Calculation of Inductance
Dab=sqrt(Vseparation^2+(Bph-Aph)^2);
Dab_=sqrt(Vseparation^2+(Bph+Aph)^2);
Dba=Dab;
Dba_=Dab_;




               DAB=sqrt(Dab*Dab_);
```

```
Dbc=sqrt(Vseparation^2+(Cph-Bph)^2);
Dbc_=sqrt(Vseparation^2+(Cph+Bph)^2);
Dcb=Dbc;
Dcb_=Dbc_;
DBC=sqrt(Dbc*Dbc_);

Dca=sqrt((Vseparation*2)^2+(Aph-Cph)^2);
Dca_=sqrt((Vseparation*2)^2+(Aph+Cph)^2);
Dac=Dca;
Dac_=Dca_;
DCA=sqrt(Dca*Dca_);

Deq = (DAB*DBC*DCA)^(1/3);

Daa=r*0.7788;
Da_a_=Daa;
Daa_=Aph*2;
Da_a=Daa_;
DSA=sqrt(Daa*Daa_);

Dbb=Daa;
Db_b_=Dbb;
Dbb_ = Bph*2;
Db_b=Dbb_;
DSB=sqrt(Dbb*Dbb_);

Dcc=Daa;
Dc_c_=Dbb;
Dcc_=Cph*2;
Dc_c=Dcc_;
DSC=sqrt(Dcc*Dcc_);

SelfGMD_inductance=(DSA*DSB*DSC)^(1/3);

InductanceM=(2*(10^(-7)))*log(Deq/SelfGMD_inductance);

InductanceKM=InductanceM*1000

%/////////////////Calculation of Capacitance
Daa=r;
Da_a_=Daa;
Daa_=Aph*2;
Da_a=Daa_;
DSA=sqrt(Daa*Daa_);

Dbb=Daa;
Db_b_=Dbb;
Dbb_ = Bph*2;
```

```
Db_b=Dbb_;
DSB=sqrt(Dbb*Dbb_);
```

```
Dcc=Daa;
Dc_c_=Dbb;
Dcc_=Cph*2;
Dc_c=Dcc_;
DSC=sqrt(Dcc*Dcc_);

SelfGMD_capacitance=(DSA*DSB*DSC)^(1/3);

CapacitanceKM=0.02412/log10(Deq/SelfGMD_capacitance);

TotalInductanceOfLine = InductanceKM*l;
TotalCapacitanceOfLine = CapacitanceKM*l;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Impedance and Admittance
TotalResistanceOfLine = ceil(Rac*l*100)/100;
TotalReactanceOfLine = ceil(2*3.14*TotalInductanceOfLine*f*100)/100;

Impedance = complex(TotalResistanceOfLine,TotalReactanceOfLine);
Impedance_Magnitude=round(abs(Impedance)*100)/100;
Impedance_Angle=ceil(angle(Impedance)*(180/pi)*100)/100;

TotalConductance=0;%for capacitor
TotalPermittance=ceil(2*3.14*TotalCapacitanceOfLine*f)/1000000;

Admittance = complex(TotalConductance,TotalPermittance);
Admittance_Magnitude=abs(Admittance);
Admittance_Angle=angle(Admittance)*(180/pi);

ZY=Impedance*Admittance;
ZY_Magnitude=abs(ZY);
ZY_Angle=angle(ZY)*(180/pi);

Param_A = 1+ZY/factorial(2);
Param_D=Param_A;
Param_B=Impedance*(1+(ZY/factorial(3))+((ZY).^2/factorial(5)));
Param_C=Admittance*(1+(ZY/factorial(3))+((ZY).^2/factorial(5)));

SendingEndVoltage_PerPhase=complex(SendingEndVoltage_V/sqrt(3),0);
SendingEndCurrent_Is_magnitude=SendingEndPower_MVA*1000000/(SendingEndVoltage_V*sqrt(3));
SendingEndCurrent_Is_angle=-acos(SendingEndPF);
SendingEndCurrent_Is=complex(abs(SendingEndCurrent_Is_magnitude)*cos(SendingEndCurrent_Is_angle),
abs(SendingEndCurrent_Is_magnitude)*sin(SendingEndCurrent_Is_angle));

ReceivingEndVoltage_Vr=Param_D*SendingEndVoltage_PerPhase-Param_B*SendingEndCurrent_Is;
ReceivingEndCurrent_Ir=-Param_C*SendingEndVoltage_PerPhase+Param_A*SendingEndCurrent_Is;

ReceivingEndPF=cos(abs(angle(ReceivingEndCurrent_Ir)-angle(ReceivingEndVoltage_Vr)));
ReceivingEndPower=3*abs(ReceivingEndVoltage_Vr)*abs(ReceivingEndCurrent_Ir)*ReceivingEndPF/100000

VoltageRegulation =
((abs(SendingEndVoltage_PerPhase)-abs(ReceivingEndVoltage_Vr))*100)/abs(ReceivingEndVoltage_Vr);
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Corona Loss
AirDensityFactor=3.86*BarometricPressure/(273+Temperature);
CriticalDisruptiveVoltage_Vd=(3000000/sqrt(2))*(radius/1000)*AirDensityFactor*0.84*log(Deq/radius
);
V_by_Vd=SendingEndVoltage_PerPhase/CriticalDisruptiveVoltage_Vd;
%for this V/Vd,
F=0.065;
CoronaLoss_Pc=((21/1000000) * f * ((SendingEndVoltage_PerPhase/1000)^2) * F ) /
(log10(Deq/radius)^2);
TotalCoronaLossOfLine=3*CoronaLoss_Pc*1;
TotalCoronaLossForDC = 2*TotalCoronaLossOfLine;
%%%%%%%%%%%Line losses for single acsr zebra conductor
Current_PerPhase=(SendingEndPower_MVA*1000)/(220*sqrt(3))
LineLossesOfSingleConductorPerConductor=(Current_PerPhase^2)*TotalResistanceOfLine/1000;
TotalLineLossesForDC=LineLossesOfSingleConductorPerConductor*6
PercentageLineLosses=TotalLineLossesForDC/(SendingEndPower_MVA*SendingEndPF*1000)*100
%50% load
PercentLoad=50;
TotalCurrent_50=PercentLoad/100*Current_PerPhase
LossesForSingleConductor_50=(TotalCurrent_50^2)*TotalResistanceOfLine/1000
TotalLineLosses_50=LossesForSingleConductor_50*6
%100% load
PercentLoad=100;
TotalCurrent_100=PercentLoad/100*Current_PerPhase
LossesForSingleConductor_100=(TotalCurrent_100^2)*TotalResistanceOfLine/1000
TotalLineLosses_100=LossesForSingleConductor_100*6
%%%%%%%%%%%%Efficiency for Single ACSR Zebra Conductor
PercentEfficiency=(ReceivingEndPower*1000)/(SendingEndPower_MW*1000+TotalCoronaLossForDC+TotalLin
eLossesForDC)*100
%Efficiency at different load of 220 kv dc line with...
%50
PercentLoad=50;
SendingEndPower_kW_50=PercentLoad/100*SendingEndPower_MW*1000;
ReceivingEndPower_kW_50=PercentLoad/100*ReceivingEndPower*1000;
PercentEfficiencyWithCoronaLoss_50=ReceivingEndPower_kW_50/(TotalCoronaLossForDC+TotalLineLosses_
50+SendingEndPower_kW_50)*100;
PercentEfficiencyWithoutCoronaLoss_50=ReceivingEndPower_kW_50/(TotalLineLosses_50+SendingEndPower
_kW_50)*100;
%100
PercentLoad=100;
SendingEndPower_kW_100=PercentLoad/100*SendingEndPower_MW*1000;
ReceivingEndPower_kW_100=PercentLoad/100*ReceivingEndPower*1000;
PercentEfficiencyWithCoronaLoss_100=ReceivingEndPower_kW_100/(TotalCoronaLossForDC+TotalLineLosse
s_100+SendingEndPower_kW_100)*100;
PercentEfficiencyWithoutCoronaLoss_100=ReceivingEndPower_kW_100/(TotalLineLosses_100+SendingEndPo
wer_kW_100)*100;

%%%%%%%%%%Total Capitalization of losses for 10 years span of Single ACSR Zebra conductor
TotalLineLoss_kWh=TotalLineLosses_100*365*24
TotalCoronaLoss_kWh=TotalCoronaLossForDC*120*24
```

```
TotalPowerLossPerAnnum_kWh=TotalLineLoss_kWh+TotalCoronaLoss_kWh
TotalEconomicLoss=TotalPowerLossPerAnnum_kWh*5
```

```
TotalCapitalization = ones(10,5);
initPowerLoss=TotalPowerLossPerAnnum_kWh*5;
for i=1:10
    TotalCapitalization(i,1)= i;
    TotalCapitalization(i,2)=initPowerLoss*i;
    if i==1
        TotalCapitalization(i,3)=0;
    else
        TotalCapitalization(i,3)=TotalCapitalization(i-1,2)*0.07;
    end
    TotalCapitalization(i,4)=TotalCapitalization(i,2)+TotalCapitalization(i,3);
    if i==1
        TotalCapitalization(i,5)=TotalCapitalization(i,4);
    else
        TotalCapitalization(i,5)=TotalCapitalization(i,4)+TotalCapitalization(i-1,5);
    end

end
```

```
set(handles.lblRdc,'String',Rdc);
set(handles.lblRac,'String',Rac);
set(handles.lblQs,'String',Qs);
set(handles.lblQr,'String',Qr);
set(handles.lblQc,'String',Qc);
set(handles.lblI,'String',I);
set(handles.lblDeq,'String',Deq);
set(handles.lblGMD_L,'String',SelfGMD_inductance);
set(handles.lblL,'String',InductanceKM);
set(handles.lblC,'String',CapacitanceKM);
set(handles.lblGMD_C,'String',SelfGMD_capacitance);
set(handles.lblL_Total,'String',TotalInductanceOfLine);
set(handles.lblC_Total,'String',TotalCapacitanceOfLine);
set(handles.lblR,'String',TotalResistanceOfLine);
set(handles.lblX,'String',TotalReactanceOfLine);
set(handles.lblZ,'String',num2str(Impedance));
set(handles.lblY,'String',num2str(Admittance));
set(handles.lblIs,'String',num2str(SendingEndCurrent_Is));
set(handles.lblVr,'String',num2str(ReceivingEndVoltage_Vr));
set(handles.lblIr,'String',num2str(ReceivingEndCurrent_Ir));
set(handles.lblRPF,'String',ReceivingEndPF);
set(handles.lblREP,'String',ReceivingEndPower);
set(handles.lblVoltageRegulation,'String',VoltageRegulation);
set(handles.lblPc,'String',CoronaLoss_Pc);
set(handles.lblTCL,'String',TotalCoronaLossOfLine);
set(handles.lblTCLDC,'String',TotalCoronaLossForDC);
set(handles.lblIp,'String',Current_PerPhase);
set(handles.lblLs,'String',LineLossesOfSingleConductorPerConductor);
set(handles.lblLsDC,'String',TotalLineLossesForDC);
set(handles.lblPLL,'String',PercentageLineLosses);
set(handles.lblPEWCL,'String',PercentEfficiencyWithCoronaLoss_100);
```

```
set(handles.lblPEWOCL,'String',PercentEfficiencyWithoutCoronaLoss_100);
set(handles.lblTLLKWH,'String',TotalLineLoss_kWh);
```

```
set(handles.lblTCLKWH,'String',TotalCoronaLoss_kWh);
set(handles.lblTPLPA,'String',TotalPowerLossPerAnnum_kWh);
set(handles.lblTEL,'String',TotalEconomicLoss);
set(handles.lblTC,'String',TotalCapitalisation(10,5));

set(handles.ACPanel,'Visible','On');


function TL_Callback(hObject, eventdata, handles)
handles.TransposedLength = str2double(get(hObject,'String'));
guidata(hObject, handles)

function TL_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function APH_Callback(hObject, eventdata, handles)
handles.HorizontalSeparationAPh = str2double(get(hObject,'String'));
guidata(hObject, handles)

function APH_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function BPH_Callback(hObject, eventdata, handles)
handles.HorizontalSeparationBPh = str2double(get(hObject,'String'));
guidata(hObject, handles)

function BPH_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function CPH_Callback(hObject, eventdata, handles)
```

```
handles.HorizontalSeparationCPh = str2double(get(hObject,'String'));
guidata(hObject, handles)

function CPH_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function VS_Callback(hObject, eventdata, handles)
handles.VerticalSeparation = str2double(get(hObject,'String'));
guidata(hObject, handles)
```

```
function VS_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function DBC_Callback(hObject, eventdata, handles)
handles.Distbetw2cond = str2double(get(hObject,'String'));
guidata(hObject, handles)

function DBC_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function SEV_Callback(hObject, eventdata, handles)

handles.SendingendVoltage = str2double(get(hObject,'String'));
guidata(hObject, handles)
function SEV_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function PL_Callback(hObject, eventdata, handles)
handles.PercentageLoad = str2double(get(hObject,'String'));
guidata(hObject, handles)

function PL_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function SEPMW_Callback(hObject, eventdata, handles)
handles.SendingendPowerMW = str2double(get(hObject,'String'));
guidata(hObject, handles)

function SEPMW_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function SEPF_Callback(hObject, eventdata, handles)
handles.Sendingendp.f = str2double(get(hObject,'String'));
guidata(hObject, handles)

function SEPF_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
```

```
function SEPMVA_Callback(hObject, eventdata, handles)
handles.SendingendPowerMVA = str2double(get(hObject,'String'));
```

```
guidata(hObject, handles)
function SEPMVA_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end



function BP_Callback(hObject, eventdata, handles)
handles.BarometricPressure = str2double(get(hObject,'String'));
guidata(hObject, handles)
function BP_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function T_Callback(hObject, eventdata, handles)
handles.Temperature = str2double(get(hObject,'String'));
guidata(hObject, handles)

function T_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end


function pushbutton2_Callback(hObject, eventdata, handles)
function OP_SELECT_Callback(hObject, eventdata, handles)
set(handles.ACPanel,'Visible','Off')
set(handles.IACPanel,'Visible','Off')
set(handles.IAAPanel,'Visible','Off')
set(handles.LLPanel,'Visible','Off')
set(handles.VRPanel,'Visible','Off')
set(handles.EPanel,'Visible','Off')
set(handles.CLPanel,'Visible','Off')
set(handles.COLPanel,'Visible','Off')
switch get(hObject,'Value')
    case 1
        set(handles.ACPanel,'Visible','On')
    case 2
        set(handles.IACPanel,'Visible','On')
    case 3
        set(handles.IAAPanel,'Visible','On')
    case 4
        set(handles.LLPanel,'Visible','On')
    case 5
        set(handles.VRPanel,'Visible','On')
    case 6



        set(handles.EPanel,'Visible','On')
    case 7
        set(handles.CLPanel,'Visible','On')
```

```
    case 8
        set(handles.COLPanel,'Visible','On')
end



function OP_SELECT_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end


function OP_AC_CreateFcn(hObject, eventdata, handles)
```

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