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Application of High-Capacity Conductors for Uprating Transmission Lines Capacity in Nepal

by

Yadab Prasad Neupane

A THESIS

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Application of High-Capacity Conductors for Uprating Transmission Lines Capacity in Nepal

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Institute of Engineering, Pulchowk Campus

Tribhuvan University

Lalitpur, Nepal

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DECLARATION

I hereby declare that the work reported in this thesis entitled "**Application of High-Capacity Conductors for Uprating Transmission Lines Capacity in Nepal**" submitted to the Institute of Engineering, Department of Electrical Engineering, Pulchowk Campus, is my original work done in partial fulfillment of the requirement for the degree of **Master of Science in Power System Engineering** under the supervision of **Prof. Nava Raj Karki, PhD** of Institute of Engineering, Pulchowk Campus. Related works on the topic by other researchers have been duly acknowledged. I owe all the liabilities relating to the accuracy and authenticity of the data and any other information included hereunder.

…………………….

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CERTIFICATE OF APPROVAL

The undersigned certify that they have read and recommended to the Institute of Engineering for acceptance, a thesis report entitled "**Application of High-Capacity Conductors for Uprating Transmission Lines Capacity in Nepal**" submitted by **Yadab Prasad Neupane** in partial fulfillment of the requirement for the degree of **Master of Science in Power System Engineering**.

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ABSTRACT

Electricity demand and market penetration in Nepal is increasing day by day due to increased industrialization, expand urbanization, large population density, change in energy consumption habits of the consumers etc. Utility has to face multiple challenges to expand new transmission line in urban and semi-urban areas due to lack of availability of corridors triggered by the high real-estate cost, infrastructure development, forest/ecology conversation etc. Additionally, transmission line projects usually have limited execution schedule to comply with the increased load demand and project completion to match with new hydropower projects. To maximize the power transfer per unit RoW, replacing the old ACSR conductors with newly developed HTLS conductors would be the best solution which have higher power transfer capacity in the order of 2 to 3 times. Moreover, it can be completed in lesser time span without any significant work and budget plan vis-à-vis a new line. The same transmission line footprint might be used without any major modification in the existing tower.

Load flow analysis of the INPS using the tool: DigSilent PowerFactory 15.1. is carried out at different generation scenario considering the maximum load constant throughout the study. Total internal generation of 2438.72 MW and maximum load of 2054.59 MW is recorded from secondary sources which are interconnected in INPS. At 100% generation scaling, load flow result is noted with the surplus power of 230.07MW and the grid losses of 154.06 MW which accounts the loss of 6.31% of the total system in-feed. At that scenario, ten (10) 132kV line sections (515.82 ckt.-km length of ACSR Bear and 28 ckt.-km of ACSR Panther) is found to be overloaded by more than 100%. Maximum line loading of 167.22% is noted at Dhalkebar-Mirchaiya section (ACSR Bear) followed by 154.44% at Kusaha-Kataiya (ACSR Bear) section. Gandak-Bardaghat line section having ACSR Panther conductor is also noted to be overloaded by 116.03%. At decreased internal generation, power deficit is fulfilled by the external in-feed which caused the total grid power loss to increase gradually. Critical 132kV line sections found at 100% generation scaling are considered for further analysis to use equivalent HTLS conductor. Replacement of insulators along with erection accessories are also considered in the study.

ACCC OSLO conductor having equivalent cross section, weight per unit length and meeting required ultimate tensile strength is considered as equivalent conductor and found the most compactible for both ACSR conductor types. 'IEEE 738 Standard' is applied to calculate the derated current carrying capacity of the candidate HTLS conductor under NEA service condition which is found to be 2.45 times higher than ACSR Bear and 2.84 times higher than ACSR Panther conductor for the value of maximum allowable current which is quite satisfactory to consider as an equivalent conductor. Line loading is reduced drastically at all critical line section after conductor uprating viz. a maximum value of 62.78% at Lamosanghuv- Khimti section and 54.83% at Dhalkebar - Mirchaiya section. Line loading value of 25.57% is minimum at Gandak- Bardaghat section. It is also remarkable that the surplus power in INPS generation is found to be 245.67 MW which is more by 15.60 MW than the case before. It means grid power loss is decreased by 15.60 MW which is only 5.67% of total internal generation and it was 6.31% before conductor replacement.

Sag-tension analysis of old ACSR and HTLS ACCC OSLO conductors is also carried out using PLS-CADD tool to study the behavior at different weather cases. It's all complied the required criteria for not violating the existing sag at any operating temperature condition of each individual conductor.

Total cost estimated for conductor replacement is found to be USD 25.798 Million which is almost equivalent to set up a new 15.60 MW hydropower plant and it is considered as an analogy of grid power loss reduction after conductor replacement.

The test of old ACSR conductors, insulators, erection hardware and fitting accessories etc. is recommended as per prevailing IS/BS at accredited laboratory to find the remaining useful life and its technical viability to re-use in new/old transmission lines.

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This thesis research entitled “Application of High-Capacity Conductors for Uprating Transmission Lines Capacity in Nepal” has been prepared in partial fulfillment of the requirements of the degree of Master of Science in Power System Engineering at Institute of Engineering, Pulchowk Campus. This research may not complete with my sole effort, many helping hands have made contributions personally and professionally to bring out in shapes. I cannot remain without acknowledging their contributions.

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Yadab Prasad Neupane

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AAAC	All Aluminum Alloy Conductor
AAC	All Aluminum Conductor
AACSR	Aluminum Alloy Conductor Steel Reinforced
AC	Alternating Current
ACSR	Aluminum Conductor Steel Reinforced
ACSS	Aluminum Conductor Steel Supported
BS	British Standard
CTE	Coefficient of Thermal Expansion
DC	Direct Current
DIgSILENT	DIgital SImuLation and Electrical NeTwork calculation program
GWh	Giga-Watt Hour
GZTACSR	Gap Type Super Thermal Resistant Aluminum Conductor Steel Reinforced
HTLS	High Temperature Low Sag
HVAC	High Voltage Alternating Current
HVDC	High Voltage Direct Current
IEEE	Institute of Electrical and Electronics Engineers
INPS	Integrated Nepal Power System
IRR	Internal Rate of Return
IS	Indian Standard
km	Kilo Meter
kV	Kilo-Volt
KWh	Kilowatt Hour
MoE	Modulus of Elasticity
MW	Mega-Watt
MVar	Mega Var
NEA	Nepal Electricity Authority
NPV	Net Present Value
PLS-CADD	Power Line System – Computer Aided Design and Drafting
PPA	Power Purchase Agreement
SZTACIR	Super Thermal Resistant Aluminum Conductor Invar Reinforced
TACSR	Thermal Resistant Aluminum Conductor Steel Reinforced

ABSTRACT

Electricity demand and market penetration in Nepal is increasing day by day due to increased industrialization, expand urbanization, large population density, change in energy consumption habits of the consumers etc. Utility has to face multiple challenges to expand new transmission line in urban and semi-urban areas due to lack of availability of corridors triggered by the high real-estate cost, infrastructure development, forest/ecology conversation etc. Additionally, transmission line projects usually have limited execution schedule to comply with the increased load demand and project completion to match with new hydropower projects. To maximize the power transfer per unit RoW, replacing the old ACSR conductors with newly developed HTLS conductors would be the best solution which have higher power transfer capacity in the order of 2 to 3 times. Moreover, it can be completed in lesser time span without any significant work and budget plan vis-à-vis a new line. The same transmission line footprint might be used without any major modification in the existing tower.

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CHAPTER 1
INTRODUCTION

1.1 Overview

Almost all the existing transmission lines in Nepal are overhead due to economy. Existing high voltage transmission line in Nepal are 78 Circuit Kilometers (Ckt. km) length of Dhalkebar-Muzzarffarpur 400 kV Cross Border Transmission Line, 524.60 Ckt. km length of 220 kV including 5 Ckt. km length of 220 kV Double Circuit Underground in Matatirtha – Matatirtha Substation in Kathmandu; 3,459.54 Ckt. km length of 132 kV Transmission Line and 514.46 Ckt. km length of 66 kV Transmission Line. Further to note that 754 Ckt. km length of 400 kV, 930 Ckt. km length of 220 kV and 1,430 Ckt. km length of 132 kV Transmission Line are under construction in Nepal. Similarly, the total high voltage substations capacity in operation till the last fiscal year 2078/079, having voltage ratings from 400/220kV to 33/11kV is 7148.60MVA. It was 6433.90 MVA at the end of the fiscal year of 2077/078, hence there was total increment of 714.70 MVA capacity in the last FY 2078/079. Substation capacity under construction is 9,719.50 MVA, voltage rating from 132kV to 400kV [20]. Those transmission lines are developed with direct funding from GoN and donor agencies; distribution capacity is also enhancing. Many international and national firms are also engaged in design and consulting services of these transmission lines and substation projects.

Demand of the electricity and market penetration is increasing day by day due to change in social and working habits of the modern society. After getting free from its scheduled power cuts to the consumers, Nepal Electricity Authority (NEA) efforts is dedicated to ensure the supply of continuous, reliable and affordable power to its consumers [15]. NEA should initiate to make the overall power system more robust with significant investment into transmission and distribution system for their strengthening.

In densely populated urban and semi-urban areas where the cost of the real-estates is increasing with multiple folds, construction of new transmission and distribution lines has been a major challenge to NEA. Continuous opposition of the land owners, for the establishment of new lines have been a common problem for most of the construction projects under NEA, generally in the urban and semi-urban areas. In this scenario, NEA has to rethink about upgrading the transmission capacity with adopting modern practices such that same transmission footprints may be used with newly developed high-capacity conductors, also called High Temperature Low Sag (HTLS) conductors in place of ACSR conductors.

1.2 Problem Statement

In today's electricity market in Nepal, energy consumption pattern is growing gradually due to industrialization; expand urbanization, population growth along with change in energy consumption habits of the consumers. Transmission and distribution lines are designed to carry the optimum load but the subsequent result of the act of large power transfer is overloading the existing lines capacity.

NEA has to face many challenges in development of the new transmission line basically due to the following reasons:

a) **Right of Way Limits:** Lack of accessibility of right of ways for development of new line projects owing to high real state cost as a result of large population, infrastructure development and forest conversation.

b) **Time constraints:** it is required to construct the new transmission line in limited time schedule. It necessitates the completion of new projects to comply with increased load growth and completion of those line projects to match with new hydropower projects.

Due to increasing the real-estate costs, cost of deforestation and replantation of plants at new location along with regular opposition of the land owners, establishment of new transmission lines have been a common challenge for delaying the projects beyond schedule. On these grounds, government has to rethink to amend the prevailing acts, regulations and directives to address the public concerns such that it opens the route for completion of the projects in schedule. Whereas NEA as an implementing agency, it has to plan to upgrade the transmission capacity of the existing lines using high-capacity conductors so that large power can be transmitted at the load center with small investment. In another way, to relieve the transmission congestion, NEA has to upgrade the capacity of its transmission system.

Building a new overhead transmission line is an expensive and longtime investment, increasing the transmission capacities of existing lines is an unavoidable necessity. It is assumed that capacity of existing lines can be increased with replacing the old

ACSR conductor by HTLS conductors with some investment and it's be a good solution to meet the increased electricity demand rather to build the new transmission lines. Those high-capacity conductors can carry higher current and reduces the line loss compared to conventional ACSR conductors. Re-conductoring rapidly provides the substantial line capacity increase at the lowest cost.

1.3 Research Objective

Main objective of the research is noted in the following points:

a) To study the current-temperature relationship of conductors under NEA service conditions to calculate the derated current carrying capacity.
b) To analyze the load flow to find the critical line sections.
c) To study the sag-tension analysis of the old and new proposed HTLS conductors at different weather condition.
d) To analyse the cost for replacing the conductor with new one.

1.4 Assumptions for the research

Following assumptions are considered to meet the scope of the research:

a) Study is limited to the 132kV overhead lines in INPS.
b) Accuracy and reliability of the data received from the secondary sources largely governs the correctness of the load flow output to find the critical lines.
c) Deficit power is provided by the swing bus during load flow study.
d) Derated current carrying capacity is analyzed based on prevailing service condition of NEA.
e) Protection and insulation systems are sufficient to supply the increased power flow after conductor replacement.
f) Replacement of high-capacity conductor is proposed only for the critical line sections.

1.5 Limitations of the Study

Following limitations are not considered during research:

a) Shut down cost of the operating transmission lines for dismantling the existing ACSR conductors and stringing the new HTLS conductors are not considered.

b) Indirect cost which might be involved in the conductor replacement is also not considered for the cost analysis.
c) Analysis of the cost of capital, benefit cost ratio, cash outflow after investment, timeline for the project execution etc. are beyond the scope of the study.

1.6 Outline of Thesis

The thesis is organized as follows:

The first chapter discusses about the background introduction of the topic, problem statement, objective along with assumptions and limitations of the research.

In the second chapter, literature review about development of HTLS conductor and its adoption in NEA, methods for increasing power transfer capability of transmission lines, literature review of IEEE 738 “IEEE Standard for Calculating the Current- Temperature Relationship of Bare Overhead Conductors”, Load Flow Study, Sag-Tension Calculation methods, Financial/cost Analysis using NPV and IRR calculation etc. are discussed. Additionally, different research papers by the prominent authors in adoption of HTLS conductor for the same are also explained.

The third chapter explains about the methodology applied for this research in detail. This includes the input parameters, study of Current - Temperature Characteristics of Conductors, Sag-tension analysis of the overhead conductor, cost analysis, degradation of ACSR conductors etc. are discussed.

In the fourth chapter, the results obtained after simulating different cases and their significance are discussed. Technical data sheet of the various conductors are considered and their impact on the results are analyzed. Further, critical line sections are identified with load flow study and it is proposed to replace with the suitable high-capacity conductor and the results are summarized.

The fifth chapter concludes the result of this thesis. Also, the recommendation for the additional works as an extension of this thesis is also outlined in this chapter.

CHAPTER 2
LITERATURE REVIEW

2.1 Background

Power transfer capacity over transmission lines can be increased following four techniques:

a) Increasing line voltage:

For increasing the line voltage level in the existing transmission lines, electrical clearance has to be increased [11]. It requires the change in insulation level to meet the requirements of the new operating voltage, strengthening the transmission line towers and change the erection hardware, accessories etc. Further, substation equipment capacity also needs to increase for increased voltage level. Voltage uprating results potentially higher power transfer but the cost of investment and time required to implement is quite high.

b) Addition of Electric Circuit in Tower:

This can probably be an option of adding electrical circuit in the existing lattice tower structures. Unfortunately, most of the existing transmission line tower structures in Nepal are not designed to accommodate the additional electric circuits.

c) Conversion of AC to DC:

Large power transfer also can be achieved using HVDC transmission lines. However, the cost of HVDC terminal stations is extremely high and it might be a feasible choice for transferring power at a distance beyond 600 km [1]. So, this is not a good choice for transmitting large electricity power in Nepal.

d) Increasing ampacity of power conductors:

For increasing the ampacity of the existing transmission lines, we have the following options [11]:

(i) Use of High Capacity Conductor in place of conventional conductors:

Replacing existing ACSR conductor with higher sized conventional ACSR conductors might be a good option rather to plan for a new transmission line. But, replacing with higher sized conductors would add extra loading in the tower structures. Thermal sag associated with the conventional conductors would also be a concern to consider for this choice.

(ii) Increasing the operating temperature of the existing conductor:

This option is possible when the line is operating below maximum temperature due to the sag restriction. In this method, height of the tower needs to be increased to increase the ground clearance of the conductor, increasing height is also an expensive option.

(iii)Increasing conductor cross section:

In this option, existing ACSR conductor is replaced with the bundled conductor with larger cross section. However, use of higher size conductor increases the loading at the towers, so that it requires to strengthen the tower capacity along with hardware and accessories etc, so, this option is also an expensive option.

(iv) Re-conductoring with high-capacity conductor:

In this method, existing conductor is replaced with higher ampacity conductor with equivalent geometry and weight per unit length. This method does not require to reinforce or replace the existing the tower structures. This method has been used worldwide in many overhead transmission lines.

2.2 Construction Challenges in Nepal for Transmission Lines

Nepal Electricity Authority has to face many challenges in development of the new transmission line basically due to the following reasons:

a) Right of Way Limits: Limited convenience of right of ways for construction of new lines due to large real state cost as a result of large population growth, infrastructure development and forest and/or ecological conversation [18].

b) Time Limits: it is required to construct the new transmission line is limited time schedule. It necessitates the completion of new construction project in line with increased load demand and transmission line to match with generation projects.

To adopt with the above challenges, it may require the following selections:

2.2.1 Adoption of EHV levels: power transmission at extra high voltage may be useful for bulk power transfer however it may require large investment and longer time span.

2.2.2 Adoption of multi-circuit towers may useful at densely populated and high land valued area to reduce the environmental impact of the line.

2.2.3 Up-gradation of transmission lines: existing line may be operated at higher voltage provided that the tower structures and insulation requirement may comply the required technical criteria [18].

2.2.4 Uprating of transmission lines through [18]

a) High-tech conductors can be used for increasing power transfer per unit RoW, which can carry bulk power without any change in the existing tower or may require minor changes. Those high-tech conductors can carry the power as much as 2 to 2.5 times without any substantial investment of time and money as required for a new line.

b) HTLS conductors can be operated at high temperature (180-210 ℃). Such feature deals for higher current carrying capacity as compared to the equivalent ACSR conductor without significant increase in sag.

c) We can also add the additional electrical circuits in the existing towers without violating the maximum tower loading.

d) For new transmission lines, we may use HTLS conductors in place of conventional ACSR conductors. This choice also reduces the use of bundle ACSR conductor thereby resulting in material savings in tower and foundations along with reduced construction effort, time, cost etc.

Above voltage up-gradation and current uprating techniques can be structured in the following figure:

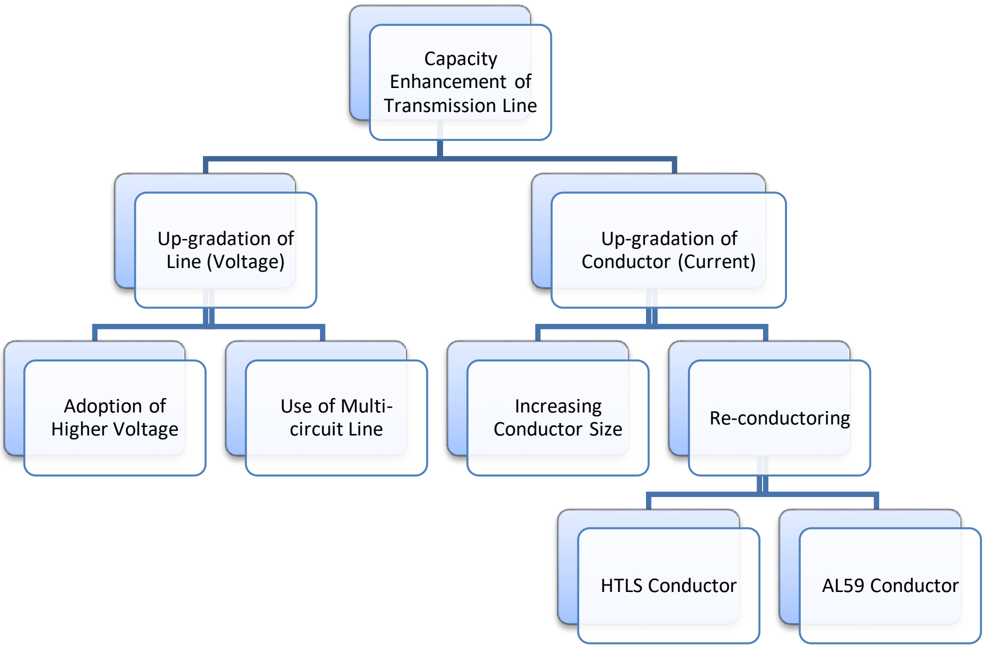


Figure 2.1 Voltage and Current Up-gradation in Transmission Line

2.2.5 AL59 Conductor

AL-59 alloy conductors [19] are manufactured from Al-Mg-Si (aluminium-magnesium-silica) rods. The conductor comprises of an inner core and concentrically arranged strands forming the inner and outer layers of the conductor.

ACSR conductors are limited by a maximum current carrying capacity of 838 amperes (ACSR Moose at 75 °C). The material of construction of AL-59 alloys conductors overcome this limitation enabling AL-59 alloy conductors to transfer up to 1307 amperes of current (56 per cent higher than ACSR Conductors). Additionally, AL-59 alloy conductors have 9 % better 'strength to weight ratio' and 8 percent lower sag compared with ACSR conductors which enables effective optimisation of tower design.

In view of development of new power transmission and distribution lines, AL-59 alloy conductors may have a special significance while designing transmission line networks, as the properties of these conductors enable superior power evacuation while optimising the cost of the entire transmission line network.

2.3 HTLS Conductors and its Application

HTLS Conductors usually have the higher thermal rating than the conventional ACSR conductors. Generally, ACSR Conductors can withstand a continuous temperature of

75°C to 85°C. For shorter duration during emergency, it can be operated up to 105°C without any sign of distortion [11]. At other side, HTLS conductors can be operated up to 250°C with less thermal elongation than ACSR conductors. It is therefore a good option to increase the thermal rating of the existing lines for large power transfer [13].

HTLS conductors normally include helically stranded aluminium wires over the supporting core. Maximum value of current flows through aluminium wires and the reinforcing core bears the tension load at high temperature [5] however part of the current is also flowing through the supporting core which is almost null in case of conventional ACSR conductors.

At another side, ACSR comprises bimetallic conductors which are mostly used in transmission lines, aluminum wires are helically stranded over steel core. But HTLS conductor involves heat resistant and offers low thermal elongation at high temperature. These conductors can be operated up to 200°C or even more, without substantial changes in mechanical and chemical properties [13]. Different HTLS conductor types are: TACSR (Thermal Aluminum Conductor Steel Supported), GTASCR (Gap-type Thermal Aluminum Conductor Steel Supported), ZTACIR (Super Thermal Aluminum Conductor Invar Reinforced), and ACSS (Aluminum Conductor Steel Supported). TACSR consists of aluminum-zirconium alloy conductor with heat-resistant reinforced steel core. Stable mechanical properties may be achieved up to 150°C using aluminum alloy.

Figure 2.2: TACSR Conductor

The GTACSR conductor consist a small gap between aluminum wires and steel core to apply tension only on the steel core [13].

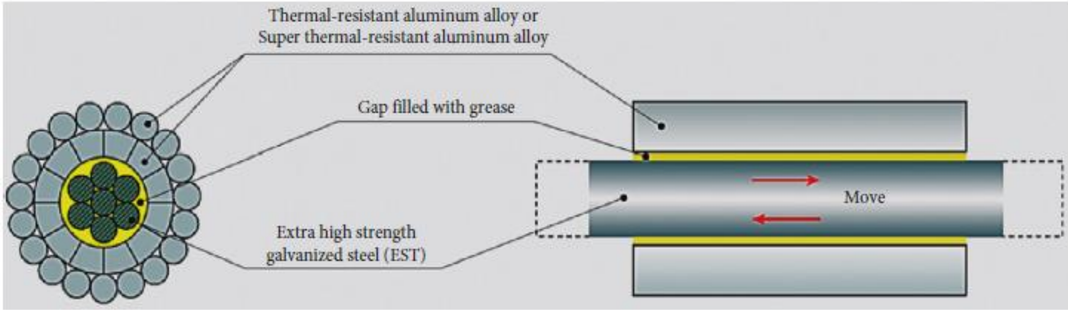


Figure 2.3: Gap-type Conductor (GTACSR)

The gap between the core and outer layers is occupied with the filler material: grease which decreases the friction between the core and outer layer and prevents the water impregnation into the core. This feature improves the corrosion resistance as well.

In ZTACIR, it comprises the steel-invar galvanized alloy core and trapezoidal shaped thermal wires in the outer layer which is made from Al-Zr (Aluminum Zirconium) alloy. Aluminum clad INVAR (36% Ni in steel) is used for the inner core of the conductor, while Super Thermal Alloy (STAL) wires are used for the outer layer. With INVAR, the coefficient of expansion becomes linear and is near to constant with the application of heat, which is why the name INVAR was given [27]. At temperature up to 210°C, high tensile strength is maintained without loss of annealing property [13].

The aluminum alloy or annealed aluminum provides the conductor to withstand high temperatures without losing mechanical properties. The special core gives the low sag characteristics due to low coefficient of thermal expansion (CTE) and high Young modulus.

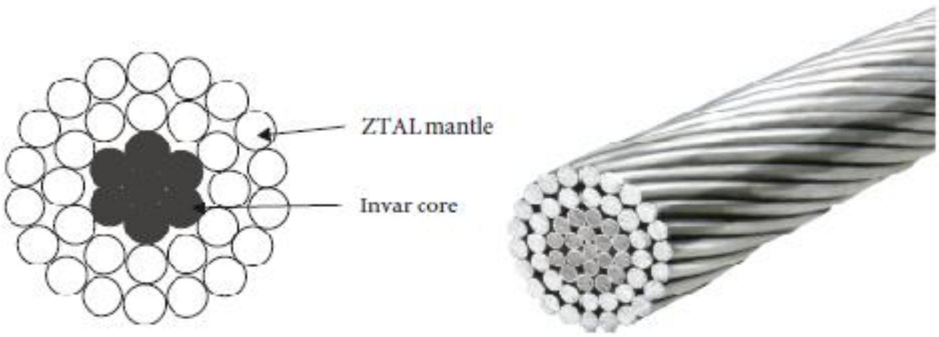


Figure 2.4: ZTACIR Conductor

ACSS conductor consist aluminum strands in the outer layers and steel wires on the core subject to an annealing process [13]. The steel wires may be the standard round or trapezoidal aluminum strand [27].

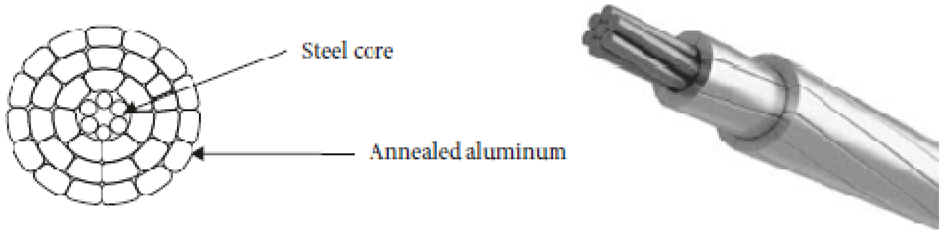


Figure 2.5: ACSS Conductor

Another type of HTLS conductor: ACCC: Aluminum Conductor Composite Core shown in Fig. 2.6 uses composition of carbon with glass fiber and aluminum strands with trapezoidal shape and those features oppose to environment degradation [13, 22].

Figure 2.6: Cross Sectional view of ACCC Conductor

The HTLS conductors described above are very much equivalent in terms of electrical and geometrical respect to the conventional ACSR conductors. These conductors can withstand the high temperature up to up to 210°C or more with low sag, low value of linear thermal expansion; having large power transport capacity [13].

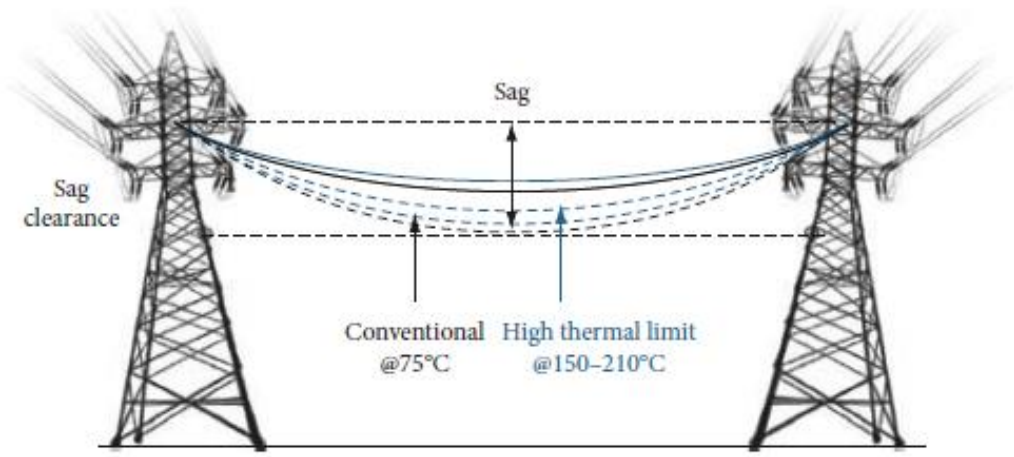


Figure 2.7: Sag of ACSR and HTLS at different temperature limit

The following table compares the electrical and mechanical characteristics of ACSR and the various equivalent HTLS conductors [13]:

Table 2.1: Electrical and Mechanical Characteristic of Equivalent HTLS Conductor

Technical Parameters	**Conductor Type**				
	ACSR	G(Z)TACSR	ZTACIR	ACSS	ACCC (OSLO)
Area (mm^2)	326.12	308.40	306.94	307.70	313.80
Rated tensile strength (kgf)	11420	10962	10066	9901	15081.60
R_{dc} at 20°C (ohm/km)	0.109	0.111	0.11068	0.1077	0.0893
Weight (kg/km)	1068	1098	1083	1068	981
Coeff. of linear expansion (10^{-6}/°C	18.9	11.5	4.7	11.5	1.61

2.4 Application of High-Capacity Conductor in Global Context

Many international research papers have been reviewed to know the practice of replacing the conventional ACSR conductor with high-capacity conductors. Few of those papers are briefed in the following:

Abdou A. et.al. (2015) [2] had researched for improving the transmission capacity of 220kV transmission line in Egyptian Power Network and concluded that the transmission capacity could be upgraded by 58-78% by replacing AAAC 506 with ACSS conductor and evaluated to be the best solution from technical and economic aspects.

Dave et. al (2012) [7] investigated the different techniques to increase the power transfer capacity in which use of HTLS conductor was tested in IEEE 9 Bus system and was found that the use of HTLS conductor eliminated the power congestion by 41% enhancing the overall power transfer capability of the system.

Beryozkina and Sauhats (2015) [23] found that the use of HTLS conductor was justified at high temperature operation.

Another case study by Matesscu et.al (2011) [24] studied the case of 220 kV transmission line in Romania in which it was found that ACSS, ZTACIR, GTACSR, ACCR and ACCC were technically feasible. However, ACSS and ACCC were found to be most economical including cost of power loss but ACSS were selected due to being familiar technology.

A cased study of re-conductor project mentioned by the manufacturer of HTLS ACCC® Core M/s CTC Global [22] is found that a major California Utility selected HTLS ACCC® conductor to increase the capacity and mitigate sag infractions on their double circuit 230kV Vestal to Magunden lines in the Big Creek Transmission Line Corridor. Re-conductoring with ACCC® conductor reduced the construction time from an estimated 48 months to 18 months; freeing up their resources and crews to focus on other projects. This re-conductor project increased line capacity from 936 amps to 1,520 amps and saved an estimated USD 85 Million vs. rebuild with conventional/larger conductor.

2.5 Adoption of High-Capacity Conductor in Nepal

Many practices have been carried out worldwide for increasing ampacity of transmission line conductors however in case of Nepal, it's almost a new one. However, many new ongoing transmission line projects in NEA at different voltage levels (132kV, 220kV, 400kV etc.) are using HTLS conductors of its suitable design. It is briefly discussed about the few upgrading plan/project under NEA in the following sections.

One of the circuits at 33 kV double circuit line (line length: 25 km) in Janakpur is upgraded with HTLS conductor [15] so that ampacity is increased by 70% than at ACSR (Dog) conductor at next circuit in the same line.

Similarly, another project in NEA; Hetauda - Birgunj 66 kV line (20.20 km length) which is using HTLS INVAR to improve the power transfer quality replacing the existing ACSR wolf conductor, to make the power supply system more reliable and uninterrupted in Hetauda – Birgunj industrial corridor [20].

Another project in NEA: 23 km long 132kV line from Inaruwa substation to new Biratnagar substation, under construction includes the HTLS Cordoba (ACSR Bear equivalent) conductor [20]. It aims to improve the power quality in Morang and Sunsari districts and minimize the power congestion problem of Duhabi Grid Substation, 33/11kV Rani Substation and 33/11kV Tankisinwari Substation [20].

Most of the transmission lines in Kathmandu valley are already upgraded with HTLS conductors replacing old aged ACSR conductors. In order to increase the power supply quality in Kathmandu valley, 7 km Suichatar-Matatirtha 132kV line, 5km Suichatar-Balaju 132kV line, 13km Suichatar-Patan 132kV line and 8.5km Suichatar-Teku 66kV line is upgraded with HTLS conductor. Similarly, Bhaktapur – Baneshwor - Patan 66kV line is also upgraded with replacing the existing conductor Chinese ACSR Conductor and ACSR Wolf Conductor from Bhaktapur to Suichatar substation running through Baneshwor and Patan substations and 5 km existing ACSR Dog Conductor between Chapali and Chabahil Substations) of 66kV transmission line with HTLS conductor [15]. Bhaktapur-Suichatar 132kV transmission line having ACSR Wolf conductor has been replaced by HTLS INVAR STACIR conductor which has almost equivalent properties of ACSR Wolf conductor [21].

In addition, 120km of Pathaliya-Dhalkebar 132kV double circuit transmission line having ACSR Bear conductor is uprating with HTLS conductor [15]. Further, transmission line Kushaha-Duhabi 28km long 132kV transmission line having ACSR Bear conductor is planned to upgrade using HTLS conductor [15]. Similarly, NEA has started to reinforce the capacity of Pokhara-Lekhnath 132kV transmission line (7km long) having ACSR Wolf with HTLS conductor [20].

2.6 IEEE Standard 738 for Calculating Current-Temperature of Bare Overhead Conductors

2.6.1 Current - Temperature Characteristics

The temperature at the conductor surface depends on the various factors: conductor material, diameter, surface condition of the conductor, ambient temperature and current in the conductor [17]. Moreover, the power transfer capacity of the transmission line is limited by the conductor maximum operating temperature, which is determined by its current carrying capacity. The conductor's temperature and therefore the ampacity is depend on environmental service conditions. This fact enables increasing the transmission capacity to calculation based on weather conditions and forecasts as opposed to static and conservation values.

For the current-temperature relationship of the conductors under service condition specified by NEA in various loading conditions, the analysis method is based on IEEE Standard 738, "IEEE Standard for Calculating the Current-Temperature of Bare Overhead Conductors". This method helps to calculate the conductor derated ampacity of the conductors based on various temperature limits. This method takes into account all the relevant weather factors (influence of sun and wind). For calculation, it will be considered the effects and adjustments due to weather, solar heat and geographical location effects.

In this method, heat balance equation will be applied in which heat is generated by ohmic loss and heat gain from solar radiation whereas heat is dissipated by convection and radiation process. Following relations can be used to find the current carrying capacity rating of the conductor under steady state condition of wind velocity, temperature, solar radiation and electric current.

2.6.2 Steady- State Conductor Temperature Calculations

a. Steady – State thermal rating

Steady state heat balance equation is used for the study of steady – state thermal rating of the bared overhead conductor [17]. The equation is given below:

$q_c+q_r=q_s+I^2R_{(Tc)}$ ……………equation (2.1)

Where-

I^2R = heat generated in the conductor due to conductor resistance, R ohm/meter.

q_s = solar heat gain, watts/length of conductor,

q_c = heat loss due to convection, watts/length of conductor,

q_r = heat loss due to radiation, watts/length of conductor and

$R_{(Tc)}$ = conductor ohmic resistance at conductor temperature.

Rearranging the above heat balance equation:

$$I = \sqrt{\frac{qc + qr - qs}{R\ (Tc)}}$$ …………………equation (2.2)

In above equation, the conductor heat gain as an effect of magnetic heat, corona heating and heat loss due to evaporation etc. is usually insignificant, therefore, these factors are not considered in this equation.

b. Steady – State conductor temperature

Since, heat losses by radiation and convection are not linearly dependent on the conductor temperature, so the equation (2.2) is solved for given operating temperature in terms of current and weather variables. It uses iterative techniques [17] to find the conductor current value. For those calculations, following steps are followed:

(i) A conductor temperature is assumed,

(ii) The corresponding heat losses are calculated,

(iii) The conductor current that generates this conductor temperature is calculated according to above equation (2.2)

(iv) The calculated current is compared with the given conductor current

(v) The conductor temperature is then increased or decreased, until the calculated current equals the given current.

Above equations (2.1) and (2.2) are heat balance equations for steady – state conditions. For non-steady state, heat balance equations can be written as:

$$q_c + q_r + mC_p\frac{dT_c}{dt} = q_s + I^2R(T_c)$$ ………………………equation (2.3a)

$$\frac{dT_c}{dt} = \frac{1}{mC_p}[R(T_c)I^2 + q_s - q_c - q_r]$$ ………………………equation (2.3b)

Forced convection heat loss is given by:

$$q_{c1} = \left[1.01 + 0.371\left(\frac{D\rho_f V_w}{\mu_f}\right)^{0.52}\right] \cdot k_f \cdot (T_c - T_a)$$ ....equation (2.4a)

..............................equation (2.4b)

$$q_{c2} = 0.1695\left(\frac{D\rho_f V_w}{\mu_f}\right)^{0.6} \cdot k_f \cdot (T_c - T_a)$$

Above equation (2.4a) is used at low wind and equation (2.4b) for high wind speed. At any wind speed, the larger value calculated from above two equations is used for convection heat loss.

Now the value of natural convection at zero wind speed is calculated as:

$q_c = 0.283\rho_f^{0.5}D^{0.75}(T_c\text{-}T_a)^{1.25}$ ....equation (2.5)

For both forced and natural convection, air density (ρ_f), air viscosity (μ_f) and coefficient of thermal conductivity of air (k_f), T_{film} can be written as:

T_{film} can be written as:

$T_{film} = \frac{Tc+Ta}{2}$ ....equation (2.6)

Now, the radiated heat loss is given by:

$$q_r = 0.138D\,\varepsilon \cdot \left[\left(\frac{T_c + 273}{100}\right)^4 - \left(\frac{T_a + 273}{100}\right)^4\right]$$ ....equation (2.7)

Solar heat gain is given by:

$q_s = \alpha Q_s \sin(\theta)A'$ ....equation (2.8)

where,

$\theta = \cos^{-1}[\cos(H_c)\cos(Z_c\text{-}Z_l)]$ ....equation (2.9)

2) Conductor Electrical Resistance

Resistance of bare conductor varies with frequency, conductor temperature and current density [17]. However, in IEEE standard 738, the value of conductor temperature is solely considered to calculate the conductor electrical resistance. Conductor resistance at any temperature (T_c) is calculated by using the following equation:

$$R(T_c) = \left[\frac{R(T_{High}) - R(T_{Low})}{T_{High} - T_{Low}}\right] \cdot (T_c - T_{Low}) + R(T_{Low})$$ ......equation (2.10)

Where, T_{high} & T_{low} are value of the conductor high and low temperature. The calculations for ampacity of HTLS conductor is based on IEEE Standard 738.

Manufacturers usually provide the DC resistance of the conductor at 20°C temperature and AC resistance corresponding to 50 Hz. Alternating current flow at specified ambient conditions can be calculated using above formula.

2.7 Load Flow Study

Load flow study [1] reveals the electrical performance and power flows (real and reactive) for specified conditions when the system is operating under steady state. It also provides the information about the transformer and line loads as well as losses throughout the system and voltages at different points in the system for evaluation and regulation of the performance of the power system under given conditions. Further alternative plans for future expansion to meet new load demands can be also analyzed and complete information is made available through this study.

Taking into account these two aspects: 1) present operation and 2) future operation, is how power system should be analyzed. From one side, an operation or control engineer requires relevant information to be available to him/her almost immediately; he/she must be able to obtain somehow the behavior of the power system under different configurations that can occur. On the other side, a planning engineer requires obtaining the behavior of the system reflecting reinforcements that have not yet been built while considering the corresponding yearly and/or monthly load increase.

A bus is a node at which one or many lines, one or many loads and generators are connected. It is not necessary that all of them be connected at every bus. The buses are classified as P-Q (load bus), P-V (Generator or voltage-controlled bus) and V-Q (slack bus).

The current flowing into the buses is written in compact form as:

$I_{bus} = [Y_{bus}]V_{bus}$ ……………………………………equation (2.12)

Where $[Y_{bus}]$ is a bus admittance matrix for 'n' bus system.

For 'n' bus system, I_{bus} is an n*1 vector with general entry I_i, V_{bus} is an n*1 vector with general entry V_i

Since, $[Y_{bus}]$ is an n*n matrix with entries

$Y_{ii} = |Y_{ii}|$ angle (γ_{ii}) = short circuit driving point admittance at i^{th} node.

$Y_{ip} = |Y_{ip}|$ angle (γ_{ip}) = short circuit transfer admittance between i^{th} and p^{th} nodes.

For 'n' bus system, current entering at i^{th} bus is given by:

$Ii = Y_{i1}V_1+Y_{i2}V_2+\ldots\ldots+Y_{ii}V_i+\ldots\ldots Y_{in}V_n$ …………equation (2.13)

$= \sum_{p=1}^{n} \mathrm{Yip.Vp}$

$= \sum_{p=1}^{n} |Yip||Vp| angle(\delta p + \gamma ip)$…………………equation (2.14)

Where, $V_p= |V_p|$ angle(δ_p) and $Y_{ip}= |Y_{ip}|$ angle (γ_{ip})

The complex power injected into the i^{th} bus can be written as;

$S_i = P_i+jQ_i = V_iI_i^*$ …………………………………………equation (2.15)

$S_i^* = P_i-jQ_i = V_i^*I_i$

$= V_i^* \sum_{p=1}^{n} \mathrm{Yip.Vp}$ …………………………equation (2.16)

Since, $V_i= |V_i|$ angle(δ_i), $V_i^*= |V_i|$ angle($-\delta_i$) and $Y_{ip}= |Y_{ip}|$ angle (γ_{ip})

$P_i-jQ_i = V_i^*\sum_{p=1}^{n} \mathrm{Yip.Vp}$

$= |V_i| \sum_{p=1}^{n} |Yip||Vp| angle(\delta p + \gamma ip - \delta i)$

$= |V_i| \sum_{p=1}^{n} |Yip||Vp| angle(-(\delta i - \delta p - \gamma ip))$

Separating the real and imaginary parts;

$P_i = |V_i|\sum_{p=1}^{n} |Yip||Vp| cos(\delta i - \delta p - \gamma ip)$………………equation (2.17a)

$Q_i = |V_i|\sum_{p=1}^{n} |Yip||Vp| sin(\delta i - \delta p - \gamma ip)$………………equation (2.17b)

These above equations (2.17a) and (2.17b) are known as static load flow equations. These equations are non-linear and therefore, only a numerical solution is possible. For each of the 'n' bus system, we have two such equations giving a total '2n' equations. At each bus, we have 4 variables P_i, Q_i, V_i and δ_i giving a total of '4n' variables. To obtain a solution, it is necessary to specify two variables at each bus so that the number of unknowns is reduced to '2n' [1]. Depending on the quantities specified, the buses can be classified into three types as shown in the table below:

Table 2.2: Bus Types for Load Flow Studies

Bus type	**Specified quantities**	**Unknown quantities**	**Approximate use**
Load bus or PQ bus	P_i, Q_i	V_i, δ_i	85%
Generator bus or voltage-controlled bus of PV bus	P_i, V_i	Q_i, δ_i	15%
Reference bus or slack bus or swing bus	V_i $\delta_i = 0$	P_i, Q_i	1%

The solution to the load flow problem consists in assuming a certain initial bus load configuration, specifying the '2n' known variables and using some numerical method to find the remaining '2n'viables for the system with known [Y_{bus}]. The final solution must satisfy some constraints. These constraints are;

i) Voltage magnitude at various buses must be within limits

ii) Active and reactive generator power at different buses must be within the minimum and maximum limits

iii) Total generation must equal total load plus losses

iv) In addition to the system stability considerations impose a limit on the maximum value with 'δ_i' can have.

The most commonly used methods for load flow studies are Gauss-Siedel method, Newton-Raphson method, and Fast Decoupled Load Flow method.

2.8.1 AC Load Flow Using DigSILENT PowerFactory

In DigSILENT PowerFactory [16] the nodal equations used to represent the analyzed networks are implemented using two different formulations:

- Newton-Raphson using current equations
- Newton-Raphson using power equations, a classical method

In both formulations, the resulting non-linear equation systems must be solved by an iterative method.

PowerFactory uses the Newton-Raphson method as its non-linear equation solver [16]. For large transmission systems, especially when heavily loaded, the standard Newton-Raphson algorithm using the "Power Equations" formulation usually converges best. Distribution systems, especially unbalanced distribution systems, usually converge better using the "Current Equations" formulation. PowerFactory allows for the calculation of both balanced (AC Load Flow, balanced positive sequence) and unbalanced (AC Load Flow Unbalanced, 3-phase (ABC)) load flows [16].

2.9 Sag and Tension Calculation

Sag-tension calculations is used to predict the catenary sags and the conductor tensions under all design condition of the conductor temperature and ice and/or wind load. Maximum conductor tension is an important factor in structure design [1]. Maximum conductor sag largely determines structures heights and locations in order to maintain electrical clearances throughout the life of the line [26]. Thus, both the mechanical and electrical integrity of an overhead transmission or distribution line is directly dependent on the accuracy of sag-tension calculations.

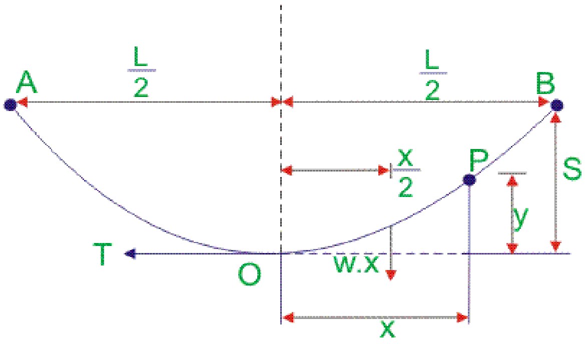


Figure 2.8: Sag when supports at same levels

It is sufficiently accurate to assume the shape of the line is that of parabola $y = ax^2$ where 'a' is constant for a given line and 'O' is the origin.

Let us suppose,
L = length of span, horizontal distance between two supports, in meters
S = sag at mid span, in meters
T = conductor tension (assumed constant over the whole span) in Newton

w = conductor weight, N/m

y = S when

$x= \frac{L}{2}$, it follows that $S = a\,(\frac{L}{2})^2$

or $a = 4S/L^2$ …………………………….. equation (2.18a) then $y = 4S(\frac{x}{L})^2$ …………………………… equation (2.18b)

Considering the equilibrium of half-line OA, assuming that the conductor is almost horizontal and making moments about A

$TS = \{\frac{wL}{2}\}\{\frac{L}{4}\}$ or $S = wL^2/8T$ ………………………… equation (2.18c)

Now substituting the value of 'S' in above equation,

$a = w/2T$ ……………………………equation (2.18d)

and $y = wx^2/2T$ …………………………… equation (2.18e)

The exact shape of a transmission line is that of catenary.

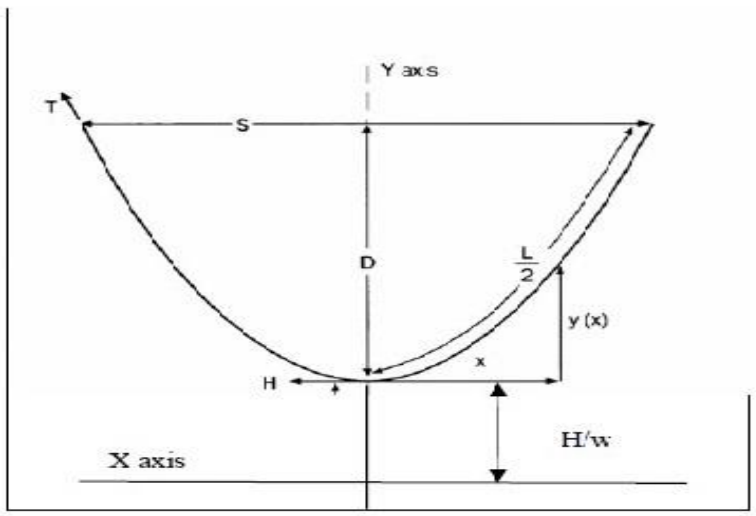


Figure 2.9: The Catenary Curve for Level Spans

The catenary equation given in above equation (2.18e) is identical for both the case of two supports at equal level or at different heights.

During sag and tension calculation, it may be noted that conductor must not violate the existing sag and tension on tower at any operating temperature condition.

2.10 Degradation of ACSR Conductor

Degradation of ACSR conductors begins as a loss of zinc from the galvanized steel core wires. These losses can be detected non-destructively using an overhead line conductor corrosion detector, which was invented by the CEGB staff in England [25].

Furthermore, it needs to carry out the mechanical tests of the conductors for the evidence of damage due to arching, localized annealing, from lighting strikes, phase to phase/ground arcing, hot joints and unusual corrosion etc. conductor tensile strength is to be determined using individual wires as per the prevailing standards. This method allows a comparison of the strength distribution of the aluminum and steel wires as well as that of individual wires within a layer. With the conductors manufactures more than two decades ago, it may not be uncommon to find difference between the strengths and corrosion condition of individual wires. In many cases, these differences can be tracked back to irregularities during manufacturing of the conductors.

Moreover, the individual wires can be tested for torsional ductility using a modified version of the ASTM E558 method [25]. For this test, the wire is held with a tensile load of 1% of the maximum strength and twisted to failure, with the number of turns being recorded.

To determine the remaining useful life of any tested conductor, an unacceptable deterioration level has to be established for each diagnostic procedure. The steel core corrosion detector measurements indicate the average thickness of the zinc remaining. Due to variation in zinc thickness and uncertainty regarding original thickness, the indicative is qualitative. A relatively coarse scale line one to four can be applied to categorize the samples. The instrument does not respond to effects that take a place within the steel wires after zinc coating is pierced or removed, such as surface rusting, pitting of the surface, or severe corrosion within the wires. Consequently, only end point that can be used for these measurements. The maximum value of four which corresponds to 80 to 100% loss of zinc.

2.11 Cost Analysis

2.11.1 Net Present Value

Net Present Value (NPV) is the difference between the present value of cash inflows and the present value of cash outflows over a period of time. NPV is used in capital budgeting and investment planning to analyze the profitability of a projected investment or project. This is an important economic measure as it includes the time factor with the interest rate. It is always unique irrespective of the cash flow patterns.

NPV is the result of calculations that find the current value of a future stream of payments, using the proper discount rate. In general, projects with a positive NPV are worth undertaking while those with a negative NPV are not. If the NPV of a project or investment is positive, it means its rate of return will be above the discount rate.

If there is one cash flow from a project that will be paid one year from now, then the calculation for the NPV of the project is as follows:

$$\text{NPV} = \frac{\text{Cash flow}}{(1+i)^{\wedge}t} - \text{initial investment}$$

where,

i = discount rate

t = time periods, generally in years.

In general, NPV can be calculated as:

$$\text{NPV}= \sum_{t=0}^{n} \frac{Rt}{(1+i)^{\wedge}t}$$

Where,

R_t = net cash inflow - outflows during a given time period 't'

i = discount rate or return that could be earned in alternative investments

t = number of time periods.

2.11.2 Internal Rate of Return

Internal Rate of Return (IRR) is the rate of return at which a project breaks even and is used by management to evaluate potential investments. IRR functions as a return on investment (ROI) calculation.

IRR is the discount rate that makes the net present value (NPV) of all cash flows equal to zero in a discounted cash flow analysis. IRR is calculated by solving the NPV formula for the discount rate required to make NPV equal zero. This method can be used to compare projects of different time spans on the basis of their projected return rates. NPV and IRR are closely related concepts, in that the IRR of an investment is the discount rate that would cause that investment to have an NPV zero. The ultimate goal of IRR is to identify the rate of discount, which makes the present value of the sum annual nominal cash flows equal to the initial net cash outlay for the investment.

The formula and calculation used to determine for IRR is:

$$0 = NPV = \sum_{t=1}^{T} \frac{Ct}{(1+IRR)^\wedge t} - C_0$$

Where:

C_t = net cash inflow during the period, t

C_0 = total initial investment costs

IRR = the internal rate of return

t = the number of time periods.

As a part of this research, the best conductor which is selected as an equivalent to the existing ACSR conductor based upon its geometry, weight per unit length, ultimate tensile strength, maximum current carrying capacity etc. is selected. Sag-tension analysis of this conductor is carried out to study the sag-tension performance under different weather cases such that the resultant sag may not violate the maximum sag of the existing conductor. Based upon the cost of the best conductor selected, its cost analysis is carried out for supply of the new items, dismantling the old conductor, insulator, erection hardware and fittings; stringing and commissioning of the new HTLS conductor at the critical line sections is analyzed in detail.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

The methodology adopted for this study is to seek the technical implication on replacing older ACSR conductor with HTLS conductors at 132 kV transmission line under INPS. Furthermore, cost analysis of conductor replacement work is carried out in this study. To meet all of these research objectives, the research flowchart is structured as below:

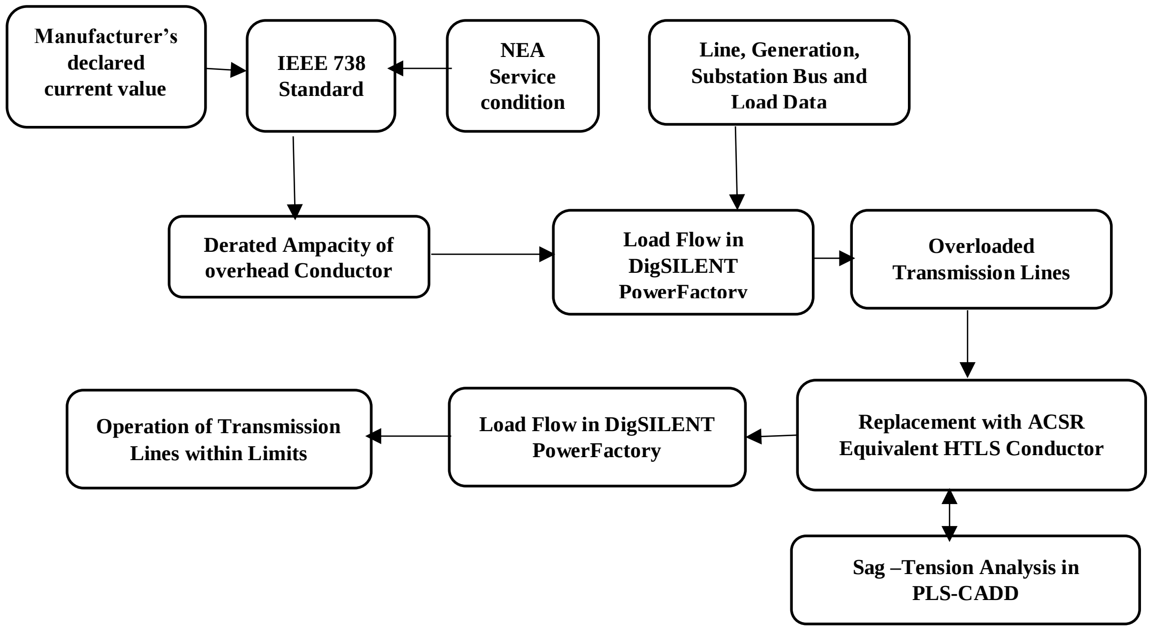


Figure 3.1 Flowchart of the Study

3.2 Data Collection

The Integrated Nepal Power System (INPS) data required like generation, transmission line, substation capacity and load etc. are collected from Grid Operation Department, System Operation Department and System Planning Department of NEA. Data and information included in NEA published annual report in the past fiscal years are also considered. Recent prices of ACSR and HTLS conductors along with erection hardware & fittings etc. are also referred from running NEA transmission line and substation augmentation projects. Technical data sheet of the conductor is also referred from the Contract Documents of those running projects along with information leaflets and web sites of the manufacturers. Standing service conditions of the overhead line in NEA is also referred from those associated projects documents. So, the secondary sources are referred for the required data and information needed for the study.

3.3 Transmission Line Service Conditions in Nepal

Nepal Electricity Authority has its own service conditions under which the conductor shall be capable to operate at 50Hz, alternating current under the prevailing ambient conditions, maximum safe operating temperature and maximum permissible sag meeting other specific technical requirements. Those prevailing service conditions is as specified below:

i) Altitude above sea level: 100 m to 2000 m from MSL

ii) Ambient air temperature= 45 °C (max.) & 0 °C (min.)

iii) Annual average temperature = 32 °C

iv) Relative humidity (in %) = 100 (max.), 20 (min.)

v) Solar intensity = 1045 watt/sq.m

vi) Emissivity constant = 0.45

vii) Wind velocity = 0.56 m/sec. considering the angle between wind and axis of conductor as 90 deg.

viii) Angle of sun ray's incidence = 90 deg.

For the 132kV transmission lines in INPS under study, the Electrical System Parameters under study is considered as the followings:

i) Rated Service Voltage: 132kV

ii) Highest System Voltage: 145kV

iii) Impulse withstand voltage: 650kV

iv) Power frequency withstand voltage: 275kV

v) Number of Phases: 3

vi) Operating frequency: 50Hz

The current rating of the conductor specified by the manufacturer in its technical data sheet is derated under NEA prevailing service conditions which is typically lower than that of manufacturer's declared value. This derated value of the conductor parameters are used in load flow study. Following is given a model for derating the ampacity of the conductor in prevailing environmental service condition in NEA.

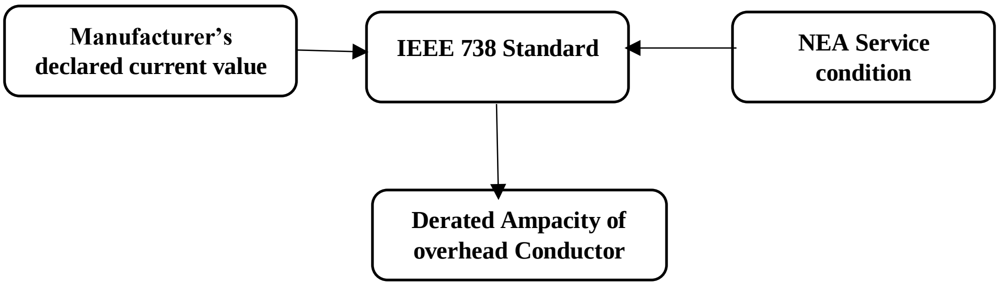


Figure 3.2 Model for Derating the Conductor Ampacity

3.4 Integrated Nepal Power System

Integrated Nepal Power System (INPS) consists of various synchronous generations, transmission lines and load connected at different buses voltages ranging from 33kV to 400kV levels. It has also the external grid integrated with INPS from Tanakpur, Nepalgunj, Shivapur (Kapilvastu district), Rampur (Parasi district), Dhalkebar and Kataiya (Saptari district).

3.5 Load Flow Study Tool

DigSilenet PowerFactory 15.1 tools is used for the load flow study of the INPS. A model is developed in DigSilent using the INPS data. For the system model development, it is considered the substation buses of 66kV and higher levels only. All the generations are interconnected at 132kV and higher voltage buses.

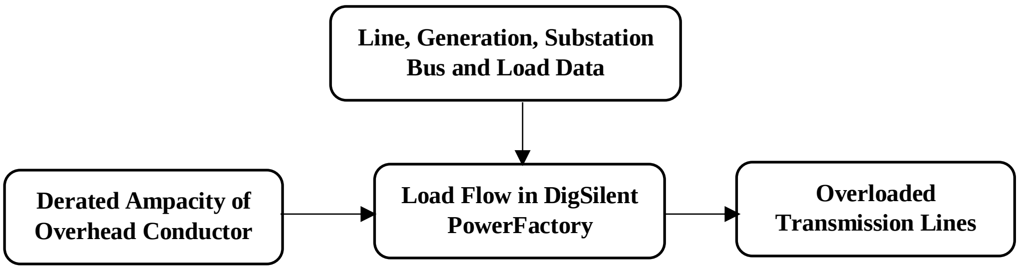


Figure 3.3 Load Flow in DigSilent PowerFactory

Using the model shown in above Figure 3.3, overloaded 132kV transmission lines has been listed out from load flow in DigSilent PowerFactory.

3.5.1 Consideration for Load Flow in DigSilent

For the load flow study of INPS in DigSilent, followings have been considered:

- Since, INPS being a grid having multiple buses for power importing from India, external grid at Dhalkebar 400kV bus interconnecting with the Dhalkebar-Muzzafarpur 400kV ex-border transmission line, external grid at Ramnagar and external grid at Kushaha is considered as reference/slack bus as required for the system load flow calculation.
- Result of the load flow may vary with the selection of the slack bus.
- In DigSilent for the load flow study, it has applied the Newton-Rapson load flow power equations. It is considered the maximum number of iterations with Newton-Rapson iteration as 25. The convergence options for the iteration step size are set as automatic adoption i.e., there is no factor of convergence put for the load flow which is also a default setting in this tool.
- AC load flow with 3-phase balanced and positive sequence has been considered during load flow study.
- Lower limit of the allowed voltage at each bus is 0.95 p.u. and upper limited of the allowed voltage is 1.05 p.u.
- Maximum thermal loading limit considered is 100%.
- Transmission line type is considered with lumped parameters.

3.6 Post Load Flow Study

After finding the critical line sections having line loading ≥ 100%, Google Earth Pro and Nava GPS Office tools are used for locating those critical line sections and end substations at ground levels. Their UTM coordinates are extracted using these tools to know the span between the towers and terrain type. However, in real project design, line surveys including total station instruments, airborne lasers or photogrammetry tools etc. are used for plan and profile coordinates of the line. But it is not possible to access all of these primary data and it is beyond the scope of this research. Therefore, above two types of tools are used to extract the coordinates. Then, another tool: Power Line Systems- Computer Aided Design and Draft (PLS-CADD) is used to generate the line plan and profiles and study the affected the structure and conductor positions at different temperature and wind case and study the sag and tension in the line conductors.

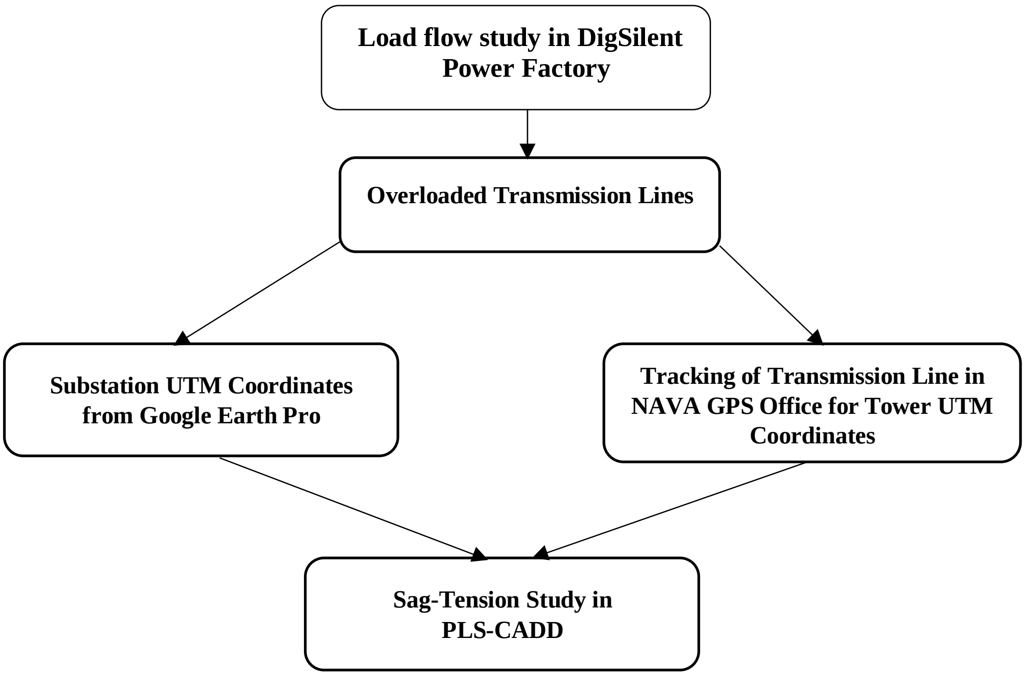


Figure 3.4 System Tools and Software

Above figure 3.4 depicts the system tools and software which are applied for targeted output of the research.

3.5.3 Sag- Tension Analysis

For sag-tension analysis, it is noted that the existing sag and tension shall not be violated by each conductor at any operating temperature condition. Following is given the minimum requirements for the sag-tension analysis of the candidate conductor:

Table 3.1: Sag-Tension Requirements for Equivalent ACSR Conductor [30]

SN	Technical parameters	Limiting Value
1	Tension at every day condition (32°C, no wind)	Must not exceed 25% UTS value of proposed conductor.
2	Sag at maximum continuous operating temp. for given ruling span (corresponding to specified current per conductor and ambient conditions)	Lower value of standard sag for existing ACSR conductor for specified span @ 75°C and measured sag of existing line @ specified span.
3	Tension at 32°C, full wind	Must not exceed 70% UTS of HTLS conductor and it must be lower than that of existing ACSR conductor.
4	Tension at designed maximum temp. and no wind condition	Not exceeding 25% of UTS at designed maximum temperature, which shall be lower than that of existing conductor.
5	Conductor tension at max. Temp. and full wind.	Must not exceed 70% UTS at max. Temp. of new HTLS conductor and it shall be

		lower than that of existing ACSR conductor.
6	Tension at knee point temperature and no wind	Must not exceed 40% UTS of core of new HTLS conductor and it shall be lower than that of existing ACSR conductor.

Following the above sag-tension criteria, the software PLS-CADD is used for sag-tension analysis to find the sag under various operating temperature conditions. Sag-tension chart will find out for maintaining the minimum electrical clearances and tension under different environmental and operating temperature conditions. Following all these process, candidate HTLS conductor will be found for the further study.

3.6 Cost Analysis

After finding the candidate HTLS conductor following all the procedures in the above steps, cost analysis which needs for the replacement of the existing ACSR conductor, insulators, erection hardware and accessories is to carry out. It is supposed that any modification of the tower and support structures may not be required to suspend the new conductor and hardware.

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Load Flow Analysis

For the load flow study, it is noted that the total generation capacity interconnected in INPS is 2438.72 MW and the maximum load is 2054.59 MW. It is assumed that the maximum load is constant throughout the study of the load flow. For these baselines, load flow study has been carried out at different generation scenario selected randomly:

4.1.1 At 100% Generation:

At 100% generation scaling, INPS load flow is converged in 6 iterations. Muzzafarpur and Ramnagar external grids have been considered as reference machines or slack buses. At this case, the result of the grid summary is noted below:

No. of Busbars: 104; No. of Lines: 178

No. of Loads: 75 No. of Shunts Capacitor: 31

Total Generation Capacity: 2438.72 MW, 646.82 MVar; 2517.26 MVA

External Infeed = -230.07 MW, 184.31 MVar, 294.79 MVA

Load P(U) = 2054.59 MW, 995.62 MVar , 2283.28 MVA

Grid Losses = 154.06 MW, 483.92 MVar

From above results, it is noted that there a surplus of 230.59 MW generation and grid power loss of 154.06 MW which is 6.31% of the total system in-feed.

In this scenario, following 132kV line sections have been found to be the most critical having maximum loading:

Table 4.1: List of 132kV Critical Transmission Lines at 100% Generation

SN	Line name/section	Line Length in ckt-km	No. of elec. circuits	Conductor type	Line Loading (%)
1	***Dhalkebar-Mirchaiya***	***63***	***2***	***ACSR Bear***	***167.22***
2	***Kusaha-Kataiya***	***13***	***1***	***ACSR Bear***	***154.44***
3	Lamosanghu-Khimti	45.84	1	ACSR Bear	146.26
4	Chapur-Dhalkebar	139	2	ACSR Bear	140.53
5	Bhaktapur-Lamoshanghu	96.60	2	ACSR Bear	137.65

6	Pathalaiya-Chapur	66	2	ACSR Bear	124.92
7	Duhabi-Damak	48.90	1	ACSR Bear	122.07
8	Gandak-Bardaghat	28	2	*ACSR Panther*	116.03
9	Hetauda-Kulekhani2	10.48	2	ACSR Bear	108.24
10	Pathalaiya-Parwanipur	33	2	ACSR Bear	103.05
Total ckt.km		**543.82**	ACSR Bear: 515.82 ct.-km ACSR Panther: 28 ckt.-km		

From the above table, it is analyzed that a total 543.82 electrical circuit kilometers of 132kV transmission line is found to be the most critical based on the percentage of maximum loading. Above critical line sections have been selected for the lines having ≥ 100% loading. From the table, Dhalkebar-Mirchaiya 132kV transmission line section is found to be the most critical having 167.22% maximum loading followed by Kushaha - Kataiya 132kV transmission line section of 154.44% loading. It is also found that the line loading is maximum at the line sections in Terai zone and Kathmandu valley.

4.1.2 At 80% Generation:

During dry season, water flow in the river will be decreased gradually so that it may not be achieved the generation of installed capacity of the hydropower plants. So, considering these scenarios, load flow pattern is analyzed under reduced internal generation cases.

At 80% generation scaling, INPS load flow is converged in 5 iterations. Muzzafarpur and Ramnagar external grids are considered as reference machine or slack bus. At this case, the result of the grid summary is noted below:

No. of Busbars: 104; No. of Lines: 178

No. of Loads: 75 No. of Shunts Capacitor: 31

Total Generation Capacity: 1947.25 MW, 634.18 MVar; 2047.91 MVA

External Infeed = 256.38 MW, 47.85 MVar, 260.81 MVA

Load P(U) = 2054.59 MW, 995.62 MVar, 2283.28 MVA

Grid Losses = 148.85 MW, 419.14 MVar

From above results, it is noted that there a deficit of 256.38 MW which is infeed from the external grid. Total grid power loss of 148.85 MW which will be 6.75% of the total system in-feed.

In this scenario, following 132kV line sections have been found to be the most critical having maximum loading:

Table 4.2: List of 132kV Critical Transmission Lines at 80% Generation

SN	Line name/section	Line Length in ckt-km	No. of elec. circuits	Conductor type	Line Loading (%)
1	Dhalkebar-Mirchaiya	63	2	ACSR Bear	100.57
2	Kusaha-Kataiya	13	1	ACSR Bear	116.49
3	Lamosanghu-Khimti	45.84	1	ACSR Bear	173.77
4	Chapur-Dhalkebar	139	2	ACSR Bear	147.92
5	Bhaktapur-Lamoshanghu	96.60	2	ACSR Bear	135.34
6	Pathalaiya-Chapur	66	2	ACSR Bear	131.17
7	***Gandak-Bardaghat***	***28***	***2***	***ACSR Panther***	***212.72***
8	***Dumkibas-Bardaghat***	***15***	***1***	***ACSR Panther***	***195.36***
9	Pathalaiya-Parwanipur	33	2	ACSR Bear	104.34
Total ckt.km		**499.44**	ACSR Bear: 456.44 ct.-km ACSR Panther: 43 ckt.-km		

From the above table, it is analyzed that a total 499.44 electrical circuit kilometers of 132kV transmission line is found to be the most critical based on the percentage of maximum loading. Above critical line sections have been selected for the lines having ≥ 100% loading. From the table, Gandak-Bardaghat 132kV transmission line section is found to be the most critical having 212.72% maximum loading followed by Dumkibas-Bardaghat 132kV transmission line section of 195.36% loading. It is also repeated that the line loading is maximum at the line sections in Terai zone and Kathmandu valley.

4.1.3 At 50% Generation:

At 50% generation scaling, INPS load flow is converged in 6 iterations. Muzzafarpur and Ramnagar external grids are considered as reference machine or slack bus. At this case, the result of the grid summary is noted below:

No. of Busbars: 104; No. of Lines: 178

No. of Loads: 75 No. of Shunts Capacitor: 31

Total Generation Capacity: 1219.05 MW, 1233.71 MVar; 1734.40 MVA

External Infeed = 1089.34 MW, -36.27 MVar, 1089.94 MVA

Load P(U) = 2054.59 MW, 995.62 MVar, 2283.28 MVA

Grid Losses = 253.61 MW, 920.53 MVar

From above results, it is noted that there a deficit of 1089.34 MW which is infeed from the external grid. Total grid power loss of 253.61 MW which will be 10.98% of the total system in-feed.

In this scenario, following 132kV line sections have been found to be the most critical having maximum loading:

Table 4.3: List of 132kV Critical Transmission Lines at 50% Generation

SN	Line name/section	Line Length in ckt-km	No. of elec. circuits	Conductor type	Line Loading (%)
1	Lamosanghu-Khimti	45.84	1	ACSR Bear	235.97
2	Chapur-Dhalkebar	139	2	ACSR Bear	173.43
3	Bhaktapur-Lamoshanghu	96.60	2	ACSR Bear	139.13
4	Pathalaiya-Chapur	66	2	ACSR Bear	154.07
5	***Gandak-Bardaghat***	***28***	***2***	***ACSR Panther***	***395.85***
6	***Dumkibas-Bardaghat***	***15***	***1***	***ACSR Panther***	***453.53***
7	Dumkibas-Kawasoti	55	1	ACSR Panther	204.33
8	New Bharatpur-Dumkibas	70	1	ACSR Bison	176.86
9	Kawasoti-Bharatpur	28.70	1	ACSR Panther	171.63
10	Bharatpur-Marsyangdi	25	1	ACSR Bear	145.03
11	Hetauda-Bharatpur	70.85	1	ACSR Panther	134.24
12	Butwal-New Butwal	66	2	ACSR Bear	125.72
13	Hetauda-Kulekhani-2	10.48	2	ACSR Bear	124.09
14	Pathalaiya-Parwanipur	33	2	ACSR Bear	109.98
15	New Butwal- Bardaght	20	2	ACSR Bear	125.72
Total ckt.km		**769.48**	ACSR Bear: 501.92 ct.-km ACSR Panther: 197.55 ckt.-km ACSR Bison: 70 ckt. km		

From the above table, it is analyzed that a total 769.48 electrical circuit kilometers of 132kV transmission line is found to be the most critical based on the percentage of maximum loading. Above critical line sections have been selected for the lines having ≥ 100% loading. From the table, Dumkibas-Bardaghat 132kV transmission line section is found to be the most critical having 453.5372% maximum loading followed by Gandak-Bardaghat 132kV transmission line section of 395.85% loading.

4.1.4 At 40% Generation:

At 40% generation scaling, INPS load flow is converged in 7 iterations. Muzzafarpur and Ramnagar external grids have been considered as reference machine or slack bus. At this case, the result of the grid summary is noted below:

No. of Busbars: 104; No. of Lines: 178

No. of Loads: 75 No. of Shunts Capacitor: 31

Total Generation Capacity: 976.33 MW, 1787.10 MVar; 2036.40 MVA

External Infeed = 1440.87 MW, -13.02 MVar, 1440.93 MVA

Load P(U) = 2054.59 MW, 995.62 MVar , 2283.28 MVA

Grid Losses = 362.42 MW, 1472.09 MVar

From above results, it is noted that there a deficit of 1440.87 MW which is infeed from the external grid. Total grid power loss of 362.42 MW which will be 15.0% of the total system in-feed.

In this scenario, following 132kV line sections have been found to be the most critical having maximum loading:

Table 4.4: List of 132kV Critical Transmission Lines at 40% Generation

SN	Line name/section	Line Length in ckt-km	No. of elec. circuits	Conductor type	Line Loading (%)
1	Lamosanghu-Khimti	45.84	1	ACSR Bear	274.10
2	Chapur-Dhalkebar	139	2	ACSR Bear	192.57
3	Bhaktapur-Lamoshanghu	96.60	2	ACSR Bear	149.57
4	Pathalaiya-Chapur	66	2	ACSR Bear	174.53
5	***Gandak-Bardaghat***	***28***	***2***	***ACSR Panther***	***484.99***
6	***Dumkibas-Bardaghat***	***15***	***1***	***ACSR Panther***	***590.75***
7	Dumkibas-Kawasoti	55	1	ACSR Panther	264.12
8	New Bharatpur-Dumkibas	70	1	ACSR Bison	231.67
9	Kawasoti-Bharatpur	28.70	1	ACSR Panther	231.67
10	Bharatpur-Marsyangdi	25	1	ACSR Bear	213.74
11	Hetauda-Bharatpur	70.85	1	ACSR Panther	155.04
12	Butwal-New Butwal	66	2	ACSR Bear	146.22
13	Hetauda-Kulekhani-2	10.48	2	ACSR Bear	160.82
14	Pathalaiya-Parwanipur	33	2	ACSR Bear	114.71
15	New Butwal- Bardaght	20	2	ACSR Bear	149.57
16	Damauli-Bharatpur	39	1	ACSR Wolf	144.09
Total ckt.km		**808.47**	ACSR Bear: 501.92 ct.-km ACSR Panther: 197.55 ckt.-km ACSR Bison: 70 ckt. Km ACSR Wolf: 39 ckt. km		

From the above table, it is analyzed that a total 808.47 electrical circuit kilometers of 132kV transmission line is found to be the most critical based on the percentage of maximum loading. Above critical line sections have been selected for the lines having ≥ 100% loading. From the table, Dumkibas-Bardaghat 132kV transmission line section is found to be the most critical having 590.75% maximum loading followed by Gandak-Bardaghat 132kV transmission line section of 484.99% loading.

4.1.5 At 35% Generation:

At 35% generation scaling, INPS load flow is converged in 8 iterations. Muzzafarpur and Ramnagar external grids have been considered as reference machine or slack bus. At this case, the result of the grid summary is noted below:

No. of Busbars: 104; No. of Lines: 178

No. of Loads: 75 No. of Shunts Capacitor: 31

Total Generation Capacity: 854.97 MW, 2275.27 MVar; 2430.60 MVA

External Infeed = 1665.02 MW, 17.51 MVar, 1665.11 MVA

Load P(U) = 2054.59 MW, 995.62 MVar , 2283.28 MVA

Grid Losses = 465.21 MW, 1982.17 MVar

From above results, it is noted that there a deficit of 1665.02 MW which is infeed from the external grid. Total grid power loss of 465.21 MW which will be 18.46% of the total system in-feed.

Table 4.5: List of 132kV Critical Transmission Lines at 35% Generation

SN	Line name/section	Line Length in ckt-km	No. of elec. circuits	Conductor type	Line Loading (%)
1	Lamosanghu-Khimti	45.84	1	ACSR Bear	305.50
2	Chapur-Dhalkebar	139	2	ACSR Bear	210.99
3	Bhaktapur-Lamoshanghu	96.60	2	ACSR Bear	153.40
4	Pathalaiya-Chapur	66	2	ACSR Bear	192.42
5	***Gandak-Bardaghat***	***28***	***2***	***ACSR Panther***	***547.13***
6	***Dumkibas-Bardaghat***	***15***	***1***	***ACSR Panther***	***694.32***
7	Dumkibas-Kawasoti	55	1	ACSR Panther	309.18
8	New Bharatpur-Dumkibas	70	1	ACSR Bison	273.36
9	Kawasoti-Bharatpur	28.70	1	ACSR Panther	277.36
10	Kamane-Pathalaiya	60	2	ACSR Bear	113.42
11	Hetauda-Bharatpur	70.85	1	ACSR Panther	167.04
12	Butwal-New Butwal	66	2	ACSR Bear	159.40
13	Hetauda-Kulekhani-2	10.48	2	ACSR Bear	190.91
14	Pathalaiya-Parwanipur	33	2	ACSR Bear	118.96

15	New Butwal- Bardaght	20	2	ACSR Bear	163.19
16	Damauli-Bharatpur	39	1	ACSR Wolf	184.35
Total ckt.km		**843.47**	ACSR Bear: 536.92 ct.-km ACSR Panther: 197.55 ckt.-km ACSR Bison: 70 ckt. Km ACSR Wolf: 39 ckt. km		

From the above table, it is analyzed that a total 843.47 electrical circuit kilometers of 132kV transmission line is found to be the most critical based on the percentage of maximum loading. From the table, Dumkibas-Bardaghat 132kV transmission line section is found to be the most critical having 694.32% maximum loading followed by Gandak-Bardaghat 132kV transmission line section of 547.13% loading.

Now analyzing above different cases at various generation scaling keeping the load demand at maximum value of 2054.78 MW, we may synthesize the result in the following Table 4.6:

Table 4.6: Grid Power Loss at Different Generation Scaling

Generation Scaling (%)	Generation Power (MW)	External Infeed	Grid Power Loss (%)
100	2,432.74	(218.18)	6.56
80	1,947.25	256.38	6.75
50	1,219.05	1,089.34	10.98
40	976.33	1,440.87	15.0
35	854.97	1,665.02	18.46

From above Table 4.6, we see that when internal generation is decreased and deficit is fulfilled by the external in-feed, total grid losses is increased. Number of overloaded transmission lines is also increased at decreased internal generation and increasing external in-feed.

Now as a part of this research, it is considered to upgrade the conductors at the line sections which are overloaded by ≥100% at full generation capacity and load is considered maximum, the same is also shown in above Table 4.1: List of 132kV Critical Transmission Lines at 100% Generation. These line sections are using the ACSR Bear and ACSR Panther conductors. Therefore, the total length of 543.82 circuit km at those critical line sections with equivalent HTLS conductor along with insulator, erection hardware and fittings are considered for further analysis.

4.2 Derating of Line Conductors

Under NEA service conditions as discussed in Section 3.3, the current – temperature relationship of the line conductors in maximum loading conditions is calculated as per IEEE Standard 738, "IEEE Standard for Calculating the Current-Temperature of Bare Overhead Conductors". Detail calculation is done in .xls sheets and the calculation results are provided in Annex D. The summary of derated current values of few ACSR conductors used in 132kV line in INPS is shown in Table 4.7 below:

Table 4.7: Derating of ACSR Conductors

Conductor Code	**ACSR Wolf**	**ACSR Panther**	**ACSR Bear**	**ACSR Duck**
Current carrying capacity at the maximum operating temp. of 75°C as per Manufacturer in Ampere (A)	470	560	650	750
Derated Ampacity under NEA service condition at maximum operating temp of 75° C in Ampere (A)	335.28	395.94	457.78	498.07

It is observed from above Table 4.7 that for all conductors, the derated current carrying capacity is less than the ratings specified by the manufacturer in its standard data sheet. The reason is that the ambient temperature and coefficient of solar absorption is less in actual service condition which cause to contribute the higher heat gain on the conductor surface. However, parameters like emissivity and wind speed are more than in actual service condition which also contributes to the heat loss. So, due to decrease in heat loss and increase in heat gain, conductor reaches higher temperature at lower current as compared to manufacturer's condition.

4.3 ACSR Equivalent HTLS Conductor

The equivalent of any conductor type is generally having an equivalent construction/geometry and weight per unit length. Further, the maximum tensile strength of the conductor should not add the extra loading in the tower structures. Following is given the few technical features of the ACSR conductor:

Table 4.8: Technical Features of ACSR Conductor

SN	**Description**	**Technical parameters**	
		ACSR Bear	**ACSR Panther**
1	Nominal diameter of the conductor	23.45mm	21 mm
2	Nominal cross-sectional area	326.12 mm^2	261.54 mm^2
3	Nominal mass of the conductor	1220 kg/km	974 kg/km
4	Ultimate tensile strength	112 kN	90.80 kN
5	R_{dc} at 20°C	0.11Ω/km	0.14 Ω/km

6	R_{ac} at 75°C	0.1382Ω/km	0.1759 Ω/km
7	Manufacturer rated current carrying capacity for the maximum operating temp. of 75˚C	650 Amp.	560 Amp
8	Derated current carrying capacity under NEA service condition at the maximum operating temp. of 75˚C	457.78 Amp.	395.94 Amp

So, the value of equivalent HTLS conductor is assumed to have an equivalent diameter and mass/km equivalent as of ACSR conductor however, the ampacity rating is required to be higher than the previous one.

For the ACSR Bear and ACSR Panther, equivalent HTLS conductor is generally considered to meet the following minimum requirements:

Table 4.9: Technical Requirements for Equivalent ACSR Conductor

SN	Technical parameters	Limiting Value	
		ACSR Bear Equivalent	**ACSR Panther Equivalent**
1	Overall diameter of complete conductor	Must not exceed 24.50 mm and not less than 21 mm	Must not exceed the existing conductor overall diameter 22.50 mm and not less than 19 mm
2	Approx. mass of complete conductor (kg/km)	Must be less than or equal to existing conductor weight per unit length- 1220 kg/km	Must be less than or equal to existing conductor weight per unit length- 974kg/km
3	Direction of lay of outer layer	Right Hand	

ACSR Bear and ACSR Panther conductors have the different limiting values. However, for the simplicity of the study, the equivalent HTLS conductor is considered to be the same for both conductor types. Moreover, it is considered to replace the insulators, erection hardware and accessories at those critical line sections which would be compactible to the candidate HTLS conductor.

Now, looking into the manufacturer’s data sheet of various HTLS conductors, following types of conductors have been considered as an equivalent based on similar diameter and weight per unit length. Derated value of the conductor under NEA service conditions is also noted in the same table.

Table 4.10: Technical Features of Equivalent HTLS Conductor

SN	Description	Technical Parameters								
		ACSR Bear	**ACSR Panther**	**G(Z)TACSR[1]**	**STACIR[2]**	**ACSS[3]**	**ACCC[4] OSLO**	**ACCC LISBON**	**ACCC AMSTERDAM**	**ACCC CORDOBA**
1	Diameter of the Al conductor, mm	*	*	*	*	*	*	*	*	*
2	Diameter of Core, mm	10.05	9.00	*	*	*	8.76	7.11	7.75	7.75
3	Diameter of complete conductor, mm	23.45	21.00	22.60	23.45	22.42	**22.40**	21.79	23.55	24.41
4	Cross sectional area of core, mm	61.70	49.48	43.11	58.07	*	60.30	39.70	47.10	47.10
5	Cross-sectional area of Al conductor, mm^2	264.42	212.06	265.30	248.87	*	313.80	315.50	367.40	399.40
6	Cross sectional area of complete conductor, mm^2	326.12	261.54	308.40	325.60	347.71	374.10	355.20	414.50	446.50
7	Nominal mass of the conductor, kg/km	1220	974	1084	1083	1203	**981**	946	1104	1191
8	Ultimate Tensile Strength of conductor, kN	112	90.80	107.50	98.71	102.50	**147.90**	103.40	122.40	123.50
9	R_{dc} at 20°C, Ω/km	0.11	0.1363	0.111	0.11068	0.09333	0.0893	0.0887	0.0762	0.070
10	Temperature Coeff. of Resistance per °C	0.00403	0.00403	0.00403	0.00403	0.00403	0.00403	0.00403	0.00403	0.00403
11	Max. operating temp. °C	75	75	210	180	150	**180**	180	180	180
12	Max. allowable emergency temp. °C	85	85	250	200	180	200	200	200	200
13	Rac at 25°C, Ω/km	0.1178	0.1378	*	*	*	0.0911	0.0910	0.0784	0.0724
14	Rac at 75°C, Ω/km	0.1382	0.1759	*	*	*	0.1091	0.1088	0.0936	0.0864
15	Rac at 180°C, Ω/km	NA	NA	*	*	*	0.1469	0.1461	0.1256	0.1158
16	Current Rating at Max. operating temp.	650	560	1335	1260	1151	**1291**	1285	1419	1495
17	Derated current carrying capacity under NEA service condition at the maximum operating temp.	457.78	395.94	1134.75	1071	978.35	**1123.17**	1117.95	1248.72	1318.24

'Z' refers to trapezoidal shape of aluminum conductor. 'G' refers to Gap between steel and aluminum conductor.

* Unknown

Note:

Manufacturer's value of current capacity is given based on referenced conductor temperature, 0.61 m/s wind, 0 m elevation, 0.5 emissivity, 0.50 absorptivity, 40 °C Ambient Temperature, 1045 W/m^2 ($96 w/ft^2$) solar

[1] Gap Type Super Thermal Aluminum Conductor Steel Reinforced
[2] Super Thermal Aluminum Alloy Conductor INVAR Reinforced
[3] Aluminum Conductor Steel Supported
[4] Aluminum Conductor Composite Core

Conductors listed in Table 4.10 are both electrically and geometrically very similar to the conventional ACSR Bear conductor mostly using in 132kV transmission line. The DC resistance value at 20 °C for G(Z)TACSR, STACIR is near to the ACSR Bear conductor and is also higher than other HTLS conductor types. This value will be higher at large operating temperature. So, the power loss will be increased while operating at large temperature which looks not so good in long run. For ACSS, it has higher weight per unit length than other HTLS ACCC conductors. Further, its derated current carrying capacity is also lower at maximum operating temperature. So, it is also not selected for the analysis.

Now looking into the ACCC conductors, the derated current for ACCC CORDOBA is 1318.24 Amp. at the maximum operating temp. of 180°C under NEA service condition which is followed by ACCC AMSTERDAM with current value of 1248.72 Amp. It is because ACCC CORDOBA has large cross section of Aluminum part than ACCC AMSTERDAM however; both have the same core diameter. The third higher current carrying value is that of ACCC OSLO which 1123.17 Amp is at maximum operating temperature value of 180 °C. It has lower current value in comparison with the previous two ACCC conductor types. Irrespective of having larger cross-sectional area, it has the larger core diameter than in other ACCC conductors. However, it has the highest tensile strength and least weight per unit length among all conductor types and it is more equivalent geometrically to both of ACSR Bear and ACSR Panther conductors. ACCC LISBON has the least derated current value among above ACCC conductors.

Now, following the optimum conductor size equivalent to the both ACSR Bear and ACSR Panther conductors, least conductor mass per unit length and largest ultimate tensile strength is more satisfactory to consider the ACCC OSLO as equivalent ACSR conductor. It has the derated capacity of 1123.17 Amp. It has almost 2.45 times higher than ACSR Bear and 2.84 times higher than ACSR Panther conductor maximum allowable current carrying capacity under derating at NEA service condition which is quite satisfactory to consider as an equivalent conductor.

4.4 Load Flow Study after HTLS Conductor

In view of the above discussion, all the 132kV critical line sections which are overloaded as shown in Table 4.1, load flow has been carried out after replacing

ACSR conductor with HTLS ACCC OSLO. During load low, it is noted that the INPS load flow is converged in 5 iterations. Muzzafarpur and Ramnagar external grids have been considered as reference machine or slack bus. At this case, the result of the grid summary is noted below:

No. of Busbars: 104; No. of Lines: 178

No. of Loads: 75 No. of Shunts Capacitor: 31

Total Generation Capacity: 2438.72 MW, 456.33 MVar; 2481.05 MVA

External Infeed = -245.67 MW, 176.97 MVar, 302.78 MVA

Load P(U) = 2054.59 MW, 992.95 MVar , 2281.95 MVA

Grid Losses = 138.45 MW, 375.76 MVar

Above result is so remarkable that the surplus power in INPS generation is 245.67 MW which is more by 15.60 MW than before conductor replacement. It means that grid power loss is decreased by about 15.60 MW than original case of 154.06 MW which is about 5.67% of the total generation and it is 6.31% before conductor replacement.

It is further analyzed the scenario of the critical lines as noted in Table 4.11 as under:

Table 4.11: Status of 132kV Critical Transmission Lines after Conductor Uprating

SN	Line name/section	Line Length in ckt-km	No. of elec. circuits	Line Loading (%)		
				ACSR Type	Loading	Loading after HTLS
1	Dhalkebar-Mirchaiya	63	2	Bear	***167.22***	54.83
2	Kusaha-Kataiya	13	1	Bear	***154.44***	62.53
3	Lamosanghu-Khimti	45.84	1	Bear	146.26	62.78
4	Chapur-Dhalkebar	139	2	Bear	140.53	60.32
5	Bhaktapur-Lamoshanghu	96.60	2	Bear	137.65	52.78
6	Nawalpur-Chapur	66	2	Bear	124.92	52.61
7	Duhabi-Damak	48.90	1	Bear	122.07	51.27
8	Gandak-Bardaghat	28	2	Panther	116.03	25.57
9	Hetauda-Kulekhani2	10.48	2	Bear	108.24	40.46
10	Pathalaiya-Parwanipur	33	2	Bear	103.05	47.12

It looks that the loading at all the line sections is drastically reduced after replacement of ACSR conductor with HTLS conductor.

4.5 Sag- Tension Study

For sag - tension analysis of the candidate HTLS conductor: ACCC OSLO, PLS-CADD tool is used. It is required that each individual conductors must be well maintained under all operating condition. The new HTLS conductor must not violate the existing sag and existing tension on tower at any operating temperature condition of each individual conductors.

Sag – tension calculation has been carried out at each criticl line sections taking the case of both ACSR and HTLS conductor. Now, the sag – tension behaviour of the conductors at different weather conditions is discussed below:

4.5.1. Kusaha – Katiya Section

At this line section, 2.83 km of line lengh from Kusaha to Kataiya is selected for the study. In the selected line length, the minimum line span is found 149 m between Tower No. 4 and Tower No. 5 and the maximum span is found 376 m between Tower No. 3 to Tower No. 4. ACSR Bear conductor is used at this line. The ambient temperature at the intial condition during stringing is considered 32 °C. Ruling span sag-tension report is analyzed in the followings:

Table 4.12: Conductor load at different weather case

SN	Weather case	Conductor Load (ACSR Bear)			Conductor Load (ACCC OSLO)		
		Hor. (N/m)	Vert. (N/m)	Resultant (N/m)	Hor. (N/m)	Vert. (N/m)	Resultant (N/m)
1	0 deg. no wind	0.00	11.90	11.90	0.00	9.81	9.81
2	0 deg. 36% wind	13.25	11.90	17.81	12.65	9.81	16.01
3	32 deg. no wind	0.00	11.90	11.90	0.00	9.81	9.81
4	32 deg. full wind	39.79	11.90	38.67	35.14	9.81	36.49
5	180 deg. no wind	-	-	-	0.00	9.81	9.81
6	75 deg. no wind	0.00	11.90	11.90	0.00	9.81	9.81

In Table 4.12, the conductor load distribution at different weather cases is shown. At no wind case, there is only the vertical load, horizontal load of the conductor is zero. At windy case, extra loading is imposed in the conductor so that the total load is the resultant value of both vertical and horizontal load of the conductor.

Table 4.13: Sag-Tension Report at Kusaha - Kataiya (T3-T4)

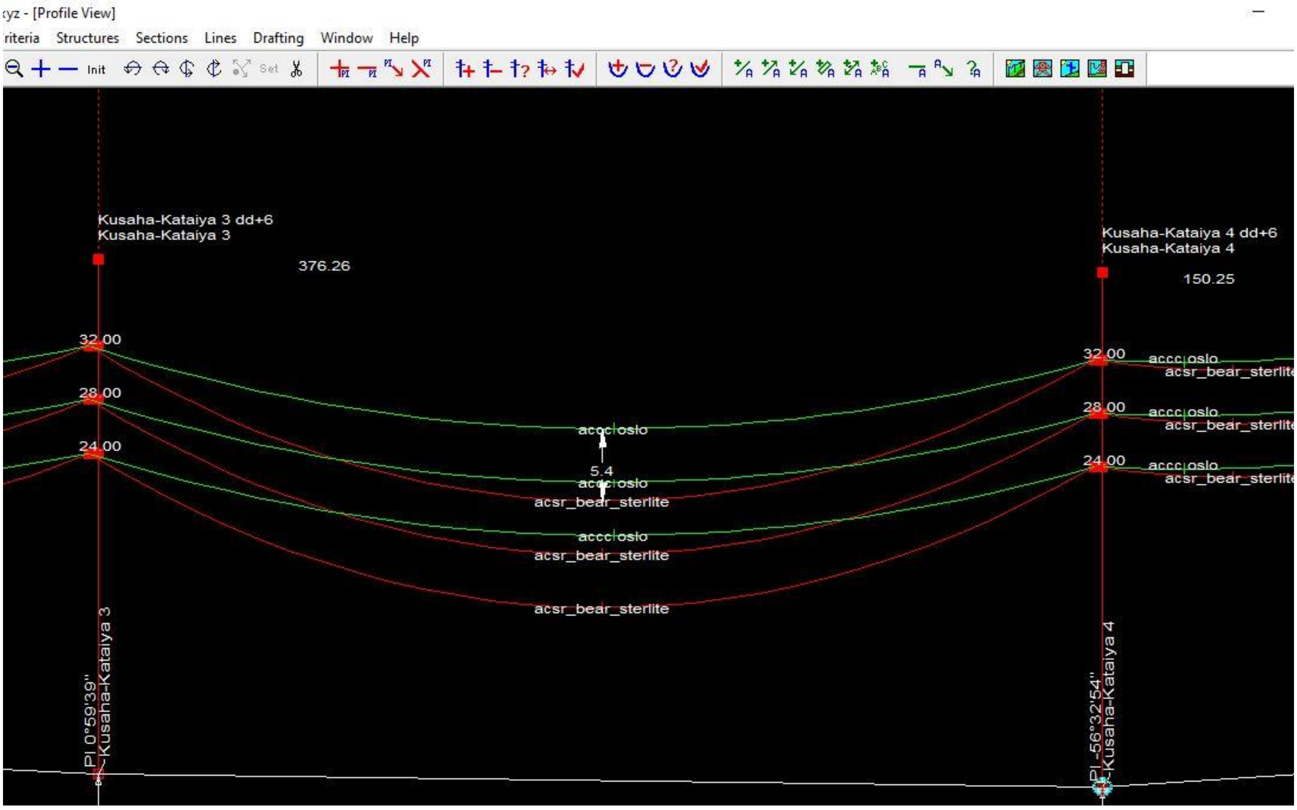
SN	Weather case	Sag-tension after load (ACSR Bear)			Sag-tension after load (ACCC OSLO)		
		Max. Tens. (N)	Hori. Tens. (N)	Sag (m)	Max. Tens. (N)	Hori. Tens. (N)	Sag (m)
1	0 deg. no wind	26268	26166	8.07	40559	40512	4.29

2	0 deg. 36% wind	34914	34746	9.10	44463	44355	6.40
3	32 deg. no wind	22609	22491	9.39	37716	37666	4.62
4	32 deg. full wind	55612	55124	12.46	56810	56386	11.49
5	180 deg. no wind	-	-	-	30910	30849	5.64
6	75 deg. no wind	19247	19109	11.06	34054	33999	5.12

Looking at the above Table. 4.13, we see the sag at different weather cases which is lower while the conductor is changed into ACCC OSLO from ACSR Bear. More tension is imposed in the the conductor than in the initial case, however it is within the limit of sag-tension criteria.

Looking at the figure 4.1 below, we may visualize the sag distribution once using both conducors at maximum operating temperature of 75 °C. At near to the knee point of the conductor catenary curve, we see that the conductor ACCC OSLO looks having less sag less than ACSR Bear by about 5.4m.

Figure 4.1 Stringing Chart at Kusaha – Kataiya (T3-T4)



4.5.2. Dhalkebar - Chapur Section

At this line section, 2.89 km of line lengh from Kusaha to Kataiya is selected for the study. The minimum line span is found to be 311 m between Tower No. 5 and Tower

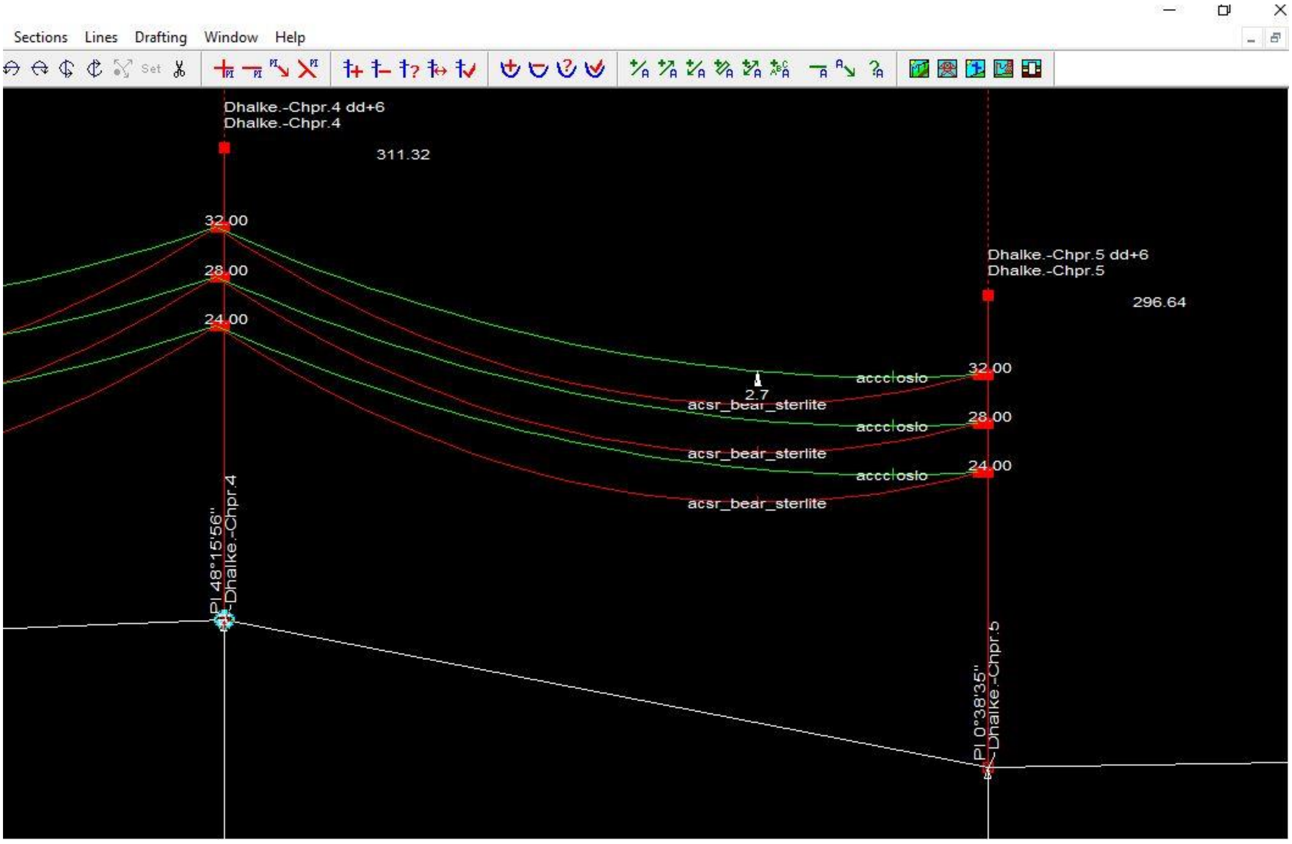
No. 6 and the maximum span is found 399 m between Tower No. 3 and Tower No. 4. We take the span between Tower No. 4 and Tower No. 5 for the study where the ruling span is 311.12 m. ACSR Bear conductor is used at this line. The ambient temperature at intial condition during stringing is considered 32 °C. Ruling span sag-tension report is given in the followings:

Table 4.14: Sag-Tension Report at Dhalkebar- Chapur (T4-T5)

SN	Weather case	Sag-tension after load (ACSR Bear)			Sag-tension after load (ACCC OSLO)		
		Max. Tens. (N)	Hori. Tens. (N)	Sag (m)	Max. Tens. (N)	Hori. Tens. (N)	Sag (m)
1	0 deg. no wind	32772	32624	4.40	38119	38001	3.12
2	0 deg. 36% wind	39915	39734	5.41	41037	40890	4.73
3	32 deg. no wind	26052	25895	5.55	35205	35087	3.37
4	32 deg. full wind	55614	55211	8.46	50491	50108	8.80
5	180 deg. no wind	-	-	-	30720	30600	3.87
6	75 deg. no wind	20361	20190	7.12	31461	31342	3.78

Again, we see in table 4.14 that the conductor sag is decreased after replacing ACSR with HTLS whereas the tension is higher in the later case but is within the limit of sag-tension criteria. Similarly, we may visualize the sag variant between two conductor types in the below figure 4.2. Here, the two supports seem to be at different level so that the knee point is at the right from the mid span length. Looking at the demarked point, there is a sag difference of 2.7 m between two conductor types i.e., ACCC OSLO is having the lower sag value.

Figure 4.2 Stringing Chart at Dhalkebar- Chapur (T4-T5)



4.5.3. Khimti - Lamosanghu Section

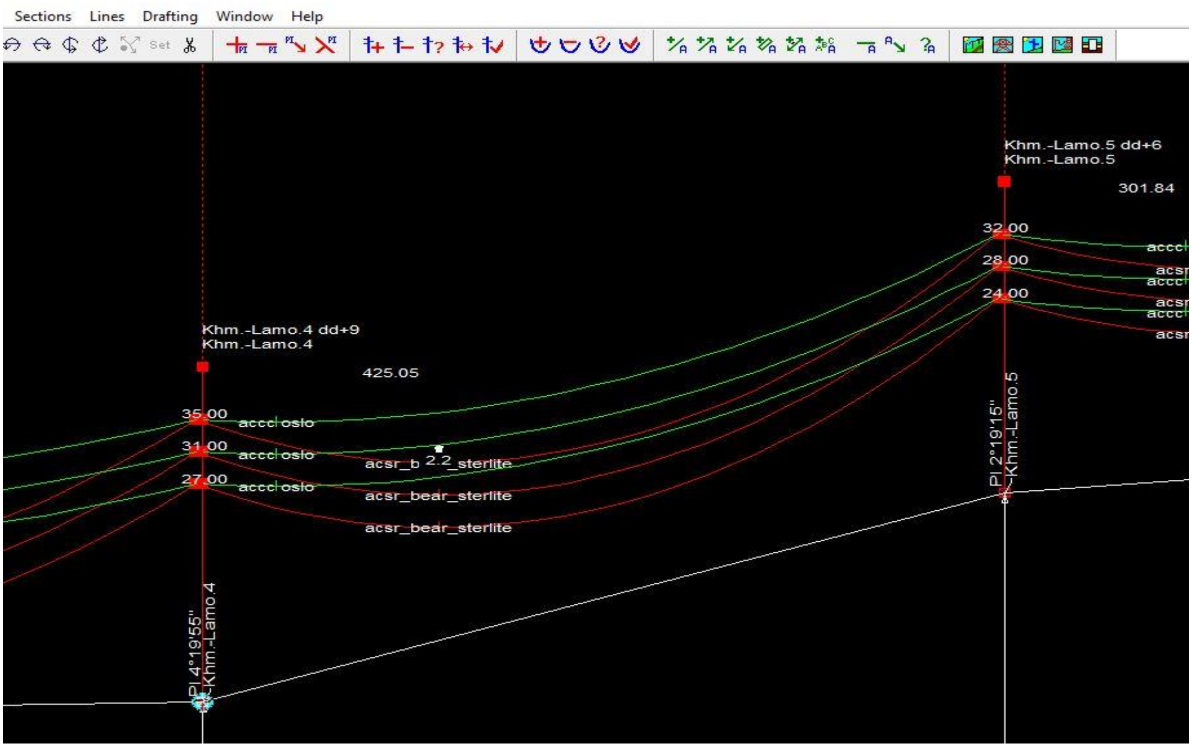
Similarly taking the another case of Khimti – Lamosanghu 132kV line section, line length of 1.680 km from Khimti to Lamosanghu is selected for the study. The minimum line span is 215.20 m between Towr No. 2 and Towr No. 3 and the maximum span is found 607.7 m between Tower No. 3 and Tower No. 4. Span between Tower No. 4 and Tower No. 5 is selected for the sag – tension analysis. Ruling span of this section is 425 m, sag-tension report is given in the followings:

Table 4.15: Sag-Tension Report at Khimti - Lamosanghu (T4-T5)

SN	Weather case	Sag-tension after load (ACSR Bear)			Sag-tension after load (ACCC OSLO)		
		Max. Tens. (N)	Hori. Tens. (N)	Sag (m)	Max. Tens. (N)	Hori. Tens. (N)	Sag (m)
1	0 deg. no wind	23665	23356	11.48	39135	38910	5.68
2	0 deg. 36% wind	32624	32244	12.45	43979	43710	8.25
3	32 deg. no wind	21248	20928	12.82	36462	36236	6.10
4	32 deg. full wind	55607	54844	15.91	58664	58025	14.18
5	180 deg. no wind	-	-	-	31062	30834	7.16
6	75 deg. no wind	18849	18512	14.50	33054	32827	6.73

Again here, the conductor sag is reduced drastically after replacing ACSR with ACCC conductor. Similarly, we may look at the conductor catenary curve suspended between two supports at Tower No. 4 and Tower No. 5 at the figure 5.3 below:

Figure 4.3 Stringing Chart at Khimti - Lamosanghu (T4-T5)



We may look that the two supports are at the different levels. The knee point of the conductor catenary curve is towards left from the mid span length. Looking at the middle phase of the line, the ACCC conductor has less sag by about 2.2 m in comparison to the existing ACSR Bear conductor.

Similarly, other line sections are also analyzed for the sag- tension behavior at different weather cases. It’s all complied the required criteria of not violating the existing sag at any operating temperature condition of each individual conductors.

4.6 Cost Analysis for Conductor Replacement

It is also a part of the study for the cost analysis which needs for the replacement of the existing ACSR conductor, insulators, erection hardware and accessories. It is supposed that any modification of the tower and support structures may not be required to suspend the new conductor and hardware.

As noted in the Table 4.1, length of 132kV transmission line selected as the most critical section is 543.82 circuit kilometers. It is proposed to replace the conductor at the whole line sections. Following is given the cost summary of the items, detail estimate of the items and the cost breakup is provided in Appendix E1 and Appendix E2.

Table 4.16: Cost Analysis for Conductor Replacement

Section A: Supply of HTLS Conductor and accessories			
SN	**Items description**	**Estimated Cost**	**Remarks**
1	HTLS ACCC OSLO Conductor (1700km)	USD 18,763,920.00	
2	Insulators with hardware fitting and accessories	USD 164,505.35	
3	Erection Hardware and other accessories required for the installation of new conductor	USD 3,621,591.00	
4	**Total of Section A: Supply Items**	**USD 22,550,016.35**	
Section B: Dismantling, Installation and Commissioning Charges			
1	Check Survey of existing Transmission line	USD 100, 000.00	
2	Dismantling and storing of Existing ACSR Conductor, hardware & accessories and Stringing, tensioning, clamping, jointing etc. of HTLS Conductor including fitting materials complete along with Testing and Commissioning of Line	USD 2,877,969.23	
3	Insulators with hardware fitting and accessories	USD 7,062.46	
4	Erection Hardware: **a**ll necessary accessories, hardware and fittings (Tension, suspension clamps, Connector etc.) required to complete the HTLS stringing works completely	USD 363,941.05	
5	**Total of Section B: Dismantling, Installation and commissioning charges**	**USD 3,248,972.74**	
6	**Sum of Section A + Section B**	**USD 25,798,989.09**	
7	**Total amount in NPR.**	**NPR. 3,353,868,581.90**	**1 USD @NRs. 130**

In the above analysis, the total cost estimated for the conductor replacement is USD 25.798 Million excluding applicable custom duty and VAT. We may also look at the section 4.4 that the grid power loss is decreased by 15.60 MW which is assumed to be equivalent to the generation of that power and it can be analyzed as the cost of establishment of 15.60 MW hydropower generation plant. In today's study, the average cost incurred to establish a hydropower is NRs. 200 million per MW so that total cost needed for setting up a 15.60 MW hydropower plan will be NRs. 3,120 million which is near to the total cost required for HTLS conductor replacement as noted in above table 4.16.

For the construction of a new 132kV double circuit line with the use of ACSR Bear conductor, the average cost required is NRs. 20 million in average [29]. This amount is excluding the cost of land for the tower footings, cost of IEE/EIA study, cost of compensation of structures, crops, forest and land falling in the right of way etc. Considering all of these various factors, the total direct cost of the new transmission line may reach up to NRs. 50 million per kilometer which is quite a large value. Indirect cost like cost of capital, cost of overhead for resolution of social and forest related issues etc., also add extra cost in the project.

Therefore, considering all of these factors, the choice of conductor replacement is the best option for uprating the transmission line capacity.

4.7 Technical Viability for Reuse ACSR Conductor

To determine the remaining useful life of the old ACSR conductors, it needs to carry out the test of the conductor. The conductor should conform the test following the Indian/International standards as noted below:

Table 4.17: List of Standards for Test of Conductors

SN	IS Name	Title	International Standard
1.	IS: 209-1992	Specification for zinc	BS:3436-1986
2.	IS: 398 Part-I -1996	Specification for Aluminum Conductors for Overhead Transmission Purposes	IEC:1089-1991 BS:215-1970
3.	IS:398 Part-II -1996	Aluminum Conductor Galvanized Steel Reinforced	BS;215-1970 IEC:1089-1991
4.	IS:398 Part-V -1992	Aluminum Conductor Galvanized Steel- Reinforced for Extra High Voltage (400 KV) and above	IEC:1089-1991 BS:215-1970
5.	IS : 1778-1980	Reels and Drums for Bare Conductors	BS:1559-1949
6.	IS : 1521-1991	Method of Tensile Testing of Steel Wire	ISO 6892-1984
7.	IS : 2629-1990	Recommended Practice for Hot Dip Galvanizing of Iron and Steel	
8.	IS : 2633-1992	Method of Testing Uniformity of Coating on Zinc Coated Articles	
9.	IS : 4826-1992	Galvanized Coating on Round Steel Wires	IEC: 888-1987 BS:443-1969
10.	IS : 6745-1990	Methods of Determination of Weight of Zinc Coating of Zinc Coated Iron and Steel Articles	BS:433-1969 ISO 1460 - 1973

11.	IS : 8263-1990	Method of Radio Interference Tests on High Voltage Insulators	IEC:437-1973 NEMA:107-1964 CISPR
12.		Zinc Coated steel wires for stranded Conductors	IEC: 888-1987
13.		Hard drawn Aluminum wire for overhead line conductors	IEC: 889-1987

Where:

BS: British Standard; IEC: International Electro technical Commission.

BIS/IS: Bureau of Indian Standards;

ISO: International Organization for Standardization.

NEMA: National Electric Manufacturing Association

As explained in Section 2.10, the degradation of ACSR conductors begins as a loss of zinc from the galvanized steel core wires [25]. These losses can be measured using corrosion detector. The steel core corrosion detector measurements indicate the average thickness of the zinc remaining. Furthermore, it needs to carry out the mechanical tests of the conductors for the evidence of damage due to arching, localized annealing, lightning impulse, unsymmetrical and symmetrical faults etc.

To determine the remaining useful life of any tested conductor, an unacceptable deterioration level has to be established for each diagnostic procedure. Due to variation in zinc thickness and uncertainty regarding original thickness, the indicative is qualitative result of the conductor remaining useful life. A relatively coarse scale line one to four can be applied to categorize the samples. The instrument does not respond to effects that take a place within the steel wires after zinc coating is pierced or removed, such as surface rusting, pitting of the surface, or severe corrosion within the wires. Consequently, only end point that can be used for these measurements. The maximum value of four which corresponds to 80 to 100% loss of zinc.

In view of the above literature, the old ACSR conductors need to carry out the test to decide its technical viability for reusing in new project. Many conductor manufacturers in Nepal have lab facilities for those needed tests. Therefore, it is recommended to carry out the test as per the prevailing international standards to determine the remaining useful life and possibility for reusing those old conductors in transmission line.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Following the analysis of the research in above sections, total of 543.82 circuit km. of 132kV line length (having ACSR Bear: 515.82 Ckt. km and ACSR Panther: 28 ckt. km) is found to be overloaded at full generation of 2438.72 MW and full load of 2054. 59 MW demand. At this case, total grid power surplus is 230.07 MW and grid power loss is 154.06 MW. When those overloaded line conductors are replaced with HTLS ACCC OSLO conductor which is equivalent to the ACSR Bear and ACSR Panther conductor, the grid power surplus is increased to 245.67 MW and decreasing the power loss by 15.60 MW from 154.06 MW which becomes 5.67% of the total system in-feed and it was 6.31% before conductor replacement. It is also found that the proposed ACCC OSLO HTLS conductor can carry the current by almost 2.45 times higher than ACSR Bear and 2.84 times ACSR Panther while derating at NEA service condition which is a quite amazing result. The line loading at each critical section is also reduced at safe zone, limiting 62.78% at maximum in Lamosanghu – Khimti 132kV Transmission Line section.

Reduction of grid power loss after conductor replacement is assumed to be equivalent to the generation of that power and it can be analyzed as the cost of establishment of 15.60 MW hydropower generation plant.

Similarly, all the critical line sections are analyzed for the sag- tension behavior at different weather cases. It's all complied the required criteria for not violating the existing sag at any operating temperature condition of each individual conductors, the new conductor has lesser sag than the at original case.

Cost analysis is also carried out for the replacement of the existing ACSR conductor, insulators, erection hardware and accessories. The total cost required for all these conductor replacement works is USD 25.798 million which is found to be more economic than constructing a new transmission line. Therefore, considering all the scenario, the choice of conductor replacement is the best option for uprating the transmission line capacity in 132kV transmission line critical sections in NEA.

To determine the remaining useful life of the old ACSR conductors, it needs to carry out the test of the conductor. The conductor should conform the test following the Indian/International standards.

5.2 Recommendation for further works

Recommendation for further work is provided in the following points:

1) Study of Initial Environmental Examination (IEE) and/or Environmental Impact Assessment (EIA) and Social Impact Assessment (SIA) is recommended to carry out before execution for the old conductor replacement.

2) Capacity enhancement of dedicated human resources, arrangement of tools and tackles, stock of spare conductors for repair and maintenance of HTLS conductor is recommended for NEA.

3) Test of old ACSR conductors, insulators, erection hardware and fitting accessories etc. is recommended as per prevailing IS/BS at accredited laboratory to find the remaining useful life and its technical viability to re-use in new/old transmission lines.

4) Use of HTLS conductors with appropriate design and current carrying capacity is recommended at new transmission lines projects in NEA.

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APPENDIX A: INPS Bus Name and Number

Bus No.	Bus Name	Bus Voltage
104	KOHALPUR'	132
105	'LAMAHI	132
106	'JHIMRUK	132
107	'SHIVPUR	132
108	'BUTWAL	132
110	'BARDGHAT	132
111	'GANDAK	132
112	'BHARATPU	132
113	'HETAUDA	132
114	'DHALKE	132
115	'LAHAN	132
116	'DUHABI	132
117	'ANARMANI	132
118	'MARSHYAN	132
119	'DAMAULI	132
120	'POKHARA	132
121	'KL-II	132
122	'SIUCH	132
123	'BALAJU	132
124	'KUSHAHA	132
125	'KG-A	132
126	'MODI	132
127	'KHIMTI1	132
128	'BHOTEKOS	132
129	'LAMOSANG	132
130	'BHAKTAPU	132
131	'ATARKHEL	132
132	'HARISIDI	132
133	'THANKOT	132
134	'PARWANI	132
135	'KL-3	132
141	'UP MODI	132
150	'MIDMARS	132
157	'CHANDRAN	132
158	'LEKHNATH	132
170	'PATHA	132
199	'KAWASOTI	132
301	'ANDHIKHO	33
302	'BUTWAL	33
303	'MULTIFL	33
304	'DUHABI	33
305	'ANARMANI	33
306	'PUWA	33
309	'DARAMKH	33
310	'PILUWA	33
311	'KHUDI	33
312	'DAMAULI	33
313	'LONYADI	33
314	'MARDI33	33
315	'MODE33	33
601	'HETAUDA	66
602	'KL-I	66
603	'HTCEM	66
604	'AMLEK	66
605	'SIMRA	66
606	'ASSTEEL	66
607	'JYOTI	66
608	'PARWANI	66
609	'BIRGUNJ	66
610	'SIUCHATA	66
611	'BALAJU	66
612	'LAINCHOU	66
613	'CHABEL	66
614	'BHAKTPUR	66
615	'BANESWOR	66
616	'PATAN	66
617	'SUNKOSHI	66
618	'TRISHULI	66
619	'DEVIGHAT	66
620	'CHILIME	66
621	'BANEPA	66
622	'INDRAWAT	66
623	'PANCHKHA	66
630	'TEKU	66
631	'K-3	66
632	'MAILUNG	66
633	'LOINDRAW	66
700	'DUMTEKU	66
1001	'MARSYANG	11
1002	'GANDAK	11
1003	'KL-I	11
1004	'MULTIFUL	11
1005	'HETUDA	11
1006	'CHILIME	11
1007	'KHIMTI	11
1008	'BHOTEKOS	11
1301	'KG-A	13.8
1500	'MIDMARS	11
3001	'LONYADI	3.3
5001	'ANDHIKOL	5.3
6001	'DEVIGHAT	6.6
6002	'TRISULI	6.6
6003	'JHIMRUK	6.6
6004	'KL-II	6.6
6005	'SUNKOSHI	6.3
6006	'MODI	6.6
6007	'PUWA	6.6
6008	'INDRAWAT	6.6
6010	'PILUWA	6.6
6012	'KHUDI	6.6
6013	'LOINDRAW	6.6
6014	'MARDI	66
6321	'MAILUNG	6.6
6346	'T-46	66

APPENDIX B: INPS Line Parameters

From Bus	To Bus	Circuit No.	R	X	B	MVA Rating	Length, KM
104	105	1	0.05985	0.21894	0.0479	142	96
104	105	2	0.05985	0.21894	0.0479	142	96
105	106	1	0.09878	0.13648	0.02299		50
105	107	1	0.03179	0.11631	0.02545	142	51
105	107	2	0.03179	0.11631	0.02545	142	51
107	108	1	0.03803	0.13912	0.03044	142	61
107	108	2	0.03803	0.13912	0.03044	142	61
108	110	1	0.02681	0.09807	0.02146	142	43
108	110	2	0.02681	0.09807	0.02146	142	43
108	125	1	0.02615	0.11161	0.02353	180	58
108	125	2	0.02615	0.11161	0.02353	180	58
110	111	1	0.01089	0.03318	0.00672	123	14
110	199	1	0.01154	0.04219	0.00923	142	35
112	113	1	0.05447	0.1659	0.0336	123	70
112	118	1	0.01362	0.05813	0.01226	180	25
112	119	1	0.04056	0.09441	0.01827	103	39
112	199	1	0.01154	0.04219	0.00923	142	35
113	121	1	0.00499	0.01814	0.00402	142	8
113	135	1	0.00187	0.00684	0.0015	142	3
113	170	1	0.0187	0.06842	0.01497	139	30
113	170	2	0.0187	0.06842	0.01497	139	30
114	115	1	0.0374	0.13684	0.02994	142	60
114	115	2	0.0374	0.13684	0.02994	142	60
114	134	1	0.07917	0.02896	0.06337	142	127
114	157	1	0.04114	0.15052	0.03293	139	66
115	116	1	0.05361	0.19613	0.04291	142	96
116	117	1	0.04736	0.17702	0.03709	142	76
116	124	1	0.02618	0.09651	0.02079	142	42
118	122	1	0.04578	0.19502	0.04116	180	84
118	150	1	0.02397	0.10231	0.02158	180	44
119	150	1	0.02743	0.10035	0.02196	139	0
119	158	1	0.04162	0.09688	0.01875	103	40
120	126	1	0.02493	0.0938	0.01942	142	40
120	158	1	0.00622	0.01448	0.0028	103	6
121	133	1	0.01908	0.06941	0.01539	142	30.6
122	123	1	0.00383	0.01598	0.0034	142	7
122	133	1	0.00212	0.00771	0.00171	142	3.4
123	131	1	0.00612	0.0221	0.00497	142	9.8
125	158	1	0.03159	0.13486	0.02844	180	48
126	141	1	0.00623	0.02281	0.00499	142	10
127	129	1	0.0293	0.10719	0.02345	139	0
128	129	1	0.01869	0.07035	0.01456	142	30
129	130	1	0.03005	0.11165	0.02369	142	48.2
129	130	2	0.03005	0.11165	0.02369	142	48.2
130	131	1	0.00748	0.027	0.00607	142	12
130	132	1	0.00623	0.02354	0.00485	142	10
132	133	1	0.00623	0.02345	0.00485	142	10
134	170	2	0.0106	0.03877	0.00848	139	17

From Bus	To Bus	Circuit No.	R	X	B	MVA Rating	Length, KM
157	170	1	0.02743	0.10035	0.02196	139	44
301	302	1	0.5036	0.7423	0.0007	19.7	20
302	309	1	1.515	2.1447	0.00213	20	60
303	304	1	0.1259	0.1856	0.0002	19.7	5
303	304	2	0.1259	0.1856	0.0002	19.7	5
304	310	1	1.0072	1.4848	0.0016	19.7	
305	306	1	1.0072	1.4848	0.0016	19.7	40
311	312	1	1.16223	1.64453	0.00164	20	46
312	313	1	0.1259	0.1856	0.0002	20	70
314	315	1	0.7554	1.1136	0.0012	20	30
601	602	1	0.06659	0.13397	0.00208	51	16
601	602	2	0.06659	0.13397	0.00208	51	16
601	603	1	0.00416	0.00875	0.00013	51	
601	603	2	0.00416	0.00875	0.00013	51	
602	610	1	0.1207	0.2537	0.00377	51	29
602	610	2	0.1207	0.2537	0.00377	51	29
603	604	1	0.06659	0.13997	0.00208	51	16
603	604	2	0.06659	0.13997	0.00208	51	16
604	605	1	0.04162	0.08748	0.013	51	10
604	605	2	0.04162	0.08748	0.013	51	10
605	606	1	0.00416	0.00875	0.00013	51	1
605	606	2	0.00416	0.00875	0.00013	51	1
606	607	1	0.00416	0.00875	0.00013	51	1
606	607	2	0.00416	0.00875	0.00013	51	1
608	609	1	0.03746	0.07873	0.00117	51	9
608	609	2	0.03746	0.07873	0.00117	51	9
610	611	1	0.02721	0.06066	0.00089	51	7
610	611	2	0.02721	0.06066	0.00089	51	7
610	616	1	0.0136	0.03563	0.00051	51	2
610	616	2	0.0136	0.03563	0.00051	51	2
610	630	1	0.01748	0.03674	0.00055	72	4.2
610	630	2	0.01022	0.0361	0.00053	72	4.1
610	700	1	0.01748	0.03674	0.00055	72	4.2
611	612	1	0.00716	0.01784	0.00034	62	2.3
611	618	1	0.18265	0.292	0.00361	40	29
611	618	2	0.18265	0.292	0.00036	40	29
611	619	1	0.20784	0.33227	0.00411	40	33
613	614	1	0.04252	0.12817	0.00177	71	14
613	619	1	0.19525	0.31214	0.00386	40	31
614	615	1	0.05914	0.08857	0.00136	44	10.5
614	621	1	0.09495	0.12756	0.00199	44	15.3
615	616	1	0.01753	0.02533	0.00039	44	3
617	623	1	0.131	0.17598	0.00275	44	27
618	619	1	0.0208	0.04348	0.00065	51	5
618	6346	1	0.08803	0.18504	0.00275	51	21.2
620	6346	1	0.06792	0.14276	0.00212	51	16.3
621	623	1	0.06179	0.08301	0.0013	44	10
622	623	1	0.19564	0.257	0.004	44	31
622	633	1	0.00252	0.00332	0.00005	44	0.4
630	631	1	0.00546	0.00004	0.00001	59.4	3.5
631	700	1	0.00546	0.00004	0.00001	59.4	3.5

632	6346	1	0.01889	0.03021	0.00037	51	3

APPENDIX C: Generator Data

Bus No	Generator No	Capacity MW	MVA Rating	Generator Impedance
1001	1	20	30	0.182
1001	2	25	30	0.182
1001	3	25	30	0.182
1002	1	5	5.88	0.32
1002	2	5	5.88	0.32
1002	3	4	5.88	0.32
1003	1	30	35.3	0.14
1003	2	30	35.3	0.14
1004	1	7	7.65	0.13
1004	2	7	7.65	0.13
1004	3	7	7.65	0.13
1004	4	7	7.65	0.13
1004	5	7	7.65	0.13
1004	6	7	7.65	0.13
1005	1	2	2.5	0.13
1005	2	2	2.5	0.13
1005	3	1	2.5	0.13
1005	4	2	2.5	0.13
1006	1	10	13	0.161
1006	2	10	13	0.161
1007	1	12	14.2	0.23
1007	2	12	14.2	0.23
1007	3	6	14.2	0.23
1007	4	12	14.2	0.23
1007	5	12	14.2	0.23
1008	1	14	25	0.166
1008	2	14	25	0.166
1301	1	48.69	56.5	0.22
1301	2	48.69	56.5	0.22
1301	3	48.69	56.5	0.22
1500	1	35	41.18	0.2
1500	2	35	41.18	0.2
3001	1	2	2.7	0.2
3001	2	2.1	2.7	0.2
5001	1	2	2.2	0.2
5001	2	1	2.2	0.2
5001	3	2	2.2	0.2
6001	1	5	6	0.2
6001	2	5	6	0.2
6001	3	4	6	0.2
6002	1	3	3.389	0.2
6002	2	3	3.389	0.2
6002	3	3	3.389	0.2
6002	4	3	3.389	0.2
6002	5	3	3.389	0.2

Bus No	Generator No	Capacity MW	MVA Rating	Generator Impedance
6002	6	1	3.389	0.2
6002	7	1	3.389	0.2
6003	1	4	5	0.16
6003	2	4	5	0.16
6003	3	1	5	0.16
6004	1	15	18.8	0.19
6004	2	15	18.8	0.19
6005	1	3	4	0.192
6005	2	3	4	0.192
6005	3	3	4	0.192
6006	1	5	7.8	0.23
6006	2	5	7.8	0.23
6007	1	3	3.64	0.2
6007	2	2	3.64	0.2
6008	1	2	2.95	0.2
6008	2	1	2.95	0.2
6010	1	1	1.76	0.2
6010	2	1	1.76	0.2
6012	1	1	2.12	0.2
6012	2	1.2	2.12	0.2
6013	1	2	2.7	0.2
6013	2	1	2.7	0.2
6014	1	1.5	1.88	0.2
6014	2	1.5	1.88	0.2
6321	1	1	2.2	0.2
6321	2	1	2.2	0.2
6321	3	2.3	2.2	0.2

APPENDIX D: Derating of Line Conductors with IEEE Standard 738

1) ACSR Bear Conductor

Parameters	Symbol	Manufacturer Data		NEA condition	
		Unit	Value	Unit	Value
Conductor diameter	D	mm	23.45	inch	0.923
Elevation of conductor above sea level	H_e	m	0	ft	0
Elevation correction factors for high altitude (See Table 4) in IEEE 738 Standard					
Ambient temperature	T_a	°C	35		45
Conductor surface Maximum temperature	T_s	°C	75		75
Conductor Temperature	T_1	°C	20		20
Conductor Temperature	T_2	°C	75		75
Temperature of boundary layer, (Ts+Ta)/2	T_{film}	°C	55		60
Azimuth of sun	Z_c	degrees		degrees	139.0
Average sun altitude between 10:00 am and 12:00 noon	H_c	degrees		degrees	72.5
Transmission line runs in east-west direction, so latitude is assumed as	N	degrees		degrees	27
wind velocity considering angle between wind and axis of conductor as 90 degrees	v	m/sec	0.61	ft/s	1.8368
Velocity of air stream	V_w			ft/h	6612.48
Density of air	ρ_f			lb/ft^3	0.055
Absolute viscosity of air	μ_f			lb/ft.hr	0.0484
Thermal conductivity of air at temperature T_{film}	K_f			w/ft (°C)	0.00875
Emissivity constant	ε		0.5		0.45
Effective angle of incidence of the sun's ray	θ	degree	78.62	degree	78.62
Solar radiation (total solar and sky radiated heat flux)	Q_s	watt/sq.m	1045	w/ft^2	97.12
Natural Convection heat loss	q_c	w/ft		w/ft	4.389
Heat loss due to natural convection at low wind	q_{c1}	w/ft		w/ft	9.946
Heat loss due to natural convection at high wind	q_{c2}	w/ft		w/ft	8.975
The larger of the heat loss due to both natural and forced convection is used in calculating thermal rating. therefore, convection heat loss is	q_c	w/ft		w/ft	9.946
Radiated heat loss calculation	q_r	w/ft		w/ft	2.5456
Solar Heat Gain Calculation					
Solar absorptivity	α		0.5		0.5
A'	ft^2/ft			ft^2/ft	0.0769

Solar heat gain	q_s	w/ft		w/ft	3.663
DC Resistance at 20°C	R_{dc20}	Ω/km	0.11	Ω/ft	3.35E-05
AC Conductor Resistance at 20°C	R_{ac20}	Ω/km	0.113	Ω/ft	3.45E-05
Temperature coefficient of resistance at 20°C	ρ_{20}	per °C	0.004	per °C	0.004
AC Conductor Resistance at 45°C	R_{ac45}	Ω/km	0.1246	Ω/ft	3.80E-05
AC Conductor Resistance at 75°C	R_{ac75}	Ω/km	0.1382	Ω/ft	4.21E-05
Derated current value	I	Amp	650	Amp	457.78

2) ACSR Panther Conductor

Parameters	Symbol	Manufacturer Data		NEA Condition	
		Unit	Value	Unit	Value
Conductor diameter	D	mm	21	inch	0.827
Elevation of conductor above sea level	He	m	0	ft	0
Elevation correction factors for high altitude (See Table 4) in IEEE 738 Standard					
Ambient temperature	Ta	°C	35		45
Conductor surface Maximum temperature	Ts	°C	75		75
Conductor Temperature	T1	°C	20		20
Conductor Temperature	T2	°C	75		75
Temperature of boundary layer, (Ts+Ta)/2	T_{film}	°C	55		60
Azimuth of sun	Z_c	degrees		degrees	139.0
Average sun altitude between 10:00 am and 12:00 noon	H_c	degrees		degrees	72.5
Transmission line runs in east-west direction, so latitude is assumed as	N	degrees		degrees	27
wind velocity considering angle between wind and axis of conductor as 90 degrees	v	m/sec	0.61	ft/s	1.8368
Velocity of air stream	V_w			ft/h	6612.48
Density of air	ρ_f			lb/ft^3	0.055
Absolute viscosity of air	μ_f			lb/ft.hr	0.0484
Thermal conductivity of air at temperature T_{film}	K_f			w/ft (°C)	0.00875
Emissivity constant	ε		0.5		0.45
Effective angle of incidence of the sun's ray	θ	degree	78.62	degree	78.62
Solar radiation (total solar and sky radiated heat flux)	Q_s	watt/sq.m	1045	w/ft^2	97.12
Natural Convection heat loss	q_c	w/ft		w/ft	4.040
Heat loss due to natural convection at low wind	q_{c1}	w/ft		w/ft	9.406
Heat loss due to natural convection at high wind	q_{c2}	w/ft		w/ft	8.400

The larger of the heat loss due to both natural and forced convection is used in calculating thermal rating. therefore, convection heat loss is	q_c	w/ft		w/ft	9.406
Radiated heat loss calculation	q_r	w/ft		w/ft	2.2797
Solar Heat Gain Calculation					
Solar absorptivity	α		0.5		0.5
A'	ft^2/ft			ft^2/ft	0.0689
Solar heat gain	q_s	w/ft		w/ft	3.280
DC Resistance at 20°C	R_{dc20}	Ω/km	0.14	Ω/ft	4.27E-05
AC Conductor Resistance at 20°C	R_{ac20}	Ω/km	0.144	Ω/ft	4.40E-05
Temperature coefficient of resistance at 20°C	ρ_{20}	per °C	0.004	per °C	0.004
AC Conductor Resistance at 45°C	R_{ac45}	Ω/km	0.1586	Ω/ft	4.83E-05
AC Conductor Resistance at 75°C	R_{ac75}	Ω/km	0.1759	Ω/ft	5.36E-05
Derated Current value	I	Amp	560	Amp	395.94

APPENDIX E: Supply, Delivery, Construction and Installation of Conductors, Insulators with Hardware Fitting and Accessories

APPENDIX E1: Supply & Delivery of HTLS Conductors, Insulators with Hardware Fitting and Accessories [28]

Item No.	Item description	Unit	Quantity	CIP Project Site including insurance, clearing, forwarding and transportation to site (Excluding Taxes and Duties applicable in Nepal)		
				Currency#	Unite Rate	Amount
	TRANSMISSION LINE CONDUCTOR UPGRADE					
	Part-A : EMPLOYER ASSESSED QUANTITIES					
	TRANSMISSION UPGRADE					
A	Design, Manufacture, Testing and Supply of HTLS Conductor with all necessary accessories to complete the specified scope of works.					
A.1	High Tension Low Sag (HTLS) Conductor	Km	1,700.0	USD	11,000	18,763,920.00
	SUB TOTAL 'A'				-	**18,763,920.00**
B	**Insulators with hardware fitting and accessories**				-	-
B.1	Design, manufacture, testing and Supply of Disc Insulators 70 KN with fittings	Nos.	1815	USD	16.80	30,492.00
B.2	Design, manufacture, testing and Supply of Disc Insulators 120 KN with fittings	Nos.	1815	USD	16.80	30,492.00
B.3	Vibration Damper for HTLS Conductor	Nos	2000	USD	18.90	37,800.00
B.5	Mid span compression joint for HTLS conductor (A.1)	Nos	150	USD	434.70	65,205.00
B.7	Repair Sleeve for HTLS conductor (A.1)	Nos	115	USD	4.49	516.35
	SUB TOTAL 'B'				-	**164,505.35**
	Part-B: CONTRACTOR ASSESSED QUANTITIES					
C	**Erection Hardware**					
1	All necessary accessories, hardware and fittings (Tension, suspension clamps, Connector etc) required to complete the HTLS stringing works completely	Lot	1	USD	3,292,356.00	3,292,356.00
2	All tools and tackles required for the installation of the HTLS conductor.	Lot	1	USD	329,235.00	329,235.00
	SUB TOTAL 'C'			USD		**3,621,591.00**

D	**Total of Supply Items [A+B+C]**					**22,550,016.35**

APPENDIX E2: Installation and Construction Charges of HTLS Conductors [28]

Sl. No.	Item Description	Installation Charges						
		Unit	Qty.	Portion in Foreign Currency			Portion in Nepalese Currency (in NPR)	
				Currency#	Unit Rate	Total Charges	Unit Rate	Total Charges
(1)	(2)	(5)	(6)	7				
	TRANSMISSION LINE CONDUCTOR UPGRADE							
	Part-A : EMPLOYER ASSESSED QUANTITIES							
PART I	**SUB TRANSMISSION UPGRADE**							
A	Check Survey of existing Transmission line	Lot	1	USD	100,000.00	100,000.00		
	SUB TOTAL 'A'					**100,000.00**		
B	Dismantling and storing of Existing ACSR Conductor, hardware & accessories and Stringing, tensioning, clamping, jointing etc of HTLS Conductor including fitting of all necessary line materials complete and Testing and Commissioning of Line							
B.1	Dismantling of Existing ACSR Conductor, hardware, accessories, fittings and storage at NEA Site store	Km	1700	USD	168.00	285,600.00	12,600.00	21,420,000.00
B.2	Stringing of HTLS conductor with installation of all *required* hardware and accessories and testing and commissioning of Transmission line as specified							
B.2.1	High Tension Low Sag (HTLS) Conductor	Km	1700	USD	840.00	1,428,000.00	76,440.00	129,948,000.00
	SUB TOTAL 'B'					**1,713,600.00**		**151,368,000.00**
C	**Insulators with hardware fitting and accessories**							
C.1	Design, manufacture, testing and Supply of Disc Insulators 70 KN with fittings	Nos.	1815			-	84.00	152,460.00
C.2	Design, manufacture, testing and Supply of Disc Insulators 120 KN with fittings	Nos.	1815			-	84.00	152,460.00
C.3	Vibration Damper for HTLS Conductor as per B2.1	Nos	2000			-	84.00	168,000.00

C.5	Mid span compression joint for HTLS conductor (B2.1)	Nos	150			-	1,680.00	252,000.00
C.7	Repair Sleeve for HTLS conductor (B2.1)	Nos	115				1,680.00	193,200.00
	SUB TOTAL 'C'				-	-		**918,120.00**
	Part-B: CONTRACTOR ASSESSED QUANTITIES				-	-	-	-
D	**Erection Hardware**				-	-	-	-
1	All necessary accessories, hardware and fittings (Tension, suspension clamps, Connector etc) required to complete the HTLS stringing works completely.	LS	1	USD	362,159.10	362,159.10	231,653.40	231,653.40
	SUB TOTAL 'D'				**-**	**362,159.10**	**-**	**231,653.40**
	Total of [(Part-A+ Part-B)]					**2,075,759.10**		**152,517,773.40**
	Total in equivalent USD @ 1 USD= 130.00 NPR					**2,075,759.10**		**1,173,213.64**
	Total in equivalent USD @ 1 USD= 130.00 NPR					**3,248,972.74**		
	Total of supply, installation and construction charges in equivalent USD (Appendix E1+ Appendix E2)					**25,798,989.09**		

APPENDIX F: Technical Data Sheet of ACSR & HTLS Conductor

Construction and dimensions

Conductor name	Steel core Number/ Size	Steel core dia. mm Nom.	Steel core area mm² Nom.	Steel core mass kg/km Nom.	Aluminium Outer layer(s) Number/ Size	Aluminium Outer layer(s) area mm² Nom.	Aluminium Outer layer(s) mass kg/km Nom.	Total Conductor dia. mm Nom.	Total Conductor area mm² Nom.	Total Conductor mass kg/km Nom.	Outer layer Lay direction	Standard drum length m	Specification
7 Steel + 30 Aluminium													
94-AL3/22-ST1A (94/22)	7 / 2.00	6.00	21.99	173	30 / 2.00	94.25	255	14.00	116.24	606	(Z) RH	2000	EN
Canna 147.1	7 / 2.25	6.75	27.83	219	30 / 2.25	119.28	322	15.75	147.11	549	(Z) RH	2000	EN
Tiger	7 / 2.36	7.08	30.62	240	30 / 2.36	131.23	355	16.52	161.85	606	(Z) RH	2000	EN
Wolf	7 / 2.59	7.77	36.88	290	30 / 2.59	158.06	427	18.13	194.94	730	(Z) RH	2000	EN
Oriole	7 / 2.69	8.07	39.78	312	30 / 2.69	170.50	461	18.83	210.28	785	(Z) RH	2000	EN
Lynx	7 / 2.79	8.37	42.80	336	30 / 2.79	183.41	496	19.53	226.20	832	(Z) RH	2000	CAN
Panther	7 / 3.00	9.00	49.48	389	30 / 3.00	212.06	573	21.00	261.54	970	(Z) RH	2000	BS
Bear	7 / 3.35	10.05	61.70	485	30 / 3.35	264.42	715	23.45	326.12	1220	(Z) RH	2000	EN
Lion	7 / 3.18	9.54	55.60	437	30 / 3.18	238.27	644	22.26	293.86	1081	(Z) RH	2000	EN
Goat	7 / 3.71	11.13	75.67	594	30 / 3.71	324.31	877	25.97	399.98	1500	(Z) RH	2000	EN
Sheep	7 / 3.99	11.97	87.53	687	30 / 3.99	375.11	1 014	27.93	462.63	1701	(Z) RH	2000	EN
Deer	7 / 4.27	12.81	100.24	787	30 / 4.27	429.60	1 161	29.89	529.84	1949	(Z) RH	2000	EN
Elk	7 / 4.50	13.50	111.33	874	30 / 4.50	477.13	1 290	31.50	588.46	2164	(Z) RH	2000	EN

Physical properties / **Electrical Properties**

Conductor name	Modulus of Elasticity Initial kN/mm² Nom.	Modulus of Elasticity Final kN/mm² Nom.	Coefficient of linear expansion x10⁻⁶/°C	UTS kN	Grease Nom. (Case 2) kg/km	Resistance dc 20°C Ω/km	Resistance ac 75°C Ω/km	Current rating A	Short circuit rating kA.1s	Creep constant mm/m	#Creep (nominal, calculated) mm/km
7 Steel + 30 Aluminium						**7 Steel + 30 Aluminium**					
94-AL3/22-ST1A (94/22)	53.4	82.0	18.43	53.53	11.48	0.3530	0.3737	330	6.33	18.92	339
Canna 147.1	49.2	75.5	18.43	54.00	0.1322	0.2430	0.2953	415	7.19	18.92	339
Tiger	54.3	83.4	18.43	58.70	15.98	0.2202	0.2684	420	7.56	18.92	339
Wolf	54.3	83.4	18.43	69.20	19.25	0.1828	0.2228	470	8.34	18.92	339
Oriole	54.3	83.4	18.45	74.20	20.77	0.1695	0.2066	498	8.68	18.92	339
Lynx	54.3	83.4	18.45	79.30	22.34	0.1572	0.1920	520	9.03	18.92	339
Panther	54.3	83.4	18.43	90.80	25.83	0.1363	0.1661	560	9.74	18.92	339
Bear	54.3	83.4	18.43	112.00	32.21	0.1093	0.1332	650	10.94	18.92	339
Lion	54.3	83.4	18.45	100.50	29.02	0.1210	0.1478	610	10.36	18.92	339
Goat	54.3	83.4	18.43	136.00	39.50	0.0891	0.1086	730	12.18	18.92	339
Sheep	54.3	83.4	18.45	156.30	45.69	0.0769	0.0939	800	13.15	18.92	339
Deer	54.3	83.4	18.45	178.50	52.33	0.0671	0.0820	870	14.13	18.92	339
Elk	54.3	83.4	18.45	198.30	58.12	0.0604	0.0738	930	14.93	18.92	339

DATA SHEET: ACCC® OSLO ACCC® 314/60/224 (619 kcmil)*	CTC GLOBAL			
For questions, please contact CTC Application Engineering Department: applicationsupport@ctcglobal.com				
Metric and US Units are considered separate				
Aluminum Specification	**Metric**		**US Units**	
Nominal Aluminum Cross-sectional Area***	313.8	mm^2	619.3	kcmil
Aluminum Conductivity/Type	63%	% IACS	1350-O	
Aluminum Nominal Weight**	867.7	kg/km	583.2	lb/kft
Coefficient of Thermal Expansion	23.0	$x10^{-6}$/°C	12.8	$x10^{-6}$/°F
Aluminum Heat Capacity	809.9	W-s/m-C	137.1	W-s/ft-F
ACCC® Core Specification (CTC Part Number 200-008)	**Metric**		**US Units**	
Nominal Cross-sectional Area of Core	60.30	mm^2	0.0935	in^2
Nominal Diameter of Composite Core	8.76	mm	0.345	in.
Core Nominal Weight	113.0	kg/km	75.8	lb/kft
Rated Strength of Core - 310 ksi (2137 MPa)	129.0	kN	29.0	kips
Coefficient of Thermal Expansion	1.61	$x10^{-6}$/°C	0.894	$x10^{-6}$/°F
Modulus of Elasticity	112.3	GPa	16.29	Msi
Core Heat Capacity	91.9	W-s/m-°C	15.6	W-s/ft-°F
ACCC® Conductor Specification	**Metric**		**US Units**	
Overall Diameter of Conductor[1]	22.40	mm	0.882	in.
Nominal Cross-sectional Area of the Conductor	374.1	mm^2	0.580	in^2
Ultimate Tensile Strength of Conductor[2]	146.7	kN	33.0	kips
Conductor Nominal Weight**	980.7	kg/km	659.0	lb/kft
Coefficient of Linear Expansion Above Thermal Kneepoint	1.61	$x10^{-6}$/°C	0.894	$x10^{-6}$/°F
Coefficient of Linear Expansion Below Thermal Kneepoint	17.1	$x10^{-6}$/°C	9.49	$x10^{-6}$/°F
Final Modulus of Elasticity Above Thermal Kneepoint	112.3	GPa	16.29	Msi
Final Modulus of Elasticity Below Thermal Kneepoint	67.4	GPa	9.8	Msi
Maximum Allowable Operating Temperature at Surface[3]	180	°C	356	°F
Electrical Specification	**Metric**		**US Units**	
Nominal DC Resistivity at 20ºC	0.0893	ohm/km	0.1437	ohm/mile
Temperature Coefficient of Resistance	0.00403	/°C	0.00209	/°F
Frequency	50	Hz	50	Hz
AC Nominal Resistance at 25ºC	0.0915	ohm/km	0.1473	ohm/mile
AC Nominal Resistance at 75ºC	0.1095	ohm/km	0.1762	ohm/mile
AC Nominal Resistance at 180ºC	0.1471	ohm/km	0.2367	ohm/mile
AC Current Rating at Given Temperatures[4]		1292	@ 180C & 50 Hz	
		1361	@ 200C & 50 Hz	
GMR (estimated)	9.25	mm	0.0303	ft.
Inductive Reactance	0.220	ohm/km	0.3535	ohm/mile
Capacitive Reactance	0.189	Mohm-km	0.1176	Mohm-mile

ACCC® is produced using 1350-O (fully annealed) aluminum.

1) Minimum hub diameter of the conductor reel must meet the requirements of CTC F-750-032.

2) Strength at ambient temperature. Based on 96% of the 1350-O minimum tensile strength (8500 psi/58.6 Mpa) and 100% of the composite core mininum tensile strength (310 ksi/2137 Mpa).

3) Maximum operating temperature of ACCC® is 180°C and a maximum emergency temperature of 200°C (10,000 hours over the life of the conductor).

4) Conditions: 2 ft/s (0.6 m/s) wind, 0 ft (0 m) Elevation, 0.5 Emis. 0.5 absorp., 25°C Ambient temp., 96 W/sq. ft (1033 W/sq. m) sun radiation

*ASTM name designation: mm² nominal aluminum area/mm² nominal core area/mm nominal diameterx10 (nominal kcmil aluminum)

**ACCC® Conductors are required to exhibit lay lengths (ratios) that conform to ASTM B 857 or EN 50540.

***Different configurations among conductor manufacturers may result in slight variations within the parameters of indicated values for a given size in accordance with the stated specification.

F-730-564-NC www.ctcglobal.com Date Produced: 7/1/2019

DATA SHEET: **ACCC® LISBON** ACCC® 316/40/218 (623 kcmil)*	CTC GLOBAL			
For questions, please contact CTC Application Engineering Department: applicationsupport@ctcglobal.com				
Metric and US Units are considered separate				
Aluminum Specification	**Metric**		**US Units**	
Nominal Aluminum Cross-sectional Area***	315.5	mm^2	622.7	kcmil
Aluminum Conductivity/Type	63%	% IACS	1350-O	
Aluminum Nominal Weight**	871.9	kg/km	586.0	lb/kft
Coefficient of Thermal Expansion	23.0	$x10^{-6}$/°C	12.8	$x10^{-6}$/°F
Aluminum Heat Capacity	814.3	W-s/m-C	137.9	W-s/ft-F
ACCC® Core Specification (CTC Part Number 200-004)	**Metric**		**US Units**	
Nominal Cross-sectional Area of Core	39.70	mm^2	0.0616	in^2
Nominal Diameter of Composite Core	7.11	mm	0.280	in.
Core Nominal Weight	74.2	kg/km	50.0	lb/kft
Rated Strength of Core - 310 ksi (2137 MPa)	85.0	kN	19.1	kips
Coefficient of Thermal Expansion	1.61	$x10^{-6}$/°C	0.894	$x10^{-6}$/°F
Modulus of Elasticity	112.3	GPa	16.29	Msi
Core Heat Capacity	60.3	W-s/m-°C	10.2	W-s/ft-°F
ACCC® Conductor Specification	**Metric**		**US Units**	
Overall Diameter of Conductor[1]	21.79	mm	0.858	in.
Nominal Cross-sectional Area of the Conductor	355.2	mm^2	0.551	in^2
Ultimate Tensile Strength of Conductor[2]	102.7	kN	23.1	kips
Conductor Nominal Weight**	946.1	kg/km	636.0	lb/kft
Coefficient of Linear Expansion Above Thermal Kneepoint	1.61	$x10^{-6}$/°C	0.894	$x10^{-6}$/°F
Coefficient of Linear Expansion Below Thermal Kneepoint	18.8	$x10^{-6}$/°C	10.47	$x10^{-6}$/°F
Final Modulus of Elasticity Above Thermal Kneepoint	112.3	GPa	16.29	Msi
Final Modulus of Elasticity Below Thermal Kneepoint	64.1	GPa	9.3	Msi
Maximum Allowable Operating Temperature at Surface[3]	180	°C	356	°F
Electrical Specification	**Metric**		**US Units**	
Nominal DC Resistivity at 20ºC	0.0887	ohm/km	0.1427	ohm/mile
Temperature Coefficient of Resistance	0.00403	/°C	0.00209	/°F
Frequency	50	Hz	50	Hz
AC Nominal Resistance at 25ºC	0.0910	ohm/km	0.1464	ohm/mile
AC Nominal Resistance at 75ºC	0.1088	ohm/km	0.1751	ohm/mile
AC Nominal Resistance at 180ºC	0.1461	ohm/km	0.2352	ohm/mile
AC Current Rating at Given Temperatures[4]		1285	@ 180C & 50 Hz	
		1353	@ 200C & 50 Hz	
GMR (estimated)	8.85	mm	0.0290	ft.
Inductive Reactance	0.222	ohm/km	0.3579	ohm/mile
Capacitive Reactance	0.191	Mohm-km	0.1186	Mohm-mile

ACCC® is produced using 1350-O (fully annealed) aluminum.

1) Minimum hub diameter of the conductor reel must meet the requirements of CTC F-750-032.

2) Strength at ambient temperature. Based on 96% of the 1350-O minimum tensile strength (8500 psi/58.6 Mpa) and 100% of the composite core mininum tensile strength (310 ksi/2137 Mpa).

3) Maximum operating temperature of ACCC® is 180°C and a maximum emergency temperature of 200°C (10,000 hours over the life of the conductor).

4) Conditions: 2 ft/s (0.6 m/s) wind, 0 ft (0 m) Elevation, 0.5 Emis. 0.5 absorp., 25°C Ambient temp., 96 W/sq. ft (1033 W/sq. m) sun radiation
*ASTM name designation: mm² nominal aluminum area/mm² nominal core area/mm nominal diameterx10 (nominal kcmil aluminum)

**ACCC® Conductors are required to exhibit lay lengths (ratios) that conform to ASTM B 857 or EN 50540.

***Different configurations among conductor manufacturers may result in slight variations within the parameters of indicated values for a given size in accordance with the stated specification.

F-730-565-NC www.ctcglobal.com Date Produced: 7/1/2019

DATA SHEET:

ACCC® AMSTERDAM

ACCC® 367/47/235 (725 kcmil)*

CTC GLOBAL

For questions, please contact CTC Application Engineering Department: applicationsupport@ctcglobal.com

Metric and US Units are considered separate

Aluminum Specification	Metric		US Units	
Nominal Aluminum Cross-sectional Area***	367.4	mm^2	725.1	kcmil
Aluminum Conductivity/Type	63%	% IACS	1350-O	
Aluminum Nominal Weight**	1015.3	kg/km	682.4	lb/kft
Coefficient of Thermal Expansion	23.0	$x10^{-6}$/°C	12.8	$x10^{-6}$/°F
Aluminum Heat Capacity	948.2	W-s/m-C	160.6	W-s/ft-F
ACCC® Core Specification (CTC Part Number 200-005)	**Metric**		**US Units**	
Nominal Cross-sectional Area of Core	47.20	mm^2	0.0731	in^2
Nominal Diameter of Composite Core	7.75	mm	0.305	in.
Core Nominal Weight	88.3	kg/km	59.3	lb/kft
Rated Strength of Core - 310 ksi (2137 MPa)	101.0	kN	22.7	kips
Coefficient of Thermal Expansion	1.61	$x10^{-6}$/°C	0.894	$x10^{-6}$/°F
Modulus of Elasticity	112.3	GPa	16.29	Msi
Core Heat Capacity	71.8	W-s/m-°C	12.2	W-s/ft-°F
ACCC® Conductor Specification	**Metric**		**US Units**	
Overall Diameter of Conductor[1]	23.55	mm	0.927	in.
Nominal Cross-sectional Area of the Conductor	414.6	mm^2	0.643	in^2
Ultimate Tensile Strength of Conductor[2]	121.7	kN	27.4	kips
Conductor Nominal Weight**	1103.6	kg/km	741.7	lb/kft
Coefficient of Linear Expansion Above Thermal Kneepoint	1.61	$x10^{-6}$/°C	0.894	$x10^{-6}$/°F
Coefficient of Linear Expansion Below Thermal Kneepoint	18.8	$x10^{-6}$/°C	10.43	$x10^{-6}$/°F
Final Modulus of Elasticity Above Thermal Kneepoint	112.3	GPa	16.29	Msi
Final Modulus of Elasticity Below Thermal Kneepoint	64.2	GPa	9.3	Msi
Maximum Allowable Operating Temperature at Surface[3]	180	°C	356	°F
Electrical Specification	**Metric**		**US Units**	
Nominal DC Resistivity at 20ºC	0.0762	ohm/km	0.1226	ohm/mile
Temperature Coefficient of Resistance	0.00403	/°C	0.00209	/°F
Frequency	50	Hz	50	Hz
AC Nominal Resistance at 25ºC	0.0784	ohm/km	0.1261	ohm/mile
AC Nominal Resistance at 75ºC	0.0936	ohm/km	0.1507	ohm/mile
AC Nominal Resistance at 180ºC	0.1256	ohm/km	0.2022	ohm/mile
AC Current Rating at Given Temperatures[4]		1419	@ 180C & 50 Hz	
		1496	@ 200C & 50 Hz	
GMR (estimated)	9.57	mm	0.0314	ft.
Inductive Reactance	0.217	ohm/km	0.3500	ohm/mile
Capacitive Reactance	0.186	Mohm-km	0.1158	Mohm-mile

ACCC® is produced using 1350-O (fully annealed) aluminum.

1) Minimum hub diameter of the conductor reel must meet the requirements of CTC F-750-032.

2) Strength at ambient temperature. Based on 96% of the 1350-O minimum tensile strength (8500 psi/58.6 Mpa) and 100% of the composite core mininum tensile strength (310 ksi/2137 Mpa).

3) Maximum operating temperature of ACCC® is 180°C and a maximum emergency temperature of 200°C (10,000 hours over the life of the conductor).

4) Conditions: 2 ft/s (0.6 m/s) wind, 0 ft (0 m) Elevation, 0.5 Emis. 0.5 absorp., 25°C Ambient temp., 96 W/sq. ft (1033 W/sq. m) sun radiation

*ASTM name designation: mm² nominal aluminum area/mm² nominal core area/mm nominal diameterx10 (nominal kcmil aluminum)

**ACCC® Conductors are required to exhibit lay lengths (ratios) that conform to ASTM B 857 or EN 50540.

***Different configurations among conductor manufacturers may result in slight variations within the parameters of indicated values for a given size in accordance with the stated specification.

F-730-566-NC www.ctcglobal.com Date Produced: 7/1/2019

DATA SHEET: **ACCC® CORDOBA** ACCC® 399/47/244 (788 kcmil)*	CTC GLOBAL

For questions, please contact CTC Application Engineering Department: applicationsupport@ctcglobal.com

Metric and US Units are considered separate

Aluminum Specification	Metric		US Units	
Nominal Aluminum Cross-sectional Area***	399.4	mm^2	788.2	kcmil
Aluminum Conductivity/Type	63%	% IACS	1350-O	
Aluminum Nominal Weight**	1102.5	kg/km	741.0	lb/kft
Coefficient of Thermal Expansion	23.0	$x10^{-6}$/°C	12.8	$x10^{-6}$/°F
Aluminum Heat Capacity	1030.8	W-s/m-C	174.5	W-s/ft-F
ACCC® Core Specification (CTC Part Number 200-005)	**Metric**		**US Units**	
Nominal Cross-sectional Area of Core	47.20	mm^2	0.0731	in^2
Nominal Diameter of Composite Core	7.75	mm	0.305	in.
Core Nominal Weight	88.3	kg/km	59.3	lb/kft
Rated Strength of Core - 310 ksi (2137 MPa)	101.0	kN	22.7	kips
Coefficient of Thermal Expansion	1.61	$x10^{-6}$/°C	0.894	$x10^{-6}$/°F
Modulus of Elasticity	112.3	GPa	16.29	Msi
Core Heat Capacity	71.8	W-s/m-°C	12.2	W-s/ft-°F
ACCC® Conductor Specification	**Metric**		**US Units**	
Overall Diameter of Conductor[1]	24.41	mm	0.961	in.
Nominal Cross-sectional Area of the Conductor	446.6	mm^2	0.692	in^2
Ultimate Tensile Strength of Conductor[2]	123.5	kN	27.8	kips
Conductor Nominal Weight**	1190.8	kg/km	800.3	lb/kft
Coefficient of Linear Expansion Above Thermal Kneepoint	1.61	$x10^{-6}$/°C	0.894	$x10^{-6}$/°F
Coefficient of Linear Expansion Below Thermal Kneepoint	19.0	$x10^{-6}$/°C	10.55	$x10^{-6}$/°F
Final Modulus of Elasticity Above Thermal Kneepoint	112.3	GPa	16.29	Msi
Final Modulus of Elasticity Below Thermal Kneepoint	62.7	GPa	9.1	Msi
Maximum Allowable Operating Temperature at Surface[3]	180	°C	356	°F
Electrical Specification	**Metric**		**US Units**	
Nominal DC Resistivity at 20ºC	0.0700	ohm/km	0.1127	ohm/mile
Temperature Coefficient of Resistance	0.00404	/°C	0.00209	/°F
Frequency	50	Hz	50	Hz
AC Nominal Resistance at 25ºC	0.0724	ohm/km	0.1165	ohm/mile
AC Nominal Resistance at 75ºC	0.0864	ohm/km	0.1390	ohm/mile
AC Nominal Resistance at 180ºC	0.1158	ohm/km	0.1864	ohm/mile
AC Current Rating at Given Temperatures[4]		1495	@ 180C & 50 Hz	
		1576	@ 200C & 50 Hz	
GMR (estimated)	9.89	mm	0.0324	ft.
Inductive Reactance	0.215	ohm/km	0.3467	ohm/mile
Capacitive Reactance	0.184	Mohm-km	0.1145	Mohm-mile

ACCC® is produced using 1350-O (fully annealed) aluminum.

1) Minimum hub diameter of the conductor reel must meet the requirements of CTC F-750-032.

2) Strength at ambient temperature. Based on 96% of the 1350-O minimum tensile strength (8500 psi/58.6 Mpa) and 100% of the composite core mininum tensile strength (310 ksi/2137 Mpa).

3) Maximum operating temperature of ACCC® is 180°C and a maximum emergency temperature of 200°C (10,000 hours over the life of the conductor).

4) Conditions: 2 ft/s (0.6 m/s) wind, 0 ft (0 m) Elevation, 0.5 Emis. 0.5 absorp., 25°C Ambient temp., 96 W/sq. ft (1033 W/sq. m) sun radiation
*ASTM name designation: mm² nominal aluminum area/mm² nominal core area/mm nominal diameterx10 (nominal kcmil aluminum)

**ACCC® Conductors are required to exhibit lay lengths (ratios) that conform to ASTM B 857 or EN 50540.

***Different configurations among conductor manufacturers may result in slight variations within the parameters of indicated values for a given size in accordance with the stated specification.

F-730-567-NC www.ctcglobal.com Date Produced: 7/1/2019

APPENDIX G: Result of Plagiarism Check for Similarity Index

Please Look at Next Page

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By Yadab Prasad Neupane

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