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Contingencies Based Strategy for Transmission System Upgradation

by

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A THESIS

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ABSTRACT

Nepal's growing market penetration and demand for electricity are causing power networks to operate above their intended limits, leading to transmission limitations. High real estate costs, infrastructure development, and the protection of forests and other natural areas make it difficult to build additional transmission lines in urban or semi-urban areas. Transmission line projects typically have short schedules to meet the growing demand for load and accommodate future hydropower projects and renewable energy generation projects.

It is preferable to replace the current, aging ACSR conductors with HTLS conductors that have a greater power transfer capability to attain the maximum amount of power transfer per unit RoW. Compared to a new line, this can be completed more quickly and with less effort and financial planning. Without requiring major changes to the current tower, the same transmission line footprint can be utilized.

A strong power system can withstand sudden disturbances without catastrophic consequences.To ascertain the effects of transmission line failure on the electricity system and transmission line outages on system performance, contingency analysis is utilized. This study calculates the performance index, or Active Power Performance Index (PIP), for a single transmission line outage using the Newton-Raphson technique and DIgSILENT Power Factory modeling software. The findings indicate which lines in the INPS grid are crucial, indicating that either compensatory devices or transmission line upgrades are necessary.

Load flow study is the backbone of power system planning, operation, and expansion. Load flow calculation of the INPS with assistance from the software DigSILENT PowerFactory 15.1 is executed at peak wet season generation scenario and Dry Peak Case. Overall national generation of 3076.29 MW and peak load of 2050.19 MW is found with surplus power of 846.60 MW and grid losses of 179.50 MW. The adoption of equivalent HTLS conductor is being investigated for further analysis of critical 66kV and 132kV line sections at maximum generation and peak load demand and minimal Dry Peak generation and peak load.

Keywords: Contingency, INPS, Newton-Raphson, Performance Index

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LIST OF ABBREVIATIONS

AC	Alternating Current
ACCC	Aluminum Conductor Composite Core
ACCR	Aluminum Conductor Composite Reinforced
ACSR	Aluminum Conductor Steel Reinforced
ACSS	Aluminum Conductor Steel Supported
ckt	Circuit
DC	Direct Current
DigSILENT	DIgital SImuLation and Electrical NeTwork calculation program
GAP	Gap-type Aluminum Partitioned
GOSF	Generation Outage Sensitivity Factor
GTACIR	Gap-type Thermal-resistant Aluminum Conductor Invar Reinforced
GTACSR	Gap-type Thermo-resistant Aluminum Conductor Steel Reinforced
GZTACSR	Gap-type Zirconium Alloy Thermo-resistant Aluminum Conductor Steel Reinforced
HSIL	High Surge Impedance Loading
HTLS	High Temperature Low Sag
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
INPS	Integrated Nepal Power System
km	Kilo Meter
kV	Kilo-Volt
LOSF	Line Outage Sensitivity Factor
MCC	Metal Matrix Composite
MW	Mega-Watt
NEA	Nepal Electricity Authority
PI	Performance Index
p.u.	Per Unit
RoW	Right of Way
SIL	Surge Impedance Loading
TACIR	Thermal-resistant Aluminum Conductor Invar Reinforced

CHAPTER ONE: INTRODUCTION

1.1 Background

The reliable operation of a power transmission system is crucial for ensuring an uninterrupted supply of electricity. With the increasing demand for electrical power, transmission networks often experience overloading, which can lead to contingencies such as line failures and system instability. The Integrated Nepal Power System (INPS) is facing significant challenges due to overloaded transmission lines, necessitating a strategic approach for system upgradation. Identifying and mitigating these issues is critical for improving system resilience and ensuring the long-term reliability of power distribution.

Nepal's transmission lines are currently primarily overhead for cost reasons. At the moment, Nepal has 384 Circuit Kilometer (Ckt-km) of high voltage transmission lines, including the Dhalkebar- Muzzarffarpur 400kV Cross-Border Transmission Line (78 Ckt.km) and the Dhalkebar-Inaruwa 400kV (306 Ckt.km). 514.46 Ckt-km of 66 kV transmission lines, 3967.87 Ckt-km of 132 kV transmission lines and there are 1105 circuit km of 220 kV lines including 5 circuit km of underground cable 220 kV double circuit lines at Matatirtha Substation. As per the NEA Annual Report 2081, Nepal is currently building transmission lines for 450 circuit km of 400 kV, 583 circuit km of 220 kV, and 1,247 circuit km of 132 kV. In the same way, 766 circuit km of transmission line and 4188 MVA capacity to the system have been added in the fiscal year 2080/081 by which INPS transmission system till date consists of 6508 Ckt-km of Transmission lines, 13050 MVA transformation capacity and 367.5 MVAr compensating capacity[1].

Due to the shifting social and economic activities of the expanding population, market penetration and electricity demand are rising daily. Electric vehicles and electric cooking is adding extra burden to the existing transmission lines making them overload. After being released from its planned power outages, the Nepal Electricity Authority (NEA) is committed to provide its customers with consistent, reasonably priced, and dependable electric power. With substantial investments in transmission and distribution systems for their strong power system network, utilities should take the initiative to strengthen the power system as a whole. The Integrated Nepal Power System (INPS) is facing significant challenges due to overloaded transmission lines, necessitating a strategic approach for system upgradation. In crowded urban and semi-urban regions where property prices have been rising, one of Nepal's biggest challenges has been the construction of additional transmission and distribution lines and substations. Repeated hindrance from the landowners and rudimentary social and environmental issues have suffered the transmission lines and other power system projects very badly. Identifying and mitigating these issues is critical for improving system resilience and ensuring the overall Power System performances[2]. High Temperature Low Sag (HTLS) conductors, which are newly developed high-capacity conductors, will be used in place of ACSR conductors. NEA and the relevant department must reconsider how to increase transmission capacity by implementing new procedures that allow the same transmission footprints to be used. When HTLS conductor use was evaluated using the IEEE 9 bus system, an investigation of various methods to increase power transfer capacity revealed that it had decreased congestion by 41%[3]. While several techniques are used throughout the world to increase the transmission lines' capacity, in Nepal, this is essentially a novel approach. Some of the major overloaded lines of INPS have already been successfully uprated with equivalent HTLS conductor and many transmission lines upgradation projects in NEA are under execution phase[1].

1.2 Problem Statement

The trend of energy consumption in Nepal's electrical market is increasing quickly these days because of modernization, globalization, urbanization, the real estate industry, population increase and changes in consumer energy consumption patterns. Transmission and distribution lines are designed for optimal load-handling capacity, but due to high power transfer capacity the lines are being overloaded.

Several transmission lines in the INPS network are operating beyond their rated capacities, leading to increased thermal stress and potential failures. In the event of a line outage, adjacent transmission lines carry the additional load, which can lead to cascading failures. NEA and related utility have to face different issues in development of the new transmission lines and substations mainly because of the following factors:

- a) Restrictions on Right of Way Accessibility: Rights of Way for New Line Projects are inaccessible because of the high cost of real estate, the large population, infrastructure development, and forest preservation.

- b) Time constraints:The new transmission line must be constructed as soon as possible. The rate at which new transmission lines are being built is slower than the rate at which power generation is increasing. Additionally, it will take significantly longer to build a new transmission line than the utility can tolerate.

Due to long-standing landowner resistance, the expense of deforestation and rebuilding vegetation at new sites, and growing real estate prices, new transmission lines have been a persistent issue that has caused project delays throughout time. Based on these tenets, the government must reconsider and revise current laws, regulations, and guidelines to accomplish public expectations in a way that facilitates timely project completion. In order to convey sufficient power to the load center with less investment, the NEA and other implementing agencies need to make plans to use high-capacity conductors to expand the current transmission lines' capacity.

Although it is inevitable to increase the transmission capacities of existing lines, it takes a lot of capital and effort to establish a new overhead transmission line. It is believed that by replacing the outdated ACSR conductor with HTLS conductors in a shorter period of time and with a lower expenditure, the capacity of current lines might be increased rather than new transmission lines being built to satisfy the increasing demand for power. The high-capacity conductors can decrease line loss and carry more current than the traditional ACSR conductors. The fastest and least expensive way to increase line capacity is through re-conductoring.

This study aims to identify critical transmission lines, analyze their contingency impact, and prioritize them for upgrades based on a Performance Index (PI) ranking. Without strategic interventions, the risk of widespread blackouts and reduced power system stability remains high.

1.3 Objectives

The primary objectives of this research work are noted below:

- To analyze the current load flow conditions of the INPS and identify overloaded transmission lines.
- To perform contingency analysis by simulating potential failures and assessing their impact on the power network.
- To rank the transmission lines based on their severity of overloading and contingency effects using Performance Index (PI) scores.
- To propose strategic transmission system upgrades for enhancing grid reliability and efficiency.

- To do load flow and analyze the results after upgrading all the critically overloaded transmission lines.

1.4 Scope

This research work focuses on the transmission lines within the INPS network, particularly those that exhibit high loading conditions. The study employs IEEE Standard 738 for evaluating conductor current ratings and utilizes DigSILENT PowerFactory for load flow and contingency analysis.

The scope of the research work assumes the following considerations :

- The primary focus of the study is on INPS overhead wires with voltages of 66kV and above.
- The load flow output's capacity to identify the important transmission lines is greatly influenced by the precision the accuracy of the information acquired from secondary sources.
- Maximum wet season generation and maximum peak load conditions have been considered.
- The swing bus receives excess power during the load flow study during the rainy season.
- The swing bus supplies the deficit electricity during the load flow study of the dry season.
- Based on the present NEA service state, the derated current carrying capacity is examined.
- After replacing the conductors, it is anticipated that protection and insulation systems will be adequate to supply the increased power flow.
- Only the severely overloaded lines are suggested to have their high-capacity conductors replaced.

1.5 Limitation

This study was not conducted with consideration for the following limitations:

- The cost of cutting the transmission lines to string the new HTLS conductors and dismantle the old ACSR conductors is not counted.

- Additionally, indirect costs that could be associated with the load curtailment parameter and conductor replacement are not taken into account.

- Replaced old ACSR conductors, project execution schedule, etc., are outside the purview of the investigation.

- Further validation is required before upgrading existing aged conductor with high current capacity conductor in the field.

1.6 Significance of the Research Work

This research work focuses on the 66kV and higher voltage transmission lines within the INPS network, particularly those that exhibit high loading conditions. By identifying the most critical transmission lines for upgradation, this study provides a data-driven approach to strengthening Nepal's power system infrastructure. Policymakers, engineers, and utility operators can use the insights to improve the INPS's efficiency and dependability. Upgrading prioritized transmission lines will reduce system overall losses, improve voltage stability, and ensure a more resilient power grid.

1.7 Thesis Organization

The dissertation is organized into five chapters. This section enlists a brief outline of each chapter and its contents.

- Chapter 1 gives brief introduction of the dissertation including background information, problem statement, objectives, and key assumptions and limitations. The problem statement is described and followed by the objectives of the thesis.

- Chapter 2 explores the necessary literature review done for this thesis covering the development and implementation of HTLS conductors in the INPS network, various methods to enhance transmission line capacity, and . It also discusses load flow analysis. Additionally, relevant studies on HTLS conductor adoption are reviewed.

- Chapter 3 explains contingency analysis, its ranking of overloaded transmission lines, input parameters, INPS modeling, and an explanation of IEEE 738 for figuring out the connection between overhead conductors' current and temperature. It also summarizes the load flow analysis of the INPS after conductor upgradation.

- Chapter 4 analyzes the simulation results, assessing their significance. The technical specifications of various conductors are examined, and critical transmission sections are identified through load flow studies and their ranking is done using contingency ranking. Recommendations for replacing these sections with high-capacity conductors are proposed and the load flow analysis of the INPS after conductor upgradation is done aswell as the findings are summarized.

- Chapter 5 concludes the thesis work and suggests further research opportunities to expand on this work.

Finally, this thesis will end with a list of references and the relevant appendices.

CHAPTER TWO: LITERATURE REVIEW

This chapter explores the necessary literature review done for this dissertation. It covers the fundamentals of Conductor uprating strategy for enhancing the power transfer capacity of existing transmission lines without extensive infrastructure modifications. Various studies and industry standards have explored methods to increase conductor current-carrying capability while maintaining system stability.

2.1 Overview of Conductor Uprating

The technique of enhancing overhead transmission lines' current-carrying capacity (Ampacity) is known as conductor uprating. This can be achieved through a variety of techniques, such as reconducting with High Temperature Low Sag (HTLS) conductors, modifying conductor operating conditions and enhancing transmission line designs.

2.2 Methods for Overhead Conductor Uprating

The overhead transmission lines' capacity to transfer power can be increased using a variety of methods. The future capacity requirements, current line specifications and line design and construction processes are the primary determinants of the best approaches or methods for uprating overhead transmission lines. Therefore, physical limits, operator considerations, economics and electrical limitations should all be taken into account. The methods of Overhead Transmission lines Uprating techniques is shown in the following Figure 2.1

The location, features, and performance of the old existing line will determine the best overhead line uprating strategies for a given situation. Upgrading an overhead line by definition means increasing its power delivery capability, which calls for either increasing its:

- Current Rating (Current Uprating) and/or
- Voltage Level (Voltage Uprating)

2.2.1 Current Uprating

The most popular choice for uprating overhead lines is current uprating. It works well for overhead wires whose thermal capacity limits the line loading. Since a higher current rating raises the conductor temperature, the method is often referred to as "Ampacity

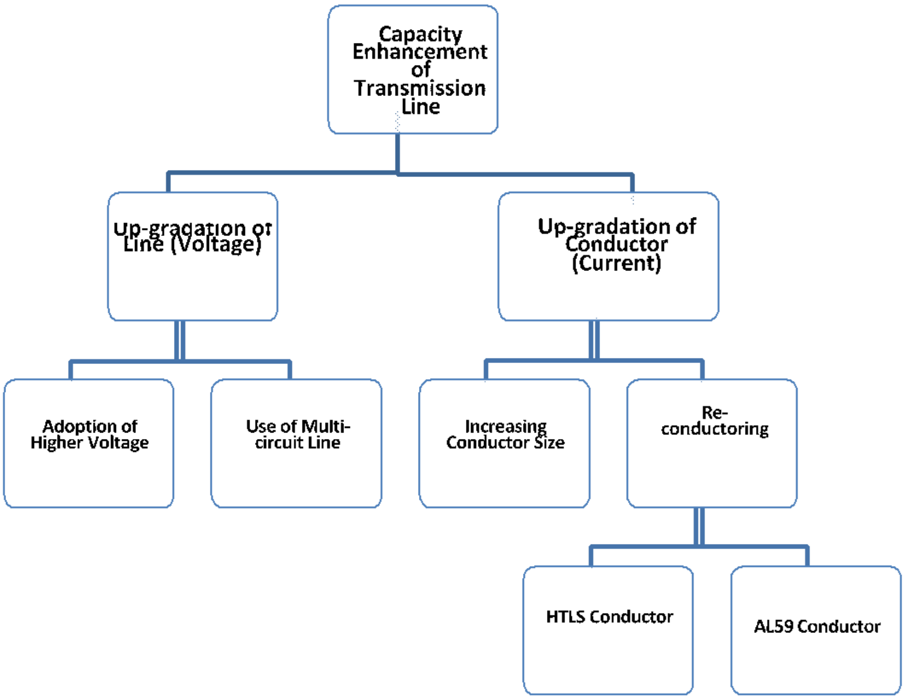

Figure 2.1: Methods of Capacity Enhancement of Transmission Line[4]

Uprating" or "Thermal Uprating." The subsequent subsections provide explanations of various overhead line current uprating techniques.

- **Re-conductoring Method**:
  The most popular and efficient way to increase current while requiring the least amount of structural alteration is re-conductoring. Without changing their structure, Current can be greatly increased using High Temperature Low Sag (HTLS) conductors[5]. HTLS conductors are designed to withstand higher temperatures while minimizing sag, making them ideal for uprating applications.

- **Deterministic Method**:
  By raising the conductor temperature while keeping the ground clearance appropriate, current uprating can be accomplished using this method. This approach determines the current rating under the worst-case weather conditions for a line by considering the highest allowable conductor temperature together with wind speed and direction, ambient temperature and solar radiation.

- **Probabilistic Method**:
  With this approach, line ampacity is predicted using statistical models based on past weather data. To ascertain how long a conductor temperature can stay over its

limiting value, the probabilistic method takes into account the real weather in the area where the line is located.

- **Real-time Monitoring Method**:
  It implements real-time monitoring of environmental conditions (e.g., wind speed, temperature) to dynamically adjust line ratings.Based on actual conductor location and meteorological circumstances, real-time monitoring assists system operators in developing and implementing line ratings in real-time. Because the conductor temperature rarely rises over the design temperature, there is less chance of the aluminium conductor's annealing temperature being exceeded.

- **High Surge Impedance Loading Method**:
  By lowering the overhead line's characteristic impedance and raising the SIL (Surge Impedance Loading) level, the most recent technological advancements have enabled an increase in power transfer capabilities. We refer to this idea as High Surge Impedance Loading (HSIL).

2.2.2 Voltage Uprating

The voltage rating of lines is raised using this technique of uprating overhead transmission lines, which is only feasible in the presence of adequate electrical clearance. Two crucial elements must be present in order to obtain this clearance. The first step is to determine whether an existing structure has the necessary air clearances for a higher voltage. The second step is to determine the amount of insulation needed to withstand overvoltages caused by power frequency, lightning impulses, and switching surges. The above methods of current uprating and voltage uprating techniques[6] are shown in the Table 2.1

Table 2.1: Methods of Conductor Uprating of Transmission Line[6]

Uprating	Method	Technique	Process
Increasing current rate (Current Uprating)	**Re-conductoring Method**	Replacement of Conductor	Increased conductivity area, Composite conductor systems, High temperature conductors
		Rating criteria modification	Study of Metrological data
	Deterministic Method	Increase conductor tension	Increment in tension, Negative Sag Device
		Increase conductor attachment height	Extension of structure body, Interspaced structures, Insulator crossarm
	Probabilistic Method	Account for actual load profile	Temporary increase in rating
		Modify rating criteria	Probability-based metrological study
	Real-time monitoring Method	Thermal of line, sag, tension and/or climatic conditions measurement	Line sag or tension monitor, Conductor distributed temperature sensing, Weather station
	High surge impedance loading Method	Conductor geometry and bundling	Physical configuration
Increasing voltage level (Voltage Uprating)	**Conductor air clearance**	Increasing conductor attachment height	Re-tensioning, Sag adjustment, Increasing conductor height at attached point, Extension of structure height, Terrain parameters
		Increasing phase-to-phase clearance	Re-Tensioning, Line compaction, Double-circuit line to high voltage single-circuit line, Inter-phase spacer
	Insulation electrical strength	Re-insulation	Adding/substituting insulators, Use of polymeric insulator, Cross-arm modification

2.3 HTLS Conductors and its Application

High-Temperature Low-Sag (HTLS) conductors are sophisticated overhead transmission line conductors made to function at high temperatures with little sag during operation. These conductors enable power utilities to increase transmission capacity without the need for significant infrastructure modifications.

2.3.1 Overview of HTLS Conductors

HTLS conductors are engineered with specialized core materials that allow higher operating temperatures while reducing sag, thus overcoming the limitations of traditional conductors like ACSR (Aluminum Conductor Steel Reinforced)[7]. Similar to ACSR, HTLS conductors are typically composed of stainless steel wires that have been helically stranded over a reinforcing core. The low density, high conductivity layers of aluminum strands are where the majority of electrical current flows. At high temperatures and loads, the reinforcing core bears the majority of the tension force. It might be significant to remember that using high temperature conductors, such as HTLS, would enable higher current and power flow, but if the line is longer than 100 km, voltage regulation may suffer. Some of the Key Features of HTLS Conductors are given below:

- May function at temperatures as high as 200–250°C, as opposed to regular ACSR's 80°C.
- Minimal sag, allowing increased power transfer without violating clearance limits.
- Higher ampacity, enabling existing transmission lines to carry more current.
- Reduced thermal expansion, maintaining system reliability under high load conditions.

2.3.2 Types of HTLS Conductors

1. **ACCC (Aluminum Conductor Composite Core)** :

    - Core Material: Carbon fiber or glass fiber composite.
    - Advantages: High strength, reduced sag, increased efficiency, and lower losses.

Figure 2.2: ACCC HTLS Conductor

- Applications: Used in long-span transmission lines and high-capacity corridors.

2. **ACCR (Aluminum Conductor Composite Reinforced)** :

- Core Material: Aluminum-based metal matrix composite (MMC).
- Advantages: Lightweight, corrosion-resistant, and suitable for harsh environments.
- Applications: Ideal for areas with extreme weather conditions and high mechanical loads.

Figure 2.3: ACCR HTLS Conductor

3. **GAP-Type Conductors (GZTACSR, GTACSR)** :

- Core Material: Grease-filled gap between aluminum and steel core.

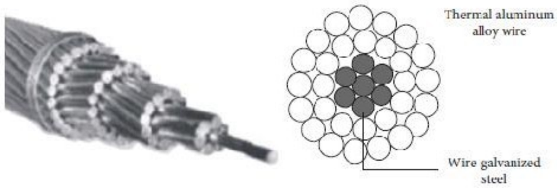

Figure 2.4: Gap Type ZTACSR HTLS Conductor

- Advantages: High thermal resistance, better mechanical stability, and suitable for retrofitting.

- Applications: Used in upgrading existing transmission lines with minimal modifications.

4. **Invar Core Conductors (TACIR, GTACIR)** :

- Core Material: Invar (Nickel-Iron alloy).

- Advantages: Low thermal expansion, high durability.

- Applications: Useful for regions with extreme temperature variations.

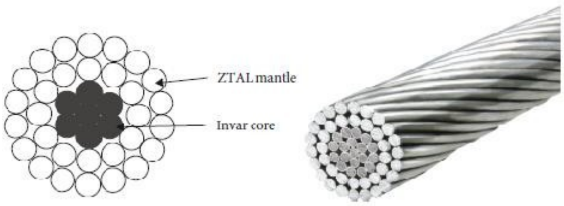

Figure 2.5: Invar Core TACIR HTLS Conductor

2.3.3 Applications of HTLS Conductors

High-Temperature Low-Sag (HTLS) conductors are used in power transmission networks worldwide to boost the efficiency and capacity of their existing transmission lines. The practice of substituting high-capacity conductors for traditional ACSR conductors in order to fulfill the rising demand for electric load has been examined in numerous international research articles [8]. The 220 kV transmission system capacities in Egyptian Power Network increased by 58%-78% after uprating by conventional conductor by HTLS conductor[9]. Some of the notable applications of HTLS conductors in world practices are listed below:

- Companies like American Electric Power and Xcel Energy have used Aluminum Conductor Composite Reinforced (ACCR) to add existing lines without having to alter tower structures.

- South California Edison has rolled out ACSS (Aluminum Conductor Steel-Supported) on urban distributions to support larger loads.

- Power Grid Corporation of India utilized TACSR (Thermal Alloy Conductor Steel Reinforced) and GAP-type conductors for the augmentation of existing 220 kV and 400 kV networks. HTLS has played a key role in bringing renewable energy to Rajasthan and Gujarat.

- Germany has also employed ACCC (Aluminum Conductor Composite Core) to increase transmission capacity without constructing new corridors.

- France and UK used ACSS conductors for long-distance high-voltage transmission.

- HTLS conductors assist to deal with high power loads in severe temperature conditions beyond 50°C in United Arab Emirates.

- Compact HTLS conductors (GTACSR, ACCC) are used to upgrade power transmission lines without increasing right-of-way in Japan.

- Florida Power & Light utility of USA has used HTLS conductors in hurricane-prone grids to improve system resilience.

2.3.4 Uses of HTLS Conductors in INPS Network

Increasing the transmission capacity of existing lines through uprating is a feasible alternative to building new overhead transmission lines. Many techniques have been used globally to increase the transmission line conductors' ampacity, but in Nepal, they are essentially brand-new. Nonetheless, many new transmission line projects in NEA are currently underway that use HTLS conductors of the proper design at different voltage levels (33kV,66kV,132kV,220kV,400kV, etc.)[1]. The following sections provide a quick overview of the few upgrade plans and projects under NEA.

- The 33 kV Dhalkebar-Mujeliya double lines (line length: 50 ckt. km) had both circuits updated with HTLS conductor, increasing ampacity by around 70–75% compared to ACSR (Dog) conductor.

- Similarly, another project in NEA; New Khimti- Lamosanghu 132kV single circuit ACSR BEAR Conductor has been successfully upgraded using equivalent HTLS Amsterdam Conductor to improve the power transfer quality and to improve the Kathmandu Valley's power supply system's dependability and continuity.

- Another NEA project is the construction of a 23-kilometer, 132-kV line that will connect the new Biratnagar substation, which houses the HTLS (ACSR Bear equivalent) conductor, to the Inaruwa substation. It aims to improve the quality of power in the Morang and Sunsari districts while also reducing power congestion at the 33/11kV Rani Substation, the 33/11kV Tankisinwari Substation and the Duhabi Grid Substation.

- The majority of the Kathmandu Valley's transmission lines have already been updated, with HTLS conductors taking the place of outdated ACSR conductors. In an attempt to enhance the quality of the power supply in the Kathmandu Valley, HTLS conductor has been added to the 7 km Suichatar-Matatirtha 132kV line, 5 km Suichatar-Balaju 132kV line, 13 km Suichatar-Patan 132kV line, and 8.5 km Suichatar-Teku 66kV line. In a similar vein, the 66kV transmission line between Bhaktapur and Baneshwor-Patan has also been upgraded with HTLS conductors[1].

- In addition, 18.5 km of Hetauda-Kamane 132kV single line and 37 km of Hetauda-Pathlaiya 132kV single circuit transmission line having ACSR Bear conductor have been successfully uprated with equivalent HTLS Conductor.

- Additionally, an upgrade employing HTLS conductor is proposed for the 28km long, 132kV transmission line between Kushaha and Duhabi, which currently uses ACSR Bear conductor. In a similar vein, NEA has begun to increase the capacity of the 7km long, 132kV Pokhara-Lekhnath transmission line with ACSR Wolf and HTLS conductor.

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

The current carrying capacity of the ACSR conductors is ascertained using IEEE standard 738. IEEE Standard 738, "IEEE Standard for Calculating the Current-Temperature of Bare Overhead Conductors," provides guidelines for determining the thermal rating of conductors used in power transmission networks[10]. Manufacturers usually provide the DC resistance of the conductor at 20 °C and the AC resistance corresponding to 50

Hz. IEEE Std.738 can be used to determine the flow of alternating current under specific ambient conditions.

2.4.1 Current Carrying Capacity of ACSR BEAR

The ACSR Bear's current carrying capacity is determined using IEEE standard 738. Properties of ACSR Bear conductor are given in Table2.2. The various parameters used for calculating current carrying capacity of ACSR Bear conductor are tabulated below in the Table2.3. If one knows the conductor surface temperature and the steady-state weather conditions, one may calculate convection, radiation, solar-caused heat gain, and conductor resistance for a bare conductor. In these weather circumstances, the corresponding current can be calculated. A numerical approach is established by IEEE Standard 738 that links the core and surface temperatures of a bare stranded overhead conductor to weather conditions and either constant or time-varying electrical current. According to IEEE Standard 738 Clause 4.4.1, the Steady State heat balance equation is:

Table 2.2: Properties of ACSR Bear conductor

Conductor Code	Strands Al/St/dia (mm)	X-section Area (mm^2)	Diameter (mm)	Resistance at 20 °C (Ω/km)
ACSR Bear	30/7/3.35	326.1	23.45	0.1093

Table 2.3: Parameters used for ACSR Overhead Conductors

Parameters	Values	Units	Remarks
Latitude	27.5	degrees	Latitude of project area
Day of Year	June 21	-	Summer Solstice
Time of Day	12:00	PM	-
Atmosphere	Clear	-	-
Elevation Above Sea Level	1500	meter	-
Ambient Temperature	40	°C	-
Conductor Surface Temperature (Max)	80	°C	-
Conductor Absorptivity	0.8	-	-
Conductor Emissivity	0.45	-	-
Wind Velocity	0.56	m/s	-

$$Q_c + Q_r = Q_s + I^2 R_T \tag{2.1}$$

where,

- Q_c: Rate of Convective heat loss

- Q_r: Rate of Radiated heat loss
- Q_s: Rate of Solar heat gain
- I: Conductor current at maximum allowable temperature T
- R: Conductor resistance at maximum allowable temperature T

1. **Convective Heat Loss:** Two types of convective heat loss are commonly recognized: forced convection and natural convection. When there is still air, natural convection, also known as free convection, takes place. In a cycle that repeats itself repeatedly, the cold air around the hot conductor heats up, rises and is displaced by cold air from the surrounding medium. Blowing air over a conductor causes forced convection, which expels the heated air. The Reynolds number, a dimensionless quantity, often determines the amount of convective heat loss is given by

$$N_{\text{Re}} = \frac{D_0 \rho_f V_w}{\mu_f}, \tag{2.2}$$

where,

- D_0: Conductor diameter
- ρ_f: Air density at the mean film temperature
- V_w: Wind velocity
- μ_f: Dynamic viscosity of air

ρ_f: Air density at the mean film temperature of conductor boundary can be calculated as

$$\rho_f = \frac{1.293 - 1.525 \times 10^{-4} H_e + 6.379 \times 10^{-9} H_e^2}{1 + 0.00367 T_{\text{film}}}, \tag{2.3}$$

where,

- T_{film}: Air temperature in boundary level, calculated as the mean of conductor surface temperature (T_s) and ambient temperature (T_a)
- H_e: Elevation of conductor above sea level
- V_w: Wind velocity

- μ_f: Dynamic viscosity of air at the mean film temperature of conductor boundary calculated as:

$$\mu_f = \frac{1.458 \times 10^{-6}(T_{\text{film}} + 273)^{1.5}}{T_{\text{film}} + 383.4} \tag{2.4}$$

Using the above equations, Reynolds number is calculated as below:

Diameter of ACSR Bear, $D_0 = 0.02345m$,
Maximum allowable conductor surface temperature, $T_s = 80°C$,
Ambient temperature, $T_a = 40°C$,
Temperature of the air film at conductor boundary, $T_{\text{film}} = \frac{T_s+T_a}{2} = 60$°C,
Elevation of conductor above sea level, $H_e = 1500$m,
Wind velocity, $V_w = 0.56$m/s,
Air density, $\rho_f = 0.8840$kg/m^3,
Dynamic air viscosity, $\mu_f = 1.98689 \times 10^{-5}$ kg/m-s,
Reynolds number, $N_{\text{Re}} = \frac{D_0 \rho_f V_w}{\mu_f} = 580.94$.

At any wind speed, IEEE Standard 738 recommends calculating forced convective heat loss using the following equations and using the larger of two:

$$q_{c1} = K_{\text{angle}} \left[1.01 + 1.35 N_{\text{Re}}^{0.52} K_f (T_s - T_a)\right], \tag{2.5}$$

$$q_{c2} = K_{\text{angle}} \cdot 0.754 N_{\text{Re}}^{0.6} K_f (T_s - T_a), \tag{2.6}$$

where,

$$K_{\text{angle}} = 1.194 - \sin(\beta) - 0.194\cos(2\beta) + 0.368\sin(2\beta), \tag{2.7}$$

$$K_f = 2.424 \times 10^{-2} + 7.477 \times 10^{-5} T_{\text{film}} - 4.407 \times 10^{-9} T_{\text{film}}^2. \tag{2.8}$$

Taking the wind to be perpendicular to the conductor axis, i.e., $\beta = 90°$, gives $K_{\text{angle}} = 1$. Using $T_{\text{film}} = 60$ °C, we find: $K_f = 0.02871$W/m°C.

Using these values, the following forced convection rates are obtained:
$q_{c1} = 43.506$W/m,
$q_{c2} = 59.161$W/m.
As per the standard, choose the forced convection rate to be 59.161 W/m.

Natural convection takes place when the wind speed is zero (”Still Air”), and the rate of heat loss is:

$$q_{cn} = 3.645\rho_f^{0.5} D_0^{0.75} K_f (T_s - T_a)^{1.25}. \tag{2.9}$$

Therefore, the natural convection rate is:
$q_c n$ = 20.658 W/m.

Now, as per the standard, the convection rate will be the maximum of forced and natural convection rates. Therefore, the rate of convection heat loss is:
q_c = 59.161 W/m.

2. **Radiated Heat Loss:** Energy is released into the environment through radiation when a bare overhead conductor is heated above room temperature. Assumed to be at ambient temperature, the difference between the conductor's and the surrounding temperatures largely determines the rate of energy radiation. Radiative heat transport is also influenced by the conductor's surface state, or emissivity. The Stefan-Boltzmann law, which is expressed in absolute (Kelvin) degrees to the fourth power, defines radiation by connecting radiative energy transfer to the difference between the ambient temperature and the conductor surface temperature. The radiated heat loss is calculated using:

$$q_r = 17.8 \cdot D_0 \cdot \varepsilon \left[\left(\frac{T_s + 273}{100} \right)^4 - \left(\frac{T_a + 273}{100} \right)^4 \right], \tag{2.10}$$

where:

- D_0: Conductor diameter (m)
- ε: Emissivity of the conductor surface
- T_s: Conductor surface temperature (°C)
- T_a: Ambient temperature (°C)

As per IEEE Standard 738 Clause 5.4, the absorptivity should be taken to be at least 0.8, and the emissivity should be a maximum of 0.1 less than the absorptivity. Using $\varepsilon = 0.45$, we calculate:
q_r = 11.137 W/m.

3. **Rate of Solar Heat Gain:** Heat energy is supplied to the conductor by the sun. The amount of solar heat energy that is transferred to the conductor is determined by the sun's position in the sky, the Solar Constant, the percentage of that energy that is transferred to the conductor through the earth's atmosphere, the conductor's orientation and its surface state, or absorptivity. The energy of the sun is mostly absorbed by black, worn conductors and reflected by bright, glossy conductors. The rate of solar heat gain is calculated as:

$$q_s = \alpha Q_{se} \sin(\theta) A', \tag{2.11}$$

where:

- α: Absorptivity, $\alpha = 0.8$
- A': Projected area of conductor per unit length
- θ: Effective angle of incidence of sun's ray
- Q_{se}: Total solar and sky radiated heat intensity corrected for elevation

The projected area of conductor per unit length is given by:

$$A' = D_0 \cdot 1\ \mathrm{m}^2/\mathrm{m} = 0.02345\ \mathrm{m}^2/\mathrm{m}. \tag{2.12}$$

The effective angle of incidence of sun's ray is obtained as:

$$\theta = \cos^{-1}\Big(\cos(H_c)\cos(Z_c - Z_l)\Big), \tag{2.13}$$

where:

- H_c: Solar altitude
- Z_l: Azimuth of the line, $Z_l = 90°$ for a line running east to west
- Z_c: Azimuth of the Sun

The azimuth of the Sun is calculated as:

$$Z_c = C + \tan^{-1}(X), \tag{2.14}$$

where:

- X: Solar azimuth variable, calculated as:

$$X = \frac{\sin(w)}{\sin(\text{Lat})\cos(w) - \cos(\text{Lat})\tan(\delta)}. \tag{2.15}$$

The solar declination δ is given by:

$$\delta = 23.46 \sin\left(\frac{284+N}{365} \cdot 360\right), \tag{2.16}$$

where:

- N: Day of the year (January 1 = 1, January 2 = 2, and so on)

For summer solstice, $N = 172$, which gives:
$\delta = 23.459°$.
w is the hour angle, the number of hours times 15 degrees from noon.
At noon $w = 0°$.
Lat is the latitude and $Lat = 27.5° N$.
This gives X = 0.
Now, the solar constant, C, is defined as shown in the Table2.4:

Table 2.4: Hour Angle and Corresponding C Values

Hour Angle (w)	C **if** $X \geq 0$ **degrees**	C **if** $X < 0$ **degrees**
$-180 \leq w < 0$	0	180
$0 \leq w < 180$	180	0

For $X = 0$ and $w = 0$, $C = 180$ which gives $Z_c = 180°$.

The solar altitude H_c is given by:

$$H_c = \sin^{-1}\Big(\cos(\text{Lat})\cos(\delta)\cos(w) + \sin(\text{Lat})\sin(\delta)\Big). \tag{2.17}$$

Substituting the values gives:

$$H_c = 85.959°,$$
$$\theta = 90°.$$

The total solar and sky radiated heat intensity corrected for elevation, Q_{se}, is obtained as:

$$Q_{se} = k_{\text{solar}} Q_s, \tag{2.18}$$

where:

$$k_{\text{solar}} = 1 + 1.148 \times 10^{-4} H_e - 1.108 \times 10^{-8} H_e^2 = 1.10372, \tag{2.19}$$

$$Q_s = A + BH_c + CH_c^2 + DH_c^3 + EH_c^4 + FH_c^5 + GH_c^6. \tag{2.20}$$

The values of the coefficients are obtained from Table 2.5 obtained from IEEE Standard 738.

Table 2.5: Polynomial Coefficients for Solar Heat Intensity as a Function of Solar Altitude

Coefficients	**Clear Atmosphere**	**Industrial Atmosphere**
A	-42.2391	53.1821
B	63.8044	14.211
C	-1.922	0.66138
D	0.0346921	-0.031658
E	-0.000361118	0.00054654
F	1.94318E-06	4.3446E-06
G	-4.07608E-09	1.3236E-08

For clear atmosphere, we obtain:

$$Q_s = 1034.685 \text{ W/m}^2,$$
$$Q_{se} = 1187.064 \text{ W/m}^2.$$

Therefore, the rate of solar gain is:

$$q_s = \alpha Q_{se} \sin(\theta) A' = 22.269 \text{ W/m}. \tag{2.21}$$

4. **Steady State Thermal Rating:** The steady state thermal rating can be obtained using:

$$q_c + q_r = q_s + I^2 R_T, \tag{2.22}$$

where:

- q_c: Rate of convection heat loss = 59.162 W/m
- q_r: Rate of radiated heat loss = 11.137 W/m
- q_s: Rate of solar heat gain = 22.269 W/m
- I: Conductor current at maximum allowable temperature of $80°\text{C}$
- R: Conductor resistance at maximum allowable temperature of $80°\text{C}$

The resistance at $20°\text{C}$ is $0.1093\Omega/\text{km}$, with a temperature coefficient of resistance of $1/228$ per°C. The resistance at $80°\text{C}$ is calculated as:

$$\begin{aligned} R(80°\text{C}) &= \frac{0.1093\left(1+\frac{80}{228}\right)}{1+\frac{20}{228}} = 0.1338\,\Omega/\text{km}, \\ &= 1.338\times10^{-4}\,\Omega/\text{m}. \end{aligned}$$

Substituting the values into the equation for current:

$$I = \sqrt{\frac{q_c+q_r-q_s}{R(80°\text{C})}}, \tag{2.23}$$

we get:

$$\begin{aligned} I &= \sqrt{\frac{59.162+11.137-22.269}{1.338\times10^{-4}}}, \\ I &= 599.24\,\text{Amperes}. \end{aligned}$$

Therefore, the thermal rating of ACSR Bear is 599.24 Amperes.

2.5 Load Flow Analysis

The flow of actual and reactive power as well as electrical performance under specific situations under steady state system operation are displayed by the load flow solution. In order to assess and regulate the power system's performance under particular circumstances, it additionally gives transformer and line loads, system losses, and voltages at specific places in the system. This analysis can also look at other alternative ideas for future growth to accommodate increasing load demands and evacuation of current and future generations.

The load flow in the power system must be examined with consideration for both 1) Present Operation and 2) Future Operation. On the one hand, an operation or control engineer needs the right information to get at work practically immediately; he or she has to be able to access the power system's behavior under many possible configurations. A planning engineer, on the other hand, is responsible for determining the system behavior while taking into account the fact that reinforcements have not yet been constructed and the corresponding monthly or annual rise in loads. The most often used approaches for load flow studies are the Newton-Raphson, Gauss-Siedel, and Fast Decoupled Load Flow methods. DigSILENT PowerFactory solves non-linear equations using the Newton-Raphson method. It is possible to calculate both balanced (AC Load Flow, balanced positive sequence) and unbalanced (AC Load Flow Unbalanced, 3-phase (ABC)) load flows using PowerFactory.

2.6 Contingency Analysis

A power system may experience contingencies due to internal component failure or external influences such as equipment overload and lightning. According to [11], contingency analysis is the qualitative assumption of various critical scenarios that might arise in power systems in the future and the optimization of solutions intended to address those issues related to the critical conditions. Contingency analysis is a significant technique used in various fields such as power systems, risk management, business continuity, and project management. It involves the evaluation of the impact of potential failures or unexpected events and developing strategies to counteract their effects[12]. The Main Objectives of Contingency Analysis are listed below:

- Point out potential contingencies (Failures, Outages, risks, etc.).
- Explain the impact of these contingencies.
- Implement response and mitigation strategies.

The Most Common methods used in Contingency Analysis of Power System Network are illustrated below:

- N-1 Criterion: Ensures the power system is operational even when one of its elements fails.
- N-k Analysis: Examines the effects of multiple failures.
- Load Flow Analysis: Examines power distribution in case of contingencies.

Contingency Analysis is done on the following basis:

- Higher priority is given to more crucial components, and their failures indicate a bigger risk to the stability and security of the system.
- The system's resilience to these interruptions is essential to its security.

2.7 Contingency Ranking and Selection

The post contingency values for various outage quantities according to interest are estimated using a quicker method based on linear sensitivity factors. Sensitivity factors can be divided into two categories, which are:

1. **Generation Outage Sensitivity Factor(GOSF)** : GOSF relates the approximate change in power flow in line'i-j' due to the outage of generator at bus 'k'.
2. **Line Outage Sensitivity Factor(LOSF)** : LOSF helps to calculate the approximate change in power flow in line'i-j' due to the outage of line 'm-n'.

In the event of a line or generator interruption, the sensitivity factors provide estimations of actual power flows in the lines that are quite accurate. The performance index (PI) is used to rank each outage event based on the findings of the sensitivity and AC load flow analyses. For contingency ranking, the performance index (PI) selection is crucial. The severity of every given contingency should be accurately reflected in the PI. There are two categories into which the PI can be separated:

1. **MW ranking method** : The changes in real power flows only are considered. The Simplest form of the PI for MW ranking method is:

$$PI_j = \sum_{i=1}^{N_L} W_i \left(\frac{P_i}{P_{\max,i}} \right)^n \tag{2.24}$$

   where, P_i = power flow in line i after contingency j
   $Pmax_i$ = rated maximum MW Capacity of line j
   N_L = total number of overloaded lines of contingency j
   W_i = weight for line i, assumed 1 in this research
   n = even integer, assumed 2 in this research

2. **Volatge security/ reactive power ranking method** : Only changes in reactive power or voltage magnitude are taken into account. The Simplest form of the PI for Voltage/ reactive power ranking method is:

$$PIv = \sum_{i=1}^{N} \frac{\alpha_i}{2} \left[\frac{\Delta V_i}{\Delta V_i^{lim}} \right]^2 \tag{2.25}$$

where, Vi = V_i - $V_i Specified$ of bus'i' after contingency j

Δ$V_i$lim = 1/2*(Vi max - Vi min) rated voltage of bus i

ΔV_i = V_i - $V_i Specified$ of bus'i'

N = Total Number of Buses in the system

αi = user selected weighting factor, assumed 1 in this research

CHAPTER THREE: METHODOLOGY

This chapter outlines the research process, beginning with the collection of data. The approach used for this study is to determine the technical implications of switching to HTLS conductors at 66 kV and higher voltage transmission lines from older, overloaded ACSR conductors. The overall methodology adopted in this research work is shown in Figure 3.1.

3.1 Research Overview

This thesis follows an applied research approach, focusing on enhancing transmission capacity of aged overloaded lines using HTLS conductors. A combination of quantitative analysis, experimental data, and simulations is used to assess the feasibility and effectiveness of HTLS conductors in power transmission system upgradation.

3.2 Data Collection

The data for INPS was obtained from various publications of NEA such as Generation Directorate[13], Transmission Directorate[1], and Power System Operation Department, Load Dispatch Center (LDC) of NEA. To perform a detailed analysis, data is gathered from various sources, which includes:

- Transmission system Annual reports and network load data.
- Technical specifications of conductors (HTLS, ACSR, and others).
- Environmental parameters affecting transmission line performance (Temperature, Wind speed, Altitude).
- Previous research papers and case studies on the implementation of HTLS.

3.3 Qualitative Validation of Data

Data obtained from various sources for INPS model were qualitatively validated.

3.3.1 Validation of Generation Data

Generation data from various hydropower plants and solar plants were validated from their operational schedules, maintenance records and plant operators. The observed generation data were verified with the annual report of NEA and Load Dispatch Center.

3.3.2 Validation of Transmission System Data

Data related to transmission system like conductors used in the transmission lines, parameters setting of lines, transmission lines type, capacity rating, transmission losses and other related data were obtained from Transmission Annual Report, Grid Operation Department of NEA, Power System Operation Department of NEA. The obtained data was verified with engineers and grid operators.

3.3.3 Validation of Load Data

Load data needed for modelling of INPS were obtained from substations, Distribution centres and Distribution and Consumers Service Directorate Annual report of NEA. The data was verified with Load Dispatch Center and engineers from Distribution Center.

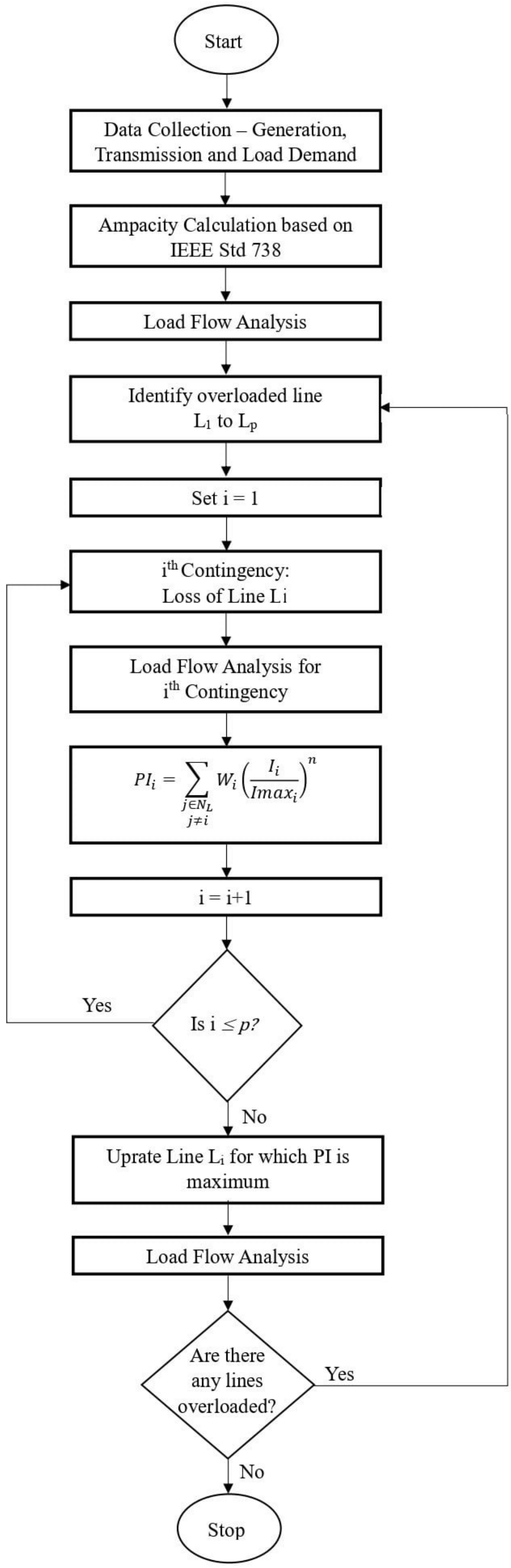

Figure 3.1: Flowchart for transmission line upgradation

3.4 Modelling of INPS

A variety of synchronous generators, a solar power plant, transmission lines, and loads coupled at various bus voltages ranging from 66 kV to 400 kV make up the Integrated Nepal Power System (INPS). Additionally, Tanakpur, Nepalgunj, Sampatiya (Mainihawa), Ramnagar (Gandak), Raxaul (Parwanipur), Dhalkebar and Kataiya (Kusaha) are also connected to the external grid via INPS. The INPS Network model consists of total 117 Nos. Busbars which icludes 3 Nos. 400 kV , 13 Nos. 200 kV, 78 Nos. 132 kV and 23 Nos. 66 kV buses for load flow and contingency analysis. Modelling of INPS was done in DigSILENT Powerfactory which is shown in the Figure3.2.

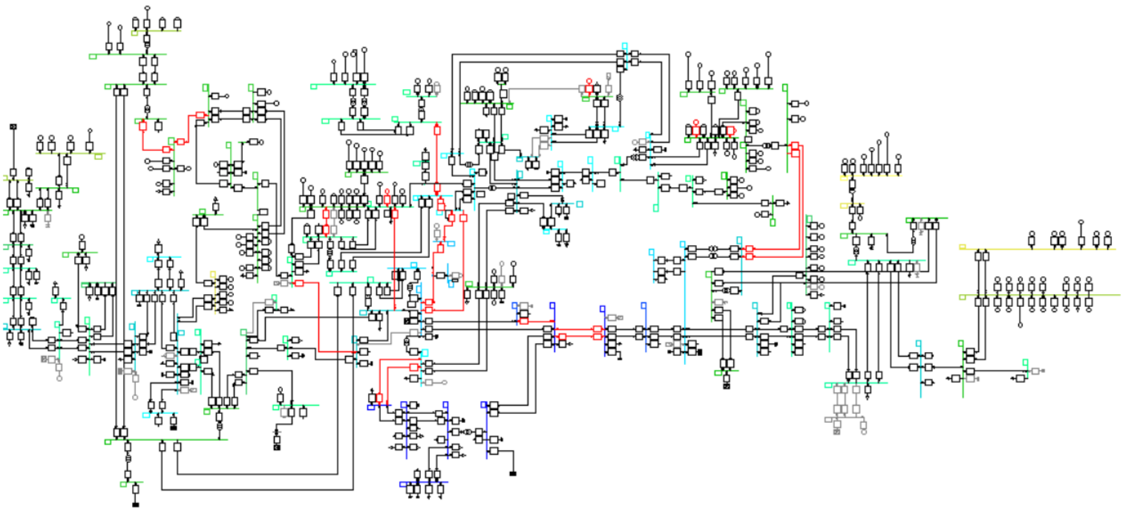

Figure 3.2: INPS Model in DigSILENT Tool

The said software was also used for load flow analysis for base case and all other cases of contingencies. The Model of INPS is shown in firure:3.3.

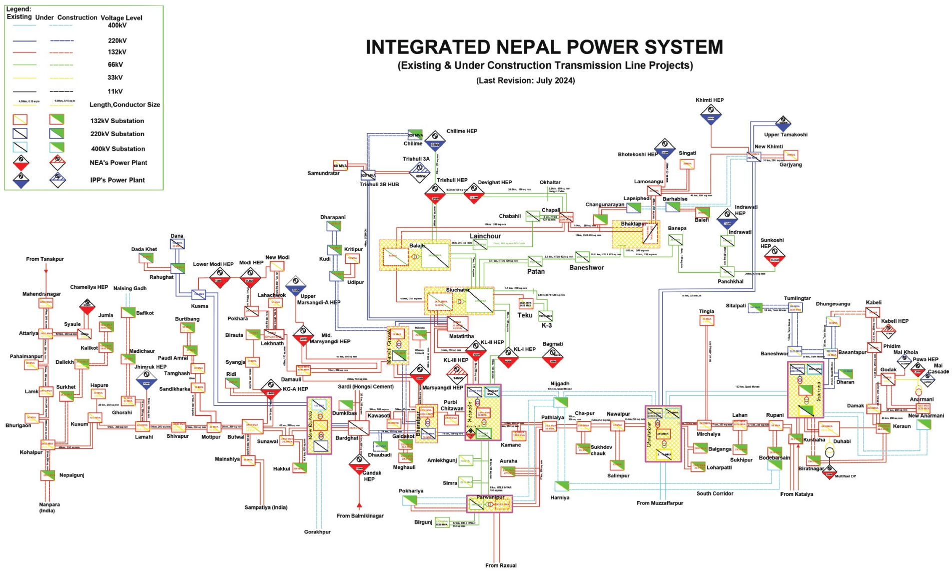

Figure 3.3: Integrated Nepal Power System (INPS)

3.5 IEEE Standard 738

IEEE Standard 738, ”IEEE Standard for Calculating the Current-Temperature of Bare Overhead Conductors,” states that thermal rating can be assessed for conductors used in power transmission networks. This standard is commonly used to calculate the current-carrying capacity of overhead conductors by taking into account the conductor’s characteristics and the surrounding environment. IEEE 738 outlines mathematical models for estimating conductor temperature under varying loading and environmental conditions. These calculations take into account parameters such as[10]:

- Solar Radiation: The effect of sunlight on conductor heating.
- Ambient Temperature: External temperature affecting the conductor.
- Wind Speed and Direction: Cooling effects that influence conductor temperature.
- Conductor Resistance: Electrical properties that determine heat generation.
- Emissivity and Absorptivity: Material properties affecting thermal radiation exchange.

This standard is employed to evaluate the current rating of various Aluminium Conductor Steel Reinforced (ACSR) used in INPS. The given excel figure3.4 shows the current calculation of ACSR Bear Conductor. Further, IEEE Standard 738 cab be also used for evaluating the current rating of equivalent HTLS Conductors for upgrading the aged overloaded lines of INPS.

Inputs:					
Parameters	**Symbol**	**Values**	**Units**	**Remarks**	**Referred Standard**
Latitude	Lat	27.5	degrees	Latitude of the location	
Year Day	N	172		Number of Days from Jan 1 (1 for Jan 1, 172 for June 21 Solstice)	IEEE-738-2012 (Table 1)
Hour Angle	w	0	degrees	15 degress per hour from Noon (0 for 12 PM, +15 for 1PM)	IEEE-738-2012 (4.5.4)
Atmosphere		Clear		Atmospheric Condition	
Elevation		1500	masl	Elevation of the location	
Ambient Temperature	T_a	40	° C		
Conductor Surface Temperature (Max)	T_max	80	° C		
Conductor		Bear		Add new conductors in Sheet Tables, if required	
Conductor Outer Diameter	Do	0.02345	m		
Coefficient of Resistance		0.00403		per °C	
Wind velocity	Wv	0.56	m/s		
beta		0	degrees	Angle between wind and perpendicular to conductor axis	
Emissivity		0.45		If not known take at most 0.1 less than absorptivity	IEEE-738-2012 (5.4)
Absorptivity		0.8		If not known take at least 0.8	IEEE-738-2012 (5.4)
Azimuth of line		90	degrees	90 For East-West Line	
Output:					
Caclulated Current Rating of Bear		**599.24**	**Amperes**		

Figure 3.4: IEEE Std. 738 Calcultion for ACSR Bear Conductor

3.6 Load Flow Study

Load flow studies are performed to assess the impact of replacing existing aged ACSR conductors with equivalent HTLS conductors in overloaded transmission lines[14]. The INPS load flow analysis is conducted using the DigSilent PowerFactory 15.1 software package. DigSilent uses the primary and secondary data to create a model. Only substation buses with voltages of 66 kV and above are taken into consideration when developing the system model. The 66kV, 132kV, and 220kV buses connect the generators to one another. Load Flow study is done for the following:

- Power flow calculations to determine current loading and voltage profiles.
- Voltage Profile assessment before and after conductor upgradation.
- Identification of critical transmission line sections for uprating.

The load flow study flowchart is shown below in the figure:3.5

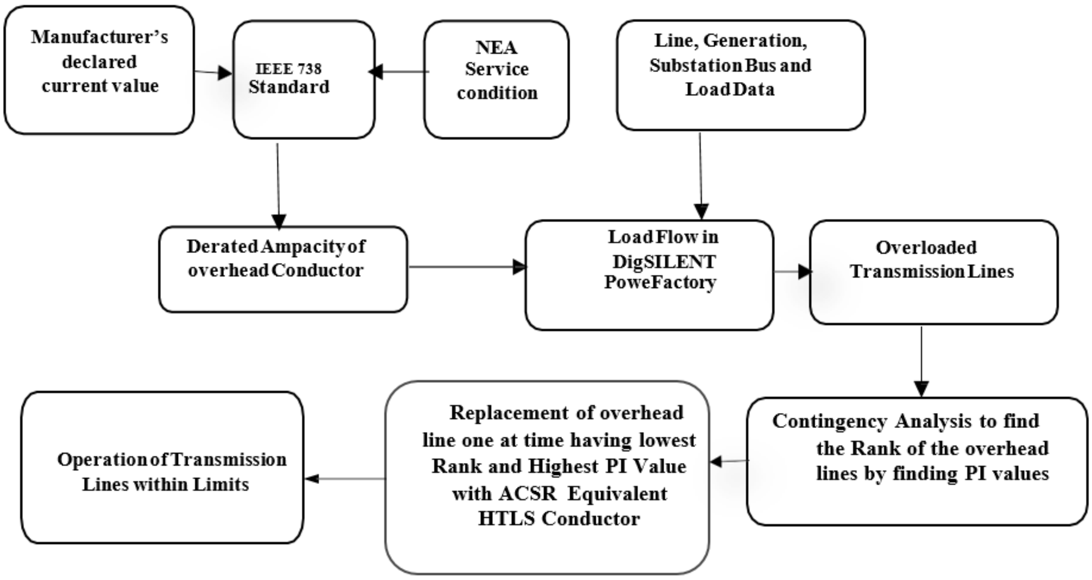

Figure 3.5: Load Flow Study Flow Chart

3.6.1 Consideration for Load Flow Study in DigSilent

Following factors have been taken into consideration for the INPS load flow research in DigSilent:

- In order to calculate the system load flow, the external grids of 400kV Bus at Dhalkebar Substation, which connects Dhalkebar -Muzafarpur 400kV cross-border transmission lines, and 132kV Bus at Mahendranagar, which connects Mahendranagar-Tanakpur 132kV cross-border transmission line, have been considered reference/slack buses. This is because INPS is a grid with multiple buses for power exchange (both import and export) from India.

- The load flow analysis outcomes may be impacted by the selection of slack bus.

- Newton-Raphson load flow power equations have been used in DigSilent for the load flow investigation. The tool's default setting for the iteration step size convergence options is automatic adoption.

- During the load flow study, three-phase balanced and positive sequence AC load flow was taken into consideration.

- Each bus has a lower limit of 0.95 p.u. and an upper limit of 1.05 p.u. for the permitted voltage.

- A maximum of 100% thermal loading is taken into consideration.

- Lumped factors are taken into consideration when determining the kind of transmission line.

3.7 Contingency Ranking

Depending on the real or active power flow across the transmission line, the contingency ranking was carried out. The Active Power has been considered here in order to determine Performance Index (PI). This index is used to evaluate the severity of line overloading during contingency conditions.

Several methods exist for ranking contingency scenarios, including Voltage Performance Index (VIP) and Line Overload Index (LOI)[15, 16]. However, the Active Power Performance Index was chosen due to its effectiveness in quantifying the impact of real power flow on system stability and its computational efficiency in large power networks.

$$PI_j = \sum_{i=1}^{N_L} W_i \left(\frac{I_i}{I_{\max,i}} \right)^n \tag{3.1}$$

where, I_i = current flow in line i after contingency j
$Imax_i$ = rated maximum current of line j
N_L = total number of overloaded lines of contingency j
W_i = weight for line i, assumed 1 in this research
n = even integer, assumed 2 in this research

A higher PI value indicates a more severe contingency, requiring immediate attention to system reinforcement.

To ensure accuracy in the ranking process, the following assumptions were made:

- Steady-State Analysis: The study considers only steady-state conditions, neglecting transient stability effects.

- Constant Load Demand: Load demand is assumed to remain constant during the contingency analysis.

- No Network Reconfiguration: The study does not account for network topology changes during contingencies.

The ranking of contingencies helps prioritize which transmission lines need urgent upgradation to prevent cascading failures.

3.8 Overleaf

Overleaf is an innovative online platform and LaTeX editor designed specifically for academics, researchers, and professionals involved in scientific writing and publishing. Overleaf provides a collaborative environment where users can create, edit, and manage LaTeX documents seamlessly, without the need for local LaTeX installations or complex setup. It offers LaTeX templates from various reputable journals. In this dissertation, the overleaf is used to prepare the reports.

CHAPTER FOUR: RESULTS AND DISCUSSION

This chapter presents the results obtained using the methodology described in Chapter 3.

4.1 ACSR Current Rating

The current rating of the ACSR conductors used in INPS is calculated using IEEE standard 738 and is compared with the manufacturer's rating[17] in Table 4.1.

Table 4.1: ACSR Current Rating

	Current Rating	
Conductor	**Manufacturer's Data [17]**	**Calculated as per IEEE Std. 738**
DOG	360 A	332.5 A
WOLF	470 A	433.65 A
PANTHER	560 A	521.73 A
BEAR	650 A	599.24 A
DUCK	*	650.58 A
BISON	800 A	745.59 A
CARDINAL	*	865.5 A
MOOSE	980 A	914.7 A

4.2 Load Flow Analysis of Wet Season Case

Integrated Nepal Power System (INPS) was modelled in the DigSILENT software tool and the model network was considered for base case study. The load flow analysis for wet peak season was considered as this is the season when the INPS transmission network will be loaded maximum. DIgSILENT Powerfactory was used for the load flow analysis. The lines given in Table 4.2 were found to be overloaded. The total overloaded circuit-km of a particular ACSR during Wet Season is summarized in Table 4.3.

4.2.1 Contingency Analysis

The overloaded lines shown in Table4.2 are expected to fail sometime in future and thus can be consider a contingency. When a line fails, the neighbour lines will carry the current that the original line was supposed to carry, and thus the new lines may be overloaded. For this research, the failure of overloaded lines shown in the Table4.2 one at a time is considered as a contingency. The effects of loss of each overloaded line one at a time is shown in the subsequent table.

Table 4.2: Overloaded Transmission Lines of INPS during Wet Peak season

Name	Voltage kV	Conductor ACSR	Ckt -Km	Line Loading (%)
Amlekhgunj-Simara	66	WOLF	25.8	85.35
Bhaktapur-Lamosanghu	132	BEAR	96.6	83.89
Damauli-Bharatpur	132	WOLF	39	104.86
Duhabi-Damak	132	BEAR	48.90	91.04
Hetauda-Amlekhgunj	66	WOLF	40.34	92.15
Hetauda-KL3-KL2-Matatirtha	132	BEAR	36	90.36
Kamane-Pathlaiya	132	BEAR	18.5	106.68
NMRS-MMRS	132	CARDINAL	40	105.07
Matatirtha-Hetauda	132	BEAR	36.24	89.75
NewBharatpur-MRS	132	DUCK	25	105.80

Table 4.3: Overloaded Conductors of INPS during Wet Case Scenario

ACSR	Ckt-km
WOLF	105.14
BEAR	236.24
CARDINAL	40
DUCK	25
Total	**406.38**

Table 4.4: Case I: Amlekhgunj-Simara 66kV lines Out

Name	Ckt	Line Loading(%)	PI
Bhaktapur-Lamosanghu	2	83.64	0.699
Damauli-Bharatpur	1	105.32	1.109
Hetauda-KL3	1	92.88	0.863
Hetauda-Pathlaiya	1	91.43	0.836
KL2-KL3	1	92.91	0.863
KL2-Matatirtha	1	93.19	0.868
Kamane-Pathlaiya	1	129.60	1.680
MMRS-NMRS	1	104.29	1.088
Matatirtha-Hetauda	1	92.57	0.857
NewBharatpur-MRS	1	106.79	1.140
Parwanipur-Birgunj	2	83.94	0.705
Pathlaiya-Parwanipur	2	94.04	0.884
Total Index			**13.880**

4.2.2 Ranking of Contingencies

The failure of each of the overloaded lines shown in Table 4.2 was considered and the contingencies were ranked based on the PI score as shown in Table 4.13 below. The Table

Table 4.5: Case II: Bhaktapur-Lamosanghu 132kV lines Out

Name	Ckt	Line Loading(%)	PI
Balaju-Laichaur	1	100.18	1.004
Damauli-Bharatpur	1	88.20	0.778
Dhalkebar-NewKhimti	2	82.30	0.677
MMRS-NMRS	1	110.98	1.232
Matatirtha-Syuchatar	2	113.44	1.287
NewBharatpur-MRS	1	85.13	0.724
Parwanipur-Birgunj	2	83.364	0.695
Total Index			**9.056**

Table 4.6: Case III: Damauli-Bharatpur 132kV line Out

Name	Ckt	Line Loading(%)	PI
Amlekhgunj-Simara	2	85.95	0.739
Bhaktapur-Lamosanghu	2	85.11	0.724
Hetauda-Amlekhgunj	2	92.98	0.865
Hetauda-KL3	1	99.86	0.993
KL2-KL3	1	99.71	0.994
KL2-Matatirtha	1	99.99	1.000
Kamane-Pathlaiya	1	106.65	1.138
Kushma-Modi	1	83.93	0.704
MMRS-NMRS	1	135.63	1.839
Matatirtha-Hetauda	1	92.57	0.857
NewBharatpur-MRS	1	143.35	2.055
Parwanipur-Birgunj	2	87.09	0.759
Total Index			**15.883**

Table 4.7: Case IV: Hetauda-Amlekhgunj 66kV lines Out

Name	Ckt	Line Loading(%)	PI
Bhaktapur-Lamosanghu	2	84.09	0.707
Damauli-Bharatpur	1	106.11	1.126
Hetauda-KL3	1	93.65	0.877
Hetauda-Pathlaiya	1	93.42	0.873
KL2-KL3	1	93.68	0.877
KL2-Matatirtha	1	93.45	0.883
Kamane-Pathlaiya	1	132.45	1.754
MMRS-NMRS	1	104.82	1.098
Matatirtha-Hetauda	1	93.31	0.871
NewBharatpur-MRS	1	107.38	1.153
Parwanipur-Birgunj	2	84.75	0.718
Pathlaiya-Parwanipur	2	96.60	0.933
Total Index			**14.230**

Table 4.8: Case V: Hetauda-KL3-KL2-Matatirtha 132kV line Out

Name	Ckt	Line Loading(%)	PI
Amlekhgunj-Simara	2	88.23	0.778
Bhaktapur-Lamosanghu	2	85.15	0.725
Damauli-Bharatpur	1	119.18	1.420
Hetauda-Amlekhgunj	2	95.32	0.908
Kamane-Pathlaiya	1	105.76	1.118
MMRS-Kirtipur	1	80.03	0.640
MMRS-NMRS	1	100.23	1.005
Matatirtha-Hetauda	1	136.20	1.855
NewBharatpur-MRS	1	124.66	1.554
Parwanipur-Birgunj	2	87.44	0.765
Total Index			**13.947**

Table 4.9: Case VI: Kamane-Pathlaiya 132kV line Out

Name	Ckt	Line Loading(%)	PI
Amlekhgunj-Simara	2	105.26	1.108
Bhaktapur-Lamosanghu	2	85.22	0.726
Damauli-Bharatpur	1	106.51	1.134
Hetauda-Amlekhgunj	2	112.73	1.271
Hetauda-KL3	1	89.97	0.809
Hetauda-Pathlaiya	1	120.95	1.463
KL2-KL3	1	90.00	0.810
KL2-Matatirtha	1	90.23	0.814
MMRS-Kirtipur	1	80.03	0.640
MMRS-NMRS	1	106.98	1.144
Matatirtha-Hetauda	1	89.62	0.803
NewBharatpur-MRS	1	106.60	1.136
Parwanipur-Birgunj	2	88.64	0.786
Total Index			**16.537**

4.13 shows that the loss of NewBharatpur-MRS 132kV line is the most severe and will be first line to be upgraded.

Table 4.10: Case VII: MMRS-NMRS 132kV line Out

Name	Ckt	Line Loading(%)	PI
Amlekhgunj-Simara	2	83.96	0.705
Bhaktapur-Lamosanghu	2	84.74	0.718
Damauli-NMRS	1	106.97	1.144
Damauli-Bharatpur	1	149.87	2.246
Hetauda-Amlekhgunj	2	90.91	0.826
Hetauda-KL3	1	81.71	0.668
KL2-KL3	1	81.74	0.668
KL2-Matatirtha	1	82	0.672
Kamane-Pathlaiya	1	103.727	1.076
Kushma-Modi	1	82.40	0.679
MMRS-Damauli	1	153.85	2.367
Matatirtha-Hetauda	1	81.45	0.663
Parwanipur-Birgunj	2	86.79	0.753
Total Index			**16.190**

Table 4.11: Case VIII: Matatirtha-Hetauda 132kV line Out

Name	Ckt	Line Loading(%)	PI
Amlekhgunj-Simara	2	88.20	0.778
Bhaktapur-Lamosanghu	2	85.14	0.725
Damauli-Bharatpur	1	119.04	1.417
Hetauda-Amlekhgunj	2	95.29	0.908
Hetauda-KL3	1	136.36	1.859
KL2-KL3	1	136.39	1.860
KL2-Matatirtha	1	136.64	1.867
Kamane-Pathlaiya	1	105.77	1.119
Kushma-Modi	1	88.98	0.792
MMRS-Damauli	1	86.90	0.755
Matatirtha-Hetauda	1	113.63	1.291
Parwanipur-Birgunj	2	88.67	0.786
Total Index			**17.669**

Table 4.12: Case IX: NewBharatpur-MRS 132kV line Out

Name	Ckt	Line Loading(%)	PI
Amlekhgunj-Simara	2	87.20	0.760
Bhaktapur-Lamosanghu	2	86.16	0.742
Damauli-Bharatpur	1	174.48	3.044
Hetauda-Amlekhgunj	2	94.56	0.894
Hetauda-KL3	1	114.16	1.303
KL2-KL3	1	114.19	1.304
KL2-Matatirtha	1	114.39	1.309
Kamane-Pathlaiya	1	106.018	1.124
MMRS-Kirtipur	1	80.01	0.640
MMRS-NMRS	1	100.28	1.006
NewBharatpur-MRS	1	124.47	1.550
Parwanipur-Birgunj	2	87.42	0.764
Total Index			**17.950**

Table 4.13: Contingency Ranking of INPS Overloaded lines

Name	Voltage kV	Conductor ACSR	Ckt -Km	PI	Contingency Rank
New Bharatpur-MRS	132	DUCK	25.00	17.950	1
Mata-Hetauda	132	BEAR	36.24	17.669	2
Kamane-Pathlaiya	132	BEAR	18.50	16.537	3
MMRS-NMRS	132	CARDINAL	40.00	16.190	4
Damauli-Bharatpur	132	WOLF	39.00	15.883	5
Hetauda-Amlekhgunj	66	WOLF	40.34	14.230	6
Hetauda-KL3-KL2-Matatirtha	132	BEAR	36.00	13.947	7
Amlekhgunj-Simara	66	WOLF	25.80	13.880	8
Bhaktapur-Lamosanghu	132	BEAR	96.60	9.056	9

4.3 Load Flow Analysis of Dry Season Case

Similarly the load flow analysis for dry peak season was also taken into consideration for finding out the critically overloaded lines during that season. Since the majority of hydropower plants in Nepal are run-of-river (ROR) type, the power system experiences a power shortfall during the dry season. So power has to be imported from the external grid (India) through cross border transmission lines in order to meet consumers load demand. The overloaded lines during dry peak season are mentioned in the following Table 4.14.

Table 4.14: Overloaded Transmission Lines of INPS during Dry Peak season

Name	**Voltage kV**	**Conductor ACSR**	**Ckt -Km**	**Line Loading (%)**
Bhaktapur-Lamosanghu	132	BEAR	96.6	127.35
Chapur-Nawalpurr	132	BEAR	69.5	133.19
Nawalpur-Dhalkebar	132	BEAR	69.5	140.41
NewKhimti-Lamosanghu	132	ACCC HTLS	45.84	98.80
Pathlaiya-Chapur	132	BEAR	61.36	117.95

Table 4.15: Overloaded Conductors of INPS during Dry Case Scenario

ACSR	**Ckt-km**
WOLF	0
BEAR	342.8
CARDINAL	0
DUCK	0
Total	**296.96**

4.4 Load Flow Analysis of Large Generation Outage

Like the failure of transmission lines, generators may also sometimes fail in the power system. Kaligandaki A (KGA) and Middle marsyangdi (MMRS) PHs were taken into account for analysing the large generators outage scenario during dry peak case. Most of the hydro power plants in Nepal power network were running at its minimum generation load due to low water discharge during peak dry season. Transmission lines of INPS shown in the Table4.3 are significantly overloaded lines during Wet season. Similarly, the transmission lines shown in the Table4.15 are critically overloaded during Dry season. After upgrading all these overloaded lines with their equivalent HTLS conductors, the line loading of previously overloaded lines decreased significantly. The overloaded lines upon outage of KGA and MMRS (Two large PHs) after upgradation of overloded lines are shown in the following Table4.16.

Table 4.16: Overloaded Lines of INPS during Outage of KGA and MMRS PH

Name	Voltage kV	Conductor ACSR	Ckt -Km	Line Loading (%)
NewKhimti-Lamosanghu	132	ACCC HTLS	45.84	102.28
NewButwal-Sunwal	132	BEAR	40	100.20
Butwal-Sunwal	132	BEAR	26	87.39
Bhaktapur-Chapali	132	BEAR	23.78	86.54
Nawalpur-Dhalkebar	132	BEAR	69.5	85.17

4.5 ACSR Equivalent ACCC HTLS Conductors

Now as a part of this research work, it is believed to increase the conductors' ability to carry more current in the overloaded line sections at full wet season generation capacity and maximum peak load. These critical line sections having ACSR conductors are up-graded with equivalent ACCC HTLS conductors. Looking through the data sheet of the manufacturer for a number of HTLS conductors, the following conductors shown in the table4.17 have been used as equivalent HTLS Conductors on the basis of similar diameter and weight per unit length.

Table 4.17: ACSR Equivalent HTLS Conductors

ACSR Conductor			ACCC HTLS Conductor		
Conductor Code	**Conductor Diameter (mm)**	**Overall Kg/Km**	**Conductor Code**	**Conductor Diameter (mm)**	**Overall Kg/Km**
WOLF	18.13	726	COPENHAGEN	18.29	659
BEAR	23.45	1213	AMSTERDAM	23.55	1104
BISON	27.00	1444	STOCKHOLM	26.39	1368
CARDINAL	30.42	1833	VIENNA	30.43	1852

Derated value of HTLS conductors in NEA service conditions is also stated in the table4.18 given below.

Table 4.18: HTLS Current Rating as per IEEE Std.738

Conductor Code	Conductor Diameter (mm)	Manufacturer Current Capacity (A)			Current Capacity (A) Calculated as per IEEE Std 738		
		85 °C	120 °C	180 °C	85 °C	120 °C	180 °C
COPENHAGEN	18.29	473	684	910	524.82	677.63	899.75
AMSTERDAM	23.55	643	944	1267	724.88	935.88	1254
STOCKHOLM	26.39	730	1081	1457	829.85	1072	1442.7
VIENNA	30.43	880	1318	1787	1013.8	1311.1	1774.7

4.6 Different Cases of Contingency Ranking after Conductor Upgradation

4.6.1 Case 1: NewBharatpur- MRS line Upgraded

The most severe line in the system is the NewBharatpur-MRS transmission line with the highest PI score (17.950) as mentioned in the above table 4.13. In case of failure, this line would lead to high stress on adjacent lines, which would cause overloading and system instability. So among the overloaded lines of INPS, NewBharatpur-MRS 132kV 25.00 Ckt.km ACSR conductor is upgraded with equivalent HTLS Amsterdam conductor. After upgradation of the most severe line having highest PI, again load flow and Contingency analysis is done. The Contingency Ranking of overloaded lines after upgradation of NewBharatpur-MRS line is shown in the following table 4.19 The total overloaded circuit-km of a particular ACSR after upgradation of overloaded ACSR Conductor of NewBharatpur- MRS line with equivalent HTLS Conductor is summarized in Table 4.20.

Table 4.19: Contingency Ranking after Upgradation of NewBharatpur- MRS line

Name	**Voltage kV**	**Ckt -km**	**Conductor ACSR**	**PI**	**Contingency Rank**
Matatirtha-Hetauda	132	36.24	BEAR	14.758	1
Damauli-Bharatpur	132	39	WOLF	14.320	2
Kamane-Pathlaiya	132	18.5	BEAR	13.960	3
MMRS-NMRS	132	40.00	CARDINAL	12.721	4
Hetauda-Amlekhgunj	66	40.34	WOLF	11.960	5
Amlekhgunj-Simara	66	25.8	WOLF	11.960	6
Hetauda-KL2-KL3-Matatirtha	132	36	BEAR	11.660	7
Bhaktapur-Lamosanghu	132	96.6	BEAR	7.697	8

Table 4.20: Overloaded Conductors after Upgradation of NewBharatpur- MRS line

ACSR	**Ckt-km**
WOLF	105.14
BEAR	187.34
CARDINAL	40
Total	**332.48**

4.6.2 Case 2: Matatirtha- Hetauda line Upgraded

After upgradtion of NewBharatpur-MRS 132kV ACSR Duck conductor with equivalent HTLS Amsterdam conductor , Matatirtha- Hetauda line becomes the most severe line having highest PI as indicated in the table 4.19 . So the second upgradation of overloaded lines is done for Matatirtha- Hetauda line after doing proper load flow and Contingency Analysis. The Contingency Ranking of overloaded lines after upgradation of Matatirtha-

Hetauda 132kV 36.24 Ckt.km ACSR Bear conductor with equivalent HTLS Amsterdam conductor is shown in the below table 4.21

Table 4.21: Contingency Ranking after Upgradation of Matatirtha- Hetauda line

Name	Voltage kV	Ckt -km	Conductor ACSR	PI	Contingency Rank
MMRS-NMRS	132	40.00	CARDINAL	12.614	1
Kamane-Pathlaiya	132	18.5	BEAR	11.071	2
Damauli-Bharatpur	132	39	WOLF	9.694	3
Hetauda-Amlekhgunj	66	40.34	WOLF	9.209	4
Amlekhgunj-Simara	66	25.8	WOLF	8.956	5
Bhaktapur-Lamosanghu	132	96.6	BEAR	7.697	6

The total overloaded circuit-km of a particular ACSR after upgradation of overloaded ACSR Conductor of Matatirtha- Hetauda line with equivalent HTLS Conductor is summarized in Table 4.22.

Table 4.22: Overloaded Conductors after Upgradation of Matatirtha- Hetauda line

ACSR	Ckt-km
WOLF	105.14
BEAR	115.10
CARDINAL	40
Total	**260.24**

4.6.3 Case 3: MMRS- NMRS line Upgraded

After upgradtion of Matatirtha- Hetauda 132kV ACSR Bear conductor with equivalent HTLS Amsterdam conductor, MMRS- NMRS 132kV line becomes the most critical line having highest PI (12.614) as indicated in the table 4.22 . So, the next upgradation of overloaded lines is done for MMRS- NMRS line after proper load flow and Contingency Analysis. The Contingency Ranking of overloaded lines after upgradation of MMRS-NMRS 132kV 40.00 Ckt.km ACSR Cardinal conductor with equivalent HTLS Vienna conductor, is shown in the table 4.23 The total overloaded circuit-km of the ACSR Conductor after upgradation of overloaded ACSR Conductor of NMRS- MMRS line with equivalent HTLS Conductor is given in the Table 4.24.

4.6.4 Case 4: Kamane- Pathlaiya line Upgraded

After upgradtion of MMRS- NMRS 132kV ACSR Cardinal conductor with equivalent HTLS Vienna conductor, Kamane- Pathlaiya 132kV line becomes critically overloaded line having highest PI as mentioned in the above table 4.23 . So the next overloaded line to

Table 4.23: Contingency Ranking after Upgradation of MMRS- NMRS line

Name	**Voltage kV**	**Ckt -km**	**Conductor ACSR**	**PI**	**Contingency Rank**
Kamane-Pathlaiya	132	18.5	BEAR	12.132	1
Damauli-Bharatpur	132	39	WOLF	10.578	2
Hetauda-Amlekhgunj	66	40.34	WOLF	10.250	3
Amlekhgunj-Simara	66	25.8	WOLF	9.307	4
Bhaktapur-Lamosanghu	132	96.6	BEAR	8.202	5

Table 4.24: Overloaded Conductors after Upgradation of MMRS- NMRS line

ACSR	**Ckt-km**
WOLF	105.14
BEAR	115.10
CARDINAL	0
Total	**220.24**

be upgraded is found as Kamane- Pathlaiya line after load flow and Contingency Analysis. The Contingency Ranking of overloaded lines after upgradation of Kamane- Pathlaiya 132kV 18.50 Ckt.km ACSR Bear conductor with equivalent HTLS Amsterdam conductor, is shown in the table 4.25 The total overloaded circuit-km of the ACSR Conductor after

Table 4.25: Contingency Ranking after Upgradation of Kamane-Pathlaiya line

Name	**Voltage kV**	**Ckt -km**	**Conductor ACSR**	**PI**	**Contingency Rank**
Damauli-Bharatpur	132	39	WOLF	8.993	1
Hetauda-Amlekhgunj	66	40.34	WOLF	8.235	2
Bhaktapur-Lamosanghu	132	96.6	BEAR	8.197	3

upgradation of overloaded ACSR Conductor of Kamane-Pathlaiya line with equivalent HTLS Conductor is given in the Table 4.26.

Table 4.26: Overloaded Conductors after Upgradation of Kamane-Pathlaiya line

ACSR	**Ckt-km**
WOLF	79.34
BEAR	96.60
CARDINAL	0
Total	**175.94**

4.6.5 Case 5: Damauli- Bharatpur line Upgraded

Damauli- Bharatpur line becomes the most overloaded line after the upgradtion ofKamane-Pathlaiya 132kV ACSR Bear conductor with equivalent HTLS Amsterdam conductor, having highest PI as mentioned in the above table 4.25. So the next overloaded line to be upgraded is found as Damauli- Bharatpur line. The Contingency Ranking of overloaded lines after upgradation of Damauli- Bharatpur 132kV 39.00 Ckt.km ACSR Wolf conductor with equivalent HTLS Copanhegan conductor, is shown in the table 4.27 The total

Table 4.27: Contingency Ranking after Upgradation of Damauli- Bharatpur line

Name	Voltage kV	Ckt -km	Conductor ACSR	PI	Contingency Rank
Bhaktapur-Lamosanghu	132	96.6	BEAR	7.338	1
Hetauda-Amlekhgunj	66	40.34	WOLF	7.131	2

overloaded circuit-km of the ACSR Conductor after upgradation of overloaded ACSR Conductor of Kamane-Pathlaiya line with equivalent HTLS Conductor is given in the Table 4.28.

Table 4.28: Overloaded Conductors after Upgradation of Damauli- Bharatpur line

ACSR	Ckt-km
WOLF	40.34
BEAR	96.60
CARDINAL	0
Total	**136.94**

4.6.6 Case 6: Bhaktapur- Lamosanghu lines Upgraded

Nawalpur- Dhalkebar lines become critically overloaded lines after the upgradtion of Damauli- Bharatpur 132kV ACSR Wolf conductor with equivalent HTLS Cohenhagen conductor, having highest PI as mentioned in the above table 4.27 . So the next overloaded lines to be upgraded are found as Nawalpur- Dhalkebar lines after proper load flow and Contingency Analysis. The Contingency Ranking of overloaded lines after upgradation of Nawalpur- Dhalkebar 132kV 69.50 Ckt.km ACSR Bear conductor with equivalent HTLS Amsterdam conductor, is shown in the table 4.29 The total overloaded circuit-km

Table 4.29: Contingency Ranking after Upgradation of Bhaktapur- Lamosanghu line

Name	Voltage kV	Ckt -km	Conductor ACSR	PI	Contingency Rank
Hetauda-Amlekhgunj	66	40.34	WOLF	4.852	1

of the ACSR Conductor after upgradation of overloaded ACSR Conductor of Bhaktapur-Lamosanghu line with equivalent HTLS Conductor is given in the Table 4.30.

Table 4.30: Overloaded Conductors after Upgradation of Bhaktapur- Lamosanghu line

ACSR	Ckt-km
WOLF	40.34
BEAR	0
CARDINAL	0
Total	**40.34**

Table 4.31: Contingency Ranking after Upgradation of Hetauda- Amlekhgunj lines

Name	Voltage kV	Ckt -km	Conductor ACSR	PI	Contingency Rank
Amlekhgunj-Simara	66	25.80	WOLF	5.009	1

4.6.7 Case 7: Hetauda- Amlekhgunj lines Upgraded

Hetauda- Amlekhgunj lines become the most overloaded lines after the upgradtion of Bhaktapur- Lamosanghu 132kV ACSR Bear conductor with equivalent HTLS Amsterdam conductor, having highest PI as mentioned in the above table 4.29 . So the next overloaded lines to be upgraded are found as Hetauda- Amlekhgunj lines after doing proper load flow and Contingency Analysis. The Contingency Ranking of overloaded lines after upgradation of Hetauda- Amlekhgunj 66kV, 40.40 Ckt.km ACSR Wolf conductor with its equivalent HTLS Copanhegan conductor, is shown in the table 4.31 The total overloaded circuit-km of the ACSR Conductor after upgradation of overloaded ACSR Conductor of Hetauda- Amlekhgunj lines with equivalent HTLS Conductor is given in the Table 4.32.

Table 4.32: Overloaded Conductors after Upgradation of Hetauda- Amlekhgunj lines

ACSR	Ckt-km
WOLF	25.80
BEARN	0
Total	**25.80**

4.6.8 Case 8: Amlekhgunj- Simara lines Upgraded

Amlekhgunj- Simara lines become the most critically overloaded lines after the upgradtion of Hetauda- Amlekhgunj 66kV ACSR Wolf conductor with equivalent HTLS Copanhegan conductor, having highest PI as mentioned in the above table 4.31 . So the next overloaded lines to be upgraded are found as Amlekhgunj- Simara lines after doing proper load flow and Contingency Analysis. The Contingency Ranking of overloaded lines after upgradation of Amlekhgunj- Simara 66kV 25.80 Ckt.km ACSR Wolf conductor with equivalent HTLS Copanhegan conductor, is not needed as no more transmission line is found to be overloaded in INPS network. So the last overloaded line to be upgraded finally for smooth and reliable operation of transmission lines of INPS, is found to be Khimti- Dhalkebar line after doing proper load flow and Contingency Analysis.

4.7 Different Cases of Conductor Upgradation for Dry Season Case

4.7.1 Case 1: Dhalkebar- Nawalpur lines Upgraded

Dhalkebar- Nawalpur lines become the most overloaded line during Dry Peak Season case of INPS. Dhalkebar-Nawalpur 132kV Bear conductors are highly overloaded as shown in the Table 4.15. This suggests that Dhalkebar- Nawalpur 132kV 69.5 ckt-km Bear line needs the urgent upgradtion with equivalent HTLS Amsterdam conductor. The line loading obtained from load flow analysis after upgrading Dhalkebar- Nawalpur lines is shown in the table 4.33

Table 4.33: Overloaded Lines of INPS during Dry Peak season after upgradation of Dhalkebar-Nawalpur lines

Name	Voltage kV	Conductor ACSR	Ckt -Km	Line Loading (%)
Bhaktapur-Chapali	132	BEAR	23.78	83.83
Chapur-Nawalpur	132	BEAR	69.5	127.83
NewKhimti-Lamosanghu	132	ACCC HTLS	45.84	99.03
Parwanipur-Birgunj	66	WOLF	18.00	80.43
Pathlaiya-Chapur	132	BEAR	61.36	113.25

4.7.2 Case 2: Nawalpur- Chapur lines Upgraded

After upgradtion of Dhalkebar-Nawalpur 132kV lines ACSR Bear conductor with equivalent HTLS Amsterdam conductor, Nawalpur- Chapur lines 132kV line becomes critically overloaded line as mentioned in the above table 4.33 . So the next overloaded line to be upgraded is found as Nawalpur- Chapur lines after doing proper analysis of load flow. Line loading obtained upon analysis of load flow after upgrading Nawalpur- Chapur 132kV, 69.5 ckt-km Bear lines with equivalent HTLS Amsterdam is shown in the table 4.34

Table 4.34: Overloaded Lines of INPS during Dry Peak season after upgradation of Nawalpur- Chapur lines

Name	Voltage kV	Conductor ACSR	Ckt -Km	Line Loading (%)
Parwanipur-Birgunj	66	WOLF	18.00	80.31
Pathlaiya-Chapur	132	BEAR	61.36	119.32
NewKhimti-Lamosanghu	132	ACCC HTLS	45.84	99.03

4.7.3 Case 3: Chapur- Pathlaiya lines Upgraded

After upgradtion of Nawalpur- Chapur 132kV lines ACSR Bear conductor with equivalent HTLS Amsterdam conductor, Chapur- Pathlaiya 132kV lines become critically overloaded lines as mentioned in the above table 4.34. So the last overloaded line to be upgraded finally for smooth and reliable operation of transmission lines of INPS, is found to be Chapur- Pathlaiya lines after doing proper load flow Analysis. The line loading obtained from load flow analysis after upgrading Chapur- Pathlaiya 132kV, 61.36 ckt-km Bear lines with equivalent HTLS Amsterdam is shown in the table 4.35

Table 4.35: Overloaded Lines of INPS during Dry Peak season after upgradation of Chapur- Pathlaiya lines

Name	Voltage kV	Conductor ACSR	Ckt -Km	Line Loading (%)
Parwanipur-Birgunj	66	WOLF	18.00	80.14
NewKhimti-Lamosanghu	132	ACCC HTLS	45.84	85.67

4.8 Observations and Insights

From the contingency ranking results:

- The NewBharatpur-MRS transmission line has the highest PI score (17.950), making it the most critical line in the system. If this line fails, it will impose significant stress on adjacent lines, leading to potential overloading and system instability.

- Other high-risk lines include Matatirtha-Hetauda (14.758), Damauli-Bharatpur (14.320), and Kamane- Pathlaiya (13.960). These lines play a crucial role in power transmission and require priority consideration for reinforcements during Wet Peak Season.

- Lines such as Dhalkebar-Nawalpur (140.41%loading), Chapur-Nawalpur (133.19%loading) and Pathlaiya-Chapur (117.95%loading) suggest their outages during Dry Peak

Season would have a serious impact on overall network stability. So, these overloaded lines need to be upgraded with its equivalent HTLS conductors.

This ranking allows Grid Owner and other related utility to prioritize upgradation efforts, focusing first on the most vulnerable transmission lines to prevent partial system collapse and system-wide blackouts.

4.8.1 Recommendations for System Reinforcement

Based on the contingency ranking results, the following mitigation strategies are proposed:

1. Immediate Upgradation of Critical Lines

   - NewBharatpur-MRS, Matatirtha-Hetauda, Damauli-Bharatpur lines should be reinforced or upgraded first to handle increased load demands at full generation during Wet Peak Season.

   - Similarly, Dhalkebar-Nawalpur, Chapur-Nawalpur and Pathlaiya-Chapur lines should be reinforced or upgraded inorder to handle increased load demands at lowest national generation during Dry Peak Season.

   - Possible solutions include using high-capacity conductors (e.g., HTLS – High-Temperature Low-Sag conductors) or doubling circuit lines to distribute load.

2. Implementation of Alternative Transmission Routes

   - Diversifying power flow paths through parallel transmission corridors will reduce the stress on the most overloaded lines.

   - This can be achieved by constructing new transmission links between major substations to balance the load demand more effectively.

3. Demand-Side Management (DSM) and Load Shedding Strategies

   - During peak loading conditions, strategic load shedding or demand response programs can help alleviate stress on transmission lines.

   - Smart grid technologies can facilitate real-time load balancing by adjusting demand patterns dynamically.

4.9 Overall System Performances of INPS

The overall system performance increases significantly after upgradation of ACSR overloaded transmission lines with the equivalent HTLS conductors. Although the initial load flow analysis of Base case suggests the upgradation of critically overloaded transmission lines of total 557.84 ckt.kM, the contingency Analysis indicates the necessity of overhead transmission lines of total 521.84 ckt.kM upgradation. The list of overloaded ACSR transmission lines upgraded with equivalent HTLS Conductors is noted in the following table 4.36. The Grid Summary of INPS after upgradation of Overloaded ACSR transmission

Table 4.36: List of Overloaded lines Upgraded with HTLS Conductors

Name	**Voltage kV**	**ACSR Conductor**	**Ckt -Km**	**Equivalent HTLS Conductor**
NewBharatpur-MRS	132	DUCK	25	AMSTERDAM
Matatirtha-Hetauda	132	BEAR	36.24	AMSTERDAM
MMRS-NMRS	132	CARDINAL	40	VIENNA
Kamane-Pathlaiya	132	BEAR	18.5	AMSTERDAM
Pathlaiya-Chapur	132	BEAR	61.36	AMSTERDAM
Damauli-Bharatpur	132	WOLF	39	COPENHAGEN
Bhaktapur-Lamosanghu	132	BEAR	96.6	AMSTERDAM
Hetauda-Amlekhgunj	66	WOLF	40.34	COPENHAGEN
Amlekhgunj-Simara	66	WOLF	25.8	COPENHAGEN
Dhalkebar-Nawalpur	132	BEAR	69.5	AMSTERDAM
Nawalpur-Chapur	132	BEAR	69.5	AMSTERDAM
Chapur-Pathlaiya	132	BEAR	61.36	AMSTERDAM
		Total	**521.84**	

lines with equivalent HTLS Conductors during Wet Peak scenario is shown below in the following table 4.37 Similarly,the Grid Summary of INPS after upgradation of Overloaded ACSR transmission lines with equivalent HTLS Conductors during Dry Peak scenario is shown below in the following table 4.38

After upgradation of overloaded ACSR Conductors with equivalent HTLS Conductors, the line loading decreases significantly. The table4.39 given below highlights the line loading before and after conductor uprating of the overloaded lines of INPS during Wet Peak Scenario.

Similarly,the table4.40 given below shows the line loading before and after conductor uprating of the overloaded lines of INPS during Dry Peak Case. The figures given below show the Grid Summary of Export/ Excess power (MW) 4.1 and Grid System overall losses (MW) 4.2 during Wet Peak Case.

Table 4.37: Grid Summary after Upgradation of Overloaded Lines of INPS Wet Peak Case

Name	Total Generation (MW)	Total System Load (MW)	Export/Excess Power (MW)	Grid Losses (MW)
Base Case Wet Peak	3076.29	2050.19	846.60	179.50
NewBharatpur-MRS	3076.29	2050.19	847.79	178.31
Matatirtha-Hetauda	3076.29	2050.19	849.03	177.07
MMRS-NMRS	3076.29	2050.19	845.23	180.87
Kamane-Pathlaiya	3076.29	2050.19	846.80	179.30
Damauli-Bharatpur	3076.29	2050.19	846.60	179.50
Bhaktapur-Lamosanghu	3076.29	2050.19	848,89	177.21
Hetauda-Amlekhgunj	3076.29	2050.19	849.26	176.84
Amlekhgunj-Simara	3076.29	2050.19	849.47	176.63

Table 4.38: Grid Summary after Upgradation of Overloaded Lines of INPS Dry Peak Case

Name	Total Generation (MW)	Total System Load (MW)	Import/ Shortage Power (MW)	Grid Losses (MW)
Base Case Dry Peak	1495.68	1922.05	550.45	124.07
Dhalkebar-Nawalpur	1495.68	1922.05	540.16	113.78
Nawalpur-Chapur	1495.68	1922.05	534.44	108.06
Chapur-Pathlaiya	1495.68	1922.05	530.18	103.80

Table 4.39: Line Loading Before and After Conductor Upgradation during Wet Peak Case

Name	Voltage (kV)	Conductor (ACSR)	Ckt-Km	Line Loading (%) Before line Upgradation	Line Loading (%) After line Upgradation
Amlekhgunj-Simara	66	WOLF	25.8	85.35	49.09
Bhaktapur-Lamosanghu	132	BEAR	96.6	83.89	39.91
Damauli-Bharatpur	132	WOLF	39	104.86	76.78
Hetauda-Amlekhgunj	66	WOLF	40.34	92.15	52.32
Hetauda-KL3-KL2-Mata	132	BEAR	36	90.36	61.69
Kamane-Pathlaiya	132	BEAR	18.5	106.68	59.30
MMRS-NMRS	132	CARDINAL	40	105.070	31.50
Matatirtha-Hetauda	132	BEAR	36.24	89.75	53.00
NewBharatpur-MRS	132	DUCK	25	105.80	49.20

Table 4.40: Line Loading Before and After Conductor Upgradation during Dry Peak Case

Name	Voltage (kV)	Conductor (ACSR)	Ckt-Km	Line Loading (%) Before Line Upgradation	Line Loading (%) After Line Upgradation
Bhaktapur-Lamosanghu	132	BEAR	96.6	127.35	53.83
Chapur-Nawalpur	132	BEAR	69.5	133.19	66.31
Nawalpur-Dhalkebar	132	BEAR	69.5	140.41	69.70
NewKhimti-Lamosanghu	132	HTLS	45.84	98.81	85.67
Pathlaiya-Chapur	132	BEAR	61.36	117.95	59.29

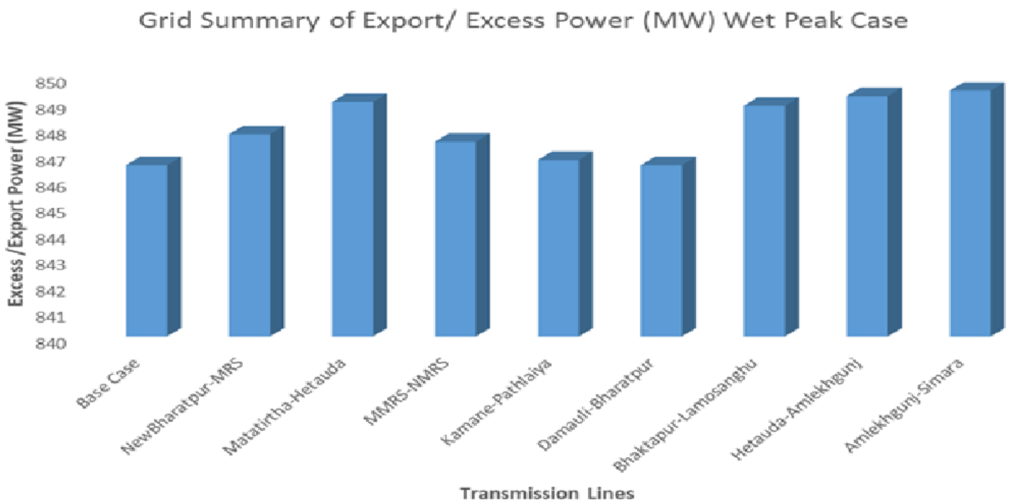

Figure 4.1: Grid Summary of Export/ Excess power (MW) for Wet Peak Case

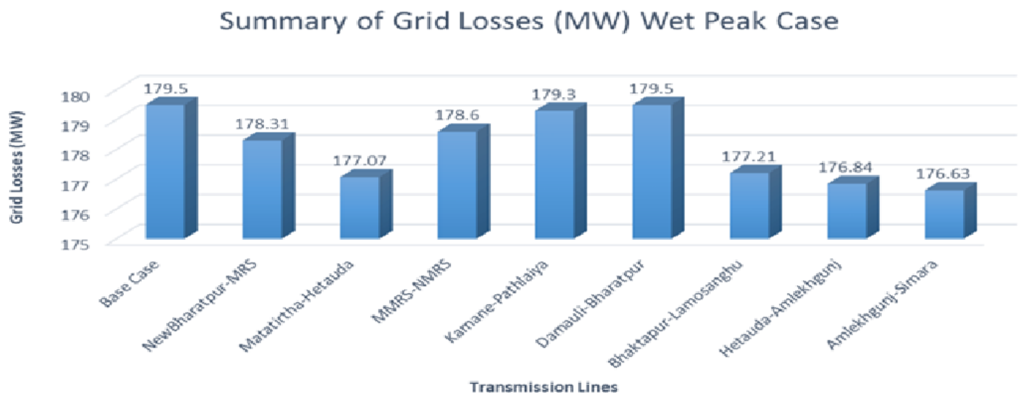

Figure 4.2: Grid System overall losses for Wet Peak Case

The Figure4.6 shown below indicates the line loading before uprating of overloaded ACSR Conductors and after upgradation of overloaded lines of INPS with equivalent HTLS conductors during Wet Peak scenario .

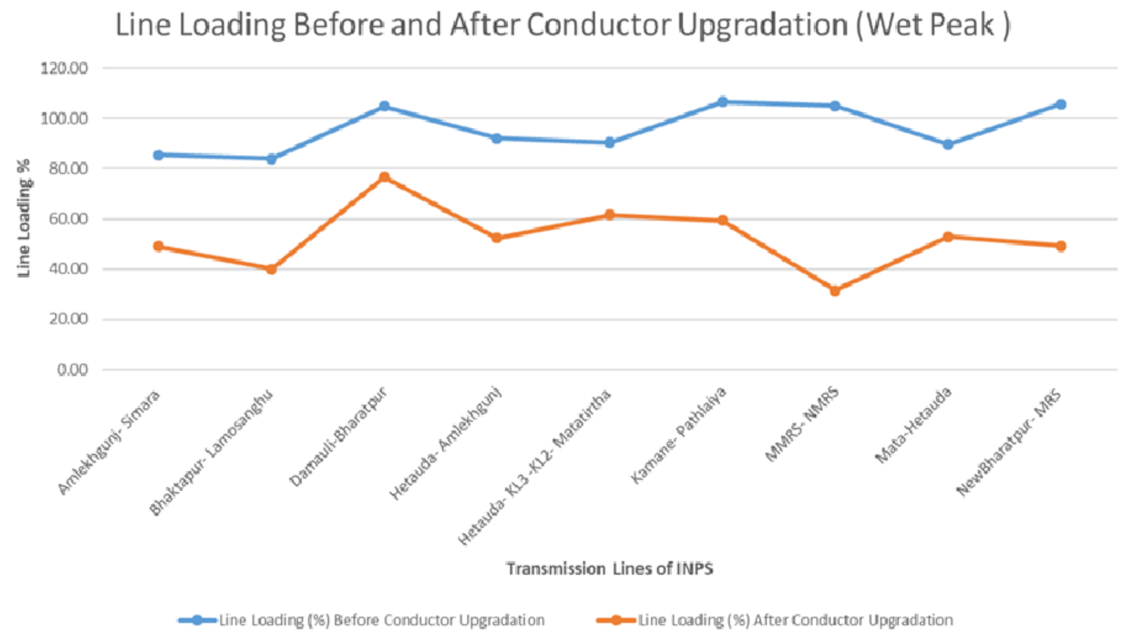

Figure 4.3: Line loading before and after conductor upgradation Wet Peak Case

The figures given below highlight the Grid Summary of Import/ Deficit power (MW) in Figure 4.4 and Grid System overall losses (MW) in Figure 4.5 during Dry Peak Case.

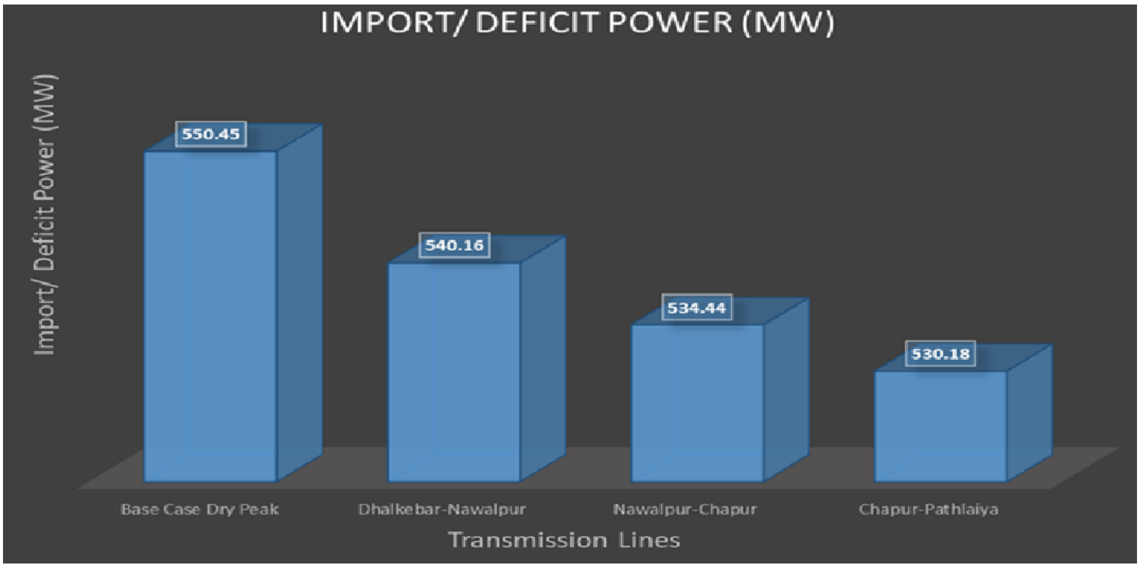

Figure 4.4: Grid Summary of Import/ Deficit power (MW) for Dry Peak Case

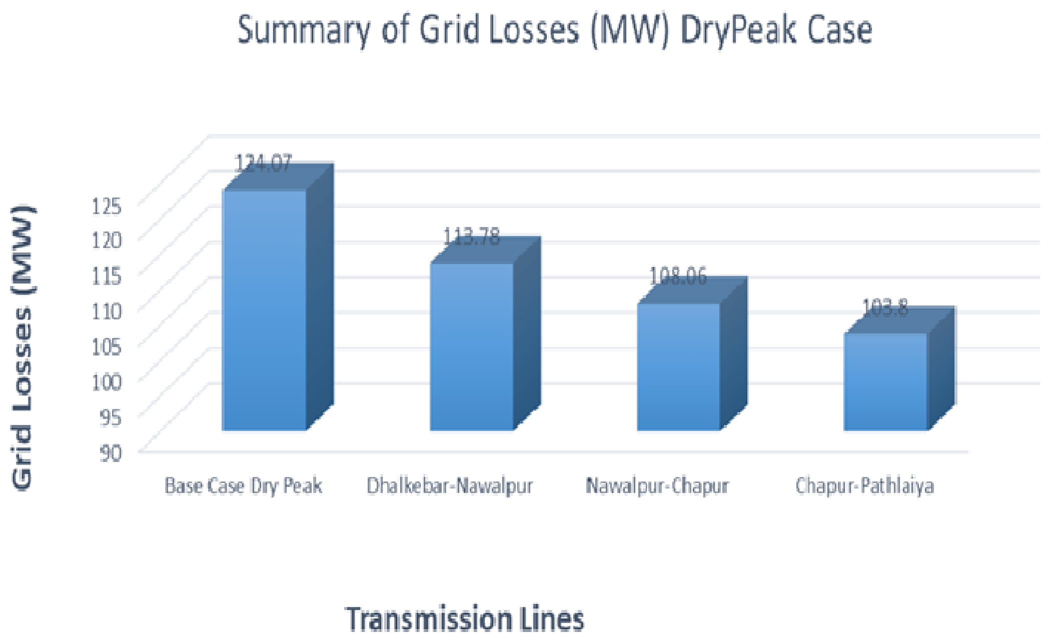

Figure 4.5: Grid System overall losses for Dry Peak Case

The Figure 4.6 shown below indicates the line loading before and after upgradation of overloaded lines of INPS with equivalent HTLS conductors during Dry Peak Case.

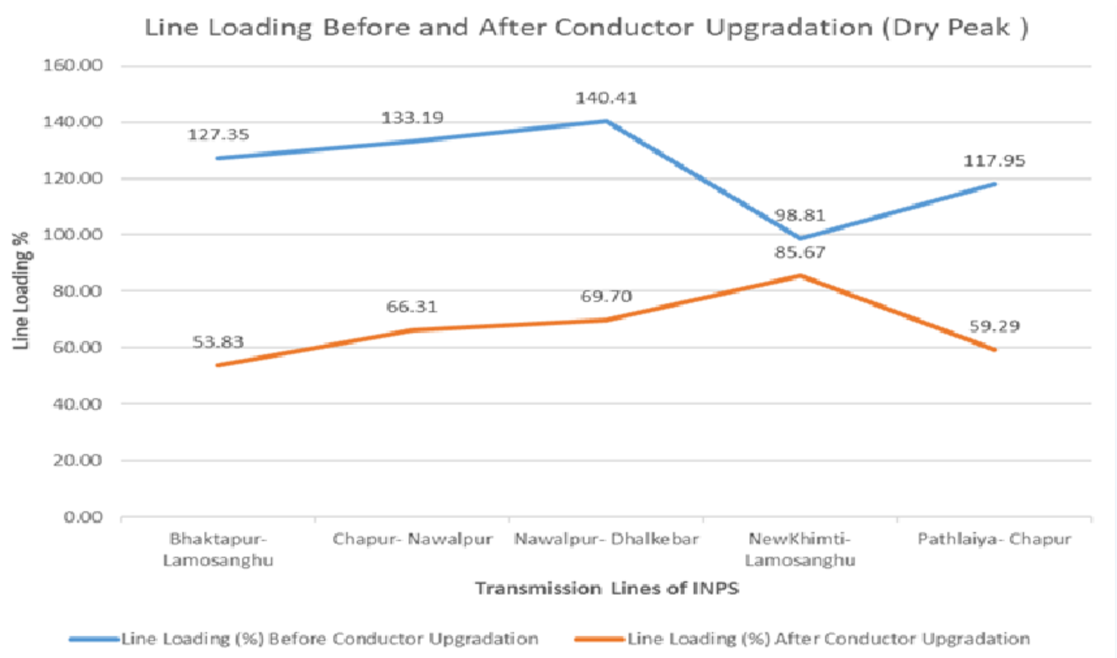

Figure 4.6: Line loading before and after conductor upgradation Dry Peak Case

4.10 Qualitative Analysis of Results

The results obtained in this thesis work after proper load flow and contingency analysis were verified with the operators of Load Dispatch Center and engineers of System Planning and Technical Department of NEA. Overloaded lines obtained in this research work were qualitatively validated. Some of the overloaded lines obtained from contingency analysis are under upgradation process by related authority which validates the obtained results.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

This study has provided a comprehensive analysis of contingency scenarios in the INPS and evaluated the need for the upgradation of overloaded transmission lines. The implementation of IEEE Standard 738 for current rating estimation has been allowed for an accurate assessment of conductor thermal limits, ensuring that the power system operates within safe parameters. The results of this study indicate that the existing transmission network, while functional, requires strategic reinforcements to accommodate the growing demand and prevent potential failures. Upgrading conductor capacities, optimizing transmission routes, and implementing modernized control strategies will be essential to mitigate the risks associated with contingencies.

Demand during the Wet Peak season is 2050.19 MW with a full generation of 3076.29 MW. It is determined that 132kV lines with a total length of 291.34 circuit km (with ACSR Bear: 187.34 circuit km, ACSR Wolf: 39 circuit km, ACSR Duck: 25 circuit km, and ACSR Cardinal: 40 circuit km) and 66kV lines with a total length of 66.14 circuit km (ACSR Wolf) are overloaded. In this instance, there is 179.50 MW of grid power loss and 846.60 MW of total surplus grid power. Following contingency analysis, the surplus/excess grid power rises to 849.47 MW and the overall grid power loss decreases to 176.63 MW when these overloaded ACSR conductors are swapped out for equivalent HTLS conductors, such as the ACCC Copenhagen conductor, which is equivalent to the ACSR Wolf; corresponding to the ACSR Bear and Duck, the ACCC Amsterdam conductor, and the ACCC Cardinal, the ACCC Vienna conductor. Additionally, it is discovered that under NEA service conditions, the suggested ACCC HTLS conductor may carry the current around 2 to 2.5 times greater than the ACSR conductor, which is an extremely remarkable result. In the safe zone, the line loading is likewise decreased at each crucial portion. During Dry Peak Case, the INPS network has lowest national generation at increasing load demand. The results of load flow analysis show that a total of 200.36 ckt. km of Bear conductor is highly overloaded. After proper load flow analysis, when these overloaded ACSR Bear conductors are upgraded with equivalent HTLS ACCC Amsterdam conductor the import power is reduced to 530.18 MW from 550.45 MW and the overall grid power loss is reduced to 103.8 MW from initial grid loss of 124.07 MW.

Overall, this research contributes valuable insights into power system planning and contingency management, reinforcing the importance of proactive upgradation strategies in maintaining a robust and resilient transmission infrastructure. HTLS Technology seems very fruitful and effective in transmission line congestion management where there are various issues like RoW issue, short period of execution time, hindrances from public and forest authority, etc. for new transmission lines being built. Nevertheless, HTLS may not be preferable for new under-construction projects, considering its higher transmission losses and higher cost compared to normal ACSR conductor.

5.1 Future Scope

The power system can be examined for two or more scenarios at once in order to apply the suggested strategy to a group of contingencies. The presence of voltage breaches has been noted in a few of the situations. By strategically deploying voltage enhancement devices across the power system, the voltage imbalance at different buses can be reduced. In the current work, there is a static load disturbance. Extending the study to dynamic load disturbances is possible. For every scenario, the power system's dependability may be ascertained.

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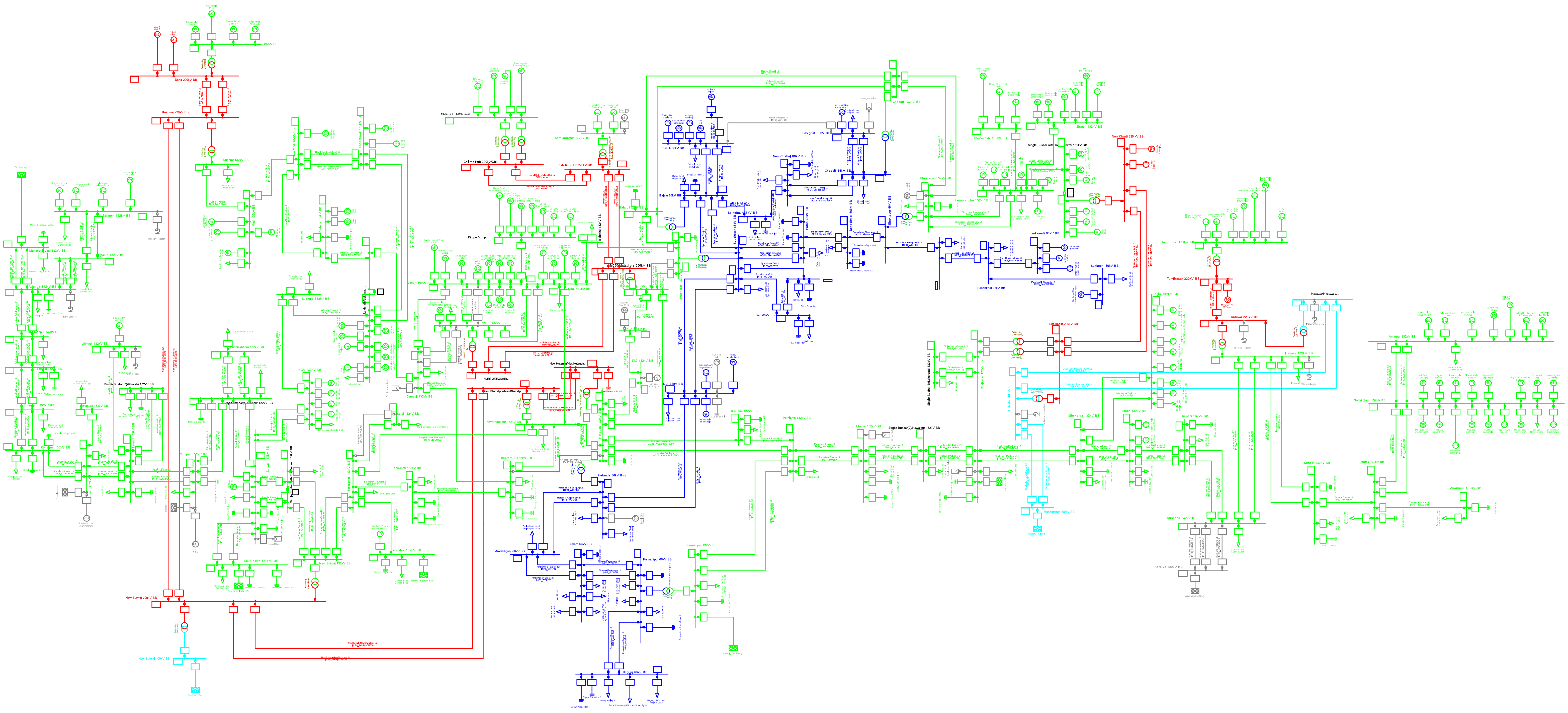
APPENDIX A: SINGLE LINE DIAGRAM (SLD) OF INPS



Dana 220kV SS
Kushma 220kV SS
New Butwal 220kV SS
Dhalkebar 220kV SS
Tumlingtar 220kV SS
Inaruwa 220kV SS
New Khimti 220kV SS
Siraha 66kV SS
Birgunj 66kV SS
Hetauda 66kV Bus

APPENDIX B: VOLTAGE PROFILE

Table B.1: Voltage Profile for Wet Season Base Case

Name	Nominal kV	Voltage (kV)	Voltage (p.u.)	V angle (°)
Amarpur 132kV BB	132	137.28	1.04	25.83
Amlekhgunj 66kV BB	66	66.035	1.001	21.58
Anarmani 132kV BB	132	131.037	0.993	16.96
Attariya 132kV BB	132	132.875	1.007	19.52
Balaju 66kV BB	66	65.844	0.998	31.55
Balaju132kV BB	132	133.801	1.014	35.26
Balanch 132kV BB	132	132	1	32.38
Banepa 66kV BB	66	65.97	1	31.63
Baneshwor 66kV BB	66	65.669	0.995	30.64
Bardaghat 132kV BB	132	137.819	1.044	33.59
Bhaktapur 132kV BB	132	133.346	1.01	36.53
Bhaktapur 66kV BB	66	66.836	1.013	32.12
Bharatpur 132kV BB	132	136.147	1.031	34.33
Bhotekoshi 132kV BB	132	140.503	1.064	45.59
Bhurigaon 132kV BB	132	134.806	1.021	16.53
Birgunj 66kV BB	66	66.863	1.013	15.91
Butwal 132kV BB	132	137.485	1.042	30.65
Chapali 132kV BB	132	133.303	1.01	35.63
Chapali 66kV BB	66	65.601	0.994	31.73
Chapur 132kV BB	132	132.349	1.003	19.98
Chilime Hub 220kV BB	220	227.999	1.036	40.9
ChilimeGrang 66kV BB	66	66	1	36.88
ChilimeHub 132kV BB	132	136.75	1.036	42.21
Damak 132kV BB	132	133.202	1.009	18.21
Damauli 132kV BB	132	137.256	1.04	40.16
Dana 132kV BB	132	140.968	1.068	41.86
Dana 220kV BB	220	234.569	1.066	41.62
Devighat 66kV BB	66	65.274	0.989	32.81
Dhalkebar 132kV BB	132	130.184	0.986	13.98
Dhalkebar 220kV BB	220	216.597	0.985	13.62

Continued on next page

Name	Nominal kV	Voltage (kV)	Voltage (p.u.)	V angle (°)
Dhalkebar 400kV BB	400	401.627	1.004	8.7
Duhabi 132kV BB	132	132.325	1.002	9.93
Gandak 132kV BB	132	138.515	1.049	33.57
Ghorahi 132kV BB	132	137.63	1.043	19.13
Godak(Ilam) 132kV BB	132	135.96	1.03	22.23
Hapure 132kV BB	132	135.964	1.03	17.26
Hetauda 132kV BB	132	134.514	1.019	29.6
Hetauda 66kV Bus	66	66.023	1	26.54
Inaruwa 132kV BB	132	132.483	1.004	10.08
Inaruwa 220kV BB	220	222.725	1.012	10.5
Inaruwa 400kV BB	400	406.107	1.015	9.81
Indrawati 66kV BB	66	67.332	1.02	33.2
Jhimruk 132kV BB	132	132	1	21.18
K-3 66kV BB	66	65.966	0.999	30.34
KGA 132kV BB	132	139.866	1.06	37.12
KL1 66kV BB	66	65.34	0.99	29
KL2 132kV BB	132	134.458	1.019	30.6
KL3 132kV BB	132	134.482	1.019	30.1
Kamane 132kV BB	132	133.064	1.008	27.28
Kataiya 132kV BB	132	0	0	0
Kawasoti 132kV BB	132	137.866	1.044	33.31
Khimti 132kV BB	132	139.129	1.054	46.17
Khimti 132kV BB(1)	132	131.574	0.997	30.65
Kirtipur 132kV BB	132	141.077	1.069	43.12
Kohalpur 132kV BB	132	135.877	1.029	15.72
Kushaha 132kV BB	132	132.694	1.005	10.44
Kushma 220kV BB	220	233.596	1.062	40.08
Kushma132kV BB	132	140.111	1.061	40.39
Kusum 132kV BB	132	136.228	1.032	17.4
Lahachowk 132kV BB	132	140.772	1.066	41.57
Lahan 132kV BB	132	133.197	1.009	12.87
Lainchaur 66kV BB	66	65.46	0.992	31.27
Lamahi 132kV BB	132	137.064	1.038	19.46
Lamaki 132kV BB	132	134.264	1.017	17.23

Continued on next page

Name	Nominal kV	Voltage (kV)	Voltage (p.u.)	V angle (°)
Lamosanghu 132kV BB	132	137.17	1.039	43.76
Lekhnath 132kV BB	132	140.496	1.064	41.67
Loharpatti 132kV BB	132	129.86	0.984	13.77
MMRS 132kV BB	132	139.87	1.06	40.38
MRS 132kV BB	132	136.578	1.035	39.47
Mahendranagar 132kV BB	132	133.037	1.008	17.65
Mainihawa 132kV BB	132	137.241	1.04	30.11
Malekhu 132kV BB	132	135.551	1.027	38.23
Matatirtha 132kV BB	132	134.7	1.02	35.57
Matatirtha 220kV BB	220	224.82	1.022	37.57
Mirchaiya 132kV BB	132	132.386	1.003	14.54
Modi 132kV BB	132	140.523	1.065	41.1
Motipur 132kV BB	132	137.005	1.038	26.17
Muzzafapur 400kV BB	400	400	1	0
NMRS 132kV BB	132	136.276	1.032	39.92
NMRS 220kV BB	220	226.572	1.03	39.09
Nawalpur 132kV BB	132	130.905	0.992	16.71
New Butwal 132kV BB	132	137.996	1.045	33.74
New Butwal 220kV BB	220	229.723	1.044	34.99
New Butwal 400kV BB	400	417.678	1.044	34.99
New Chabel 66kV BB	66	65.386	0.991	31.36
New Khimti 220 kV BB	220	220	1	26.05
New Modi 132kV BB	132	140.529	1.065	41.13
NewBharatpur 132kV BB	132	136.142	1.031	34.32
NewBharatpur 220kV BB	220	227.535	1.034	33.73
NewHetauda 220kV BB	220	224.945	1.022	30.63
Pahalmanpur 132kV BB	132	133.494	1.011	18.15
Panchkhal 66kV BB	66	66.196	1.003	31.86
Parwanipur 132kV BB	132	132.79	1.006	21.62
Parwanipur 66kV BB	66	67.442	1.022	17.88
Patan 66kV BB	66	65.631	0.994	30.66
Pathlaiya 132kV BB	132	132.568	1.004	23.62
Pokhara 132kV BB	132	140.15	1.062	41.35
Rupani 132kV BB	132	133.36	1.01	11.55

Continued on next page

Name	Nominal kV	Voltage (kV)	Voltage (p.u.)	V angle (°)
Samundartar 132kV BB	132	137.294	1.04	41.49
Sandhikharka 132kV BB	132	136.811	1.036	26.02
Sardi 132kV BB	132	137.087	1.039	33.3
Shivpur 132kV BB	132	136.582	1.035	23.78
Simara 66kV BB	66	66.442	1.007	18.67
Singati 132kV BB	132	139.742	1.059	48.1
Sunkoshi 66kV BB	66	67.212	1.018	32.39
Sunwal 132kV BB	132	137.239	1.04	31.71
Syangja 132kV BB	132	139.843	1.059	39.49
Syaule 132kV BB	132	131.69	0.998	25.26
Syuchatar 132kV BB	132	134.101	1.016	35.24
Syuchatar 66kV BB	66	66.163	1.002	31.23
Teku 66kV BB	66	65.996	1	30.45
Tingla 132kV BB	132	135.85	1.029	23.81
Trishuli 66kV BB	66	66	1	35.81
Trishuli3B Hub 220kV BB	220	227.974	1.036	40.84
Tumlingtar 132kV BB	132	135.686	1.028	17.86
Tumlingtar 220kV BB	220	227.095	1.032	16.73

Table B.2: Voltage Profile for Wet Season after Conductor Upgradation

Name	Nominal kV	Voltage (kV)	Voltage (p.u.)	V angle (°)
Amarpur 132kV BB	132	137.28	1.04	25.87
Amlekhgunj 66kV BB	66	66.272	1.004	21.7
Anarmani 132kV BB	132	131.043	0.993	17
Attariya 132kV BB	132	132.904	1.007	18.83
Balaju 66kV BB	66	66.28	1.004	29
Balaju132kV BB	132	135.115	1.024	32.55
Balanch 132kV BB	132	132	1	31.69
Banepa 66kV BB	66	66.575	1.009	28.99
Baneshwor 66kV BB	66	66.211	1.003	28.07
Bardaghat 132kV BB	132	137.952	1.045	32.93
Bhaktapur 132kV BB	132	134.867	1.022	33.82
Bhaktapur 66kV BB	66	67.431	1.022	29.48

Continued on next page

Name	Nominal kV	Voltage (kV)	Voltage (p.u.)	V angle (°)
Bharatpur 132kV BB	132	136.21	1.032	33.84
Bhotekoshi 132kV BB	132	141.133	1.069	39.48
Bhurigaon 132kV BB	132	134.853	1.022	15.84
Birgunj 66kV BB	66	66.891	1.013	16.54
Butwal 132kV BB	132	137.61	1.042	29.93
Chapali 132kV BB	132	134.683	1.02	32.93
Chapali 66kV BB	66	66.013	1	29.16
Chapur 132kV BB	132	132.749	1.006	20.14
Chilime Hub 220kV BB	220	230.293	1.047	37.98
ChilimeGrang 66kV BB	66	66	1	34.54
ChilimeHub 132kV BB	132	138.128	1.046	39.26
Damak 132kV BB	132	133.208	1.009	18.25
Damauli 132kV BB	132	136.413	1.033	38.6
Dana 132kV BB	132	141.053	1.069	41.03
Dana 220kV BB	220	234.711	1.067	40.79
Devighat 66kV BB	66	65.274	0.989	30.47
Dhalkebar 132kV BB	132	130.251	0.987	14.04
Dhalkebar 220kV BB	220	216.659	0.985	13.67
Dhalkebar 400kV BB	400	401.69	1.004	8.73
Duhabi 132kV BB	132	132.35	1.003	9.97
Gandak 132kV BB	132	138.648	1.05	32.91
Ghorahi 132kV BB	132	137.697	1.043	18.43
Godak(Ilam) 132kV BB	132	135.96	1.03	22.27
Hapure 132kV BB	132	136.026	1.031	16.57
Hetauda 132kV BB	132	135.12	1.024	28.78
Hetauda 66kV Bus	66	66.416	1.006	25.14
Inaruwa 132kV BB	132	132.509	1.004	10.12
Inaruwa 220kV BB	220	222.765	1.013	10.53
Inaruwa 400kV BB	400	406.177	1.015	9.84
Indrawati 66kV BB	66	67.927	1.029	30.53
Jhimruk 132kV BB	132	132	1	20.5
K-3 66kV BB	66	66.45	1.007	27.82
KGA 132kV BB	132	139.961	1.06	36.32
KL1 66kV BB	66	65.34	0.99	27.43

Continued on next page

Name	Nominal kV	Voltage (kV)	Voltage (p.u.)	V angle (°)
KL2 132kV BB	132	135.232	1.024	29.46
KL3 132kV BB	132	135.174	1.024	29.12
Kamane 132kV BB	132	133.694	1.013	26.14
Kataiya 132kV BB	132	0	0	0
Kawasoti 132kV BB	132	137.966	1.045	32.73
Khimti 132kV BB	132	139.765	1.059	40.05
Khimti 132kV BB(1)	132	131.574	0.997	30.69
Kirtipur 132kV BB	132	142.212	1.077	42.45
Kohalpur 132kV BB	132	135.935	1.03	15.02
Kushaha 132kV BB	132	132.724	1.005	10.48
Kushma 220kV BB	220	233.738	1.062	39.25
Kushma132kV BB	132	140.19	1.062	39.53
Kusum 132kV BB	132	136.291	1.033	16.71
Lahachowk 132kV BB	132	140.749	1.066	40.62
Lahan 132kV BB	132	133.246	1.009	12.92
Lainchaur 66kV BB	66	65.893	0.998	28.71
Lamahi 132kV BB	132	137.13	1.039	18.76
Lamaki 132kV BB	132	134.306	1.017	16.54
Lamosanghu 132kV BB	132	137.814	1.044	37.67
Lekhnath 132kV BB	132	140.384	1.064	40.62
Loharpatti 132kV BB	132	129.927	0.984	13.84
MMRS 132kV BB	132	141.011	1.068	39.75
MRS 132kV BB	132	138.113	1.046	36.25
Mahendranagar 132kV BB	132	133.067	1.008	16.95
Mainihawa 132kV BB	132	137.367	1.041	29.39
Malekhu 132kV BB	132	137.049	1.038	35.13
Matatirtha 132kV BB	132	135.992	1.03	32.82
Matatirtha 220kV BB	220	227.126	1.032	34.72
Mirchaiya 132kV BB	132	132.444	1.003	14.59
Modi 132kV BB	132	140.552	1.065	40.2
Motipur 132kV BB	132	137.113	1.039	25.46
Muzzafapur 400kV BB	400	400	1	0
NMRS 132kV BB	132	137.971	1.045	36.62
NMRS 220kV BB	220	229.181	1.042	35.94

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Name	Nominal kV	Voltage (kV)	Voltage (p.u.)	V angle (°)
Nawalpur 132kV BB	132	131.136	0.993	16.82
New Butwal 132kV BB	132	138.134	1.046	33.06
New Butwal 220kV BB	220	229.982	1.045	34.3
New Butwal 400kV BB	400	418.15	1.045	34.3
New Chabel 66kV BB	66	65.813	0.997	28.8
New Khimti 220 kV BB	220	220	1	26.09
New Modi 132kV BB	132	140.555	1.065	40.22
NewBharatpur 132kV BB	132	136.256	1.032	33.8
NewBharatpur 220kV BB	220	227.893	1.036	33.13
NewHetauda 220kV BB	220	225.753	1.026	29.86
Pahalmanpur 132kV BB	132	133.53	1.012	17.46
Panchkhal 66kV BB	66	66.799	1.012	29.22
Parwanipur 132kV BB	132	133.283	1.01	21.94
Parwanipur 66kV BB	66	67.468	1.022	18.52
Patan 66kV BB	66	66.145	1.002	28.11
Pathlaiya 132kV BB	132	133.12	1.008	23.8
Pokhara 132kV BB	132	140.075	1.061	40.32
Rupani 132kV BB	132	133.402	1.011	11.6
Samundartar 132kV BB	132	138.666	1.05	38.56
Sandhikharka 132kV BB	132	136.92	1.037	25.31
Sardi 132kV BB	132	137.221	1.04	32.64
Shivpur 132kV BB	132	136.678	1.035	23.07
Simara 66kV BB	66	66.414	1.006	19.63
Singati 132kV BB	132	140.379	1.063	41.97
Sunkoshi 66kV BB	66	67.808	1.027	29.74
Sunwal 132kV BB	132	137.368	1.041	31
Syangja 132kV BB	132	139.83	1.059	38.54
Syaule 132kV BB	132	131.706	0.998	24.57
Syuchatar 132kV BB	132	135.394	1.026	32.52
Syuchatar 66kV BB	66	66.636	1.01	28.7
Teku 66kV BB	66	66.478	1.007	27.93
Tingla 132kV BB	132	135.908	1.03	23.85
Trishuli 66kV BB	66	66	1	33.47
Trishuli3B Hub 220kV BB	220	230.269	1.047	37.92

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Name	Nominal kV	Voltage (kV)	Voltage (p.u.)	V angle (°)
Tumlingtar 132kV BB	132	135.709	1.028	17.89
Tumlingtar 220kV BB	220	227.134	1.032	16.76

Table B.3: Voltage Profile for Dry Season Base Case

Name	Nominal kV	Voltage (kV)	Voltage (p.u.)	V angle (°)
Amarpur 132kV BB	132	137.28	1.04	-5.08
Amlekhgunj 66kV BB	66	67.625	1.025	-34.96
Anarmani 132kV BB	132	133.209	1.009	-9.58
Attariya 132kV BB	132	134.048	1.016	-44.61
Balaju 66kV BB	66	65.207	0.988	-31.91
Balaju132kV BB	132	131.712	0.998	-28.28
Balanch 132kV BB	132	132	1	-38.29
Banepa 66kV BB	66	63.864	0.968	-31.68
Baneshwor 66kV BB	66	64.658	0.98	-32.36
Bardaghat 132kV BB	132	137.508	1.042	-33.81
Bhaktapur 132kV BB	132	129.208	0.979	-25.73
Bhaktapur 66kV BB	66	65.376	0.991	-30.66
Bharatpur 132kV BB	132	136.798	1.036	-31.29
Bhotekoshi 132kV BB	132	131.028	0.993	-13.81
Bhurigaon 132kV BB	132	135.064	1.023	-48.51
Birgunj 66kV BB	66	69.333	1.05	-37.92
Butwal 132kV BB	132	136.75	1.036	-37.91
Chapali 132kV BB	132	130.342	0.987	-27.38
Chapali 66kV BB	66	65.004	0.985	-31.68
Chapur 132kV BB	132	134.909	1.022	-23.84
Chilime Hub 220kV BB	220	224.956	1.023	-25.97
ChilimeGrang 66kV BB	66	66	1	-29.96
ChilimeHub 132kV BB	132	134.958	1.022	-25.29
Damak 132kV BB	132	135.173	1.024	-8.44
Damauli 132kV BB	132	135.903	1.03	-28.28
Dana 132kV BB	132	139.046	1.053	-29.33
Dana 220kV BB	220	231.551	1.053	-29.45
Devighat 66kV BB	66	65.274	0.989	-31.72

Continued on next page

Name	Nominal kV	Voltage (kV)	Voltage (p.u.)	V angle (°)
Dhalkebar 132kV BB	132	135.244	1.025	-8.46
Dhalkebar 220kV BB	220	223.912	1.018	-6.01
Dhalkebar 400kV BB	400	408.372	1.021	-4.17
Duhabi 132kV BB	132	137.545	1.042	-9.97
Gandak 132kV BB	132	137.928	1.045	-33.92
Ghorahi 132kV BB	132	135.161	1.024	-47.58
Godak(Ilam) 132kV BB	132	135.96	1.03	-6.61
Hapure 132kV BB	132	135.023	1.023	-48.94
Hetauda 132kV BB	132	135.442	1.026	-30.38
Hetauda 66kV Bus	66	66.532	1.008	-32.39
Inaruwa 132kV BB	132	137.591	1.042	-9.24
Inaruwa 220kV BB	220	227.969	1.036	-5.93
Inaruwa 400kV BB	400	413.854	1.035	-5.33
Indrawati 66kV BB	66	64.371	0.975	-31.04
Jhimruk 132kV BB	132	132	1	-46.58
K-3 66kV BB	66	65.224	0.988	-32.81
KGA 132kV BB	132	137.821	1.044	-34.15
KL1 66kV BB	66	65.34	0.99	-30.7
KL2 132kV BB	132	135.265	1.025	-29.95
KL3 132kV BB	132	135.362	1.025	-30.15
Kamane 132kV BB	132	135.119	1.024	-30.28
Kataiya 132kV BB	132	0	0	0
Kawasoti 132kV BB	132	138.054	1.046	-33.21
Khimti 132kV BB	132	132.993	1.008	-6.16
Khimti 132kV BB(1)	132	132.993	1.008	-6.16
Kirtipur 132kV BB	132	138.294	1.048	-26.44
Kohalpur 132kV BB	132	135.615	1.027	-49.89
Kushaha 132kV BB	132	137.851	1.044	-9.35
Kushma 220kV BB	220	231.034	1.05	-30.24
Kushma132kV BB	132	138.511	1.049	-30.12
Kusum 132kV BB	132	135.272	1.025	-48.8
Lahachowk 132kV BB	132	138.417	1.049	-29.6
Lahan 132kV BB	132	138.379	1.048	-9.2
Lainchaur 66kV BB	66	64.848	0.983	-32.15

Continued on next page

Name	Nominal kV	Voltage (kV)	Voltage (p.u.)	V angle (°)
Lamahi 132kV BB	132	135.307	1.025	-47.33
Lamaki 132kV BB	132	134.848	1.022	-47.47
Lamosanghu 132kV BB	132	129.206	0.979	-14.84
Lekhnath 132kV BB	132	137.798	1.044	-29.61
Loharpatti 132kV BB	132	134.956	1.022	-8.64
MMRS 132kV BB	132	137.627	1.043	-27.86
MRS 132kV BB	132	136.218	1.032	-28.12
Mahendranagar 132kV BB	132	134.012	1.015	-43.55
Mainihawa 132kV BB	132	136.566	1.035	-38.42
Malekhu 132kV BB	132	134.954	1.022	-28.47
Matatirtha 132kV BB	132	133.198	1.009	-28.44
Matatirtha 220kV BB	220	223.026	1.014	-27.65
Mirchaiya 132kV BB	132	137.382	1.041	-8.5
Modi 132kV BB	132	138.484	1.049	-29.81
Motipur 132kV BB	132	136.158	1.032	-41.75
Muzzafapur 400kV BB	400	400	1	0
NMRS 132kV BB	132	136.068	1.031	-27.87
NMRS 220kV BB	220	225.457	1.025	-27.83
Nawalpur 132kV BB	132	132.917	1.007	-16.37
New Butwal 132kV BB	132	137.619	1.043	-33.89
New Butwal 220kV BB	220	229.182	1.042	-32.59
New Butwal 400kV BB	400	416.695	1.042	-32.59
New Chabel 66kV BB	66	64.794	0.982	-32.06
New Khimti 220 kV BB	220	220	1	-3.39
New Modi 132kV BB	132	138.477	1.049	-29.8
NewBharatpur 132kV BB	132	136.796	1.036	-31.26
NewBharatpur 220kV BB	220	228.385	1.038	-31.39
NewHetauda 220kV BB	220	227.172	1.033	-30.61
Pahalmanpur 132kV BB	132	134.342	1.018	-46.28
Panchkhal 66kV BB	66	63.758	0.966	-31.76
Parwanipur 132kV BB	132	135.878	1.029	-31.82
Parwanipur 66kV BB	66	69.686	1.056	-36.13
Patan 66kV BB	66	64.746	0.981	-32.41
Pathlaiya 132kV BB	132	135.268	1.025	-29.54

Continued on next page

Name	Nominal kV	Voltage (kV)	Voltage (p.u.)	V angle (°)
Pokhara 132kV BB	132	137.594	1.042	-29.88
Rupani 132kV BB	132	138.595	1.05	-9.5
Samundartar 132kV BB	132	135.226	1.024	-25.66
Sandhikharka 132kV BB	132	135.981	1.03	-41.89
Sardi 132kV BB	132	136.822	1.037	-34.09
Shivpur 132kV BB	132	135.545	1.027	-43.77
Simara 66kV BB	66	68.528	1.038	-36.34
Singati 132kV BB	132	130.723	0.99	-12.39
Sunkoshi 66kV BB	66	64.068	0.971	-31.67
Sunwal 132kV BB	132	136.637	1.035	-36.47
Syangja 132kV BB	132	137.443	1.041	-31.79
Syaule 132kV BB	132	132.971	1.007	-41.88
Syuchatar 132kV BB	132	132.359	1.003	-28.57
Syuchatar 66kV BB	66	65.383	0.991	-31.95
Teku 66kV BB	66	65.248	0.989	-32.7
Tingla 132kV BB	132	139.502	1.057	-4.27
Trishuli 66kV BB	66	66	1	-30.5
Trishuli3B Hub 220kV BB	220	224.943	1.022	-25.99
Tumlingtar 132kV BB	132	138.033	1.046	-2.4
Tumlingtar 220kV BB	220	230.513	1.048	-2.94

Table B.4: Voltage Profile for Dry Season after Conductor Upgradation

Name	Nominal kV	Voltage (kV)	Voltage (p.u.)	V angle (°)
Amarpur 132kV BB	132	137.28	1.04	-7.23
Amlekhgunj 66kV BB	66	67.206	1.018	-30.13
Anarmani 132kV BB	132	133.293	1.01	-11.46
Attariya 132kV BB	132	133.875	1.014	-42.5
Balaju 66kV BB	66	65.13	0.987	-28.01
Balaju132kV BB	132	131.427	0.996	-24.37
Balanch 132kV BB	132	132	1	-36.59
Banepa 66kV BB	66	63.747	0.966	-27.91
Baneshwor 66kV BB	66	64.574	0.978	-28.48
Bardaghat 132kV BB	132	136.211	1.032	-30.05

Continued on next page

Name	Nominal kV	Voltage (kV)	Voltage (p.u.)	V angle (°)
Bhaktapur 132kV BB	132	129.419	0.98	-21.96
Bhaktapur 66kV BB	66	65.31	0.99	-26.86
Bharatpur 132kV BB	132	135.696	1.028	-27.29
Bhotekoshi 132kV BB	132	132.169	1.001	-15.3
Bhurigaon 132kV BB	132	134.658	1.02	-46.11
Birgunj 66kV BB	66	68.746	1.042	-32.77
Butwal 132kV BB	132	135.353	1.025	-34.44
Chapali 132kV BB	132	130.284	0.987	-23.53
Chapali 66kV BB	66	64.941	0.984	-27.82
Chapur 132kV BB	132	134.317	1.018	-20.2
Chilime Hub 220kV BB	220	223.941	1.018	-22.13
ChilimeGrang 66kV BB	66	66	1	-26.3
ChilimeHub 132kV BB	132	134.35	1.018	-21.49
Damak 132kV BB	132	135.256	1.025	-10.32
Damauli 132kV BB	132	134.875	1.022	-24.47
Dana 132kV BB	132	137.663	1.043	-25.7
Dana 220kV BB	220	229.256	1.042	-25.82
Devighat 66kV BB	66	65.274	0.989	-27.94
Dhalkebar 132kV BB	132	136.033	1.031	-10.21
Dhalkebar 220kV BB	220	224.498	1.02	-7.43
Dhalkebar 400kV BB	400	408.458	1.021	-5.12
Duhabi 132kV BB	132	137.821	1.044	-11.44
Gandak 132kV BB	132	136.608	1.035	-30.17
Ghorahi 132kV BB	132	134.417	1.018	-44.71
Godak(Ilam) 132kV BB	132	135.96	1.03	-8.62
Hapure 132kV BB	132	134.357	1.018	-46.23
Hetauda 132kV BB	132	134.374	1.018	-25.82
Hetauda 66kV Bus	66	66.23	1.003	-27.86
Inaruwa 132kV BB	132	137.874	1.044	-10.66
Inaruwa 220kV BB	220	228.118	1.037	-7.14
Inaruwa 400kV BB	400	413.985	1.035	-6.44
Indrawati 66kV BB	66	64.197	0.973	-27.33
Jhimruk 132kV BB	132	132	1	-43.94
K-3 66kV BB	66	65.127	0.987	-28.88

Continued on next page

Name	Nominal kV	Voltage (kV)	Voltage (p.u.)	V angle (°)
KGA 132kV BB	132	136.351	1.033	-30.75
KL1 66kV BB	66	65.34	0.99	-26.54
KL2 132kV BB	132	134.285	1.017	-25.49
KL3 132kV BB	132	134.337	1.018	-25.64
Kamane 132kV BB	132	134.012	1.015	-25.4
Kataiya 132kV BB	132	0	0	0
Kawasoti 132kV BB	132	136.821	1.037	-29.33
Khimti 132kV BB	132	133.459	1.011	-7.84
Kirtipur 132kV BB	132	137.235	1.04	-22.7
Kohalpur 132kV BB	132	135.053	1.023	-47.33
Kushaha 132kV BB	132	138.182	1.047	-10.82
Kushma 220kV BB	220	228.764	1.04	-26.58
Kushma132kV BB	132	137.15	1.039	-26.47
Kusum 132kV BB	132	134.607	1.02	-46.09
Lahachowk 132kV BB	132	137.033	1.038	-25.99
Lahan 132kV BB	132	138.935	1.053	-10.87
Lainchaur 66kV BB	66	64.783	0.982	-28.27
Lamahi 132kV BB	132	134.564	1.019	-44.46
Lamaki 132kV BB	132	134.53	1.019	-45.17
Lamosanghu 132kV BB	132	130.466	0.988	-16.25
Lekhnath 132kV BB	132	136.418	1.033	-26.01
Loharpatti 132kV BB	132	135.747	1.028	-10.39
MMRS 132kV BB	132	136.6	1.035	-24.06
MRS 132kV BB	132	135.319	1.025	-24.29
Mahendranagar 132kV BB	132	133.835	1.014	-41.44
Mainihawa 132kV BB	132	135.149	1.024	-34.96
Malekhu 132kV BB	132	134.172	1.016	-24.61
Matatirtha 132kV BB	132	132.688	1.005	-24.45
Matatirtha 220kV BB	220	222.094	1.01	-23.72
Mirchaiya 132kV BB	132	138.028	1.046	-10.25
Modi 132kV BB	132	137.107	1.039	-26.18
Motipur 132kV BB	132	134.909	1.022	-38.5
Muzzafapur 400kV BB	400	400	1	0
NMRS 132kV BB	132	135.187	1.024	-24.06

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Name	Nominal kV	Voltage (kV)	Voltage (p.u.)	V angle (°)
NMRS 220kV BB	220	224.159	1.019	-23.97
Nawalpur 132kV BB	132	134.385	1.018	-15.29
New Butwal 132kV BB	132	136.313	1.033	-30.15
New Butwal 220kV BB	220	227.02	1.032	-28.79
New Butwal 400kV BB	400	412.763	1.032	-28.79
New Chabel 66kV BB	66	64.725	0.981	-28.18
New Khimti 220 kV BB	220	220	1	-5.07
New Modi 132kV BB	132	137.099	1.039	-26.17
NewBharatpur 132kV BB	132	135.694	1.028	-27.25
NewBharatpur 220kV BB	220	226.47	1.029	-27.34
NewHetauda 220kV BB	220	225.418	1.025	-26.17
Pahalmanpur 132kV BB	132	134.094	1.016	-44.07
Panchkhal 66kV BB	66	63.618	0.964	-28.02
Parwanipur 132kV BB	132	134.612	1.02	-26.45
Parwanipur 66kV BB	66	69.125	1.047	-30.95
Patan 66kV BB	66	64.656	0.98	-28.51
Pathlaiya 132kV BB	132	134.027	1.015	-24.08
Pokhara 132kV BB	132	136.209	1.032	-26.28
Rupani 132kV BB	132	139.055	1.053	-11.08
Samundartar 132kV BB	132	134.603	1.02	-21.84
Sandhikharka 132kV BB	132	134.728	1.021	-38.65
Sardi 132kV BB	132	135.517	1.027	-30.33
Shivpur 132kV BB	132	134.427	1.018	-40.65
Simara 66kV BB	66	68.02	1.031	-31.32
Singati 132kV BB	132	131.898	0.999	-13.99
Sunkoshi 66kV BB	66	63.881	0.968	-27.96
Sunwal 132kV BB	132	135.261	1.025	-32.91
Syangja 132kV BB	132	136.011	1.03	-28.28
Syaule 132kV BB	132	132.903	1.007	-39.95
Syuchatar 132kV BB	132	131.963	1	-24.62
Syuchatar 66kV BB	66	65.289	0.989	-28.02
Teku 66kV BB	66	65.152	0.987	-28.77
Tingla 132kV BB	132	140.036	1.061	-6.32
Trishuli 66kV BB	66	66	1	-26.8

Continued on next page

Name	Nominal kV	Voltage (kV)	Voltage (p.u.)	V angle (°)
Trishuli3B Hub 220kV BB	220	223.928	1.018	-22.15
Tumlingtar 132kV BB	132	138.06	1.046	-3.81
Tumlingtar 220kV BB	220	230.529	1.048	-4.33

APPENDIX C: PUBLICATION

Conference paper

Notifications

[IOEGC16] Editor Decision

2025-04-06 01:48 AM

Sujeet Mahato, Nava Raj Karki, Basanta Kumar Gautam:

We are pleased to inform you that your manuscript titled "Contingencies Based Strategy for Transmission System Upgradation" submitted to 16th IOE Graduate Conference is **Accepted** for presentation in the Conference as well as inclusion in the Peer-Reviewed Proceedings. Please note that inclusion in hard copy proceedings is contingent upon your timely response to further edits, if any, during the publication process.

With Warm Regards,
IOEGC-16 Editorial Team

Paper Acceptance Notification of IOE GC

IOE GC[16] Certificate of Participation

Contingencies Based Strategy for Transmission System Upgradation

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Abstract
A stable and dependable power system is crucial for ensuring uninterrupted electricity supply. The growing demand for electrical energy has led to power systems operating beyond their design limits, resulting in various transmission constraints. A secure power system is one that can withstand unexpected disruptions without significant consequences. Contingency analysis helps assess the impact of transmission line outages on system performance and the effects of transmission line failures on the power grid. This paper presents a contingency analysis of Integrated Nepal Power System network, evaluating its resilience under different outages scenarios. Load flow analysis is a fundamental aspect of power system planning, operation, and expansion. This study employs the Newton-Raphson method using DIgSILENT Power Factory simulation software to compute performance Index-Active Power Performance Index (PIP) for single transmission line outages. The results identify critical lines in the INPS network, suggesting necessary upgradation of existing transmission lines or the installation of compensatory devices. The results highlight system vulnerabilities and suggest measures to enhance overall grid reliability.

Keywords
Contingency, INPS, Newton-Raphson, Performance Index

1. Introduction

1.1 Background

The reliable operation of a power transmission system is crucial for ensuring an uninterrupted supply of electricity. With the increasing demand for electrical power, transmission networks often experience overloading, which can lead to contingencies such as line failures and system instability. The Integrated Nepal Power System (INPS) is facing significant challenges due to overloaded transmission lines, necessitating a strategic approach for system upgradation. Identifying and mitigating these issues is critical for improving system resilience and ensuring the overall Power System performances[1]. Analysis of different techniques to increase power transfer capacity in which the usage of High Temperature Low Sag (HTLS) conductor was tested in IEEE 9 bus system finds that the usage of HTLS conductor has eliminated congestion by 41%[2]. The 220 kV transmission system capacities in Egyptian Power Network increased by 58%-78% after uprating by conventional conductor by HTLS conductor[3].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. Some of the major overloaded lines of INPS have already been successfully uprated with equivalent HTLS conductor and many transmission lines upgradation projects in NEA are ongoing[4].

1.2 Problem Statement

Several transmission lines in the INPS network are operating beyond their rated capacities, leading to increased thermal stress and potential failures. A new overhead transmission line is a long-term and expensive investment plan and a common issue in delaying the transmission lines project are Right of Ways (RoW), escalation of real-estate cost and Time constraints. However, increasing the transmission capacities of existing lines is an unavoidable necessity. It is assumed that capacity of existing overloaded lines could be increased by replacing the aged ACSR conductor by equivalent HTLS conductors with a small investment and less time period to meet the increasing electricity demand. In the event of a line outage, adjacent transmission lines carry the additional load, which can lead to cascading failures. This study aims to identify critical transmission lines, analyze their contingency impact, and prioritize them for upgrades based on an Active Power Performance Index (PI) ranking.

1.3 Objective

The primary objectives of this study are:

- To analyze the current load flow conditions of the INPS and to identify overloaded transmission lines and simulate potential failures to assess their impact on the power network by performing contingency analysis.
- To rank the overloaded transmission lines based on their severity of overloading and contingency effects using Active Power PI scores and propose strategic transmission system upgrades based on priority order for enhancing overall grid performance.

1.4 Scope of the Study

This research focuses on the transmission lines of voltage level 66 kV and above within the INPS network, particularly those that exhibit high loading conditions. The study employs IEEE

Standard 738 for evaluating conductor current ratings and utilizes DigSILENT PowerFactory for load flow and contingency analysis inorder to rank and upgrade the overloaded lines of INPS. The contingency analysis of 33kV and lower voltage level distribution lines are not under scope since only overloaded transmission lines are being studied for uprating. New distribution lines can be completed in a timely manner at reasonable cost as compared to high voltage lines.

1.5 Significance of the Study

By identifying the most critical transmission lines for upgradation, this study provides a data-driven approach to strengthening Nepal's power infrastructure. The findings help policymakers, engineers, and utility operators make informed decisions to enhance the System performance of INPS. Upgrading prioritized transmission lines will reduce system losses, improve voltage stability, and ensure a more resilient power system network. Also prioritized overloaded line upgradtion helps utility and system operators to meet increasing load demands and economic dispatch from generators.

2. Methodology

The overall methodology adopted in this research is shown in Figure 1.

2.1 Data Collection

The data for INPS was obtained from various publications of NEA such as Generation Directorate[5], Transmission Directorate[4], and Load Dispatch Center (LDC) of NEA.

2.2 Modelling of INPS

Modelling of INPS was done in DigSILENT Powerfactory as shown in Figure 2. The said software was also used for load flow analysis for base case and all contingencies. The INPS Network model consists of total 117 Nos. Busbars which icludes 3 Nos. 400 kV , 13 Nos. 200 kV, 78 Nos. 132 kV and 23 Nos. 66 kV Busses for load flow and contingency analysis.

2.3 IEEE Standard 738

IEEE Standard 738, titled "IEEE Standard for Calculating the Current-Temperature of Bare Overhead Conductors," provides guidelines for evaluating the thermal rating of conductors used in power transmission networks[6]. This standard is widely adopted for determining the current-carrying capacity of overhead conductors based on environmental conditions and conductor properties. IEEE 738 outlines mathematical models for estimating conductor temperature under varying loading and environmental conditions. These calculations take into account parameters such as solar radiation, ambient temperature, conductor resistance and other electrical and material properties,etc.[6]. This standard is employed to evaluate the current rating of various Aluminium Conductor Steel Reinforced (ACSR) used in INPS and current carrying capacity of equivalent HTLS Conductors at various temperature.

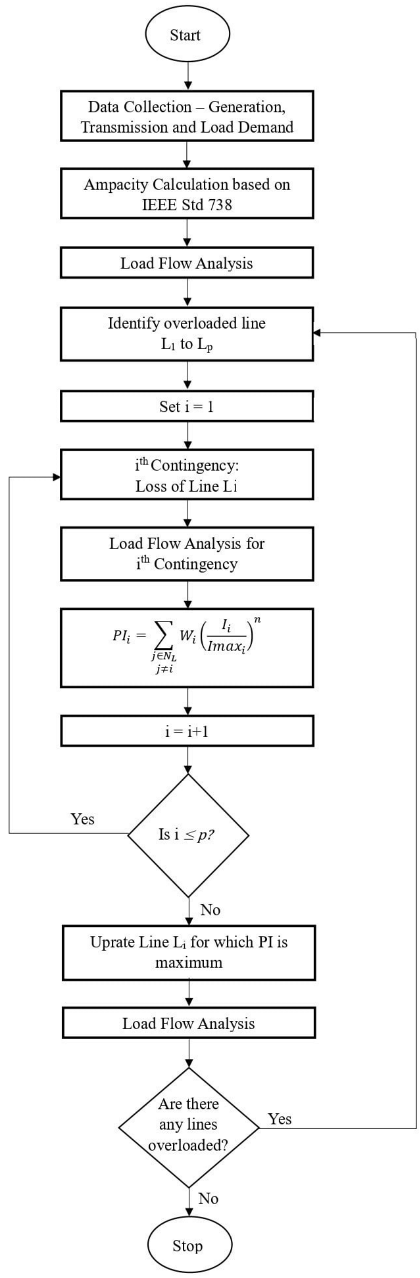

Figure 1: Flowchart for transmission line upgradation

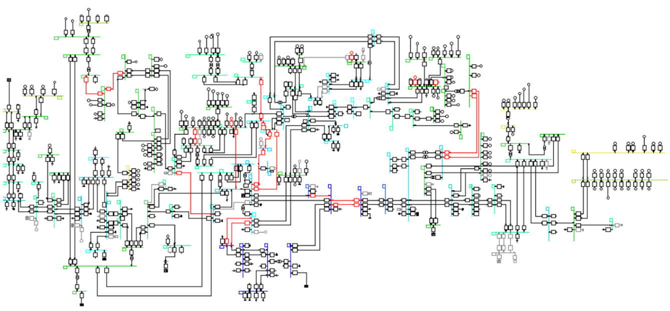

Figure 2: INPS Network Model in DigSILENT Powerfactory

2.4 Contingency Ranking

The contingency ranking has been performed based on the real/active power flow in the transmission line using the Active Power Performance Index (PI). This index is used to evaluate the severity of line overloading during contingency conditions. Several methods exist for ranking contingency scenarios [7, 8]. However, the Active Power Performance Index was chosen due to its effectiveness in quantifying the impact of real power flow on system stability and its computational efficiency in large power networks.

$$PI_j = \sum_{i=1}^{N_L} W_i \left(\frac{I_i}{I_{\max,i}} \right)^n \tag{1}$$

where, I_i = current flow in line i after contingency j
$Imax_i$ = rated maximum current of line j
N_L = total number of overloaded lines of contingency j
W_i = weight for line i, assumed 1 in this research
n = even integer, assumed 2 in this research

A higher PI value indicates a more severe contingency, requiring immediate attention for system reinforcement.

To ensure accuracy in the ranking process, the following assumptions were made:

- Steady-State Analysis: The study considers only steady-state conditions, neglecting transient stability effects.
- Constant Load Demand: Load demand is assumed to remain constant during the contingency analysis.
- No Network Reconfiguration: The study does not account for network topology changes during contingencies.

The ranking of contingencies helps prioritize which transmission lines need urgent upgradation to prevent cascading failures.

3. Result and Discussion

3.1 ACSR Current Ratings

The current rating of the ACSR conductors used in INPS is calculated using IEEE standard 738 and is compared with the manufacturer's rating in Table 1.

Table 1: ACSR Current Rating

	Current Rating	
Conductor	**Manufacturer's [9]**	**Calculated as per IEEE Std.738**
DOG	360 A	332.5 A
WOLF	470 A	433.65 A
PANTHER	560 A	521.73 A
BEAR	650 A	599.24 A
DUCK	*	650.58 A
BISON	800 A	745.59 A
CARDINAL	*	865.5 A
MOOSE	980 A	914.7 A

3.2 Base Case

Integrated Nepal Power System (INPS) as it is was considered for base case study. The The load flow analysis for wet peak season was considered as this is the season when the INPS will be loaded maximum. DIgSILENT Powerfactory was used for the load flow analysis. The lines given in Table 2 were found to be overloaded. The total overloaded circuit-km of a particular ACSR is summarized in Table 3.

Table 2: Overloaded lines in INPS

Name	kV	ACSR	Ckt -Km	Line Loading (%)
Amlekh-Simara	66	WOLF	25.8	104.48
Chapur-Nabalpur	132	BEAR	69.5	100.25
Damauli-Bharatpur	132	WOLF	39	133.08
Hetauda-Amlekhgunj	66	WOLF	40.34	106.11
Hetauda-Kul2(1)	132	BEAR	5.24	107.24
Hetauda-Kul2(1a)	132	BEAR	3	107.26
Kamane-Pathlaiya	132	BEAR	18.5	134.60
Khimti-Dhalke	220	BISON	150	123.76
Kule2-Matatirtha	132	BEAR	28.5	107.36
Kusma-Modi132kV	132	BEAR	6	150.25
Mata-Hetauda	132	BEAR	36.24	108.82
Mata-Tri220L1	220	BISON	49	112.25
Modi-New Modi	132	BEAR	0.3	121.48
NB-Sunwal	132	BEAR	110.58	103.99
Newbharatpur-mars	132	BEAR	25	135.34
NMRS-MMRS(1)	132	CARDINAL	40	122.89
Pathlaiya-Chapur	132	BEAR	61.36	113.43

Table 3: Overloaded Conductors of INPS

ACSR	Ckt-km
WOLF	105.14
BEAR	364.22
BISON	199
CARDINAL	40
Total	**708.36**

3.3 Contingency Analysis

The overloaded line shown in 2 are expected to fail sometime in future and thus can be consider a contingency. When a line fails, the neighboring lines will carry the current that the original line was supposed to carry and thus the new lines may be overloaded. For this research, the failure of seventeen (17) overloaded lines shown in Table 2 one at a time is considered as a contingency. The effects of loss of Amlekh-Simara line, and Pathlaiya-Chapur line is shown Table 4 and Table 5 respectively for reference.

3.4 Ranking of Contingencies

The failure of each of the overloaded lines shown in Table 2 was considered and the contingency were ranked based on PI score as shown in Table 6 below. The Table 6 shows that the loss of line Pathaiya-Chapur is the most severe and will be first line to be upgraded.

Table 4: Case I: Amlekh-Simara Out

Name	Ckt	Line Loading(%)	PI
Chapur-Nabalpur	2	102.16	2.09
Damauli-Bharatpur	1	135.01	1.82
Hetauda-Pathlaiya	1	123.29	1.52
Kusma-Modi132kV	1	152.11	2.31
Mata-Hetauda	1	114.6	1.31
Mata-Tri220L1	1	113.66	1.29
Modi-New Modi	1	123.29	1.52
NB-Sunwal	2	104.58	2.19
Newbharatpur-MARS	1	138.39	1.92
Pathlaiya-Chapur	1	116.82	1.36
Hetauda-Kamane	1	100.37	1.01
Hetauda-kul2(1)	1	112.99	1.28
Hetauda-Kul2(1a)	1	113	1.28
Kamane-Pathlaiya	1	169.88	2.89
Khimti-Dhalke	2	124.09	3.08
Kule2-Matatirtha	1	113.06	1.28
NMRS-MMRS(1)	1	123.11	1.52
Pathlaiya-Chapur	1	116.82	1.36
Total			**31.03**

Table 5: Case II: Pathlaiya-Chapur Out

Name	Ckt	Line Loading(%)	PI
But-Sun	2	229.31	10.52
Butwal-Motipur	2	168	5.65
Damauli-Bharatpur	1	143.42	2.06
Kusma-Modi132kV	1	176.04	3.1
Lamahi-Jhimruk	1	233.98	5.47
Mata-Tri220L1	1	112.6	1.27
Modi-New Modi	1	145.89	2.13
Motipur-Shivpur	2	157.29	4.95
NB-Sunwal	2	251.27	12.63
Newbharatpur-MARS	1	157.87	2.49
Khimti-Dhalke	2	123.44	3.05
Lamahi-Shivpur	2	141.22	3.99
NMRS-MMRS(1)	1	120.93	1.46
Syangja-Kaligandaki	1	101.38	1.03
Total			**59.80**

3.4.1 Observations and Insights

From the contingency ranking results it can be analyzed that Pathlaiya-Chapur transmission line has the highest PI score (59.80), making it the most critical line in the system. If this line fails, it would impose significant stress on adjacent lines, leading to potential overloading and system instability. Other high-risk lines include Chapur-Nabalpur (48.76), Kamane-Pathlaiya (32.07), Damauli- Bharatpur (31.15) and so on. These lines play a crucial role in Power System network and require priority consideration for reinforcements. Lines exhibiting lower PI scores, suggest that their outages would have comparatively a lesser impact on overall network stability. This ranking of overloaded lines of INPS allows Grid Owner and other related utility to prioritize upgradation efforts, focusing first on the most vulnerable transmission lines to prevent system-wide blackouts.

Table 6: Contingency Ranking

Name	PI	Rank
Amlekh-Simara	31.03	12
Chapur-Nabalpur	48.76	2
Damauli-Bharatpur	31.15	9
Hetauda-Amlekhgunj	31.11	10
Hetauda-Kul2(1)	28.20	13
Hetauda-kul2(1a)	28.20	14
Kamane-Pathlaiya	32.07	7
Khimti-Dhalke	26.59	16
Kule2-Matatirtha	28.20	15
Kusma-Modi132kV	38.91	3
Mata-Hetauda	33.38	5
Mata-Tri220L1	12.17	17
Modi-New Modi	35.35	4
NB-Sunwal	31.04	11
Newbharatpur-MARS	33.20	6
NMRS-MMRS(1)	31.43	8
Pathlaiya-Chapur	59.80	1

3.4.2 Overall System Performances of INPS

The overall system performances increases significantly after upgradation of ACSR over-loaded transmission lines with the equivalent HTLS conductors. Although the initial load flow analysis of Base case suggests the upgradation of 17 major overloaded transmission lines of total 708.36 ckt.kM, the contingency Analysis indicates the necessity of only 12 overhead transmission lines of total 644.24 ckt.kM upgradation. The list of overloaded ACSR transmission lines upgraded with equivalent HTLS Conductors is noted in the following table 4.32. The Grid Summary of INPS after upgradation of Overloaded ACSR transmission lines with equivalent HTLS Conductors is shown below in the following table 7. The graph shown belowin the Figure3 indicates the line loading before uprating of overloaded ACSR Conductors and after upgradation of overloaded lines of INPS with equivalent HTLS conductors. After upgradation of overloaded lines of INPS with equivalent HTLS conductor, the voltage profile of different busses of overloded lines also improved as shown in the Figure4

Table 7: Grid Summary after Upgradation of Overloaded Lines of INPS

Name	ACSR Conductor	Equivalent HTLS Conductor	Export/Excess Power (MW)	Grid Losses (MW)
Base Case	-	-	754.28	252.39
Pathlaiya-Chapur	Bear	Amsterdam	757.62	249.05
Chapur-Nawalpur	Bear	Amsterdam	790.57	216.11
NewBharatpur-MRS	Bear	Amsterdam	792.16	214.52
NMRS-MMRS	Cardinal	Vienna	795.85	210.83
Kamane-Pathlaiya	Bear	Amsterdam	797.94	208.74
Nawalpur-Dhalkebar	Bear	Amsterdam	800.13	206.55
Hetauda-Matatirtha	Bear	Amsterdam	801.71	204.97
Damauli-Bharatpur	Wolf	Copenhagen	801.71	204.97
Hetauda-Amlekhgunj	Wolf	Copenhagen	802.43	204.24
Amlekhgunj-Simara	Wolf	Copenhagen	802.98	203.69
Matatirtha-Trishuli3B	Bison	Stockholm	802.98	203.69
Khimti-Dhalkebar	Bison	Stockholm	810.86	195.81

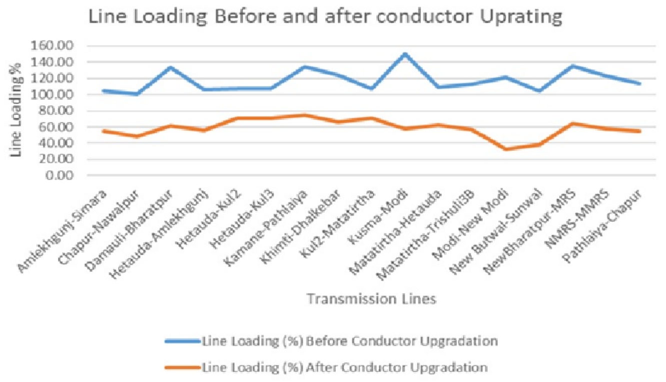

Figure 3: Line loading before and after conductor upgradation

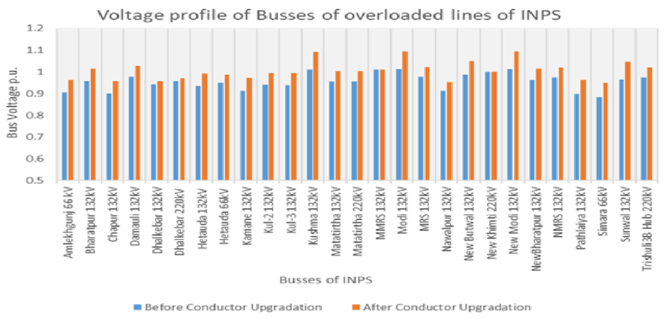

Figure 4: Voltage Profile of Busses before and after conductor upgradation

4. Conclusion

This study has provided a comprehensive analysis of contingency scenarios in the INPS and evaluated the need for transmission system upgradation. The implementation of IEEE Standard 738 for current rating estimation has allowed for an accurate assessment of conductor thermal limits, ensuring that the power system operates within safe parameters. The results of this study indicate in 66kV lines a total of 66.14 Ckt. km lenght (ACSR Wolf), in 132kV lines a total of 443.22 circuit km. length (having ACSR Bear: 364.22 Ckt. km, ACSR Wolf: 39 ckt. km and ACSR Cardinal: 40 ckt. km) and in 220 kV lines a total of 199 ckt. km (ACSR Bison: 199 ckt. km) are found to be overloaded at full generation of 3032.10 MW and full load of 2025.42 MW demand. At this case, total grid power surplus is 754.28 MW and grid power loss is 252.39 MW. After contingency analysis, when only 12 Nos. of overloaded lines out of 17 Nos. of overloaded line conductors are replaced with equivalent HTLS , the grid surplus power is increased to 810.86 MW and the overall grid power loss is reduced by 56.58 MW. Overall, this research contributes valuable insights into power system planning and contingency management, reinforcing the importance of proactive upgradation strategies in maintaining a robust and resilient transmission infrastructure.

Acknowledgments

The authors would like to express their sincere gratitude to the Institute of Engineering, Tribhuvan University, for providing the necessary resources and academic guidance for this research. Special thanks to the Nepal Electricity Authority (NEA) for providing crucial data and technical support. We extend our appreciation to our mentors, colleagues, and reviewers for their valuable insights and constructive feedback. Finally, we acknowledge the support of our families and friends for their encouragement throughout this study.

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APPENDIX D: PLAGIARISM TEST REPORT

Sujeet Mahato

Contingencies Based Strategy for Transmission System Upgradation

Tribhuvan University

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