GOVERNMENT OF NEPAL

MINISTRY OF ENERGY, WATER RESOURCES & IRRIGATION

TRANSMISSION SYSTEM DEVELOPMENT PLAN OF NEPAL

RASTRIYA PRASARAN GRID COMPANY LIMITED

July 2018

TABLE OF CONTENTS

A. EXECUTIVE SUMMARY 9
B. INTRODUCTION 14
1. INTRODUCTION 14
1.1. Context and Purpose of Transmission System Development Plan (TSDP) 14
1.2. Objectives and Scope 15
1.3. Structure of the Document 16
2. PRESENT SITUATION OF INPS 18
2.1. Background 18
2.2. Existing Generation 18
2.3. Existing Network 23
2.4. Existing Transmission System Master Plan 25
2.5. Cross-Border Transmission 27
2.6. Load Forecast 27
3. CONSOLIDATION OF TRANSMISSION SYSTEM DEVELOPMENT PLAN 30
C. DATA, TECHNICAL CRITERIA & DESIGN RULES 31
1. DATA 31
2. PLANNING TIME FRAME 31
3. DESIGN CONCEPT 31
4. OPERATING SCENARIOS 32
4.1. Scenario 1: Wet season – Minimum Load (Wet-Min Load) 32
4.2. Scenario 2: Wet season - Maximum Load (Wet-Max Load) 33
4.3. Scenario 3: Dry season - Maximum Load (Dry-Max Load) 33
5. LOAD FLOW ANALYSIS 34
5.1. Introduction 34
5.2. System Representation 34
5.3. Input Data 34
5.4. Bus Data 35
5.5. Generator Data 35
5.6. Line Data 36
5.7. Transformer Data 36
6. CONTINGENCY ANALYSIS 37
6.1. N-1 contingency: 37
6.2. Tower contingency: 38
7. GENERATION OUTAGE STUDY 38
8. INVESTMENT COST 38
D. PROPOSED TRANSMISSION NETWORK 39
1. ZONE 1 41
1.1. Presentation of the Zone 41
1.2. Existing Network 42
1.3. Overview of Committed and Planned Lines 42

1.4. Demand Forecast *44*
1.5. Generation Plan and Definition of Clusters of Power Plants *44*
1.6. Future Transmission Lines *48*
1.7. Target Network Model *51*
1.8. Load Flow and Voltage *52*
1.9. Investment Cost *54*
2. ZONE 2 56
2.1. Presentation of the Zone *56*
2.2. Existing Network *57*
2.3. Overview of Committed and Planned Lines *57*
2.4. Demand Forecast *59*
2.5. Generation Plan and Definition of Clusters of Power Plants *59*
2.6. Future Transmission Lines *62*
2.7. Target Network Model *64*
2.8. Load Flow Analysis *65*
2.9. Investment Cost *67*
3. ZONE 3 69
3.1. Presentation of the Zone *69*
3.2. Existing Network *70*
3.3. Overview of Committed and Planned Lines *71*
3.4. Demand Forecast *72*
3.5. Generation Plan and Definition of Clusters of Power Plants *73*
3.6. Future Transmission Lines *80*
3.7. Target Network Model *83*
3.8. Load Flow Analysis of Zone-3 .... *84*
3.9. Investment Cost *86*
4. ZONE 4 89
4.1. Presentation of the Zone *89*
4.2. Existing Network *90*
4.3. Overview of Committed and Planned lines *91*
4.4. Demand Forecast *93*
4.5. Generation Plan and Definition of Clusters of Power Plants *93*
4.6. Future Transmission Lines *99*
4.7. Target Network Model *103*
4.8. Load Flow Analysis *104*
4.9. Investment Cost *106*
5. ZONE 5 109
5.1. Presentation of the Zone *109*
5.2. Existing Network *110*
5.3. Overview of Committed and Planned lines *111*
5.4. Demand Forecast *112*
5.5. Generation Plan and Definition of Clusters of Power Plants *112*
5.6. Future Transmission Lines *117*
5.7. Target Network Model *121*
5.8. Load Flow Analysis *122*

5.9. *Investment Cost* ... 124

E. LOAD FLOW STUDY ... 127

1. Scenario-1: Wet Season Peak load (Wet- Peak Load) ... 127
2. Scenario-2: Wet Season Minimum load (Wet- Min Load) ... 127
3. Scenario-3: Dry Season Peak load (Dry- Peak Load) ... 128

F. CONTINGENCY STUDY ... 132

1. N-1 Contingency ... 132
2. Tower Contingency ... 135

G. GENERATION OUTAGE STUDY ... 136

H. CROSS BORDER TRANSMISSION LINE ... 137

1. Proposed Cross Border Line with India ... 137
   - 1.1. *Attariya-Bareily Cross Border Transmission Line* ... 137
   - 1.2. *Dododhara–Bareily Cross Border Transmission Line* ... 138
   - 1.3. *Phulbari–Lukhnow Cross Border Transmission Line* ... 138
   - 1.4. *New Butwal–Gorakhpur Cross Border Transmission Line* ... 138
   - 1.5. *Dhalkebar – Muzzafarpur Cross Border Transmission Line* ... 138
   - 1.6. *Inaurwa – Purnea - Cross Border Transmission Line* ... 139
2. Proposed Cross Border Line with China ... 139
   - 2.1. *Chilime-Keyrung Cross Border Transmission Line* ... 139
   - 2.2. *Kimanthanka – Latse Cross Border Transmssion Line* ... 140

I. CONCLUSIONS ... 141

J. REFERENCES ... 145

K. ANNEX-1 ... 146

1. Element Modeling ... 146
   - 1.1. *Transmission Line* ... 146
   - 1.2. *Transformer* ... 149
   - 1.3. *Bus/substation* ... 153

L. ANNEX-2 ... 154

M. ANNEX-3 ... 167

N. ANNEX- 4 ... 180

LIST OF FIGURES

FIGURE 1: GENERATION SCENARIO 18
FIGURE 2: LOAD AND GENERATION SCENARIO OF LAST 8 YEAR 22
FIGURE 3: EXISTING NETWORK 24
FIGURE 4: PROPOSED TRANSMISSION LINE NETWORK FOR 2035 26
FIGURE 5: PROPOSED TRANSMISSION LINE NETWORK FOR 2035 27
FIGURE 6: ENERGY SALES AMONG VARIOUS PARTICULARS 28
FIGURE 7: LOAD DEMAND SCENARIO OF SYSTEM ZONE WISE. 39
FIGURE 8: ZONE WISE GENERATION SCENARIO OF NEPAL. 39
FIGURE 9: PROPOSED TRANSMISSION LINE NETWORK FOR 2040 40
FIGURE 10: OVERVIEW OF ZONE-1 41
FIGURE 11: OVERVIEW OF EXISTING AND COMMITTED NETWORK AND SUBSTATION OF ZONE 1 FOR YEAR 2040 43
FIGURE 12: GENERATION CHART OF ZONE 1 FOR YEAR 2040 43
FIGURE 13: DODODHARA SUBSTATION AND PERIPHERY 48
FIGURE 14: TARGET NETWORK OF ZONE-1 FOR YEAR 2040. 51
FIGURE 15: VOLTAGE PROFILE OF 400KV SUBSTATION UNDER DIFFERENT SCENARIO BY 2040 OF ZONE-1. ... 52
FIGURE 16: PERCENTAGE OF LINE LOADING OF LINE UNDER DIFFERENT SCENARIO OF ZONE-1 BY 2040. 53
FIGURE 17: PRESENTATION OF ZONE-2 56
FIGURE 18: OVERVIEW OF EXITING AND COMMITTED NETWORK AND SUBSTATION OF ZONE-2 FOR YEAR 2040. 58
FIGURE 19: GENERATION CHART OF ZONE-2 FOR YEAR 2040. 58
FIGURE 20: PHULBARI SUBSTATION AND PERIPHERY 62
FIGURE 21: TARGET NETWORK OF ZONE-2 FOR YEAR 2040. 64
FIGURE 22: BAR GRAPH OF VOLTAGE OF SUBSTATION OF DIFFERENT SCENARIO OF ZONE-2 BY 2040. 65
FIGURE 23: PERCENTAGE OF LINE LOADING OF LINE OF DIFFERENT SCENARIO OF ZONE-2 BY 2040. 66
FIGURE 24: PRESENTATION OF ZONE-3 69
FIGURE 25: OVERVIEW OF EXISTING AND COMMITTED NETWORK AND SUBSTATION OF ZONE-3 FOR YEAR 2040. 72
FIGURE 26: GENERATION CHART OF ZONE-3 FOR YEAR 2040. 72
FIGURE 27: NEW BUTWAL SUBSTATION AND PERIPHERY 76
FIGURE 28: NEW MARSYANGDI SUBSTATION AND PERIPHERY 79
FIGURE 29: TARGET NETWORK AND SUBSTATION OF ZONE-3 FOR YEAR 2040 83
FIGURE 30: BAR CHART OF VOLTAGE PROFILE OF DIFFERENT SCENARIO OF ZONE-3 BY 2040. 84
FIGURE 31: LINE LOADING OF 400KV AND 220KV UNDER DIFFERENT SCENARIO OF ZONE-3. 85
FIGURE 32: PRESENTATION OF ZONE-4 89
FIGURE 33: OVERVIEW OF EXISTING AND COMMITTED NETWORK AND SUBSTATION OF ZONE-4 FOR YEAR 2040 92
FIGURE 34: GENERATION CHART OF ZONE-4 FOR YEAR 2040 92
FIGURE 35: KATHMANADU VALLEY AND PERIPHERY 96
FIGURE 36: NEW DHALKEBAR SUBSTATION AND PERIPHERY 99
FIGURE 37: TARGETED NETWORK AND SUBSTATION OF ZONE-4 FOR YEAR 2040. 103
FIGURE 38: VOLTAGE PROFILE OF SUBSTATION ON ZONE-4 BY 2040. 104

Figure 39: Percentage of line loading under scenario of Zone-4 by 2040. 105
Figure 40: Presentation of Zone -5 109
Figure 41: Overview of existing and committed network of Zone-5 for year 2040 111
Figure 42: Generation Chart of Zone-5 for year 2040 111
Figure 43: Inaruwa substation and Periphery 115
Figure 44: Overview of targeted network and substation of zone-5 for year 2040 121
Figure 45: Bar graph of voltage profile by 2040 for Zone-5 122
Figure 46: Line loading in percentage of Zone-5 123
Figure 47: Voltage profile under different scenario by 2040 129
Figure 48: Voltage Profile under different scenario by 2040 129
Figure 49: Line Loss under different scenario by 2040 130
Figure 50: Line loss under different scenario by 2040 131
Figure 51: Types of bundle conductor 148
Figure 52: Positive sequence model of 2-winding transformer (in Ohms). 150
Figure 53: Positive sequence model of 2-winding transformer (in p.u.) 150
Figure 54: Transformer model with tap changer modeled at HV – side 152
Figure 55: Transformer model with tap changer modeled at LV – side 152
Figure 56: Complex tap changer model 152
Figure 57: Power Map of Nepal (2040) 180

LIST OF TABLES

Table 1: List of HPPs owned by NEA 19
Table 2 : List of HPPs owned by IPPs 19
Table 3: List of TPPs owned by NEA 22
Table 4: List of PV plants 22
Table 5: Total final electricity demand and average growth gates 29
Table 6: Total load demand in different scenarios 29
Table 7: Substation load demand of Zone-1 44
Table 8: Power plant connected to Pancheswor substation by 2040 45
Table 9: Power plant intending to connect at Attariya hub 45
Table 10: Power plant intending to connect at West Seti hub 46
Table 11: Power plant intending to connect at Dododhara substation 47
Table 12: Existing, Under Construction, Planned and Proposed Transmission Line of Zone 1 50
Table 13: Cost Estimate of Transmission Line in Zone 1 54
Table 14: Cost Estimate of Substation in Zone 1 55
Table 15: Substation load demand of zone-2 59
Table 16: Power plant intending to connect at MainaTara for year 2040 59
Table 17: Power plant intending to connect at Nalgad hub for year 2040 60
Table 18: Power plant intending to connect at Bafikot hub for year 2040 61
Table 19: Power plant intending to connect at Phulbari hub for year 2040 61
Table 20: Existing, Under Construction, Planned and Proposed Transmission Line of Zone 2 63
Table 21: Cost Estimate of Transmission Line in Zone 2 67
Table 22: Cost Estimate of substation in Zone 1 68
Table 23: Substation load demand of Zone-3 73
Table 24: Power intended to evacuate from Burtibang substation 73
Table 25: Power intended to evacuate from Kushma substation 74
Table 26: Power intended to evacuate from New Butwal substation 75
Table 27: Power intended to evacuate from New Damauli substation 76
Table 28: Power intended to be evacuate from New Marsyandi substation. 77
Table 29: Power intended to evacuate from Bharatpur substation 79
Table 30: Existing, Under Construction, Planned and Proposed Transmission Line of Zone 3 81
Table 31: Cost Estimate of Transmission Line in Zone 3 86
Table 32: Cost Estimate of Substation in Zone 3 88
Table 33: Substation load demand of Zone-4 93
Table 34: Power intended to be evacuate from Ratmate substation 94
Table 35: Power intended to be evacuated from New Hetauda substation 94
Table 36: Power intended to be evacuated from Matatirtha substation 95
Table 37: Power intended to be evacuated from Suichatar substation 96
Table 38: Power intended to be evacuated from Lapsephedi substation 96
Table 39: Power intended to be evacuated from Bahrabise substation 97
Table 40: Power intended to be evacuated from New Khimti substation 98
Table 41: Power intended to be evacuated from Dhalkebar substation 99
Table 42: Existing, Under Construction, Planned and Proposed Transmission Line of Zone 4 .. 101

TABLE 43: COST ESTIMATE OF TRANSMISSION LINE IN ZONE 4 106
TABLE 44: COST ESTIMATE OF SUBSTATION IN ZONE 4 108
TABLE 45: SUBSTATION LOAD DEMAND OF ZONE-5 112
TABLE 46: POWER INTENDED TO BE EVACUATED FROM MIRCHIYA SUBSTATION 113
TABLE 47: POWER INTENDED TO BE EVACUATED FROM TINGLA SUBSTATION 113
TABLE 48: POWER INTENDED TO BE EVACUATED FROM ARUN-3 SUBSTATION 114
TABLE 49: POWER INTENDED TO BE EVACUATED FROM INARUWA SUBSTATION 115
TABLE 50: POWER INTENDED TO BE EVACUATED FROM NEW BASANTAPUR SUBSTATION 116
TABLE 51: POWER INTENDED TO BE EVACUATED FROM HANGPANG SUBSTATION 116
TABLE 52: EXISTING, UNDER CONSTRUCTION, PLANNED AND PROPOSED TRANSMISSION LINE OF ZONE 5 .. 119
TABLE 53: COST ESTIMATE OF TRANSMISSION LINE IN ZONE 5 124
TABLE 54: COST ESTIMATE OF SUBSTATION IN ZONE 5 126
TABLE 55: RESULT OF N-1 CONTINGENCY STUDY 132
TABLE 56: RESULT OF N-1 CONTINGENCY STUDY AFTER RECOMMENDED CHANGES 133
TABLE 57: RESULT OF N-1 CONTINGENCY STUDY AFTER SWITCHING TO HTLS 134
TABLE 58: RESULT OF TOWER CONTINGENCY STUDY FOR LINE LOADING 135
TABLE 59: POWER FLOW BETWEEN ATTARIYA-BARELY CROSS BORDER TRANSMISSION LINE 138
TABLE 60: POWER FLOW BETWEEN DODODHARA–BARELY CROSS-BORDER TRANSMISSION LINE 138
TABLE 61: POWER FLOW BETWEEN PHULBARI–LUKHNOW CROSS BORDER TRANSMISSION LINE 138
TABLE 62: POWER FLOW BETWEEN NEW BUTWAL–GORAKHPUR CROSS BORDER TRANSMISSION LINE 138
TABLE 63: POWER FLOW BETWEEN DHALKEBAR – MUZZAFAPUR CROSS BORDER TRANSMISSION LINE 139
TABLE 64: POWER FLOW BETWEEN INAURWA – PURNEA - CROSS BORDER TRANSMISSION LINE 139
TABLE 65: POWER FLOW BETWEEN CHILIME-KERYUNG CROSS BORDER TRANSMSSION LINE 139
TABLE 66: POWER FLOW BETWEEN KIMANTHANKA – LATSE CROSS BORDER TRANSMSSION LINE 140
TABLE 67: BUS INFORMATION 154
TABLE 68: GENERATOR RATING 155
TABLE 69: LOAD DATA 161
TABLE 70: EXISTING, UNDER CONSTRUCTION, PLANNED AND PROPOSED TRANSMISSION LINE 162
TABLE 71: PLANNED AND PROPOSED CROSS-BORDER TRANSMISSION LINES 166
TABLE 72: BUS VOLTAGE IN P.U. OF DIFFERENT SCENARIO 167
TABLE 73: LINE LOADING IN PERCENTAGE FOR DIFFRENT SCENARIO 170
TABLE 74: VOLTAGE FOR DIFFERENT GENERATION OUTAGE SCENARIO 172
TABLE 75: LINE LOADING FOR DIFFERENT GENERATION OUTAGE SCENARIO 175
TABLE 76: TRANSMISSION LINE COST FOR DIFFERENT ZONES 178
TABLE 77: SUBSTATION COST FOR DIFFERENT ZONES 179

ABBREVIATIONS AND ACRONYMS

AC	Alternating Current
ACSR	Aluminum Conductor Steel Reinforced
DC	Direct Current
DCS	Distribution and Consumer Services
DoED	Department of Electricity Development
GW	Gigawatt
GWh	Gigawatt-Hour
HEP	Hydro Electric Project
HPP	Hydropower Project
HTLS	High Tension Low Sag
IEEE	Institute of Electrical and Electronics Engineers
INPS	Integrated Nepal Power System
IPP	Independent Power Producer
JTT	Joint Technical Team
km	Kilometer
kV	KiloVolt
kWh	Kilo Watt-Hour
MCC	Millennium Challenge Corporation
MUSD	Million US Dollar
MVA	Mega Volt Ampere
MVAR	Mega Volt Ampere (reactive)
MW	Megawatt
NEA	Nepal Electricity Authority
NPC	National Planning Commission
POI	Point of Interconnection
PRoR	Peaking Run-of-river
p.u.	Per Unit
RoR	Run-of-the-River
RPGCL	Rastriya Prasaran Grid Company Limited
V	Voltage
WECS	Water and Energy Commission Secretariat

A. Executive Summary

Nepal is a mountainous country rich in running water resources with huge potential for hydropower electricity generation. The rivers originating in the mountains in the north and flowing down to the lowlands in the south are very suitable for hydropower generation. Despite an enormous potential, less than 5% of the viable resource is harnessed to generate electricity. Consequently, majority of people are currently deprived of reliable electricity with a large portion of the country beyond the reach of the national grid. Inadequate electricity generation and underdeveloped grid network are affecting not only the daily life of people but also hindering the overall economy of the country. The Government of Nepal has realized that the economic growth of the country can be accelerated with the optimum development of its hydropower resources. Therefore, GoN has envisaged developing 15GW of hydropower in 10 years and around 40GW by the year 2040. Optimal evacuation of the developed power for domestic consumption and export requires secure and reliable transmission network. So, to achieve high economic growth with the development of hydropower, transmission network should be developed simultaneously with high priority. Development of transmission line requires substantial investment in the form of capital, skilled manpower, state of the art technology and large amount of land for substations and RoWs. So, a transmission development plan with national consensus of related stakeholders is important for developing an optimal grid network at national level.

There have been a few efforts to develop a long-term plan for the development of the transmission system. So far, transmission master plans and network interconnection plans have been proposed by different studies (NEA, JTT) for target year 2035. These master plans mainly focus on the development of the transmission network in the country with the objective of facilitating the export of hydropower to India. These reports suggest a 400kV East-West highway along the Terai region for countrywide connection of hydroelectric projects. Likewise, six cross-border connection points have been identified along the 400kV East-West highway along the Terai region for power export to India and additional two cross-border connections points with China for power exchange.

The Transmission System Master Plan prepared by NEA is a comprehensive transmission system development plan for the period of 2015 to 2035. It presents the clustering of hydropowers to evacuate power along the river corridor in an optimal way and presents a reliable network for the purpose of power export to India. However, as per the GoN's new vision for the economic development target with 7.2 % GDP growth (as per WECS report), a large national demand for electricity (approximately 18 GW peak) can be expected by the year 2040. Thus, a new vision for the design of the transmission system master plan is required that aims to reliably supply such large national level demand throughout the country while also facilitating export of power to India and China. There is also an imperative need to address the large change in the generation and load plan for the country since the publication of the previous transmission masterplan.

GoN established Rastriya Prasaran Grid Company Limited (RPGCL) in July 2015 to plan, construct and operate the transmission grid of Nepal. RPGCL has prepared a preliminary consolidated transmission development plan which incorporates the new vision for the design of the transmission system while imbibing the framework of previous transmission plans.

The transmission system development plan proposed by RPGCL suggests a 400kV East-West highway along the hilly region of the country connecting major hubs in this region. It is additional to the previously proposed 400kV East-West transmission line along the Terai region and hence forms mesh network of 400kV interconnected by radial lines along the river corridors. Such a mesh network provides an alternative path for power evacuation in case of complete failure of any dedicated north-south line via the path in the adjacent loops, thus addressing the tower contingency. This network also facilitates distribution of electric power in the hilly region throughout the country. The proposed transmission network has six Nepal-India cross-border connection points in the Terai region and two Nepal-China cross-border connection points in the Himalayan region. The power grid of Nepal is divided into 5 zones from West to East, with at least one interconnection point with India and China. Zone 1 in the far-west consists of Mahakali, West Seti and Karnali corridors where Dododhara and New Attariya substations are the proposed interconnection points with Bareilly of India for power exchange. The major generations in this zone are Pancheswor (3240MW), Humla Karnali Cascade (916MW) and West Seti (750MW). Zone 2 consists of Bheri Corridor with major generations such as Bheri-3 Storage (480MW), Nalgadh (410MW), Naumure Storage (342MW), etc. The export point at this zone is Phulbari substation which is proposed to be connected to the Lukhnow substation of India. Similarly, Zone 3 consists of Kali Gandaki and Marsyangdi corridors, with major generations such as Upper Marsyangdi-2 (600MW), Kali Gandaki Kowan (400MW), Manang Marsyangdi (282MW), etc. The proposed interconnection point for this zone is the New Butwal substation for connection with Gorakhpur of India. Zone 4 includes Trishuli-Chilime, Khimti, and Tamakoshi Corridor and consists of major generations such as Sunkoshi-2 (1110MW), Tamakoshi-3 (650MW), Sunkoshi-3 (536MW), etc. This zone is proposed to have interconnection point at New Dhalkebar for power exchange with Muzzafarpur of India and Chilime 400kV substation for power exchange with Kerung of China. Finally, Zone 5 in the far-east includes Koshi, Arun and Kabeli corridors consists of major generations such as Tamor Storage (765MW), Kimathanka Arun (450MW), Upper Tamor (415MW), Arun-4 (372MW), etc. The proposed interconnection points in this zone are Inaruwa substation for power exchange with Purnea of India and Kimanthanka substation for power exchange with Latse of China.

The transmission system development plan presents the transmission network for the updated generation and load scenario of the year 2040. The computer model of the proposed network consists of the data of existing, under construction and planned/proposed hydroelectric projects and transmission lines, and load forecast of the target year 2040. For simplification, only transmission lines of 220kV and above voltage level with few major transmission lines of 132kV is considered for load flow and contingency analysis. The maximum installed capacity of 38GW, maximum domestic load of 18GW and maximum export capacity of 16GW with 3GW spinning reserve is predicted for the year 2040 and computer model is developed accordingly. In the proposed network, 3192 km of 400kV including cross-border lines and 1160 km of 220kV major transmission line needs to be completed across the country. In addition, 40 number of 400kV highest voltage substation and 19 number of 220kV highest voltage substation is included in the network. Most of the generation in 2040 is still expected to be from RoR type hydroelectric projects, with 60% of the installed capacity contributed by such generation. However, the share of storage type generation is expected to increase to 30% of the installed capacity with the addition of new large-scale storage type projects. Likewise, 10% of the generation is expected to be contributed by PRoR hydropower.

Summary of ProposedTransmission Network		
• Summary of Transmission Line		
SN	**Voltage Level (kV)**	**Length (km)**
1	400	3192
2	220	1160
• Summary of Sub-Station		
SN	**Highest Voltage Level (kV)**	**Number**
1	400	40
2	220	19

The estimated cost to construct proposed transmission lines including 2515 km of 132 kV line is 3767.91 MUSD. The estimated cost to construct proposed substations including 132 kV highest voltage substations is 2269.76 MUSD. In summary, the proposed network is estimated to have a total cost of 6037.68 MUSD.

The overall generation in the country is expected to have a seasonal variation, with minimum generation capability being maximum during the wet season and minimum during the dry season due to the large share of RoR type generation in the country's installed capacity. Coupled with daily load variations, the seasonal variations result in drastically varying loading conditions which require investigation of the system's resilience in extreme conditions. The following extreme loading scenarios have been considered in this report:

- Wet Season Maximum Load: This scenario is considered during the wet season of the country when the hydroelectric generation is maximum and domestic loading is considered to be equal to the peak load. This is the scenario when the loading of the transmission line is assumed to be maximum and is hence considered for both load flow analysis and contingency analysis.
- Wet Season Minimum Load: This scenario is also considered in the wet season but during the minimum loading instance of the daily load curve. This scenario is considered to study the generation dispatch management for handling low loading condition during high availability of generation.
- Dry Season Maximum Load: This scenario is considered during the dry season when the hydroelectric generation is reduced to the minimum of the year and the domestic loading is at its peak. This scenario is considered to study the system's ability to meet the domestic load demand when the generation capacity is reduced in the dry season.

The proposed network is subjected to various analysis techniques, mainly load flow analysis and contingency analysis, for the aforementioned scenarios. The load flow analysis results indicate that the voltages of all major substations and line loadings of all major transmission lines are within safe limits for all the above steady-state scenarios. Likewise, the overall loss in the system is also seen to be within the acceptable limits for all scenarios. For the wet season, Nepal is seen to be capable of exporting large quantity of power whereas for the dry season, export needs to be curtailed in order to meet the domestic load demand due to the drop in the generation capacity.

The contingency analysis for the network indicates that the proposed system is capable of handling all N-1 line contingencies, i.e. the outage of one circuit from any major transmission line at a time, within the ring network. Likewise, for the tower contingency analysis, i.e. the complete failure of any major transmission line, the result from the computer simulation indicates that the proposed ring network satisfies the necessary criteria. A few circuits in the radial lines were seen to be overloaded beyond the normal limits but the loading remained within the emergency loading limit.

Similarly, generation outage study was conducted for the major generations. The results indicate that the outage of any of these generations does not cause overloading in any healthy transmission lines or over/under-voltage in any healthy substation buses.

Thus, the transmission system development plan proposed by RPGCL presents a complete transmission network of Nepal and incorporates the concept of a robust, reliable transmission network for supplying the national peak load demand and catering to the power export to the neighbouring countries.

B. Introduction

1. Introduction

Power network consists of electricity generating sources and electric loads along with transmission lines, which transmit electricity from sources to loads. For reliable and uninterruptible uninterrupted electric service in the modern power grid, a robust transmission network is required. The robust network can be accomplished by proper planning of the transmission line. Transmission network planning is a continuous process which involves determining and scheduling changes to be made in various voltage levels of transmission grid as future condition including demand for power and generation change. Transmission planning decisions are based on an integrated planning approach which considers forecasted load growth, planned/proposed generations, inter-area exchange, etc.

1.1. Context and Purpose of Transmission System Development Plan (TSDP)

Nepal is a mountainous country, rich in water resources. The majority of rivers originate from the mountains in the Northern side and flow down to the southern plain and eventually to the Indian Ocean via India. The abundance of water resources provides huge potential of hydropower. This is reflected in the Integrated Nepal Power System (INPS) as the majority of power in the country is hydropower. Despite the high potential of hydropower, less than 5% of this resource has been harnessed until now. The Government of Nepal (GoN) has realized that the economic growth of the country can be accelerated with the optimum hydroelectricity generation and has set forth to develop around 15 GW in 10 years and around 40 GW by the year 2040. The government, government-owned entities, IPPs and donor agencies are already involved in the development of the hydropower projects to meet the set target, but the activities in the field of transmission line development have not been up to par. The planning of transmission system is crucial for optimal evacuation of hydropower and creating a secure and reliable transmission grid. Transmission System Master Plan 2015 had presented a Master Plan for transmission system of Nepal from the year 2015 to the year 2035. Similarly, Joint Technical Team (JTT) of Nepal and India has formulated an Integrated Master Plan for evacuation of power from Nepal to India up to the year 2035. These master plans mainly focus on the development of the transmission network in the country with the objective of facilitating the export of hydropower to India. They suggest the clustering of hydropowers to evacuate power along the river corridor in an optimal way and presents a reliable network for the purpose of power export to India. Although, both the plans have presented a layout for the development of Transmission System Network but they fall short in incorporating the newly identified generations and have been pessimistic about the load forecast of Nepal. GoN has conceived a vision for the economic development of the country with a higher GDP growth which implies a large domestic load demand for electricity can be expected. As per WECS load forecast report [5], 18 GW peak load demand is expected by the year 2040 with a 7.2 % GDP growth rate. Thus, an update on current master plan is required to have a robust and secure transmission network which can cater to the future load demand and evacuate power from all the hydropowers in timely and optimized manner for domestic use and export as well.

Government of Nepal has realized the importance of development of transmission line for the economic growth of country through the development of hydropower. Unlike hydropower generation there will be very low interest of private organization in the development of transmission line, further operation of transmission line is regulated by government in the most of the countries. Hence, a dedicated transmission company Rastriya Prasaran Grid Company Limited (RPGCL) was established in July 2015 with the objective of planning, constructing and operating transmission grid of Nepal. RPGCL has been planning the transmission system of Nepal and this Trasnmission System Development Plan is published to inform the stakeholders about the transmission system plan and proposed developments in the transmission network.

1.2. Objectives and Scope

1.2.1. Objectives

The main objective of this Transmission System Development Plan is to provide an updated transmission system network development plan capable of timely evacuation of power from HPPs and catering to future domestic load and export surplus energy to neighboring countries with agreed security and reliability measures.

1.2.2. Scope of Works

The main scope of work is to provide transmission system development plan for year 2020-2040. The main scope is divided into three sections to obtain the objectives defined. The three sections of the scopes of works as follows:

i. Presentation of transmission network
   1. Collection of data of existing, under construction, planned and proposed HPPs

2. Collection of data of existing, under construction, planned and proposed transmission lines including cross-border transmission lines
3. Load forecast for years 2020-2040
4. Identification of generation corridor, transmission corridor, generation hub and load substations to form transmission network

ii. Technical analysis of transmission network
1. Load flow analysis
2. Short circuit analysis
3. Contingency analysis
4. Generation outage Study
5. Dynamic analysis

iii. Financial analysis and Feasibility study
1. Cost estimate of transmission line and substations
2. Cost estimate of alternative network
3. Estimate wheeling charges

Short circuit and dynamic analysis of technical analysis and cost estimate of alternative network and estimate of wheeling charges of financial analysis and feasibility study will be presented in the future report of transmission system development plan.

1.3. Structure of the Document

Section A: This section provides executive summary of the transmission system development plan report.

Section B: The first part of the report introduces context of the master plan development with objective, scope of works and existing network and transmission system development plan.

Section C: This section introduces the design concept, operating scenarios and various study analysis of the transmission system development plan

Section D: This section introduces the details of the proposed master plan along with zone wise study of generation, load and transmission line and estimate of transmission line and substations.

Section E: This section provides load flow analysis of the transmission network for various scenarios.

Section F: This section provides N-1 contingency and tower contingency analysis of the transmission network proposed in the transmission system development plan.

Section G: This section provides generation outage study of the transmission network proposed in the transmission system development plan.

Section H: This section introduces the cross-border interconnection of existing and future network.

Section I: This section provides conclusion of the proposed transmission development plan.

Section J: References

Section K: Annex-1 for element modeling.

Section L: Annex-2 for generation, transmission and load data.

Section M: Annex-3 for line parameters, load flow results, and generation outage results and summary of cost of transmission line and substation.

Section N: Annex-4 for Power Map of Nepal for 2040

2. Present Situation of INPS

2.1. Background

In the existing INPS, the hydropower projects contribute 94.9% of total power generation while multi-fuel, diesel power plants and PV generations contribute the remaining. NEA, the government owned utility owns about half of the hydropower plants in termas of capacity and other grid connected multi-fuel and diesel power plant. Independent power plants (IPP) own the remaining of the hydro power plants. The transmission network of INPS is solely owned and operated by NEA. In 2015, GoN established RPGCL to develop transmission lines and operate transmission grid of Nepal. Distribution and Consumer Services (DCS) directorate of NEA undertakes distribution of electricity in major part of country.

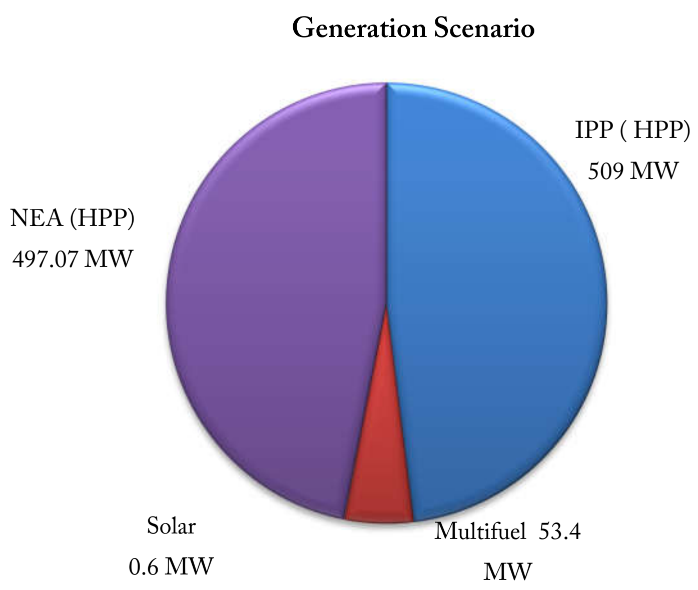

Figure 1: Generation Scenario[1]

2.2. Existing Generation

The main source of electricity generation in Nepal is hydropower. Along with hydropower, thermal power plants are used to generate electricity and are connected to national grid. Alternative energy like solar and wind are used as distributed sources and are mostly used in rural electrification. As of May 2018, the total installed capacity of Nepal is 1060.78 MW, among which 1006.78 MW power is contributed by hydropower, 53.4 MW by Multifuel and 0.6 MW by solar power. As per data from

Department of Electricity Development (DoED) and NEA's "A Year in Review Fiscal Year 2016/17", existing power plants are as following:

Table 1: List of HPPs owned by NEA

S.N	Hydropower Project	River	Installed Capacity (MW)
1	Phewa	Seti Khola	1.00
2	Tinau	Tinau	1.02
3	Seti	Seti Khola	1.50
4	Tatopani	Tatopani	2.00
5	Panauti	Roshi	2.40
6	Puwa	Puwa	6.20
7	Sun Koshi	Sun Koshi	10.05
8	Devighat	Trishuli	14.10
9	Modi Khola	Modi Khola	14.80
10	Gandak	Narayani	15.00
11	Trishuli	Trishuli	24.00
12	Chameliya Khola	Chameliya Khola	30.00
13	Kulekhani-ll	Kulekhani	32.00
14	Kulekhani-I	Kulekhani	60.00
15	Marsyangdi	Marsyangdi	69.00
16	Madhya Marsyangdi	Marsyangdi	70.00
17	Kali Gandaki A	Kali Gandaki	144.00
Total			**497.07**

Table 2 : List of HPPs owned by IPPs

SN	Hydropower Project	River	Promoter	Installed Capacity (MW)
1	Thoppal Khola	Thoppal	Thoppal Khola Hydropower Company	1.65
2	Lower Chaku Khola	Chaku	Laughing Buddha Power Nepal	1.8
3	Middle Chaku Khola	Chaku	Laughing Budha Power Nepal	1.8
4	Jhyari Khola	Jhyari Khola	Electrocom and Research Centre,	2
5	Khani Khola	Khani Khola	Khani Khola Hydropower	2
6	Chhandi Khola	Chhandi	Chhyandi Hydropower Co. P.Ltd	2

SN	Hydropower Project	River	Promoter	Installed Capacity (MW)
7	Ridi Khola	Ridi	Ridi Hydropower Development	2.4
8	Jiri Khola SHP	Jiri Khola	Bojini Company (P.) Ltd	2.4
9	Daram Khola-A	Daram	Sayapatri Hydropower Pvt. Ltd.	2.5
10	Sunkoshi Small	Sun Koshi	Sanima Hydripower Pvt. Ltd	2.6
11	Chake Khola	Chake Khola	Garjang Upatyaka HP Company Ltd	2.83
12	Piluwa Khola	Piluwa Khola	Arun Valley Hydropower	3
13	Chaku Khola	Chaku	Alliance Power Nepal P.Ltd	3
14	Bhairab Kund Khola	Bhairab Kund	Bhairabkund Hydropower Pvt. Ltd.	3
15	Midim Khola	Midim Khola	Union Hydropower P.Ltd	3
16	Upper Puwa-1	Puwa	Joshi Hydropower Co. P.Ltd	3
17	Sabha Khola	Sabha Khola	Dibyaswari Hydropower P Ltd	3.3
18	Charnawati Khola	Charnawati	Nepal Hydro Developer Pvt Ltd	3.52
19	Dwari Khola	Dwari	Bhugol Energy Development	3.75
20	Khudi Khola	Khudi	Khudi hydropower Ltd	4
21	Sardi Khola	Sardi	Mandakini Hydropower Pvt. Ltd.	4
22	Puwa Khola-1	Puwa	Puwa Khola -1 Hydropower Pvt. Ltd	4
23	Baramchi Khola	Baramchi	Unique Hydel Pvt Ltd	4.2
24	Tungun-Thosne	Tugun	Khani Khola Hydropower Company	4.36
25	Radhi Small	Radhi	Radhi Bidyut Co. Ltd	4.4
26	Hewa khola	Hewa Khola	Barun Hydropower Development Co.	4.46
27	Mai Khola	Mai Khola	Himal Dolkha Hydropower Co Ltd	4.5
28	Bijayapur-1	Bijayapur	Bhagawati Hydropower Development	4.5
29	Mardi Khola	Mardi	Gandaki Hydropower Development	4.8
30	Mailung Khola	Mailung Khola	Mailun Khola Hydropower Company	5
31	Siuri Khola	Siuri	Nyadi Group Pvt Ltd	5
32	Phawa khola	Phawa Khola	Shiwani Hydropower Company	5
33	Tadi Khola (thaprek)	Tadi Khola	Aadi Shakti Bidhut Bikash Co. P. Ltd	5
34	Upper Hugdi	Hugdi	Ruru Jalbidyut Pariyojana Pvt. Ltd	5
35	Daraundi A	Daraundi	Daraundi Kalika Hydro	6
36	Upper Mai -C	Mai Khola	Mai Valley Hydropower P.L.,	6.1
37	Ankhu Khola -1	Ankhu Khola	Ankhu Jalvidut Co. Pvt. Ltd	7

SN	Hydropower Project	River	Promoter	Installed Capacity (MW)
38	Mai Cascade	Mai Khola	Sanima Mai Hydropower Ltd	7
39	Molun Khola SHP	Molun	Molun Hydropower Co. Pvt. Ltd	7
40	Indrawati -III	Indrawati	National Hydropower Company	7.5
41	Jogmai Khola	Jogmai Khola	Sanvi Energy Pvt. Ltd.	7.6
42	Mai Cascade HPP	Mai Khola	Himal Dolkha Hydropower Company	8
43	Nau Gad Khola	Naugad	Api Power Company Pvt. Ltd	8.5
44	Andhi Khola	Andhi Khola	Butwal Power Company	9.4
45	Sipring Khola	Sipring	Synergy Power Development P Ltd	10
46	Lower Modi -1	Modi Khola	United Modi Hydropower Pvt. Ltd.,	10
47	Thapa Khola	Thapa Khola	Mount Kailash Energy Co. Pvt. Ltd	11.2
48	Upper Mai	Mai Khola	Mai Valley Hydropower P Ltd.	12
49	Jhimruk Khola	Jhimruk	Butwal Power Company	12.5
50	Madkyu Khola	Madkyu	Silkes Hydropower Pvt. Ltd	13
51	Hewa Khola A	Hewa Khola	Panchthar Power Company Pvt. Ltd.	14.9
52	Chilime	Chilime	Chilime Hydropower Company Ltd	22
53	Mai	Mai Khola	Sanima Mai Hydropower Ltd	22
54	Upper Madi	Madi Khola	Madi Power Pvt Ltd.,	25
55	Upper Bhotekoshi	Bhote Koshi	Bhotekoshi Power Company	45
56	Upper Marsyangdi A	Marsyangdi	Sinohydro-Sagarmatha Power	50
57	Khimti -I	Khimti Khola	Himal Power Ltd	60
Total				**499.47**

Table 3: List of TPPs owned by NEA

S.N	Thermal Plant	Installed Capacity (MW)
1	Duhabi Multifuel Center	39
2	Hetauda Diesel Centre	14.41
Total		53.41

Table 4: List of PV plants

S.N	Solar Power Plant	Installed Capacity (MW)
1	Solar Energy	0.68
Total		0.68

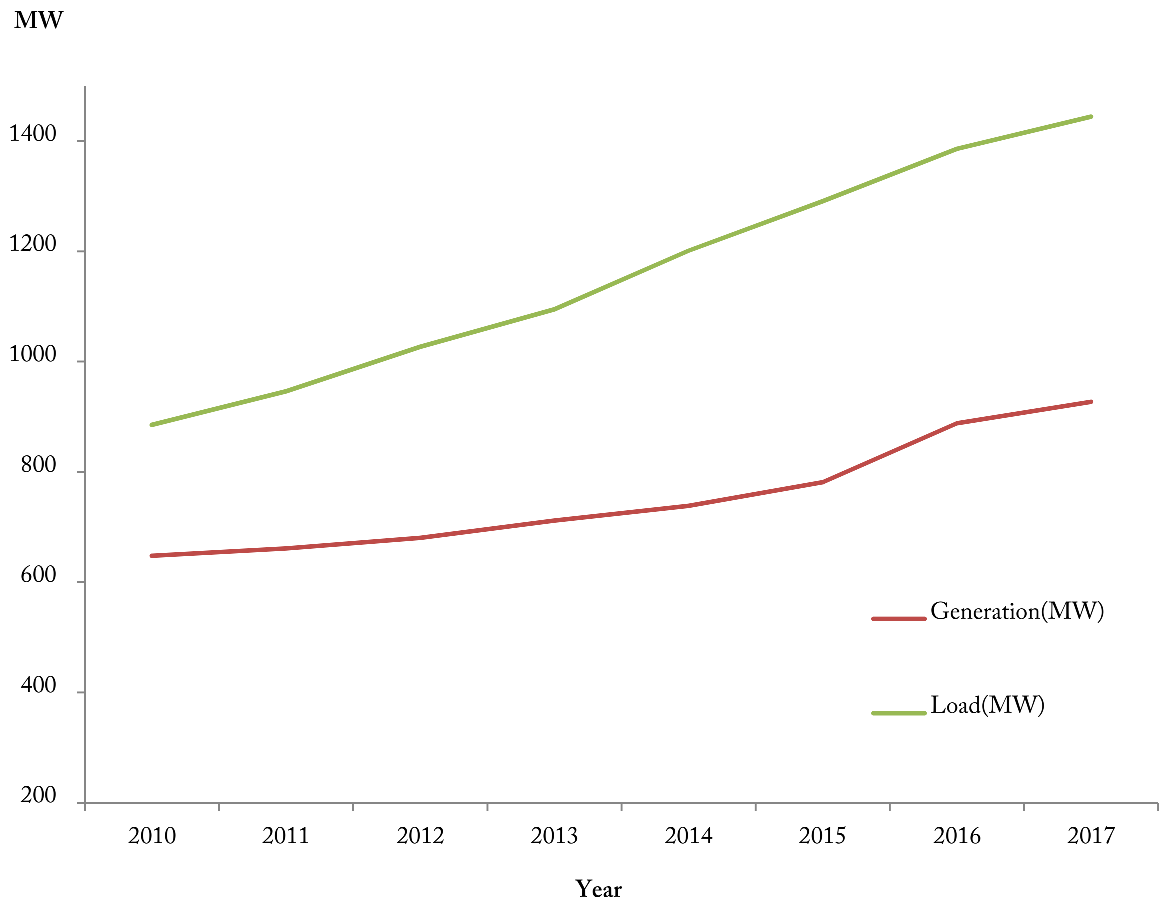

Figure 2: Load and generation scenario of last 8 year [2]

2.3. Existing Network

The majority of high voltage transmission line in Nepal is 132kV. With increase in the installed power and load demand, new lines of 220kV and 400kV have been introduced. With the completion of 400kV Dhalkebar-Muzzafarpur cross-border transmission line in February 2016, the highest level of voltage in Nepal is 400kV. The line is currently charged in 132kV but with the upgradation of Dhalkebar substation to 220kV voltages, the line will be charged in 220kV and upto 230MW will be imported from India. Hetauda-Dhalkebar-Inaruwa 400kV transmission line is under construction and completion of the line will strengthen the East-West transmission network. Likewise, Khimiti-Dhalkebar 220kV transmission line was completed in January 2017 and few other 220kV transmission lines like Kaligandaki Corridor, Marsyangdi Corridor, Marsyangdi-Kathmandu and Koshi Corridor are under construction.

As per data of NEA's “A Year in Review Fiscal Year 2016/17”, transmission network comprises of 2,819 circuit km of 132kV lines, 153 circuit km of 400/220kV lines and 1,996 MVA of substation capacity at the 132kV level. The country also has a 66kV transmission network comprising of 493.76 circuit km of lines and transformer capacity of 621.5 MVA. Currently, a total of 1,108.2 circuit km of transmission lines for 132kV level, a total of 1,357 circuit km for 220kV level and a total of 740 circuit km for 400kV level are under construction. In addition, a total of 533 MVA capacity new substations are currently under construction. Furthermore, Dhalkebar-Muzzafarpur cross-border transmission line interlinks the transmission grid of Nepal with India via 6 links in Uttar Pradesh and 7 links in Bihar at the 132kV, 33kV and 11kV levels. About 200 MW of power is exchanged between the two countries in radial mode via these links.

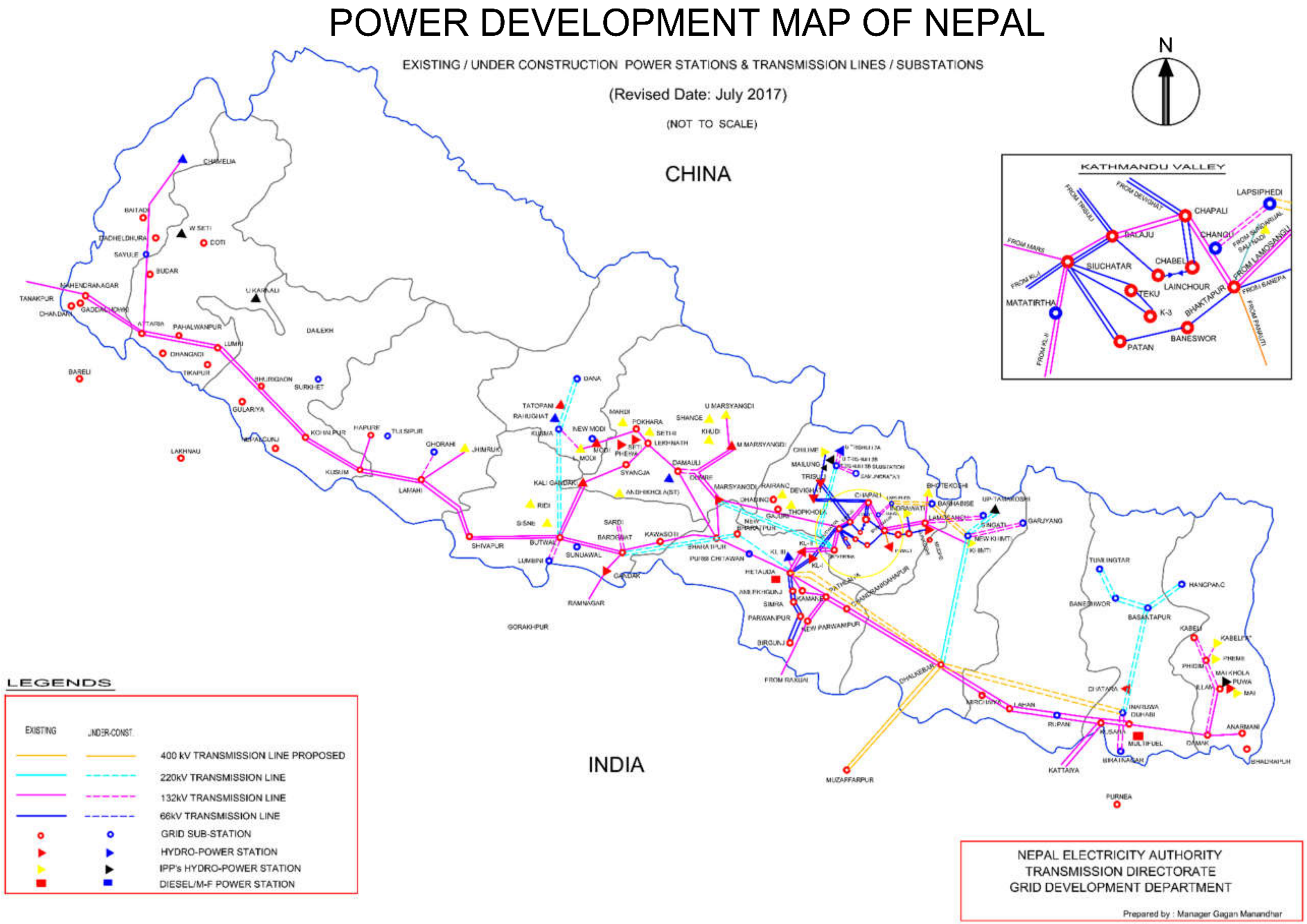

Figure 3: Existing network[2]

2.4. Existing Transmission System Master Plan

In recent years, construction and detailed study for construction of hydropower projects has increased. To ensure grid connection to these hydropowers, a systematic development of transmission line is required. For systematic development of transmission lines and coordination among the stakeholders, few studies have been conducted to develop a long-term transmission line development plan. The Joint Technical Team (JTT) of Nepal and India prepared Integrated Master Plan for Evacuation of Power from Hydro Projects in Nepal in June 2016. The report was mainly focused on the design of the transmission line system in Nepal for the future scenario upto the year 2035 to export power from future hydro power stations in Nepal to India. The report assumed installed capacity of 45 GW and peak domestic load of 6.2 GW by the year 2035. A 400kV "East-West Power Highway" is proposed in the report, functioning as a backbone network connecting all major pooling points in the Terai region. Major hydro power projects are connected to this backbone via dedicated radial transmission routes.

NEA Transmission Master Plan 2015 was prepared covering the period from 2015 to 2035. The Master Plan presents river corridor based radial transmission lines to connect to the cross-border transmission line to export power to India. Furthermore, East-West trunk line is presented to transmit power within the country for national demand. The Master Plan assumed the installed capacity of 25.6 GW and peak domestic load of 4.7 GW by the year 2035. The proposed network in this report is fundamentally similar to the above report.

Transmission networks proposed by the two reports present the country as a power exporter, mainly to India while considering small load growth in the country. By now, however, the domestic load growth s can be expected to be much higher to accomodate to the GoN's new target for economic development with 7.2% GDP growth. This, in turn, demands a transmission network with higher level of reliability and robustness for supplying the domestic load demand throughout the country while also catering to the export requirements. The transmission network must be reliable enough to consider more severe cases of contingencies, such as the complete failure of dedicated transmission lines along the river corridor.

.

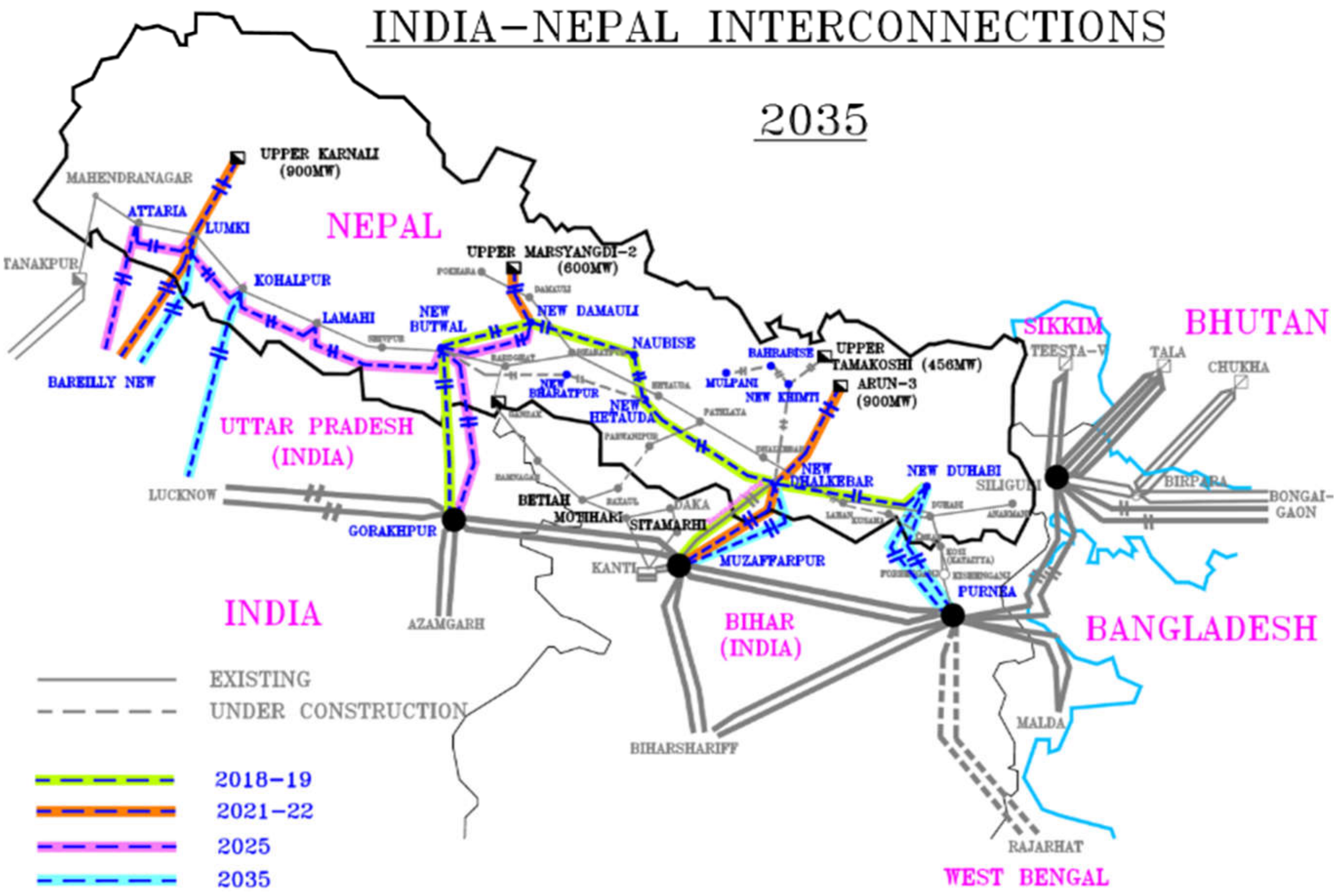

Figure 4: Proposed transmission line network for 2035[3]

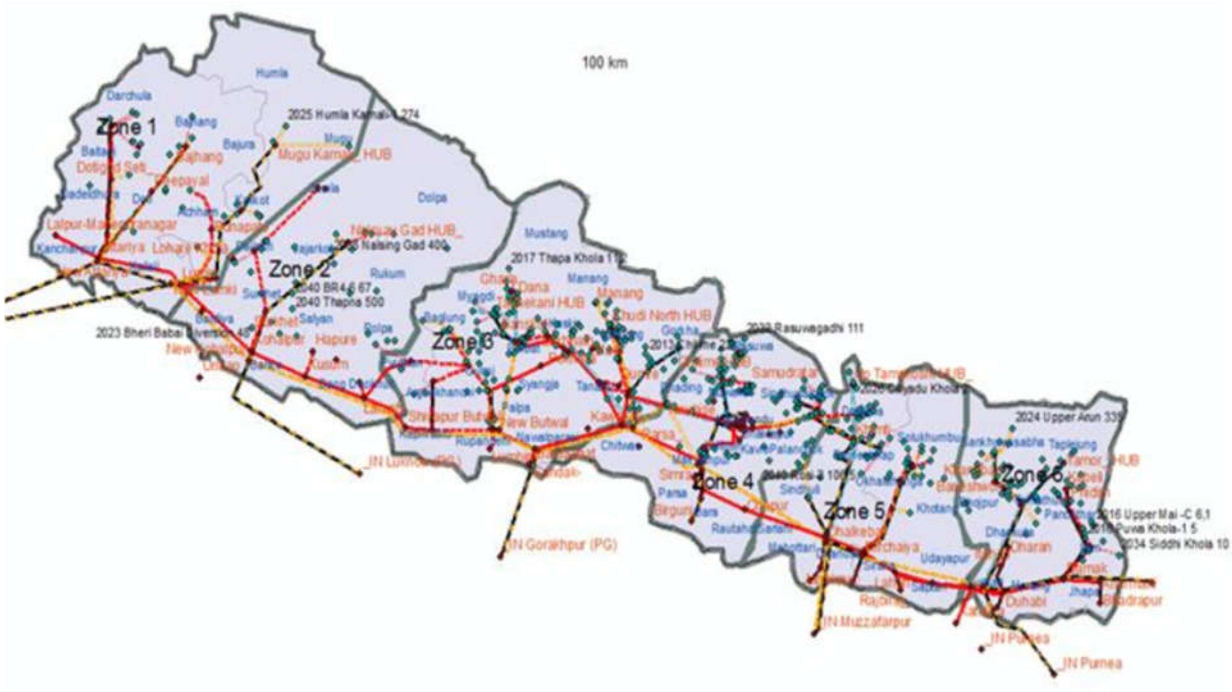

Figure 5: Proposed transmission line network for 2035 [4]

2.5. Cross-Border Transmission

Cross-border transmission lines at 132kV, 33kV and 11kV levels are under operation and currently imports power from Uttar Pradesh and Bihar of India to reduce the power deficit. With a number of hydropowers under construction and in planning, Nepal will have surplus power with capability to export power in future. Dhalkebar-Muzzafarpur 400kV cross-border transmission line is currently charged at 132kV to import power from India but will be charged at 400kV to export power in near future. The Transmission System Master Plan and Nepal-India JTT have identified 6 locations for the cross-border power transmission with India. The Transmission System Development plan prepared by RPGCL has explored new cross-border transmission line not only with India but with China as well.

2.6. Load Forecast

The peak demand of electricity was 1444 MW in 2017 and 1385 MW in 2016. The total electricity generation has been less than demand from last few years. The power deficit has been curtailed through power import from India. Present trend of load growth from the NEA annual report shows that, load demand increases by around 8% annually. Domestic load is the major load in the present scenario contributing almost 50% of the total load. Industrial load is second largest load with 33% share of the total load and commercial load with 8% share is third largest load.

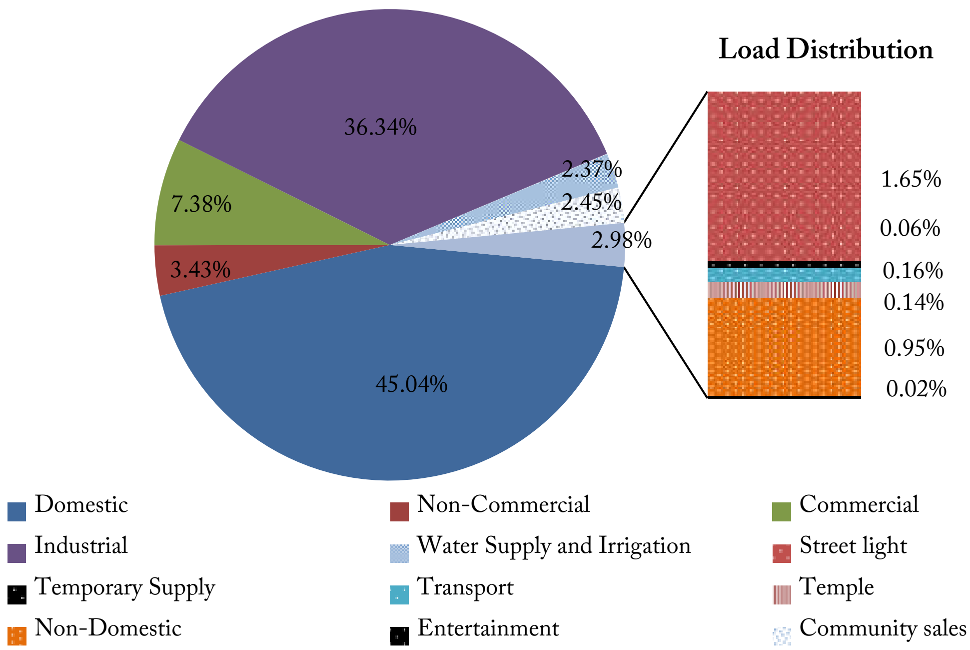

Figure 6: Energy sales among various particulars[2]

As cooking energy source is expected to shift from biomass to electric, the largest load in the system will still be domestic in future. Industrial load will continue to be the second largest load as many industries are being planned and developed across the country. Presently, energy consumption in transportation is very low, but trend of energy consumption in this sector in other developed country is increasing rapidly. Considering this fact, energy consumption in transportation is also expected to be another major load in the country. Besides the annual load forecast in the Annual Report of NEA, few other entities have also published short as well as long term load forecast. The "Integrated Master Plan for Evacuation of Power from Hydro Projects in Nepal" has forecasted the load to be around 4.7 GW and the report from JTT of Nepal and India has estimated a load demand of 6.1 GW for year 2040. Water and Energy Commission Secretariat (WECS) has also published an energy forecast for 2040, considering the five different scenarios as given below:

- Business-as-usual (BAU) scenario at rate of 4.5 percent.
- Moderately high growth(reference) scenario at rate of 7.2 percent
- High growth scenario at rate of 9.2 percent.
- Additional policy interference in the basis of the annual economic growth rate of 7.2 percent.
- Additional policy interference in the basis of the annual economic growth rate of 9.2 percent.

Table 5: Total final electricity demand and average growth gates [5]

Year	Final Electricity Demand (GWh)					Growth Rate of Final Electricity Demand (% p.a.)				
	BAU	Reference Scenario	High Scenario	Policy Intervention @ 7.2%	Policy Intervention @ 9.2%	BAU	Reference Scenario	High Scenario	Policy Intervention @ 7.2%	Policy Intervention @ 9.2%
2015	3866.36	3866.36	3866.36	3866.36	3866.36					
2020	7600.75	8110.66	8522.97	14870.92	15304.29	14.5	15.1	17.13	30.92	31.67
2025	12998.25	14863.67	16545.84	22431.68	24265.05	11.3	12.19	14.19	8.57	9.66
2030	20073.83	24956.79	29864.09	35334.66	41264.82	9.1	10.25	12.54	9.51	11.2
2035	29744.69	40709.77	52983.16	51771.84	65657.5	8.2	9.64	12.15	7.94	9.73
2040	43016.68	66096.6	94851.06	81958.97	115294.44	7.7	9.5	12.35	9.62	11.92

For maximum load demand, reference scenario at rate of 7.2 percent is considered from above table with a capacity factor of 52% and outage factor as 25%.

Table 6: Total load demand in different scenarios [5]

	BAU 4.50%	Reference Scenario 7.20%	High Scenario 9.20%	7.2% growth with policy intervention	9.2% growth with policy intervention
2020	4338.32	2225.65	2338.80	4080.75	4199.67
2025	7419.09	4078.60	4540.37	6155.51	6658.61
2030	11457.67	6848.43	8195.05	9696.24	11323.55
2035	16977.56	11171.23	14539.20	14206.80	18017.18
2040	24552.9	**18137.67**	26028.24	22490.50	31638.14

Domestic load demand in year 2040 is expected to reach around 18 GW with moderately high growth rate of 7.20%. The .Transmission System Development Plan considers 18 GW as load demand for year 2040 with 7.2% growth rate which is reference scenario.

3. Consolidation of Transmission System Development Plan

In order to address the gap of the existing Transmission System Master Plan, the need of a consolidated transmission development plan with generation and load scenario up to the year 2040 was realized. The development plan report suggests the construction of 400kV "East-West Power Highway" in Terai region and in the hilly region while incorporating the proposed dedicated lines connecting the hub substations in the north to the power evacuation points in the Terai region. This results in the formation of a mesh network grid instead of the radial grid concentrated in river corridor as proposed by the previous studies. Such grid is expected to provide alternative path for evacuation from major hydropower projects in case of complete failure of the dedicated transmission line due to tower contingency via adjacent branches along the 400kV backbone and through other interconnecting lines between the two 400kV backbones. The additional 400kV backbone in the hilly region also facilitates equitable distribution of power throughout the hilly region.

C. Data, Technical Criteria & Design Rules

1. Data

Generation data: Data required for this study was taken from the various governmental organizations like DOED, NEA and JTT of Nepal and India and their publications

Transmission line data: The required data of transmission line for this study was taken from NEA Annual Report, Final Transmission Master Plan Report, and JTT Report.

Load Data: Load data was taken from the Report of WECS, Final Transmission Master Plan Report, NEA Annual Report and JTT Report.

2. Planning Time Frame

This report will cover the planning of the country's grid network from 2020 to 2040, with operation scenario considered for every 5 years' span. This volume of the report however contains the scenario for target year 2040 only.

3. Design Concept

The transmission system is required to be planned considering following general principle considering both steady state as well as contingency operation scenario:

i. Normal thermal rating and voltage limits indicate equipment limits that the equipment can sustain on a continuous basis. Emergency thermal ratings represent equipment limits that can be tolerated for a relatively short time which may be 1-2 hours depending on the design of the equipment. The voltage limit for all condition, however, is set from 95% to 105% of the nominal value.
ii. For steady state condition, i.e., with all elements of the transmission system network available for service, all connected elements' parameters like voltage, loadings, frequency, etc., must stay within the permissible normal limits under all loading or generation scenario.
iii. Disturbance in the system due to the loss of an element, in this case a single circuit from a double circuit transmission line due to faults, is assumed to be highly probable. Hence, the system should be designed such that all the system parameters shall remain within the permissible normal limits even in the event of such faults. However, it is expected that the loading in the second circuit of the faulted double circuit transmission line will be increased as it is expected to carry the loading of both circuits by itself.

iv. After suffering one contingency, the network is still susceptible to another contingency, although such occurrence is less likely. If such condition does arise, some of the equipment may be permitted to temporarily operate within their emergency limits. In case of a temporary fault in the second element, the system is expected to survive the disturbance until the fault is cleared. However, for permanent faults, the system shall operate in a new steady state condition with none of the equipment exceeding their respective emergency limits. However, it may be required to perform load shedding or rescheduling of generation so as to bring back the system parameters within normal limits before the fault is completely cleared.

v. In some loading scenario, the load demand may be less than the available generation at a given instance. In such cases, it is required to limit the generation dispatch from some of the generators in order to maintain a balance between load and generation. For such condition, a merit order-based priority has to be considered for the control of the dispatch of generations. The assumed merit order is presented below:

   1. IPP Run of River
   2. NEA Run of River
   3. NEA Storage
   4. Import
   5. Diesel

4. Operating Scenarios

Nepal's electric grid is highly dependent on domestic hydropower generations for production of electricity, with most of the hydropower projects being run-of-the-river (RoR) type. Even though generation from storage type of projects is highly likely to increase in the future, major share of HPPs will be of the RoR type. Due to this, the overall generation capability of Nepal's electric grid will continue to have a seasonal nature somewhat similar to the present situation as the discharge in the rivers of the country varies with the season of the year.

Considering the above conditions, three extreme operation cases are considered for the study purpose in the future time frame in order to represent the extreme but realistic constraints that the network will face.

4.1. Scenario 1: Wet season – Minimum Load (Wet-Min Load)

This scenario is considered during the wet season in the country when the discharge in rivers throughout most of the country is at the highest. All hydropower projects in the country is expected to operate at maximum capacity. It is anticipated that by the start of the time period considered for this report, i.e. 2020, the total generation capability in the system is expected to be higher than the forecasted load in the same time frame. Imports of electricity and thermal generations are thus kept to a minimum. The electricity export capability to India is also expected to be high for this scenario as the cross-border transmission infrastructure with India is also expected to expand steadily.

In addition, the load flow analysis was conducted for the lowest loading instance in the daily load curve, when the load demand is assumed to reduce to approximately 40% of the peak load.

In such scenario, if available generation exceeds the load demand, merit order based priority has to be considered for the dispatch of generators as defined in section C.3. In general, all run-of-river type hydroelectric projects are assumed to be fully dispatched as per the corresponding available discharge while the storage type projects are expected to have a flexible generation within their corresponding maximum generating capability.

4.2. Scenario 2: Wet season - Maximum Load (Wet-Max Load)

This scenario is also considered during the wet season but in contrast to the Scenario 1 the operating condition is considered for the peak load time of the daily load curve. The generation scenario is the same as in Scenario 1 and all other assumptions also hold true here.

Here, the export to India is assumed to be constant for the 24-hour period and thus same as in Scenario 1. However, export may have to be curtailed in some instances, such as during the outage of major generations, in order to meet the domestic load demand.

This scenario represents the maximum loading condition in the network during steady state condition and thus, point out any overloading and transmission bottlenecks in the proposed system.

In case of available generation exceeding the load demand, the merit order based generation dispatch has to be considered as defined in section C.3.

4.3. Scenario 3: Dry season - Maximum Load (Dry-Max Load)

This condition is considered during the time of the year when the discharge in the rivers throughout the country is minimum, leading to reduction in generations from RoR hydroelectric projects to 35% of the installed capacity. This scenario looks into the system's loading condition during reduced generation and peak domestic loading condition. The storage type projects are assumed to be capable of running at their peak capacity. Similarly, export to India is also expected to be curtailed in order to allocate enough generation capability with sufficient spinning generation to meet the domestic load demand. Here, similar load flow setting is used as in case of Scenario 1, except for the fact that all RoR generators are fixed at 35% of their individual capacity.

5. Load flow analysis

5.1. Introduction

Load flow analysis is an important and essential approach for investigating problems in power system operation and planning. Based on a specified generating state and transmission network structure, load flow analysis solves the steady operation state with node voltages and branch power flow in the power system. Load flow analysis can provide a balanced steady operation state of the power system, without considering system transient processes.

Analyzing the solution of this problem for numerous conditions helps ensure that the power system is designed to satisfy its performance criteria while incurring the most favorable investment and operation costs. Load flow study basically calculates the magnitude and phase of the voltage at each bus, and the real and reactive power flowing in each line and losses of the system, thus helping in planning the future expansion of the power system as well as determining the best operation of existing system.

5.2. System Representation

A simplified visual means of representing the complete system is essential for understanding the operation of the system under its various possible operating modes. The system single-line diagram serves this purpose. The single-line diagram consists of the schematic representation of power system elements such as load, buses, generations, interconnecting lines, etc. The position of loads, generators, transformers, reactors, capacitors, etc., in the single line diagram also represent their relative position in the actual network.

5.3. Input Data

The system information, shown on the single-line diagram defines the system configuration and the location and size of loads, generation, and equipment. The preparation of this data file is the foundation of all load flow analysis, as well as other analysis requiring the network model, such as short- circuit and stability analysis. It is therefore essential that the data preparation be performed in a consistent, thorough manner. The data is presented in readable format and sub divided into various classes according to their characteristics i.e. Load data, Transformer data, Generator data, Bus data and System data.

5.4. Bus Data

The bus data describes each bus and the load and shunts connected to that bus. The data includes the following:

- Bus number
- Bus name
- Bus type
- Load
- Shunt

The bus number/name is normally the primary index to the information about the bus. Typically, the four bus types used are as follows:

- Load buses
- Generator buses
- Swing buses
- Disconnected buses

The terms "load" bus and "generator" bus should not be taken literally. A load bus is any bus that does not have a generator. A load bus need not have load, it may simply be an interconnection point for two or more lines. A generator bus could also have load connected to it. The "swing" or "slack" bus is a special type of generator bus that is needed by the solution process. The swing generator adjusts its scheduled power to supply the system MW and MVar losses that are not otherwise accounted for.

Load is normally entered in MW and MVar at nominal voltage. Normally, the load is treated as a constant MVA, that is, independent of voltage. In some cases, a constant current or constant impedance component of load will also be entered so that the load is a function. Shunts generally are entered in MVar at nominal voltage.

5.5. Generator Data

Generator data is entered for each generator in the system including the system swing generator. The data defines the generator power output and types i.e. Swing types, Voltage control types, MVars types and PF Control types. The data items normally entered are as follows:

- Real power output in MW

- Maximum reactive power output in MVar (i.e., machine maximum reactive limit)
- Minimum reactive power output in MVar (i.e., machine minimum reactive limit)
- Generator in-service/out-of-service code

Other data items that may be included are the generator MVA base and the generator's internal impedance for use in short-circuit and dynamic studies.

5.6. Line Data

The line data items include the following:

- Resistance
- Reactance
- Charging susceptance (shunt capacitance)
- Line ratings
- Line in-service/out-of-service code
- Line-connected shunts

The π model of the line is adopted with the series resistance and the reactance of the line in series and one-half of the charging susceptance placed in shunt on each end of the line. The resistance, reactance, and susceptance are usually input in either per unit or percent, depending on program convention. Line rating is normally input in amperes or MVA.

5.7. Transformer Data

This can either be entered as part of the branch data or as a separate data category depending on the particular load flow program being used. This additional data usually includes the following:

- Tap setting in per unit
- Tap angle in degrees
- Maximum tap position
- Minimum tap position
- Scheduled voltage range with tap step size or a fixed scheduled voltage using a continuous tap approximation

The organization of transformer tap data requires an understanding of the tap convention used by the load flow program to ensure the representation gives the correct boost or buck in voltage. Transformers whose rated primary or secondary voltages do not match the system nominal (base kV) voltages on the terminal buses will require an off-nominal tap representation in the load flow (and possibly require corresponding adjustment of the transformer impedance).

6. Contingency Analysis

Contingency Analysis of a power system is a major activity in power system planning and operation. In general, an outage of one or more transmission lines or transformers may put the entire or part of the network under stress, leading to overloading in other branches and/or sudden system voltage rise or drop. Contingency analysis is used to evaluate (loading and voltage-wise) post-fault load flows, with each case representing the "outage" of a single or group of elements (such as transformers, busbars, transmission lines, etc.). Such analysis can be used to determine power transfer margins or for detecting the risk inherent in changed loading conditions and also helps identify the weak elements in the network whose outage leads to the most severe system parameters violations.

In the event of a contingency, the following type of violations may be experienced:

- Voltage violations: This type of violation occurs at the buses. This suggests that the voltage at the bus is less than the specified value. The operating range of voltage at any bus is generally 0.95-1.05 p.u. Thus if the voltage falls below 0.95 p.u then the bus is said to have low voltage. If the voltage rises above the 1.05 p.u then the bus is said to have a high voltage problem. It is known that in the power system network generally reactive power is the reason for the voltage problems. Hence in the case of low voltage problems reactive power is supplied to the bus to increase the voltage profile at the bus. In the case of the high voltage reactive power is absorbed at the buses to maintain the system normal voltage.
- Line MVA limits violation: This type of contingency occurs in the system when the MVA loading of the line exceeds given rating due to the increase in the amplitude of the current flowing in that line. The lines are designed in such a way that they should be able to temporarily withstand 120% of their MVA limit.

6.1. N-1 contingency:

Here, the outage of one of the two circuits of the major transmission lines at 220kV or 400kV levels is considered, assuming that all major transmission lines have a double circuit design. Since only one power system component is considered to be taken out in such event, such outage falls within the "N-1" type contingency analysis. Such outage is mostly attributed to faults in the transmission lines whereupon only a single circuit among the double circuit transmission system is affected. For such contingencies, the acceptable post-fault condition of the network should be such that the power flow in the other circuit should be within 120% of its thermal rating, i.e. their emergency loading limit, whereas other functioning transmission lines should be operating within 100% of their thermal rating without load shedding or rescheduling of generation.

6.2. Tower contingency:

Such contingency is said to occur when both circuits of a double circuit transmission system suffer outage at the same time. Such outage is attributed to unwanted events such as faults affecting both circuits of a double circuit transmission system, damage to one or more of the double circuit towers, etc. Here also, such outages are considered for major transmission lines at 220kV and 400kV levels. For such contingencies, the acceptable post-fault condition of the network should be such that other functioning transmission lines should be operating within 120% of their thermal rating, i.e. their emergency loading limit.

7. Generation Outage Study

During normal operation, hydropower projects may not always be available for dispatch due to various reasons, such as scheduled maintenance, unexpected breakdown of essential components, faults, etc. This is true for hydropower projects of all sizes. Hence, during the outages of large-scale hydropower projects, the country's electric network may suffer from a large generation deficit. To avoid network blackouts due to load-generation mismatch, adequate spinning reserve should be maintained in other power plants. In addition, compensation of generation outage using spinning reserve from other power plants should not lead to overloading of transmission lines and voltage violations in any part of the electric network during steady state operation. As such, outage conditions of major hydropower projects need to be studied to check the electric network's capability to handle such outages.

8. Investment Cost

The investment cost of the committed and planned transmission line and substation are estimated based on several data obtained from several projects which are i) executed, ii) under execution or iii) on the process of tender. The estimation of these project cost gives a very close approximation, however the cost are subjected to change depending upon the several factors during execution. During the calculation of the cost of the transmission line the cost of the power plant connection lines are not considered assuming the fact that the hydropower owner shall develop their own transmission line up to the substation. The investment cost of indivudal transmission line and substation is calculated separately and is presented in Section: D Subsection: Investment Cost of Zone wise presentation.

D. Proposed Transmission Network

The transmission network is proposed to evacuate power from every hydropower station with high reliability. The proposed transmission network will cater to 38 GW of operating, planned and proposed hydropower generation and estimated peak load demand of 18 GW by the year 2040. Major hub substation is identified near a cluster of major hydropower and major load center. The transmission lines run across the major river corridors connecting major hub substation. Connections between the major corridor transmission line along the southern Terai region and the mid- hill region create a loop of 400kV backbone trunk line.

The transmission network of Nepal is divided into 5 zones, where each zone is self-sufficient in terms of generation as per the regional load demand, with minimum inter-zonal power exchange needed, however, each zone is capable of operating in inter-area operations. The analysis of the proposed transmission network is performed zone-wise to focus on regional problems as well as to address issues like inter-areas and interconnections flows.

The details of each zonal division are presented below. Summary of total load demand and total power generation across each zone is presented in pie chart as shown below:

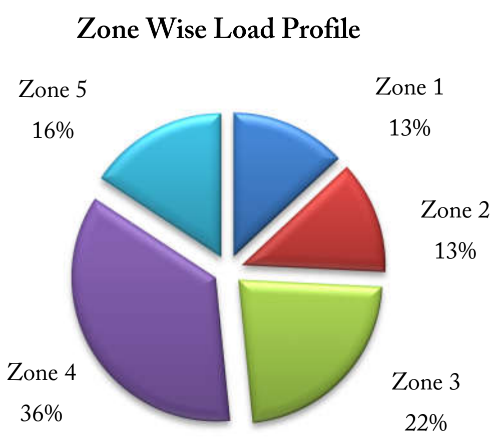

Figure 7: Load demand scenario of system zone wise.

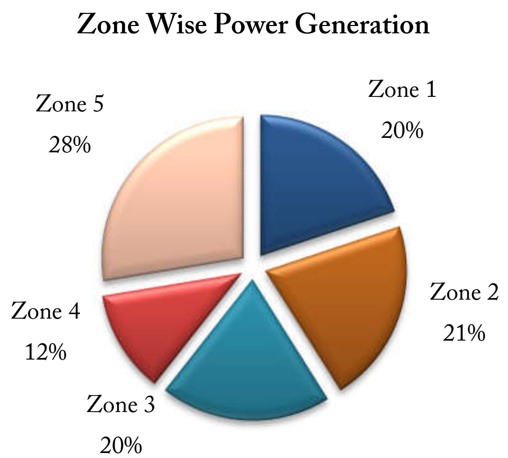

Figure 8: Zone wise generation scenario of Nepal

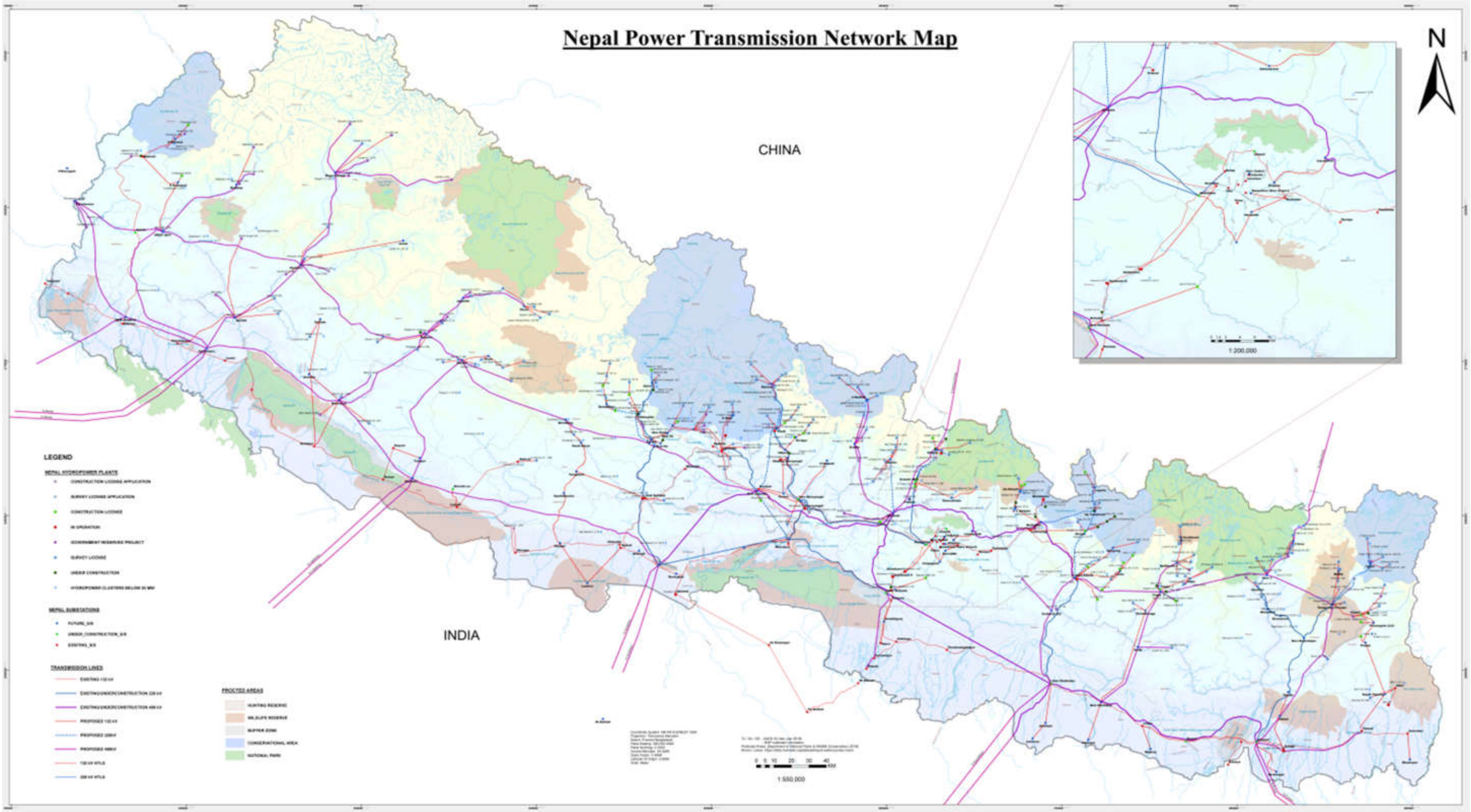

Figure 9: Proposed transmission line Network for 2040

1. Zone 1

1.1. Presentation of the Zone

Zone 1 covers entire Province No 7 (Current Far Western Development Region) and some districts of Province-6 (Current MidWestern Development Region). The zone consists of Kanchanpur, Kailali, Doti, Achham, Dadeldhura, Baitadi, Darchula, Bajhang, Bajura, Kalikot, Jumla, Mugu, Humla districts and some part of Surkhet district. Pancheswor Multipurpose, West Seti, Humla Karnali, Upper Karnali, SR6, Betan Karnali are the major hydro-power projects located in this zone. This zone consists of hydropowers in Karnali and Seti corridors. Karnali corridor extending from Mugu Karnali to Dododhara and other 400kV Double circuit transmission lines in Seti corridor like West Seti - Dododhara, West Seti -Phukhot, and Pancheswor - Dododhara are the major transmission lines in this zone. Major substations planned to evacuate the power generated are located in New Attariya, Phukot, Dododhara, Betan and West Seti. The total installed capacity of hydro power plants and load demand by 2040 is expected to reach about 9.92 GW and 2.3 GW respectively.

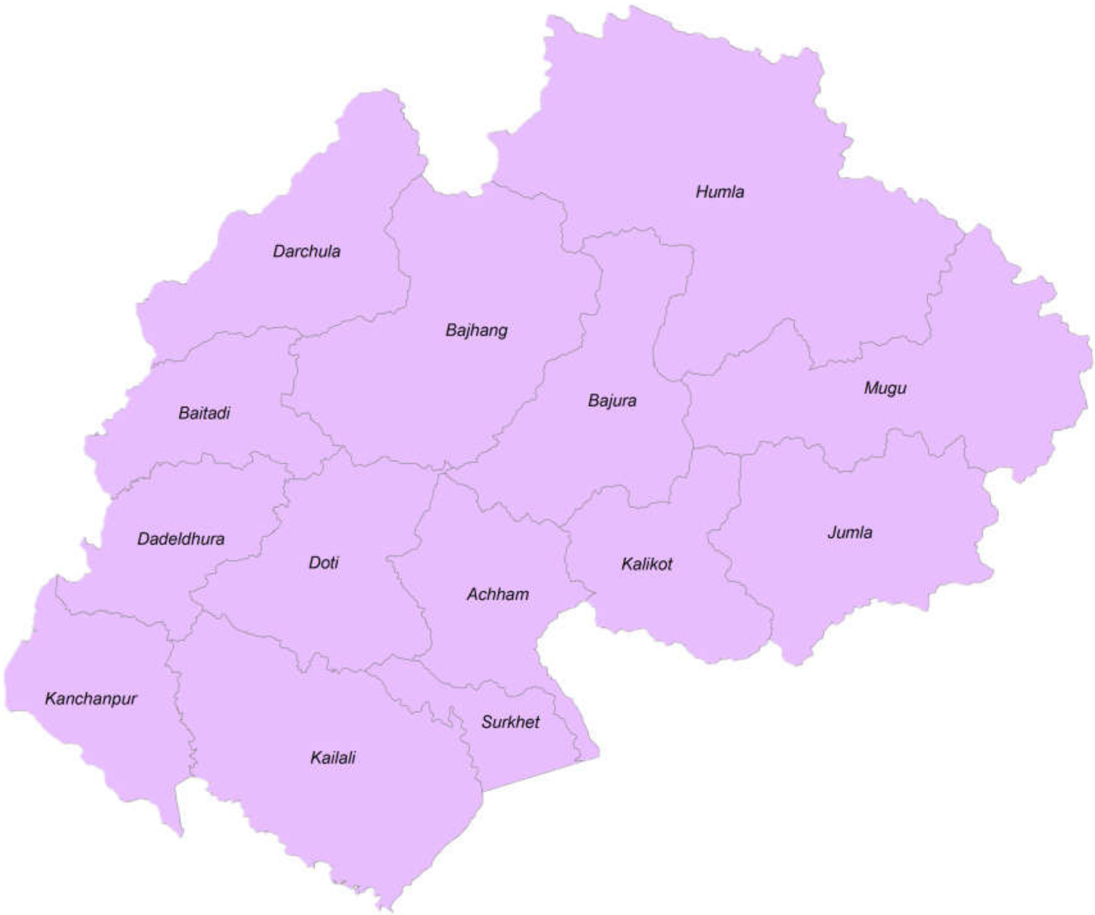

Figure 10: Overview of Zone-1

1.2. Existing Network

Currently, three major 132kV substations are present in the southern belt of this zone.

- Mahendranagar substation is located in Lalpur in Kanchanpur district with 132/33kV, 17.5 MVA transformer.
- Attariya substation is located at Attariya in Kailali district with 132/33kV, 60 MVA transformer.
- Lumki substation is located at Lumki in Kailali district with 132/33kV, 22.5 MVA transformer.

Existing lines in this zone are:

- Attariya-Mahendranagar-Gaddachauki 132kV doubles circuit line with total length of 98 km.
- Attariya-Lumki 132kV doubles circuit line with total length of 64.15 km.
- Balanch-Attariya 132kV single circuit line with total length of 118 km was charged in November 2017.

The following substations and transmission lines are under construction or committed:

- Syaule substation is located at Syaule of Dadeldhura district with 132/33kV, 30 MVA transformer of total installed capacity is under construction.
- Phukot (Kalikot) -Karmadev (Indo-Nepal) 400kV double circuit transmission line of 130 km length with ACSR quad Moose conductor with substations at Phukot (Kalikot), Betan (Surkhet) and Dododhara (Kailali) is committed. The terminal point at Karmadev will be connection point at Nepali side for Dododhara- Bareilly for cross-border transmission line.
- West Seti-Dododhara 400kV double circuit line of about 100 km length with ACSR quad Moose Conductor is committed

1.3. Overview of Committed and Planned Lines

Figure below shows the committed and planned line of Zone 1. 400kV lines are planned to evacuate power from Mahakali, West Seti and Karnali corridor. These lines will evacuate power from Pancheswor (Pancheswor, Rupaligad Re-regulating, etc), Mugu Karnali Substation (Mugu Karnali-Cascade, etc), Phukot substation (Phukot Karnali, Tila 1, Tila 2 etc), West Seti (West Seti, etc) Betan (Betan, SR 6, etc) and Dododhara substation is major load subsation. The portion of transmission line from Phukot to Dododhara is undergoing detailed study by RPGCL. 400kV transmission line is planned from Pancheswor to New Attariya substation in Kailali. 400kV transmission line is planned from West Seti to Dododhara substation in Kailali. Dododhara and New Attariya substation is connection point in 400kV East West transmission line as well as export point for cross-border connection to Bareli of India.

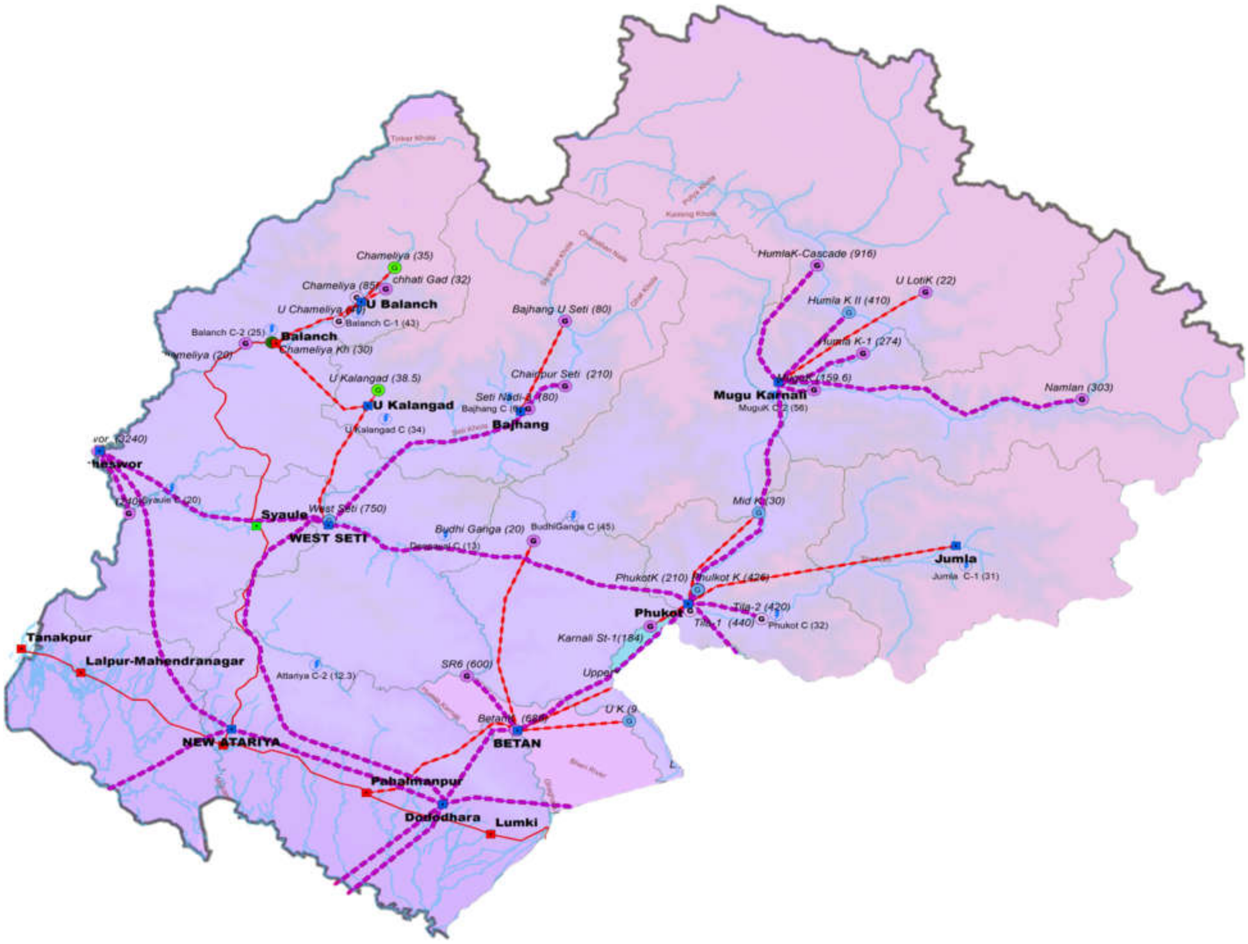

Figure 11: Overview of existing and committed network and substation of Zone 1 for year 2040

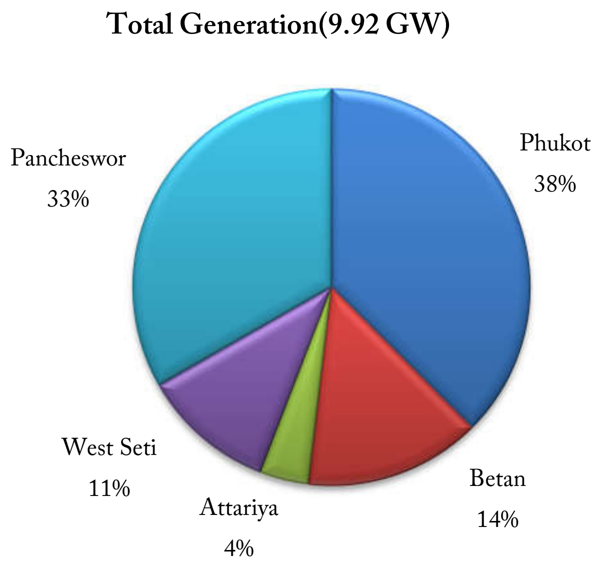

Figure 12: Generation chart of Zone 1 for year 2040

1.4. Demand Forecast

There are nine main load substations with the combined capacity of 2360 MW that supply power demand to domestic, commercial, industrial, transportation load in Zone 1. The concentration of load is assumed to be high at the Terai region and low at the Himalayan region. Load at 400kV and 132kV substation is tabulated below. Attariya 400kV and 132kV is the substation planned to supply power to two major cities of this zone i.e. Dhangadi and Mahendranagar. 400kV substation at Dododhara is planned to supply power to Tikapur, Lamki and their periphery.

Table 7: Substation load demand of Zone-1

S.N	Substation	Load (MW)	Total (MW)
1	Dododhara	1300	**2360**
2	Attariya	400	
3	Balanch	50	
4	MuguKarnali	75	
5	Phukhot	155	
6	Sayule	50	
7	Pahalmanpur	100	
8	Betan	80	
9	West Seti	150	

1.5. Generation Plan and Definition of Clusters of Power Plants

This section gives detail about the different hydropower project that would connect (evacuate power) to the substation (existing, committed or proposed). Main factors taken in consideration for the evacuation of power are:

- Location of power generation project
- Existing and committed lines/ substation

1.5.1. Pancheswor Hub

The largest project planned in Zone 1 is the Pancheswor Multipurpose (3240 MW Nepal side out of 6480 MW), which will be connected to Pancheswaor hub, along with Rupaligad Re-regulating, 240 MW.

Table 8: Power plant connected to Pancheswor substation by 2040

Substation	Hub	Hydropower	Capacity	Total
Pancheswor	Pancheswor	Rupaligad Re - regulating	240	3480
		Pancheswor Multipurpose	3240	
	Total			3480

1.5.2. Attariya substation

Power from Chameliya river and surroundings area are collected in Balanch and Kalangad hub and evacuated to Attariya substation through 132kV transmission line. Chameliya (Chetigad), 85 MW along with other hydropower projects amounting to total of 310.85 MW is connected via Balanch Hub to this substation. Power from Pancheswar is connected to 400kV East West backbone in Terai through Attariya. A double circuit cross-border transmission lines will be connected from Attariya to New Bareilly substation in India to export upto 700 MW of power. The detail of generation plan connected to Attariya 400kV substation is tabulated below.

Table 9: Power plant intending to connect at Attariya hub

Substation	Hub	Hydropower	Capacity	Total
Attariya	Balanch Hub	Chameliya Khola	30	310.85
		Chameliya Hydropower Project	35	
		Chhati Gad	32	
		Chameliya (Chhetigad)	85	
		Upper Chameliya HP	40	
		Lower Chameliya	20	
		Balanch Cluster 1	43.85	
		Balanch Cluster 2	25	
	Upper Kalangad	Upper Kalangad	38.46	72.46
		Upper Kalangad Cluster	34	
	Syaule	Syaule Cluster 1	20.81	20.81
	Attariya	Attariya Cluster 2	12.3	12.3
	Total			416.42

1.5.3. West Seti Hub

West Seti (750 MW) Storage, which lies in 70 km north from Dhangadi in Doti district, is a project with high priority. West Seti hub is created to evacuate power from West Seti Project and other neighbouring projects from Bajhang and Deepayal hub. Around 1139 MW power will be evacuated from West Set substation.

Table 10: Power plant intending to connect at West Seti hub

Substation	Hub	Hydropower	Capacity	Total
West Seti	Bajhang	Chainpur Seti HEP	210	376
		Seti Nadi-3 HPP	80	
		Bajhang Upper Seti Hydropower Project	80	
		Bajhang Cluster	6	
	Deepayal	Deepayal Cluster	13	13
	West Seti	West Seti	750	750
	Total			**1139**

1.5.4. Dododhara and Phukot substation

Dododhara substation will be a major substation in Zone 1 with connection to major transmission line viz Karnali corridor and East West 400kV transmission line, and connection point for power export to Bareilly of India. Hydropower projects in Karnali corridor will be collected in Mugu Karnali hub, Phukot hub and Betan hub and subsequently connected to Dododhara substation though 400kV double circuit transmission line. Humla Karnali-Cascade (916 MW), Namlan (303 MW), Humla Karnali-1(274 MW), Humla Karnali II (410 MW) and Mugu Karnali HPP (159.62 MW) are the major hydropower projects to be connected to Mugu Karnali hub. Additional 1532.8 MW from Phukot Karnali (426 MW), Tila 1 (440 MW) and Tila 2 (420 MW) will be connected to Phukot hub. 1438MW power from Betan Karnali and other hydropower projects will be connected through Betan Hub. Hence, a total of 5214.9MW is evacuated to Dododhara substation through Karnali corridor. Quad circuit cross-border transmission lines will be connected from Dododhara to New Bareilly substation in India to export upto 3000 MW of power.

Table 11: Power plant intending to connect at Dododhara substation

Substation	Hub	Hydropower	Capacity	Total
Dododhara	Betan	Betan Karnali	688	1114
		Upper Karnali	90	
		Upper Karnali B	60	
		SR-6	276	
	Mugu Karnali	Upper Loti karnali	22	2141.4
		Mugu Karnali HPP	159.62	
		Humla Karnali-1	274	
		Namlan	303	
		Humla Karnali-Cascade	916	
		Humla Karnali II HEP	410	
		Mugu Karnali Cluster 2	56.8	
	Budhi Ganga	Budhiganga Cluster	44.95	64.95
		Budhi Ganga	20	
	Jumla	Jumla Cluster 1	37.73	37.73
	Phukot	Tila-2 Hydropower Project	420	1532.8
		Tila-1 Hydropower Project	440	
		Phukot Karnali	426	
		Middle Karnali	30	
		Karnali St-1	184	
		Phukot Cluster	32.8	
	Total			**4890.9**

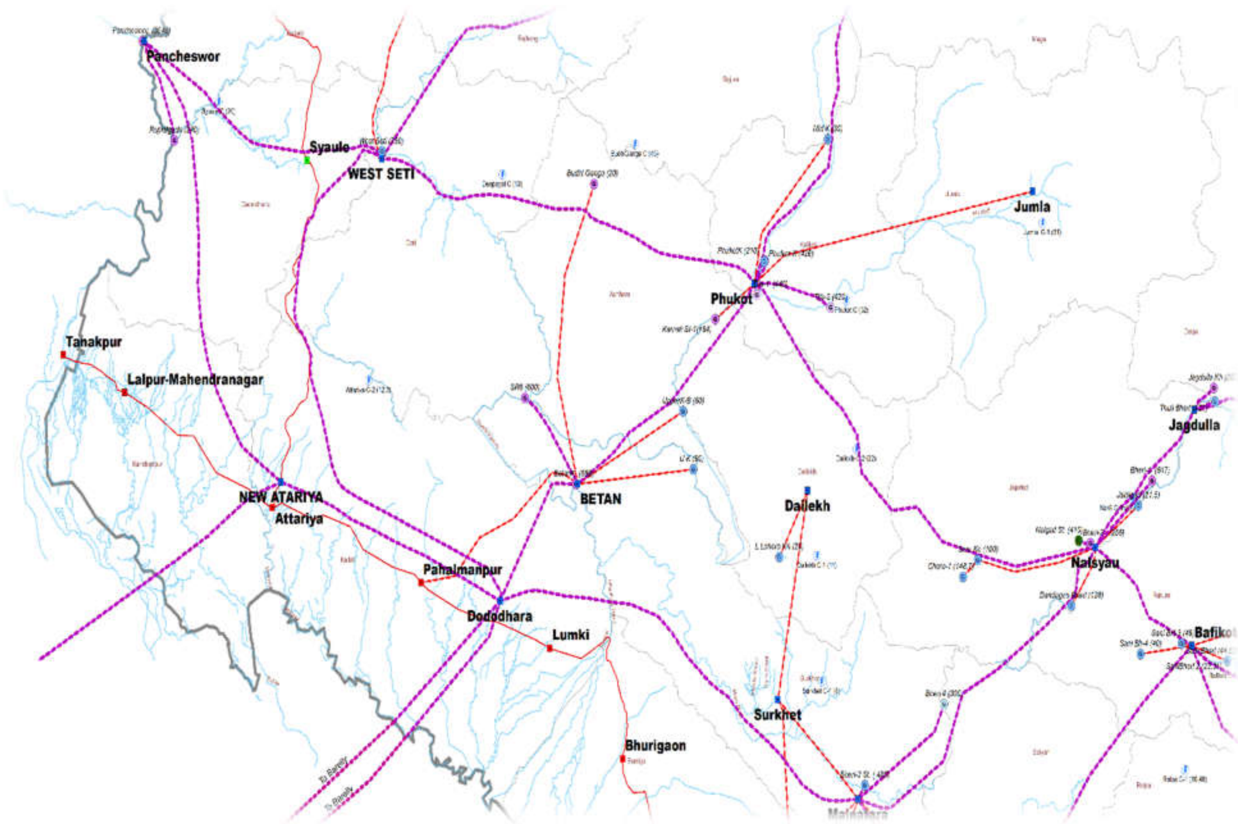

Figure 13: Dododhara Substation and periphery

1.6. Future Transmission Lines

Several transmission lines are under study in Zone 1. Transmission lines are proposed to evacuate powers from Mahakali corridor, West Seti Corridor and Karnali Corridor.

i. Transmission Line from Pancheshowr substation of Baitadi district to Attariya substation of Kailali district is proposed to evacuate the power from Pancheshwor region. Around 3480 MW of power is needed to be evacuated from Pancheshwor substation. Around 88 km of Quad Moose 400kV double circuit line is proposed between Pancheshwor and Attariya. This transmission line shall be the part of the proposed ring network.
ii. Transmission line from Bajhang substation of Bajhang district to West Seti substation of Doti district is proposed to evacuate power from Bajhang Region. Around 380 MW of power is needed to be evacuated from Bajhang substation. Around 60 km of Twin Bison double circuit line is proposed between Bajhang substation and West Seti substation. West Seti substation shall be linked to the Dododhara substation via 400kV line. Around 1140MW of power is needed to be evacuated from West Seti substation. Around 109 km of Quad Moose 400kV double circuit line is proposed between West Seti to Dododhara.

iii. Transmission line from Mugu Karnali substation of Mugu district to Phukot substation of Kalikot district is proposed to evacuate power from Mugu Region. Around 2141 MW of power is needed to be evacuated from Mugu substation. Around 71 km of Quad Moose 400kV double circuit line is proposed between Mugu Karnali substation and Phukot substation. From Phukot substation Transmission line shall be linked to the Dododhara substation of Kailali district via Betan substation of Surkhet district and extended upto Karmadev at Indo-Nepal Border around 1532 MW of power is expected to be connected at Phukot substation and additional 1114 MW of power at Betan substation needed to be evacuated. Around 138 km of Quad Moose 400kV double circuit line is proposed between Phukot and Karmadev. The section from Phukot to Kamadev is under study by RPGCL. Karmadev is a point of cross-border transmission line between Nepal and India. Two double circuit transmission lines are proposed from Karmadev to Bareliy in India.

iv. Transmission line from Pancheshwor to Phukot via West Seti shall also be developed as Mid Hill Transmission Line. Around 143 km of Quad Moose 400kV double circuit line is proposed between Pancheshwor and Phukot. This transmission line shall be the part of the proposed ring network. In the long term a maximum of 2000 MW only shall be transmitted for each line of ring network.

v. Transmission Line from Attariya to Dododhara is proposed to complete the ring network in Zone 1. 68 km of Double Circuit Quad Moose 400kV Transmission line from Attariya to Dododhara is under study by NEA as a part of Butwal - Attariya 400kV Transmission Line. A double cicuit 400kV cross-border transmission line will connect New Attariya to Bareily of India.

Table 12: Existing, Under Construction, Planned and Proposed Transmission Line of Zone 1

Proposed 400 kV Transmission Line						
S.N.	**Project Name**	**Voltage Level**	**Starting Point**	**Ending Point**	**Conductor**	**Length (km)**
1	Dododhara- Attariya	400kV	Dododhara	Attariya	Quad Moose	68
2	Betan- Dododhara	400kV	Betan	Dododhara	Quad Moose	30
3	Bajhang- West Seti	400kV	Bajhang	West Seti	Twin Bison	60
5	Mugu Karnali- Phukhot	400kV	Mugu Karnali	Phukhot	Quad Moose	71
6	Pancheswor- Attariya	400kV	Pancheswor	Attariya	Quad Moose	88
7	Phukhot- Betan	400kV	Phukhot	Betan	Quad Moose	50
8	Nalgadh- Phukhot	400kV	Nalgadh	Phukhot	Quad Moose	94
9	West Seti- Dododhara	400kV	West Seti	Dododhara	Quad Moose	109
10	Phukhot- West Seti	400kV	Phukhot	West Seti	Quad Moose	87
11	West Seti- Pancheswor	400kV	West Seti	Pancheswor	Quad Moose	56
Proposed 400 kV Cross BoderTransmission Line						
S.N.	**Project Name**	**Voltage Level**	**Starting Point**	**Ending Point**	**Conductor**	**Length (km)**
1	Dododhara- Bareli	400kV	Dododhara	Nepal- India Border	Quad Moose	58
2	Attariya- Bareli	400kV	Attariya	Nepal- India Border	Quad Moose	30

1.7. Target Network Model

Transmission network for this Zone is given below:

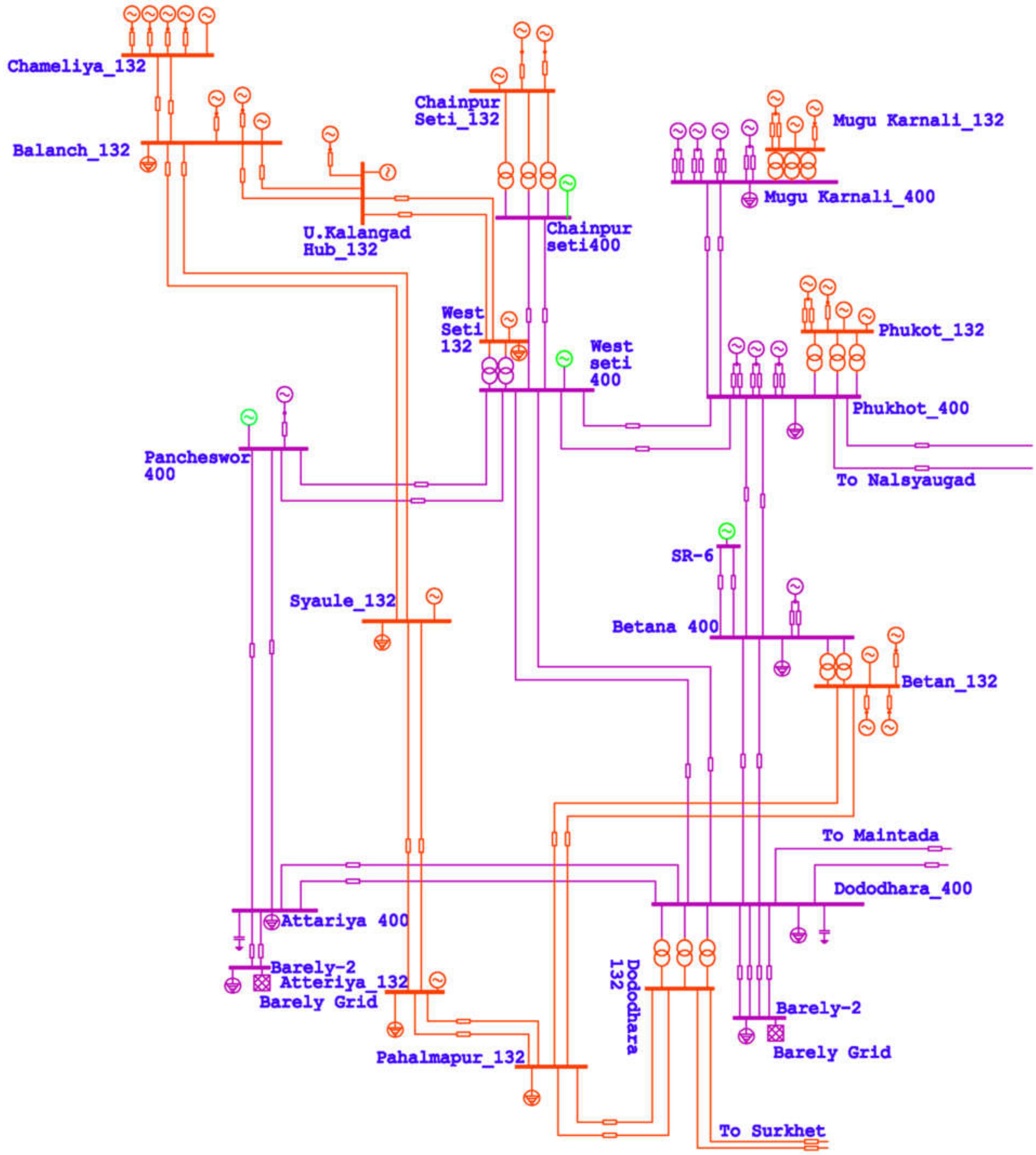

Figure 14: Target network of Zone-1 for year 2040.

1.8. Load Flow and Voltage

1.8.1. Voltage Profile of Zone-1

Voltage profile of load and generation substation under various scenarios (i.e. Wet-maximum, Wet-minimum and Dry-peak) by 2040 of Zone-1 is shown in the figure below.

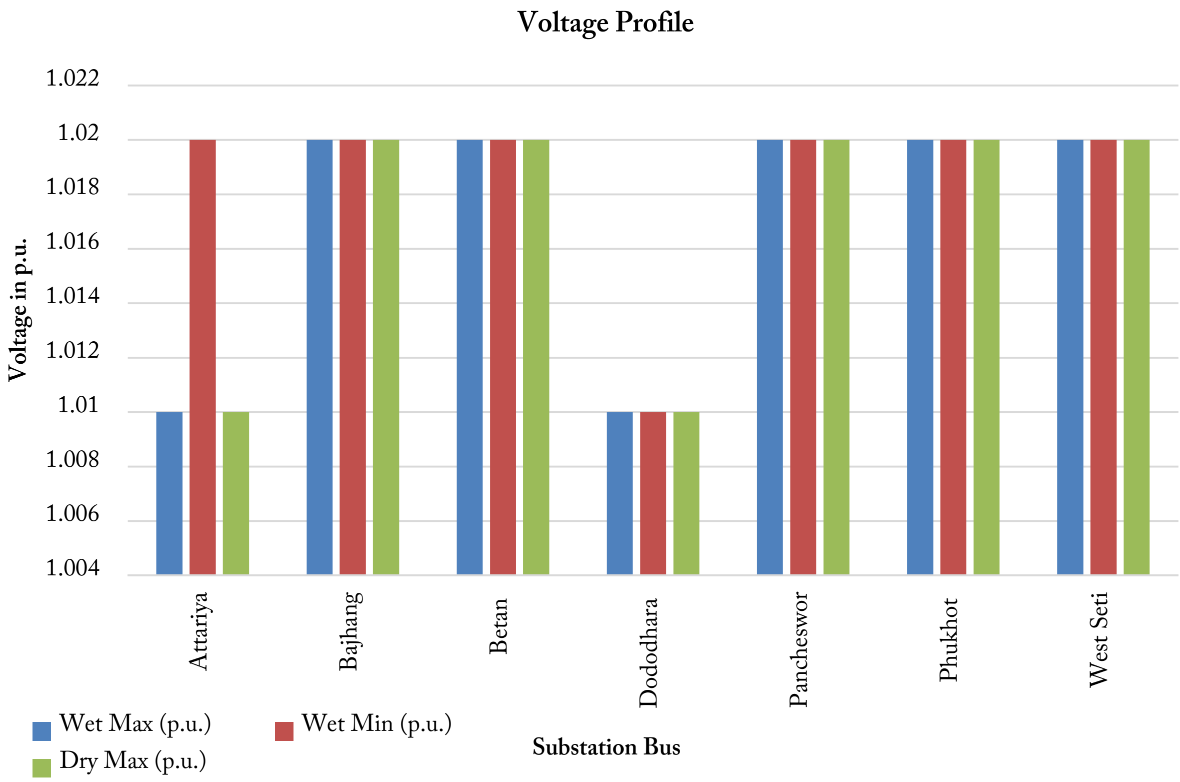

Figure 15: Voltage profile of 400kV substation under different scenario by 2040 of Zone-1.

The graph shows that the substation voltage in the Terai region is low during peak loading times in 2040, which is due to high concentration of load but within the voltage limit in all scenarios at all substation. New Attariya 400kV substation and Dododhara 400kV substation, which are proposed as the interconnection points between Nepal and India for the purpose to export the power, are also within the acceptable voltage limit for all scenarios. Overall, the bus voltages in all the major hub substations are within the acceptable range as per the grid code.

1.8.2. Line Loading of Zone-1

Line loading of major transmission lines of Zone-1 under different scenario is shown in the figure below

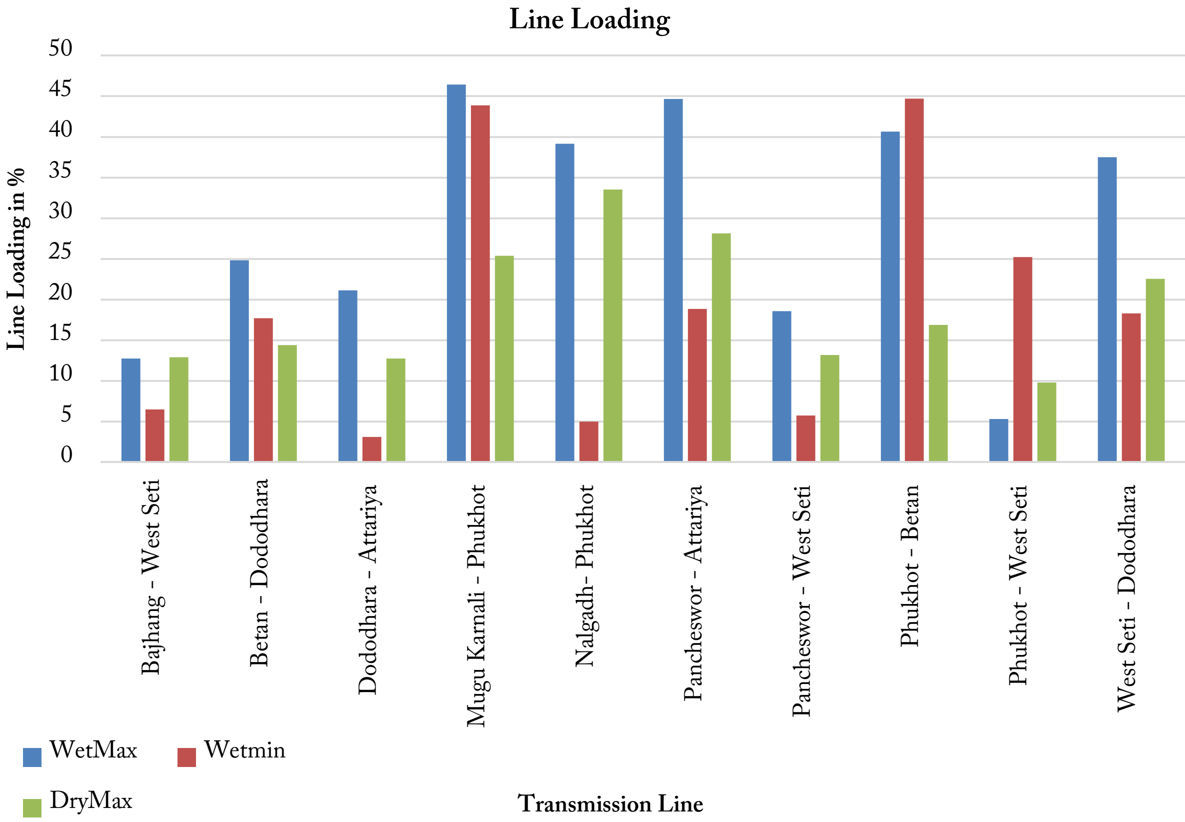

Figure 16: Percentage of line loading of line under different scenario of Zone-1 by 2040.

It is seen that the maximum loading in the lines occurs during the Wet-maximum scenario where the generation and load both are at peak level. The maximum line loading occurs in Mugu Karnali - Phukhot line, which is 46.43% of the thermal limit during the Wet-maximum scenario. Hence, all major lines are loaded within 50% of their loading capacity for all scenarios, which implies that these lines can safely withstand N-1 line contingencies without overloading.

1.9. Investment Cost

Investment cost of the transmission line and the substation of Zone 1 is calculated individually. The total cost of transmission line and the substation are 688.12 MUSD and 361.31MUSD respectively.

1.9.1. Transmission Line

1162 km of transmission line is planned in Zone 1. Among which 801 km of 400kV transmission line is proposed in Zone 1 which shall cost around 600.21 MUSD. Similarly, a total of 361 km of 132kV transmission line is proposed in Zone 1 with an estimated cost of 87.91 MUSD.

Table 13: Cost Estimate of Transmission Line in Zone 1

S.N	Type	Project Name	Length (km)	Total Cost	Remarks
1	400kV	Dododhara- Attariya	68	53.18	
2	400kV	Betan- Dododhara	30	24.66	
3	400kV	Bajhang- West Seti	60	40.34	
4	400kV	Dododhara- Bareli	58	39.19	
5	400kV	Attariya- Bareli	30	24.66	
6	400kV	Mugu Karnali- Phukhot	71	55.27	
7	400kV	Pancheswor- Attariya	88	67.61	
8	400kV	Phukhot- Betan	50	39.51	
9	400kV	Nalgadh- Phukhot	94	72.28	
10	400kV	West Seti- Dododhara	109	82.96	
11	400kV	West Seti- Pancheswor	56	43.34	
12	400kV	Phukhot- West Seti	87	57.22	
Subtotal 400kV			**801**	**600.21**	
1	132kV	Phukot - Jumla	122	28.03	
2	132kV	Balanch - Upper Kalangad	54	13.52	
3	132kV	Balanch - Makari Gad	43	10.76	
4	132kV	U Kalangad - West Seti	64	15.88	
5	132kV	Pahalmanpur - Betan	79	19.72	
Subtotal 132kV			361	87.91	
Total			1162	688.12	

*All costs are in MUSD

1.9.2. Substation

Nine substations are planned in Zone 1. Among which eight substations with highest voltage level of 400kV with estimated cost of 352.76 MUSD and one substation with highest voltage level of 132kV with estimated cost of 8.55 MUSD is proposed in Zone 1.

Table 14: Cost Estimate of Substation in Zone 1

S.N.	Substation	Voltage Level	Total Price	Remarks
1	Attariya	400/132	44.91	
2	Bajhang	400/132	37.5	
3	Betan	400/132	44.75	
4	Dododhara	400/132	59.33	
5	Mugu Karnali	400/132	40.3	
6	Pancheswor	400	34.15	Switching
7	Phukhot	400/132	58.76	
8	West Seti	400/132	33.06	
9	U Kalangad	132/33	8.55	
Total			**361.31**	

*All costs are in MUSD

2. Zone 2

2.1. Presentation of the Zone

Zone 2 is located in the western region of Nepal and covers disitricts in Province 6 and Province 5. Districts covered in this zone are Banke, Bardiya, Dang, Surkhet, Salyan, Rolpa, Pyuthan, Dailekh, Jajarkot, Rukum and Dolpa. Major hydropowers in this Zone are located in Bheri corridor. Nalgad, Naumure Storage, Jagdulla, Uttar Ganga Storage are the major hydro power plants in this zone. Powers from Bheri corridor will be evacuated through 400kV transmission line starting from Dunai to Jagdulla, Nalgad and Maintada. Nalgad substation will be connected to 400kV mid-hilly transmission line while Maintada will be connected to 400kV East-West transmission line. The estimated installed capacity of hydropower and load demand by 2040 is expected to reach about 4.47 GW and 2.3 GW respectively in this zone.

Figure 17: Presentation of Zone-2

2.2. Existing Network

Currently, three major substations of 132kV voltage lie in the southern belt of this zone.

- Kohalpur substation is located at Kohalpur of Banke district with 132/33kV, 60 MVA transformer.
- Lamahi substation is located at Lamahi of Dang district with 132/33kV, 60 MVA transformer.
- Kusum substation is located at Kuskhusma in Banke district with 132/33kV, 12.5 MVA transformer.

Existing transmission lines in this zone are:

- Lamahi - Kohalpur-Lumki 132kV double circuit line with total length of 151.2 km.
- Lamahi- Jhimruk P/S 132kV single circuit line with total length of 45.5 km.

Substation and Transmission Lines under Construction

Ghorahi substation is located at Ghorahi of Dang district with 132/33kV, 30 MVA transformer of total installed capacity is under construction. Ghorahi-Lamahi 132 double circuit transmission line of 16 km length is under construction. Committed projects in this area:

- Nalsyau Hub (Jajarkot) – MaintadaMaintada (Surkhet)-Phulbari (Dang) 400kV double circuit line of 55 km length with ACSR quad Moose Conductor by RPGCL.
- New Kohalpur-New Lumki-New Attariya 400kV Double circuit transmission line is under study by NEA.
- New Butwal-New Kohalpur-Surkhet-Upper Karnali 400kV transmission line project is under study by NEA.

2.3. Overview of Committed and Planned Lines

Figure below shows the committed and planned line of Zone 2. A 400kV line is planned to evacuate power from Bheri corridor. The line will evacuate power from Duani Substation (ThuliBheri 1, etc), Jagdulla substation (Jagdulla, Jagdulla Kh, etc), Nalgad (Nalgad, Bheri 2, etc) and Maintada substation (Bheri-3 St, Bheri 4, etc). The portion of transmission line from Nalgad to Maintada is undergoing detailed study by the consultant of Nalgad Hydropower Project, which will be handed over to RPGCL for further development of line. 400kV transmission line is planned from Bafikot (Uttar Ganga St., Pelma, Sanu Bheri, etc) to Phulbari substation in Dang. Phulbari substation is the connection point in 400kV East-West transmission line as well as the export point for cross-border connection to Lukhnow of India.

Figure 18: Overview of exiting and committed network and substation of Zone-2 for year 2040.

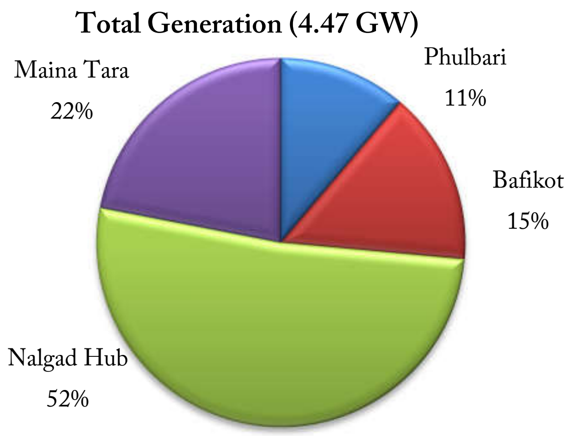

Figure 19: Generation chart of Zone-2 for year 2040.

2.4. Demand Forecast

There are two major load substations with total load demand of 2300 MW and supply the power to the domestic, commercial, industrial, transportation load of the Zone-2. Table below shows the load demand at different substation of Zone 2. Each substation is assumed to supply the power demand of its nearest load center. Maintada substation will supply power to Surkhet, Kohalpur, Nepalgunj and periphery whereas Phulbari substation will supply power to Dang Valley and various industrial areas including cement factories.

Table 15: Substation load demand of zone-2

S.N	Substation	Load (MW)	Total
1	Hapure	350	**2300**
2	Kohalpur	1950	

2.5. Generation Plan and Definition of Clusters of Power Plants

This section gives details about clustering of different hydropower project that would evacuate their power to substation (existing, committed or proposed). Main factors taken in consideration for the evacuation of power are:

- Location of power generation project
- Existing and committed lines/ Substation

2.5.1. Maintada

Maintada substation will be a major substation located in Surkhet district about 10 km east of Chinchu. Bheri-3 storage project of capacity of 480 MW, Bheri 4 (300 MW), and Sharada Babai Storage HPP (93 MW) are the major hydropower projects connected to this substation. Transmission line from Bheri Corridor will be connected to this substation for power evacuation though 400kV East West transmission line for domestic use and export. The list of hydropower projects expected to connect to this substation by year 2040 are shown in table below:

Table 16: Power plant intending to connect at MainaTara for year 2040

Substation	Hub	Hydropower	Capacity	Total
Maintada	Maintada	Bheri-Babai Diversion Project	48	921
		Bheri 4	300	
		Sharada Babai Storage HPP	93	
		Bheri-3 storage Hydropower Project (BR-3)	480	

Substation	Hub	Hydropower	Capacity	Total
	Surkhet	Surkhet Cluster 1	8	8
	Dailekh	Dailekh Cluster 1	10.976	53.336
		Lower Lohore Khola HPP	20	
		Dailekh Cluster 2	22.36	
	Total			982.33

2.5.2. Nalgad

Nalgad Reservoir project (410MW), Bheri-1 Hydropower Project (617 MW), Jagadulla Khola (307 MW), Bheri-2 Hydropower Project (256 MW), Dadagau Khalanga Bheri Hydropower Project (128 MW), Thuli Bheri (121 MW), Thuli Bheri-1 HPP (110 MW) are the major hydropower projects connected to this substation. The list of hydropower projects expected to be connected to this substation by year 2040 as shown in table below.

Table 17: Power plant intending to connect at Nalgad hub for year 2040

Substation	Hub	Hydropower	Capacity	Total
Nalgad Hub	Nalgad Hub	Jaldigad	21.48	1608.1
		Dadagau Khalanga Bheri Hydropower Project	128	
		Bheri-2 Hydropower Project	256	
		Bheri-1 Hydropower Project	617	
		Nalgad Reservoir	410	
		Saru Khola HPP	15	
		Chera 1(148.7 MW)	148.7	
		NalG Cluster 1	11.87	
	Dunai	Dunai Cluster	25	270.39
		Lawan Saharta Bheri HPP	85.39	
		Thulibheri	30	
		Thuli Bheri-1 HPP	110	
		Lower Burbangkhola	20	
	Jagdulla	Jagadulla Khola	307	428
		Thuli Bheri	121	
	Total			2306.4

2.5.3. Bafikot

Uttarganga Storage Hydropower Project of capacity 300 MW is the major hydropower project connected to this substation. The list of hydropower projects expected to be connected to this substation by year 2040 as shown in table below.

Table 18: Power plant intending to connect at Bafikot hub for year 2040

Substation	Hub	Hydropower	Capacity	Total
Bafikot	Bafikot Hub	Sani Bheri 4 HEP	40.71	453.17
		Sani Bheri 3 HEP	49.59	
		Sani Bheri-2 HEP	23.31	
		Uttarganga Storage Hydropower Project	300	
		Rolpa Cluster 1	10.48	
		Bafikot Cluster 3	29.08	
	Sisne	Sani Bheri HPP	44.52	227.52
		Pelma 2	93	
		Pelma	90	
	Total			**680.69**

2.5.4. Phulbari

Phulbari substation will be one of the major substations in East-West transmission line. A 400kV line will be connected from Bafikot. Upper Jhimruk Storage Project (100 MW) is connected to this substation via Jhimruk Hub. Naumure Storage (342 MW) is the major hydropower project which will be directly connected to the Phulbari substation. The list of hydropower projects expected to connect to this substation by year 2040 as shown in table below.

Table 19: Power plant intending to connect at Phulbari hub for year 2040

Substation	Hub	Hydropower	Capacity	Total
Phulbari	Phulbari	Naumure Storage Project	342	342
	Jhimruk	Upper Jhimruk Storage Project	100	159.48
		Jhimruk Cluster 1	18.12	
		Jhimruk Cluster 2	41.36	
	Total			**501.48**

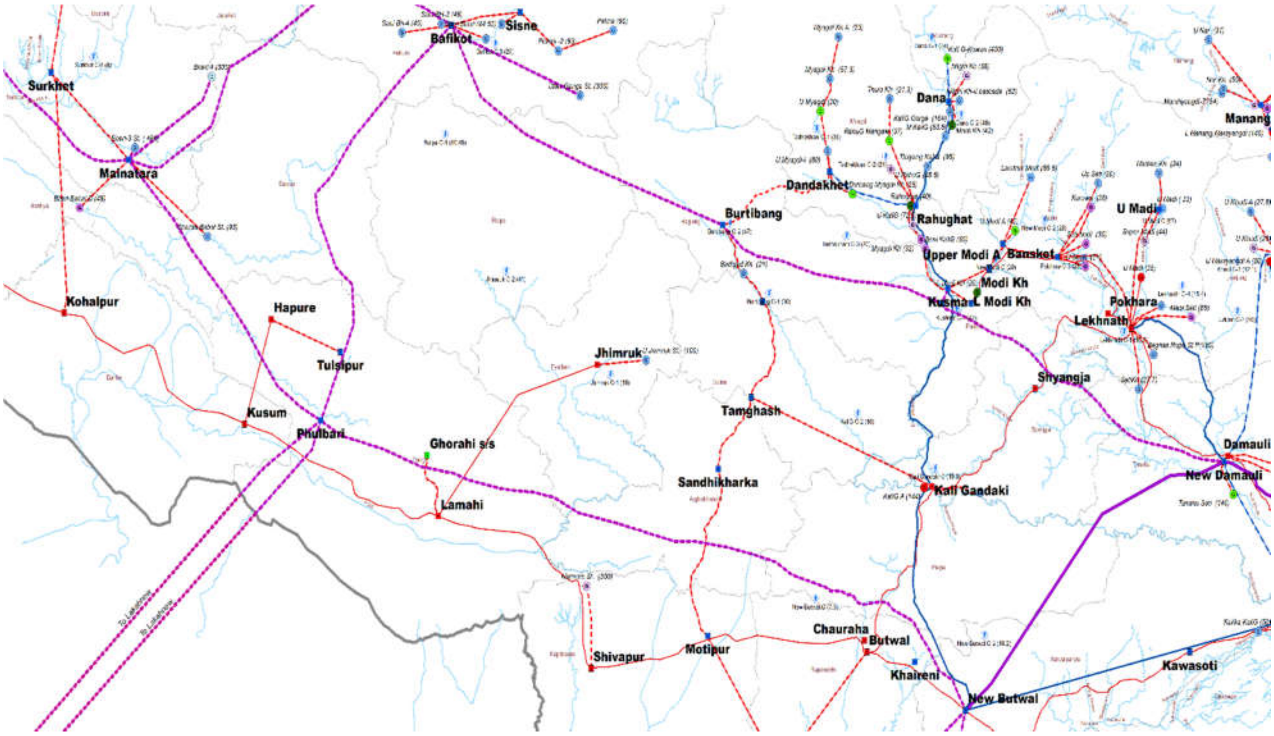

Figure 20: Phulbari Substation and periphery

2.6. Future Transmission Lines

Several transmission lines are under study in Zone 2. Transmission lines to evacuate power from Bheri corridor and other projects are proposed in this zone as described below:

i. Transmission line from Dunai substation of Dolpa district to Jagadulla substation of Dolpa district is proposed to evacuate power from Dunai Region. Around 270 MW of power is needed to be evacuated from Dunai substation. Around 50 km of Twin Bison double circuit line is proposed between Dunai substation and Jagadulla substation. Jagadulla substation shall be linked to the Nalgad substation of Jajarkot district via Twin Moose 400kV double circuit transmission line and extended to Maintada substation of Surkhet district. Around 428 MW of power is expected to be connected to Jagadulla substation and additional 1608 MW of power at Nalgad substation is needed to be evacuated. Additional 921 MW power is directly connected to Maintada substation. Around 40 km of Twin Moose 400kV double circuit Transmission line is proposed between Jagadulla and Nalgad and 70 km of Quad Moose 400kV double circuit line is proposed between Nalgad and Maintada.

ii. Transmission Line from Bafikot substation of Rukum district to Phulbari substation of Dang district is proposed to evacuate the power from Bafikot region. Around 680 MW of power is needed to be evacuated from Bafikot substation. Around 85 km of Quad Moose 400kV double circuit line is proposed between Bafikot and Phulbari. This transmission line shall be the part of the proposed ring network. Phulbari has been identified as a point for cross border transmission line between Nepal and India. Two double circuit Quad Moose 400kV transmission line from Phulbari to Lukhnow is proposed.

iii. Transmission line from Phukot to Bafikot via Nalgad shall also be developed as Mid Hill Transmission Line. Around 120 km of Quad Moose 400kV double circuit line is proposed between Phukot and Bafikot. This transmission line shall be the part of the proposed ring network. In long term at maximum of 2000 MW shall only be transmitted for each line of ring network.

iv. Transmission Line from Dododhara to Phulbari is proposed to complete the ring network in Zone 2. 148 km of Double Circuit Quad Moose 400kV Transmission line from Dododhara to Phulbari is under study by NEA as a part of Butwal - Attariya 400kV Transmission Line.

Table 20: Existing, Under Construction, Planned and Proposed Transmission Line of Zone 2

Proposed 400 kV Transmission Line						
S.N.	**Project Name**	**Voltage Level**	**Starting Point**	**Ending Point**	**Conductor**	**Length (km)**
1	Nalgadh- Bafikot	400kV	Nalgadh	Bafikot	Quad Moose	26
2	Bafikot- Phulbari	400kV	Bafikot	Phulbari	Quad Moose	85
3	Bheri-4- Maina Tara	400kV	Bheri-4	Maina Tara	Quad Moose	21
4	Dunai- Jagdulla	400kV	Dunai	Jagdulla	Twin Bison	50
5	Dododhara- Maina Tara	400kV	Dododhara	Maina Tara	Quad Moose	86
6	Nalgadh- Maina Tara	400kV	Nalgadh	Maina Tara	Quad Moose	70
7	Nalgadh- Jagdulla	400kV	Nalgadh	Jagdulla	Twin Moose	40
8	Phulbari- Maina Tara	400kV	Phulbari	Maina Tara	Quad Moose	62
9	Maina Tara-Kohalpur	400kV	Maina Tara	Kohalpur	Quad Moose	31
Proposed 400 kV Transmission Line						
S.N.	**Project Name**	**Voltage Level**	**Starting Point**	**Ending Point**	**Conductor**	**Length (km)**
1	Phulbari- Lakhnow	400kV	Phulbari	Nepal- India Border	Quad Moose	44

2.7. Target Network Model

Transmission network for this zone is given below:

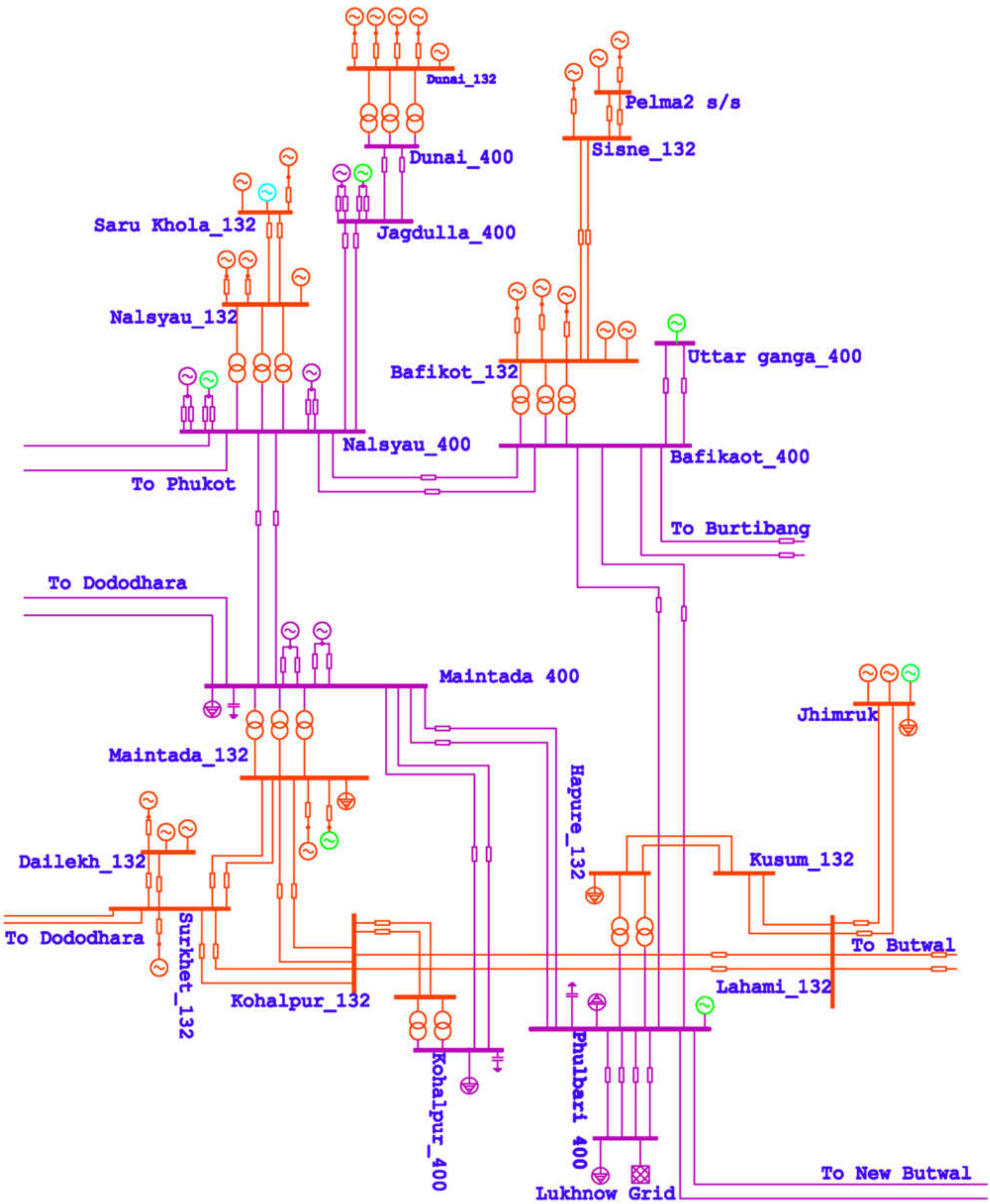

Figure 21: Target network of zone-2 for year 2040.

2.8. Load Flow Analysis

2.8.1. Voltage Profile of Zone-2

Voltage profile of load and generation substation under various scenarios (i.e. Wet-maximum, Wet-minimum and Dry-peak) by 2040 of Zone-2 is shown in the figure below.

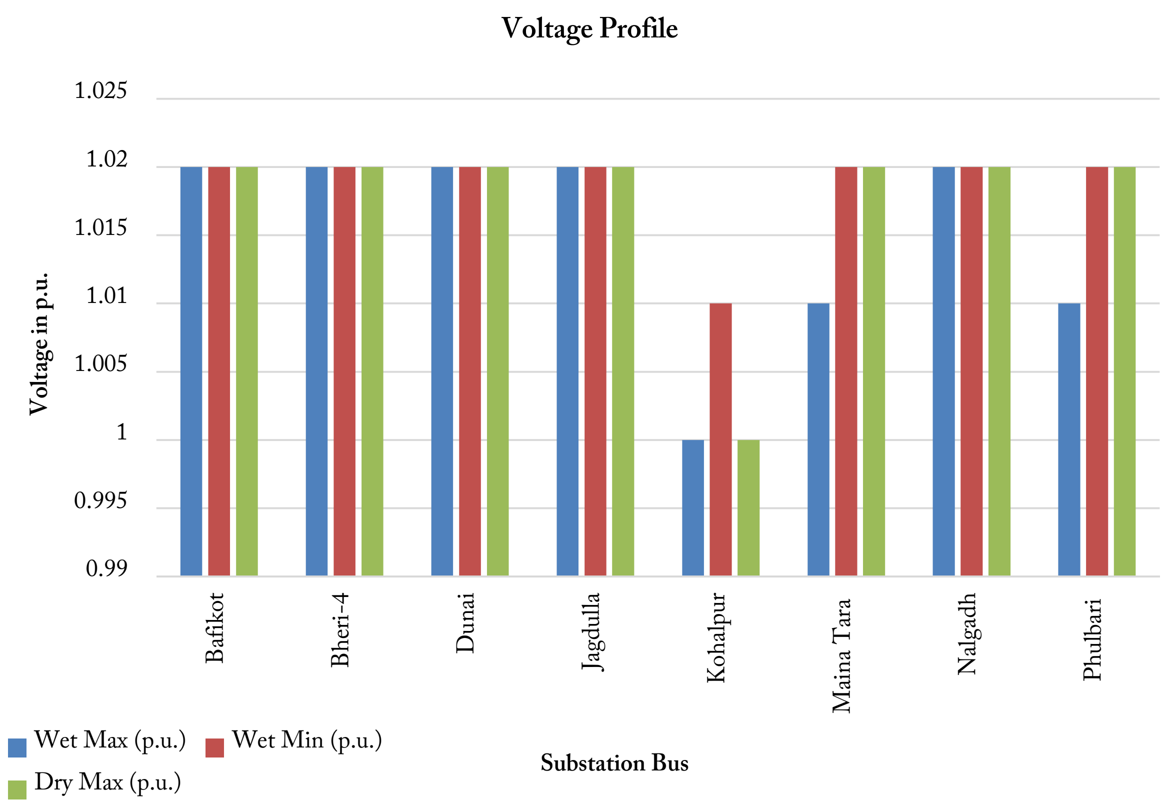

Figure 22: Bar graph of voltage of substation of different scenario of Zone-2 by 2040.

The graph shows that voltage profile at all substations are within range of 0.95 to 1.05 p.u. as per the grid code. Phulbari 400kV substation, which is proposed as the interconnection point between Nepal and India for export power to India in the future, is also seen to be within acceptable voltage limit for all scenarios.

2.8.2. Line Loading of Zone-2

Line loading of major transmission line of Zone-2 under different scenarios is as shown the figure below.

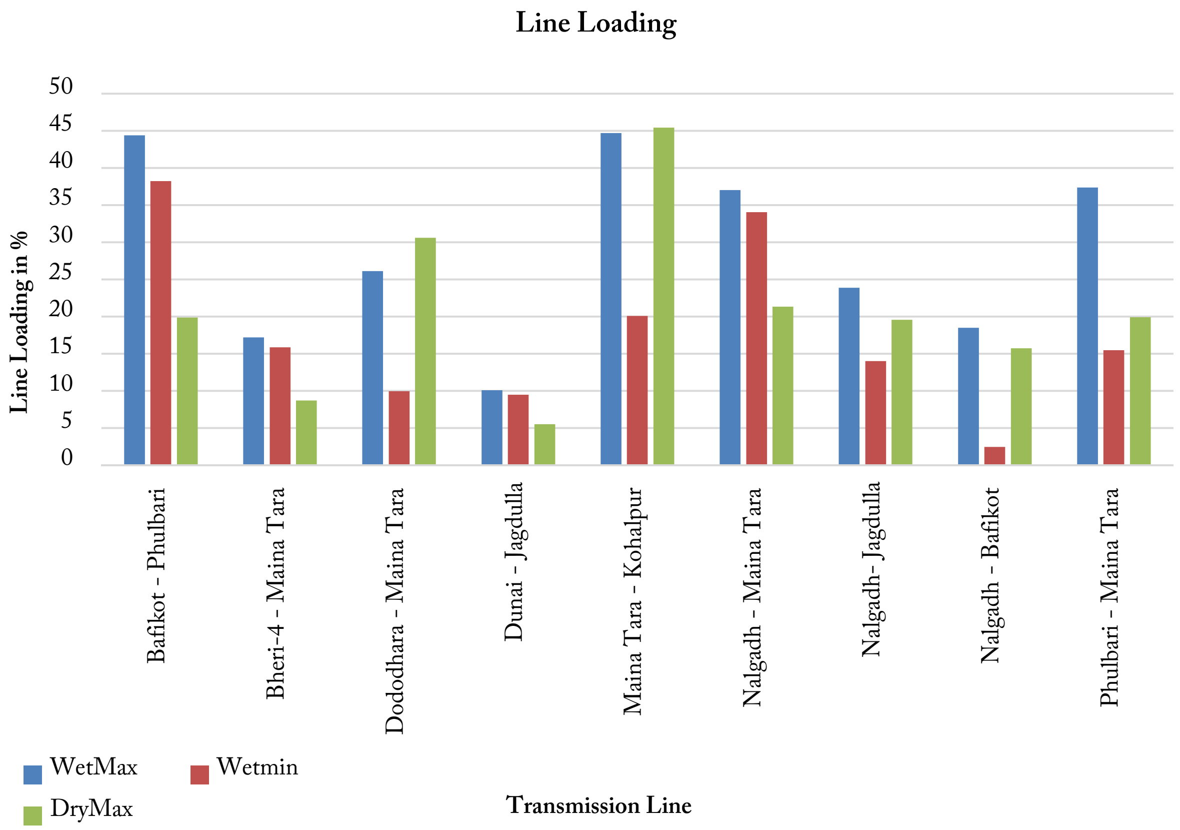

Figure 23: Percentage of line loading of line of different scenario of Zone-2 by 2040.

The graph shows that the maximum line loading occurs in Maintada - Kohalpur line, i.e. 45.43% of the thermal limit during the dry season peak load hour. Hence, all major lines are loaded within 50% of their loading capacity for all scenarios, which implies that these lines can safely withstand N-1 line contingencies without overloading.

2.9. Investment Cost

Investment cost of the transmission line and the substation of Zone 2 is calculated individually. The total cost of transmission line and the substation are 480.65 MUSD and 299.97 MUSD respectively.

2.9.1. Transmission Line

859 km of transmission line is planned in Zone 2. Among which 515 km of 400kV transmission line is proposed in Zone 2 which shall cost around 392.27 MUSD. Similarly, total of 344 km of 132kV transmission line is proposed in Zone 2 with an estimated cost of 88.38 MUSD.

Table 21: Cost Estimate of Transmission Line in Zone 2

S.N	Type	Project Name	Length (km)	Total Cost (MUSD)	Remarks
1	400kV	Nalgadh- Bafikot	26	22.13	
2	400kV	Bafikot- Phulbari	85	65.03	
3	400kV	Bheri-4- Maina Tara	21	16.04	
4	400kV	Dunai- Jagdulla	50	34.15	
5	400kV	Dododhara- Maina Tara	86	66.38	
6	400kV	Nalgadh- Maina Tara	70	54.44	
7	400kV	Nalgadh- Jagdulla	40	29.83	
8	400kV	Phulbari- Maina Tara	62	48.18	
9	400kV	Maina Tara-Kohalpur	31	25.42	
10	400kV	Phulbari- Lakhnow	44	30.67	
Subtotal 400kV			**515**	**392.27**	
1	132kV	Surkhet to Dailekh	65	16.32	
2	132kV	Kohalpur to Surkhet	85	19.54	
3	132kV	Lamahi to Ghorahi	25	8.00	
4	132kV	Hapure 132/33 kV S/S to Tulsipur	32	8.91	
5	132kV	Surkhet to Mainatara	46	11.85	
6	132kV	Bafikot to Sisne	31	8.55	
7	132kV	Kohalpur to Mainatara	61	15.21	
Subtotal 132kV			**344**	**88.38**	
Total			**859**	**480.65**	

*All costs are in MUSD

2.9.2. Substation

Nine substations are planned in Zone 2. Among which eight substations with highest voltage level of 400kV with estimated cost of 289.47 MUSD and one substation with highest voltage level of 132kV with estimated cost of 10.5 MUSD is proposed in Zone 2.

Table 22: Cost Estimate of substation in Zone 1

S.N.	Substation	Voltage Level	Total Price	Remarks
1	Bafikot	400/132	46.8	
2	Bheri-4	400/132	25.3	
3	Dunai	400/132	23.12	
4	Jagdulla	400/132	24.11	
5	Maintada	400/132	45.35	
6	Nalgadh	400/132	49.03	
7	Phulbari	400/132	53.4	
8	Kohalpur	400/132	22.36	
9	Sisne	132/132	10.5	
Total			**299.97**	

*All costs are in MUSD

3. Zone 3

3.1. Presentation of the Zone

Kapilvastu, Rupandehi, Nawalparasi, Chitwan, Arghakhanchi, Palpa, Tanahu, Syangja, Gulmi, Baglung, Parbat, Gorkha, Lamjung, Kaski, Myagdi, Mustang and Manag are the districts included in Zone 3. This zone covers the hydropower projects in Kaligandaki corridor and Marsyangdi corridor. 400kV double circuit line between New Damauli to New Butwal substation, 220kV line between New Butwal to Kusma substation and New Bharatpur to New Marsyandi are the main transmission line considered for evacuating the power from main generation substation. The total installed capacity of hydropower plants and load demand by the year 2040 is expected to reach about 7.4 GW and 4.095 GW respectively.

Figure 24: Presentation of Zone-3

3.2. Existing Network

Major substations in this zone are:

- Shivapur substation is located at Shivapur of Kapilbastu district with 132/33kV, 35MVA transformer.
- Butwal substation is located at Butwal of Rupandehi district with 132/33kV, 189 MVA transformer.
- Bardghat substation is located at Bardaghat of Nawalparasi district with 132/11kV, 30 MVA transformer.
- Kawasoti substation is located at Kawasoti of Nawalparasi district with 132/33kV, 30 MVA transformer.
- Bharatpur substation is located at Bharatpur of Chitwan district with 132/33, 67.5 MVA transformer.
- Syangja substation is located in Syangja district with 132/33kV, 30 MVA transformer.
- Pokhara substation is located in Kaski district with 132/11kV, 60 MVA transformer.
- Lekhnath substation is located in Kaski district with 132/11kV, 22.5 MVA transformer.
- Damauli substation is located in Tanahu district with 132/33kV, 60 MVA transformer.

Existing lines in this zone are:

- Bharatpur-Marsyangdi 132kV single circuit line with total length of 25 km.
- Bharatpur-Damauli 132kV single circuit line with total length of 39 km.
- Bharatpur- Kawasoti-Bardghat 132kV single circuit with total length of 70 km.
- Bardghat-Gandak P/S 132kV double circuit line with total length of 14 km.
- Bardaghat- Butwal 132kV double circuit line with length of 43 km.
- Butwal-KGA P/A 132kV double circuit line with length of 58 km.
- KGA P/S- Lekhnath 132kV double circuit line with length of 48 km.
- Lekhnath-Damauli 132kV single circuit line with length of 45 km.
- Lekhnath-Pokhara 132kV single circuit line with length of 7 km.
- Butwal-Shivapur-Lamahi 132kV double circuit line with length of 115 km.

Substation and Lines under construction

- Butwal-Lumbini 132kV double circuit transmission line of 22 km length is under construction.
- Gulmi-Argahakhanchi-Gorusinghe 132kV double circuit transmission line of 110 km is under construction.
- Modi-Lekhnath 132kV double circuit transmission line of 42 km is under construction.
- Bardaghat-Sardi 132kV double circuit transmission line of 20 km is under construction.
- Kusma-Lower Modi single circuit transmission line of 6.2 km is under construction.
- Bharatpur-Bardaghat 220kV double circuit transmission line of 75 km is under construction.

- Marsyandi Corridor 220kV double circuit transmission line of 115 km is under construction.

Committed projects in this area are:

- New Damauli-New Butwal 400kV double circuit transmission line with total length of 271 km which extend to Ratmate-Lapsiphedi and Ratmate-New Hetauda of Zone 4.
- Kaligandaki corridor 200kV double circuit transmission line.
- 400/220kV GIS substation at Butwal and Damauli.

3.3. Overview of Committed and Planned Lines

Figure below shows the committed and planned line of Zone 3. Numerous 400kV and 220kV transmission lines are under construction or under study in this zone. New Butwal- Phulbari (Kohalpur) section of 400kV East-West transmission line is under study by NEA. Similarly, MCC Nepal has started study for construction of New Damauli- New Butwal 400kV transmission line. 220kV line in Kaligandaki corridor and 115 km line of Marsyandi Corridor is also under construction by NEA.

Figure 25: Overview of existing and committed network and substation of Zone-3 for year 2040.

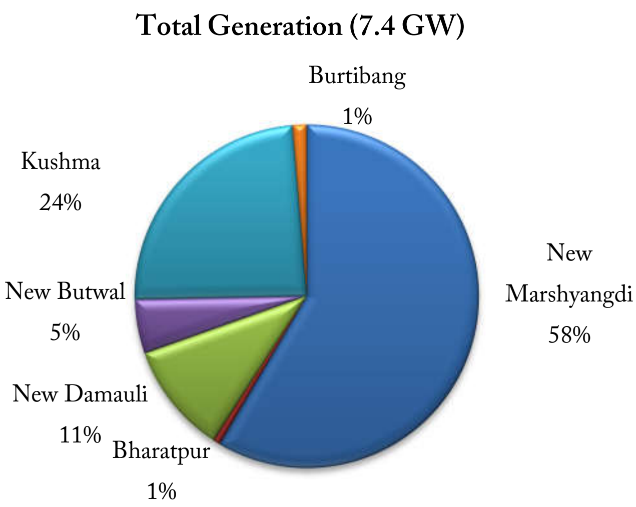

Figure 26: Generation chart of Zone-3 for year 2040.

3.4. Demand Forecast

Butwal, Bharatpur, Lekhnath and New Damauli are the major load centers, with the total load demand of 4095 MW. These substations supply the power to the domestic, commercial, industrial and transportation load of the Zone-3. Table below shows the load demand at different substation of Zone-3. Bharatpur and its periphery areas are expected to be one of the major tourist destinations and medical hub. The power required for this area will be supplied by Bharatpur substation. New Butwal substation will supply power to Butwal, Bhairahawa and the future international airport. Lekhnath substation will supply power to Pokhara, Lekhnath Metropolitan city and its periphery. The tourism and industrial sectors in this region are expected to grow. Hence, large quantity of power is required in these regions in the future.

Table 23: Substation load demand of Zone-3

S.N	Substation	Load (MW)	Total
1	Andhi Khola	60	**4095**
2	Bharatpur	1700	
3	Butwal	1660	
4	Damauli	100	
5	Dumre	30	
6	Khundi	50	
7	Kusma	100	
8	Lekhnath	250	
9	Marsyangdi	155	
10	Udipur	50	

3.5. Generation Plan and Definition of Clusters of Power Plants

This section gives details about clustering of different hydropower project that would evacuate their power to same substation (existing, committed or proposed). Main factors taken in consideration for the evacuation of power are:

- Location of power generation project
- Existing and committed lines/ substation

3.5.1. Burtibang

Badigad Khola HPP (21 MW) is the major hydropower projects connected to this substation.

Table 24: Power intended to evacuate from Burtibang substation.

Substation	Hub	Hydropower	Capacity	Total
Burtibang	Burtibang	Badigad Khola HPP	21	68.21
		Burtibang Cluster 2	47.21	
	Paudi Amrai	Burtibang Cluster 1	30.76	30.76
	Total			**98.97**

3.5.2. Kusma substation

Dadakhet, Dana and New Modi are the major hub connected to 400kV Kusma substation. Tiplyang Kaligandaki of capacity 58 MW is one of the major hydropower project connected to Rahughat Hub. Likewise, Kaligandaki Upper (72.5 MW) is directly connected to this substation. Kali Gandaki-Kowan (400 MW) and Kaligandaki Gorge Hydroelectric Project (164 MW) are connected to this substation via Dana hub. List of hydropower project connected to specific hub and substation is as shown in table below.

Table 25: Power intended to evacuate from Kushma substation.

Substation	Hub	Hydropower	Capacity	Total
Kushma	Dadakhet Hub	Upper Myagdi-I HEP	80	264.72
		Upper Myagdi	20	
		Myagdi Khola A HEP	23.7	
		Myagdi Khola Hydropower Project	57.3	
		Durbang Myagdi Khola	25	
		Tadhekhani Cluster 1	38.52	
		Tadhekhani Cluster 3	20.2	
	New Modi	Upper Modi A	42	214.78
		Landruk Modi HPP	86.59	
		New Modi Cluster 2	25.114	
		New Modi Cluster	61.08	
	Rahughat Hub	Rahughat	40	333.44
		Thulo Khola Hydropower Project	21.3	
		Tadhekhani Cluster 2	24.14	
		Myagdi Khola	32	
		Rahughat Mangale	37	
		Upper Rahughat	48.5	
		Kaligandaki Upper	72.5	
		Tiplyang Kaligandaki HEP	58	
	Kushma	Lower Modi Khola	20	92
		Beni Kaligandaki	50	
		Kushma Cluster 1	22	
	Dana	Nilgiri Khola-II cascade Project	62	833.7
		Nilgiri Khola	38	

Substation	Hub	Hydropower	Capacity	Total
		Mristi Khola	42	
		Middle Kaligandaki	53.539	
		Kaligandaki Gorge Hydroelectric Project	164	
		Kali Gandaki-Kowan	400	
		Dana Cluster 1	24.55	
		Dana Cluster 2	49.61	
	Total			**1738.6**

3.5.3. New Butwal

Andhi Khola Storage Hydropower Project (180 MW) and Kali Gandaki A (144 MW), are some of the major projects to connect to Butwal substation via Kaligandaki hub. Kali Gandaki A (144 MW) is currently connected to Butwal and Lekhnath substation of 132kV. 400kV transmission line will be connected from New Damauli to New Butwal substation. The substation will be used to export power to Gorakhpur substation of India, via two 400kV double circuit transmission line. This substation is located in Province No 5.

Table 26: Power intended to evacuate from New Butwal substation

Substation	Hub	Hydropower	Capacity	Total
New Butwal	Kali Gandaki	Kali Gandaki A	144	349.65
		Andhi Khola Storage Hydropower Project	180	
		Kali Gandaki Cluster 2	10.35	
		Kali Gandaki Cluster	15.3	
	New Butwal	New Butwal Cluster 2	19.16	26.824
		New Butwal Cluster	7.664	
	Total			**376.47**

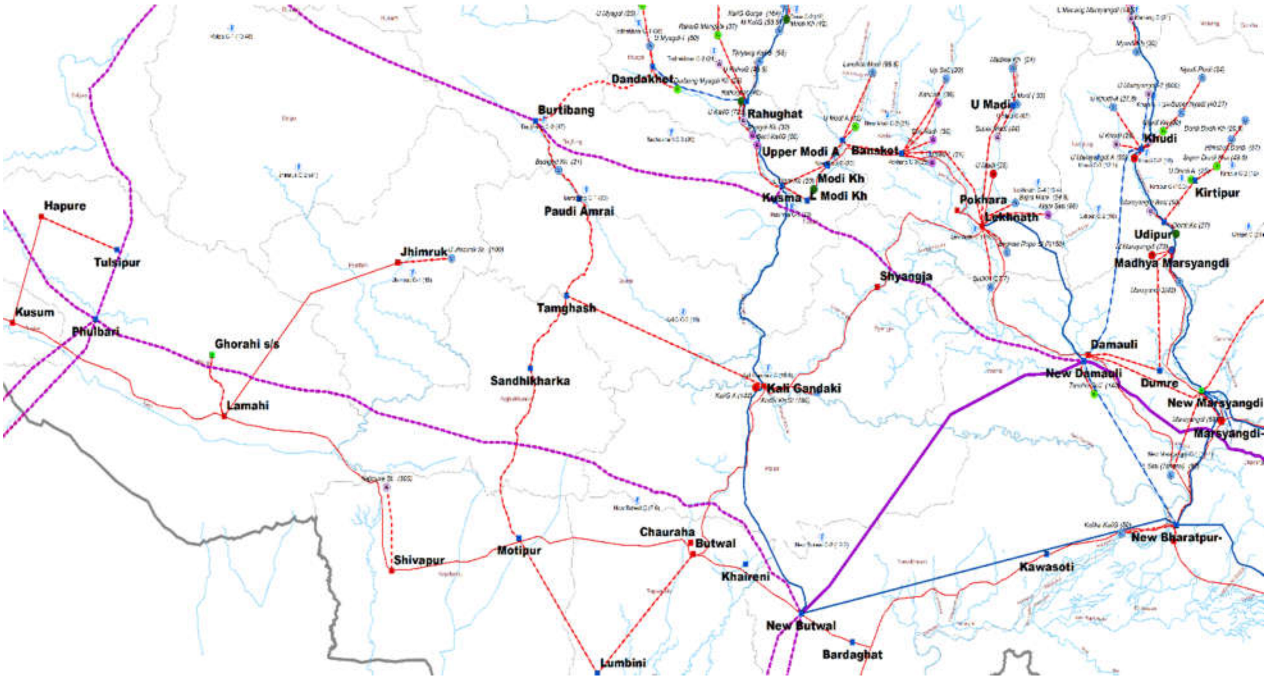

Figure 27: New Butwal substation and Periphery

3.5.4. New Damauli

Lekhnath hub is connected to New Damauli substaion for the purpose of power evacuation and load supply. Begnas Rupa Storage (150 MW) is a major HPP connected to Lekhnath Hub. Tanahu Seti HEP (140 MW) is a major hydropower project directly connected to New Damauli substation. This substation is located in Province No 4.

Table 27: Power intended to evacuate from New Damauli substation

Substation	Hub	Hydropower	Capacity	Total
New Damauli	New Damauli	Tanahu Seti HEP	140	140
	Banskot Hub	Upper Seti-1 HPP	21	128.1
		Upper Seti Hydropower Project	20	
		Seti Khola HPP	30	
		Karuwa Seti HPP	32	
		Pokhara Cluster 3	25.1	
	Upper Madi-0 Hub	Upper Madi-0 Cluster 3	67.66	168.66
		Super Madi	44	
		Madme Khola HPP	24	
		Upper Madi-0 Hydropower Project	33	
	Lekhnath	Upper Madi	25	339.4

Substation	Hub	Hydropower	Capacity	Total
		Begnas- Rupa Storage Project	150	
		Setikhola Hydroelectric Project	27.7	
		Madi Siti	86	
		Bajra Madi Hydropower Project	24.8	
		Lekhnath Cluster 1	10.5	
		Lekhnath Cluster 4	15.4	
	Total			**776.16**

3.5.5. New Marshyangdi

Budhi Gandaki Prok Khola Hydroelectric (420 MW), Budhi Gandaki Syar Khola Hydroelectric (270 MW), Upper Budhigandaki HPP (203 MW), Upper Budhi Gandaki Hydropower Project (254 MW), Budhi Gandaki Kha (260 MW), Budhi Gandaki Ka (130 MW) are some of major hydropower projects connected to this substation via Gumda Hub. Upper Marsyangdi 2 (600 MW), Upper Marsyangdi 1(138 MW), Upper Marsyangdi A (50 MW), are some of major hydropower projects connected to this substation via Khudi Hub. Super Trishuli (100 MW), Lower Seti HEP (92 MW), are connected to this substation directly. Manang-Marsyangdi (282 MW), Lower Manang Marsyangdi (140 MW), are connected to this substation via Manang Hub. This substation lies in Province No 4.

Table 28: Power intended to be evacuate from New Marsyandi substation.

Substation	Hub	Hydropower	Capacity	Total
New Marshyangdi	Gumda	Upper Budhigandaki HPP	203	863.35
		Upper Budhi Gandaki Hydropower Project	254	
		Gumda Cluster 1	16.35	
		Budhi Gandaki Ka	130	
		Budhi Gandaki Kha	260	
	Upper Budhigandaki Hub	Budhi Gandaki syar Khola Hydroelectric	60	961.35
		Super Budhigandaki	52	
		Syar Khola HPP	59.5	
		Budhi Gandaki Prok Khola Hydroelectric	420	
		Budhi Gandaki syar Khola Hydroelectric	270	
		Budhi Gandaki Nadi HPP	91.15	
		Gumda Cluster 2	8.7	

Substation	Hub	Hydropower	Capacity	Total
	Udipur	Dordi Khola	27	93.1
		Marsyangdi Besi	50	
		Udipur Cluster 2	16.1	
	Kirtipur hub	Upper Dordi A HEP	25	180.43
		Super Dordi Kha Hydropower Project	49.6	
		Himchuli Dordi Hydropower Project	57	
		Kirtipur Cluster 2	11.73	
		Dordi Dudh Khola Small Hydropower	20.8	
		Kirtipur Cluster	16.3	
	Manang	Upper Dudh khola HPP	21.16	753.84
		Suti Khola	17	
		Upper Nar Hydropower Project	31.77	
		Nar Khola Hydropower Project	50	
		Marshyangdi-7 Hydropower Project	54	
		Myadi Khola	30	
		Manang Marsyangdi	282	
		Lower Manang Marsyangdi	140	
		Dudhkhola HPP	65	
		Bhimdang Khola	32	
		Manang Cluster	30.91	
	Khudi	Upper Marsyangdi A	50	988.47
		Upper Marsyangdi 1	138	
		Upper Marsyangdi -2	600	
		Upper Khudi-A HPP	27.8	
		Upper Khudi	26	
		Super Nyadi Hydropower Project	40.27	
		Nyadi-Phidi HPP	24	
		Nyadi Khola	30	
		Khudi Cluster 1	24.3	
		Khudi Cluster 2	16	
		Khudi Cluster 3	12.1	
	New Marsyangdi	Marsyangdi	69	383.42
		Super Trishuli	100	

Substation	Hub	Hydropower	Capacity	Total
		Lower Seti Storage Project	92	
		Marsyangdi 3	42	
		Madhya Marsyangdi	70	
		New Marsyangdi Cluster 1	10.42	
	U Daraundi Hub	Chepe Cluster 1	51.56	104.6
		Daraundi Cluster 2	53.04	
	Total			4328.56

3.5.6. Bharatpur

Kalika Kali Gandaki HEP (49.5 MW) is the only projects to be connected to Bharatpur substation. This substation lies in Province No 3.

Table 29: Power intended to evacuate from Bharatpur substation

Substation	Hub	Hydropower	Capacity	Total
Bharatpur	Bharatpur	Kalika Kaligandaki HEP	49.5	49.5
	Total			49.5

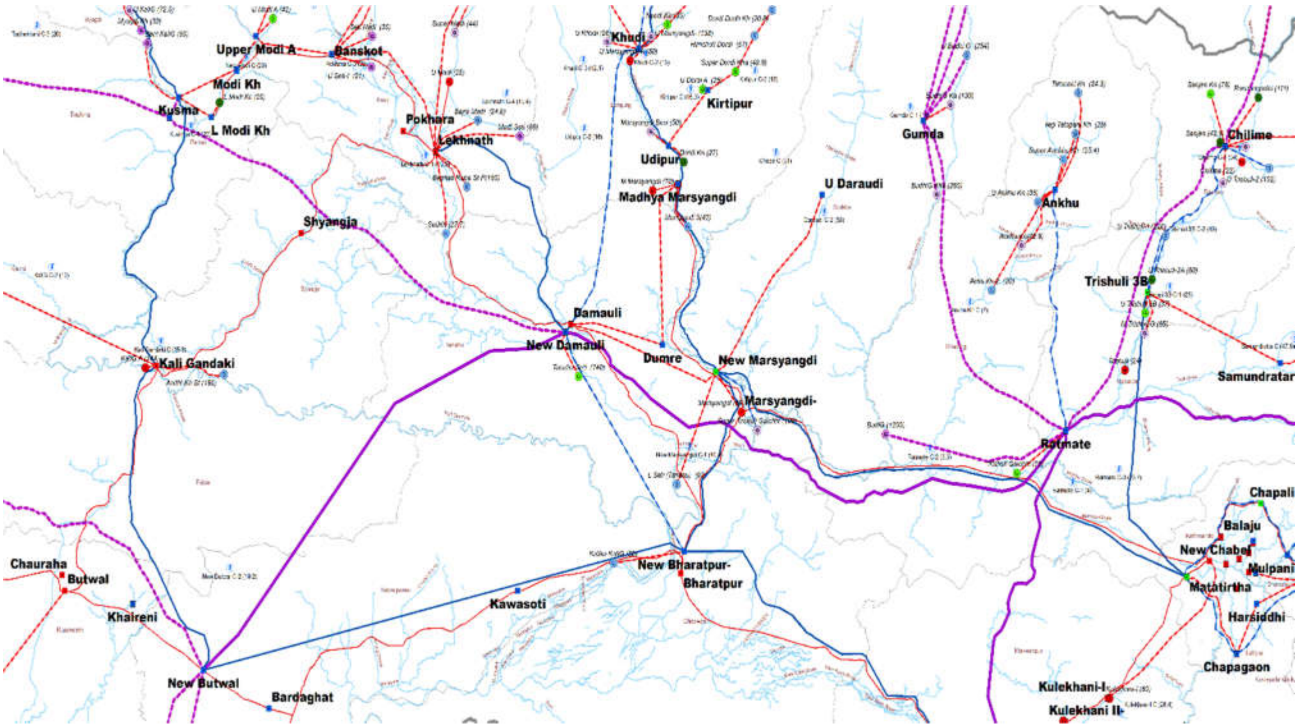

Figure 28: New Marsyangdi substation and periphery

3.6. Future Transmission Lines

Several transmission lines are under study in Zone 5. Transmission lines to evacuate power from Kaligandaki Corriodor, Marshyangi Corridor and other projects are proposed in this zone as described below:

i. Transmission line from Dana of Myagdi district to Kusma of Parbat district via Rahughat is under construction to evacuate power from Upper Kaligandaki region. Around 833 MW of power is needed to be evacuated from Dana substation with additional 333 MW to be added at Rahughat substation. Around 50 km of 220kV Twin Moose double circuit line is proposed between Dana and Kusma. From Kusma substation Transmission line shall be linked to the Butwal substation of Rupandehi district. Around 152 km of Quad Moose 220kV double circuit Transmission line is under construction between Kusma and Butwal.
ii. Transmission line from Manang substation of Manang district to Khudi substation of Lamjung district is under construction to evacuate power from Marsyangdi region. Around 753 MW of power is needed to be evacuated from Manang substation. Around 27 km of 220kV Twin Zebra equivalent HTLS double circuit line is under construction between Manang and Khudi. From Khudi substation transmission line is linked to the Matatirtha substation of Kathmandu district with Udipur and Markichok substation of Lamjung district in between. 16 km of Twin Bison equivalent HTLS 220kV double circuit Transmission line is under construction between Khudi and Udipur, 31 km Twin Zebra equivalent 220kV double circuit transmission line is under construction between Udipur to New Marsyangdi and 85 km Twin Moose 220kV double circuit Transmission line is under construction between New Marsyangdi and Matatirtha.
iii. Transmission line of 60 km length from Damauli substation of Tanahu district to Khudi substation of Lamjung district is proposed.
iv. Transmission line from Butwal substation of Rupandahi district to Bharatpur of Chitwan district is under construction. Around 75 km of Twin Bison 220kV double circuit line is under construction between Butwal and Bharatpur. Butwal has been identified as a point for cross Border transmission line between Nepal and India. Two double circuit Quad Moose 400kV transmission line from Butwal to Gorakhpur is proposed.
v. Transmission line from New Butwal substation of Rupandahi district to New Damauli substation of Tanahu district is under study by MCC. Around 75 km of Quad Moose double circuit line is proposed between New Butwal and New Damauli.
vi. Transmission Line from Dadakhet to Rahughat is under study NEA. 15 km of Double Circuit Twin Bison 220kV Transmission line from Dadakhet to Rahughat is under study to evacuate power from Myagdi river area.

Table 30: Existing, Under Construction, Planned and Proposed Transmission Line of Zone 3

Existing and Under Construction 400 kV TL						
S.N	**Project Name**	**Voltage Level**	**Starting Point**	**Ending Point**	**Conductor**	**Length (km)**
1	New Damauli- New Butwal	400kV	New Damauli	Butwal	Quad Moose	75
Proposed 400 kV Transmission Line						
S.N	**Project Name**	**Voltage Level**	**Starting Point**	**Ending Point**	**Conductor**	**Length (km)**
1	Kusma- New Damauli	400kV	Kusma	New Damauli	Quad Moose	69
2	Bafikot- Burtibang	400kV	Bafikot	Burtibang	Quad Moose	72
3	Burtibang- Kusma	400kV	Burtibang	Kusma	Quad Moose	50
4	Phulbari- Butwal	400kV	Phulbari	Butwal	Quad Moose	229
Proposed 400 kV Transmission Line						
S.N	**Project Name**	**Voltage Level**	**Starting Point**	**Ending Point**	**Conductor**	**Length (km)**
1	Butwal- Gorakhpur	400kV	Butwal	Nepal-India Border	Quad Moose	30
Existing and Under Construction 220 kV TL						
S.N	**Project Name**	**Voltage Level**	**Starting Point**	**Ending Point**	**Conductor**	**Length (km)**
1	Andhi Khola - Butwal	220kV	Andhi Khola	Butwal	Twin Bison	76
3	Barghat- Bharatpur	220kV	Butwal	Bharatpur	Twin Bison	75
4	Rahughat- Dana	220kV	Rahughat	Dana	Twin Bison	20
5	Khudi- Udipur	220kV	Khudi	Udipur	Twin Bison equ. HTLS	16
6	Kusma- Andhi Khola	220kV	Kusma	Andhi Khola	Twin Bison	76
7	Lekhnath- Damauli	220kV	Lekhnath	Damauli	Single Moose	40
8	Marsyangdi- Bharatpur	220kV	Marsyangdi	Bharatpur	Twin Zebra equ. HTLS	32
9	Manang- Khudi	220kV	Manang	Khudi	Twin Zebra equ. HTLS	27
10	New Marsyangdi- Suichatar (Mata)	220kV	Marsyangdi	Suichatar (Mata)	Twin moose	85
11	Udipur- New Marsyangdi	220kV	Udipur	Marsyangdi	Twin Zebra equ. HTLS	31
Proposed 220 kV Transmission Line						
S.N	**Project Name**	**Voltage Level**	**Starting Point**	**Ending Point**	**Conductor**	**Length (km)**

1	Khudi- Damauli	220kV	Khudi	Damauli	Twin Moose	60
2	Damauli- Bharatpur	220kV	Damauli	Bharatpur	Twin Zebra equ. HTLS	44
3	Rahughat- Kusma	220kV	Rahughat	Kusma	Twin Zebra equ. HTLS	30
4	Dadakheti Hub- Rahughat	220kV	Dadakheti Hub	Rahughat	Twin Bison	15

3.7. Target Network Model

Transmission network for this zone is given below:

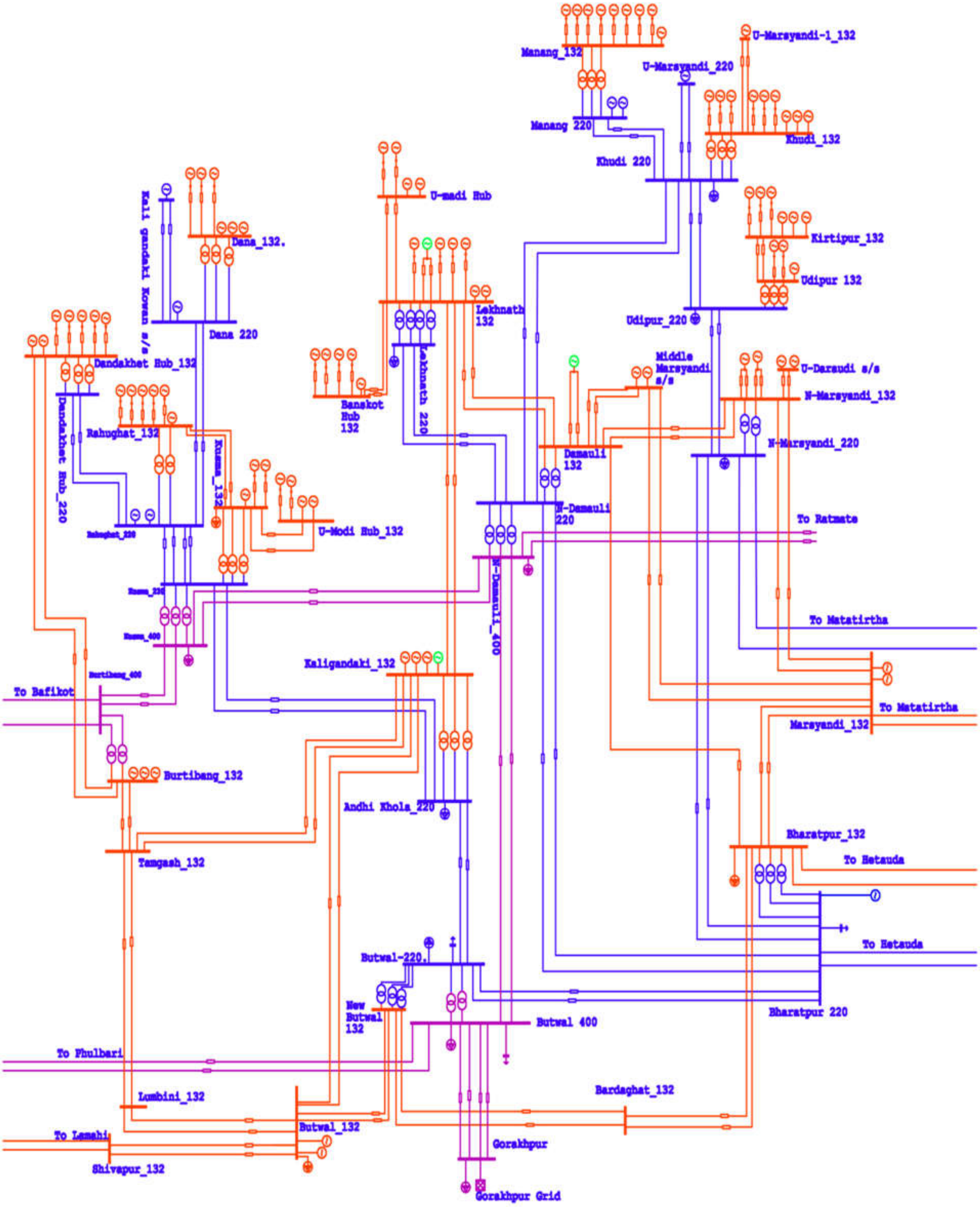

Figure 29: Target network and substation of Zone-3 for year 2040

3.8. Load Flow Analysis of Zone-3

3.8.1. Voltage Profile of Zone-3

Voltage level considered for the study mostly consists of major hub substations, which are mainly 220kV and 400kV level. Voltage profile of load and generation substation under various scenarios (i.e. wet maximum, wet minimum and dry peak) by the year 2040 of Zone-3 is as shown in the figure below.

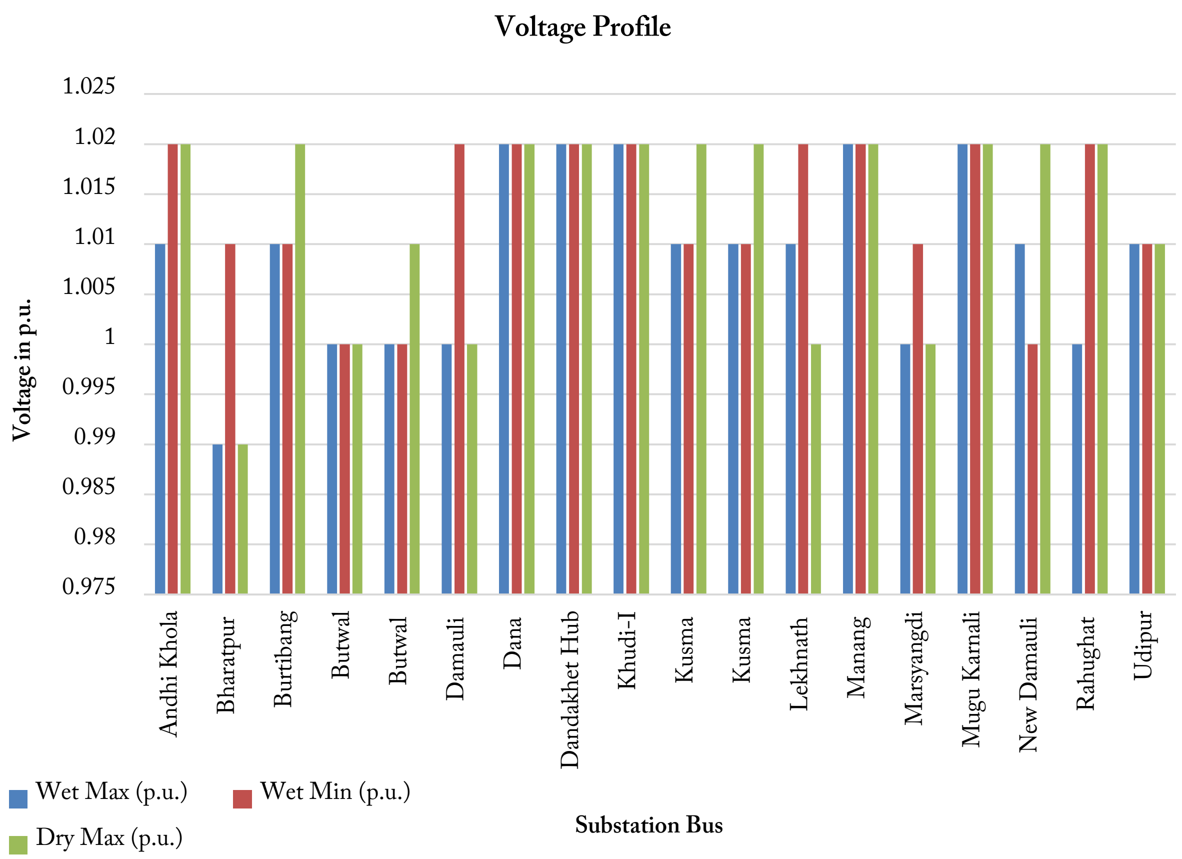

Figure 30: Bar chart of voltage profile of different scenario of Zone-3 by 2040.

The graph shows that voltage profile at all substations is within the range provided by the grid code i.e. 0.95 to 1.05 p.u. The New Butwal 400kV substation, which is considered as the interconnection point between Nepal and India for power export to India, is also seen to be within acceptable voltage range.

3.8.2. Line Loading of Zone-3

Line loading of major transmission lines of Zone-3 under different scenario is as show in the figure below

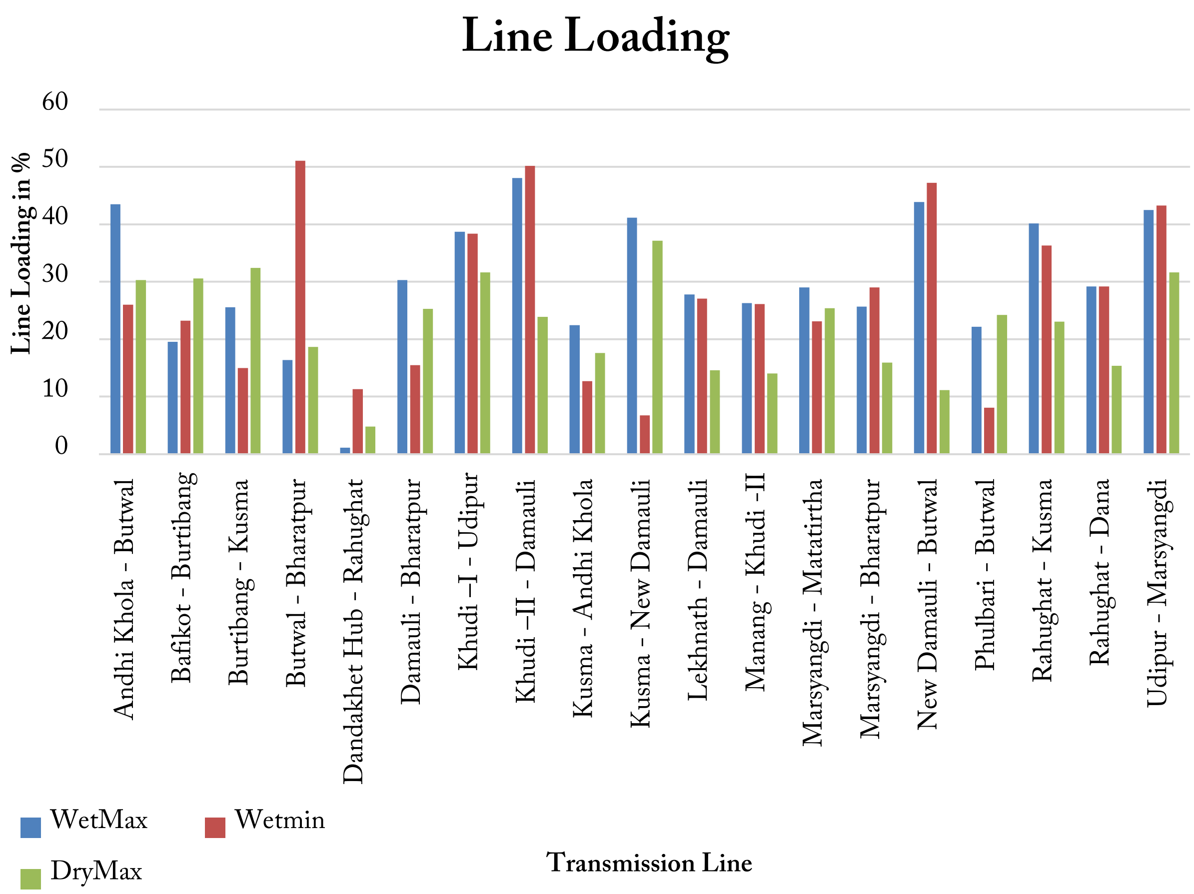

Figure 31: Line loading of 400kV and 220kV under different scenario of Zone-3.

The graph shows that among all the major lines in this zone, the maximum loading occurs during Wet-Minimum scenario in Khudi - Damauli 220kV line at 50.19% of the thermal limit Hence, all major lines can safely withstand N-1 line contingencies either without overloading or with marginal overloading.

3.9. Investment Cost

Investment cost of the transmission line and the substation of Zone 3 is calculated individually. The total cost of transmission line and the substation are 935.35 MUSD and 523.13 MUSD respectively.

3.9.1. Transmission Line

1879 km of transmission line is planned in Zone 3 with total estimated cost of 935.35 MUSD. Among which 525 km of 400kV transmission line is proposed in Zone 3 which shall cost around 404.08 MUSD. Similarly, a total of 626 km of 220kV transmission line is proposed in Zone 3 with an estimated cost of 337.78. Likewise, a total of 728 km of 132kV transmission line is proposed in Zone 3 with an estimated cost of 193.49 MUSD.

Table 31: Cost Estimate of Transmission Line in Zone 3

S.N.	Type	Project Name	Length	Total Cost (MUSD)	Remarks
1	400kV	Bafikot- Burtibang	72	55.8	
2	400kV	Burtibang- Kusma	50	39.51	
3	400kV	Butwal- Gorakhpur	30	25.77	
5	400kV	Kusma- New Damauli	69	54.04	
6	400kV	New Damauli- Butwal	75	57.81	
7	400kV	Phulbari- Butwal	229	171.15	
Subtotal 400 kV			525	404.08	
1	220kV	Andhi Khola - Butwal	76	37.26	
3	220kV	Butwal- Bharatpur	75	34.51	
4	220kV	Damauli- Bharatpur	44	29.33	
5	220kV	Khudi- Damauli	60	29.87	
6	220kV	Khudi- Udipur	16	10.58	HTLS
7	220kV	Kusma- Andhi Khola	76	34.51	
8	220kV	Lekhnath- Damauli	40	20.82	
9	220kV	Manang- Khudi	27	18.57	HTLS
10	220kV	Marsyangdi- Bharatpur	32	21.93	
11	220kV	Marsyangdi- Suichatar (Mata)	85	38.05	
12	220kV	Rahughat- Dana	20	11.46	
13	220kV	Rahughat- Kusma	30	20.87	
14	220kV	Udipur- Marsyangdi	31	21.31	HTLS
15	220kV	Dadakheti Hub- Rahughat	15	8.69	

Subtotal 220 kV			**626**	**337.78**	
1	132kV	Kaligandaki to Gulmi	85	20.34	
2	132kV	Kiritpur to Udipur	19	6.08	
3	132kV	Damauli to Dumre	29	8.22	
4	132kV	Dumre to Madhya Marsyangdi	45	11.62	
5	132kV	Damauli to New Marsyangdi	49	12.15	
6	132kV	Marsynagdi to New Marsyangdi	13	4.71	
7	132kV	Banskot to New Modi	24	7.34	
8	132kV	Lekhnath to Basnkot	48	11.99	
9	132kV	Kusma HUB to Lower Modi	11	4.53	
10	132kV	Motipur to Lumbini	56	14.09	
11	132kV	Sandhikharka (Argakhanchhi) to Motipur (Gorunsighe)	66	15.75	
12	132kV	Tamghash (Gulmi) to Sandhikharka (Argakhanchhi)	30	8.54	
13	132kV	Paudi Amrai to Tamghash (Gulmi)	41	10.6	
14	132kV	Burtibang to Paudi Amrai	34	9.27	
15	132kV	Butwal to Lumbini	56	14.05	
16	132kV	Kusma Hub to New Modi Hub	19	6.21	
17	132kV	Trishuli 3B HUB to Samundratar	45	11.75	
18	132kV	Upper Modi A to New Modi	11	4.25	
19	132kV	Lekhnath to Upper Madi hub	46	12.03	
Subtotal 132 kV			**728**	**193.49**	
Total			**1879**	**935.35**	

*All costs are in MUSD

3.9.2. Substation

18 substations are planned in Zone 3. Among which four substations with highest voltage level of 400kV with estimated cost of 211.23 MUSD, ten substations with highest voltage level of 220kV with estimated cost of 245.68 MUSD is proposed in Zone 3 and four substations with highest voltage level of 132kV with estimated cost of 66.22 MUSD is proposed in Zone 3.

Table 32: Cost Estimate of Substation in Zone 3

S.N.	Substation	Voltage Level	Total Price	Remarks
1	Burtibang	400/132	36.57	
2	New Butwal	400/220/132	69.59	
3	Kusma	400/220/132	59.93	
4	New Damauli	400/220/132	45.14	
5	Andhi Khola	220/132	28.65	
6	Bharatpur	220/132	41.22	
7	Dana	220/132	17.88	
8	Khudi	220/132	28.84	
9	Lekhnath	220/132	15.97	
10	Manang	220/132	23.52	
11	Marsyangdi	220/132	21.36	
12	Rahughat	220/132	26.26	
13	Tadekhani Hub	220/132	20.12	
14	Udipur	220/132	21.86	
15	Banskot Hub	132/33	17	
16	New Modi	132/33	17	
17	U Daraudi	132/33	15.22	
18	UMadi	132/33	17	
Total			523.13	

*All costs are in MUSD

4. Zone 4

4.1. Presentation of the Zone

Zone 4 covers the central region of Nepal. Parsa, Bara, Rautahat, Makwanpur, Dhading, Kathmandu, Lalitpur, Bhaktapur, Kavrepalanchok, Nuwakot, Sindhupalchok, Rasuwa, Dhanusa, Mahottari, Sarlahi, Sindhuli, Ramechhap and Dolakha are the districts within Zone 4. Budhi Gandaki Storage Hydropower Project (1200 MW), Sunkoshi-2 (1110 MW), Sunkoshi-3 (536 MW), Tamakoshi-3 TA-3 (650MW) are the major hydro power plants located in Zone 4. Power generation from hydro power plants and load demand by the year 2040, expected to reach about 8.03 GW and 6.48 GW respectively

Figure 32: Presentation of Zone-4

4.2. Existing Network

Major substations on this zone are:

- Hetauda substation located at Hetauda of Makwanpur district with 132/66kV, 90MVA transformer.
- Parwanipur substation located at Bara district with 132/66kV, 193.5 MVA transformer.
- Chandranigaharpur substation located at Rautahat district with 132/33kV, 60 MVA transformer.
- Pathlaiya substation located at Bara district with 132/11kV, 22.5 MVA transformer.
- Dhalkebar substation located at Dhanusa district with 132/33kV, 93 MVA transformer.
- Lamosagu substation located at Sindhupalchowk district with 132/33, 30 MVA transformer.
- Bhaktapur substation located at Bhaktapur district with 132/11kV, 94.5 MVA transformer.
- Balaju substation located at Balaju in Kathmandu district with 132/66kV, 45 MVA transformer.
- Suichatar substation located at Suichatar in Kathmandu district with 132/66, 113.4 MVA transformer.
- Matatirtha substation located at Matatirtha in Kathmandu district with 132/11, 22.5 MVA transformer.
- Chapali substation located at Chapali in Kathmandu district with 132/66, 30 MVA transformer.

Existing lines in this zone are:

- Dhalkebar-Muzzaffarpur Cross Border 400kV Double circuit transmission line.
- Khimti- Dhalkebar 220kV 1st circuit transmission line.
- Hetauda-KL2 132kV doubles circuit line with total length of 8 km.
- Hetauda-Bharatpur 132kV single circuit line with total length of 70 km.
- Marsyangdi -Suichatar 132kV single circuit line with total length of 84 km.
- Suichatar-KL2 132kV doubles circuit line with total length of 36 km.
- Suichatar-Balaju-Chapali-New Bhaktapur 132kV doubles circuit line with total length of 13.45 km.
- New Bhaktapur-Lamosangu 132kV double circuit line with total length of 48 km.
- Lamosangu-Khimti 132kV single circuit line with total length of 46 km.
- Lamosangu-Bhotekoshi 132kV single circuit line with total length of 31 km.

Substation and Lines under Construction:

- Thankot-Chapagaon 132kV doubles circuit transmission line.
- Ramechap-Garjyang-Khimti 132kV doubles circuit transmission line.
- Hetauda - Bharatpur 220kV transmission line 1st circuit.
- Khimti- Dhalkebar 220kV 2nd circuit transmission line.
- Chilime-Trishuli 220kV transmission line
- Marsyangdi-Kathmandu 220kV doubles circuit transmission line.

- Trishuli 3B 220kV Hub substation
- Tamakoshi -Kathmandu 220/400kV double circuit transmission line.
- Hetauda-Dhalkebar 400kV doubles circuit transmission line, which extend to Duhabi of Zone 5.

Committed projects in this area:

- Trishuli 3B Hub- Jharlyang- Malekhu 220kV transmission line

4.3. Overview of Committed and Planned lines

Figure below shows the committed and planned line of Zone 4. New Khimti- Dhalkebar 200kV transmission line is under operation. Numerous 400kV and 220kV transmission lines are under construction or under study in this zone. New Dhalkebar-Hetauda section of 400kV East-West transmission line is under construction by NEA. Similarly, MCC Nepal has started study to construct Lampsangu-Lapsiphedi-Ratmate 400kV transmission line. 220kV Upper Tamakoshi – New Khimti is also under construction by NEA.

Figure 33: Overview of existing and committed network and substation of Zone-4 for year 2040

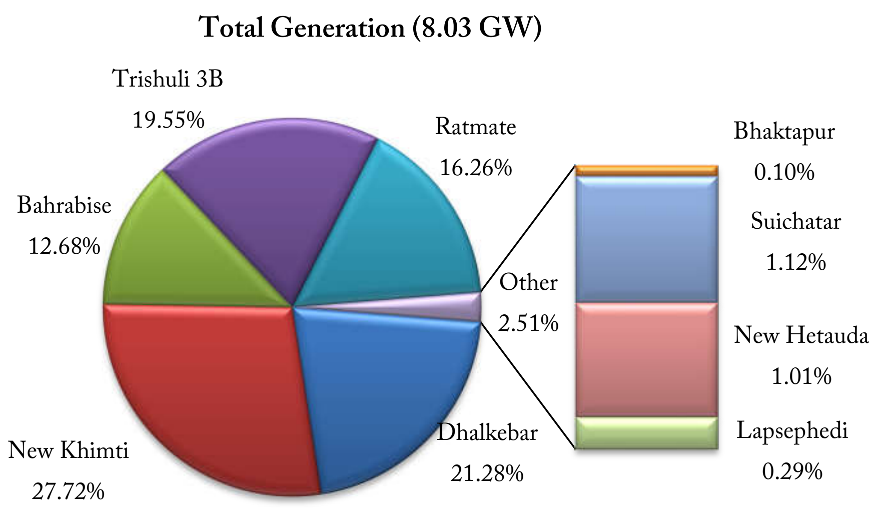

Figure 34: Generation chart of Zone-4 for year 2040

4.4. Demand Forecast

Hetauda, Dhalkebar and Kathmandu valley are the major load center of Zone-4, with total load demand of 6480 MW.These substations supply the power to the domestic, commercial, industrial and transportation load of the Zone-4. Table 34 shows the load demand at different substation of Zone-4. Balaju, Bhaktapur Harisidhi and Matatirtha substation, will supply the power required for the Kathmandu valley. Hetauda substation will supply power to Hetauda, Birgunj, Chandranigapur and its peripher. Dhalkebar substation will supply power to Janakpur along with Jaleshowr and its periphery. Railway and industrial load are expected to be the major loads, which is planned to be supplied by Dhalkebar substation.

Table 33: Substation load demand of Zone-4

S.N	Substation	Load (MW)	Total
1	Bahrabise	50	
2	Balaju	400	
3	Bhaktapur	220	
4	Chapali	150	
5	Dhalkebar	1600	
6	Harisidhi	300	
7	Hetauda	2250	**6480**
8	Khimti	260	
9	Matatirtha	550	
10	Mulpani	200	
11	Ratmate	150	
12	Suichatar	150	
13	Trishuli	200	

4.5. Generation Plan and Definition of Clusters of Power Plants

This section gives details about clustering of different hydropower project that would evacuate their power to substation (existing, committed or proposed). Main factors taken in consideration for the evacuation of power are:

- Location of power generation project
- Existing and committed lines/ substation

4.5.1. Ratmate substation

Budhi Gandaki Storage Hydropower Project (1200 MW) and Trishuli Galchhi (75 MW) are major hydropower projects connected to this substation. This substation lies in Province No 3.

Table 34: Power intended to be evacuate from Ratmate substation

Substation	Hub	Hydropower	Capacity (MW)	Total
Ratmate	Ratmate	Budhi Gandaki Storage Hydropower Project	1200	1305.67
		Trishuli Galchhi	75	
		Ratmate Cluster 1	3.67	
		Balaju Cluster	23.7	
		Ratmate Cluster 2	3.3	
	Total			**1305.67**

4.5.2. New Hetauda substation

Kulekhani-II (32 MW) is the major hydropower project connected to this substation. This substation lies in Province no. 3.

Table 35: Power intended to be evacuated from New Hetauda substation

Substation	Hub	Hydropower	Capacity (MW)	Total
New Hetauda	New Hetauda	Kulekhani-II	32	81.04
		Kulekhani III	14	
		Bagmati Nadi	22	
		New Hetauda Cluster	13.04	
	Total			**81.04**

4.5.3. Matatirtha

Lantang Khola Reservoir Hydropower Project (310 MW), Rasuwa Bhotekoshi (120 MW), Rasuwagadhi (111 MW), Upper Trishui-2 HPP (102 MW), Sanjen Khola (78 MW), are some of major hydropower projects which are connected to this substation via Chilime hub. Upper Trishuli-1 (216 MW), Middle Trishuli Ganga Nadi (65 MW), Upper Trishuli 3A (60 MW) are connected to this substation via Trishuli 3B hub. This substation lies in Province no. 3

Table 36: Power intended to be evacuated from Matatirtha substation

Substation	Hub	Hydropower	Capacity	Total
Trishuli 3B	Trishuli 3B	Upper Trishuli-1	216	476.77
		Upper Trishuli 3B	37	
		Upper Trishuli 3A	60	
		Middle Trishuli Ganga nadi	65	
		Trishuli	24	
		Trishuli 3B Cluster 1	25.55	
		Trishuli 3B Cluster 2	49.22	
	Samundratar	Samundratar Cluster	44.69	69.39
		Super Melamchi Hydropower Project	24.7	
	Ankhu Hub	Super Aankhu Khola Hydropower Project	25.4	179.6
		Akhu Khola-2 HPP	20	
		Tatopani khola HPP	24.3	
		Ilep Tatopani Khola HPP	25	
		Upper Ankhu Khola	35	
		Ankhu Khola	42.9	
		Ankhu Khola Cluster	7	
	Chilime	Upper Trishui-2 HPP	102	844.15
		Sanjen	42.5	
		Mathillo Langtang HEP	24.35	
		Chilime	22	
		Sanjen Khola	78	
		Rasuwagadhi	111	
		Rasuwa Bhotekoshi	120	
		Lantang Khola Reservoir Hydropower Project	310	
		Chilime Cluster 1	34.3	
	Total			**1569.91**

4.5.4. Suichatar

Kulekhani-I (60 MW) is currently connected to this substation. This substation lies in Province no. 3.

Table 37: Power intended to be evacuated from Suichatar substation

Substation	Hub	Hydropower	Capacity	Total
Suichatar	Kulekhani I	Kulekhani-I	60	89.71
		Kulekhani-I Cluster	29.71	
	Total			**89.71**

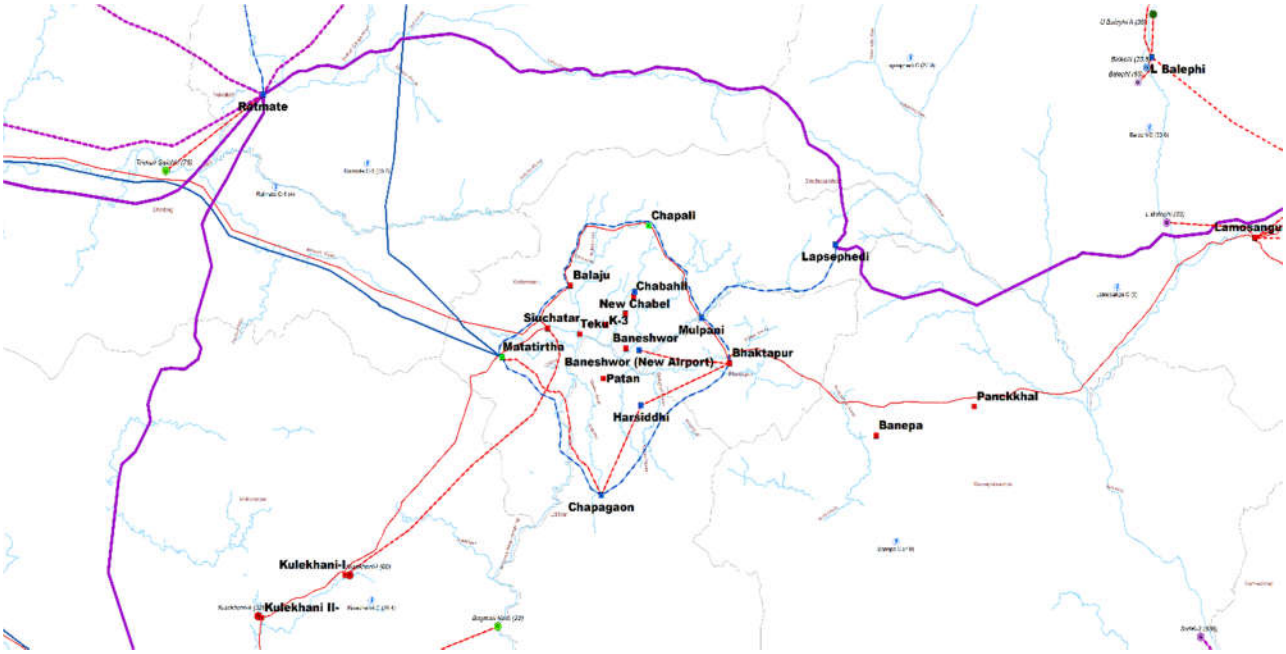

Figure 35: Kathmanadu Valley and Periphery

4.5.5. Lapsephedi

22.9 MW of total power is planned to be connected to this substation via different small hydropower nearby. This substation lies in Province no. 3.

Table 38: Power intended to be evacuated from Lapsephedi substation

Substation	Hub	Hydropower	Capacity	Total
Lapsephedi	Lapsephedi	Lapsephedi Cluster	22.9	22.9
	Total			**22.9**

4.5.6. Bahrabise

Madhya Bhotekoshi (102 MW), is one of major hydropower project planned to be connected to this substation directly. Upper Nyasim Khola (43 MW), are connected to this substation via Upper Balephi

Hub. Upper Chaku A (45 MW), Upper Bhotekoshi (46 MW) are connected to this substation via Bhotekoshi Hub. This substation lies in Province No 3.

Table 39: Power intended to be evacuated from Bahrabise substation

Substation	Hub	Hydropower	Capacity	Total
Bahrabise	Bahrabise	Madhya Bhotekoshi	102	128.25
		Bahrabise Cluster	26.25	
	Lower Balephi hub	Upper Balephi A	36	93.08
		Balephi	23.52	
		Balephi Cluster	33.56	
	Upper Balephi Hub	Nyasim Hydropower Project	35	209.68
		Upper Balephi Cluster	7.27	
		Upper Brahmayeni HEP	20.07	
		Brahmayani HPP	40	
		Balephi Khola HEP	42.14	
		Upper Nyasim Khola	43	
		Upper Balefhi	22.2	
	Bhotekoshi	Upper Chaku A	45	210.68
		Upper Bhotekoshi	46	
		Middle Bhotekoshi -1	40	
		Bhotekoshi 1 Hydropower Project	44	
		Bhotekoshi Cluster	35.68	
	Lamosangu	Lower Balephi	20	89
		Lamosangu Cluster	9	
		Bhotekoshi 5	60	
	Singati	Khani Khola - 1	40	287.79
		Khare Hydropower Project	24.1	
		Khani Khola (Dolakha	30	
		Tamakoshi-V	87	
		Sagu Khola HEP	20	
		Singati Cluster 1	51.24	
		Singati Cluster 2	35.45	
	Total			**1018.49**

4.5.7. New Khimti

Upper Tamakoshi HPP (456 MW), Rolwaling Khola HPP (88 MW) are some of major HPP that have been planned to be connected to this substation via Upper Tamakosi Hub. Tamakoshi-3 TA-3(650 MW), Khimti Shivalaya Storage HPP (200 MW), are connected to this substation directly. This substation lies in Province no 3.

Table 40: Power intended to be evacuated from New Khimti substation

Substation	Hub	Hydropower	Capacity	Total
New Khimti	New Khimti	Tamakoshi-3 TA-3	650	1002.02
		Lower Likhu	28.1	
		Khimti -I	60	
		Khimti II	48.8	
		New Khimti Cluster	15.12	
		Khimti Shivalaya Storage HPP	200	
	Garjyang Hub	Khimti Shivalaya Cluster	30.23	87.73
		Nupche Likhu HEP	57.5	
	Likhu Hub	Likhu Khola HPP	30	296.92
		Likhu-4	52.4	
		Likhu Khola 'A'	51	
		Likhu Cluster	31.52	
		Likhu -2	55	
		Likhu -1	77	
	Lapche	Upper Lapche Khola	52	274
		Lapche Khola	160	
		Jum Khola Hydropower Project	62	
	Up Tamakoshi Hub	Rolwaling Khola	22	566
		Rolwaling Khola HPP	88	
		Upper Tamakoshi HPP	456	
	Total			**2226.67**

4.5.8. Dhalkebar

Sunkoshi-2 (1110MW) and Sunkoshi-3 (536 MW) are two major hydropower planned to be connected directly to this substation. This substation lies in Province no 2.

Table 41: Power intended to be evacuated from Dhalkebar substation

Substation	Hub	Hydropower	Capacity	Total
Dhalkebar	Dhalkebar	Sunkoshi 3	536	1673.6
		Sunkoshi 2	1110	
		Sunkoshi 3 Cluster	27.606	
	Chandranigahapur	Lower Bagmati HPP	35.9	35.9
	Total			**1709.5**

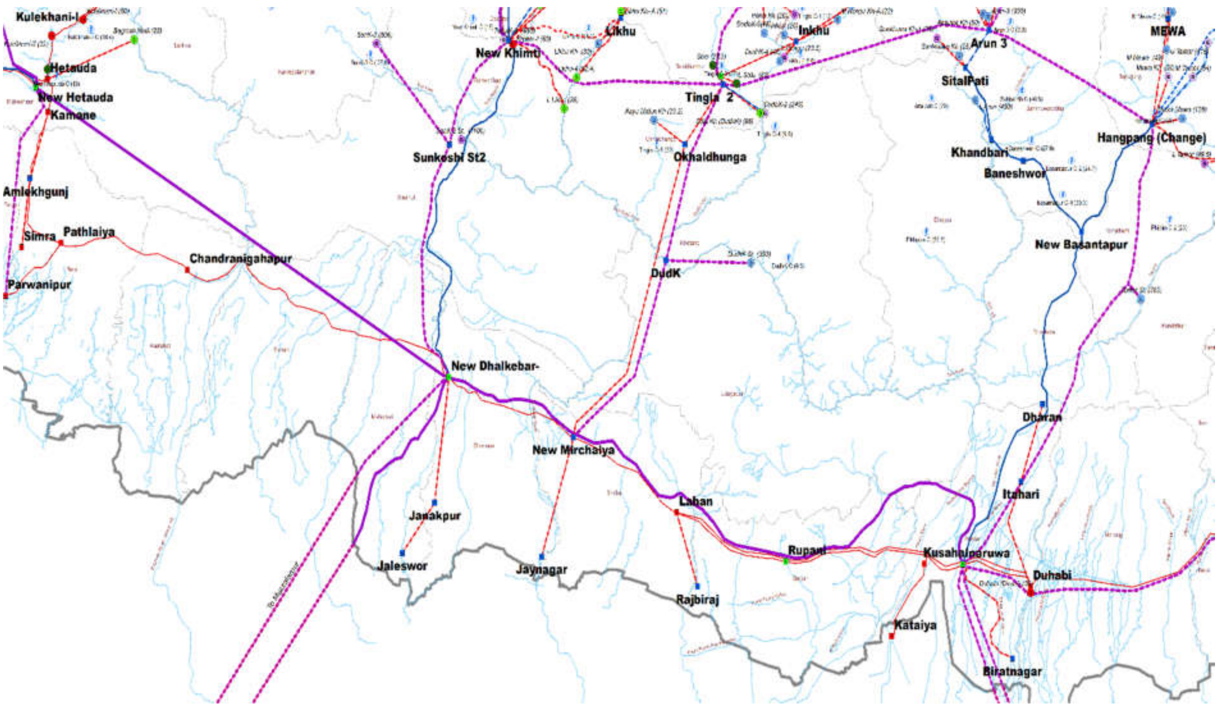

Figure 36: New Dhalkebar substation and Periphery

4.6. Future Transmission Lines

Several transmission lines are under study in Zone 5. Transmission lines to evacuate power from Budigandaki Corridor, Trishuli Corridor, Tamakoshi corridor and other projects are proposed in this zone.

i. Transmission line from Upper Budhigandaki substation of Gorkha district to Gumda substation of Gorkha district is proposed to evacuate power from Upper Budhigandaki Region. Around 961 MW of power is needed to be evacuated from Upper Budhigandaki substation. Around 23 km of Twin Moose double circuit line is proposed between Upper Budhigandaki substation and Gumda substation. Around 863 MW of power is expected to be connected directly at Gumda substation. From Gumda substation Transmission line shall be linked to the Ratamate substation of Dhading district. Around 75 km of Quad Moose 400kV double circuit Transmission line is proposed between Gumda and Ratamate.

ii. Transmission line from Chilime substation of Rasuwa district to Ratamate substation of Dhading district is proposed as a cross border link between Nepal and China. Around 50 km of Quad Moose double circuit line is proposed between Ratmate and Chilime which will be extended up to Keryung in China. This transmission line is proposed as the cross-border link between China and Nepal.

iii. Transmission Line from Damauli to Lapsiphedi via Ratamate with line coming from Hetauda is proposed and under study by MCC. 107 km of Quad Moose double circuit line is proposed between Damauli and Lapsiphedi and 41 km of Quad Moose double circuit line is proposed between Ratamate and Hetauda.

iv. Transmission line from Lapche Hub of Dolakha district to Upper Tamakoshi hub of Dolakha district is proposed to evacuate power from Lapche Khola area. Around 274 MW of power is needed to be evacuated from Lapche substation. Around 15 km of Twin Moose 220kV double circuit line is proposed between Lapche and Upper Tamakoshi. Around 566 MW of power is expected to be connected directly at Upper Tamakoshi substation. From Tamakoshi substation Transmission line shall be linked to the Khimti substation of Ramachhap district. Around 46 km of Quad Moose 220kV double circuit Transmission line is proposed between Upper Tamakoshi and Khimti.

v. Transmission line from Lapsiphedi to Khimti via Barhabise is under construction and shall be developed as Mid Hill Transmission Line. Around 134 km of Quad Moose 400kV double circuit line is proposed between Lapsiphedi and Khimti. This transmission line shall be the part of the proposed ring network. In long term at maximum of 2000 MW shall only be transmitted for each line of ring network.

vi. Transmission Line from Dhalkebar to Khimti is under operation. 75 km of Double Circuit Twin Bison 220kV Transmission line from Dhalkebar to Khimti is under operation by NEA and is currently charged at voltage level of 132kV. Dhalkebar Muzzafarpur 400kV Transmission line is under operation current high voltage cross Border transmission line between Nepal and India. Additional double circuit Quad Moose 400kV transmission line from Dhalkebar to Muzzafarpur is proposed.

vii. Transmission Line from Hetauda to Dhalkebar under construction 128 km of Double Circuit Quad Moose 400kV Transmission line from Hetauda to Dhalkebar under construction by NEA

viii. Butwal has been identified as a point for cross Border transmission line between Nepal and India. Two double circuit Quad Moose 400kV transmission line from Butwal to Gorakhpur is proposed.

Table 42: Existing, Under Construction, Planned and Proposed Transmission Line of Zone 4

Existing and Under Construction 400 kV TL						
S.N	**Project Name**	**Voltage Level**	**Starting Point**	**Ending Point**	**Conductor**	**Length (km)**
1	Lapsephedi- Ratmate	400kV	Lapsephedi	Ratmate	Quad Moose	28
2	Ratmate- Hetauda	400kV	Ratmate	Hetauda	Quad Moose	41
3	Dhalkebar- Hetauda	400kV	Dhalkebar	Hetauda	Quad Moose	128
4	Lapsephedi- Bahrabise	400kV	Lapsephedi	Bahrabise	Quad Moose	60
5	Bahrabise- New Khimti	400kV	Bahrabise	New Khimti	Quad Moose	46
6	New Damauli- Ratmate	400kV	New Damauli	Ratmate	Quad Moose	79
Proposed 400 kV Transmission Line						
S.N	**Project Name**	**Voltage Level**	**Starting Point**	**Ending Point**	**Conductor**	**Length (km)**
1	Chilime- Ratmate	400kV	Chilime	Ratmate	Quad Moose	50
2	Gumda- Ratmate	400kV	Gumda	Ratmate	Quad Moose	75
3	New Khimti- Sunkoshi-2	400kV	New Khimti	Sunkoshi-2	Quad Moose	22
4	Sunkoshi-2- Dhalkebar	400kV	Sunkoshi-2	Dhalkebar	Quad Moose	38
5	U-Budhi- Gumda	400kV	U-Budhi400	Gumda	Twin Moose	23
Existing and Under Construction 400 kV Cross Boder Transmission Line						
S.N	**Project Name**	**Voltage Level**	**Starting Point**	**Ending Point**	**Conductor**	**Length (km)**
1	Dhalkebar- Muzzaffarpur	400kV	Dhalkebar	Nepal-India Border	Quad Moose	39
Proposed 400 kV Cross Boder Transmission Line						
S.N	**Project Name**	**Voltage Level**	**Starting Point**	**Ending Point**	**Conductor**	
1	Kerung- Chilime	400kV	Kerung	Nepal-China	Quad	14

				Border	Moose	
2	Dhalkebar-Muzzaffarpur*	400kV	Dhalkebar	Nepal-India Border	Quad Moose	39
Existing and Under Construction 220 kV Transmission Line						
S.N	**Project Name**	**Voltage Level**	**Starting Point**	**Ending Point**	**Conductor**	**Length (km)**
1	Khimti- Dhalkebar	220kV	Khimti	Dhalkebar	Twin Bison	75
2	Bharatpur- Hetauda	220kV	Bharatpur	Hetauda	Twin Bison	73
3	Chilime Hub – Trishuli	220kV	Chilime Hub	Trishuli	Twin Bison	40
4	Suichatar (Mata)-Trishuli	220 kV	Suichatar (Mata)	Trishuli	Twin Moose	42
Proposed 220 kV Transmission Line						
S.N	**Project Name**	**Voltage Level**	**Starting Point**	**Ending Point**	**Conductor**	**Length (km)**
1	Lapche- U Tamakoshi	220kV	Lapche	Tamakoshi	Twin Bison	15
2	U Tamakoshi- Khimti	220kV	Tamakoshi	Khimti	Twin Moose	46
3	Ankhu –Ratamate	220 kV	Ankhu	Ratamate	Single Bison	32

**Second Double Circuit*

4.7. Target Network Model

Transmission network for this zone is given below:

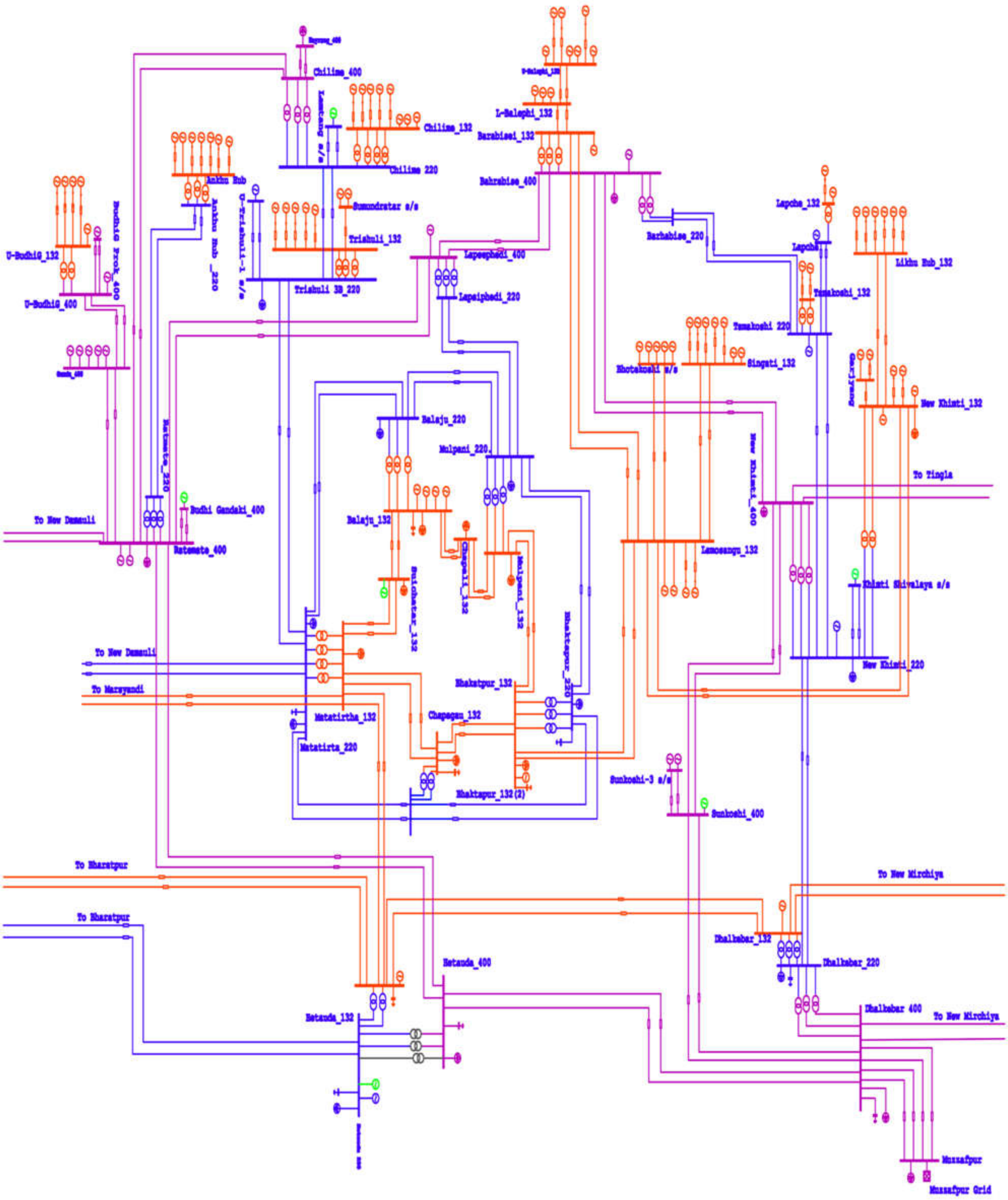

Figure 37: Targeted network and substation of Zone-4 for year 2040.

4.8. Load Flow Analysis

4.8.1. Voltage Profile of Zone-4

Voltage level considered for the study mostly consists of major hub substations, which are mainly 220kV and 400kV level. Voltage profile of load and generation substation under various scenarios (i.e. Wet maximum, wet minimum and dry peak) by 2040 of Zone-4 is shown in the graph below:

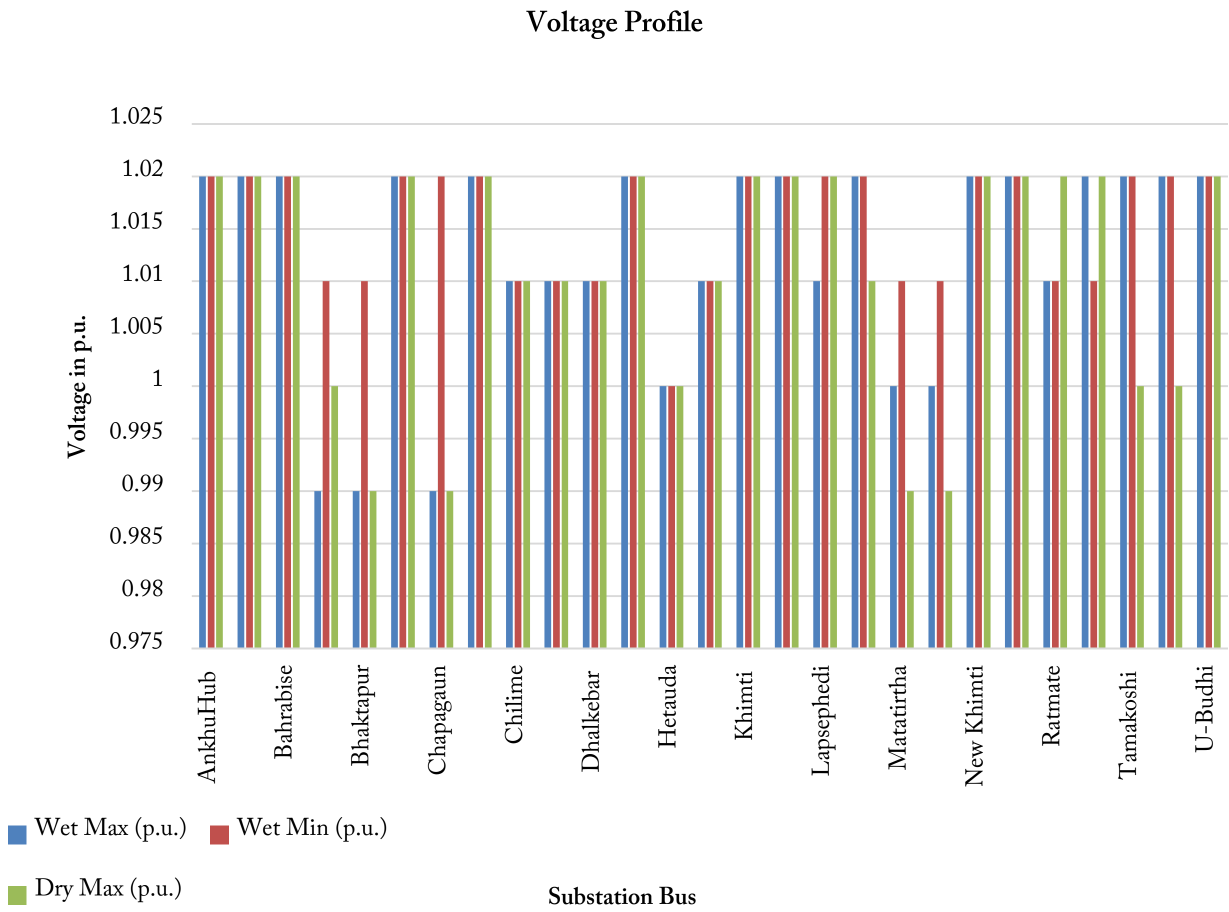

Figure 38: Voltage profile of substation on Zone-4 by 2040.

The graph shows that the voltage at all substations are with in range of 0.95 to 1.05 p.u. as per the grid code. Dhalkebar 400kV substation, which is proposed as the interconnection point between Nepal and India for power export to India, is also seen to be within acceptable voltage range.

4.8.2. Line Loading of Zone-4

Line loading of major transmission line of Zone-4 under different scenario is as shown in the graph below.

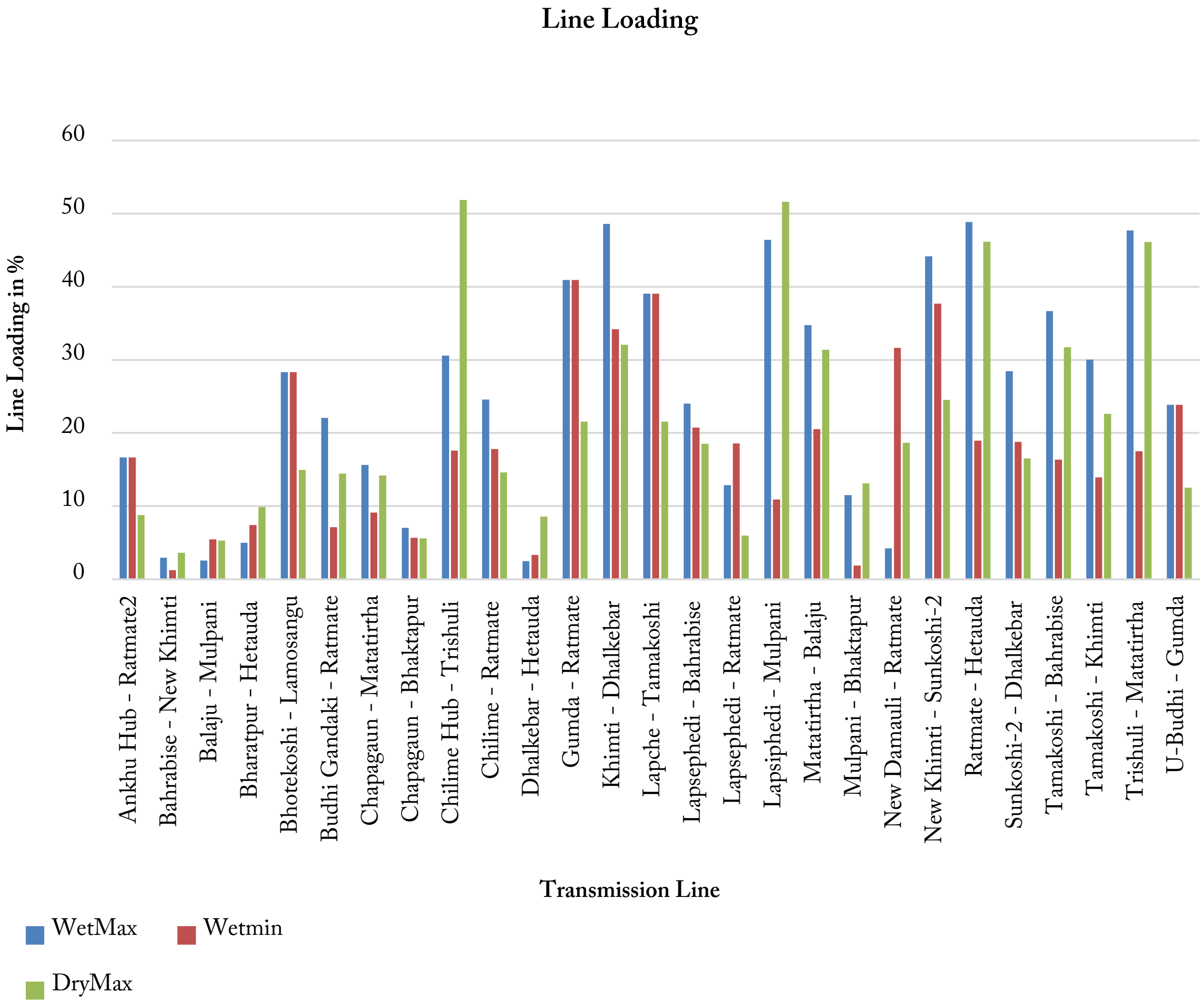

Figure 39: Percentage of line loading under scenario of Zone-4 by 2040.

The graph shows that among all the lines in this zone, the highest loading occurs in Chilime Hub – Trishuli Hub 220kV line i.e. 51.86% of thermal limit during Dry-maximum scenario. Hence, all major lines can safely withstand N-1 line contingencies either without overloading or with marginal overloading.

4.9. Investment Cost

Investment cost of the transmission line and the substation of Zone 4 is calculated individually. The total cost of transmission line and the substation are 806.71 MUSD and 522.24 MUSD respectively.

4.9.1. Transmission Line

1418 km of transmission line is planned in Zone 4 with total estimated cost of 806.71 MUSD. Among which 642 km of 400kV transmission line is proposed in Zone 4 which shall cost around 499.78 MUSD. Similarly, total of 323 km of 220kV transmission line is proposed in Zone 4 with an estimated cost of 177.37 MUSD. Likewise, total of 454 km of 132kV transmission line is proposed in Zone 4 with an estimated cost of 129.55 MUSD.

Table 43: Cost Estimate of Transmission Line in Zone 4

S.N.	Type	Project Name	Length	Total Cost (MUSD)	Remarks
1	400kV	Bahrabise- New Khimti	46	36.56	
3	400kV	Chilime- Ratmate	50	39.51	
4	400kV	Dhalkebar- Hetauda	128	96.61	
5	400kV	Dhalkebar- Muzzaffarpur	39	31.74	
7	400kV	Gumda- Ratmate	75	57.87	
8	400kV	Kerung- Chilime	14	13.54	
9	400kV	Lapsephedi- Bahrabise	60	40.31	
10	400kV	Lapsephedi- Ratmate	28	20.3	
11	400kV	New Damauli- Ratmate	79	60.64	
12	400kV	New Khimti- Sunkoshi-2	22	19.28	
13	400kV	Ratmate- Hetauda	41	33.1	
14	400kV	Sunkoshi-2- Dhalkebar	38	31.31	
15	400kV	U-Budhi400- Gumda	23	19.01	
Subtotal 400 kV			**642**	**499.78**	
1	220kV	Bharatpur- Hetauda	73	34.19	
2	220kV	Chilime Hub - Trishuli	40	25.45	
3	220kV	Khimti- Dhalkebar	75	34.19	
4	220kV	Lapche- Tamakoshi	15	10.21	
5	220kV	Suichatar (Mata)- Trishuli	42	25.45	
6	220kV	Tamakoshi- Khimti	46	27.85	

7	220kV	Ankhu -Ratamate	32	20.04	
Subtotal 220 kV			**323**	**177.37**	
1	132kV	Hetauda to New Hetauda	6.206	3.29	
2	132kV	Chapagaon to Harsidi	14.308	5.01	
3	132kV	Harsiddhi to Bhaktapur	15.136	5.45	
4	132kV	Bhaktapur to Baneshwor New Airport	14	5.02	
5	132kV	Trishuli 3B HUB to Samundratar	39	10.16	
6	132kV	Mulpani to Lapsephedi	27	7.96	
7	132kV	Matatirtha to Chapagaon	28	7.92	
8	132kV	Khimti to Garjyang	56	14.04	
9	132kV	Dhalkebar to Janakpur	46	12.06	
10	132kV	Janakpur_ to Jaleswor	24	7.07	
11	132kV	Michalya to Jaynagar	46	11.94	
12	132kV	Kamane to Amelkhgunj	26	7.68	
13	132kV	Amelkhgunj to Simra	25	7.64	
14	132kV	Lower Balephi Hub to U balephi	21	6.53	
15	132kV	Lamosangu Hub to Barahabise Hub	16	5.74	
16	132kV	Kulekhani I to Siuchatar	48	12.04	
Subtotal 132kV			**454**	**129.55**	
Total			**1418**	**806.71**	

*All costs are in MUSD

4.9.2. Substation

19 substations are planned in Zone 4. Among which 9 substations with highest voltage level of 400 kV with estimated cost of 380.55 MUSD, 4 substation with highest voltage level of 220kV with estimated cost of 75.23 MUSD is proposed in Zone 4 and 6 substation with highest voltage level of 132kV with estimated cost of 66.46 MUSD is proposed in Zone 4.

Table 44: Cost Estimate of substation in Zone 4

S.N.	Substation	Voltage Level	Total Price	Remarks
1	Bahrabise	400/220/132	44.45	
2	Chilime	400	28.42	Switching
3	Dhalkebar	400/220/132	63.84	
4	Gumda	400/132	39.48	
5	Hetauda	400/220/132	31.83	
6	Lapsephedi	400/132	32.78	
7	New Khimti	400/220/132	42.37	
8	Ratmate	400/132	64.22	
9	U-Budhi	400/132	33.16	
10	Lapche	220/132	15.8	
11	Tamakoshi	220/132	17.45	
12	Trishuli	220/132	22.73	
13	Ankhu Hub	220/132	19.25	
14	Bhotekoshi	132/33	10.14	
15	L Balephi	132/33	10.14	
16	Lamosangu	132/33	14.36	
17	Likhu Hub	132/33	12.73	
18	Samundratar	132/33	7.77	
19	U-Balephi	132/33	11.33	
Total			**522.24**	

*All costs are in MUSD

5. Zone 5

5.1. Presentation of the Zone

Zone 5 covers eastern region of Nepal. Jhapa, Illam, Panchthar, Tapejung, Morang, Dhankuta, Sankhuwasabha, Sunsari, Bhojpur Tehrathum Solukhumbu, Udayapur, Khotang, Okhaldhunga, Siraha, and Saptari are districts in this zone. Power generation from hydro power plants and load demand by the year 2040, expected to reach about 7.78 GW and 2.85 GW respectively.

Figure 40: Presentation of Zone -5

5.2. Existing Network

Major substations on this zone are:

- Lahan substation located at Lahan of Siraha district with 132/33kV, 63 MVA transformer.
- Duhabi substation located at Sunsari district with 132/33kV, 126 MVA transformer.
- Anarmani substation located at Jhapa district with 132/33kV, 60 MVA transformer.
- Mirchaiya substation located at Siraha district with 132/33kV, 30 MVA transformer.
- Damak substation located at Jhapa district with 132/33kV, 30 MVA transformer.
- Phidim substation located at Panchthar district with 132/33kV, 16 MVA transformer.
- Kabeli substation located at Panchthar district with 132/33kV, 30 MVA transformer.

Existing lines in this zone are:

- Anarmani-Duhabi 132kV single circuit transmission line.
- Duhabi-Lahan-Cha-pur-Pathaliya/Parwanipur-Hetauda 132kV single circuit transmission line.

Substation and Lines under Construction:

- Rupani 132/33kV, 63 MVA, substation is under construction.
- Kabeli-Godak 132kV double circuit transmission line.
- Solu Corridor 132kV double circuit transmission line.
- Kushaha- Biratnagar 132kV double circuit transmission line.
- Koshi Corridor 220kV double circuit transmission line.

Committed projects in this area:

- Arun 3- Kimanthanka 400kV double circuit Transmission Line.

5.3. Overview of Committed and Planned lines

Figure below shows the committed and planned line of zone 5. Numerous 400kV and 220kV transmission lines are under construction or under study in this zone. Inaruwa - New Mirchaiya section of 400kV East West transmission line is under study by NEA. Similarly, NEA has started study to construct Arun- Inaruwa 400kV transmission line. 220kV Koshi Corridor is also under construction by NEA.

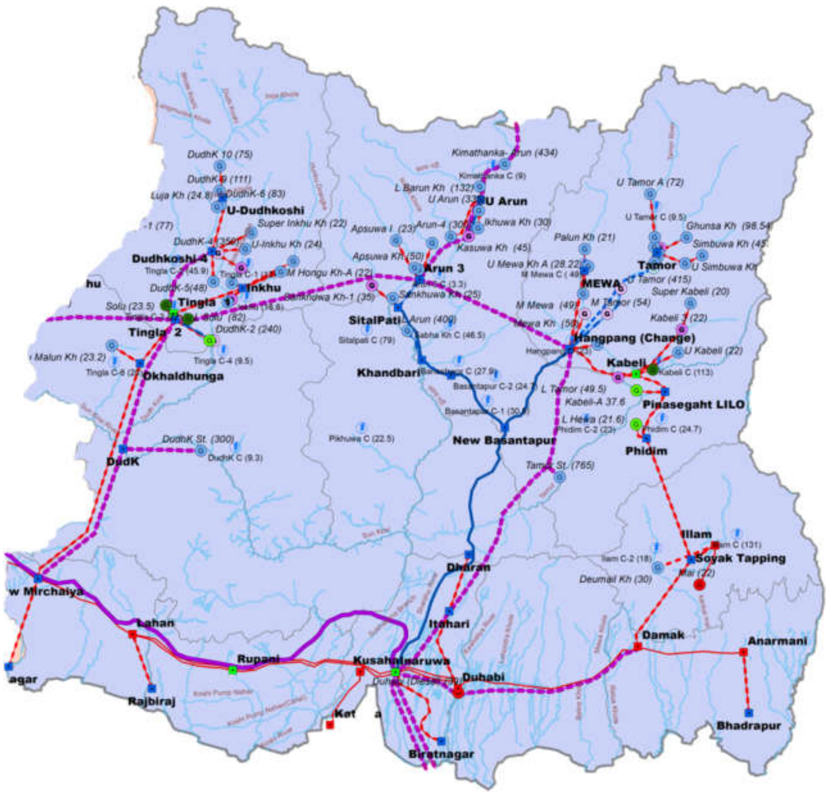

Figure 41: Overview of existing and committed network of Zone-5 for year 2040

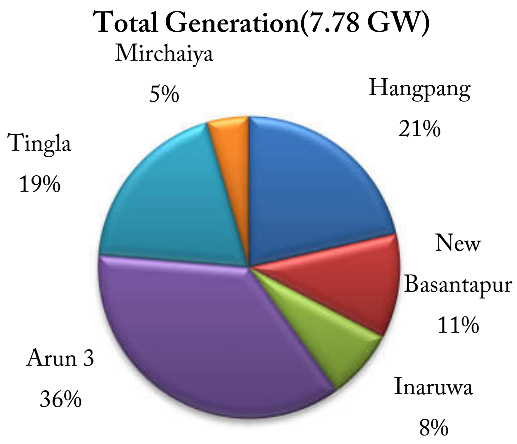

Figure 42: Generation Chart of Zone-5 for year 2040

5.4. Demand Forecast

Biratnagar, Itahari, Damak and Inaruwa are the major load center of Zone-5, with total load demand of 2850.5 MW. These substations supply the power to the domestic, commercial, industrial and transportation load of the Zone-5. Table below shows the load demand at different substation of Zone-5. Inaruwa substation, will supply the power required for Biratnagar, Inaruwa, Itahari and its periphery. Damak substation will supply power to Damak and its periphery. Mirchiya substation will supply power to Lahan and its periphery. Railway and industrial load are expected to be the major loads, which is planned to be supplied by Inaruwa substation.

Table 45: Substation load demand of Zone-5

S.N	Substation	Load (MW)	Total
1	Inaurwa	600	2850.5
2	Tingla	100	
3	Mirchiya	1100	
4	Duhabi	600	
5	Phidim	50	
6	Illam	100	
7	Anarmani	50	
8	Arun-Hub	150	
9	Kabeli	50	
10	Tamor	25	
11	Hangpang	25.5	

5.5. Generation Plan and Definition of Clusters of Power Plants

This section gives details about of clustering different hydropower project that would evacuate their power to same substation (existing, committed or proposed). Main factors taken into consideration for the evacuation of power are:

- Location of power generation project
- Existing and committed lines/ substation

5.5.1. Mirchaiya

Dudhkoshi Storage (300 MW) is the major hydropower directly connected to this substation.23. Aayu Malun Khola Hydro-Electric Project (23.2 MW) is connected to this substation via Okhaldhunga Hub This substation lies in Province No 2.

Table 46: Power intended to be evacuated from Mirchiya substation

Substation	Hub	Hydropower	Capacity	Total
Mirchaiya	Tapping to Dudhkoshi Storage	Dudhkoshi Storage	300	302.78
		Dudhkoshi Cluster	2.78	
	Okhaldhunga	Aayu Malun Khola Hydro-Electric Project	23.2	38.7
		Tingla Cluster 6	15.5	
	Total			**341.48**

5.5.2. Tingla

Dudhkoshi-2 (Taksindu) (240 MW), Dudhkoshi-2 (Jaleswar) HPP (350 MW), Solu Khola (Dudha Koshi) (86 MW), are some of major hydropower projects connected to this substation. This substation lies in Province No 1.

Table 47: Power intended to be evacuated from Tingla substation

Substation	Hub	Hydropower	Capacity	Total
Tingla	Upper Dudh Koshi Hub	Luja Khola HPP	24.8	293.8
		Dudhkoshi-6 HEP	83	
		Dudh koshi 10 HPP	75	
		Dudhkoshi-9 HPP	111	
	Dudh Koshi 4 Hub	Tingla Cluster 5	32.9	477.24
		Dudh Koshi -V	48	
		Dudhkoshi-2 (Jaleswar) HPP	350	
		Upper Inkhu Khola HEP	24.22	
		Super Inkhu Khola	22.12	
	Inkhu Hub	Middle Hongukhola A Hydropower Project	22	215.6
		Tingla Cluster 2	18.64	
		Inkhu Khola	20	
		Tingla Cluster 1	13.99	
		Dudh Koshi-IV	46	
		Hongu Khola HPP	21.87	
		Middle Hongu Khola HEP	22.9	
		Inkhu Khola	20	
		Lower Hongu Khola	30.2	
	Tingla 2	Solu Hydropower Project	23.5	122.8

Substation	Hub	Hydropower	Capacity	Total
		Tingla Cluster 3	17.3	
		Lower Solu Hydropower Project	82	
	Tingla 1	Dudhkoshi-2 (Taksindu)	240	335.5
		Solu Khola	86	
		Tingla Cluster 4	9.5	
	Total			**1444.94**

5.5.3. Arun 3

Lower Arun (659 MW) is one of major hydropower connected to this substation via Khandbari Hub. Kimanthanka Arun (482 MW), Upper Arun (725 MW), Arun 3(300 MW), Lower Barun Khola HPP (132 MW) are connected to this substation via. Upper Arun Hub. Arun 3 (300 MW), Isuwa Khola HP (97.2 MW) are connected directly to this substation. This substation lies in Province no 1.

Table 48: Power intended to be evacuated from Arun-3 substation

Substation	Hub	Hydropower	Capacity	Total
Arun 3	Arun 3 Hub	Apsuwa I HEP	23	473.511
		Arun 3	300	
		Isuwa Khola Hydropower Project	97.2	
		Apsuwa Khola	50	
		Arun 3 Cluster	3.31	
	Upper Arun Hub	Kasuwa Khola HPP	45	1680
		Upper Arun	725	
		Ikhuwa Khola	30	
		Arun 4	372	
		Kimanthanka Arun	482	
		Lower Barun Khola HPP	132	
	Sitalpati	Sankuwa Khola 1	35.34	138.064
		Sankhuwa Khola	25	
		Sitalpati Cluster	77.72	
	Khandbari	Lower Arun	659	733.79
		Khandbari Cluster 1	28.28	
		Khandbari Cluster 2	46.51	
	Total			**3031.37**

5.5.4. Inaruwa

Lower Tamor (49.5 MW), Kabeli-A (37.6 MW) are some of major hydropower projects connected to this substation via Kabeli Hub. This substation lies in Province No 1.

Table 49: Power intended to be evacuated from Inaruwa substation

Substation	Hub	Hydropower	Capacity	Total
Inaruwa	Illam	Mai	22	201.55
		Illam Cluster	131.63	
		Illam Cluster 2	17.92	
		Deumai Khola	30	
	Phidim	Phidim cluster	24.7	69.4
		Phidim cluster 2	23.1	
		Lower Hewa	21.6	
	Kabeli	Kabeli 3	22	290.21
		Lower Tamor	49.5	
		Upper Kabeli HPP	22.9	
		Super Kabeli Khola HPP	20	
		Kabeli B - 1	25	
		Kabeli-A	37.6	
		Kabeli Cluster	113.21	
	Total			**561.16**

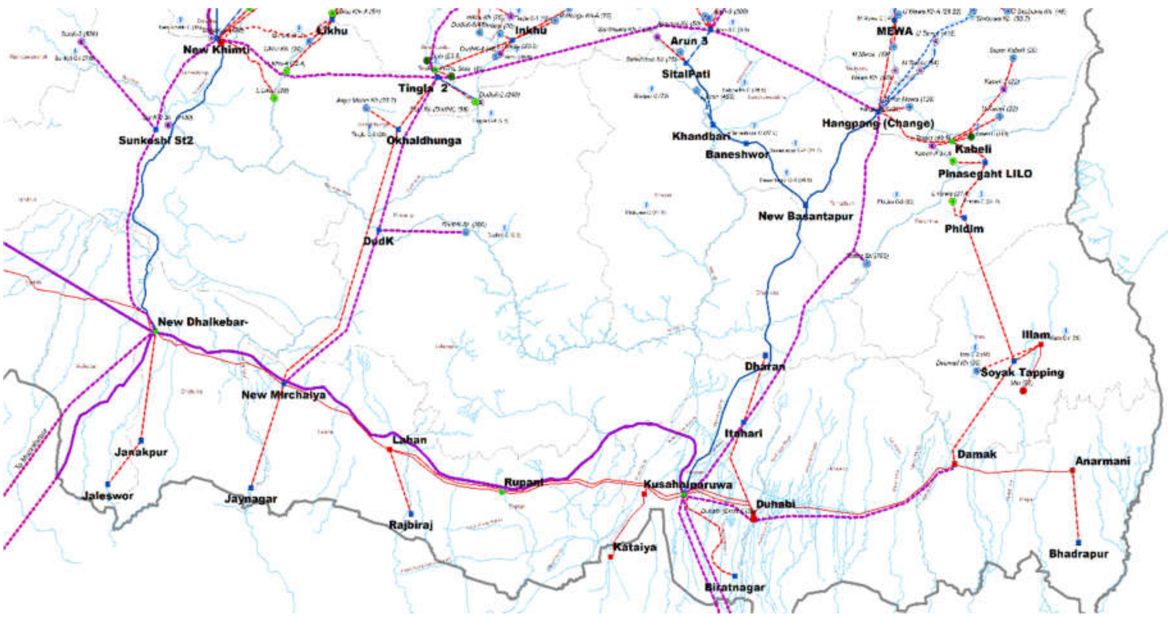

Figure 43: Inaruwa substation and Periphery

5.5.5. New Basantapur

Tamor Storage (762 MW) is one of major hydropower connected to this substation directly. This substation lies in Province No 1.

Table 50: Power intended to be evacuated from New Basantapur substation

Substation	Hub	Hydropower	Capacity	Total
New Basantapur	New Basantapur	Tamor Storage	762	792.5
		Basantapur Cluster 1	30.498	
	Baneshwor	Baneshwor Cluster 2	23.17	50.93
		Baneshwor Cluster	27.76	
	Total			843.43

5.5.6. Hangpang

Super Tamor HEP (155 MW), Ghunsa Khola HPP (98.54 MW) are some major hydropower connected to this substation via Tamor Hub. Upper Tamor (415 MW), Tamor Mewa (128 MW), Middle Mewa Cluster (48.86 MW) are connected directly to this substation. This substation lies in Province No 1.

Table 51: Power intended to be evacuated from Hangpang substation

Substation	Hub	Hydropower	Capacity	Total
Hangpang	Hangpang	Middle Tamor	54	670.26
		Tamor Mewa	128	
		Mewa Khola Hydropower project	50	
		Upper Tamor	415	
		Hangpang Cluster	23.26	
	Mewa Hub	Middle Mewa Cluster	48.86	147.08
		Middle Mewa HPP	49	
		Palun khola small Hydropower Project	21	
		Upper Mewa Khola -A HPP	28.22	
	Tamor hub	Ghunsa Khola HPP	71.5	745.55
		Simbuwa Khola	53.7	
		Ghunsa Khola	78	
		Simbuwa Khola HPP	45	

Substation	Hub	Hydropower	Capacity	Total
		Upper Tamor A HPP	72	
		Ghunsa Khola HPP	98.54	
		Ghunsa-Tamor HPP	43	
		Upper Simbuwa Khola HPP	46.81	
		Upper Tamor Cluster	9.5	
		Super Tamor HEP	155	
		Tamor Khola-5 HEP	40	
		Upper Tamor HEP	32.5	
	Total			1562.89

5.6. Future Transmission Lines

Several transmission lined are under study in Zone 5. Transmission lines to evacuate power from Dudhkoshi, Tamor/Arun Corridor and other projects are proposed in this zone.

i. Transmission line from Upper Dudhkoshi substation of Solukhumbu district to Dudhkoshi 4 substation of Solukhumbu district is proposed to evacuate power from Upper Dudhkoshi Region. Around 293 MW of power is needed to be evacuated from Upper Dudhkoshi substation. Around 477 MW of power is expected to be connected at Dudhkoshi 4 substation. From Dudhkoshi 4 substation Transmission line shall be linked to the Tingla substation of Solukhumbu district and extended up to Mirchiya substation of Sarlahi district. 458 MW of Power shall be directly connected at Tingla1 and Tingla2 substation and 215 MW power from Inkhu Hub also coming to Tingla substation. A provision of tapping in section of Tingla to Mirchiya is made to incorporate power from Dudhkoshi Storage at Khotang district. Around 20 km of Twin Moose 400kV double circuit Transmission line is proposed between Dudhkoshi-4 and Tingla and 126 km of Quad Moose 400kV double circuit line is proposed between Tingla and Mirchaiya.
ii. Transmission line from Upper Arun substation of Sankuwasabha district to Arun 3 substation of Sankhusabha district is proposed to evacuate power from Upper Arun Region. Around 1680 MW of power is needed to be evacuated from Upper Arun substation. Around 18 km of Twin Moose double circuit line is proposed between Upper Arun substation and Arun 3 substation. Around 475 MW of power is expected to be connected directly at Arun 3 substation. From Arun 3 substation Transmission line shall be linked to the Hangpang substation of Taplejung district and extended up to Inaruwa substation of Sunsari district. 670 MW of power shall be directly connected at Hangpang substation with around 745 MW additional power from Tamor Hub also coming to Hangpang substation. Around 46 km of Quad Moose 400kV double circuit Transmission line is

proposed between Arun hub and Hangpang and 101 km of Quad Moose 400kV double circuit line is proposed between Hangpang and Inaruwa. Upper Arun has been identified as a point for cross Border transmission line between Nepal and China. Whereas Inaruwa has been identified as point for cross border transmission line between Nepal India. Double circuit Quad Moose 400kV transmission line from Upper Arun to Latse as well as two double circuit Quad Moose 400kV transmission line from from Inaruwa to Purnea is proposed.

iii. Around 25 km of 132kV double circuit Transmission line from Mewa (Taplejung) to Hangpang (Taplejung) and 23 km of 220kV double circuit Transmission line from Tamor (Taplejung) to Hangpang is under study by RPGCL.

iv. Transmission line from Khimti to Arun hub via Tingla shall also be developed as Mid Hill Transmission Line. Around 119 km of Quad Moose 400kV double circuit line is proposed between New Khimti and Arun hub. This transmission line shall be the part of the proposed ring network. In long term at maximum of 2000 MW shall only be transmitted for each line of ring network.

v. Transmission Line from Dhalkebar to Inaruwa is under construction. This line shall be extended to Damak.128 km of Double Circuit Quad Moose 400kV Transmission line from Dhalkebar to Inaruwa is under construction by NEA. Additional 80 km of Double Circuit Twin bison 220kV Transmission line from Inaruwa to Damak is proposed.

Table 52: Existing, Under Construction, Planned and Proposed Transmission Line of Zone 5

Existing and Under Construction 400 kV TL						
S.N	**Project Name**	**Voltage Level**	**Starting Point**	**Ending Point**	**Conductor**	**Length (km)**
1	Mirchiya- Dhalkebar	400kV	Mirchiya	Dhalkebar	Quad Moose	64
2	Mirchiya- Inaurwa	400kV	Mirchiya	Inaurwa	Quad Moose	64
Proposed 400 kV Transmission Line						
S.N	**Project Name**	**Voltage Level**	**Starting Point**	**Ending Point**	**Conductor**	**Length (km)**
1	New Khimti- Tingla	400kV	New Khimti	Tingla	Quad Moose	57
2	Arun-Hub- Hangpang	400kV	Arun-Hub	Hangpang	Quad Moose	46
3	Hangpang- Inaruwa	400kV	Hangpang	Inaruwa	Quad Moose	101
4	Dudhkoshi- Mirchiya	400kV	Dudhkoshi	Mirchiya	Quad Moose	81
5	Duhabi- Damak	400kV	Duhabi	Damak	Quad Moose	50
6	Duhabi- Inaruwa	400kV	Duhabi	Inaruwa	Quad Moose	30
7	Tingla- Arun-Hub	400kV	Tingla	Arun-Hub	Quad Moose	62
8	Tingla- Dudhkoshi	400kV	Tingla	Dudhkoshi	Quad Moose	45
9	Tingla- Dudhkoshi-4	400kV	Tingla	Dudhkoshi-4	Twin Moose	20
10	U-Arun- Arun-Hub	400kV	U-Arun	Arun-Hub	Twin Moose	18
Proposed 400 kV Cross Boder Transmission Line						
S.N	**Project Name**	**Voltage Level**	**Starting Point**	**Ending Point**	**Conductor**	**Length (km)**
1	Inaurwa- Purnera	400kV	Inaurwa	Nepal-India Border	Quad Moose	50
2	U-Arun Latse	400 kV	U-Arun	Nepal-China Border	Quad Moose	23

Existing and Under Construction220 kV Transmission Line						
S.N	**Project Name**	**Voltage Level**	**Starting Point**	**Ending Point**	**Conductor**	**Length (km)**
1	Baneshwor- Basantapur	220kV	Baneshwor	Basantapur	Twin Moose	21
2	Basantapur- Inaurwa	220kV	Basantapur	Inaurwa220	Quad Moose	77
3	Hangpang S/S- Basantapur	220kV	Hangpang S/S	Basantapur	Twin Bison	46
4	Khadbari- Baneshwor	220kV	Khadbari	Baneshwor	Twin Moose	10
5	Sitalpati- Khadbari	220kV	Sitalpati	Khadbari	Twin Bison	24
Proposed 220 kV Transmission Line						
S.N	**Project Name**	**Voltage Level**	**Starting Point**	**Ending Point**	**Conductor**	**Length (km)**
1	Arun- Sitalpati	220kV	Arun	Sitalpati	Twin Bison	9
2	Hangpang S/S- Tamor Hub	220kV	Hangpang S/S	Tamor Hub	Twin Moose	23

5.7. Target Network Model

Transmission network for this zone is given below:

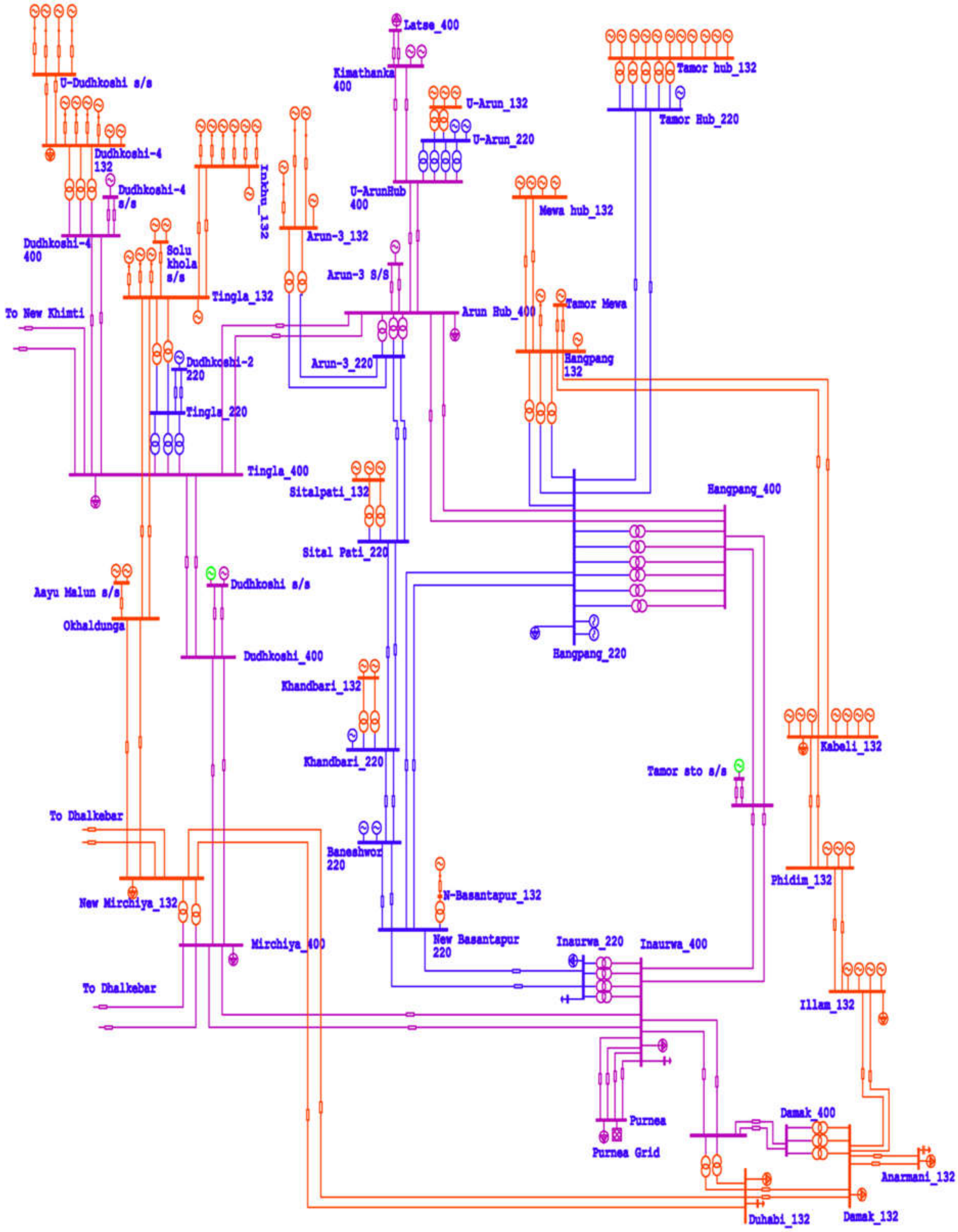

Figure 44: Overview of targeted network and substation of zone-5 for year 2040

5.8. Load Flow Analysis

5.8.1. Voltage Profile of Zone-5

Voltage level considered for the study mostly consists of major hub substations, which are mainly 220kV and 400kV level. Voltage profile of load and generation substation under various scenarios (i.e. Wet maximum, wet minimum and dry peak) by 2040 of Zone-5 is shown in the graph below.

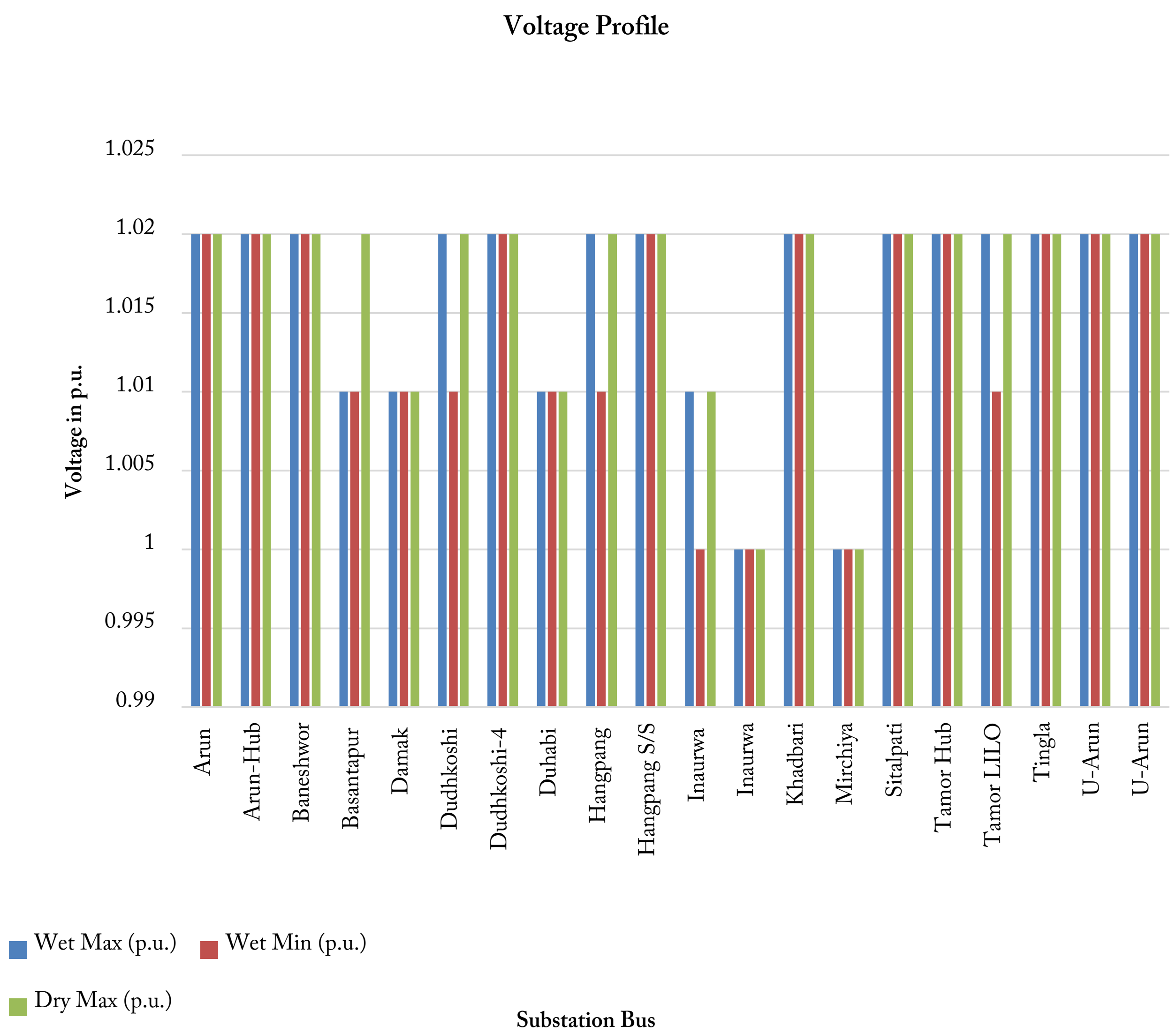

Figure 45: Bar graph of voltage profile by 2040 for Zone-5

The graph shows that the voltages at all substations are with in range of 0.95 to 1.05 p.u. as per the grid code. Inaurwa 400kV substation, which is proposed as the interconnection point between Nepal and India for power export to India, is also seen to be within acceptable voltage range.

5.8.2. Line Loading of Zone-5

Line loss and line loading of major transmission line of Zone-5 under different scenario is shown in the graph below.

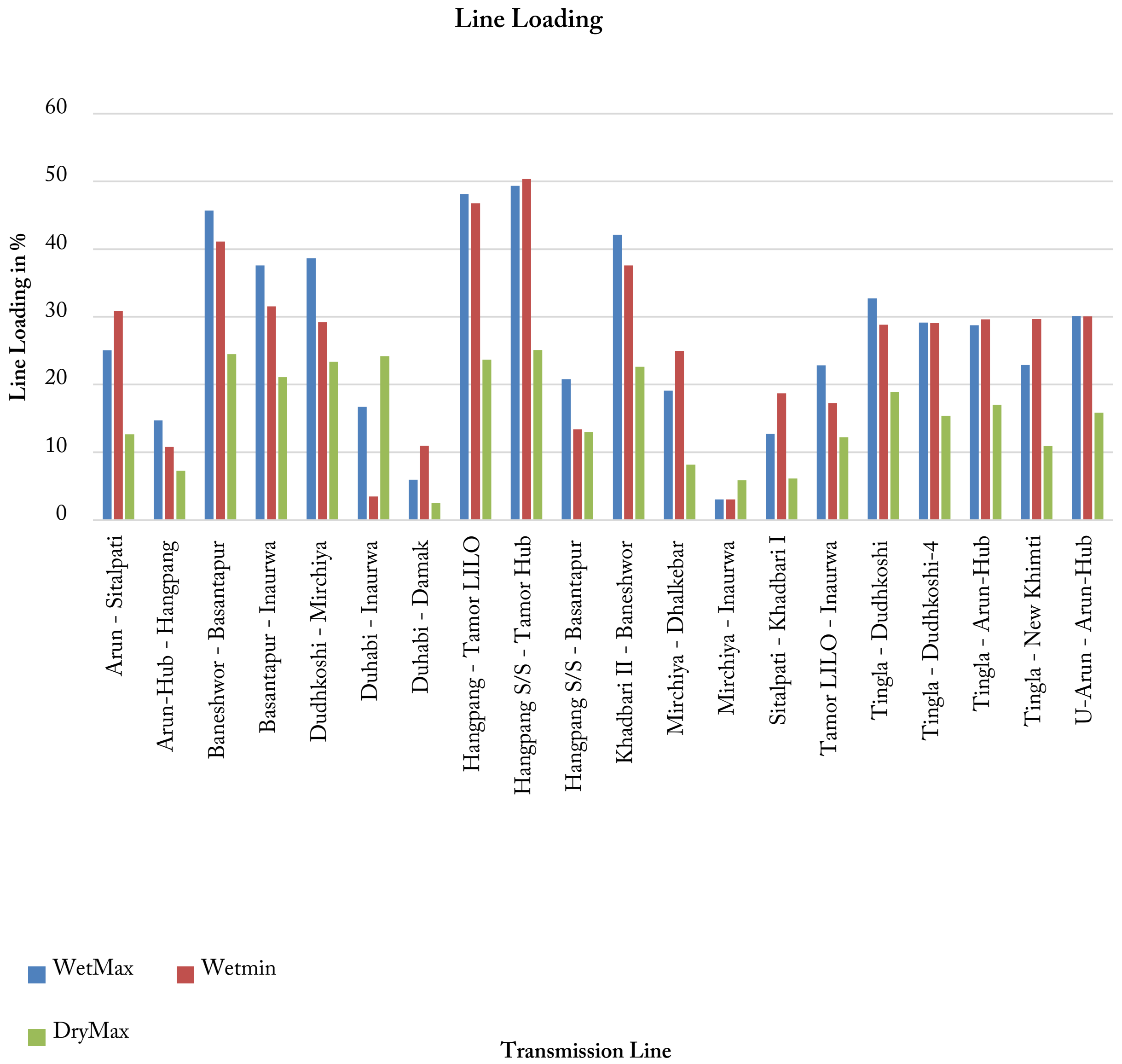

Figure 46: Line loading in percentage of Zone-5

The graph shows that among all the major lines in this zone, the highest line loading occurs in Hangpang - Tamor Hub 220kV line with 50.32% of line loading during Wet minimum scenario. Hence, all major lines in this zone can safely withstand N-1 line contingencies either without overloading or with marginal overloading.

5.9. Investment Cost

Investment cost of the transmission line and the substation of Zone 5 is calculated individually. The total cost of transmission line and the substation are 857.09 MUSD and 563.12 MUSD respectively.

5.9.1. Transmission Line

1,547 km of transmission line is planned in Zone 5 with total estimated cost of 857.09 MUSD. Among which 710 km of 400kV transmission line is proposed in Zone 5 which shall cost around 580.27 MUSD. Similarly, total of 210 km of 220kV transmission line is proposed in Zone 5 with an estimated cost of 115.66. Likewise, total of 627 km of 132kV transmission line is proposed in Zone 5 with an estimated cost of 161.16.

Table 53: Cost Estimate of Transmission Line in Zone 5

S.N.	Type	Project Name	Length	Total Cost (MUSD)	Remarks
1	400kV	Arun-Hub- Hangpang	46	36.83	
2	400kV	Dudhkoshi- Mirchiya	81	58.31	
3	400kV	Duhabi- Damak	50	34.15	
4	400kV	Duhabi- Inaruwa	30	21.45	
5	400kV	Hangpang- Inaruwa	101	76.66	
6	400kV	Inaurwa- Purnera	50	83.5	
8	400kV	Mirchiya- Dhalkebar	64	49.68	
9	400kV	Mirchiya- Inaurwa	64	49.68	
10	400kV	New Khimti- Tingla	57	41.53	
11	400kV	Tingla- Arun-Hub	62	48.21	
12	400kV	Tingla- Dudhkoshi	45	31.75	
13	400kV	Tingla- Dudhkoshi-4	20	15.96	
14	400kV	U-Arun- Arun-Hub	18	14.7	
15	400kV	U-Arun- Latse	23	17.85	
Subtotal 400 kV			**710**	**580.27**	
1	220kV	Arun- Sitalpati	9	5.89	
2	220kV	Baneshwor- Basantapur	21	11.88	
3	220kV	Basantapur- Inaurwa220	77	44.59	
4	220kV	Hangpang S/S- Basantapur	46	21.74	
5	220kV	Hangpang S/S- Tamor Hub	23	12.61	
6	220kV	Khadbari- Baneshwor	10	6.9	

7	220kV	Sitalpati- Khadbari	24	12.04	
Subtotal 220 kV			**210**	**115.66**	
1	132 kV	Mirchalya to Okhalkdhunga	122	28.17	
2	133 kV	Inaruwa to Biratnagar (Belgachhiya)	51	12.68	
3	134 kV	Duhabi to Itahari	42	10.85	
4	135 kV	Itahari to Dharan	30	8.34	
5	136 kV	Anarmani to Bhadrapur	30	8.49	
6	137 kV	Illam to Damak	66	15.82	
7	138 kV	Lahan to Rajbiraj_	29	8.01	
8	139 kV	Phidim to Kabeli	45	11.7	
9	140 kV	Tingla 1 Hub to Inkhu Hub	36	9.85	
10	141 kV	Tingla 1 Hub to Tingla 2 Hub	3	2.72	
11	142 kV	Mewa Hub to Hangpang Hub	39	10.27	
12	143 kV	U - DudhKohsi to to DudhKoshi IV HUb	28	7.71	
13	144 kV	Okhaldhunga to Tingla 2	28	7.82	
14	145 kV	Phidim to Ilam	78	18.73	
Subtotal 132 kV			**627**	**161.16**	
Total			**1,547**	**857.09**	

*All costs are in MUSD

5.9.2. Substation

18 substations are planned in Zone 5. Among which 11 substations with highest voltage level of 400kV with estimated cost of 449.41 MUSD, 5 substation with highest voltage level of 220kV with estimated cost of 92.83 MUSD is proposed in Zone 5 and 2 substation with highest voltage level of 132kV with estimated cost of 20.88 MUSD is proposed in Zone 5.

Table 54: Cost Estimate of substation in Zone 5

S.N.	Substation	Voltage Level	Total Price	Remarks
1	Arun-Hub	400/220/132	56.91	
2	Damak	400/220/132	26.34	
3	Dudhkoshi	400	25.57	Switching
4	Dudhkoshi-4	400/132	27.67	
5	Duhabi	400/132	31.18	
6	Hangpang	400/220/132	56.42	
7	Inaurwa	400/220	67.06	
8	Mirchiya	400/132	38.51	
9	Sunkoshi-Hub	400	27.45	Switching
10	Tingla	400/132	58.91	
11	U-Arun	400/220/132	33.39	
12	Baneshwor	220/132	14.28	
13	Basantapur	220/132	18.69	
14	Khadbari	220/132	17.63	
15	Sitalpati	220/132	17.97	
16	Tamor Hub	220/132	24.26	
17	U-Dudh Koshi	133/33	10.74	
18	Mewa Hub	132/33	10.14	
Total			**563.12**	

*All costs are in MUSD

E. Load Flow Study

Load flow analysis is performed for the planned network for 2040, considering the generation that will connect to the grid or network by 2040. The INPS for 2040 is expected to have more than 322 major hydroelectric plants above 20MW. The generating plants less than 20 MW are clustered together to form a single unit in the nearby major hub substations. Generators less than 50 MW are operated as MVar and power Factor control mode and remaining others are operated in voltage control mode. For all cases of steady-state load flow, Budhi Gandaki HEP is considered as the swing bus. For the purpose of the study (considering the existing scenario), the concentration of load is assumed to be high in the South of the country (Terai region) and Kathmandu valley, whereas that of generation is assumed to be high in the North of the country (Himalayan region). To consider the extreme case scenario during the planning process, mainly three cases are considered (i.e. Wet Season Peak load, Wet Season Minimum load and Dry Season Peak load). For all scenarios, minimum of 3GW of spinning reserve is considered. The details of the proposed network performance for load flow study of each scenario is presented below.

1. Scenario-1: Wet Season Peak load (Wet- Peak Load)

In this scenario, the peak domestic load is taken as 18 GW. The maximum generation capacity in this scenario from RoR type hydro generations is approximately 22.8GW, that from PRoR is about 3.8 GW and that from storage-type generations is around 11.3 GW. With 3GW of spinning reserve considered, around 15.9GW of power export to India and China is considered. The transmission line loss (at 132kV level and above) is approximately 4.03% of the total generated power.

2. Scenario-2: Wet Season Minimum load (Wet- Min Load)

In this scenario, the minimum loading condition of the daily load curve is considered and is taken as 7.25GW, which is around 40% of the peak load. The maximum generation capacity in this scenario from all types of hydro generations is the same as that in Scenario-1. However, due to decreased load demand, almost all storage and PRoR hydro generations are considered to be shut during this period. Considering the same amount of power export to China and India, the transmission line loss (at 132kV level and above) is approximately 4.32% of the total generated power.

3. Scenario-3: Dry Season Peak load (Dry- Peak Load)

In this scenario, the peak domestic load is taken as 18GW. Due to the dry season, the maximum generation capacity in this scenario from RoR type hydro generations is considered to be decreased and amounting to approximately 7.5GW, while that from PRoR is about 3.8GW and that from storage-type generations is around 11.3GW. With 3GW of spinning reserve considered, around 2GW of power export to India and China is considered. The transmission line loss (at 132kV level and above) is approximately 3.57% of the total generated power.

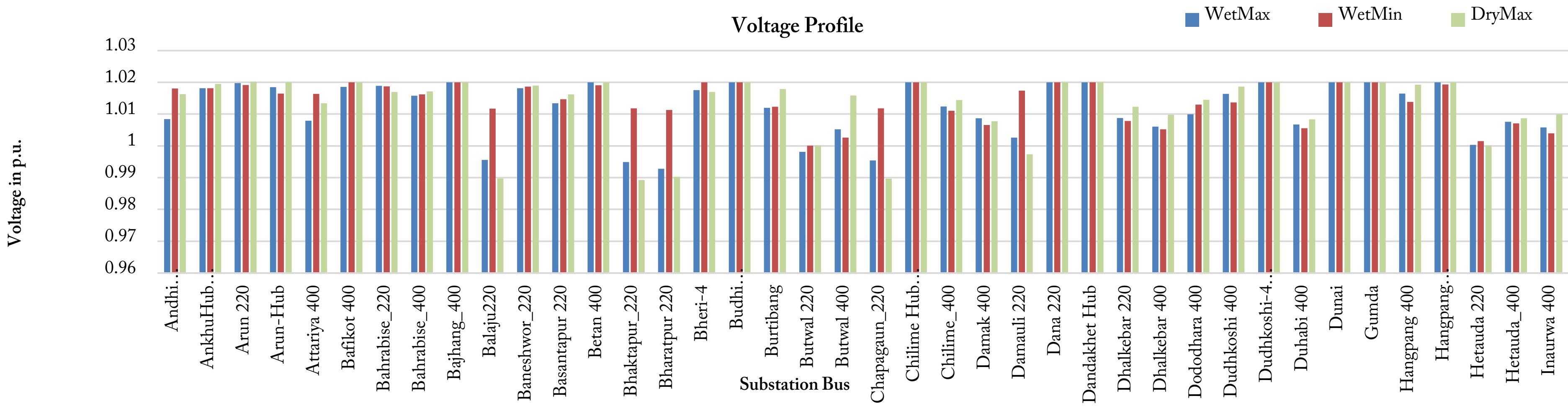

Figure 47: Voltage profile under different scenario by 2040

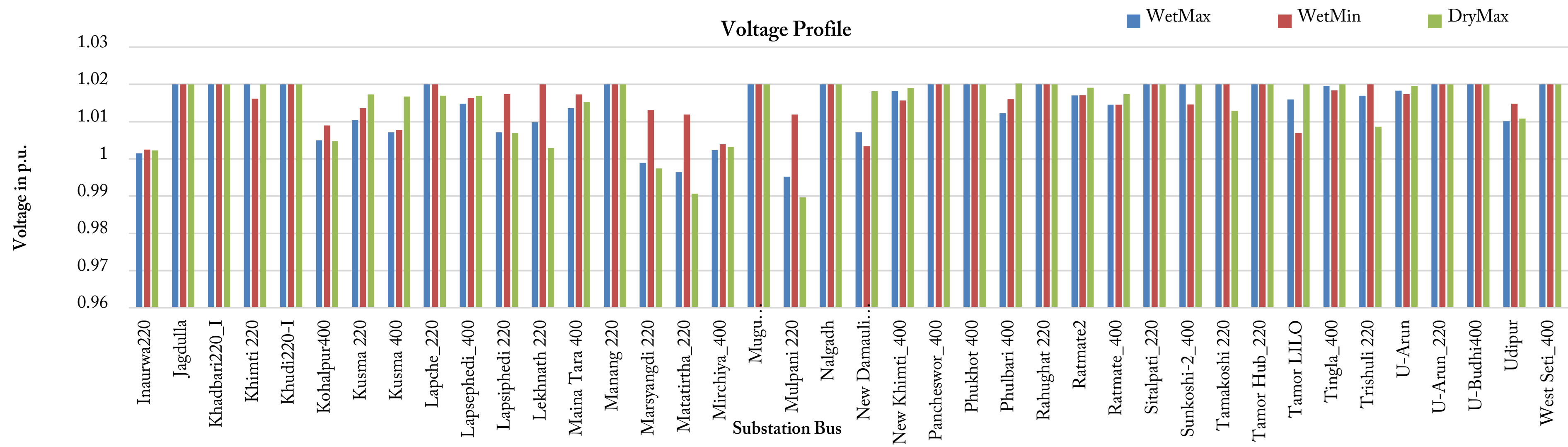

Figure 48: Voltage Profile under different scenario by 2040

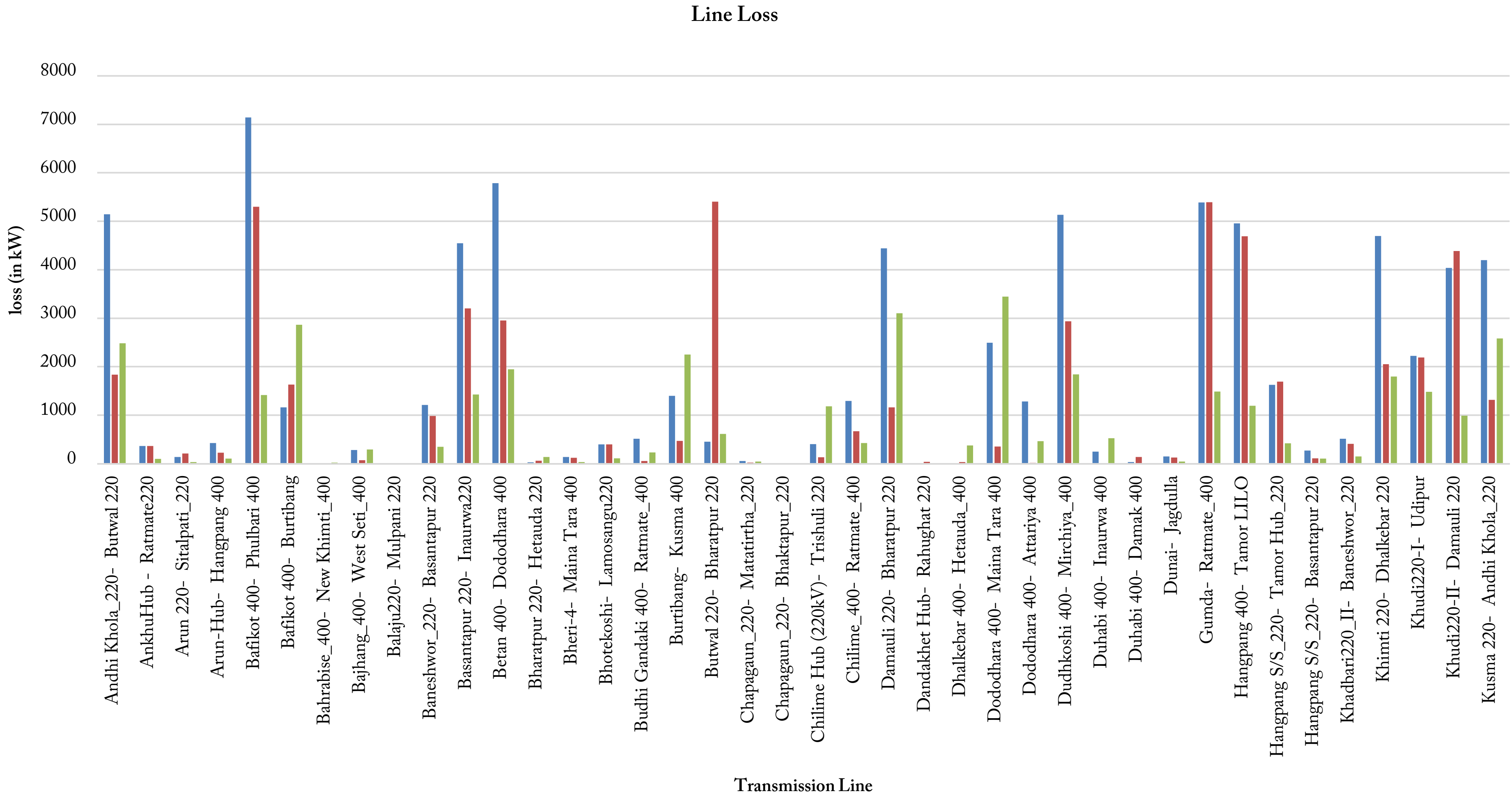

Figure 49: Line Loss under different scenario by 2040

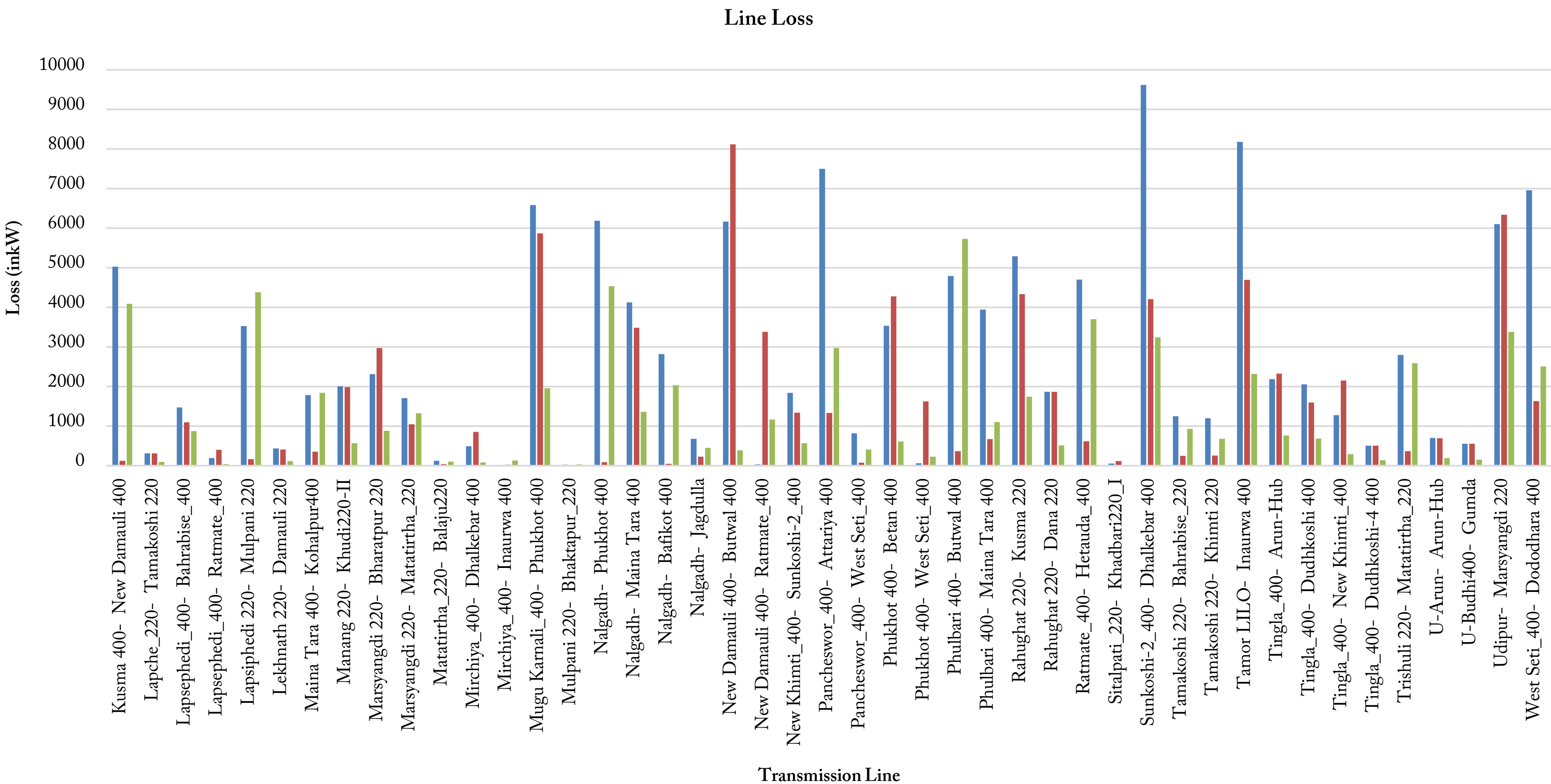

Figure 50: Line loss under different scenario by 2040

F. Contingency Study

1. N-1 Contingency

N-1 contingency analysis was performed for the proposed 2040 network and tabulated below.

Table 55: Result of N-1 contingency study

S.N.	Line Violation Case					Contingency Case		
	Starting Terminal	Ending Terminal	Base Voltage [kV]	Loading Post-Contingency [%]	Loading Base Case [%]	Starting Terminal	Ending Terminal	Base Voltage [kV]
1	Sunkoshi	New Dhalkebar	400	131.3	81.8	Sunkoshi	New Dhalkebar	400
2	Betan	Dododhara	400	109.7	65	Betan	Dododhara	400
3	Bafikot	Nalgadh	400	104.8	58.8	Bafikot	Nalgadh	400
4	Tamor LiLo	Inaruwa	400	105.6	62.5	Tamor LiLo	Inaruwa	400

The result showed that none of the contingency cases resulted in voltage violation in any major hub substations. However, some sections of the proposed meshed network could not meet the N-1 contingency criteria, which was one of the essential criteria in the design of the proposed network. As per these criteria, each circuit of a double circuit transmission line should have sufficient capacity to carry the entire load of both circuits in case of the failure of the other circuit without overloading. The following line loading violations were observed in the proposed network.

Hence, for the above transmission lines, it was recommended to replace the conductor in these transmission lines with their HTLS equivalent conductors. The N-1 contingency result after the recommended change in conductor is as follows:

Table 56: Result of N-1 contingency study after recommended changes

S.N.	Line Violation Case					Contingency Case		
	Starting Terminal	Ending Terminal	Base Voltage [kV]	Loading Post-Contingency [%]	Loading Base Case [%]	Starting Terminal	Ending Terminal	Base Voltage [kV]
1	Sunkoshi	New Dhalkebar	400	56.84	28.42	Sunkoshi	New Dhalkebar	400
2	Betan	Dododhara	400	49.64	24.82	Betan	Dododhara	400
3	Bafikot	Nalgadh	400	37	18.5	Bafikot	Nalgadh	400
4	Tamor LiLo	Inaruwa	400	45.68	22.84	Tamor LiLo	Inaruwa	400

As seen from the above results, the proposed system after making the recommended changes is seen to be robust enough to withstand N-1 line contingencies at 220kV and 400kV level.

In addition, some of the double circuit radial lines at 132kV voltage level were seen to have line loadings higher than 50% of the maximum limit, suggesting that a N-1 line contingency in such lines would result in unsustainable overloading of the healthy circuit. In some cases of 132kV system, it is seen that even switching to the highest capacity conductor for this voltage range (ACSR Duck) does not provide the required transmission capacity for N-1 contingency sustainability. Hence, it is recommended to use HTLS type conductor instead of the scheduled conductor. In this study, ACCC Amsterdam is considered as the replacement for the scheduled conductor. The line loading after switching to the HTLS conductor is listed below.

Table 57: Result of N-1 contingency study after switching to HTLS

S. N.	Starting Terminal	Ending Terminal	Voltage Level (kV)	Length	Scheduled loading condition		Recommended loading condition	
				Km	Conductor	Loading (%)	Conductor	Loading (%)
1	U-Balephi	L Balephi	132	10.75	ACSR DUCK	73.2	ACCC Amsterdam	35.8
2	Bafikot132	Sisne	132	14.08	ACSR DUCK	70.5	ACCC Amsterdam	34.6
3	Inkhu	Tingla 132	132	14.3	ACSR DUCK	76.2	ACCC Amsterdam	37.3
4	Dandakhet 132	Burtibang 132	132	28	ACSR DUCK	63.7	ACCC Amsterdam	31.5
5	Upper Dudhkoshi 132	Dudhkoshi-4 Hub 132	132	13.8	ACSR DUCK	92.3	ACCC Amsterdam	45.2

Hence, it is seen that the above lines, after switching to the recommended conductor can sustain a N-1 line contingency without overloading.

2. Tower Contingency

After running N-2 contingency analysis for all double circuit fault cases for major 220kV and 400kV transmission lines, the following lines were seen to be overloaded beyond their normal thermal loading limit.

Table 58: Result of tower contingency study for line loading

S.N.	Line Violation Case					Contingency Case		
	Starting Terminal	Ending Terminal	Base Voltage [kV]	Loading Post-Contingency [%]	Loading Base Case [%]	Starting Terminal	Ending Terminal	Base Voltage [kV]
1	Khimti	Dhalkebar	220	114.1	49.8	Sunkoshi	Dhalkebar	400
2	Hangpang	Basantapur	220	108.8	20.7	Tamor Storage LiLo	Inarurwa	400

The overloading of these lines can be interpreted as the flow of power from generations through alternative routes after the complete outage of the dedicated transmission line. It is seen that the lines that exceed the continuous maximum thermal loading limit are, however, within the emergency loading limit (120% of the maximum loading) which can be sustained for a temporary period till the fault is removed. In case of a very few lines where the post-contingency loading is above the emergency loading limit, temporary load shedding or rescheduling of generation in the affected area may be required to bring the system parameters within normal limits.

Overall, it is seen that most of the lines have sufficient capacity to operate within either normal loading limit or emergency loading limits.

G. Generation Outage Study

The generation outage was studied for the case of Wetmax condition as the maximum line loading is expected for this scenario. Generation outage for some of the largest generating plants was studied viz., Budhi Gandaki HEP (1200MW), Sunkoshi-2 HEP (1100MW), Humla Karnali Cascase HEP (916MW), Tamor Storage HEP (765MW) and West Seti HEP (750MW).

As seen from the load flow result for the outage of each generation, it was seen that the loading of the transmission lines and the bus voltage in the electric grid did not experience significant changes. Overall, no major transmission lines were overloaded and no major hub substation voltages were out of the acceptable voltage range after the outage of each considered generating plants. The details of the generation outage are presented in Annex 3.

H. Cross Border Transmission Line

The main purpose of Nepal–India Cross Border is to exchange the power between two countries through various lines operating at various voltage levels from 11kV to 220kV. Presently Nepal is importing power from Bihar and Utter Pradesh power grid from India. List of cross Border transmission lines are

1. Gandak - Ramnagar – 132kV
2. Dhalkebar - Muzaffarpur- 400kV (Presently charged at 132kV)
3. Kusaha-Kataiya. - 132kV
4. Mahendranagar – Tanakpur -132kV
5. Siraha – Jaynagar - 33kV
6. Birpur – Kataiya - 33kV
7. Jaleswar - Sursand - 33kV
8. Birgunj – Raxaul -33kV
9. Bhairahwa – Nautanawa– 33kV
10. Koilabas – Lamhi – 33kV
11. Nepalgunj – Nanpara– 33kV
12. Dhangadhi – Paliya – 33kV
13. Mahendranagar – Lohiahed – 33kV
14. Chandragadhi – Thakurgunj – 33kV

1. Proposed Cross Border Line with India

To cut existing power deficit and export surplus power in future cross-border transmission line is required. The report has continued previously identified six locations for cross-border power line with India. Two more locations have been identified for cross-border transmission line to exchange power with China. The cross-border location is proposed in such way that the load center and generation hub is closer to each other. The details of the existing and proposed cross-border links are given below.

1.1. Attariya-Bareily Cross Border Transmission Line

This interconnection is especially dedicated to export the bulk amount of power to India from export-oriented HPP in the Mahakali, Karnali and Seti corridors in Zone-1 area of Nepal. A single line of double circuit 400kV quad Moose transmission line of distance about 140 is proposed. The subsequent power flows on these lines for wet peak scenarios by 2040 is tabulated below. The possibilities of this cross-border transmission line will be explored.

Table 59: Power flow between Attariya-Barely Cross Border Transmission Line

ID	From Bus	To Bus	MW Flow	% Loading
Attariya-Bareily	Attariya 400	Bareily	700	16.3

1.2. Dododhara–Bareily Cross Border Transmission Line

This interconnection is especially dedicated to export the bulk amount of power to India from export-oriented HPP in the Mahakali, Karnali and Seti corridors in Zone-1 area of Nepal. Two numbers of double circuit 400kV quad Moose transmission line of distance about 200 is proposed. The subsequent power flows on these lines for wet peak scenarios by 2040 is tabulated below.

Table 60: Power flow between Dododhara–Barely Cross-Border Transmission Line

ID	From Bus	To Bus	MW Flow	% Loading
Bareily-Dododhara	Dododhara 400	Bareily	3000	34.6

1.3. Phulbari–Lukhnow Cross Border Transmission Line

This interconnection line is planned for evacuating the power from Nalsyau Gad, Bheri Corridor in Zone-2 of Nepal to Lukhnow, India by 2040. Two numbers of double circuit 400kV quad Moose transmission line of distance about 200 is proposed. The flow of power for wet peak scenario for 2040 year is tabulated below.

Table 61: Power flow between Phulbari–Lukhnow Cross Border Transmission Line

ID	From Bus	To Bus	MW Flow	% Loading
Lukhnow-Phulbari	Phulbari 400	Lukhnow	2600	29.9

1.4. New Butwal–Gorakhpur Cross Border Transmission Line

This interconnection line is planned for evacuating the power from Marsyandi, Kaligandaki and Gandaki Corridor in Zone-3 of Nepal to Gorakhpur, India by 2040. Two numbers of double circuit 400kV quad Moose transmission line of distance about 125 is proposed. The flow of power for wet peak scenario for 2040 year is tabulated below.

Table 62: Power Flow between New Butwal–Gorakhpur Cross Border Transmission Line

ID	From Bus	To Bus	MW Flow	% Loading
Butwal-Gorakhpur	Butwal 400	Gorakhpur	2500	28.8

1.5. Dhalkebar – Muzzafarpur Cross Border Transmission Line

This interconnection line is planned for evacuating the power from Khimti, Tamakoshi and Dudhkoshi Corridor in Zone-4 of Nepal to Muzafarpur, India by 2040. Two numbers of double circuit 400kV quad Moose transmission line of distance about 130 is proposed. The flow of power for wet peak scenario for 2040 year is tabulated below.

Table 63: Power flow between Dhalkebar – Muzzafapur Cross Border Transmission Line

ID	From Bus	To Bus	MW Flow	% Loading
Muzzafpur-Dhalkebar	Dhalkebar 400	Muzzafpur	3100	35.7

1.6. Inaurwa – Purnea - Cross Border Transmission Line

This interconnection line is planned for evacuating the power from major corridor likes Arun and Koshi in Zone-5 of Nepal to Purnea, India by 2040. Two numbers of double circuit 400kV quad Moose transmission line of distance about 110 is proposed. The flow of power for wet peak scenario for 2040 year is tabulated below.

Table 64: Power flow between Inaurwa – Purnea - Cross Border Transmission Line

ID	From Bus	To Bus	MW Flow	% Loading
Purnea-Inaurwa	Inaurwa 400	Purnea	1800	20.9

2. Proposed Cross Border Line with China

For the purpose of large scale export of power from various hydroelectric projects in Nepal to China by 2040, two main cross-border links of 400kV quad circuit transmission lines are proposed. The substation area is proposed in such way that load center and generation hub is closer to each other. The details of the proposed cross-border links are given below.

2.1. Chilime-Keyrung Cross Border Transmission Line

This interconnection is especially dedicated to export the bulk amount of power to China from export-oriented HPP in the Trishuli river corridor in Zone-4 area of Nepal. Two numbers of double circuit 400kV quad Moose transmission line of distance about 80 is proposed. The subsequent power flows on these lines for wet peak scenarios by 2040 is tabulated below

Table 65: Power flow between Chilime-Keryung Cross Border Transmssion Line

ID	From Bus	To Bus	MW Flow	% Loading
Chilime-Keryung	Chilime	Keyrung	1500	34.3

2.2. Kimanthanka – Latse Cross Border Transmssion Line

This interconnection line is planned for evacuating the power from major corridor likes Arun and Koshi Corriodor in Zone-5 of Nepal to Latse in China by 2040. The exporting point will be from Kimanthank Arun substation. Two numbers of double circuit 400kV quad Moose transmission line of distance about 250 is proposed.

Table 66: Power flow between Kimanthanka – Latse Cross Border Transmssion Line

ID	From Bus	To Bus	MW Flow	% Loading
Kimanthanka – Latse	Kimanthanka	Latse	700	15.9

I. Conclusions

The Government of Nepal has identified the development of hydropower resource as the path to the country's economic development in the long term. Consequently, GoN has set forth a target to develop 15 GW by 10 years, and around 40 GW by the year 2040, which GoN plans to utilize mainly for domestic load demand and for export to neighboring countries. GoN, various government owned entitites, IPPs and internationally funded power producers are actively involved in the hydropower development in Nepal. However, the development of robust and reliable national transmission network is equally essential to properly transmit, distribute and export power generated from these hydroelectric plants. At present, much attention and investment have been focused mostly on the development of hydroelectric generating plants. Planned development of the transmission system has so far been a less discussed topic, resulting in an ad hoc approach of transmission system development.

Hitherto, transmission master plans and network interconnection plans have been proposed by different studies (NEA, JTT) for up to the year 2035. The common theme of these plans is to design a 400kV radial line along the river corridor to connect to the 400kV East-West highway along the Terai region for domestic load and exporting power to India through six export points. Further, segregation of transmission network of country into six zones with cross-border connection points with India in each zone are presented in the reports. The main focus of these master plan reports has been the development of the transmission network in the country with the objective of facilitating the export of the hydropower to India. However, as per the GoN's new vision for economic development target with 7.2% GDP growth (as per WECS report), it is anticipated that domestic load demand for electricity is expected to be 18 GW by the year 2040. Hence, it is necessary to develop a robust consolidated transmission system development plan that focuses on a reliable supply of electricity for the domestic load and at the same time, facilitate export of power to India and China. RPGCL which was established in July 2015 by the GoN of Nepal to plan, construct and operate transmission grid of Nepal, has prepared an updated transmission development plan which adapts most of the network design and analysis concept from previous transmission line master plans. The Transmission System Development Plan adds new concepts regarding reliable distribution of power in the country for domestic consumption and contains updated network information including updated generation and load scenario up to the year 2040.

The transmission system development plan proposed by RPGCL suggests that, in addition to the 400kV East-West highway along the Terai region of the country as proposed by the previous master plan, there should be a similar 400kV East-West highway along the hilly region connecting major hub substation connected to large-scale hydroelectric generations. This, along with the 400kV dedicated lines along the river corridors, results in the formation of a countrywide mesh transmission network instead of a radial transmission line along the river corridors. A clear advantage of such mesh network is seen in the event of the fault in any north-south line where unlike radial line along river corridor, power from HPPs will be evacuated through alternative route in mesh network.

The power grid of Nepal is divided into 5 zones from west to east, with at least one interconnection points with India and China. Zone 1 in the far-west consists of Mahakali, West Seti and Karnali corridors where Dododhara and New Attariya substations are the proposed interconnection points with Bareilly of India for power exchange. The major generations in this zone are Pancheswor (3240MW), Humla Karnali Cascade (916MW) and West Seti (750MW). Zone 2 consists of Bheri Corridor with major generations such as Bheri-3 Storage (480MW), Nalgadh (410MW), Naumure Storage (342MW), etc. The export point at this zone is Phulbari substation which is proposed to be connected to the Lukhnow substation of India. Similarly, Zone 3 consists of Kali Gandaki and Marsyangdi corridors, with major generations such as Upper Marsyangdi-2 (600MW), Kali Gandaki Kowan (400MW), Manang Marsyangdi (282MW), etc. The proposed interconnection point for this zone is the New Butwal substation for connection with Gorakhpur of India. Zone 4 includes Trishuli-Chilime, Khimti, and Tamakoshi Corridor and consists of major generations such as Sunkoshi-2 (1110MW), Tamakoshi-3 (650MW), Sunkoshi-3 HEP (536MW), etc. This zone is proposed to have interconnection point at New Dhalkebar for power exchange with Muzzafarpur of India and Chilime 400kV substation for power exchange with Kerung of China. Finally, Zone 5 in the far-east includes Koshi, Arun and Kabeli corridors consists of major generations such as Tamor Storage (765MW), Kimathanka Arun (450MW), Upper Tamor (415MW), Arun-4 (372MW), etc. The proposed interconnection points in this zone are Inaruwa substation for power exchange with Purnea of India and Kimanthanka substation for power exchange with Latse of China.

The INPS for 2040 is expected to have more than 322 major hydroelectric plants above 20 MW. The generation plants less than 20 MW are clustered together to form a single unit in the nearby major hub substations. The computer model of the proposed network consists of the data of existing, under construction and planned/proposed hydroelectric projects and transmission lines, and load forecast of the target year 2040. For simplification, only transmission lines of 220kV and above voltage level with few major transmission lines of 132kV is considered for load flow and contingency analysis. The maximum installed capacity of 38 GW, maximum domestic load of 18 GW and maximum export capacity of 16 GW with 3 GW spinning reserve is predicted for the year 2040 and computer model is developed accordingly. In the proposed network, 3192 km of 400kV including cross-border lines and 1160 km of 220kV major transmission line needs to be completed across the country. In addition, 40 number of 400kV highest voltage substation and 19 number of 220kV highest voltage substation is included in the network. Most of the generation in 2040 is still expected to be from RoR type hydroelectric projects, with 60% of the installed capacity contributed by such generation. However, the share of storage type generation is expected to increase to 30% of the installed capacity with the addition of new large-scale storage type projects. Likewise, 10% of the generation is expected to be contributed by PRoR hydropower.

To evaluate the performance of the proposed network from various aspects, the network has undergone various computer analysis techniques. Due to the seasonal nature of generation from RoR hydropower plants and dynamic nature of load, three different scenarios are defined to include the extreme conditions in which the proposed network is required to perform. These scenarios are defined as i) Wet Season Maximum Load during the wet season when the generation is at maximum capacity and the domestic load is at the daily peak, ii) Wet Season Minimum Load during the wet season when generation is at maximum capacity and the domestic load is at the daily minimum and iii) Dry Season Maximum Load during the dry season when the generation is at the minimum and the load is at the daily maximum. Scenario i) is expected to be the one in which the network is at the maximum loading condition and is hence used to evaluate the line loading and bus voltage during steady state and contingency conditions.

The load flow analysis results indicated that the voltages of all major hub substations and line loadings of all major transmission lines in the proposed network are within safe limits for steady state operation in all the above scenarios. For the wet season, Nepal is seen to be capable of exporting large quantity of power whereas for the dry season, export needs to be curtailed in order to prioritize the domestic load demand due to the drop in the generation capacity of the RoR projects.

The contingency analysis for the network indicates that the proposed system is capable of handling all N-1 line contingencies, i.e. the outage of one circuit from any major transmission line at a time, within the ring network either without overloading or with marginal overloading. In case of N-2 or Tower contingency analysis, only two of the major transmission lines, viz., Khimti-Dhalkebar 220kV line for the outage of Sunkoshi Hub-New Dhalkebar 400kV line and Hangpang-Basantapur 220kV line for the outage of Tamor Storage Hub-Inaruwa 400kV line, were seen to be overloaded above the maximum normal loading but were still less than the allowed emergency loading (120% of normal loading capacity).

In addition, generation outage case studies for major generations such as Budhi Gandaki Storage (1200 MW), Sunkoshi-2 HEP (1110 MW), Humla Cascade HEP (916 MW), Tamor Storage HEP (765 MW) and West Seti HEP (750 MW), were also carried out to examine their impact on the line loading and voltage profile of the proposed network. It was seen that the change in the power flow resulting from the outages of the above-mentioned generations neither caused overloading of any major transmission lines nor resulted in over/undervoltage in any major substations in the proposed network.

Thus, through computer analysis techniques, it can be concluded that the network proposed for 2040 by this transmission system development plan is capable of performing satisfactorily while supplying power for large domestic load as well as for export under various steady state conditions. The Transmission System Development Plan is also robust enough to withstand contingency cases.

Overall, the proposed network will need to construct 3192 km of 400kV transmission lines, 1160 km of 220kV transmission lines and 2515 km of 132kV transmission lines with an estimated cost of 3767.91 MUSD. Likewise, the network consists of 40 substations with highest voltage level of 400kV, 19 substations with highest voltage level of 220kV and 14 substations of 132kV, which shall cost an estimated 2269.76 MUSD. Thus, the proposed network is estimated to have a total cost of 6037.68 MUSD.

The Transmission System Development Plan presents comprehensive details of the proposed network however additional studies like 5 years plan from 2020 onwards, dynamic analysis, short-circuit study, reliability analysis, optimal capacitor placement, estimation of wheeling charges, etc will be included in subsequent auxilliary reports.

J. References

[1]: Department of Electricity Development, http://www.doed.gov.np/

[2]: Nepal Electricity Authority, "A Year in Review Fiscal Year 2016/17"

[3]: Integrated Master Plan for Evacuation of Power from Hydro Projects in Nepal, Prepared by Joint Technical Team (JTT) of India and Nepal, June 2016

[4]: Final Transmission Master Plan R-7, Nepal Electricity Authority (NEA), Project Technical Assistance for Preparing Transmission System Master Plan of NEA

[5]: Electricity Demand Forecast Report (2015-2040), Government of Nepal, Water and Energy Commission Secretariat

K. Annex-1

1. Element Modeling

1.1. Transmission Line

A transmission line is an electrical conductor used for transmitting bulk electrical power through long distance. It is one of the most important components of the power system.

A transmission line system consists of parameters such as series resistance, inductance and shunt capacitance per unit length which are required for its mathematical modeling. These data are basically determined by conductor size and type and by transmission tower design. These values determine the power carrying capacity of the transmission line, line losses and the voltage drop across the power network during the load flow analysis under various loading conditions.

Overhead transmission system considered in this report consists of long bare conductors supported by towers mostly made up of steel lattice structure to maintain the necessary clearance over ground and other nearby structures. The bare wire conductors used are generally made of aluminum (either plain or reinforced with steel, or composite materials such as carbon and glass fiber), though some copper wires are used in medium-voltage distribution and low-voltage connections to customer premises. Here, as per the common practice in Nepal, it is assumed that the conductors used are ACSR (Aluminum Conductor Steel Reinforced) type conductor. ACSR consists of a galvanized steel core of 1 wire, 7 wires or 19 wires surrounded by concentric layers of aluminum wire.

The designs of transmission lines with ACSR conductors are normally based on a thermal limit of the conductor. The thermal loading limit of a line in turn is determined by design parameters based on ambient temperature, maximum permissible conductor temperature, wind speed, solar radiation, absorption coefficient, emissivity coefficient etc.

To calculate the electrical parameters of the line, various data are taken as the input. The required input parameters are listed below.

- Types of conductor
- Tower configuration.
- Number of circuits.
- Number of conductors in bundle.

- AC and DC resistance of the conductor for a given temperature.
- Maximum operating temperature of conductor

The line parameters that need to be calculated are discussed as follows.

- Resistance of the conductor for different temperature.

  Resistance is the properties of the conductor by which it resists the flow of electrical current through it and which determine the heat loss in the transmission line. Higher the value of resistance, higher will be the loss in the power network. The value of ac resistance for different conductor types is taken from conductor table given at 20°C whereas the maximum conductor temperature is taken as 75 °C. As the temperature increases, the value of resistance increase, thus loss increases. Resistance of the conductor for the different temperature is calculated by using the expression:

$$\boldsymbol{R_2 = R_1 + (T_2 - T_1) * \alpha} \text{ (Ohm per km)}$$

  Where, R_1= Resistance at base temperature T_1

  R_2=Resistance at temperature T_2

  α = Calculated linear coefficient per °Cx10^{-6}

- Inductance of conductor

  Current in AC transmission line varies sinusoidally with time, so the associated magnetic field which is proportional to the current also varies sinusoidally. This varying magnetic field induces an emf in the conductor. This emf opposes the current flow in the line. This emf is equivalent shown by a parameter known as inductance. The inductance value depends upon the relative configuration between the conductor and magnetic field. Inductance is the flux linking with the conductor divided by the current flow in the conductor.

$$\boldsymbol{L = 2 * 10\text{^} - 7Ln(\frac{D}{r_1'})}$$

  Here D is the distance between the centers of the conductor i.e. GMD and r_1' is the GMR.

  GMD and GMR stands for the Geometrical Mean Distance and Geometrical Mean radius. GMD is the geometric mean distance between conductors of a transmission system and GMR is the geometric mean distance between the strands of a single composite conductor. These parameters are essential for the calculation of inductance and capacitance of transmission lines. GMD depends on the tower geometry while GMR depends on the conductor bundling. The geometric mean radius (GMR) of bundled conductor is given by

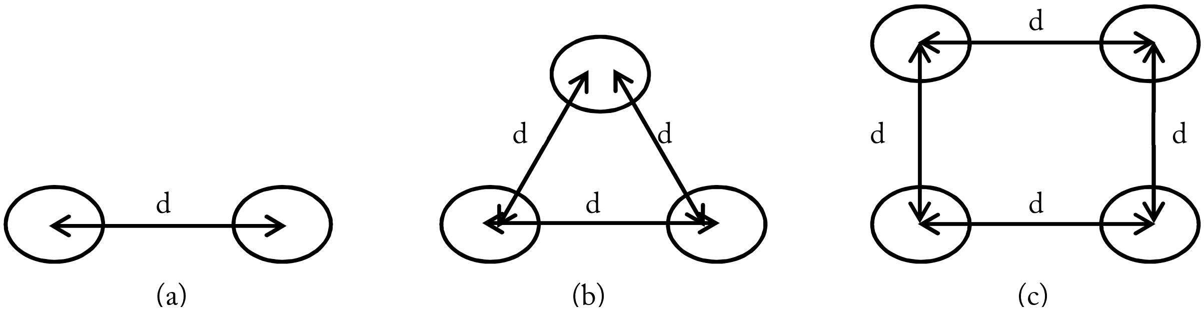

Figure 51: Types of bundle conductor

$$D_{s,2b} = \sqrt[4]{(D*d)^2} \text{(Fig a)}$$

Where D_s is the GMR of conductor.

The GMR for three-conductor and four-conductor bundles are given respectively by bundles are given respectively by

$$D_{s,3b} = \sqrt[9]{(D*d*d)^3} \text{ (Fig b)}$$

$$D_{s,4b} = \sqrt[16]{\left(D*d*d*\sqrt{2}d\right)^3} \text{(Fig c)}$$

- Susceptance of conductor

Earth affects the calculation of capacitance of three-phase lines as its presence alters the electric field lines. Usually the height of the conductors placed on transmission towers is much larger than the spacing between the conductors. Under a normal condition, combination of conductor, earth and air in between the ground act as the capacitor. A long transmission line can draw substantial quantity of charging current due its high capacitance with ground. If such a line is open circuited or very lightly loaded at the receiving end, the receiving end voltage will be greater than sending end voltage, which is known as Ferranti effect. Line capacitance supply reactive power and are connected parallel to the transmission lines at the receiving end so as to compensate the reactive power consumed by the line inductance. Capacitance between the two lines each of radius r is C farad per meter of line length is

$$C = \frac{\pi*K}{Ln\left(\frac{D}{r}\right)}$$

Where D stand for GMD and r for GMR of the conductors.

- Calculation of Ampacity

The thermal capabilities of transmission lines are evaluated based on the criteria of maximum operating or design temperatures of the transmission line conductors. It is dependent on different factors such as meteorological/environmental conditions, solar radiation, wind velocity, ambient temperature, and sage of the Conductor. The calculation of current carrying capacity of the conductor is based on IEEE standard. Conductor surface temperatures are a function of:

- Conductor material
- Conductor outer diameter.
- Conductor surface conditions.
- Ambient weather Conditions.
- Conductor electrical current.

Based on the steady-state heat balance equation of a bear overhead conductor, the conductor current and temperature relationship can be given as the following equation.

$$\mathbf{I} = \sqrt{\frac{\mathbf{Q_c + Q_r - Q_s}}{\mathbf{R(T_c)}}}$$

Where I is the conductor current, q_c is the convected heat loss, q_r is the the radiated heat loss, q_s is the heat gain from the sum, and R is the conductor AC resistance at conductor temperature T_c.

1.2. Transformer

Transmission line nominal voltage is chosen as the optimal solution between performance and economy. Hence, different sections of electric power network may have different transmission line voltages, which may converge at some point, mainly at hub substations. Transformers are installed in substations to provide a safe interconnection between systems with different nominal voltages. A transformer is an electrical device that transfers electrical energy between two or more circuits, usually with varying operating voltages, through electromagnetic induction.

Figure below represents the positive sequence model for a 2-winding transformer as modeled in the computer simulation. It contains the leakage reactance and the winding resistance of the HV and LV side and the magnetization reactance and the iron loss admittance close to the ideal transformer.

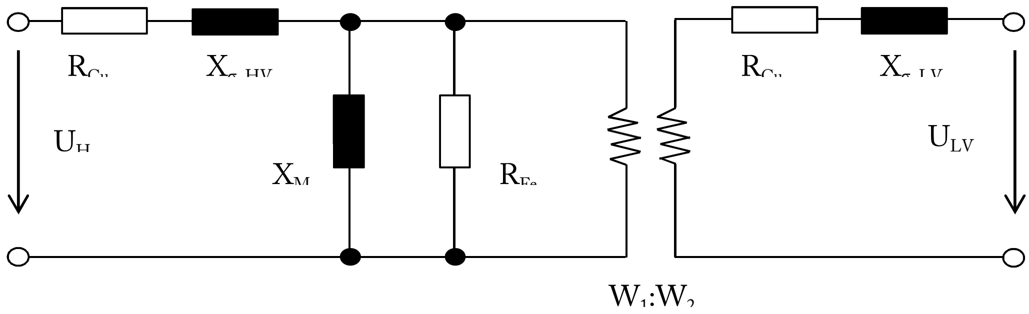

Figure 52: Positive sequence model of 2-winding transformer (in Ohms).

The model with relative impedances (in p.u.) is shown in Figure below. The ideal transformer of the per-unitized model has a complex winding ratio with a magnitude of 1:1 and models the phase shift representing the vector groups of the two windings.

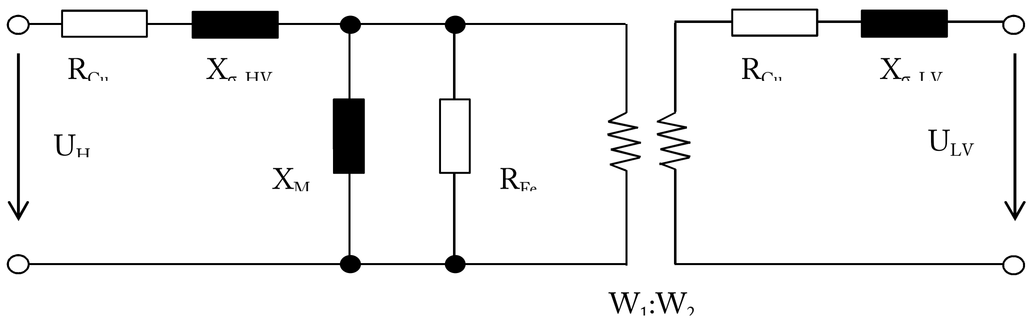

Figure 53: Positive sequence model of 2-winding transformer (in p.u.)

The relation between the mathematical parameters in the model and the parameters in the type and element dialogs are described as follows:

$$z_{sc} = \frac{U_{sc}}{100}$$

$$r_{sc} = \frac{P_{Cu}/1000}{S_r}$$

$$x_{sc} = \sqrt{z_{sc}^2 - r_{sc}^2}$$

$$r_{Cu,HV} = \gamma_{R,HV,1} \cdot r_{sc}$$

$$r_{Cu,LV} = (1 - \gamma_{R,HV,1}) \cdot r_{sc}$$

$$x_{\sigma,HV} = \gamma_{X,HV,1} \cdot x_{sc}$$

$$x_{\sigma,LV} = (1 - \gamma_{X,LV,1}) \cdot x_{sc}$$

$$Z_M = \frac{1}{i_0/100}$$

$$\mathbf{r_{Fe}} = \frac{\mathbf{S_r}}{\mathbf{P_{Fe}/1000}}$$

$$\mathbf{x_M} = \frac{\mathbf{1}}{\sqrt{\frac{\mathbf{1}}{\mathbf{z_M^2}} - \frac{\mathbf{1}}{\mathbf{r_{Fe}^2}}}}$$

where,

$Z_{r,HV}$	Ω	Nominal impedance, HV side
$Z_{r,LV}$	Ω	Nominal impedance, LV side
$U_{r,HV}$, $U_{r,LV}$,	kV	Rated voltages on HV/LV side
S_r	MVA	Rated power
P_{Cu}	kW	Copper losses
u_{SC}	%	Relative short-circuit voltage
z_{SC}	p.u	Short-circuit impedance
r_{SC}	p.u	Short-circuit resistance
x_{SC}	p.u	Short-circuit reactance
$\Upsilon_{X,HV,1}$	p.u	Share of transformer short circuit reactance on HV side in the positive-sequence system
$\Upsilon_{R,HV,1}$	p.u	Share of transformer short circuit resistance on HV side in the positive-sequence system
$r_{Cu,HV}$, $r_{Cu,LV}$	p.u	Resistances on HV/LV sides
$x_{\sigma,HV}$, $x_{\sigma,LV}$	p.u	Leakage reactances on HV/LV side
I_0	%	no-load current
P_{Fe}	kW	No-load losses
x_M	p.u	Magnetizing impedance
r_{Fe}	p.u	Shunt resistance

The following minimum parameters are required for modeling a 2-winding transformer:

- Nominal frequency (Hz)
- Winding 1 & 2 Nominal Voltage (kV)
- Rated Power (MVA), i.e., transformer capacity
- Series Resistance R in p.u., (assumed to be negligible)
- Series Reactance X (pu). Since the series resistance was assumed to be negligible, reactance (X) was assumed to be equal to the percentage impedance (Z).
- Shunt Conductance G in p.u., (assumed to be negligible)
- Shunt Susceptance B in p.u., (assumed to be negligible)

Tap changers are either "off-load" or "on-load." Off-load tap changers may only have their tap adjusted when they are de-energized. On-load tap changers may change their tap under loading. Both kinds of tap changers have common modeling requirements.

An additional, ideal transformer connected to either the HV or the LV side (see Figure 47 and 48) represents the tap changer. In most application, the winding ratio of this transformer is real and is defined by the actual tap position (in number of steps) times the additional voltage per steps.

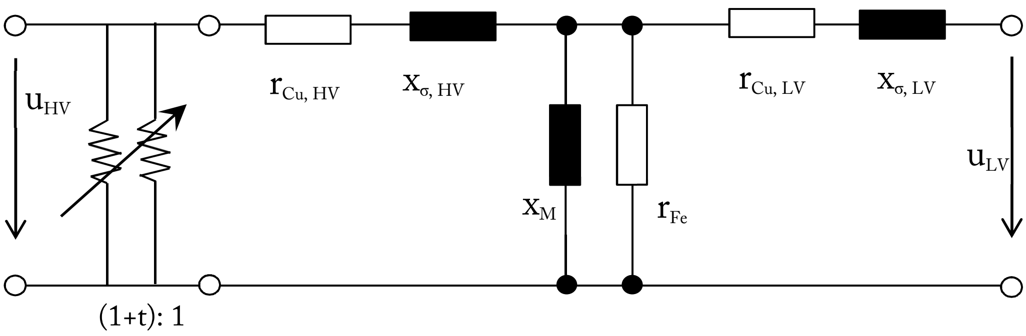

Figure 54: Transformer model with tap changer modeled at HV – side

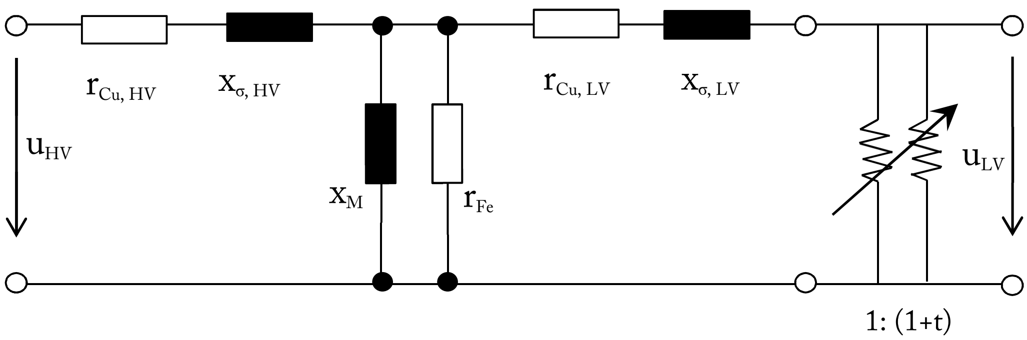

Figure 55: Transformer model with tap changer modeled at LV – side

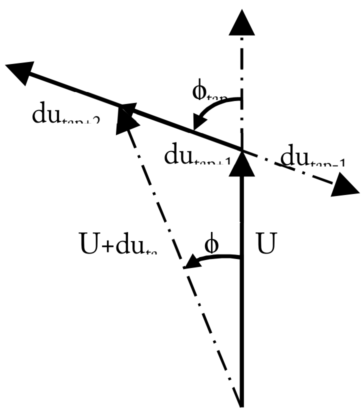

Figure 56: Complex tap changer model

Phase shifters are modelled by a complex ratio using a complex value of d_{utap} according to Figure 5. There are two possibilities of specifying a phase shifting transformer, either by entering magnitude and angle (du_{tap} and ϕ_{tap}) of the additional voltage per tap step or by defining magnitude and angle at each individual tap-step ($|U + dutap|$, ϕ_u).

1.3. Bus/substation

Substations are designed to facilitate safe and reliable connection between the electric power source lines and power outgoing lines. They act as a common node or junctions for several incoming and outgoing lines in an electric network. Several configurations are available for establishing connections between the lines as per the requirement for reliability, operability and economy. For the sake of simplicity in the load flow analysis, all substations are modeled as having a single busbar configuration as it does not impact the results of computer analysis methods such as load flow and contingency analysis. In the electric network, two concepts of substations are usually found:

- Dedicated substations: Such substations are usually constructed either near or within (in case of GIS type substation) the generating power plants to connect the generating station to the electric grid for dispatch of generated electric power.
- Hub substation: Such substations are constructed in areas with several generating power plants to provide a common connection point to the electric grid. Such substations also serve to connect generating plants with lower transmission voltages to step up to a higher transmission voltage using transformers for power evacuation through a common transmission line of higher voltage. The advantage of the hub concept is that it minimizes the need for substations, thereby minimizing the global investment costs and as a consequence, avoiding excessive increases in transmission tariffs. However, for the sake of simplicity and conciseness in the load flow analysis, generating power plants with short transmission lines from the location of the hub substations are assumed to be connected directly to the hub substation.

In short, the nearest substation, existing, committed or planned can be a "connection substation" for generators, but this is true if its voltage level is appropriate to the envisaged generators: the substations serve as "hub" substation for evacuating the power of several IPP's, each IPP being connected by its own private connection line.

L. Annex-2

Table 67: Bus information

S.N.	Name	Type	S.N.	Name	Type
1	Andhi Khola 220	220kV	2	AnkhuHub 220	220kV
3	Arun 220	220kV	4	Arun-Hub	400kV
5	Attariya 400	400kV	6	Bafikot 400	400kV
7	Bahrabise 220	220kV	8	Bahrabise 400	400kV
9	Bajhang 400	400kV	10	Balaju220	220kV
11	Baneshwor 220	220kV	12	Basantapur 220	220kV
13	Betan 400	400kV	14	Bhaktapur 220	220kV
15	Bharatpur 220	220kV	16	Bheri-4	400kV
17	Budhi Gandaki 400	400kV	18	Burtibang	400kV
19	Butwal 220	220kV	20	Butwal 400	400kV
21	Chapagaun 220	220kV	22	Chilime Hub (220kV)	220kV
23	Chilime 400	400kV	24	Damak 400	400kV
25	Damauli 220	220kV	26	Dana 220	220kV
27	Dandakhet Hub	220kV	28	Dhalkebar 220	220kV
29	Dhalkebar 400	400kV	30	Dododhara 400	400kV
31	Dudhkoshi 400	400kV	32	Dudhkoshi-4 400	400kV
33	Duhabi 400	400kV	34	Dunai	400kV
35	Gumda	400kV	36	Hangpang 400	400kV
37	Hangpang S/S 220	220kV	38	Hetauda 220	220kV
39	Hetauda 400	400kV	40	Inaurwa 400	400kV
41	Inaurwa220	220kV	42	Jagdulla	400kV
43	Khadbari220 I	220kV	44	Khimti 220	220kV
45	Khudi220-I	220kV	46	Kohalpur400	400kV
47	Kusma 220	220kV	48	Kusma 400	400kV
49	Lapche 220	220kV	50	Lapsephedi 400	400kV
51	Lapsiphedi 220	220kV	52	Lekhnath 220	220kV
53	Maintada 400	400kV	54	Manang 220	220kV
55	Marsyangdi 220	220kV	56	Matatirtha 220	220kV
57	Mirchiya 400	400kV	58	Mugu Karnali 400	400kV

S.N.	Name	Type	S.N.	Name	Type
59	Mulpani 220	220kV	60	Nalgadh	400kV
61	New Damauli 400	400kV	62	New Khimti 400	400kV
63	Pancheswor 400	400kV	64	Phukhot 400	400kV
65	Phulbari 400	400kV	66	Rahughat 220	220kV
67	Ratmate2	220kV	68	Ratmate 400	400kV
69	Sitalpati 220	220kV	70	Sunkoshi-2 400	400kV
71	Tamakoshi 220	220kV	72	Tamor Hub 220	220kV
73	Tamor LILO	400kV	74	Tingla 400	400kV
75	Trishuli 220	220kV	76	U-Arun	400kV
77	U-Arun 220	220kV	78	U-Budhi400	400kV
79	Udipur	220kV	80	West Seti 400	400kV

Table 68: Generator rating

S.N.	Hydroelectric Projects	Capcity (MW)	S.N.	Hydroelectric Projects	Capcity (MW)
1	Middle Tamor	54	2	Tamor Mewa	128
3	Mewa Khola Hydropower project	50	4	Upper Tamor	415
5	Hangpang Cluster	23.26	6	Middle Mewa Cluster	48.86
7	Middle Mewa HPP	49	8	Palun khola small Hydropower Project	21
9	Upper Mewa Khola -A HPP	28.22	10	Ghunsa Khola HPP	71.5
11	Simbuwa Khola	53.7	12	Ghunsa Khola	78
13	Simbuwa Khola HPP	45	14	Upper Tamor A HPP	72
15	Ghunsa Khola HPP	98.54	16	Ghunsa-Tamor HPP	43
17	Upper Simbuwa Khola HPP	46.81	18	Upper Tamor Cluster	9.5
19	Super Tamor HEP	155	20	Tamor Khola-5 HEP	40
21	Upper Tamor HEP	32.5	22	Tamor Storage	762
23	Basantapur Cluster 1	30.5	24	Baneshwor Cluster	27.76
25	Baneshwor Cluster 2	23.17	26	Mai	22
27	Illam Cluster	131.63	28	Illam Cluster 2	17.92
29	Deumai Khola	30	30	Phidim cluster	24.7
31	Phidim cluster 2	23.1	32	Lower Hewa	21.6
33	Kabeli 3	22	34	Lower Tamor	49.5
35	Upper Kabeli HPP	22.9	36	Super Kabeli Khola HPP	20
37	Kabeli B - 1	25	38	Kabeli-A	37.6

S.N.	Hydroelectric Projects	Capcity (MW)	S.N.	Hydroelectric Projects	Capcity (MW)
39	Kabeli Cluster	113.21	40	Apsuwa I HEP	23
41	Arun 3	300	42	Isuwa Khola Hydropower Project	97.2
43	Apsuwa Khola	50	44	Arun 3 Cluster	3.31
45	Kimanthanka Arun	450	46	Kasuwa Khola HPP	45
47	Lower Barun Khola HPP	132	48	Arun 4	372
49	Upper Arun	725	50	Ikhuwa Khola	30
51	Sankuwa Khola 1	35.34	52	Sankhuwa Khola	25
53	Sitalpati Cluster	77.72	54	Lower Arun	659
55	Khandbari Cluster 1	28.28	56	Khandbari Cluster 2	46.51
57	Luja Khola HPP	24.8	58	Dudhkoshi-6 HEP	83
59	Dudh koshi 10 HPP	75	60	Dudhkoshi-9 HPP	111
61	Tingla Cluster 5	32.9	62	Dudh Koshi -V	48
63	Dudhkoshi-4	350	64	Upper Inkhu Khola HEP	24.22
65	Super Inkhu Khola	22.12	66	Middle Hongukhola A Hydropower Project	22
67	Tingla Cluster 2	18.64	68	Inkhu Khola	20
69	Tingla Cluster 1	13.99	70	Dudh Koshi-IV	46
71	Hongu Khola HPP	21.87	72	Middle Hongu Khola B HPP	22.9
73	Inkhu	20	74	Lower Hongu Khola	30.2
75	Solu Hydropower Project	23.5	76	Tingla Cluster 3	17.3
77	Lower Solu Hydropower Project	82	78	Dudhkoshi-2	240
79	Solu Khola	86	80	Tingla Cluster 4	9.5
81	Dudhkoshi Storage	300	82	Dudhkoshi Cluster	2.78
83	Aayu Malun Khola Hydro-Electric Project	23.2	84	Tingla Cluster 6	15.5
85	Sunkoshi 2	1110	86	Sunkoshi 3	536
87	Sunkoshi 3 Cluster	27.61	88	Lower Bagmati HPP	35.9
89	Tamakoshi-3 TA-3	650	90	Lower Likhu	28.1
91	Khimti -I	60	92	Khimti II	48.8
93	New Khimti Cluster	15.12	94	Khimti Shivalaya Storage HPP	200
95	Khimti Shivalaya Cluster	30.23	96	Nupche Likhu HEP	57.5
97	Likhu Khola HPP	30	98	Likhu-4	52.4
99	Likhu Khola 'A'	51	100	Likhu Cluster	31.52
101	Likhu -2	55	102	Likhu -1	77
103	Upper Lapche Khola	52	104	Lapche Khola	160
105	Jum Khola Hydropower Project	62	106	Rolwaling Khola	22
107	Rolwaling Khola HPP	88	108	Upper Tamakoshi HPP	456
109	Madhya Bhotekoshi	102	110	Bahrabise Cluster	26.25

S.N.	Hydroelectric Projects	Capcity (MW)	S.N.	Hydroelectric Projects	Capcity (MW)
111	Upper Balephi A	36	112	Balephi	23.52
113	Balephi Cluster	33.56	114	Nyasim Hydropower Project	35
115	Upper Balephi Cluster	7.27	116	Upper Brahmayeni HEP	20.07
117	Brahmayani HPP	40	118	Balephi Khola HEP	42.14
119	Upper Nyasim Khola	43	120	Upper Balefhi	22.2
121	Upper Chaku A	45	122	Upper Bhotekoshi	46
123	Middle Bhotekoshi -1	40	124	Bhotekoshi 1 Hydropower Project	44
125	Bhotekoshi Cluster	35.68	126	Lower Balephi	20
127	Lamosangu Cluster	9	128	Bhotekoshi 5	60
129	Khani Khola - 1	40	130	Khare Hydropower Project	24.1
131	Khani Khola	30	132	Tamakoshi-V	87
133	Sagu Khola HEP	20	134	Singati Cluster 1	51.24
135	Singati Cluster 2	35.45	136	Lapsephedi Cluster	22.9
137	Banepa Cluster	7.8	138	Kulekhani-I	60
139	Kulekhani-I Cluster	29.71	140	Upper Trishuli-1	216
141	Upper Trishuli 3B	37	142	Upper Trishuli 3A	60
143	Middle Trishuli Ganga nadi	65	144	Trishuli	24
145	Trishuli 3B Cluster 1	25.55	146	Trishuli 3B Cluster 2	49.22
147	Samundratar Cluster	44.69	148	Super Melamchi Hydropower Project	24.7
149	Super Aankhu Khola Hydropower Project	25.4	150	Akhu Khola-2 HPP	20
151	Tatopani khola HPP	24.3	152	Ilep Tatopani Khola HPP	25
153	Upper Ankhu Khola	35	154	Ankhu Khola	42.9
155	Ankhu Khola Cluster	7	156	Upper Trishui-2 HPP	102
157	Sanjen	42.5	158	Mathillo Langtang HEP	24.35
159	Chilime	22	160	Sanjen Khola	78
161	Rasuwagadhi	111	162	Rasuwa Bhotekoshi	120
163	Lantang Khola Reservoir Hydropower Project	310	164	Chilime Cluster 1	34.3
165	Kulekhani-II	32	166	Kule Khani Third	14
167	Bagmati Nadi	22	168	New Hetauda Cluster	13.04
169	Budhi Gandaki Storage Hydropower Project	1200	170	Trishuli Galchhi	75
171	Ratmate Cluster 1	3.67	172	Balaju Cluster	23.7
173	Ratmate Cluster 2	3.3	174	Upper Budhigandaki HPP	203
175	Upper Budhi Gandaki Hydropower Project	254	176	Gumda Cluster 1	16.35

S.N.	Hydroelectric Projects	Capcity (MW)	S.N.	Hydroelectric Projects	Capcity (MW)
177	Budhi Gandaki Ka	130	178	Budhi Gandaki Kha	260
179	Budhigandaki Syar Khola HEP	60	180	Super Budhigandaki	52
181	Syar Khola HPP	59.5	182	Budhi Gandaki Prok Khola Hydroelectric	420
183	Budhi Gandaki syar Khola Hydroelectric	270	184	Budhi Gandaki Nadi HPP	91.15
185	Gumda Cluster 2	8.7	186	Dordi Khola	27
187	Marsyangdi Besi	50	188	Udipur Cluster 2	16.1
189	Upper Dordi A HEP	25	190	Super Dordi Kha Hydropower Project	49.6
191	Himchuli Dordi Hydropower Project	57	192	Kirtipur Cluster 2	11.73
193	Dordi Dudh Khola Small Hydropower	20.8	194	Kirtipur Cluster	16.3
195	Upper Dudh khola HPP	21.16	196	Suti Khola	17
197	Upper Nar Hydropower Project	31.77	198	Nar Khola Hydropower Project	50
199	Marshyangdi-7 Hydropower Project	54	200	Myardi Khola	30
201	Manang Marsyangdi	282	202	Lower Manang Marsyangdi	140
203	Dudhkhola HPP	65	204	Bhimdang Khola	32
205	Manang Cluster	30.91	206	Upper Marsyangdi A	50
207	Upper Marsyangdi 1	138	208	Upper Marsyangdi -2	600
209	Upper Khudi-A HPP	27.8	210	Upper Khudi	26
211	Super Nyadi Hydropower Project	40.27	212	Nyadi-Phidi HPP	24
213	Nyadi Khola	30	214	Khudi Cluster 1	24.3
215	Khudi Cluster 2	16	216	Khudi Cluster 3	12.1
217	Marsyangdi	69	218	Super Trishuli	100
219	Lower Seti	92	220	Marsyangdi 3	42
221	Madhya Marsyangdi	70	222	New Marsyangdi Cluster 1	10.42
223	Chepe Cluster 1	51.56	224	Daraundi Cluster 2	53.04
225	Kalika Kaligandaki HEP	49.5	226	Tanahu Seti HEP	140
227	Upper Seti-1 HPP	21	228	Upper Seti Hydropower Project	20
229	Seti Khola HPP	30	230	Karuwa Seti HPP	32
231	Pokhara Cluster 3	25.1	232	Upper Madi-0 Cluster 3	67.66
233	Super Madi	44	234	Madme Khola HPP	24
235	Upper Madi-0 Hydropower Project	33	236	Upper Madi	25
237	Begnas- Rupa Storage Project	150	238	Setikhola Hydroelectric Project	27.7

S.N.	Hydroelectric Projects	Capcity (MW)	S.N.	Hydroelectric Projects	Capcity (MW)
239	Madi Siti	86	240	Bajra Madi Hydropower Project	24.8
241	Lekhnath Cluster 1	10.5	242	Lekhnath Cluster 4	15.4
243	Kali Gandaki A	144	244	Andhi Khola Storage Hydropower Project	180
245	Kali Gandaki Cluster 2	10.35	246	Kali Gandaki Cluster	15.3
247	New Butwal Cluster 2	19.16	248	New Butwal Cluster	7.66
249	Upper Myagdi-I HEP	80	250	Upper Myagdi	20
251	Myagdi Khola A HEP	23.7	252	Myagdi Khola Hydropower Project	57.3
253	Durbang Myagdi Khola	25	254	Tadhekhani Cluster 1	38.52
255	Tadhekhani Cluster 3	20.2	256	Upper Modi A	42
257	Landruk Modi HPP	86.59	258	New Modi Cluster 2	25.11
259	New Modi Cluster	61.08	260	Rahughat	40
261	Thulo Khola Hydropower Project	21.3	262	Tadhekhani Cluster 2	24.14
263	Myagdi Khola	32	264	Rahughat Mangale	37
265	Upper Rahughat	48.5	266	Kaligandaki Upper	72.5
267	Lower Modi Khola	20	268	Beni Kaligandaki	50
269	Kushma Cluster 1	22	270	Nilgiri Khola-II cascade Project	62
271	Nilgiri Khola	38	272	Mristi Khola	42
273	Middle Kaligandaki	53.54	274	Kaligandaki Gorge Hydroelectric Project	164
275	Kali Gandaki-Kowan	400	276	Dana Cluster 1	24.55
277	Dana Cluster 2	49.61	278	Badigad Khola HPP	21
279	Burtibang Cluster 2	47.21	280	Burtibang Cluster 1	30.76
281	Naumure Storage Project	342	282	Upper Jhimruk Storage Project	100
283	Jhimruk Cluster 1	18.12	284	Jhimruk Cluster 2	41.36
285	Sani Bheri 4 HEP	40.71	286	Sani Bheri 3 HEP	49.59
287	Sani Bheri-2 HEP	23.31	288	Uttarganga Storage Hydropower Project	300
289	Rolpa Cluster 1	10.48	290	Bafikot Cluster 3	29.08
291	Sani Bheri HPP	44.52	292	Pelma 2	93
293	Pelma	90	294	Nalgad Reservoir	410
295	Jaldigad	21.48	296	Dadagau Khalanga Bheri Hydropower Project	128
297	NalG Cluster 1	11.87	298	Saru Khola HPP	15
299	Chera 1	148.7	300	Bheri-1 HEP	617
301	Bheri-2 Hydropower Project	256	302	Dunai Cluster	25
303	Lawan Saharta Bheri HPP	85.39	304	Thulibheri	30

S.N.	Hydroelectric Projects	Capcity (MW)	S.N.	Hydroelectric Projects	Capcity (MW)
305	Thuli Bheri-1 HPP	110	306	Lower Burbangkhola	20
307	Thuli Bheri	121	308	Jagadulla Khola	307
309	Bheri-3 storage Hydropower Project	480	310	Bheri 4	300
311	Sharada Babai Storage HPP	93	312	Bheri-Babai Diversion Project	48
313	Surkhet Cluster 1	8	314	Dailekh Cluster 1	10.98
315	Lower Lohore Khola HPP	20	316	Dailekh Cluster 2	22.36
317	Upper Lotikarnali	22	318	Namlan	303
319	HUmla Karnali II HEP	410	320	Mugu Karnali HPP	159.62
321	Humla Karnali-Cascade	916	322	Humla Karnali-1	274
323	Mugu Karnali Cluster 2	56.8	324	Jumla Cluster 1	37.73
325	Tila-2 Hydropower Project	420	326	Tila-1 Hydropower Project	440
327	Karnali St-1	184	328	Phulkot Karnali	210
329	Phukot Karnali	426	330	Middle Karnali	30
331	Phukot Cluster	32.8	332	SR-6 Storage	276
333	Betan Karnali	688	334	Upper Karnali	90
335	Upper Karnali B	60	336	Budhi Ganga	20
337	Budhiganga Cluster	44.95	338	Chameliya	35
339	Chhati Gad	32	340	Upper Chameliya HP	40
341	Lower Chameliya	20	342	Chameliya Khola	30
343	Chameliya	85	344	Balanch Cluster 1	43.85
345	Balanch Cluster 2	25	346	Upper Kalangad	38.46
347	Upper Kalangad Cluster	34.03	348	Syaule Cluster 1	20.81
349	Attariya Cluster 2	12.3	350	Seti Nadi-3 HPP	80
351	Chainpur Seti HEP	210	352	Bajhang Upper Seti Hydropower Project	80
353	Bajhang Cluster	6	354	Deepayal Cluster	13.03
355	West Seti	750	356	Rupaligad Re - regulating	240
357	Pancheswor Multipurpose	3240			

Table 69: Load data

S.N.	Terminal	Act.Pow. MW	App.Pow. MVA	Power Factor
1	Anarmani	50	58.82	0.85
2	Andhi Khola	60	70.58	0.85
3	Arun-Hub	150	176.47	0.85
4	Attariya 132	100	117.64	0.85
5	Bahrabise	50	58.82	0.85
6	Balaju	400	470.58	0.85
7	Balanch 132	50	58.82	0.85
8	Betan132	80	94.11	0.85
9	Bhaktapur-I	220	258.82	0.85
10	Bharatur 132	1700	2000	0.85
11	Butwal132	1600	1882.35	0.85
12	Chapali_132	150	176.47	0.85
13	Damauli132	100	117.64	0.85
14	Dhalkebar132	1600	1882.35	0.85
15	Dododhara132	1300	1529.41	0.85
16	Duhabi	600	705.88	0.85
17	Dumre	30	35.29	0.85
18	Hangpang	25.5	30	0.85
19	Hapure	350	411.76	0.85
20	Harisidhi 220	300	352.94	0.85
21	Illam-132	100	117.64	0.85
22	Inaurwa 220	600	705.88	0.85
23	Kabeli	50	58.82	0.85
24	Khimti 132	260	305.88	0.85
25	Khudi 220-II	50	58.82	0.85
26	Kohalpur 400	1950	2294.11	0.85
27	Kusma 132	100	117.64	0.85
28	Lekhnath 132	250	294.11	0.85
29	Marsyangdi	155	182.35	0.85
30	Matatirtha132	550	647.05	0.85
31	Mirchiya 400	1100	1294.11	0.85
32	Mugu Karnali	75	88.23	0.85

S.N.	Terminal	Act.Pow. MW	App.Pow. MVA	Power Factor
33	Mulpani	200	235.29	0.85
34	New Attariya	300	352.94	0.85
35	Pahalmanpur	100	117.64	0.85
36	Phidim	50	58.82	0.85
37	Phukhot	155	182.35	0.85
38	Ratmate	150	176.47	0.85
39	Sayule	50	58.82	0.85
40	Suichatar	150	176.47	0.85
41	Tamor Hub 220	25	29.41	0.85
42	Tingla 400	100	117.64	0.85
43	Trishuli 132	200	235.29	0.85
44	Udipur	50	58.82	0.85
45	West Seti	150	176.47	0.85
46	New Hetauda	2250	2647.05	0.85

Table 70: Existing, Under Construction, Planned and Proposed Transmission Line

S. N.	Project Name	Voltage Level	Starting Point	Ending Point	Conductor	Length (km)
1	Dododhara- Attariya	400kV	Dododhara	Attariya	Quad Moose	68
2	Betan- Dododhara	400kV	Betan	Dododhara	Quad Moose	30
3	Bajhang- West Seti	400kV	Bajhang	West Seti	Twin Bison	60
4	Mugu Karnali- Phukhot	400kV	Mugu Karnali	Phukhot	Quad Moose	71
5	Pancheswor- Attariya	400kV	Pancheswor	Attariya	Quad Moose	88
6	Phukhot- Betan	400kV	Phukhot	Betan	Quad Moose	50
7	Nalgadh- Phukhot	400kV	Nalgadh	Phukhot	Quad Moose	94
8	West Seti- Dododhara	400kV	West Seti	Dododhara	Quad Moose	109
9	Phukhot- West Seti	400kV	Phukhot	West Seti	Quad Moose	87
10	West Seti- Pancheswor	400kV	West Seti	Pancheswor	Quad Moose	56
11	Dododhara- Bareli	400kV	Dododhara	Nepal India Border	Quad Moose	58
12	Attariya Bareli	400kV	Attariya	Nepal India Border	Quad Moose	30

S. N.	Project Name	Voltage Level	Starting Point	Ending Point	Conductor	Length (km)
13	Nalgadh- Bafikot	400kV	Nalgadh	Bafikot	Quad Moose	26
14	Bafikot- Phulbari	400kV	Bafikot	Phulbari	Quad Moose	85
15	Bheri-4- Maina Tara	400kV	Bheri-4	Maina Tara	Quad Moose	21
16	Dunai- Jagdulla	400kV	Dunai	Jagdulla	Twin Bison	50
17	Dododhara- Maina Tara	400kV	Dododhara	Maina Tara	Quad Moose	86
18	Nalgadh- Maina Tara	400kV	Nalgadh	Maina Tara	Quad Moose	70
19	Nalgadh- Jagdulla	400kV	Nalgadh	Jagdulla	Twin Moose	40
20	Phulbari- Maina Tara	400kV	Phulbari	Maina Tara	Quad Moose	62
21	Maina Tara-Kohalpur	400kV	Maina Tara	Kohalpur	Quad Moose	31
22	Phulbari- Lakhnow	400kV	Phulbari	Nepal India Border	Quad Moose	44
23	New Damauli- Butwal	400kV	New Damauli	Butwal	Quad Moose	75
24	Kusma- New Damauli	400kV	Kusma	New Damauli	Quad Moose	69
25	Bafikot- Burtibang	400kV	Bafikot	Burtibang	Quad Moose	72
26	Burtibang- Kusma	400kV	Burtibang	Kusma	Quad Moose	50
27	Phulbari- Butwal	400kV	Phulbari	Butwal	Quad Moose	229
28	Butwal- Gorakhpur	400kV	Butwal	Nepal India Border	Quad Moose	30
29	Andhi Khola - Butwal	220kV	Andhi Khola	Butwal	Twin Bison	76
30	Barghat- Bharatpur	220kV	Butwal	Bharatpur	Twin Bison	75
31	Rahughat- Dana	220kV	Rahughat	Dana	Twin Bison	20
32	Khudi- Udipur	220kV	Khudi	Udipur	Twin Bison equ. HTLS	16
33	Kusma- Andhi Khola	220kV	Kusma	Andhi Khola	Twin Bison	76
34	Lekhnath- Damauli	220kV	Lekhnath	Damauli	Single Moose	40
35	Marsyangdi- Bharatpur	220kV	Marsyangd i	Bharatpur	Twin Zebra equ. HTLS	32
36	Manang- Khudi	220kV	Manang	Khudi	Twin Zebra equ. HTLS	27
37	Marsyangdi- Suichatar (Mata)	220kV	Marsyangd i	Suichatar (Mata)	Twin moose	85
38	Udipur- Marsyangdi	220kV	Udipur	Marsyangdi	Twin Zebra equ. HTLS	31

S. N.	Project Name	Voltage Level	Starting Point	Ending Point	Conductor	Length (km)
39	Khudi- Damauli	220kV	Khudi	Damauli	Twin Moose	60
40	Damauli- Bharatpur	220kV	Damauli	Bharatpur	Twin Zebra equ. HTLS	44
41	Rahughat- Kusma	220kV	Rahughat	Kusma	Twin Zebra equ. HTLS	30
42	Dadakheti Hub- Rahughat	220kV	Dadakheti Hub	Rahughat	Twin Bison	15
43	Lapsephedi- Ratmate	400kV	Lapsephedi	Ratmate	Quad Moose	28
44	Ratmate- Hetauda	400kV	Ratmate	Hetauda	Quad Moose	41
45	Dhalkebar- Hetauda	400kV	Dhalkebar	Hetauda	Quad Moose	128
46	Lapsephedi- Bahrabise	400kV	Lapsephedi	Bahrabise	Quad Moose	60
47	Bahrabise- New Khimti	400kV	Bahrabise	New Khimti	Quad Moose	46
48	New Damauli- Ratmate	400kV	New Damauli	Ratmate	Quad Moose	79
49	Chilime- Ratmate	400kV	Chilime	Ratmate	Quad Moose	50
50	Gumda- Ratmate	400kV	Gumda	Ratmate	Quad Moose	75
51	New Khimti- Sunkoshi-2	400kV	New Khimti	Sunkoshi-2	Quad Moose	22
52	Sunkoshi-2- Dhalkebar	400kV	Sunkoshi-2	Dhalkebar	Quad Moose	38
53	U-Budhi- Gumda	400kV	U-Budhi400	Gumda	Twin Moose	23
54	Dhalkebar- Muzzaffarpur	400kV	Dhalkebar	Nepal India Border	Quad Moose	39
55	Dhalkebar- Muzzaffarpur(second Double ckt)	400kV	Dhalkebar	Nepal India Border	Quad Moose	39
56	Kerung- Chilime	400kV	Kerung	Nepal China Border	Quad Moose	14
57	Khimti- Dhalkebar	220kV	Khimti	Dhalkebar	Twin Bison	75
58	Bharatpur- Hetauda	220kV	Bharatpur	Hetauda	Twin Bison	73
59	Chilime Hub - Trishuli	220kV	Chilime Hub	Trishuli	Twin Bison	40
60	Suichatar (Mata)- Trishuli	220 kV	Suichatar (Mata)	Trishuli	Twin Moose	42
61	Lapche- Tamakoshi	220kV	Lapche	Tamakoshi	Twin Bison	15
62	Tamakoshi- Khimti	220kV	Tamakoshi	Khimti	Twin Moose	46
63	Ankhu -Ratamate	220 kV	Ankhu	Ratamate	Single Bison	32

S. N.	Project Name	Voltage Level	Starting Point	Ending Point	Conductor	Length (km)
64	Mirchiya- Dhalkebar	400kV	Mirchiya	Dhalkebar	Quad Moose	64
65	Mirchiya- Inaurwa	400kV	Mirchiya	Inaurwa	Quad Moose	64
66	New Khimti- Tingla	400kV	New Khimti	Tingla	Quad Moose	57
67	Arun-Hub- Hangpang	400kV	Arun-Hub	Hangpang	Quad Moose	46
68	Hangpang- Inaruwa	400kV	Hangpang	Inaruwa	Quad Moose	101
69	Dudhkoshi- Mirchiya	400kV	Dudhkoshi	Mirchiya	Quad Moose	81
70	Duhabi- Damak	400kV	Duhabi	Damak	Quad Moose	50
71	Duhabi- Inaruwa	400kV	Duhabi	Inaruwa	Quad Moose	30
72	Tingla- Arun-Hub	400kV	Tingla	Arun-Hub	Quad Moose	62
73	Tingla- Dudhkoshi	400kV	Tingla	Dudhkoshi	Quad Moose	45
74	Tingla- Dudhkoshi-4	400kV	Tingla	Dudhkoshi-4	Twin Moose	20
75	U-Arun- Arun-Hub	400kV	U-Arun	Arun-Hub	Twin Moose	18
76	Inaurwa- Purnera	400kV	Inaurwa	Nepal India Border	Quad Moose	50
77	U-Arun Latse	400kV	U-Arun	Nepal China Border	Quad Moose	23
78	Baneshwor- Basantapur	220kV	Baneshwor	Basantapur	Twin Moose	21
79	Basantapur- Inaurwa	220kV	Basantapur	Inaurwa220	Quad Moose	77
80	Hangpang S/S- Basantapur	220kV	Hangpang S/S	Basantapur	Twin Bison	46
81	Khadbari- Baneshwor	220kV	Khadbari	Baneshwor	Twin Moose	10
82	Sitalpati- Khadbari	220kV	Sitalpati	Khadbari	Twin Bison	24
83	Arun- Sitalpati	220kV	Arun	Sitalpati	Twin Bison	9
84	Hangpang S/S- Tamor Hub	220kV	Hangpang S/S	Tamor Hub	Twin Moose	23

Table 71: Planned and proposed cross-border transmission lines

S.N	Project Name	Voltage (kV)	Proposed Conductor
Cross Border Interconnection with India			
1	Dododhara- Barelly	400kV	Quad Moose
2	Attariya-Bareli	400kV	Quad Moose
3	Phulbari- Lukhnow	400kV	Quad Moose
4	New Butwal - Gorakhpur	400kV	Quad Moose
5	New Dhalkebar- Muzzafarpur	400kV	Quad Moose
6	Inaruwa-Purniya	400kV	Quad Moose
Cross Border Interconnection with China			
1	Kimanthanka - Latse	400kV	Quad Moose
2	Chilime Hub- Kerung	400kV	Quad Moose

M. Annex-3

Table 72: Bus Voltage in p.u. of different scenario

S.N.	Name	Nominal Voltage	Bus Voltage in p.u.		
			WetMax	WetMin	DryMax
		kV	p.u.	p.u.	p.u.
1	Andhi Khola 220	220	1.01	1.02	1.02
2	AnkhuHub (220kV)	220	1.02	1.02	1.02
3	Arun 220	220	1.02	1.02	1.02
4	Arun-Hub	400	1.02	1.02	1.02
5	Attariya 400	400	1.01	1.02	1.01
6	Bafikot 400	400	1.02	1.02	1.02
7	Bahrabise 220	220	1.02	1.02	1.02
8	Bahrabise 400	400	1.02	1.02	1.02
9	Bajhang 400	400	1.02	1.02	1.02
10	Balaju220	220	1.00	1.01	0.99
11	Baneshwor 220	220	1.02	1.01	1.02
12	Basantapur 220	220	1.01	1.01	1.02
13	Betan 400	400	1.02	1.02	1.02
14	Bhaktapur 220	220	0.99	1.01	0.99
15	Bharatpur 220	220	0.99	1.01	0.99
16	Bheri-4	400	1.02	1.02	1.02
17	Budhi Gandaki 400	400	1.02	1.02	1.02
18	Burtibang	400	1.01	1.01	1.02
19	Butwal 220	220	1.00	1.00	1.00
20	Butwal 400	400	1.01	1.00	1.02
21	Chapagaun 220	220	1.00	1.01	0.99
22	Chilime Hub (220kV)	220	1.02	1.02	1.02
23	Chilime 400	400	1.01	1.01	1.01
24	Damak 400	400	1.01	1.00	1.01
25	Damauli 220	220	1.00	1.01	1.00
26	Dana 220	220	1.02	1.02	1.02
27	Dandakhet Hub	220	1.02	1.02	1.02
28	Dhalkebar 220	220	1.01	1.00	1.01
29	Dhalkebar 400	400	1.01	1.00	1.01
30	Dododhara 400	400	1.01	1.01	1.01

S.N.	Name	Nominal Voltage	Bus Voltage in p.u.		
			WetMax	WetMin	DryMax
		kV	p.u.	p.u.	p.u.
31	Dudhkoshi 400	400	1.02	1.00	1.02
32	Dudhkoshi-4 400	400	1.02	1.02	1.02
33	Duhabi 400	400	1.01	1.00	1.01
34	Dunai	400	1.02	1.02	1.02
35	Gumda	400	1.02	1.02	1.02
36	Hangpang 400	400	1.02	1.01	1.02
37	Hangpang S/S 220	220	1.02	1.01	1.02
38	Hetauda 220	220	1.00	1.00	1.00
39	Hetauda 400	400	1.01	1.00	1.01
40	Inaurwa 400	400	1.01	1.00	1.01
41	Inaurwa220	220	1.00	1.00	1.00
42	Jagdulla	400	1.02	1.02	1.02
43	Khadbari220 I	220	1.02	1.02	1.02
44	Khimti 220	220	1.02	1.01	1.02
45	Khudi220-I	220	1.02	1.02	1.02
46	Kohalpur400	400	1.00	1.00	1.00
47	Kusma 220	220	1.01	1.01	1.02
48	Kusma 400	400	1.01	1.00	1.02
49	Lapche 220	220	1.02	1.02	1.02
50	Lapsephedi 400	400	1.01	1.01	1.02
51	Lapsiphedi 220	220	1.01	1.01	1.01
52	Lekhnath 220	220	1.01	1.02	1.00
53	Maintada 400	400	1.01	1.01	1.02
54	Manang 220	220	1.02	1.02	1.02
55	Marsyangdi 220	220	1.00	1.01	1.00
56	Matatirtha 220	220	1.00	1.01	0.99
57	Mirchiya 400	400	1.00	1.00	1.00
58	Mugu Karnali 400	400	1.02	1.02	1.02
59	Mulpani 220	220	1.00	1.01	0.99
60	Nalgadh	400	1.02	1.02	1.02
61	New Damauli 400	400	1.01	1.00	1.02
62	New Khimti 400	400	1.02	1.01	1.02

S.N.	Name	Nominal Voltage	Bus Voltage in p.u.		
			WetMax	WetMin	DryMax
		kV	p.u.	p.u.	p.u.
63	Pancheswor 400	400	1.02	1.02	1.02
64	Phukhot 400	400	1.02	1.02	1.02
65	Phulbari 400	400	1.01	1.01	1.02
66	Rahughat 220	220	1.02	1.02	1.02
67	Ratmate2	220	1.02	1.01	1.02
68	Ratmate 400	400	1.01	1.01	1.02
69	Sitalpati 220	220	1.02	1.02	1.02
70	Sunkoshi-2 400	400	1.02	1.01	1.02
71	Tamakoshi 220	220	1.02	1.02	1.01
72	Tamor Hub 220	220	1.02	1.02	1.02
73	Tamor LILO	400	1.02	1.00	1.02
74	Tingla 400	400	1.02	1.01	1.02
75	Trishuli 220	220	1.01	1.02	1.01
76	U-Arun	400	1.02	1.01	1.02
77	U-Arun 220	220	1.02	1.02	1.02
78	U-Budhi400	400	1.02	1.02	1.02
79	Udipur	220	1.01	1.01	1.01
80	West Seti 400	400	1.02	1.02	1.02

Table 73: Line loading in percentage for diffrent scenario

S.N.	Starting Terminal	Ending Terminal	Line Loading in %			Nominal Voltage
			WetMax	Wetmin	DryMax	
			%	%	%	kV
1	Andhi Khola 220	Butwal 220	43.522	26.033	30.266	220
2	AnkhuHub (220kV)	Ratmate2	16.649	16.651	8.76	220
3	Arun 220	Sitalpati 220	25.047	30.867	12.667	220
4	Arun-Hub	Hangpang 400	14.694	10.766	7.242	400
5	Bafikot 400	Phulbari 400	44.373	38.22	19.889	400
6	Bafikot 400	Burtibang	19.565	23.201	30.577	400
7	Bahrabise 400	New Khimti 400	2.928	1.22	3.623	400
8	Bajhang 400	West Seti 400	12.746	6.502	12.904	400
9	Balaju220	Mulpani 220	2.563	5.459	5.276	220
10	Baneshwor 220	Basantapur 220	45.695	41.132	24.506	220
11	Basantapur 220	Inaurwa220	37.575	31.539	21.099	220
12	Betan 400	Dododhara 400	24.819	17.722	14.41	400
13	Bharatpur 220	Hetauda 220	4.969	7.414	9.875	220
14	Bheri-4	Maintada 400	17.198	15.868	8.729	400
15	Bhotekoshi	Lamosangu	28.339	28.339	14.933	220
16	Budhi Gandaki 400	Ratmate 400	22.066	7.086	14.453	400
17	Burtibang	Kusma 400	25.578	14.99	32.434	400
18	Butwal 220	Bharatpur 220	16.367	51.087	18.651	220
19	Chapagaun 220	Matatirtha 220	15.633	9.101	14.184	220
20	Chapagaun 220	Bhaktapur 220	7.011	5.642	5.592	220
21	Chilime Hub (220kV)	Trishuli 220	30.605	17.579	51.86	220
22	Chilime 400	Ratmate 400	24.572	17.806	14.614	400
23	Damauli 220	Bharatpur 220	30.277	15.463	25.304	220
24	Dandakhet Hub	Rahughat 220	1.105	11.268	4.795	220
25	Dhalkebar 400	Hetauda 400	2.446	3.322	8.547	400
26	Dododhara 400	Maintada 400	26.101	9.956	30.577	400
27	Dododhara 400	Attariya 400	21.125	3.106	12.748	400
28	Dudhkoshi 400	Mirchiya 400	38.626	29.209	23.357	400
29	Duhabi 400	Inaurwa 400	16.682	3.478	24.179	400
30	Duhabi 400	Damak 400	5.949	10.959	2.498	400
31	Dunai	Jagdulla	10.109	9.469	5.542	400
32	Gumda	Ratmate 400	40.926	40.925	21.526	400
33	Hangpang 400	Tamor LILO	48.123	46.765	23.685	400

S.N.	Starting Terminal	Ending Terminal	Line Loading in %			Nominal Voltage
			WetMax	Wetmin	DryMax	
			%	%	%	kV
34	Hangpang S/S 220	Tamor Hub 220	49.329	50.325	25.091	220
35	Hangpang S/S 220	Basantapur 220	20.766	13.41	12.999	220
36	Khadbari220 II	Baneshwor 220	42.121	37.588	22.619	220
37	Khimti 220	Dhalkebar 220	51.799	34.224	32.07	220
38	Khudi220-I	Udipur	38.688	38.365	31.621	220
39	Khudi220-II	Damauli 220	48.086	50.19	23.862	220
40	Kusma 220	Andhi Khola 220	22.442	12.678	17.594	220
41	Kusma 400	New Damauli 400	41.183	6.755	37.162	400
42	Lapche 220	Tamakoshi 220	39.04	39.04	21.557	220
43	Lapsephedi 400	Bahrabise 400	24.011	20.755	18.528	400
44	Lapsephedi 400	Ratmate 400	12.837	18.579	5.966	400
45	Lapsiphedi 220	Mulpani 220	46.441	10.923	51.613	220
46	Lekhnath 220	Damauli 220	27.783	27.044	14.557	220
47	Maintada 400	Kohalpur400	44.702	20.085	45.428	400
48	Manang 220	Khudi220-II	26.295	26.139	14.025	220
49	Marsyangdi 220	Matatirtha 220	28.994	23.091	25.398	220
50	Marsyangdi 220	Bharatpur 220	25.694	28.99	15.925	220
51	Matatirtha 220	Balaju220	34.75	20.512	31.402	220
52	Mirchiya 400	Dhalkebar 400	19.106	24.973	8.186	400
53	Mirchiya 400	Inaurwa 400	3.046	3.026	5.859	400
54	Mugu Karnali 400	Phukhot 400	46.437	43.86	25.396	400
55	Mulpani 220	Bhaktapur 220	11.498	1.861	13.125	220
56	Nalgadh	Phukhot 400	39.17	5.012	33.554	400
57	Nalgadh	Maintada 400	37.012	34.025	21.339	400
58	Nalgadh	Jagdulla	23.883	14.018	19.558	400
59	Nalgadh	Bafikot 400	18.493	2.482	15.717	400
60	New Damauli 400	Butwal 400	43.873	50.259	11.125	400
61	New Damauli 400	Ratmate 400	4.212	31.626	18.647	400
62	New Khimti 400	Sunkoshi-2 400	44.192	37.684	24.532	400
63	Pancheswor 400	Attariya 400	44.65	18.853	28.147	400
64	Pancheswor 400	West Seti 400	18.604	5.752	13.213	400
65	Phukhot 400	Betan 400	40.675	44.718	16.904	400
66	Phukhot 400	West Seti 400	5.341	25.216	9.801	400
67	Phulbari 400	Maintada 400	37.378	15.484	19.93	400

S.N.	Starting Terminal	Ending Terminal	Line Loading in %			Nominal Voltage
			WetMax	Wetmin	DryMax	
			%	%	%	kV
68	Phulbari 400	Butwal 400	22.168	8.06	24.236	400
69	Rahughat 220	Kusma 220	40.149	36.324	23.068	220
70	Rahughat 220	Dana 220	29.171	29.171	15.343	220
71	Ratmate 400	Hetauda 400	52.022	18.948	46.189	400
72	Sitalpati 220	Khadbari220 I	12.749	18.709	6.115	220
73	Sunkoshi-2 400	Dhalkebar 400	28.425	18.776	16.51	400
74	Tamakoshi 220	Bahrabise 220	36.661	16.337	31.751	220
75	Tamakoshi 220	Khimti 220	30.023	13.91	22.631	220
76	Tamor LILO	Inaurwa 400	22.843	17.284	12.202	400
77	Tingla 400	Dudhkoshi 400	32.697	28.816	18.935	400
78	Tingla 400	Dudhkoshi-4 400	29.126	29.067	15.38	400
79	Tingla 400	Arun-Hub	28.77	29.634	17.006	400
80	Tingla 400	New Khimti 400	22.874	29.661	10.934	400
81	Trishuli 220	Matatirtha 220	47.703	17.516	46.113	220
82	U-Arun	Arun-Hub	30.11	30.072	15.826	400
83	U-Budhi400	Gumda	23.826	23.826	12.539	400
85	Udipur	Marsyangdi 220	42.478	43.267	31.635	220
86	West Seti 400	Dododhara 400	37.51	18.32	22.573	400

Table 74: Voltage for different generation outage scenario

S.N	BusBar	Nominal Voltage	Base case	Outage Case Per Unit Voltage				
				Sunkoshi	Budhi Gandaki	Hulma Karnali Cascade	Tamor Storage	West Seti
		kV	p.u.	p.u.	p.u.	p.u.	p.u.	p.u.
1	Andhi Khola 220	220	1.01	1.01	1	1.01	1.01	1.01
2	AnkhuHub (220kV)	220	1.02	1.02	1.02	1.02	1.02	1.02
3	Arun 220	220	1.02	1.02	1.02	1.02	1.02	1.02
4	Arun-Hub	400	1.02	1.02	1.02	1.02	1.02	1.02
5	Attariya 400	400	1.01	1.01	1.01	1.01	1.01	1.01
6	Bafikot 400	400	1.02	1.02	1.02	1.02	1.02	1.02
7	Bahrabise 220	220	1.02	1.02	1.02	1.02	1.02	1.02
8	Bahrabise 400	400	1.02	1.01	1.02	1.02	1.02	1.02
9	Bajhang 400	400	1.02	1.02	1.02	1.02	1.02	1.02

S.N	BusBar	Nominal Voltage	Base case	Outage Case Per Unit Voltage				
				Sunkoshi	Budhi Gandaki	Hulma Karnali Cascade	Tamor Storage	West Seti
		kV	p.u.	p.u.	p.u.	p.u.	p.u.	p.u.
10	Balaju220	220	0.99	0.99	0.99	0.99	0.99	0.99
11	Baneshwor 220	220	1.02	1.02	1.02	1.02	1.02	1.02
12	Basantapur 220	220	1.01	1.01	1.01	1.01	1.01	1.01
13	Betan 400	400	1.02	1.02	1.02	1.02	1.02	1.02
14	Bhaktapur 220	220	0.99	0.99	0.99	0.99	0.99	0.99
15	Bharatpur 220	220	0.99	0.99	0.99	0.99	0.99	0.99
16	Bheri-4	400	1.02	1.02	1.02	1.02	1.02	1.02
17	Budhi Gandaki 400	400	1.02	1.02	1.02	1.02	1.02	1.02
18	Burtibang	400	1.01	1.01	1.01	1.01	1.01	1.01
19	Butwal 220	220	1	0.99	0.99	1	1	1
20	Butwal 400	400	1	1	1	1	1	1
21	Chapagaun 220	220	0.99	0.99	0.99	0.99	0.99	0.99
22	Chilime Hub (220kV)	220	1.02	1.02	1.02	1.02	1.02	1.02
23	Chilime 400	400	1.01	1.01	1.01	1.01	1.01	1.01
24	Damak 400	400	1.01	1.01	1.01	1.01	1.01	1.01
25	Damauli 220	220	1	1	1	1	1	1
26	Dana 220	220	1.02	1.02	1.02	1.02	1.02	1.02
27	Dandakhet Hub	220	1.02	1.02	1.02	1.02	1.02	1.02
28	Dhalkebar 220	220	1.01	1.01	1.01	1.01	1.01	1.01
29	Dhalkebar 400	400	1.01	1.01	1.01	1.01	1.01	1.01
30	Dododhara 400	400	1.01	1.01	1.01	1.01	1.01	1.01
31	Dudhkoshi 400	400	1.02	1.02	1.02	1.02	1.02	1.02
32	Dudhkoshi-4 400	400	1.02	1.02	1.02	1.02	1.02	1.02
33	Duhabi 400	400	1.01	1.01	1.01	1.01	1.01	1.01
34	Dunai	400	1.02	1.02	1.02	1.02	1.02	1.02
35	Gumda	400	1.02	1.02	1.02	1.02	1.02	1.02
36	Hangpang 400	400	1.02	1.02	1.02	1.02	1.01	1.02
37	Hangpang S/S 220	220	1.02	1.02	1.02	1.02	1.02	1.02
38	Hetauda 220	220	1	1	1	1	1	1
39	Hetauda 400	400	1.01	1.01	1.01	1.01	1.01	1.01
40	Inaurwa 400	400	1.01	1.01	1.01	1.01	1	1.01
41	Inaurwa220	220	1	1	1	1	1	1

S.N	BusBar	Nominal Voltage	Base case	Outage Case Per Unit Voltage				
				Sunkoshi	Budhi Gandaki	Hulma Karnali Cascade	Tamor Storage	West Seti
		kV	p.u.	p.u.	p.u.	p.u.	p.u.	p.u.
42	Jagdulla	400	1.02	1.02	1.02	1.02	1.02	1.02
43	Khadbari220 I	220	1.02	1.02	1.02	1.02	1.02	1.02
44	Khimti 220	220	1.02	1.02	1.02	1.02	1.02	1.02
45	Khudi220-I	220	1.02	1.02	1.02	1.02	1.02	1.02
46	Kohalpur400	400	1.01	1	1.01	1.01	1.01	1.01
47	Kusma 220	220	1.01	1.01	1.01	1.01	1.01	1.01
48	Kusma 400	400	1.01	1	1	1.01	1.01	1.01
49	Lapche 220	220	1.02	1.02	1.02	1.02	1.02	1.02
50	Lapsephedi 400	400	1.01	1.01	1.01	1.01	1.01	1.01
51	Lapsiphedi 220	220	1.01	1.01	1.01	1.01	1.01	1.01
52	Lekhnath 220	220	1.01	1.01	1.01	1.01	1.01	1.01
53	Maintada 400	400	1.01	1.01	1.01	1.01	1.01	1.01
54	Manang 220	220	1.02	1.02	1.02	1.02	1.02	1.02
55	Marsyangdi 220	220	1	1	1	1	1	1
56	Matatirtha 220	220	0.99	0.99	0.99	0.99	0.99	0.99
57	Mirchiya 400	400	1	1	1	1	1	1
58	Mugu Karnali 400	400	1.02	1.02	1.02	1.02	1.02	1.02
59	Mulpani 220	220	0.99	0.99	0.99	0.99	0.99	0.99
60	Nalgadh	400	1.02	1.02	1.02	1.02	1.02	1.02
61	New Damauli 400	400	1.01	1	1	1.01	1	1.01
62	New Khimti 400	400	1.02	1.02	1.02	1.02	1.02	1.02
63	Pancheswor 400	400	1.02	1.02	1.02	1.02	1.02	1.02
64	Phukhot 400	400	1.02	1.02	1.02	1.02	1.02	1.02
65	Phulbari 400	400	1.01	1.01	1.01	1.01	1.01	1.01
66	Rahughat 220	220	1.02	1.02	1.02	1.02	1.02	1.02
67	Ratmate2	220	1.02	1.02	1.02	1.02	1.02	1.02
68	Ratmate 400	400	1.01	1.01	1.01	1.01	1.01	1.01
69	Sitalpati 220	220	1.02	1.02	1.02	1.02	1.02	1.02
70	Sunkoshi-2 400	400	1.02	1.01	1.02	1.02	1.02	1.02
71	Tamakoshi 220	220	1.02	1.02	1.02	1.02	1.02	1.02
72	Tamor Hub 220	220	1.02	1.02	1.02	1.02	1.02	1.02
73	Tamor LILO	400	1.02	1.02	1.02	1.02	1.01	1.02

S.N	BusBar	Nominal Voltage	Base case	Outage Case Per Unit Voltage				
				Sunkoshi	Budhi Gandaki	Hulma Karnali Cascade	Tamor Storage	West Seti
		kV	p.u.	p.u.	p.u.	p.u.	p.u.	p.u.
74	Tingla 400	400	1.02	1.02	1.02	1.02	1.02	1.02
75	Trishuli 220	220	1.02	1.02	1.02	1.02	1.02	1.02
76	U-Arun	400	1.02	1.02	1.02	1.02	1.02	1.02
77	U-Arun 220	220	1.02	1.02	1.02	1.02	1.02	1.02
78	U-Budhi400	400	1.02	1.02	1.02	1.02	1.02	1.02
79	Udipur	220	1.01	1.01	1.01	1.01	1.01	1.01
80	West Seti 400	400	1.02	1.02	1.02	1.02	1.02	1.02

Table 75: Line loading for different generation outage scenario

S.N	Starting Terminal	Ending Terminal	Nominal Voltage (kV)	Base Case	Outage Cases line loading				
					Tamor Storage	West Seti	Humla Cascade	Budhi Gandaki	Sunkoshi
				Loading	Loading	Loading	Loading	Loading	Loading
				%	%	%	%	%	%
1	Andhi Khola 220	Butwal 220	220	44.19	45.31	44.03	43.93	46.19	45.86
2	AnkhuHub (220kV)	Ratmate2	220	16.64	16.64	16.64	16.64	16.63	16.63
3	Arun 220	Sitalpati 220	220	25.23	21.94	25.39	25.46	25.57	25.54
4	Arun-Hub	Hangpang 400	400	14.48	20.64	14.13	13.98	13.76	13.85
5	Bafikot 400	Phulbari 400	400	44.84	44.9	44.69	44.02	44.93	44.94
6	Bafikot 400	Burtibang	400	18.53	23.21	15.05	13.38	27.43	25.56
7	Bahrabise 400	New Khimti 400	400	3.19	3.97	4.37	4.96	6.07	6.24
8	Bajhang 400	West Seti 400	400	12.72	13.13	12.98	13.28	13.5	13.34
9	Balaju220	Mulpani 220	220	3.39	2.42	3.71	3.85	2.46	2.23
10	Baneshwor 220	Basantapur 220	220	45.56	48.04	45.43	45.38	45.3	45.31
11	Basantapur 220	Inaurwa220	220	37.45	38.03	37.45	37.45	37.44	37.41
12	Betan 400	Dododhara 400	400	24.83	24.85	25.04	22.77	24.85	24.87
13	Bharatpur 220	Hetauda 220	220	9.2	5.47	11.27	12.24	5.33	5.01
14	Bheri-4	Maintada 400	400	17.2	17.21	17.19	17.19	17.21	17.21
15	Bhotekoshi	Lamosangu	220	28.34	28.34	28.34	28.34	28.34	28.34
16	Budhi Gandaki 400	Ratmate 400	400	22.03	23.41	23.34	23.92	8.2	24.21
17	Burtibang	Kusma 400	400	24.58	29.09	21.24	19.64	33.16	31.34
18	Butwal 220	Bharatpur 220	220	21.18	16.7	24.15	25.46	14.21	14.53
19	Chapagaun 220	Matatirtha 220	220	16.19	16.74	16.03	15.96	16.75	17.07
20	Chapagaun 220	Bhaktapur 220	220	7.52	8.09	7.37	7.31	8.18	8.43

S.N	Starting Terminal	Ending Terminal	Nominal Voltage (kV)	Base Case	Outage Cases line loading				
					Tamor Storage	West Seti	Humla Cascade	Budhi Gandaki	Sunkoshi
				Loading	Loading	Loading	Loading	Loading	Loading
				%	%	%	%	%	%
21	Chilime Hub (220kV)	Trishuli 220	220	32.61	32.13	33.1	33.32	29.17	31.9
22	Chilime 400	Ratmate 400	400	25.07	24.59	24.86	24.76	23.53	24.36
23	Damauli 220	Bharatpur 220	220	29.63	30.66	29.17	28.96	30.97	31.15
24	Dandakhet Hub	Rahughat 220	220	1.25	0.71	2.01	2.39	1.27	0.91
25	Dhalkebar 400	Hetauda 400	400	4.9	2.39	6.23	6.83	7.23	3.59
26	Dododhara 400	Maintada 400	400	25.94	28.67	21.99	22.35	31.08	30.05
27	Dododhara 400	Attariya 400	400	21.01	22.69	19.87	22.41	24.18	23.52
28	Dudhkoshi 400	Mirchiya 400	400	37.94	37.7	38.19	38.3	38.38	38.12
29	Duhabi 400	Inaurwa 400	400	16.65	16.58	16.7	16.72	16.74	16.8
30	Duhabi 400	Damak 400	400	5.95	6.01	5.95	5.95	5.95	5.94
31	Dunai	Jagdulla	400	10.11	10.15	10.15	10.17	10.2	10.18
32	Gumda	Ratmate 400	400	40.93	40.93	40.93	40.93	40.93	40.94
33	Hangpang 400	Tamor LILO	400	47.93	54.71	47.54	47.37	47.13	47.26
34	Hangpang S/S 220	Tamor Hub 220	220	49.33	49.24	49.33	49.33	49.33	49.33
35	Hangpang S/S 220	Basantapur 220	220	20.68	18.66	20.82	20.89	20.96	20.88
36	Khadbari220 II	Baneshwor 220	220	41.98	44.45	41.86	41.8	41.72	41.74
37	Khimti 220	Dhalkebar 220	220	49.77	51.07	50.16	50.34	50.37	50.2
38	Khudi220-I	Udipur	220	38.73	38.74	38.73	38.72	38.76	38.76
39	Khudi220-II	Damauli 220	220	48.1	48.12	48.08	48.08	48.13	48.13
40	Kusma 220	Andhi Khola 220	220	22.64	23.05	21.96	21.62	23.26	23.25
41	Kusma 400	New Damauli 400	400	40.01	44.55	36.85	35.33	48.73	46.82
42	Lapche 220	Tamakoshi 220	220	39.04	39.04	39.04	39.04	39.04	39.04
43	Lapsephedi 400	Bahrabise 400	400	28.31	22.65	30.23	31.1	32.59	19.42
44	Lapsephedi 400	Ratmate 400	400	16.4	11.3	18.19	19	21.36	8.37
45	Lapsiphedi 220	Mulpani 220	220	49.58	47.34	50.14	50.38	46.91	46.08
46	Lekhnath 220	Damauli 220	220	27.27	28.82	27.64	27.82	30.12	29.59
47	Maintada 400	Kohalpur400	400	44.69	44.7	44.74	44.68	44.63	44.72
48	Manang 220	Khudi220-II	220	26.3	26.32	26.29	26.29	26.33	26.33
49	Marsyangdi 220	Matatirtha 220	220	28.23	29.76	27.33	26.93	31.19	30.58
50	Marsyangdi 220	Bharatpur 220	220	26.08	25.5	26.67	26.93	24.92	25.18
51	Matatirtha 220	Balaju220	220	35.61	36.77	35.23	35.06	36.74	37.45
52	Mirchiya 400	Dhalkebar 400	400	18.14	11.25	18.81	19.14	19.45	18.75
53	Mirchiya 400	Inaurwa 400	400	2.94	5.92	3.1	3.18	3.3	3.17
54	Mugu Karnali 400	Phukhot 400	400	46.44	46.44	46.44	25.9	46.44	46.44
55	Mulpani 220	Bhaktapur 220	220	11.95	11.29	12.13	12.21	11.17	10.91

S.N	Starting Terminal	Ending Terminal	Nominal Voltage (kV)	Base Case	Outage Cases line loading				
					Tamor Storage	West Seti	Humla Cascade	Budhi Gandaki	Sunkoshi
				Loading	Loading	Loading	Loading	Loading	Loading
				%	%	%	%	%	%
56	Nalgadh	Phukhot 400	400	38.9	41.64	34.82	30.59	44.07	43.03
57	Nalgadh	Maintada 400	400	37.28	36.5	38.04	36.74	35.8	36.13
58	Nalgadh	Jagdulla	400	23.83	24.5	24.46	24.74	25.08	24.83
59	Nalgadh	Bafikot 400	400	18.27	19.89	16.8	15.87	21.33	20.7
60	New Damauli 400	Butwal 400	400	48.84	46.49	50.35	50.94	44.1	45.33
61	New Damauli 400	Ratmate 400	400	8.37	4.87	12.01	13.76	7.87	5.47
62	New Khimti 400	Sunkoshi-2 400	400	41.33	41.61	40.81	40.58	40.02	52.74
63	Pancheswor 400	Attariya 400	400	44.52	46.29	43.39	46.04	47.86	47.18
64	Pancheswor 400	West Seti 400	400	18.44	20.51	23.09	22.13	22.33	21.54
65	Phukhot 400	Betan 400	400	40.77	40.05	40.74	34	39.4	39.68
66	Phukhot 400	West Seti 400	400	5.1	8.02	3.95	13.3	10.67	9.53
67	Phulbari 400	Maintada 400	400	37.46	40.12	34.86	34.38	42.47	41.45
68	Phulbari 400	Butwal 400	400	22.68	25.65	20.5	19.64	28.28	27.15
69	Rahughat 220	Kusma 220	220	40.11	40.47	39.8	39.66	40.8	40.66
70	Rahughat 220	Dana 220	220	29.17	29.16	29.17	29.17	29.15	29.16
71	Ratmate 400	Hetauda 400	400	49.28	52.5	48.48	48.11	44.13	53.7
72	Sitalpati 220	Khadbari220 I	220	12.93	9.7	13.09	13.17	13.28	13.26
73	Sunkoshi-2 400	Dhalkebar 400	400	27.32	27.91	27.58	27.69	27.73	24.27
74	Tamakoshi 220	Bahrabise 220	220	38.16	36.49	38.98	39.36	39.96	35.42
75	Tamakoshi 220	Khimti 220	220	28.86	30.15	28.23	27.94	27.48	30.92
76	Tamor LILO	Inaurwa 400	400	22.74	20.22	22.92	23	23.08	23
77	Tingla 400	Dudhkoshi 400	400	32.03	31.42	31.95	31.91	31.81	31.7
78	Tingla 400	Dudhkoshi-4 400	400	29.13	29.15	29.12	29.12	29.12	29.06
79	Tingla 400	Arun-Hub	400	29.03	22.33	29.42	29.59	29.83	29.72
80	Tingla 400	New Khimti 400	400	23.85	17.73	24.31	24.51	24.86	24.94
81	Trishuli 220	Matatirtha 220	220	49.46	49.18	49.91	50.1	47.06	49.07
82	U-Arun	Arun-Hub	400	30.11	30.08	30.11	30.11	30.11	30.1
83	U-Budhi400	Gumda	400	23.83	23.83	23.83	23.83	23.83	23.83
84	Udipur	Marsyangdi 220	220	42.52	42.53	42.52	42.51	42.55	42.54
85	West Seti 400	Dododhara 400	400	37.42	38.77	33.55	37.64	39.97	39.46

Table 76: Transmission line cost for different zones

Zone	400kV		220kV		132kV		Length of Line (km)	Cost Transmission line
	Length (km)	Cost	Length (km)	Cost	Length (km)	Cost		
1	801	600.21	-	-	361	87.91	1,162	688.12
2	515	392.27	-	-	344	88.38	859	480.65
3	525	404.08	626	337.78	728	193.49	1,879	935.35
4	642	499.78	323	177.37	454	129.55	1,418	806.71
5	710	580.27	210	115.66	627	161.16	1,547	857.09
Total	**3,192**	**2476.62**	**1,160**	**630.81**	**2,515**	**660.49**	**6,866**	**3767.91**

*All costs are in MUSD

Table 77: Substation cost for different zones

Zone	400kV		220kV		132kV		No	Cost
	Nos	Cost	Nos	Cost	Nos	Cost		
b	8	352.76	0	0	1	8.55	9	361.31
2	8	289.47	0	0	1	10.5	9	299.97
3	4	211.23	10	245.68	4	66.22	18	523.13
4	9	380.55	4	75.23	6	66.46	19	522.24
5	11	449.41	5	92.83	2	20.88	18	563.12
Total	40	1,683.42	19	413.74	14	172.6	73	2,269.76

*All costs are in MUSD

N. Annex - 4

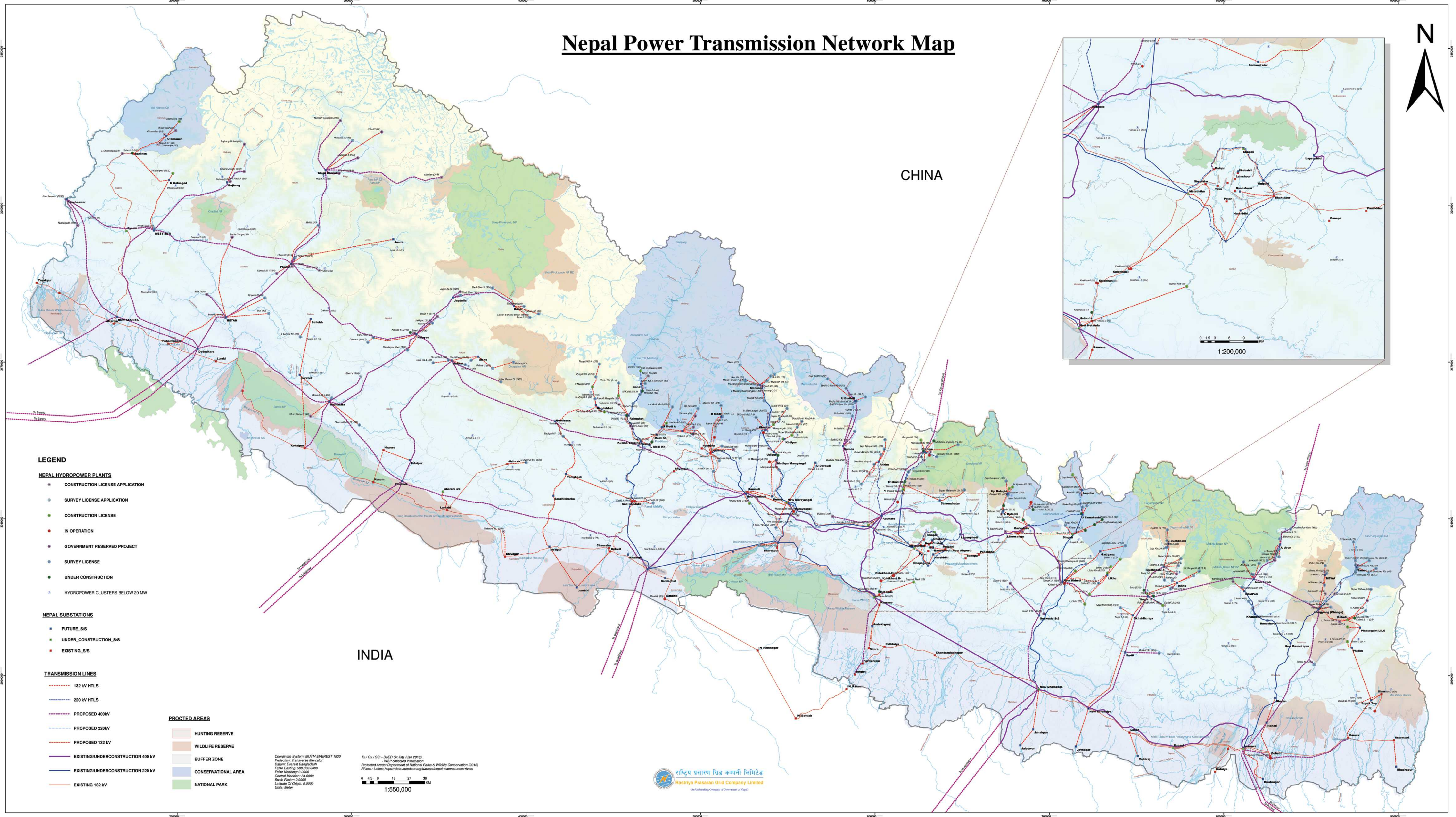

Figure 57 : Power Map of Nepal (2040)

"Empowering Economic Development of the Country by Providing Reliable Transmission Services through the Robust and Efficient Power Grid"

Rastriya Prasaran Grid Company Limited
Rudramati Marga, Buddhanagar, Kathmandu
01-4788680
info@rpgcl.com
http://www.rpgcl.com/