Task 1: Technical Assessment of Network Improvements

Detailed Feasibility Studies: Transmission Projects in Nepal

Volume 1 (Report)

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TETRA TECH

Feasibility Study:
Nepal Priority Transmission Projects

Volume 1: Technical Feasibility Assessment

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Acronyms

ACSR	Aluminum conductor steel reinforced
ADB	Asian Development Bank
ASTM	American Society for Testing and Materials
ATS	Automatic transfer switch
AIS	Air-insulated switchgear
BIL	Basic insulation level
BOM	Bill of Materials
BS	British Standard
CF Base Case	Counterfactual base case
CIF	Compact Implementation Funding
CSA	Canadian Standards Association
CT	Current Transformer
DCPT	Dynamic Cone Penetration Test
EHV	Extra High Voltage
EIF	Entry in force
EPC	Engineering, procurement and construction
FACTS	Flexible AC Transmission System
GIS	Gas-Insulated Switchgear or geographic information system
HPP	Hydropower plant
HVDC	High Voltage Direct Current)
IACS	International Annealed Copper Standard
IE	Indian Electricity Rules
IEC	International Energy Commission
IED	Intelligent Electronic Devices
IEEE	Institute of Electrical and Electronic Engineers
IFC	International Finance Corporation
IFC	Issued for construction
I/O	Input/output
ION	Brand name for Schneider Electric-Power & Energy Meter
IPP	Independent power producer
IS	Indian Standards
KfW	The German Development Bank
LAN	Local Area Network
LDC	Load Dispatch Center
LiDAR	Light Imaging Detection and Ranging
LRT	Linear Routing Tool
MCC	Millennium Challenge Corporation
MVAR	Mega-Volt Ampere Reactive
NEA	Nepal Electricity Authority
NPS	Nominal pipe size

OHGW	Overhead ground wire
OPGW	Optical ground wire
OMCN	Office of Millennium Challenge/Nepal
PGCIL	Power Grid Power Corporation of India Ltd
PI	Point of inflection
PSS®E	Power Transmission System Planning Software
RMS	Root mean squared
RTU	Remote Terminal Units
SCADA	Supervisory Control and Data Acquisition
SPT	Standard Penetration Test
TOR	Terms of reference
VDE	German Standard
VT	Voltage Transformer
WB	World Bank

Executive Summary

The Millennium Challenge Corporation (MCC) is a US Government agency that provides aid to developing countries in order to encourage economic growth. Nepal suffers from one of the worst electricity supplies in South Asia. In December 2014, MCC selected Nepal as an eligible country and began work on developing a program to stimulate its economic growth. The objective of MCC's compact in Nepal is to reduce load shedding by increasing the amount of power supplied to the national grid as well as facilitating increased power trade between Nepal and India. The key areas of improvement are the transmission network, extension of grid projects that can help transfer power from generating projects, and upgrades of existing stations to supply electricity to locals who are living far from urban centers.

MCC selected Tetra Tech to perform a detailed feasibility analysis of proposed projects considering a compact implementation period of five years (2018-2023). MCC's due diligence contractor; WSP, conducted a pre-feasibility assessment; its findings (WSP: Transmission Network Analysis (Final No 151-09979-01) formed the basis of this detailed feasibility assessment. After assessing the feasibility of all proposed MCC projects, Tetra Tech further defined and prioritized them. The feasibility assessment was carried out through stakeholder engagement, site surveys, technical assessments, environmental and social assessments, cost assessments, etc.

MCC compact projects include east-west transmission backbone; NR1, transmission network reinforcements; NR3, NR4, cross-border electricity transmission; XB1 and generation pooling to the national grid or Nepal/India Border; T2', T3 and T8.

The following are key results of the technical feasibility assessment.

- The implementation of all projects under review will meet all compact objectives, including reducing load shedding, increasing generation utilization, and maximizing power trade potential.
- With the implementation of the NR1 and XB1 projects, load shedding can be reduced up to 56%.
- With the implementation of the T8 project, electricity export potentials can be significantly increased (290%), the overall generation utilization will increase to 83% in base case in 2023, and increase to 75% in base case in 2030.
- T2', T3, NR3, and NR4 are remote transmission projects. These projects enhance the remote area transmission capacities, therefore, to accommodate increasing remote generation projects.
- Some roads and bridges in Nepal are not capable to carrying heavy equipment, due to this constraints substation transformers are limited to single phase 55MVA transformers or three phase 160MVA transformers.
- In the project implementation schedule, project float of 8 month is considered in the overall schedule.

The following are key recommendations of technical feasibility assessment.

- It is also recommended to model sub-transmission level system 132kV and 66kV to do the power system assessment and evaluate the benefit to distribution level loads.
- It is recommended that the loop flow situation within these two tie lines be closely studied in the detailed engineering stage with details from India's network.
- It is recommended that all station access routes shall be surveyed by a logistics transporter company for movement of transmission and other construction material.
- It is recommended that further more detailed geotechnical studies should take place during detail design phase.
- To facilitate upcoming desktop routing study, Airborne LiDAR survey should be used for transmission line routing.
- Considering the aggressive timeline for compact implementation, Tetra Tech recommends that implementation be split into four engineering, procurement and construction (EPC) or design-build packages based on geography.
- It is recommended that the EPC contractor be responsible for land acquisition, permitting, resettlement, engineering, procurement, construction, testing, and commissioning and project closeout.
- In order to manage the program, Tetra Tech recommends hiring a firm to provide program supervision services including project management, technical oversight, environmental monitoring, social safeguard services, construction oversight, procurement oversight and overall financial monitoring.

1. Introduction

Following the identification of power as a constraint to economic growth, the Government of Nepal (GoN) submitted concept papers to MCC requesting funding for a diverse set of projects and activities in the power sector. The Nepali electricity network suffers low throughput capacity, high losses, and inability to evacuate power from supply sources, whether generation or imports. Consequently, the GoN has proposed a program that will address this through critical investments in network infrastructure (transmission lines and substations) to provide a stronger national transmission network.

Tetra Tech was retained by MCC to conduct a detailed feasibility study (DFS) of the proposed projects, further refining the Pre-Feasibility Study by WSP.

The East-West Transmission Backbone

- NR1: 400 kV East-West Transmission Backbone

Transmission Network Reinforcements

- NR3: Upgrade of the Ilam-Inaruwa 132 kV transmission line
- NR4: Upgrade of the Balanch-Attariya 132 kV transmission line

Enabling Generation – Connecting Generation Pooling Points to the National Grid or Nepal/India Border

- T2’: Likhu Hub – New Khimti transmission line
- T3: New Tadhekani-Kusma transmission line
- T8: New Lamki substation and transmission line to the Nepal border

Cross-Border Electricity Transmission

- XB1: New Butwal 400 kV transmission line to the Nepal border

Note: The NR1.1 project, which includes the Dhalkebar substation and the Dhalkebar – Hetauda transmission line upgrade to 400 kV, is already designed by private firm from India. So, NR1.1 is not part of MCC compact projects and excluded from Detail Feasibility Study.

1.1Task 1 Objectives

The primary objective of Task 1 of the DFS is to assess the technical feasibility of the proposed transmission projects in Nepal.

Tetra Tech has provided a review of the technical feasibility and cost (+/- 20%) of each of the projects, as shown in Table 1, by performing an engineering assessment and determining the specifications of substations and transmission lines in accordance with relevant technical standards in Nepal, India and other international standards. The assessment will include the determination of optimal configurations and locations for both the transmission lines and the substations, and constraints and risks associated with each projects. Whenever possible, recommendations will be made in order to optimize project execution and reduce cost.

Following activities were performed for feasibility assessment:

- Power system analysis to determine technical feasibility, estimate power flows, and determine power system losses for different scenarios
- Preliminary assessment of proposed developments
- Transmission line route selection and substation site selection
  - Data gathering
  - Site reconnaissance
  - Walk down along routes (transmission line routes of NR4, NR3 and almost 50% of T8 were drove down and all NR1, T2', T3 were visited several time by helicopter.
  - Stakeholder engagement
  - Alternate route options analysis
  - Participatory route selection workshops
  - Geotechnical investigation
- Conceptual design of transmission line and substations
  - Digital Terrain Model of potential transmission line route
  - Substation layouts
- Risk assessment
- Detailed project cost estimates (to +/- 20 % accuracy)
- Project implementation schedule (overall and for each project)
- Recommendation of contract procurement packages
- Terms of reference (TOR) and cost estimates for the firm(s) to be hired following the compact's signing to produce tender documents for all engineering, procurement, and construction (EPC) contract(s) (Annex B).

Table 1.1 Projects

Project	Component	Transmission Lines	Substations	
			New	Existing*
NR 1, XB1	NR 1	400 kV, 270 km	Lapsiphedi**	
		Lapsiphedi to Naubise (48 km)	New Damauli	
		Naubise to New Hetauda (41 km)	Naubise	
		Naubise to New Damauli (98 km)	New Butwal**	
		New Damauli to New Butwal (84 km)	New Hetauda***	
	XB1	New Butwal to Nepal/India border (23 km)		
NR 3		132 kV, 110 km		
		Ilam* to Inaruwa*		Ilam Inaruwa
NR4		132 kV, 131 km		
		Balanch* to Attariya*		Balanch Attariya
T8		400 kV, 47 km		
		New Lamki to Nepal/India border	New Lamki	
T2’		220 kV, 30 km		
		Likhu Hub to New Khimti*	Likhu Hub	New Khimti
T3		220 kV, 30 km		
		Tadhekani to Kusma*	Tadhekani	Kusma
Total		642 km	8	6

* Bay extensions will be provided at these existing substations.
** 220 kV system of these substations are funded by the Asian Development Bank.
*** 220 kV system of this substations is funded by the World Bank.

2. Approach and Methodology

This section describes the approach and methodology employed for feasibility assessment.

2.1 Data Collection and Review

Tetra Tech interacted with various government and non-government organizations in Nepal in order to collect transmission system data and to understand other project developments taking place in the region.

Technical, environmental and financial details were gathered from various stakeholders. Table 2.1 illustrates the source and type of data collected Information.

Table 2.1 Data Collection

	Sources	Data/Information Collected
1	MCC / WSP / OMCN	PSS®E files, due diligence report, power map and other information relevant to the projects
2	Statistics Department	Information related to gross domestic product growth rate, population growth rate
3	Meteorological Department	Information related to weather, wind speed, rainfall, snow fall, isoceraunic level
4	Mining and Geotechnical Survey Department	Geological map of Nepal
5	NEA Project Planning Department	Various information about existing and upcoming projects, their associated transmission lines, generation, existing substation details, drawings of existing substation, etc.
6	NEA Power Trade Department	Information about power trades between India and Nepal
7	NEA Operation and Maintenance Department	Information regarding maintenance schedules, fault levels, etc.
8	NEA Financial Department	Wheeling charges and tariff information
9	Data Collection from NEA Website	Various tender documents, drawings, etc.
10	Data Collection from PGCIL	Various drawings, technical specifications and other information
11	NEA System Planning Department	Only positive sequence data for short circuit analysis and dynamic data of generating units for stability analysis
12	MCC/EPG	Nepal Grid Code Compliance & Power quality Requirements

All the above relevant data and reports were reviewed by technical leaders and engineers in further detail. The collected data has formed the basis of the Detailed Feasibility Study. The missing information / any gaps were further discussed with appropriate sources.

In order to achieve this objective of detail feasibility assessment, a number of meetings were held at the beginning of the project, and great deal of data was obtained that are directly and indirectly related to elements of this compact. In various meetings with NEA, transmission development and construction managers, NEA managers of ADB projects, construction managers of NEA projects, and local professionals, we understood NEA's design approach and standards, the materials that have been used to build Nepal's network, transmission line construction constraints, the factors that might contribute to construction delays, etc. We also met with other donors on Nepal's electricity network development and heard their experiences and points of views about project implementation. In parallel, we studied many NEA tender documents in order to understand NEA's desired technical specifications, contractor scopes, and activities in NEA projects. We also visited all the MCC project sites and became familiar with the climatic and terrain features of project areas.

2.2 Power System Assessment

The technical feasibility of the East-West Transmission Trunk Lines, Transmission Network Reinforcements, and Transmission Extension Cords were evaluated by using PSS®E, a power system analysis tool, employing the model developed previously by MCC's due diligence consultants. The studies were performed for the year of 2023 and the year of 2030 considering the timely generation and transmission developments as described in the WSP due diligence report for the year of 2020 and the year of 2025. For each year, two extreme power flow scenarios considering wet conditions with minimum loading ("Wetmin") and dry conditions with maximum loading ("Drypeak") were considered.

2.2.1 Counterfactual Base Cases

For each study year, a set of "counterfactual base cases" (CF Base Cases) without any of the MCC projects was created to demonstrate the base case situation without the MCC investment. In order to create realistic (i.e., solvable) cases with no excessive overloads or voltage violations, the following are required: power flow scenarios, reduction of loads (load shedding) and adjustment of import/exports from the original cases provided by WSP. These load-shedding figures were later used to demonstrate the benefits of the MCC projects. The following base case counterfactuals were created:

- 2023 Drypeak
- 2023 Wetmin
- 2030 Drypeak
- 2030 Wetmin

Note: the transmission project NR1.1 will be built by another donor. However, because it is part of Nepal's power system, was included at 400 kV in both the 2023 and 2030 scenarios.
The following techniques were used to create the aforementioned power flow scenarios. Please refer to WSP Report.

- 2023 Supply (generation) is based on WSP model generation for 2020 (implying a lag of 3 years)
- 2023 Demand is based on WSP model demand for 2020 by feeder, scaled up by the factor of 7.5% per year for 3 years (which equates to a 24.2% total increase over the three years)
- 2030 Supply (generation) is based on WSP model generation for 2025 (implying a lag of 5 years)
- 2030 Demand is based on WSP model demand for 2025 by feeder, scaled up by the factor of 7.5% per year for 5 years (which equates to a 43.5% total increase over the five years)

The power flow cases provided by WSP included the following information. A complete set of network elements is provided in Annex A.

- The transmission system above 132 kV was modeled in detail and some 66 kV and 33 kV buses were included. The distribution system was not included.
- The loads were placed on the buses 66 kV and above.
- The load power factor was set to about 0.98 lagging.
- All the transformers were modeled as lossless (copper and iron losses are ignored)
- There are considerable number of switch shunts (capacitor banks and reactors) available in the system (please refer to Annex A)
  In the power flow models, the generator transformers were embedded into the generator model and the transformer reactance was considered to be 15%.
- Most of the generators were consuming the reactive power (leading PF).

For the energy benefit studies, the provided models were used since there is no significant impact of reactive power transfer of the system on the transmission system losses. For the cases used for the technical benefit studies the following modifications were done.

- The load power factor was set to 0.85 lagging, which is a realistic value for typical system loads.
- The generator transformers were separated from the generator model by introducing the generator terminal buses at 13.8 kV (a typical value).
- The generator transformer reactances were set to 10%, which is more realistic.
- The generator voltage set points were adjusted to within a realistic range of 1.05-0.95pu, in order to maintain the leading power factors above 0.95.

Note: The modelling is adequate to determine the transmission level (66 kV and up) system upgrades required to facilitate the MCC projects and to demonstrate the importance of the MCC projects with respect to the Nepal transmission system performance. However, the sub transmission and distribution level (66 kV and below) system upgrades needs to be evaluated at a later stage. It is also recommended that to analyze actual benefit on MCC projects, further studies of sub-transmission system should be completed. Furthermore, the losses estimated in the study are relevant to the transmission system only and therefore considered as "transmission losses".

Assumptions and Major Considerations

One of the major considerations is the power transfer capabilities of the tie lines to India. As agreed upon, the following transfer limits were considered.

- Dhalkebar-Muzzaffarpur interconnector (1st tie line)
    - Maximum of 700 MW in 2023
    - Maximum of 1200 MW in 2030
- XB1 – second interconnector (considering 40%:60% power distribution between the first tie line and XB1)
    - Maximum of 1050 MW in 2023
    - Maximum of 1800 MW in 2030.

The following assumptions were made:

- It was assumed that the power flows provided by the due diligence team accurately represent the existing system and the system upgrades other than the MCC projects in Nepal Transmission Network.
- It was not possible to obtain an equivalent model of the India power system. Therefore, the tie line terminals were individually modeled without considering the transfer impedances between the terminals. The power transfers were modeled as described above.

2.2.2 Scenarios with MCC Projects

Based on each base case built, the MCC projects were added to the system one by one as listed in Table 2.2, and the impact of each project was evaluated. In addition to that, one case with all the MCC projects was also included for each base case.

Table 2.2 Power Flow Scenarios Considered for Base Analysis

Case	Supply/Demand	Set of MCC Projects Included
1	2023 Drypeak	CF Base Case
2		CF Base Case + NR1
3		CF Base Case + NR1 + XB1
4		CF Base Case + NR1+ XB1 + T2' + T3
5		CF Base Case + NR3
6		CF Base Case + NR4
7		CF Base Case + T8
8		CF Base Case + all MCC Projects
9	2023 Wetmin	CF Base Case
10		CF Base Case + NR1
11		CF Base Case + NR1 + XB1
12		CF Base Case + NR1+ XB1 + T2' + T3
13		CF Base Case + NR3
14		CF Base Case + NR4
15		CF Base Case + T8
16		CF Base Case + all MCC Projects
17	2030 Drypeak	CF Base Case
18		CF Base Case + NR1
19		CF Base Case + NR1 + XB1
20		CF Base Case + NR1+ XB1 + T2' + T3
21		CF Base Case + NR3
22		CF Base Case + NR4
23		CF Base Case + T8
24		CF Base Case + all MCC Projects
25	2030 Wetmin	CF Base Case
26		CF Base Case + NR1
27		CF Base Case + NR1 + XB1
28		CF Base Case + NR1+ XB1 + T2' + T3
29		CF Base Case + NR3
30		CF Base Case + NR4
31		CF Base Case + T8
32		CF Base Case + all MCC Projects

2.2.3 Scenarios for Sensitivity Studies

Key scenarios were tested for sensitivity of the system in response to different supplies and demands. The key scenarios were the base cases and the cases with all the MCC projects, as listed in Table 2.3.

Table 2.3 Power Flow Scenarios for Sensitivity Studies

Case	Supply/Demand	Set of MCC Projects Included
1	2023 Drypeak	CF Base Case
8		CF Base Case + all MCC Projects
9	2023 Wetmin	CF Base Case
16		CF Base Case + all MCC Projects
17	2030 Drypeak	CF Base Case
24		CF Base Case + all MCC Projects
25	2030 Wetmin	CF Base Case
32		CF Base Case + all MCC Projects

The above mentioned cases were used for the following sensitivity studies.

(1) Impact of Different Supply Scenarios

The generation dispatch of the cases described in Table 2.3 was selected considering a reasonable expected growth rate in Nepal as described in Section Counter Factual Base Case. It was further tested for the sensitivity to different supply (generation) scenarios by 2023 and 2030. As agreed upon, the following two alternative supply scenarios were considered.

- Alternative Generation Scenario - 1, a higher supply forecast, which is based on the NEA plan in the WSP due diligence report dated 15 July 2016.
- Alternative Generation Scenario - 2, a lower supply forecast, with 5 years additional lag.

Table 5 shows the different supply scenarios that were set up.

Please note that the Generation Distribution Zones mentioned below are different than Procurement package zones.

Table 2.4 Generator Dispatch for Different Supply Scenarios

Case	Supply Forecast		Generation Distribution by Zones (MW)						
	Generation On-Line	Generation Available	Zone 1 Far West	Zone 2 Mid West	Zone 3 West	Zone 4 Central	Zone 5 East	Zone 6 Far East	TOTAL
Base cases:									
2023 Drypeak	3,946	29%	35	4	402	331	282	104	1,158
2023 Wetmin	3,946	54%	63	7	736	606	516	190	2,118
2030 Drypeak	4,836	30%	35	4	584	331	298	176	1,428
2030 Wetmin	4,836	64%	75	9	1,268	720	648	382	3,102
Low Supply Cases:									
2023 Drypeak	2,230	29%	58	-	243	127	181	38	647
2023 Wetmin	2,230	54%	107	-	452	236	337	72	1,204
2030 Drypeak	3,680	30%	63	7	414	264	283	73	1,104
2030 Wetmin	3,680	64%	134	14	884	563	605	155	2,355
High Supply Cases:									
2023 Drypeak	4,907	29%	61	20	476	269	338	259	1,423
2023 Wetmin	4,907	54%	113	38	886	501	630	482	2,650
2030 Drypeak	9,735	30%	589	21	816	452	742	301	2,921
2030 Wetmin	9,735	64%	1,256	45	1,742	964	1,583	642	6,231

(2) Impact of Different Demand Forecast

As described in Sections 3 and 4 of the WSP due diligence report, a moderate demand forecast was used in their studies, which equates to a growth rate of about 7.5% per year. To test sensitivity, it is necessary to consider the variations in demand forecast as well. Therefore, the following sensitivity cases were considered.

- Low forecast – demand growth at 5% per year
- High forecast – demand growth at 10% per year.

(3) Impact of Reduced Sales to India

A sensitivity case was run for both 2023 and 2030 in which “all MCC Projects” were included ***except*** XB1. This case was run using the base analysis supply and demand forecasts (as described in Section 2.2.1). Sales to India through other supply lines remained as modeled in the case with “all MCC Projects.”

2.2.4 Methodology – Technical Feasibility Study

The technical feasibility study was performed for the following cases.

Table 2.5 Power Flow Scenarios used for Technical Feasibility Studies

Supply/Demand	Set of MCC Projects Included
2023 Drypeak	CF Base Case
	CF Base Case + all MCC Projects
2023 Wetmin	CF Base Case
	CF Base Case + all MCC Projects
2030 Drypeak	CF Base Case
	CF Base Case + all MCC Projects
2030 Wetmin	CF Base Case
	CF Base Case + all MCC Projects

The following studies were performed.

Power Flow Analysis and Loss Evaluation
The steady state power flow analysis was performed in PSS®E for the aforementioned power flow scenarios to identify:

- Voltage violations and voltage stability issues
- Thermal overloads
- Steady state system instabilities (blown up cases) related to the project.

All the N-1 contingencies in the transmission network (132 kV and up) were considered in the analysis. In addition to these, the following N-2 contingencies relevant to the MCC projects were also considered.

- NR1 trunk lines
    - D/C transmission line from New Hetauda to Naubise
    - D/C transmission line from Naubise to Lapsiphedi
    - D/C transmission line from Naubise to New Damauli
    - D/C transmission line from New Damauli to New Butwal.

- Apart from the abovementioned N-2 contingencies, we also considered the double circuit outages of the all three tie lines (Dhalkebar, XB1 and T8). To do this, it was necessary to adjust the imports/exports when one of these tie lines is out of service; therefore, these outages were considered separately from the others.

The study kept track of lower voltage violations in case these might signal the need for investment in upgrades at the distribution voltage level. As in the Nepal grid code, voltages within 0.9 pu and 1.1 pu are acceptable. However, for reporting purposes, the voltage violations beyond 0.95 pu and 1.05 pu were considered and the mitigation measures evaluated only if the voltages moved beyond 0.9 pu and 1.1 pu.

The overloads of the transmission lines and transformers were monitored and for the overloads, the mitigation measures such as adding parallel circuits were proposed.
A loss evaluation of the system expansions along with the related upgrades was performed for selected power flow scenarios. For each power flow scenario, the followings were determined:

- System losses in MW before adding the project (at each voltage level and in each zone)
- System losses in MW after adding the project
    - Losses related to the transmission components of the project
    - Losses related to the rest of the system (at each voltage level and at each zone)
- Net impact in terms of losses.

2.2.5 Short Circuit Analysis

A short circuit analysis was performed to determine the maximum short-circuit levels in order to ensure breaker ratings are not exceeded. The analysis was done for all the new stations as well as the existing stations under system intact conditions. The impact on the system expansions are identified by comparing against the short circuit levels before adding the expansions.
The following limitations were faced in the studies.

- No sequence impedance data of the Nepal system was available for the studies and only the positive sequence impedances were available for the calculations. Therefore, only the three phase fault levels can be calculated accurately. For the single phase fault level calculations, the negative and zero sequence impedances are required.
- The short circuit contribution from Indian grid was unknown to the date on which the studies were done and therefore the calculations were done without considering the contribution from Indian grid. It is proposed to consider some short circuit contribution and add it into the results of this analysis. The following short circuit contributions were added to the results of the short circuit levels calculated.
    - 400 kV buses – 15 kA
    - 220 kV buses – 10 kA
    - 132 kV buses – 5 kA

Because of the unavailability of zero sequence and negative sequence impedance data, only the three phase short circuit levels were calculated. Note that for the generators, the zero sequence impedance is usually smaller than the positive sequence impedance and therefore the single phase fault level would be higher than the three phase fault levels. Furthermore, the calculations were done considering some reasonable supply/demand scenarios for year 2023 and 2030. However, there is a possibility of having a higher supply and hence a larger short circuit current. Therefore, it is necessary to consider an extra margin from the calculated values when determining the breaker ratings. In order to cover these short comings, a 30% margin was considered for the minimum breaker ratings.

2.2.6 Transient Stability Analysis

The transient stability analysis was performed for the aforementioned power flow scenarios considering the critical contingencies related to the expansions. This included transmission line and generator outages after a fault. The faults on the busses relevant to the MCC projects were considered. The following dynamic performance issues were evaluated:

a. Rotor angle stability
b. Frequency stability and inertia requirements
c. Temporary over- and under-voltage
d. Dynamic reactive power requirements
e. Need for Special Protection Schemes (SPSs) such as cross tripping of generators

If any dynamic performance criteria violation was found, appropriate mitigation was investigated.

2.2.7 Methodology – Technical Benefit Study

A technical benefit study was done in PSS®E for all the cases described in Table 2.2 (Section 2.2.2). The following procedure was followed for the evaluation of the technical benefits.

It was assumed that Nepal's annual load patterns are represented by the dry and wet seasons. In order to estimate the annual energy requirements, an equal number of months for the dry and wet seasons were assumed– 6 months for the wet season and 6 months for the dry season.

The daily load profile of the Nepal system recorded in 2015 is shown in Figure 2.1. It was agreed to consider a projected version of this load profile for 2023 and 2030, and the profile represented three different loading conditions.

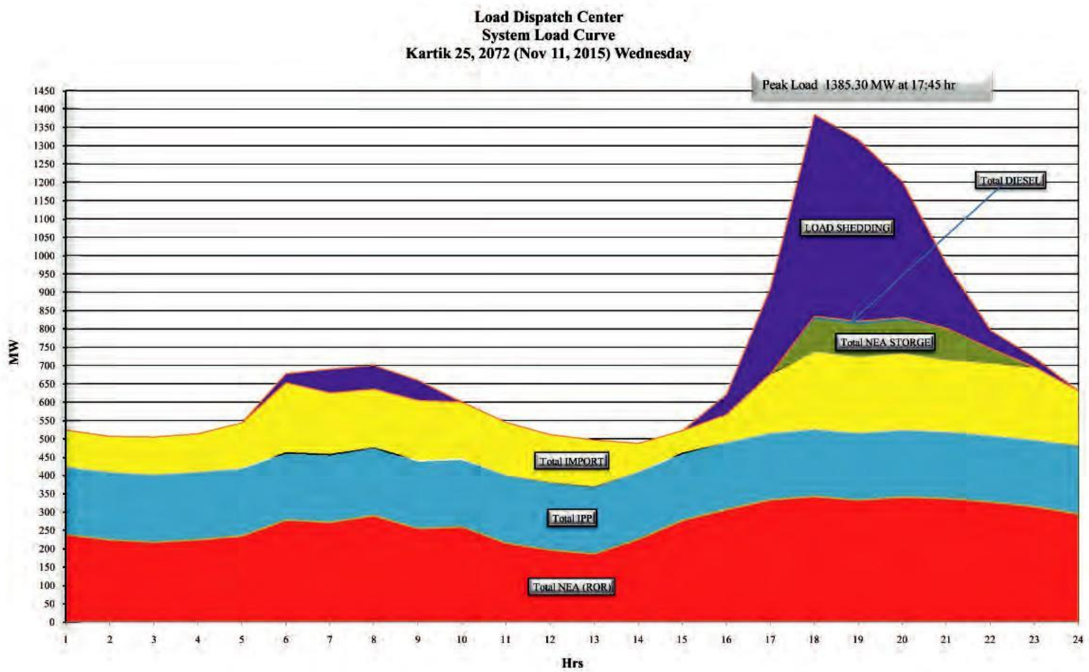


Figure 2.1 2015 Daily Load Profile

Table 2.6 Nepal Load Profile, 2015			
	MW	Hr/day	MWh/day
Peak load	1385	4	5541
Base load	492	9.5 at 35.5% of peak	4672
Shoulder load	651	10.5 at 47% of peak	6837
Total		24	17050
		Load factor =	0.51

It was assumed that the "Drypeak" scenarios represent the average loading in the Nepal system on a day in the dry season and "Wetmin" scenarios represent the average loading in the Nepal system on a day in the wet season. Considering the average loadings in these scenarios, the peak, shoulder and base load cases were developed for the wet and dry seasons for 2023 and 2030.

For each power flow scenario the losses (in MWh) were calculated for the list of cases relevant to years 2023 and 2030 given in Section 2.2.2. In any of these cases, if the power flows were not solvable, the following adjustments were made.

- For the dry season cases, the loads were shed and the imports were adjusted until the load flow is solvable. The amount of load reduction is considered as the energy not supplied (load shed).
- For the wet season, the exports were reduced and the generations were adjusted until the load flow is solvable. The amount of export reduction is considered as the energy not supplied (generation shed).

If the existing lines are heavily overloaded or very low/high voltages were observed in certain buses, the local loads were reduced and these amounts were also considered as the energy not supplied (load shed).

The annual energy losses and the energy not supplied were calculated considering the daily values and the duration of each season. The benefit of each MCC project was shown as the annual savings in energy (MWh). The following information was derived for each scenario relevant to years 2023 and 2030:

- Annual MWh supply – with and without MCC project(s)
- Annual MWh consumption – with and without MCC project(s)
- Annual MWh loss – with and without MCC project(s)
- Annual load shedding in MWh – with and without MCC project(s)
- Annual import amounts in MWh – with and without MCC project(s)
- Annual export amounts in MWh – with and without MCC project(s)
- Annual generation shedding in MWh (lost exports) - with and without MCC project(s).

2.3 Substations – Engineering Assessment

Tetra Tech has performed feasibility level engineering for the substation proposed in MCC compact in Nepal. Substation engineering assessment includes assessment of electrical, civil, structural, protection, SCADA, telecommunication, environmental requirements. Tetra Tech has conducted different site surveys, site selection assessment to study the feasibility of substation in the proposed area. Based on the land selected, substation footprint and basic layout for each substation are created. This helped in identifying the major equipment to be used. The major equipment are part of the Bill of Material (BOM) which is required in providing the cost of the MCC compact varying from +/-20% range.

2.3.1 Substation Site Selection

The substation site selection process was based on a multi-criteria approach. The following criteria were considered for substation site selection. While it is recognized that it is not always possible to find sites that meet all the criteria, the site that met most of these criteria is selected.

- MCC/OMCN recommendations
- Space availability
    - Space provision for ultimate layout

- Availability of laydown area
- Site condition
  - Relatively flat sites with slopes no more than 1% to 2%
  - Site elevation: preferably higher than the surrounding land
  - Soil type
  - not in a dense forest area, not located on a flood plain
  - Proximity to imported fill
  - proximity to distribution line for station service supply
  - proximity to water supply
  - Aviation routes
  - Land cost
  - Proximity to load centers (for stations serving load centers)
  - Risk of security threat
- Environmentally-sensitive area adjacent to the site
  - Wetlands
  - Bird or wildlife habitants
- Community
  - Proximity to local communities (noise, visual impact could be issues)
  - Heritage sites
  - Archeological sites
- Infrastructure
  - Feasibility of year-round access
  - Available access roads
  - Nearby highway or major road (this is required to determine an internal access road)
  - Nearest transport infrastructure (railway or highway)
  - Accessibility for maintenance and emergency response (fire, ambulance)
  - Pipelines

As a first step in the site selection process, a preliminary site visit was conducted for most of the proposed sites along with other proposed sites. Each site was evaluated using the above criteria. There were three different alternate locations were selected. The location best aligned with the site selection criteria – were selected further for each new substation.

After the initial site selection evaluation, a second round of site visits was conducted to confirm which of the short-listed sites are the most viable. As a next step, the site selection was finalized based upon space availability for the ultimate layout. A final round of site visits was conducted to obtain geotechnical data for the selected sites.

The following provides a high-level summary of the site selection for each substation. Further details are provided in Section 3 of this report.

New Hetauda Susbtation
The World Bank is developing a 220 kV substation and has purchased land for a 400 kV extension. For this station, no desktop study or site visit was conducted as the site is already selected.

Naubise Substation
Initially, three alternatives sites were selected near Galcchi District. However, it was determined through OMCN that NEA's preference is to build the substation near Naubise District. Subsequently, site options near Naubise were selected and evaluated.

New Damauli Substation
During the site visit, it was determined that the proposed sites have steeper slopes than what is acceptable. Two additional alternative sites were then identified (one on farmland and one on a brick factory site). After further evaluation of both sites, the farm land site was selected.

Lapsiphedi and New Butwal Substations
These stations have not gone through the site selection process as the land is already purchased by NEA for the development of a 220 kV substation by the ABD and World Bank. For this reason, a desktop study has not been completed.

New Lamki Substation
The New Lamki site selection process included a site visit and a desktop study to get acceptance from different groups within the team (environmental, resettlement, etc.).

Tadhekani Substation
The first location selected during the desktop studies was found to be adequate during the site visits.

Likhu Hub Substation
A desktop study was conducted to determine an appropriate location for the substation. However, the final location was chosen based on the fact that an independent power producer (IPP) is already constructing a 132 kV substation. Based on discussion with NEA and IPP, the IPP has agreed to reserve space for the 220 kV-132 kV substation on the land that they have already purchased.

Balanch, Attariya, Kusma, New Khimti, Ilam and Inaruwa Substations
These stations are NEA's existing stations. No site selection was required for these stations.

Table 2.7 provides a high-level summary of the site alternatives and selection criteria.

Table 2.7 Site Alternatives and Selection Criteria

Substation	Alternative #1	Alternative #2	Alternative #3	Selected
New Hetauda	N/A	N/A	N/A	Site selected by NEA/World Bank.
Galcchi	27° 47' 55.72'' N 84° 54' 53.79'' E	27° 47' 09.25'' N 84° 56' 02.21'' E	N/A	Galchhi was initially proposed as an alternative for the Naubise site. These alternatives were dropped after Naubise was selected as final substation location.
Naubise	27° 43' 59.40'' N 85° 06' 57.56'' E	27° 44' 09.15'' N 85° 07' 13.77'' E	N/A	Alternative #1 was selected as it offers better land topography and a larger footprint.
New Damauli	27° 57' 13.8" N 84° 17' 10" E	27° 56' 54.26'' N 84° 17' 54.20'' E	27° 58' 04.94" N 84° 17' 33.97" E	Alternatives #1 and #2 are on steep slopes. Alternative #3 is located on farmland and offers better topography. The selected site is alternative #3.
New Butwal	27° 34' 31.83'' N 83° 41' 25.49'' E	27° 35' 46.27'' N 83° 37' 25.78'' E	27° 35' 32.03'' N 83° 41' 8.03'' E	Three alternatives were proposed initially. Alternative #1 was selected as it was found that the ADB has already purchased this land for its 220 kV substation.
Lapsiphedi	N/A	N/A	N/A	The substation is to be built adjacent to ADB's 220 kV substation.
Tadhekani	28° 23' 40.43'' N 83° 25' 04.86'' E	28° 26' 48.40'' N 83° 30' 10.98'' E	28° 23' 25.69'' N 83° 26' 21.53'' E	Alternative #1 was selected as the other two alternatives are not suitable from a geotechnical and land topography perspective.
Likhu Hub	27° 29' 58.74'' N 86° 17' 18.95'' E	27° 29' 17.23'' N 86° 18' 19.66'' E	27° 31' 36.84'' N 86° 21' 25.32'' E	Alternative #3 is the land purchased land by an IPP. This site was selected.
New Lamki	28° 36' 55.50'' N 81° 13' 39.13'' E	N/A	N/A	This location was selected through site visits and since all stakeholders agreed, no other alternative sites were explored.

Table 2.8 presents the final site locations.

Table 2.8 Final Substation Locations

Item	Station	Coordinates					
		North			East		
		o	'	"	o	'	"
1	New Hetauda	27	25	45.97	85	00	24.17
2	Naubise	27	44	0.12	85	06	59.63
3	New Damauli	27	58	04.80	84	17	37.11
4	New Butwal	27	34	31.83	83	41	25.49
5	Lapsiphedi	27	44	42.44	85	30	33.03
6	Ilam	26	52	36.30	87	55	32.69
7	Inaruwa	26	36	46.53	87	07	16.72
8	Attariya	28	48	19.40	80	33	11.15
9	Balanch (Chameliya)	29	41	06.52	80	39	0.47
10	Tadhekani	28	23	40.43	83	25	04.86
11	Kusma	28	14	34.16	83	38	55.76
12	New Lamki	28	36	55.50	81	13	39.13
13	Likhu Hub	27	31	36.84	86	21	25.32
14	New Khimti	27	29	41.69	86	05	54.28

2.3.2 Substation Design

The physical layout and configuration of any high-voltage substation is based on two underlying principles:

- COMS
  - **C**onstructability – practical design including provisions for future expansion with minimal impact on the normal operation of existing components
  - **O**perability – ensure substation operators can control substation components and systems according to their precise design intent in any switching configuration, and assuming extreme environmental conditions specific to the substation location
  - **M**aintainability – of each individual substation component and of the substation yard in general (vehicle access, snow clearing, etc.) with minimal impact on the normal operation of other substation components
  - **S**afety - of people who may come in contact with any substation component (starting at the fence) intentionally or by accident.
- Reliability
  - Substation must be able to operate with minimal or no interruptions in power flow under various static (component failures) and dynamic (system transients) contingencies
  - Due to cost impacts, each substation is evaluated individually based on its overall importance to the power system, and criticality of loads/generators interconnected through the substation.
  - No Restriction of power transfer during the maintenance of one breaker

Each factor has a significant impact on the overall cost and size of the substation.

Bus bar Configuration
Substation reliability is most obviously reflected in the selected bus bar configuration.

The final selection was based on the following factors:

- Available land area and shape
- Effect of failure on the rest of the power system, such as overloads on adjacent substations or transmission lines
- Critical loads and/or generators interconnected by the substation
- Estimated cost of components.

A comparative analysis of commonly used switching schemes is presented in Table 2.9, based on standard IEEE 605 (Guide for Bus Design in Air Insulated Substations) and white paper titled “Reliability of Substation Configurations” by Daniel Nack, Iowa State University. The failure rate shown is considering substation buses and components only; line failures are not included. Cost in percent is given to illustrate the cost relationship among the different bus arrangements with the Single Bus Single Breaker design as the base. Relative footprints were compared in a similar manner.

Table 2.9. Comparison of the Different Busbar Schemes

Switching Scheme	Failure Rate (Failure/yr)	Mean Time Between Failures (years)	Relative Cost	Footprint (m^2)	Remarks
Single Bus Single Breaker (Figure 7)	0.0489	20	100%	100%	▪ Failure of the bus or any circuit breaker leads to the loss of the entire substation. ▪ Simple protection relaying schemes.
Breaker-and-a-Half (Figure 8)	0.00301	332	145%	146%	▪ Flexible operation. ▪ Allows for breaker maintenance. ▪ Breaker failure on bus side removes only one line from service. The circuit can rapidly be put back in service by closing the tie breaker and connecting to the other bus. ▪ One of the main buses can be taken out of service at any time when conducting maintenance. ▪ Protection and relaying can be involved since the middle breaker must be responsive to both associated breakers.
Ring Bus (Figure 9)	0.0174	57	125%	181%	▪ Flexible operation. Double feed for each circuit. ▪ Complex protection and relaying schemes. ▪ Requires only one breaker per circuit. ▪ When a fault occurs, the splitting of the bus might lead to undesirable circuit combinations. ▪ Limited number of circuit positions (4 to 6 is usually the maximum). When more circuits are required, the circuit is usually upgraded to a breaker-and-a half scheme.

Switching Scheme	Failure Rate (Failure/yr)	Mean Time Between Failures (years)	Relative Cost	Footprint (m^2)	Remarks
Main and Transfer Bus (Figure 10)	N/A	N/A	140%	189%	▪ Allows continuity of service to be maintained a during circuit breaker maintenance. ▪ Complex protection and relying schemes. ▪ Failure of the bus or any circuit breaker leads to the shutdown of the entire substation.
Double Bus – Double Breaker (Figure 11)	0.00567	176	190%	184%	▪ Very flexible. All circuit breakers can be taken out for maintenance. ▪ Allows isolation of any bus or any breaker without disrupting service. ▪ High cost since 2 breakers are used per circuit.

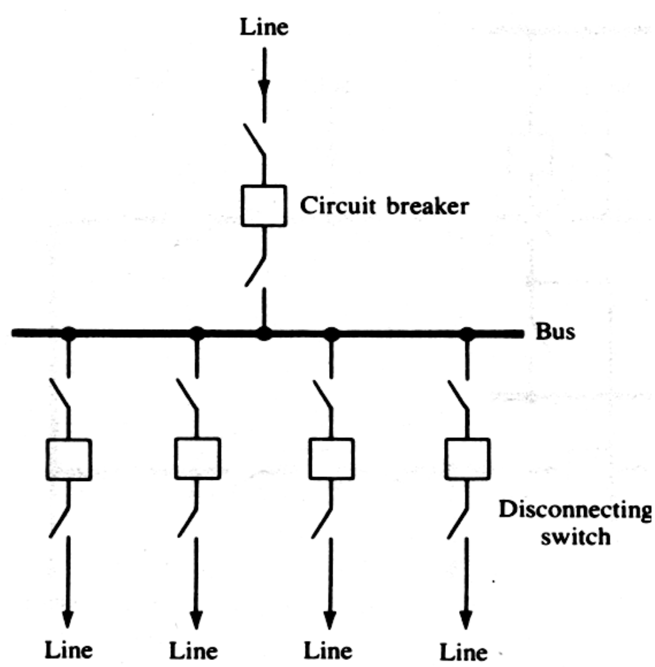


Figure 2.2 Single Bus Bar Scheme

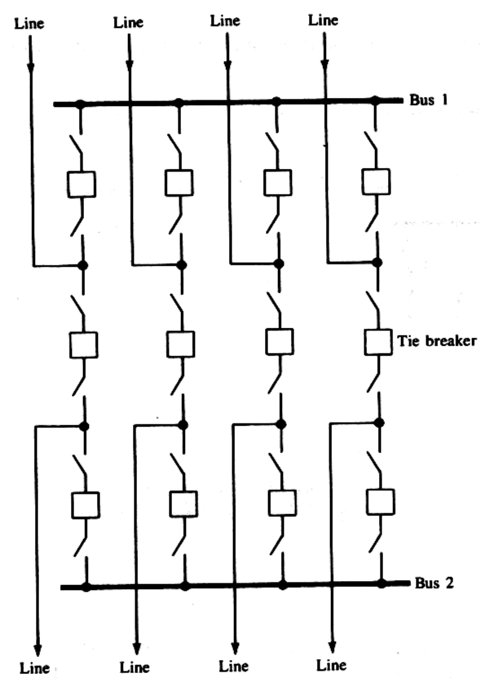


Figure 2.3 Breaker-and-a Half Busbar Scheme

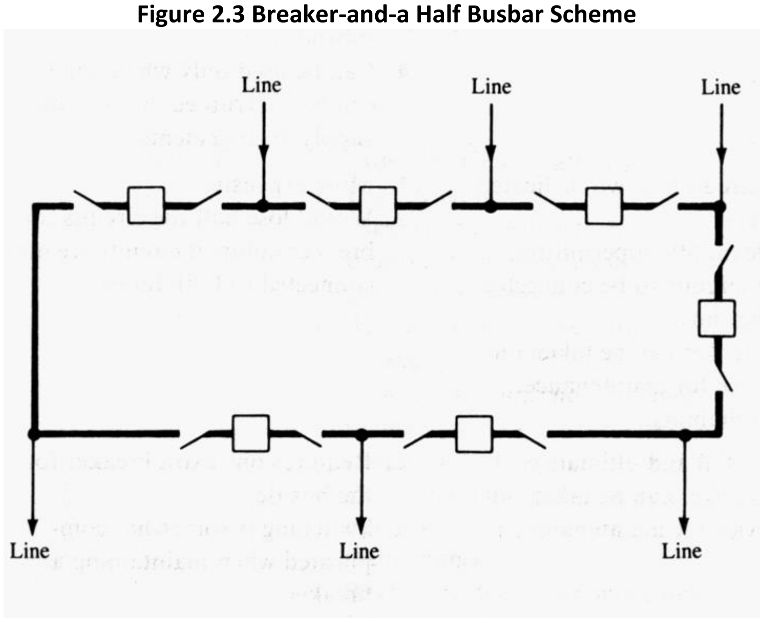


Figure 2.4 Ring Bus Scheme

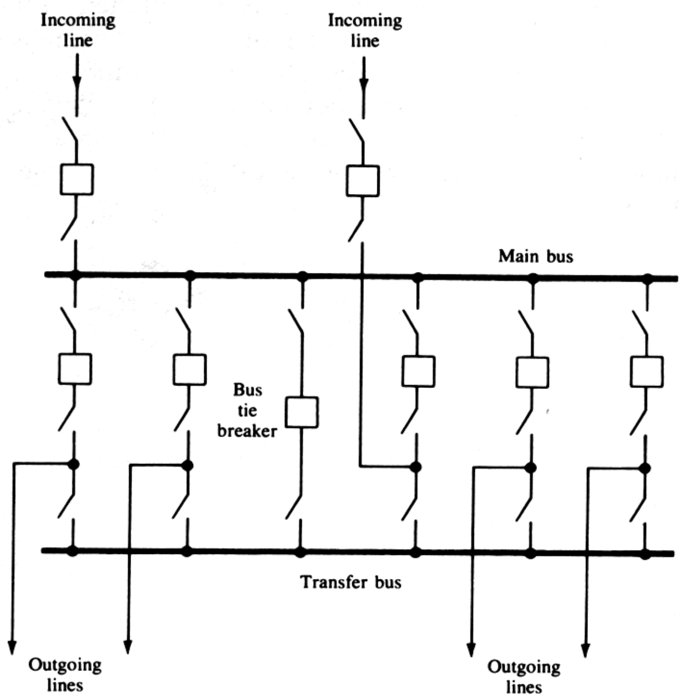


Figure 2.5 Main and Transfer Bus Scheme

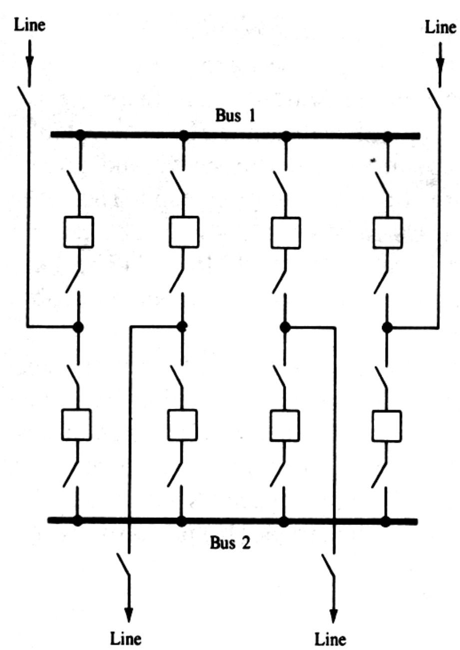


Figure 2.6 Double Bus – Double Breaker Scheme

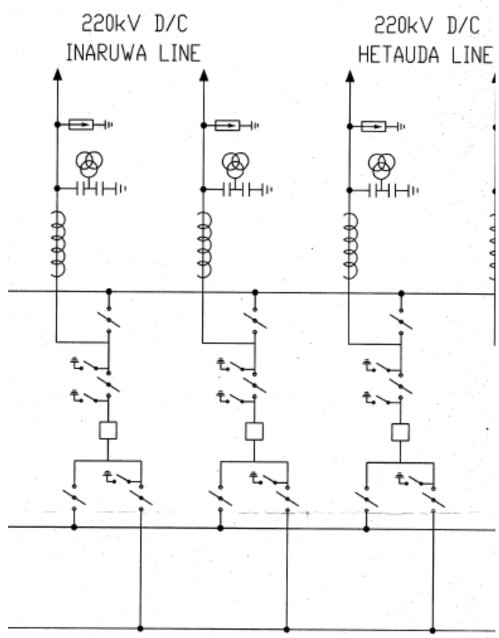


Figure 2.7 Mixed Double Bus – Single Breaker and Transfer Bus Scheme

As per the data collected, NEA's existing substations use either a main and transfer bus arrangement or a double bus single breaker arrangement, as shown in Figure 2.7. These configurations are not considered reliable enough for the planned 400 kV bulk power substations for the following reasons:

- The system is vulnerable to the loss of circuit breakers as there is only one per line. If one circuit breaker is lost, the tie breaker can be used to protect the line for which the circuit breaker has failed. However, only one breaker can be lost before protection of the lines is compromised. If the tie breaker cannot be used to protect the transferred line, the line has to be protected by a protection element on the source side of the station. This means that the protection will be most likely be on a second or third zone and will therefore be slower.
- The use of three buses leads to an increased foot print. At 400 kV this can lead to larger land requirements. This is the case for most of the substations under consideration.

After a review and analysis of all the data obtained, the breaker-and-a-half scheme was selected for all new 400 kV stations. In this scheme, three circuit breakers are used for controlling two circuits that are connected between two bus bars. Either bus is designed to carry the entire station load in case the other bus is lost due to fault, equipment failure, etc. Fault clearing can occur without affecting the continuity of supply. In addition, the space requirement is less exhaustive and the configuration can be easily expanded.

Selection of Equipment Insulation Levels and Minimum Design Clearances

The insulation levels selected for equipment have a direct impact on substation footprint and determine most clearances including metal-to-metal and safe limits of approach. All equipment to be installed in the substation must be rated to meet or exceed the selected insulation levels. The basic insulation level (BIL) has been determined for each site based on IEC 60071 Parts 1 and 2, and the following factors:

- Rated maximum operating voltage
- Elevation above sea level
- Estimated pollution level.

Design clearances were selected based on the BIL level such that the minimum requirements outlined in standard IEC 61936 Part 1 are met or exceeded. The following table summarizes the insulation levels and clearances selected for all substations located at maximum 1000 m elevation above sea level, assuming a low-to-medium level of pollution.

Table 2.10 Electrical Ratings

Type of Data	Unit	400 kV System	220 kV System	132 kV System
Nominal system voltage	kV rms	400	220	132
Maximum continuous voltage	kV rms	440	242	145.2
Minimum voltage	kV rms	360	198	118.8
Fault level	kA	50	40	40
Fault duration	sec	1	1	1
Number of phases and wires	-	3 ph, 3w	3 ph, 3w	3 ph, 3w
Power frequency	Hz	50	50	50
BIL/full wave threshold	kV peak	1425	1050	650
Substation main bus rating	A	5000	4000	4000
Line rating	A	3000	3000	3000
Auxiliary AC voltage	V ac	415, 3 ph.		
Auxiliary DC voltage	V dc	220, 48		

Table 2.11 Minimum Design Clearances (for All Substations below 1000 m from Sea Level)

Clearance Type	400 kV System (mm)	220 kV System (mm)	132 kV System (mm)
Phase to earth (metal-to-metal)	3000	2100	1300
Phase to phase (metal-to-metal)	4200	2100	1300
Sectional clearance (center-to-center adjacent phases)	6500	5000	4000
Finished grade to live part	7000	5000	4300
Road surface to live part	12000	10000	9000

Three substations are located above 1000 m sea level:

- Likhu Hub (220/132 kV), 1370 m; BIL correction factor calculated per IEC 60071 Part 2, Eq. 11: 1.18; adjusted BIL levels:
    - 220kV: 1300 kV
    - 132kV: 750 kV

Table 2.12 Design Clearances Adjusted to BIL level

Clearance Type	220 kV System (mm)	132 kV System (mm)
Phase to earth (metal-to-metal)	2600	1500
Phase to phase (metal-to-metal)	2600	1500
Sectional clearance (center-to-center adjacent phases)	5000	4000
Finished grade to live part	5000	4300
Road surface to live part	10000	9000

- Tadhekani (220/132 kV), 1100 m; BIL correction factor calculated per IEC 60071 Part 2, Eq. 11: 1.14, adjusted BIL levels:
    - 220kV: 1300 kV
    - 132kV: 750 kV

Table 2.13 Design Clearances Adjusted to BIL level

Clearance Type	220 kV System (mm)	132 kV System (mm)
Phase to earth (metal-to-metal)	2600	1500
Phase to phase (metal-to-metal)	2600	1500
Sectional clearance (center-to-center adjacent phases)	5000	4000
Finished grade to live part	5000	4300
Road surface to live part	10000	9000

- Lapsiphedi (400/220 kV), 1600 m; BIL correction factor calculated per IEC 60071 Part 2, Eq. 11: 1.22; adjusted BIL levels:
    - 400 kV: 1800 kV
    - 220 kV: 1300 kV

Table 2.14 Design Clearances Adjusted to BIL level

Clearance Type	400kV System (mm)	220kV System (mm)
Phase to earth (metal-to-metal)	3700	2600
Phase to phase (metal-to-metal)	4900	2600
Sectional clearance (center-to-center adjacent phases)	6500	5000
Finished grade to live part	7000	5000
Road surface to live part	12000	10000

Substation Layout Design

After the selection of a breaker switching scheme and the establishment of the design basis related to insulation levels and clearances, the next step in the design process was to define the minimum requirements and constraints for each substation. Some significant challenges had to be overcome:

- Available land area for placement of the substation is very constrained at most of the sites. This is due to the geographic location of the substation or existence of adjacent infrastructure/built-up areas. Ideally, substations must be located at sites with relatively flat slopes, no more than 1% to 2%. Site grading represents a significant challenge for larger slopes. To minimize the economic impact in such situations (moving large quantities of native soil, building retaining walls, non-standard structures, etc.), gas-insulated switchgear (GIS) was selected for the following substations:

- New Hetauda
- New Damauli
- Lapsiphedi
- Likhu Hub
- Tadakhani.

Using GIS results in an approximately 60% reduction of the required footprint and more efficient use of limited space available than the air-insulated switchgear (AIS) substations.

- Based on the site visit observations and discussions with NEA managers, existing infrastructure in Nepal is not adequate for transporting very heavy loads, most notably power transformers. A road assessment study was conducted by the site team; it revealed that the size of the transformers should not exceed 160 MVA in the best case locations, based on the 120 metric tons weight limit. Auto-transformer instead of power transformer will be used for 400/220kV and 220/132kV which are of less weight and lower cost than power transformer.

- For some substations, a different mitigating solution had to be used due to inadequate infrastructure. Three single-phase transformer units operated as a parallel bank were required to create the three-phase connections. Even in such circumstances, the bank power is limited to 160 MVA (approx. 55 MVA per single-phase unit) to reduce tank weights. Table 2.15 provides the allowed transformer sizes based on the road study for respective substations. This approach resulted in major design challenges related to the required space:
  - Overall number of transformers had to be increased in order to meet power flow requirements.
  - Three single-phase transformer units operated as a parallel bank require a larger containment footprint than a single three-phase unit of similar MVA rating.
  - Limiting the capacity of the 400 kV stations based on transformer MVA ratings reduces significantly the return on investment. At the detailed design stage, it would be worth investing time in studying the road networks as well as possible upgrades in order to allow the transport of larger equipment.

Table 2.15 Maximum Transformer Size for Each Site

Site	Allowable Transformer
Likhu Hub	55 MVA, single phase transformers
Tadhekani	55 MVA, single phase transformers
Lapsiphedi	55 MVA, single phase transformers
New Damauli	160 MVA, Three phase transformer
Naubise	160 MVA, Three phase transformer
New Butwal	160 MVA, Three phase transformer
New Lamki	160 MVA, Three phase, phase shifter transformer
New Hetauda	160 MVA, Three phase transformer

The following subsections discuss in more detail the design of specific substation systems and components.

Substation Buildings

The following buildings were considered for each new substation:

- A control building housing battery/chargers, AC/DC panels, protection and control panels, office and washroom.
- Switchgear building at substations where GIS switchgear has been specified.
- A storage and maintenance building; spare parts for major equipment are intended to be housed here if they are unsuitable for long-term outdoor storage. Space for water pumps has been allocated in this building as well.
- A guard house.
- The substations will be manned. As such the following amenities are provided:
    - Water treatment building
    - Drinkable water tank
    - Septic tank
    - Living quarters
    - Parking garages
    - Firefighting water tank.

Living Quarters and Parking Garage Space

The parking garage size was obtained from the following drawings provided by NEA:

- CCPG-HDI-CP-CIV-01 OF 02
- CCPG-HDI-CP-CIV-02 OF 02
- CCPG-HDI-CP-STR-01 OF 02
- CCPG-HDI-CP-STR-02 OF 02.

These drawings show a five-car garage with overall dimensions of 28 m x 5 m.

The living quarters sizes were obtained from the bidding documents for the construction of the staff quarters building in Dhalkebar substation (IFB number NIETTP/W/NCB-4.4/DSQB). According to the drawings included with the bid package, a five apartment building has dimensions of 22 m x 8 m.

Given the dimensions above, a 40 m x 40 m fenced area has been provided adjacent to the substations for the construction of living quarters and one garage.

Substation Earthing

Each substation must be provided with a buried ground grid extending up to 1.5 m around the total fence perimeter. The conductors must be of sufficient size to withstand the maximum considered fault currents, as listed in the "Electrical Ratings" table. Due to significant cost impact from material and labor, the amount of earthing material was estimated using the following approach.

The conductor quantities were approximated based on the overall substation footprint and based on reference data available for similar substations. The typical ground potential rise limit at a substation is 3000 V, dependent on grid impedance and available fault current. The grid impedance is inversely proportional to its overall footprint; typically, large substations can easily achieve low impedance due to the ground grid area. Therefore, different mesh sizes were considered based on the overall dimensions of the station. Table 17 presents a breakdown of the different mesh sizes considered for the substations. An allowance of 25% of the total length of buried conductor was considered for above-grade connections to equipment.

The following conductor sizes, per IEC 60228, were considered in the earthing bill of material:

- 300mm^2 CU conductors for the main ground grid and major outdoor equipment connections
- 120 mm^2 for fence earthing and indoor earthing.

Table 2.16 Ground Grid Dimensions Considered

Substation	Size of ground grid mesh (m)
Likhu Hub	6 x 6
New-Hetauda	15 x 15
Lapsiphedi	6 x 6
Naubise	15 x 15
New Damauli	15 x 15
New Butwal	15 x 15
Tadhekani	6 x 6
New Lamki	15 x 15

Bus Selection

The substation layouts were developed considering a mixed use of strain and rigid bus in order to use available space as efficiently as possible. For the air-insulated substations, only a limited amount of rigid bus, mainly used for breaker bay interconnections in the breaker-and-a-half diameters, and around the power transformers, were considered.

Due to limited space and tight clearances, rigid bus conductors were mostly considered for GIS substations.

Rigid bus selection was based on the methods and parameters described in IEEE 605-2008 and ASTM B317/B317-10. As is typical for high-voltage installations, span length and fault currents are the determining factors. Therefore, 6” (152 mm) nominal pipe size (NPS) aluminum tubular bus was selected for the 230 kV system, and 8” (203 mm) NPS bus for the 400 kV system. Bus material will be aluminum alloy typically used in electrical application, code 6101, and temper T6, with rated conductivity of 56% of IACS (International Annealed Copper Standard). This alloy provides an optimal balance between tensile strength and conductivity. Alloy 6061-T6 (40% IACS) may be substituted to allow for maximum rigid bus span lengths. The ampacity rating of these conductors will greatly exceed the 4000A design value of the main bus.

The following conductors were considered for air-insulated substations:

- Main bus (5000A): 2 x 1250 mm^2 ACSR, 76/19 Stranding per phase
- Feeder bus (3000A): 2 x 700 mm^2 ACSR, 76/19 Stranding per phase.

Phase Shifting Transformer

GMR (an IPP) will build a dedicated 400 kV line from Upper Karnali hydropower plant (HPP) of 900 MW capacity for export to India. ‘Free-Power’ of 12% (energy) of the Upper Karnali HPP is to be evacuated by NEA from the Upper Karnali project. In order to evacuate the defined 12% of project capacity and control the power flow, one 132 kV/132 kV, 160 MVA power shifting transformer is required to be installed at New Lamki Substation.

Between Nepal and India’s interconnected power network system (except the proposed power-flow-controlled dedicated tie line T8), there is one existing tie line (1^{st} tie line) between Dhalkebar and Muzzaffarpur . In addition, an XB1 tie line is proposed between New Butwal and Gorakhpur. With these two tie lines between Nepal and India, depending on the system’s condition at the connection point, one tie could run in an energy import mode, and the other tie line could run in an energy export mode. Therefore, a loop flow would be created within these tie lines of the first tie line and XB1. A loop flow within these two tie lines should be avoided. Since India power system data are not available at this time, the loop flow situation cannot be simulated. It is recommended that the loop flow situation within these two tie lines be closely studied in the detailed engineering stage with details from India’s network.

However, in case a loop flow situation occurs within these two tie lines, two solutions should be further investigated for engineering implementation.

- Phase shifting transformer: This is a popular power flow control method between two nodes in an interconnected network. It creates a phase shift between the primary (source) and secondary (load) sides, therefore regulating the load flow within the line.
- Back-to-back HVDC (high voltage direct current): The rectifier (conversion of AC to DC) and inverter (conversion of DC to AC) are located in the same station. Back-to-back HVDC is used:
    - To connect asynchronous high-voltage power systems or systems with different frequencies
    - To stabilize weak AC links
    - To supply more active power where the AC system is already at the limit of its short-circuit capability
    - For grid power-flow control within synchronous AC systems.

Flexible AC transmission system (FACTS) devices: This is a modern trend in power flow control for AC power networks. FACTS devices are installed in AC power systems to increase the power flow transfer capability of the transmission systems and to enhance continuous control over the voltage profile. The ability to control power rapidly can increase stability margins as well as the damping of the power system, to minimize losses, to work within the thermal limits range, etc.

Substation Auxiliary Power Supply

The rating of the stations' service transformer were selected based on transformer sizes typically seen in the region:

- 2 x 630 kVA for 400 kV substations
- 2 x 300 kVA for 200 kV substations
- 2 x 200 kVA for 132 kV substations
- A diesel generator set shall be provided to allow for black starts and to provide backup power when no other sources are available. An 800 kVA generator set has been assumed for all substations. It is assumed sufficient to provide power to all critical loads.

2.3.3 Protection Systems

Electrical protection schemes are intended to promptly, precisely and reliably isolate from service any element of the power system when that element is subjected to an abnormal condition detrimental to its effective operation, while leaving other unaffected elements in service and/or undamaged. The protection schemes are designed so that they do not operate under load conditions or faults external to the relevant zone.

The protection system are designed based on the following:

- The power transformer and transmission line are protected by two protection schemes, identified as Scheme A (Primary) and Scheme B (Backup). Multifunctional, software-based, digital relays shall be specified for this purpose. Relaying for each scheme shall be selected from a different manufacturer to minimize the possibility of common-mode software and hardware failure. Common uses of current and voltage AC inputs shall be minimized.
- Each system is independently capable of detecting and isolating all faults on its respective elements.
- The minimum protection scheme for short transmission lines consists of a pilot wire differential or current differential through fiber optics or directional comparison relays with over-current and earth fault relays as backup.
- The minimum protection scheme for long transmission kV lines consist of one protection distance relay and carrier transfer trip with over-current and earth-fault relays as backup.
- The distance protection scheme should be a permissive under-reaching or blocking scheme with protection zones 2 and 3 delayed trip.
- The distance protection relays are built-in facilities for fault locators, event recorders and disturbance recorders.
- Out-of-step relays have been provided with both primary and backup protection to check the operation of relays due to power swings.
- Each relay line terminal is provided with circuit breaker-failure protection for each circuit breaker.
- Each line terminal breaker includes single-pole tripping and three-pole tripping with single shot auto-reclose.
- If the grid transformer with primary voltage is equal to or greater than 66 kV and is connected to the distribution system, the high and low voltage sides of the transformer are connected in Wye with neutral brought out for earthing.
- Power transformers will be equipped with on-load tap-changers (OLTC) and voltage regulator to enable voltage regulation by varying the transformer ratio under load without interruption.
- Transformers will have winding thermal and oil level monitoring equipment and will be connected to the station RTU/SCADA through fiber optic.
- A differential scheme is to be provided for all sizes of transformers with capacities above 5 MVA with over-current and earth fault as backup.
- Over-current and earth-fault relays are to be provided for all capacity transformers with directional features for parallel transformer operations.
- Restricted earth-fault relays have been provided for all transformers with capacities equal to or higher than 30 MVA.
- Other protection requirements regarding gas-operated relays, and oil and winding temperature protection are to conform to best industry practice.
- Critical features, such as protection operation or circuit breaker operation, are monitored by a disturbance fault recorder.
- The two protection systems are supplied from separate current and voltage transformers.

- Separate blocking switches for inputs and outputs of the protective relays are provided.
- Separate blocking switches for AC current, AC voltage, and DC are provided.
- Separately fused and monitored DC sources are used with the two protection systems.
- Protection system circuitry and physical arrangements are designed to minimize the possibility of incorrect operations from personnel error.
- The protection system is equipped with breaker failure protection to protect the system when the breaker fails to clear the fault. The time needed to clear the fault can be set depending on the maximum permissible fault duration at that location. This can be achieved by using the transfer trip signal transmitted to the remote ends via telecommunication systems if such a facility exists.
- The DC voltage supplied to the tripping coils of the breaker is fed from two separately fused and monitored DC supplies.
- Any signal that opens remote breakers on the transmission system (Tt Signal – if any) can be automatically removed when the main local disconnect switch opens.
- Low-impedance bus protection schemes will be one of the solutions to protecting the double-bus, breaker-and-a-half scheme. These schemes will monitor all currents, as well as the positions of breakers and isolators, and dynamically adjust their zones of protection for optimum selectivity while the bus is being switched. They make it easier to accommodate added generation or expand existing buses because it not necessary to change existing current transformers (CTs) or add slip-on CTs as is sometimes required for high-impedance bus differentials.

2.3.4 Control, Metering, Telecommunication and SCADA

The engineering assessment for substations is based on following design criteria for control, metering, telecommunication and SCADA.

- Telecommunication facilities are installed between the system operator at NEA's load dispatch center (LDC) and the generators, distributors and other users at their respective control centers in order to ensure adequate monitoring and control of the grid and the exchange of information during normal and emergency conditions. Such facilities will also be established between adjacent grid substations.
- The communication and SCADA equipment installed at substations are compatible with those installed by NEA at the remote end of the grid, including the LDC.
- A combination of communication media is used. These could be power line carriers, microwave radio or fiber optics. Base radios, cellular phones and e-mail could serve as backup communication.
- Fiber optical cables, where technically and economically feasible, are the preferred communication media between NEA LDC and substations. Power line carriers or satellite communication will be the communication media, where fiber optics is not practical.
- Two independent voice communication and two data transfer channels are installed, with one serving as backup. These will be used only for operational purposes.

- The remote terminal unit, which provides the NEA LDC with telemetry equipment facilities for monitoring real time data and remote control at the connection point, are installed.
- The substation equipment is to have three levels of control as follows:
    - Local, at the equipment for maintenance – the default position of the normal/ maintenance switch is normal for remote operation from the control building or through SCADA.
    - Remote, from the control panel – the local/remote switch on the control panel is on the "local" position to enable control from the panel. In the "remote" position, the control is remote through SCADA.
    - Remote, from SCADA for breaker reclosing.

The following values and status will be monitored and metered:

- Voltage (phasors, true root mean squared (RMS) values, and symmetrical components), current (phasors, symmetrical components, true RMS values), real, reactive, and apparent power, power factor, demand, energy, and frequency. A separate intelligent electronic device (IED) shall be used for metering purposes.
- The metering point will be located at the connection point; if this is not possible, a procedure should be established to adjust the energy loss between the metering and connection points. The location of the metering point and the procedure for adjusting losses, if necessary, shall be specified in the connection agreement.
- Each power transformer in the grid substation shall have separate metering on the high-voltage side and the low-voltage side.
- The auxiliary consumption of grid substations shall be measured on the primary side of the auxiliary station service transformer. Energy supplied to the office and staff quarters shall be measured separately and not be considered as auxiliary consumption.
- MW and MVAR four quadrant.
- Total harmonic distortion.
- Voltage and current harmonics.
- The meter shall require LAN + SCADA + local access.
- User-programmable oscillography.
- Trip circuit monitoring.
- DC supervision with time delay (100 msec.) on drop-out to prevent nuisance alarms.
- Programmable logic including non-volatile latches.
- VT fuse fail detection: this logic detects one, two, or three blown potential fuses.
- Status of all circuit breakers, disconnect switches, transformer tap positions, ATS position.
- Operating circuit breakers, disconnect switches, ULTC remotely and ATS remote control.
- Control cabinet with control switches, mimic diagram and meters (ION preferred) is provided.
- Annunciation system.
- Equipment to be provided with remote/maintenance switches, when in remote control through the control panel or SCADA, when equipment is under local control.

- Control panel to be provided with local /remote switches for equipment, when in local, control from the control panel, when in remote, and control from SCADA.

The following key assumptions are made for SCADA design:

- The existing communication system supports the additional connection and has spares for single-mode fiber connection available for integrating the new signal from new stations.
- There is an undergoing project by KFW that includes the construction of a new load dispatch center, the installation of telecontrol systems, and the expansion of the related data transfer system in the Nepalese transmission grid. As per recent communication with KFW, the SCADA system which will be installed at LDC will get connected with all the existing 132kV and 66kV station. KFW will ensure connections at LDC ends for connection of future 220kV and 400kV stations. The project is delayed and revised schedule for completion of LDC is last quarter of 2018 now. Since the projects' progress and schedule were delayed few times and possibility of more delays in future, we assumed the existing SCADA system at the LDC will accommodate the new SCADA signal from the new stations. We have included upgrading the existing energy management system (Spectrum Power) and adding new SCADA/RTU (remote telemetry units) panels in the existing LDC to incorporate the new SCADA signal and I/O from the new stations.
- The existing station has spare AC and DC station service circuits that can be used for the new development.
- The control buildings at existing substations have space to house new panels.

2.3.5 Bridge study

After consulting with the concerned transportation officer in Nepal, it has been confirmed that all the bridges along the National highway and feeder road are designed according to the AA Class loading. Class AA loading comprise a track vehicle of 70 tonnes or wheeled vehicle of 40 tonnes to dimension and track/axle spacing. Nose to tail distance between two vehicles is 90m on bridge. The maximum loads for the wheeled vehicle shall be 20 tonnes for a single axle or 40 for bage of 2 axle spaced not more than 1.2 m centers.

Vehicle Dimensions:
The maximum dimensions of vehicles considered for design of roads in Nepal are as follows:
Maximum Width= 2.50 m
Maximum Height= 4.75 m
Maximum Length = 18.00 m
Maximum single axle load= 100 kN (10 ton)

General calculation:

If we require 10 ton per axle then
Total = 120 ton
Required axle = 12
Minimum spacing between axle= 1.2m
Length of the vehicle required = 12*1.2=14.4m
Letting 3m extra for vehicle body allowance= 14.4+3=17.4
This is under permissible limit of length of vehicle i.e. 18m
If we require 20 ton per axle then
Total = 120 ton
Required axle = 6
Minimum spacing between axle= 1.2m
Length of the vehicle required = 6*1.2=7.2m
Letting 3m extra for vehicle body allowance= 7.2+3=10.2
This is under permissible limit of length of vehicle i.e. 18m
Therefore loads upto 120 tonnes can be transported in Nepal.

Also, all station access routes shall be route surveyed by a logistics transporter company for movement of transformer and other construction materials.

2.4 Transmission Lines - Engineering Assessment

2.4.1 Transmission Line Design Criteria

Design Criteria

The transmission line design was provided based on design criteria. The design criteria developed using Nepal Electricity Act 2050, IEC standards, IEEE guidelines, ASTM, BS, CSA, VDE as other standards (such as Indian Standard - IS) were not available. The design criteria outline the general design requirements, with site-specific information for 132 kV, 220 kV and 400 kV transmission lines in Nepal.

The criteria include safety clearances for operating transmission lines, the weather and climatic conditions applicable to areas of all the projects, and load and strength factors of materials. The climatic data applicable to all the transmission line projects have been obtained from various sources such as NEA tender documents, Ministry of Environment, Science and Technology, etc. They include parameters such as temperatures, thickness of snow and/or ice, wind speed, seismic activities, Iso-Keraunic (lightening activity) data, humidity, pollution and altitude above sea level. They also include major and important weather cases, load factors and strength factors for structures, cable tension criteria, insulator swing criteria, equipment and materials including conductors, overhead shield wires and insulators, tower types for the project, and electrical vertical and horizontal external clearances.

Paying attention to corona phenomenon in design of 400 kV transmission lines is important otherwise corona losses, electrical field intensity at the edge or outside the right-of-way and radio and television interference can become an issue. Corona in EHV transmission lines is a parameter of size of conductor and sharpness of its surface curve, conductor surface smoothness, conductor age, transmission line area elevation, humidity and precipitation. In MCC compact 400 kV transmission line designs we have utilized a four bundle phase conductor which gives a proper conductor diameter to the design and we have avoided high altitudes (above 2,000 m). Comprehensive corona calculations shall be conducted in detail design stage to insure that the corona of 400 kV transmission lines are in acceptable range. In case any action required there are available solutions to mitigate the corona. The most effective solution in terms of technical and economic aspects is increasing the bundle spacing which is associated with very low cost which won’t affect the feasibility of the project.

Design Codes and Regulations

The design of 132 kV, 220 kV and 400 kV transmission lines is based on both a deterministic approach and a reliability approach. In the deterministic approach, the various clearances from transmission line conductors to different features like traffic roads, pedestrian roads, railways, farms, etc. are referenced from the Nepal Electricity Act. Indian Electricity Rules (IE) and IS have been used for the cases not covered by the Nepal Electricity Act. Further, some deterministic approaches that were not found in the abovementioned sources were adopted from CSA C22.3 No. 1. The reliability approach was adopted as per IEC 60826, while each locality will use climate information specific to its area. The conditions outlined in the deterministic approach are minimum design requirements for transmission line design, and the reliability approach outlines additional extreme weather conditions and design requirements for the line.

In addition to these references, some other design codes and regulations have been followed for the design of transmission lines. For details of design criteria, refer to Annex D.

2.4.2 Equipment and Material Selection

Selection of Phase Conductors

The phase conductors were selected based on the ampacity calculations per IEEE 738. The continuous thermal ratings for single conductors have been calculated under project-specific operating conditions and total line thermal ratings have been calculated.

Ampacity calculation is to verify conductor sufficiency for the target loads. However, it appears that the load of NR1 lines are considerable lower than target loads in year 2030. However, by considering transmission line life expectancy we concluded that even by considering the above fact, it is not recommendable to change NR1 line conductors to a smaller sizes.

NR1 T-Line name	Target	2030		2033		2043		2053		2063		2073	
	MVA	MVA	%	MVA	%	MVA	%	MVA	%	MVA	%	MVA	%
New Hetauda-Naubise	2177.53	371.97	17.08%	443.02	20.35%	793.39	36.44%	1420.83	65.25%	2544.49	116.85%	4556.80	209.26%
Lapsiphedi-Naubise	2177.53	456.2	20.95%	543.34	24.95%	973.04	44.69%	1742.57	80.03%	3120.68	143.31%	5588.66	256.65%
Naubise-New Damauli	2177.53	543.1	24.94%	646.84	29.71%	1158.39	53.20%	2074.51	95.27%	3715.12	170.61%	6653.22	305.54%
New Damauli-New Butwal	2177.53	781.99	35.91%	931.36	42.77%	1667.93	76.60%	2987.01	137.17%	5349.27	245.66%	9579.73	439.94%

Annex D specifies the selected conductors for each transmission line.

Selection of Overhead Optical Ground Wire (OHGW)

Optical ground wire (OPGW) is designed to replace traditional overhead shield ground wires on the transmission lines with the added benefits of containing optical fibers that can be used for telecommunications purposes. OPGW, while providing electrical protection to transmission line conductors by its steel wires, operates as the foundation for communication systems. OPGW has the advantage of large capacity and high speed fiber optic wires laid over the long-distance transmission lines. Hence, OPGW was considered for all transmission lines of this compact.

OPGW short-circuit capacity remains to be checked against the output of the PSS®E calculation on 132 kV, 220 kV and 400 kV transmission lines at this time. The following parameters were considered for the selection of OPGW type:

- Cable tensile strength
- Sag characteristics
- NEA's common practice.

For transmission line towers carrying two overhead ground wires, OHGW have been selected for the second wire. For detailed specifications of selected OPGW and OHGW, refer to Annex D.

Selection of Insulators

Composite-type insulators were selected for 132 kV and 220 kV transmission lines, and porcelain or glass (ball and socket) type insulators were selected for 400 kV transmission lines. The electrical and mechanical properties for selected 132 kV, 220 kV and 400 kV insulators are specified Annex D.

The composite-type insulators are in the shape of fiber-reinforced rods that are used as insulator cores and carry the mechanical loads. There are many advantages to these type of insulators:

- Low weight
- High mechanical strength
- Low maintenance requirements
- Shorter length allowing electrical clearances to be met easier
- Easy to transport and store.

These types of insulators are less pollution absorbent due to the hydrophobicity property of the silicone rubber material. Thus, they are generally preferred in polluted areas (such as in coastal areas and in proximity to industrial areas such as cement factories). Also, these types of insulators are more or less not vulnerable to vandalism (such as shooting, stone throws, etc.).

On the negative side, the composite insulator’s performance is compromised at extra-high voltage transmission lines. In those transmission lines, one of the mechanical failure modes of the insulators is a failure process called brittle fracture, which is caused by stress-corrosion cracking of glass-reinforced polymer rods. This causes the rapid aging of insulators and hence the traditional cap and pin insulators are still the most favorable in transmission voltages above 230 kV.

Cap and pin type insulators attach to each other, forming an insulator string by inserting the ball of one unit in the socket of the next unit and securing the connection with a locking key. The advantage of using these types of insulators is that the insulator strings can form by using different numbers of basic units and also if one unit in the string breaks, it can be replaced without discarding the entire string. Another advantage of cap and pin insulators that is beneficial in hilly and mountainous areas is their relatively higher weight in comparison to composite insulators. This additional weight increases the vertical load on the tower and can cancel or alleviate insufficient weight spans.

Selection of Towers

Due to the cost and huge length of the lines, the best option is to use self-supporting lattice type galvanized steel frame tower structures for 132 kV, 220 kV and 400 kV transmission lines. However, in some urban areas or congested residential areas, compact design steel poles can be used.

The following types of towers have been used in 132 kV, 220 kV and 400 kV transmission lines. For more details and tower drawings refer to Annex D.

- **Suspension Towers**

These towers are used in lines for straight-run or minor angle deviations of up to 2 degrees. These type of towers are called “DA-type” for double-circuit line. The conductors on these types of towers are supported by suspension (passing through) clamps. Suspension towers can be designed to take larger angles (up to 10-15 degrees). These suspension towers are called running angle/corner towers.

- **Angle/Tension Towers**
  These towers are used at locations where the deviation angle exceeds 2 or 3 degrees or where the towers are subjected to uplift loads. These towers are further classified as small angle towers for deviation angles of 2 or 3 to 15 degrees (called B/DB), medium angle towers for deviation angles of 15 – 30 degrees (called C/DC), and large angle towers for deviation angles of 30 to 60 degrees or in some tower family designs, 90 degrees (called D/DD). The conductors on these type of towers are supported by tension (dead end) clamps.

- **Dead End Towers**
  Dead-end towers (D/DD/DE) are used at line termination points and can hold a deviation angle of about 30 to 60 degrees. They are also used as anti-cascading towers, which are used at certain intervals in line routes to prevent the propagation of a failure.

Preparation of PLS-CADD and Terrain Model

The transmission line models were prepared using PLS-CADD software. It puts together all the data and algorithms necessary for the layout and structural design of a transmission line. This software supports transmission line design activities from line routing to developing construction documents and drawings.

Transmission line designers create a three-dimensional model (including terrain data and technical information on transmission line components (structures, wires and conductors, etc.) and use this model to develop the line design. Transmission lines in this environment are designed using interactive graphics and optimum spotting or sagging algorithms.

This software utilizes different program modules in order to analyze and assist with the design and fine-tune of routing and structures (including lattice towers and poles of different materials), conducting various calculations such as sag and tension and structure spotting, and the production of construction documents (such as plan and profile drawings, staking tables, stringing charts and bills of material).

Importing routing output into PLS-CADD and providing digital terrain model. The optimal corridors were identified and imported in PLS-CADD. The file that was imported contained topographical data (geo-referenced X, Y, Z data of the ground points in the form of Auto-Cad, Excel sheet or ASCII file). This file needed to include feature codes (in detailed design when the survey data come from a LiDAR survey or detailed land survey, feature codes will have to be included in the survey data). However, since detailed survey work is not intended to be conducted for feasibility-level design, the survey data did not include feature codes in order to label broad categories of terrain or obstacle points that have unique requirements together with obstacles elevation data. These requirements include minimum code clearances to be met above or to the side of the points as well as symbols to be used to display these points on the screen or final drawings. This three-dimensional labeled model will be the transmission line corridors of the three-dimensional terrain model.

Fine-tuning of the line route in a given corridor. The fine tuning of the transmission line route in an optimal corridor or in the presence of multi-criteria, the centerline is selected by locating the points of inflection (PIs) in the corridor or slightly moving the PIs to improve line routes from a technical perspective without compromising the environmental, social or resettlement criteria. Critical PIs are assumed to be fixed and other PIs have been slightly changed in order to moderate sharp angles, steep slopes and inefficient line sections. This determines the transmission line's exact route and its centerline. Inserting PIs in a given corridor can be done manually or automatically. The automatic positioning of PIs requires review and verification, and manual fine tuning. Here, PIs were manually positioned due to the quality of feasibility-level survey data.

Tower Locations. After the centerline of the transmission lines is finalized, tower spotting is carried out. The intermediate (suspension/tangent) structures are spotted in the line route based on the line design criteria. The plan and profile drawings in Annex D provide the locations of all the towers along the transmission lines.

Access Roads for Transmission Line and Towers. The transmission line routes were selected to be as close as possible to roads and highways. However, if the route is far from the roads and highways, line material will be carried to tower locations by other means than dedicated access roads. The traditional way of transporting construction material, wherever access road is not available, is hiring porters and/or utilizing animals. This method can be used by construction contractors for line projects. As a result no access road needs to be considered for transmission line projects.

Right of Way

The right of way corridor is a particular parcel of land that should be kept clear so to ensure the safety of people and their properties. It is also used to allow access to transmission lines for routine maintenance work.

As per the Nepal Electricity Act, standard right of way widths for transmission lines are 18 m, 30 m and 46 m for 132 kV, 220 kV and 400 kV transmission lines, respectively.

It should be mentioned that right of way is not a constant value throughout the line route. It is recommended that the right of way be calculated for each line section based on the actual sag of conductors, width of tower cross arms, swing of insulator strings, conductors and safety clearance between conductors, and adjacent objects at the detailed design stage.

Based on the discussion with NEA officers in the Project and Planning Department, the standard right of way widths in Nepal are as follows:

- 400 kV double circuit line = 46.00 meters
- 220 kV double circuit line = 36.00 meters
- 132 kV double circuit line = 27.00 meters.

However, Nepal's regulatory bodies have decided to decrease the right of ways to the values below and NEA has recently adopted these widths for many projects. For this assessment, the following right of way was used:

- 400 kV double circuit line = 46.00 meters (no change)
- 220 kV double circuit line = 30.00 meters
- 132 kV double circuit line = 18.00 meters.

Preparation of Plan and Profile Drawings

After the PLS-CADD model was completed and thoroughly checked for errors and defaults, the plan and profile drawings were prepared for all transmission lines. These drawings show transmission line routes with aerial imagery and profile views showing structures, conductors and OPGWs with required ground clearance.

Preparation of Bills of Material

Bills of material (BOM) for all transmission lines have been prepared and presented using the cost estimate documents.

Assessment of Nepal's Existing Transmission Infrastructure

Although there are no 400 kV transmission line in Nepal, there are some transmission lines built to 400 kV design, and double circuit towers have been used for these lines. These towers have vertical configuration and two overhead ground wires: galvanized steel on one side and OPGW on the other side. The conductors are of ACSR type, which are commonly used in transmission lines around the world.

The 220 kV transmission lines consist of double circuit towers with vertical configuration and single ground wires, either galvanized steel or OPGW cables and ACSR conductors.

Similar to 220 kV lines, the 132 kV lines have towers with vertical configuration and single ground wires, either galvanized steel or OPGW cables and ACSR conductors.

Structural Design

The sample tower and foundation drawings received for existing transmission lines were used to estimate the required steel weight and cost of the tower. Similarly, foundations from similar transmission lines in the region were used to calculate the expected material quantities for the transmission line foundations. Based on the examples available, six different soil conditions are considered for the 400 kV transmission lines.

- Normal Dry Soil
- Normal Wet Soil
- Fully Submerged
- Wet Black Cotton
- Soft Fissured Rock
- Hard Rock

Further information on soil type and soil characteristics can be found in Geo Technical Reports (Annex E)

For the 220 kV and 132 kV transmission lines, four different soil conditions were considered based on the examples available:

- Dense Sand or Stiff Clay (Type I)
- Medium Sand or Medium Clay (Type II)
- Loose Sand or Soft Clay (Type III)
- Hard Rock.

Assumptions were made with respect to the anticipated types of soil along the transmission line routes; although a limited number of boreholes were drilled along the route of most transmission lines, these assumptions must be validated based on more thorough soil investigation work at the detailed design stage. As the number of boreholes drilled along the transmission line was not sufficient to provide reliable, consistent data, each of the soil types was given an expected frequency of occurrence based on the past experience of NEA staff. The assumed frequencies are:

Transmission line towers in hilly terrain:
- Hard rock: 40%,
- Submerged fissured rock: 40%,
- Normal dry soil 10%,
- Submerged loose soil: 10%

Transmission line towers in plain terrain:
- Normal dry soil: 35%,
- Normal wet soil: 10%,
- Submerged fissured rock: 30%
- Hard rock: 5%

- Wet black cotton soil: 20%.

Transmission line towers near river beds:
- Wet black cotton soil 70%,
- Normal dry soil: 10%,
- Normal wet Soil: 10%
- Submerged fissured rock: 10%

The above methodology provided the basis for calculating the expected material requirements for the transmission lines. However, it must be understood that there is a very high degree of uncertainty pertaining to the material required for the foundations. The actual conditions in the field may be drastically different than what is assumed for this report and could add significant costs to the foundations for the project. Contingency factors have been applied for this uncertainty as outlined in the risk section.

The risks below may result in increased foundation sizes and subsequent higher cost for the transmission lines:
- Poor soil that would increase the size of the foundation footing.
- Poor soil that would not support shallow foundations. Design may need to be changed to a deep foundation, such as a helical pile foundation.
- Sound bearing strata is deeper than expected, increasing the depth of footing or using piles to reach the sound bearing strata.

A higher water table than anticipated and/or poor soil requiring the side slope of excavations to be decreased and increasing the volume of excavation/fill required for the foundations.

2.4.3 Transmission Line Route Selection

Transmission Line Routing Approach
For transmission line routing, multi-criteria routing was used for all transmission lines and a Linear Routing Tool (LRT) approach. The initial intent was to apply the LRT approach to all line routing; however, the routes were later selected based on a combination of the multi-criteria approach as well as the use of (LRT) models. For optimal line routing, consideration was given to social, environmental, economic and engineering factors.

The LRT approach was applied at full scale to NR1 transmission lines. The outputs of the LRT model were used in multi-criteria meetings and the required minor adjustments were applied to the suggested routes. The multi-criteria meetings were attended by the task 1, 2 and 3 leaders, key members and local professionals. Center lines were developed for each line corridor and the *.XYZ files as well as the aerial images provided. The *.XYZ files were imported in PLS-CADD in order to develop a PLS model for each line. Additional improvements were made on the PLS-CADD model to complete the transmission routing selection process. Tower spotting was then carried out on these models. The outputs of this exercise – plan and profile drawings – are shown in Annex D. For all other lines in this project we used multi-criteria routing method to identify the centerline.

We proposed up to 3 alternative line routes for different lines (except for NR4 & T8) in this project. The first alternative was due diligence proposed route, second alternative for NR1 was LRT based route and for NR3 one alternative route was beside the river and another through the forest. The alternate line route we have selected in the design is the most cost effective and having the least historical challenges (which are minimum impact on the properties and natural resources).

Volume 2 of this report presents the details of routing using the LRT approach.

Multi-criteria and Participatory Line Routing

The following criteria/considerations were applied to transmission line routing at all stages of the selection process:

- The route alignments, as far as practicable, were kept straight and short.
- Location of the angle points were approximated in order to determine the requirements for angle/tension tower.
- Angles were kept as small as possible to avoid sharp direction changes.
- The route between one angle point to the adjacent angle point were appropriate with regards to longitudinal and transversal slopes, and have an acceptable side profile.
- The route between angle points passes, as much as possible, through the land that is the easiest and least expensive to acquire.
- The section lengths (distance between two consecutive angle points) were maintained as close as possible to a multiplier of transmission line ruling span.
- The line sections avoid the following as far as possible:
  - Buildings and dense settlements
  - Conservation areas, national parks and environmentally sensitive areas (wildlife habitat)
  - Rivers and water bodies
  - Traffic roads and highways
  - Deep valleys, which may require extra-long spans
  - Heavy forest areas or expensive land for rights of way
  - Swampy areas
  - Highly productive land and difficult terrain
- If crossing existing transmission lines, roads, railways, rivers, etc. is unavoidable, then the crossing was kept as close to a right angle as possible.
- Proximity to access roads for construction, operation and maintenance work.
- Towers were located on geologically stable ground.

The figures below show the final transmission line routes selected.

Figure 2.9 NR1- Naubise to Lapsiphedi 400 kV Transmission Line

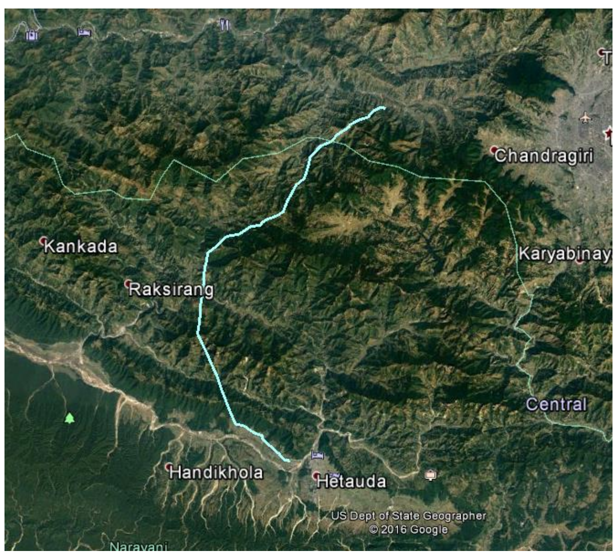


Figure 2.10 NR1 - Naubise to New Hetauda 400 kV Transmission Line

The final route for the Naubise to New Hetauda line deviates from both NEA's (which was developed further by WSP) and LRT practices. The final line route was moved to the west in order to avoid high elevation areas (2200 – 2300 m). The new route's elevation is in the range of 1500 – 1600 m. This is an important factor, especially for 400 kV lines, to minimize corona losses. The new line route was suggested in the helicopter site visits with OMCN and MCC representatives, and was studied further in multi-criteria line routing selection sessions.

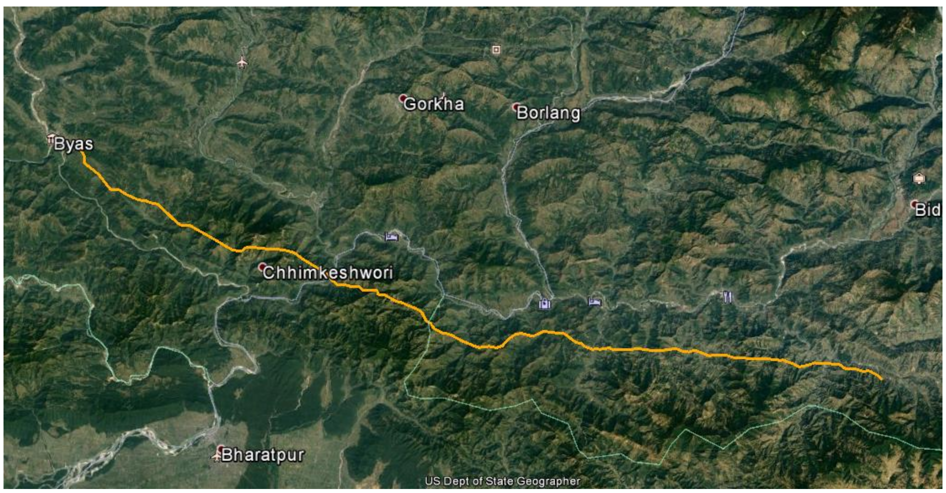


Figure 2.11 NR1 - Naubise to New Damauli 400 kV Transmission Line

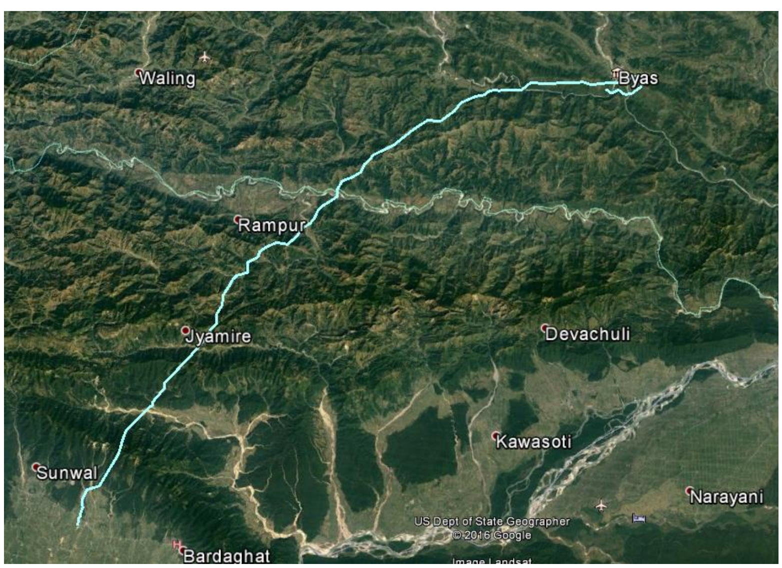


Figure 2.12 NR1 - New Damauli to New Butwal 400 kV Transmission Line

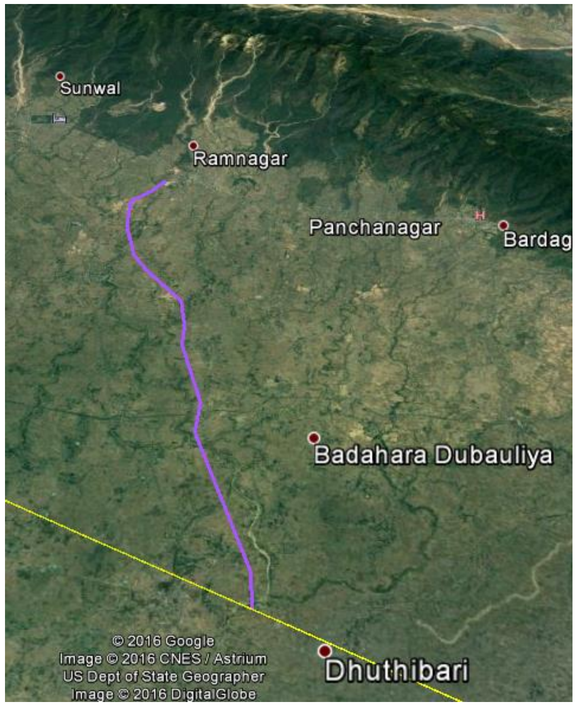


Figure 2.13 XB1 - New Butwal to Nepal/India border 400 kV Transmission Line

The XB1 line is routed from New Butwal substation to Rampuruwa Maheshpur (near the Nepal/India border, N 27, 25, 57 E 83, 42, 28.6) based on the recommendation for MCC/OMCN.

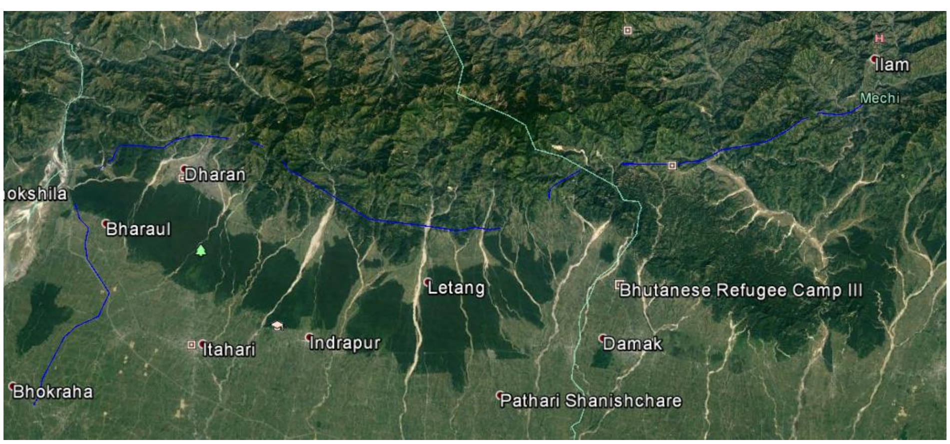


Figure 2.14 NR3 - Ilam to Inaruwa 132 kV Transmission Line

Figure 2.15 T8 New Lamki to Nepal/India border 400 kV Transmission Line

This line follows the same route as the GMR line with small modifications in order to avoid houses as much as possible.

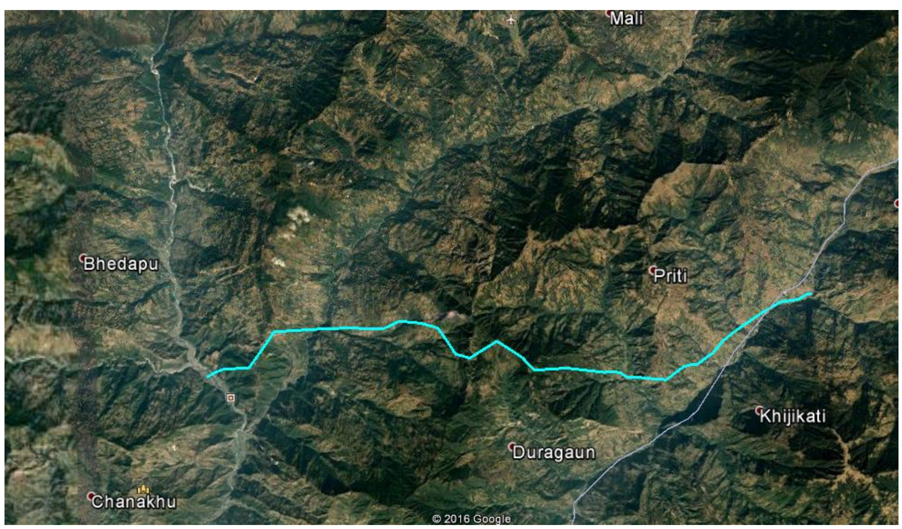


Figure 2.16 T2' - 220 kV Transmission Line from Likhu Hub to New Khimti:

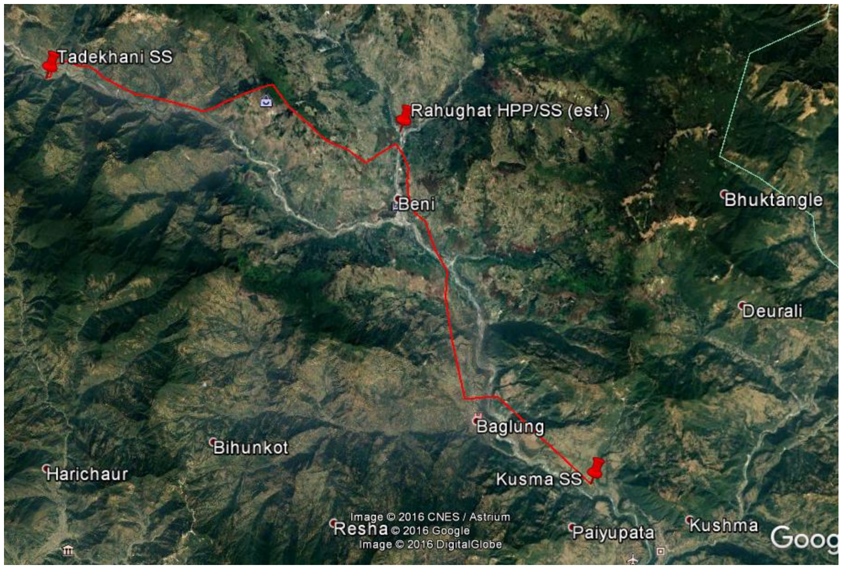


Figure 2.17 T3 – 220 kV Transmission Line from Tadhekani to Kusma

2.5 Geotechnical Investigation

The objectives of the exploration work for this assignment were to determine the foundation types and their safe bearing capacities while considering the soil strata. Here, a short geotechnical investigation program on soil parameters and strata is considered to determine the safety of newly constructed 132 kV tower foundations along the transmission line corridor.

2.5.1 General Geology and Geomorphology

The sites are located in the mountainous region of the middle part of Nepal, which is part of the Lesser Himalayan Crystalline Group. The geological formation of the Group is igneous rocks, which contain mainly Precambrian and probably Paleozoic formations with Augn, Gneisses and two Mica Granites mainly in the Kuncha Group, with some in the Nawakot Group.

The project site is in a hilly area formed by residual and alluvial soil deposits with sandy gravels, pebbles, cobbles and boulders, rock fragments with fines and rock mass in their textures around the vicinity of the sites. The deposits are medium to very dense/hard in state. Moreover, the foundation structure on these soil layers would be comparatively economical.

The data on epicenters and magnitude of the historical earthquakes show that Nepal is located in high-hazard seismic zones. The substation and transmission line assessment has considered this criteria during detail feasibility study.

2.5.2 Methodology

Field Work Procedures

At the time of investigation, a team of experts and workers with a helical hand auger, wash boring, percussion drilling sets and other necessary equipment were mobilized to the site to make 150 mm diameter boreholes, sampling and in-situ testing (e.g., Standard Penetration Tests (SPT) and Dynamic Cone Penetration Tests (DCPT)).

Initially, the bore holes were advanced by auguring, wash boring, pit excavation, percussion drilling and rotary drilling up to the required depths. Where applicable, SPTs and DCPTs were carried out at an interval of 1.0 m up to required depth of investigation. These values will be presented in the borehole logs (Annex E).

Method of Drilling
The borehole locations were drilled using the following methods:

- **Auger Boring Method**
  This method is generally used in soft to stiff cohesive soils and semi cohesion less sandy soils above the water table. A helical auger is used for boring and retrieving disturbed samples from sub surface layers following the IS: 1498 Method
- **Wash Boring Method**
  This system was developed for clayey and sandy soils only. Here, a boring pipe is driven manually with water or bentonite slurry up to the required depth and the SPT values are recorded. The retrieved disturbed samples are collected and preserved for identification and required laboratory tests.
- **Pit Excavation**
  Pit excavation is used when the soil layers are medium to dense sandy or gravelly layers with cobbles, pebbles, small to medium size boulders, and weathered to fissured rock mass. Then, the pit excavation method is widely used for digging and sampling of sub-surface layers while conducting SPT/DCPT observations. Pit excavation should proceed by digging soil strata with the help of mechanical tools such as shovels, picks, chisels, crow bars and hammers up to the proposed foundation depth (≅ 3.5m) and then DCPT tests will be carried out in the lower depths.
- **Percussion Drilling Method**
  This method is carried out using heavy chisel bits and bailers with casing. A heavy chisel bit is used to chop the clayey to gravelly soil layers having pebbles to cobbles. The soil samples could be retrieved from bailers and SPT tubes.
- **Rotary Drilling Method**
  This method is employed by rotating the bit fixed at the lower end of the drill rod (i.e., barrel) with drilling fluid, water or Bentonite slurry. The total weight of the rotary machine and its accessories would be 3000 to 4000 kg. The transport, shifting and handling of the equipment is quite difficult. When water courses, streams, rivers, etc. cannot be found in hilly and jungle areas to produce the continuous flow of water needed for drilling works, this method is uneconomical and not generally used in Nepal. However, this method could be adopted in the project area where fissured and hard rocks are encountered.

Field Tests
The field tests were conducted using two methods:

***Standard Penetration Tests (SPT)*:** This consists of driving a split spoon sampler with an outside diameter of 50 mm into the soil at the bottom of boreholes or pits. Driving is accomplished by dropping a hammer weighing 63.5 kg from a height of 750 mm onto the drive head. First, the spoon is driven 150 mm into the soil at the bottom of the boreholes/pits. It is then driven another 300 mm and the number of blows (N values) required to drive this distance are recorded.

Dynamic Cone Penetration Test (DCPT): This consists of using a hammer to drive a cone into the soil. The number of blows needed to drive the cone a specified distance is the measurement of the dynamic cone resistance.

A DCPT is performed using a 50.0 mm cone. The driving energy is given by a 63.5 kg hammer falling freely from a height of 750.0 mm onto the drive head. It is then driven 300 mm and the number of blows (DCP_{rec} values) required to drive this distance is recorded.

The dynamic cone resistance value is converted into the SPT value and used for the analysis of bearing capacity.

Sampling
Samples from the field can be retrieved in two ways as per soil profiles:

Disturbed Samples. Before any sample is taken, the boreholes/pits should be clear of loose disturbed soil deposited during boring/excavation operations. The samples obtained by auguring/drilling or pit excavation and SPT tubes are collected as representative disturbed samples for determining physical and engineering properties. The samples thus obtained must be placed in airtight double plastic bags, labeled properly for identification, and transported to the laboratory for analysis.

Undisturbed Sample. Here, soils are extracted by a thin wall tube (Shelby Tube) that is used to determine strength and compressibility characteristics. The tube is pushed into the subsurface layers and the sample is recovered mechanically. The tube is then sealed with wax and wrapped with airtight polythene sheets, and then bound by adhesive tape and labeled. The tube is properly packed and transported to the laboratory.

Laboratory Tests
The following laboratory tests shall be conducted for the retrieved soil samples to obtain the physical and strength properties of the sub soil, as per IS & ASTM standards:

- ***Grain Size Distribution Analysis.*** Grain size distribution is determined by wet and dry mechanical processes. Sieve analysis is carried out by sieving a soil sample through a set of sieves, with the largest at the top and the smallest at the bottom. The soil retained in each sieve is weighed and expressed as a percentage of the weight of the sample (see Annex D).
- ***Atterberg's Limit***. Liquid limits and plastic limits are determined on fine grained soils using standard methods. Casagrande's Plasticity Chart is used to classify the fine grained soil according to the Unified Soil Classification System.
- ***Natural Moisture Contents, Bulk & Dry Density.*** The natural water content and bulk density are determined from samples recovered through a split spoon sampler or barrels and the corrected SPT values.

- ***Specific Gravity Tests***. The specific gravity test is conducted on soil samples that pass through a 200 mm sieve. The density bottle method is widely used in laboratory tests for determining the specific gravity value.
- ***Direct Shear Tests***. Direct shear tests are conducted on representative disturbed samples collected from boreholes. The samples are carefully molded to have almost the same moisture contents using standard molds of 6.0 x 6.0 cm^2 cross-sectional areas and trimmed to 2.5 cm high. Solid metal plates are placed on both surfaces of the samples to prevent the dissipation of pore water during shearing. The direct shear test equipment is mechanically operated and shearing should be applied at a more or less constant strain rate. The samples are to be sheared at three different normal stress levels. The test results are presented in terms of the failure of envelops to obtain the angle of internal friction and the cohesion intercepts.
- ***Consolidation Tests***. These tests are performed on disturbed samples of 75 mm diameter and 22 mm height as per laboratory requirements. Two-way drainages are provided and each increment of load must be maintained for a sufficient period before primary consolidation is reached.

Soil Types

After drilling or excavation, the retrieved soil samples can be found in different states in in-situ soil layers. The general soil types as per their in-situ states are:

- Normal dry soil
- Wet soil
- Fully submerged soil
- Sandy soil
- Dry fissured rock
- Wet fissured rock
- Submerged fissured rock
- Hard rock

Site Description

The site description facilitates the categorization of different types of tower foundations following the crude estimation of:

- Types of land
- Types of landscape
- Size of soil grains
- Rate of permeability
- Possibility of water courses nearer to the site location
- Probability of raising water table

Further, all the site locations will be explored as per site description following the above points.

Bearing Capacity

The allowable safe bearing capacity, considering permissible settlement, is proposed in Annex E.

Type and Depth of Foundation

The type of foundation depends on types of soil, subsoil water level, and presence of surface water as per the technical specifications:

- Normal dry/ wet soil foundation
- Fully submerged foundation
- Dry fissured rock foundation
- Wet fissured rock foundation
- Hard rock foundation

Different depths of foundation should be proposed from the original ground level. The bearing capacity of soil at the boreholes for those depths is calculated as the square, mat or pile foundation as per requirements. Generally, the technical specification recommended is to rest tower legs at 3.0 to 4.0 m depth (≅ 3.5m) from ground level.

Recommendations

The following procedures are recommended for the project site locations:

- Soft to very stiff cohesive soils, sandy soils, and silty soil layers should be drilled by auger and wash boring systems, and the samples retrieved and field observations made at required intervals.
- In sandy soils, gravelly sands, silty sands with fine gravels, and pebbles, the percussion drilling method should be adopted if the location is accessible and lies in flat terrain.
- For soils having sandy gravels with pebbles, cobbles, and small to medium size boulders, pit excavation should be carried out up to the required depth of foundation level and SPT/DCPT tests should be taken to determine the allowable bearing capacity values.
- The rotary drilling method is not quite feasible for the soil investigation of tower foundations, but could be done at some locations where its requirements will be fulfilled.
- There should be borehole testing for every 5 to 7 KM of Transmission line and 3 boreholes / stations for detail design phase.

2.5.3 Depth of Investigation

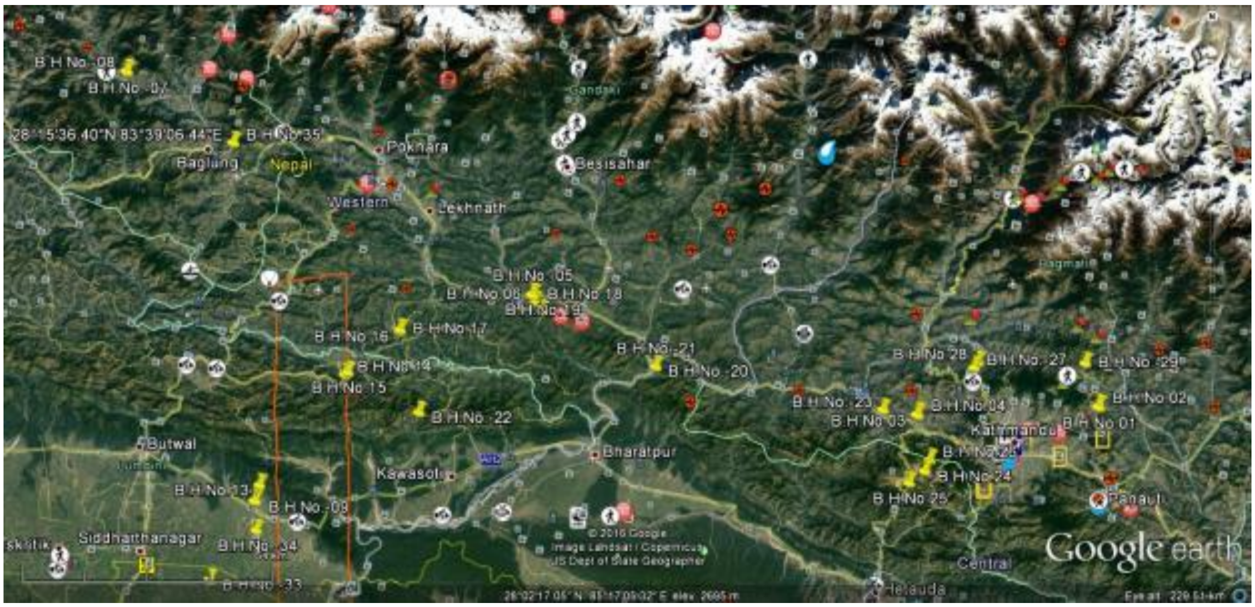
The required depth of investigation depends on many factors, including the type of structure and the associated magnitude of the loading, the subsurface conditions and their variability, the depth of planned excavation, and the types of foundations to be constructed.

In regards to the foundation loading, if a building will be founded on spread footing foundations, the general practice is to investigate to a depth below the planned founding level equal to at least 2 to 3 times the footing width (noting however that the founding level and/or footing widths are not always known at the time of investigation). If however weaker or compressible strata could exist at greater than this depth (such as is often the case in the sensitive marine Champlain Sea clays) and could compress under the loading from foundations or the weight of site grading fill and lead to foundation settlements, then greater depth of investigation is required. The investigation should extend to at least sufficient depth to investigate the most compressible (i.e., softest) portions of the deposit (which are generally the upper few meters of the un-weathered clay, below the weathered surficial crust). If the grade on a site will be raised (i.e., if underslab and/or landscaping fills will be placed on the site), the additional loading will increase the stress level in the underlying clay over a significant depth. In this case, the investigation should extend to sufficient depth to show that the *preconsolidation pressure* of the deposit is in excess of the final stress level that will be achieved.

Where deep foundations (such as piles or caissons) may be required, the investigation should extend at least to the bedrock surface.

Where a site is to be developed with a building and is underlain by generally cohesionless (granular/sandy) soil, which extends below the groundwater level, the depth of investigation should be sufficient to address the potential for seismic liquefaction.

Figure 2.5.3


Baglung
Pokhara
Besisahar
Western
Lekhnath
Butwal
Bharatpur
Kawasoti
Siddharthanagar
Kathmandu
Panauti
Central
Hetauda
Google earth

2.5.4 Complete Profile of Soil Investigation

Transmission Line Photograph

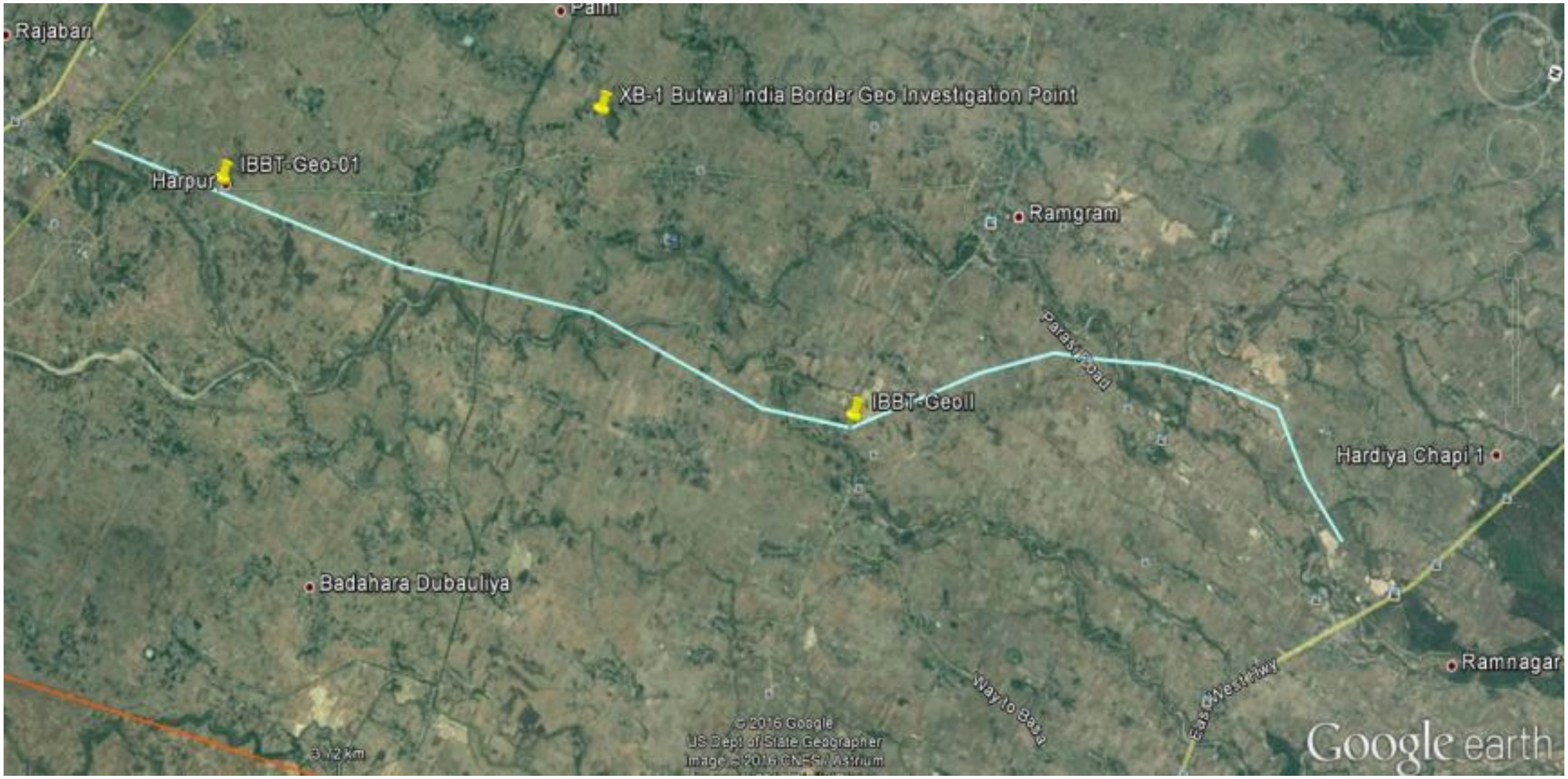


Figure 2.5.4 : New Butwal – India Border Transmission Line

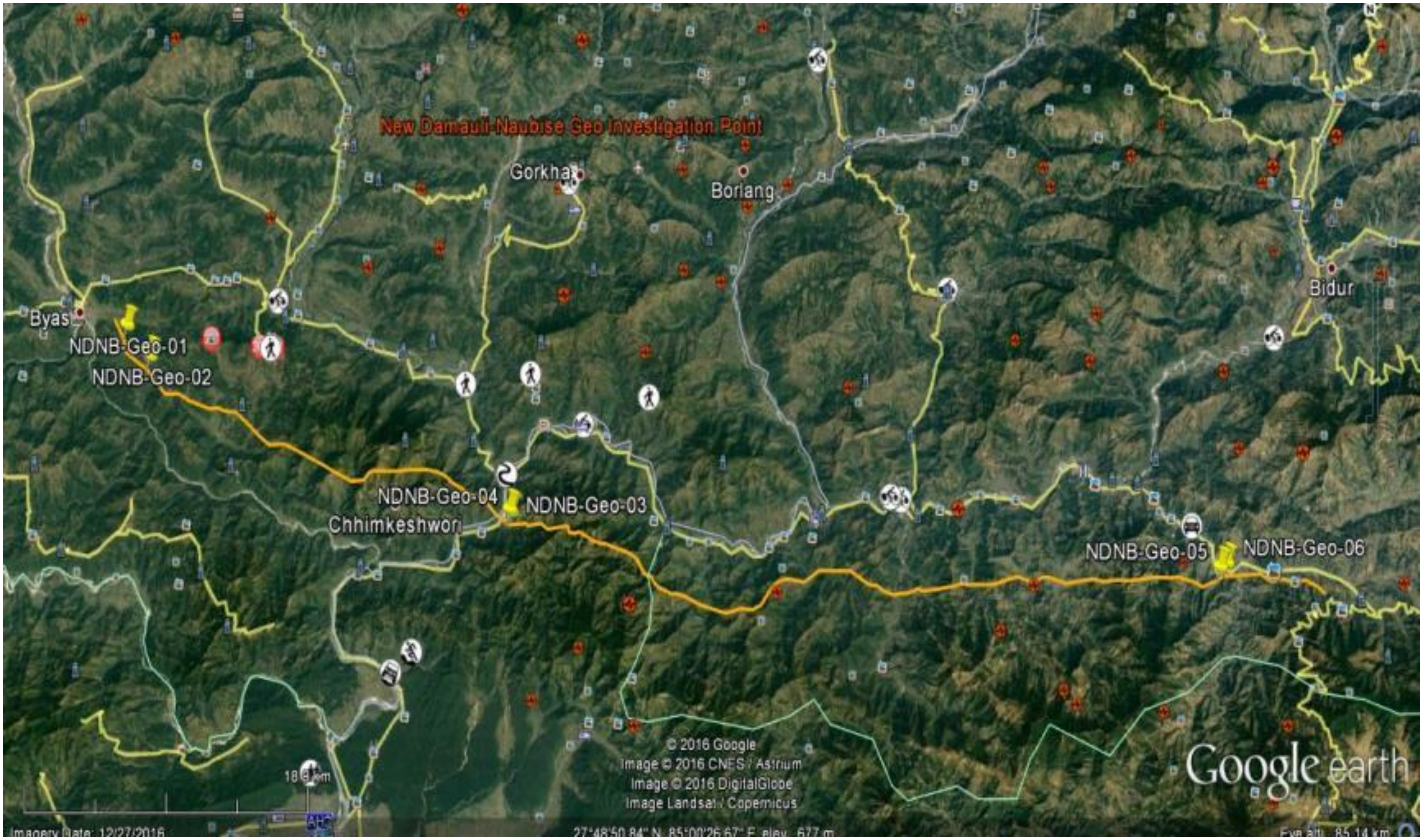


Figure 2.5.4.1 : New Damauli – Naubise Transmission Line (Complete View)

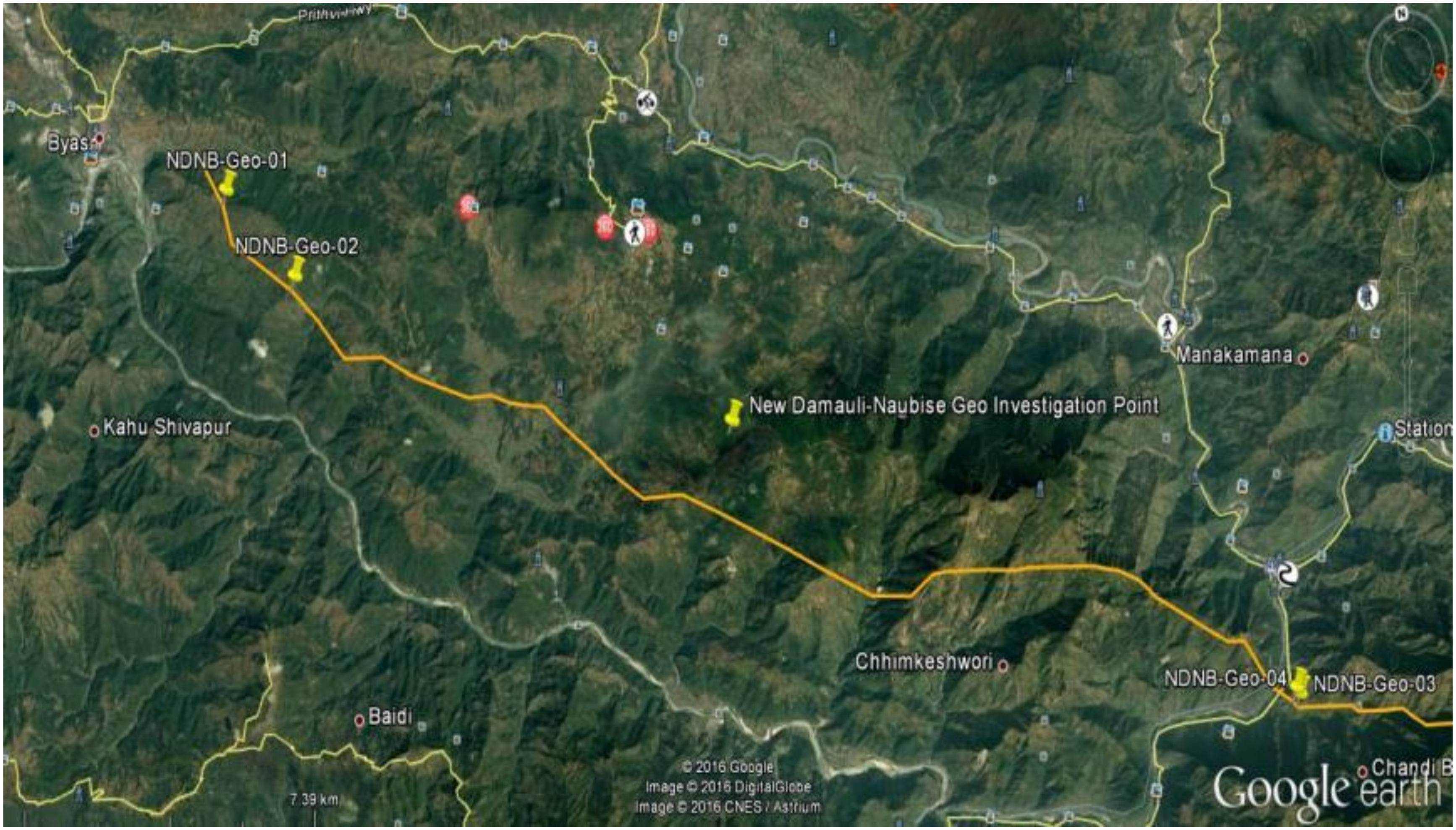


Figure 2.5.4.2: Damauli – Naubise Transmission Line Part – I

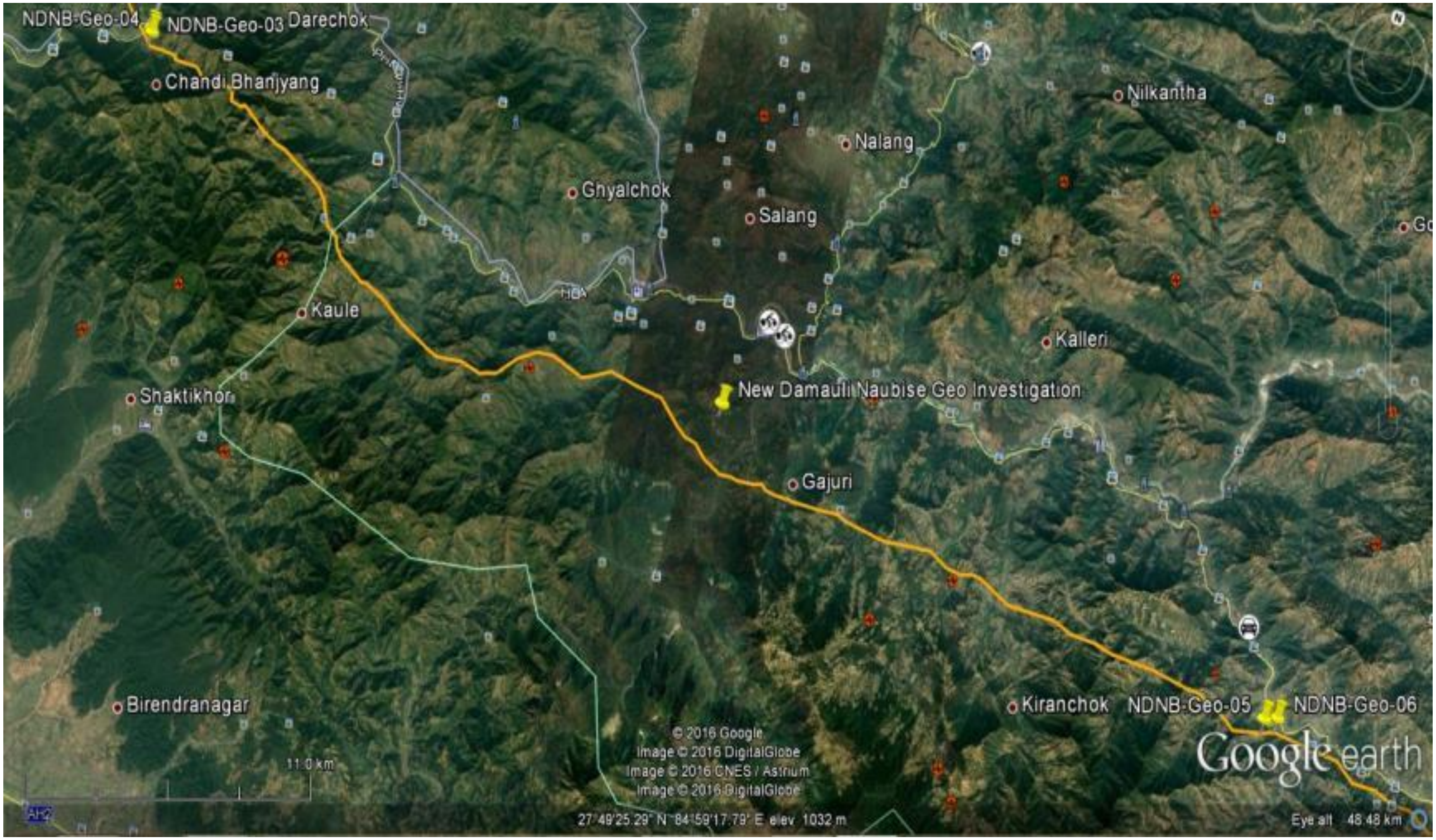


Figure 2.5.4.3 : Damauli – Naubise Transmission Line Part – II

Figure 2.5.4.4 : Lamki – India Border Transmission Line

Figure 2.5.4.5 : Naubise – Lapsiphedi Transmission Line

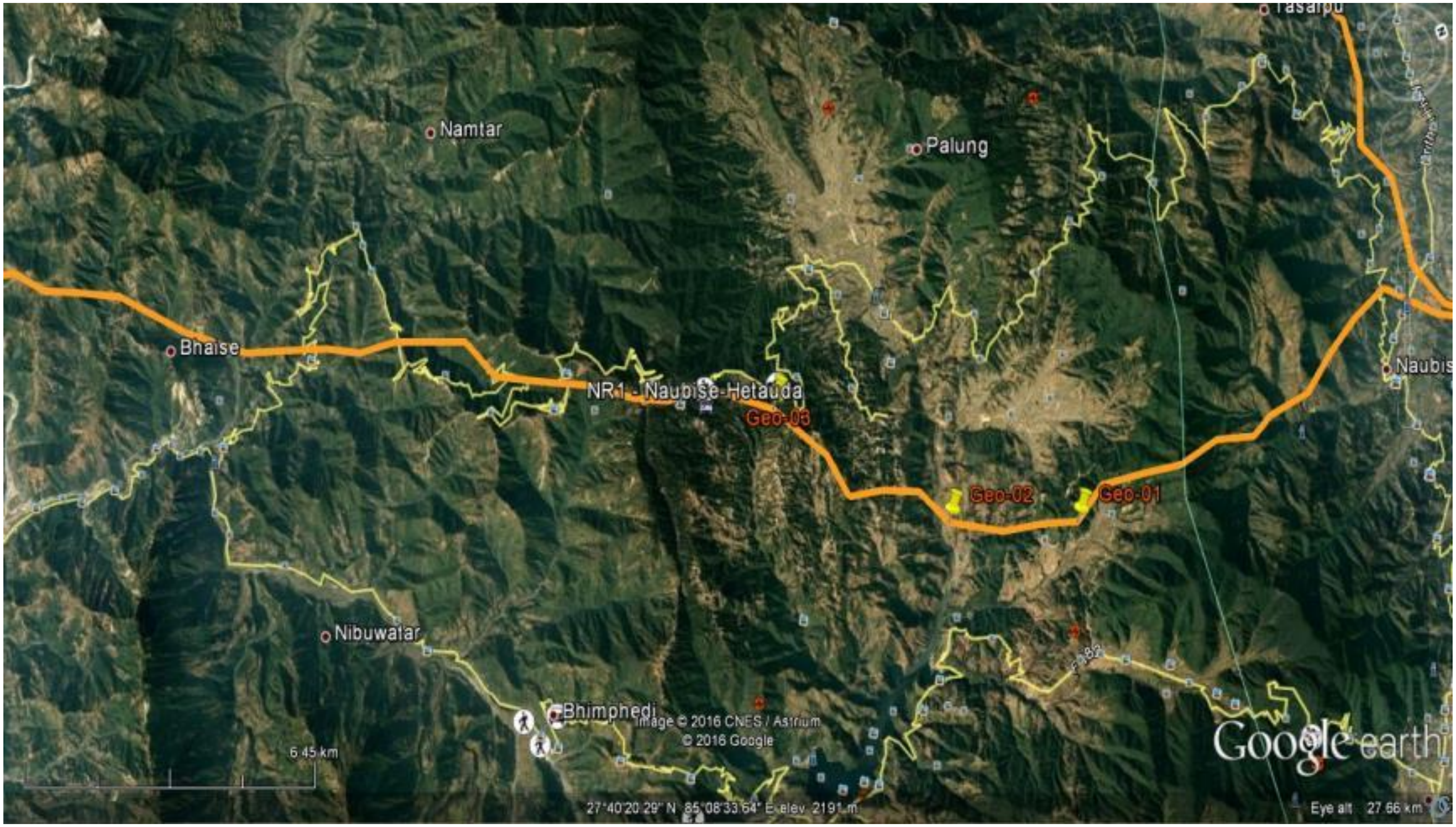


Figure 2.5.4.6 : Naubise – New Hetauda Transmission Line

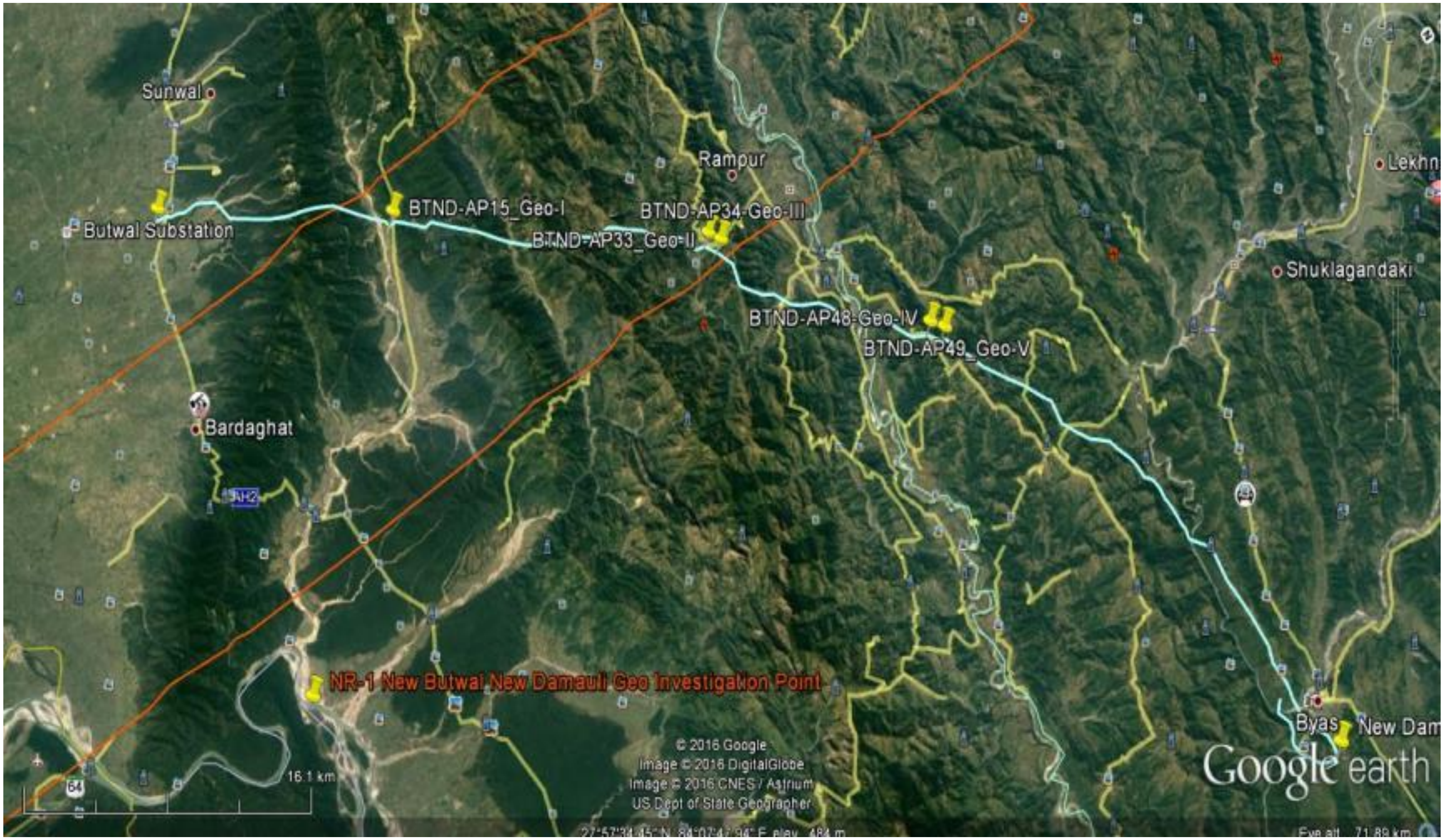


Figure 2.5.4.7 : New Butwal – New Damauli Transmission Line

Figure 2.5.4.8 : Tadhekani – Kusma Transmission Line

Substation Photograph

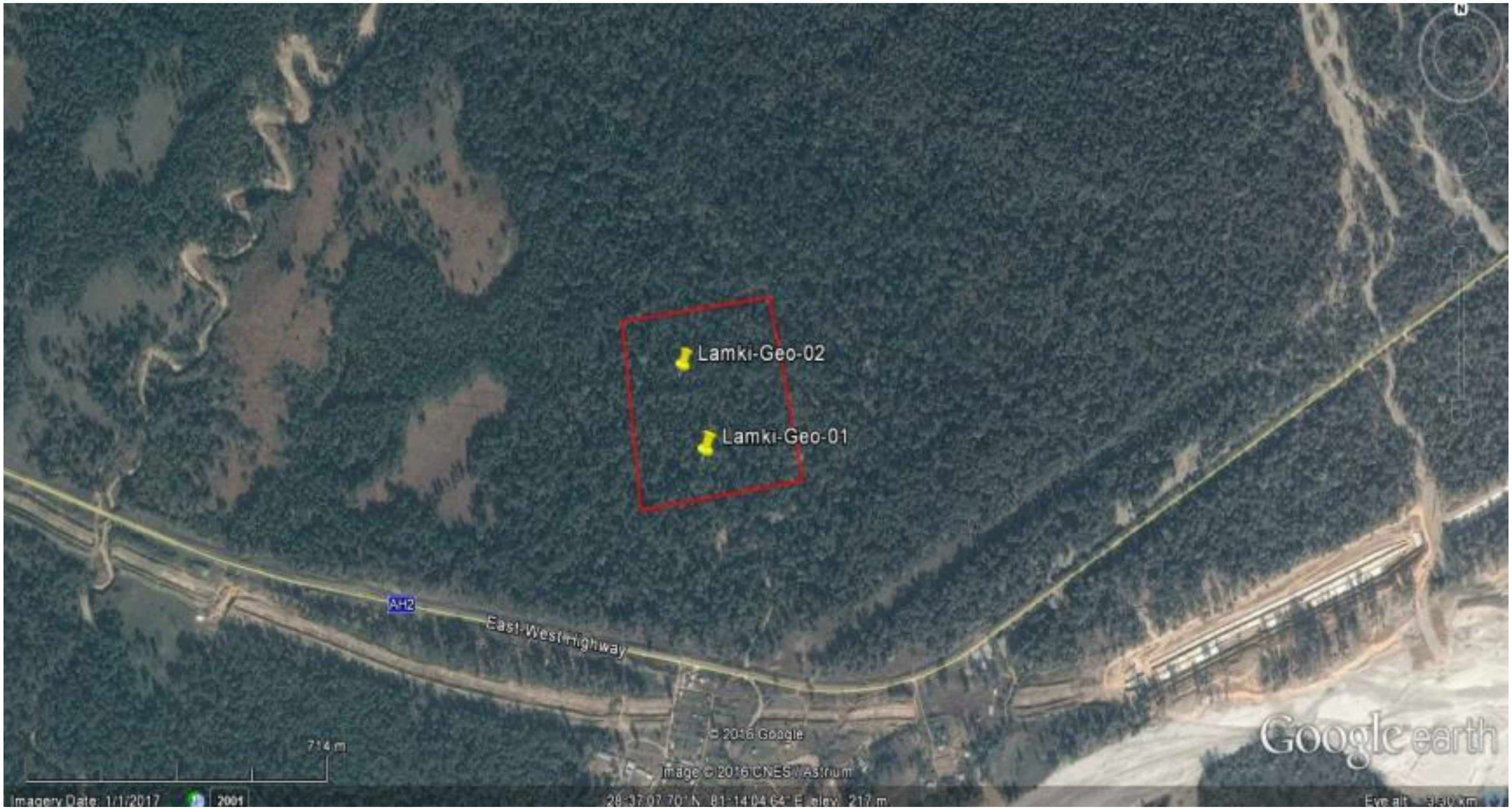


Figure 2.5.4.9 : Lamki Substation

Figure 2.5.4.10: Lapsiphedi Substation (Zoom out)

Figure 2.5.4.11: Lapsiphedi Substation (Zoom In)

Figure 2.5.4.12 : Naubise Substation (Zoom Out)

Figure 2.5.4.13: Naubise Substation (Zoom In)

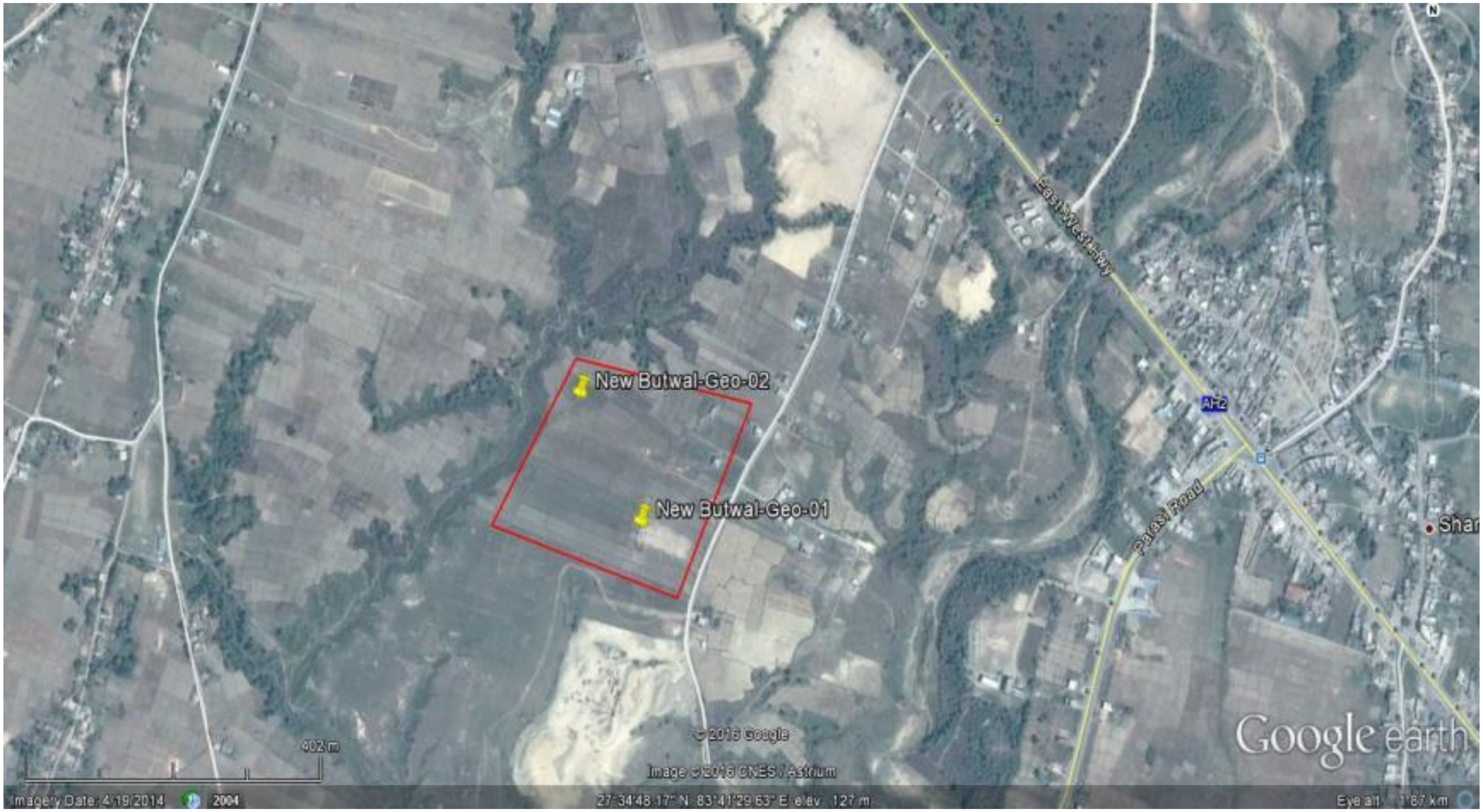


Figure 2.5.4.14: New Butwal Substation

Figure 2.5.4.15: New Damauli Substation (Zoom Out)

Figure 2.5.4.16: New Damauli Substation (Zoom In)

Figure 2.5.4.17: Tadhekani Substation (Zoom Out)

Figure 2.5.4.18: Tadhekani Substation (Zoom In)

2.6 Operations and Maintenance

The proper maintenance of transmission systems and substation not only improves reliability but also generates revenue. Preventive or periodic maintenance is very relevant for keeping equipment continuously in service. This forms the basis for "condition-based maintenance," which helps in providing advance information about the health of the equipment for planning for major maintenance/overhauls.

2.6.1 Maintenance Strategy

The objective of the O&M strategy will be:

- To achieve system availability as specified by the regulator/system administrator at the most economic cost
- To carry out periodic preventive maintenance so as to maximize the life of transmission lines
- To minimize the down time of the transmission lines for maintenance purposes.

The operation and maintenance of the transmission system shall be done in an efficient, coordinated and economical manner, in compliance with the latest IE rules, safety regulations, grid code, Electricity Act, CBIP Manual, Standards of Performance Regulation, and other applicable regulations and laws.

The maintenance philosophy to be adopted should cover both cold and hot line techniques so as to maximize system availability.

Experienced and trained manpower should be deputed for O&M to carry out preventive maintenance and condition monitoring of the transmission system. Also, all necessary tools and equipment will be procured and kept in storage to reduce downtime. An adequate number of stores will be established across the project area

Proven practices as described below shall be implemented:

- Routine patrolling of transmission lines at regular intervals.
- Visual inspection of insulator discs and jumpers.
- Lopping & chopping and bush clearance not involving tree cutting/crop compensation and right of way problems.
- Inspection of foundations and completeness of tower members.
- Thermo-vision scanning.
- Replacement of missing/damaged tower members.
- Minor rectification/repair works not involving tower collapse or foundation failure under shut down.
- Pre- and post-monsoon inspections.
- Special patrolling on tripping of the line.
- Repair of conductors.

- Punctured insulator detection in insulator failure prone stretches on an as-needed basis without availing shut down.
- Replacement of accessories like spacers and vibration dampers.
- Rectification in respect of conductor and earth-wire snapping not involving tower collapse.

Regular maintenance of each transmission line should be conducted to achieve the desired level of performance. The maintenance activities must be predefined and the schedules developed in advance. The scheduling of the regular maintenance shall be as under:

- ***Ground patrolling:*** For trimming of overgrown trees, liaise with locals to prevent the development of plantations/structures that could infringe the statutory clearances, detection/ replacement of stolen tower members and accessories, detection of displaced vibration dampers, spacers, etc., detection of hot spots/broken insulators/thermo vision scanning, soil erosion, rusting of tower members, tower earthing, etc.
- ***Pre-monsoon patrolling:*** Inspect each of the tower locations that are not likely to be approachable, or are vulnerable to water logging, soil erosion due to heavy flow of water, mid-stream tower locations, revetments, etc.
- ***Post-monsoon patrolling*:** Inspect each of the locations that could not be visited during the monsoon, checking for any damage to/exposure of the foundations, missing tower parts, damaged revetments, and all others that are scheduled for regular ground patrolling.
- ***Pre/Post-winter/summer patrolling:*** In addition to the activities listed for regular ground patrolling, intensive checks should be made for broken insulators, hot spots, tower earthing, and live line washing of insulators.

2.6.2 Maintenance Schedule for Substation Equipment

Maintenance is defined as a combination of actions carried out to return/restore equipment to an acceptable condition. Different types of maintenance being done on equipment are:

- ***Breakdown Maintenance:*** This maintenance is carried out when the equipment fails. It may be appropriate for low-value items. However, for costly substation equipment, it is not desirable to wait until a breakdown occurs, as it costs more to the utility as well as lessens power availability.
- ***Preventive Maintenance:*** This maintenance has been adopted by almost all utilities. In this type of maintenance, equipment is inspected at a predetermined period, which is based on past experience and also guidance from the manufacturer. This type of maintenance would require specific periods of shutdown.
- ***Condition-Based Monitoring:*** This type of maintenance is used to assess the condition of the equipment by carrying out tests. Some of the tests are done on-line and some off-line. However, this type of maintenance would need sophisticated testing equipment and skills for analyzing the test results.

- ***Reliability Centered Maintenance:*** This is a recent technique based on the life cycle cost concept. The decision to replace equipment is taken based on techno-economic considerations. Its objective is to devise a system that does not need periodic maintenance and at the same time predicts in advance possible equipment failures/problems.

2.6.3 Tentative Maintenance Schedule for Substation Equipment

Activity	**Date**	**Condition**				**Remarks / Remedy with Target date**
Maintenance Schedules for ICT						
Checking of bushing oil level						
Checking of oil level in conservator						
Checking of oil level in OLTC conservator						
Checking of cooler oil pumps and fans						
Manual actuation						
Checking of oil leaks						
Checking condition of silica gel in breather						
Checking oil level in oil seal of breather						

Sr. No.	**Activity**	**Date**	**Condition**	**Remarks / Remedy with Targeted date**
2). CIRCUIT BREAKERS :				
2.2 C	Checking of oil leaks			

Activity		Date	Condition	Remarks / Remedy with Target date
Maintenance Schedules for ICT				
3). CURRENT TRANSFORMER :				
3.2 a	Checking of below expansion/ oil level			
B	Visual inspection of CT for oil leakage/ oil level and cracks in insulator, etc.			
4). CAPACITIVE VOLTAGE TRANSFORMERS :				
4.1 d	Checking of oil leaks			
5) PROTECTION SYSTEMS :				
5.1 a	Testing of DR/EL for time synchronization			
6). BATTERIES AND DC DISTRIBUTION SYSTEM :				
A	Measurement of specific gravity and voltage of cell with charger off			
B	Checking electrolyte level and topping up with DM water, if required			
C	Checking of emergency DC lighting			
	To control room			
I	Checking of any earth fault			
	(If E/F relay not provide)			

2.6.4 Tentative O&M Expenses per Annum

Item Description	Unit	Qty	Cost	No of Month	Annual Charges
R&M – Building					
R&M-Office maintenance & running expenses	Per Month				
R&M-Stores	Per Month				
R&M-Guest house including monthly maintenance	Per Month				
Repair & Maintenance - other					
R&M-Vehicles Including fuel	Nos				
Electricity Charges					
Electricity-Office	Nos				
Gen set running exp	Nos				
Electricity-Stores	Nos				
Travelling & Conveyance					
Railway tickets inland	Nos				
Local travel at outstation	Lot				
Travelling - Other expenses	Lot				
Caretaking and Support Staff					
Caretaker for offices	Nos				
Cook/sweeper, etc. at guest house	Nos				
Manpower					
O&M project in charge	Nos				
Commercial head	Nos				
Engineers	Nos				
Miscellaneous Expenses					

Item Description	Unit	Qty	Cost	No of Month	Annual Charges
Management Meetings	Nos				
Audit Fees	Nos				
Legal Fees	Nos				
Safety Audit	Nos				
R&M - Plant & Machinery					
R&M-Office equipment	Lot				
R&M-Towers	Lot				
DA Type	No				
DB Type	No				
DC	No				
DD	No				
R&M Tools & tackles					
General maintenance resident					
R&M land crop/way leave charges	Yearly				
R&M earth wire	Kms				
R&M Hardware Fittings					
120 KN single I pilot string for 400 kV quad moose	Nos				
120 KN for single suspension string for 400 kV quad moose	Nos				
2*160 KN double tension for 132 kV, 220 kV,400 kV quad moose	Nos				
1x160 kN single tension strings for transposition tower	Nos				
R&M conductor & earthwire acce					
Mid-span compression joint	Nos				
Repair sleeves for conductor	Nos				
T-Connector for transposition tower	Nos				
Quad vibration damper for 132 kV, 220 kV, 400 kV	Nos				
Quad rigid spacer for 132 kV, 220 kV 400 kV	Nos				

Item Description	Unit	Qty	Cost	No of Month	Annual Charges
Dead end clamp for tension towers for 400 kV	Nos				
T-connector for dead end clamp	Nos				
Bundle spacer for ACSR moose	Nos				
EW accessories					
Mid-span compression joint	Nos				
Repair sleeves	Nos				
Flexible copper Bond	Nos				
Vibration damper	Nos				
Earthwire suspension clamp	Nos				
Earthwire tension clamp	Nos				
R&M tower accessories	Lot				
R&M conductor	Kms				
R&M insulator					
120 KN	Nos				
160 KN	Nos				
R&M OPGW & Fitting					
OPGW conductor (24 Fiber) DWSM	Kms				
Tension – single	Nos				
Tension – double	Nos				
Suspension	Nos				
Down lead clamps	Nos				
Joint box	Nos				
OPGW holder bracket	Nos				
Vibration dampers	Nos				
Fiber optic distribution frame	Nos				
Per annum maintenance charges					

As per the inputs obtained from NEA officials, NEA have their Routine Maintenance Schedule for Basic Maintenance of Transmission Lines and Substations such as Patrolling of Transmission Lines, Periodical Tree Cutting , Maintenance of Batteries , Verification of Leakages in SF6 Breakers .They do have the Basic Tools & Equipments such as Oil Filtration Machines, Testing Equipments for Transformers CTs, Breakers, Relays etc .They also have the line Construction Equipments for EHV Lines up to 220kV. As regards Providing Training and Tools, we may include the provision in the Bid Specifications. We have made a Provision of 5 % of the total material cost for special tools & Spares, in the cost Estimates.

2.7 Project Cost Estimates

Cost estimates for all MCC projects were prepared as follows:

NR-1: East-West 400kV Transmission Backbone

- 400 kV double circuit transmission line with quad moose ACSR (hilly terrain in Central Nepal)
    - New Butwal – New Damauli – 84 km
    - New Damauli – Naubise – 98 km
    - Naubise to New Hetauda- 41 km
    - Naubise to Lapsiphedi- 48 km
- Five New 400 kV substations at
    - New Hetauda
    - Naubise
    - New Damauli
    - New Butwal
    - Lapsiphedi

NR-3 Ilam- Inaruva 132 kV Network Reinforcement

- Ilam – Inaruwa double circuit 132 kV 110 km transmission line with single bison ACSR (mostly hilly terrain in far eastern Nepal)
- 2 new 132 kV Line bays at Ilam substation
- 2 new 132 kV line bays at Inaruwa substation

NR-4 Balanch – Attariya 132kV Network Reinforcement

- Second circuit stringing on existing 132 kV Balanch – Attariya transmission line with single bear ACSR (mostly hilly terrain in far western Nepal)
- 1 x 132 kV line bay at Balanch substation
- 1 x 132 kV line bay at Attariya substation

T3 Tadhekani-Kusma 220kV Network Reinforcement

- 2 x 220 kV lines from Tadhekani to Kusma approximately 27 km, double-circuit transmission line through hilly regions in western Nepal
- 2 x, 220 kV-132 kV, 165 MVA transformers
- 2 X 220 kV line bays at Kusma substation

T-2' New Khimiti – Likhu Hub 220 kV Transmission Cord Extension

- New Khimti – Likhu Hub double circuit 220 kV 30 km transmission line with twin bison ACSR (hilly terrain in eastern Nepal)
- 220 kV substation at Likhu Hub
- 2 X 220 kV line bays at New Khimti substation

T-8 New Lamki 400 kV Transmission Cord Extension

- New Lamki to Nepal/India border 400 kV 30 km double circuit transmission line with quad moose ASCR (flat Terai terrain in western Nepal)
- New 400 kV Substation at Lamki

XB-1 400 kV Cross Border transmission Line

- New Butwal - Cross border 400 kV 30 km double circuit transmission line from with quad moose ACSR (flat Terai terrain in central Nepal)

Key Assumptions

The estimates presented in this report are based on following data and assumptions:

- The unit prices for the project cost estimation are determined using the schedule of prices loaded by Indian utilities and the costs of completed projects in India and Nepal.
- The price structure of contracts awarded by utilities in Nepal during 2011 and 2014-2015 for 132 kV and 220 kV transmission lines and 132 kV bays are used as references.
- The contracted rates for 220 kV and 400 kV substations and transmission lines in India during the 2011-2013 and 2015-2016 were considered.
- The effect of price inflation with respect to materials/equipment at the rate of 2% per annum for materials supply and at the rate of 5 % per annum for services. (WPI – https://dbie.rbi.org.in CPI – http://labourbureau.nic.in)
- The rates of conversion of Indian Rupees and Nepali Rupees to US Dollars used are 68 INR/USD and 104 NRS/USD, respectively.
- The provision of contingencies was considered as 10% on the total project cost.
- The cost of administrative expenses, accounts and audit expenses, supervision costs, were considered in this estimate.
- Interest during the construction is not considered in the estimate.
- Land costs, environmental and permit application costs are included.
- It should be pointed out that today's prices exhibit a broad scattered range around the estimated prices due to the current high fluctuation of the costs of raw materials (steel, copper, galvanizing

zinc, oil, etc.), the volatility of the USD exchange rate to other major currencies and the current situation of contractors.

Methodology Adopted
The following were considered while preparing the cost estimates:

- Design criteria followed in the design of the transmission line and substation civil and electrical works
- Terrain of the route of the transmission line and site of the substation
- Details of river crossings encountered in the route of transmission lines
- Results and recommendations from the survey and soil investigations conducted for the proposed transmission lines and substations
- Type of tower configuration used and type of conductor and earth wire used in the construction of the transmission line
- Switchyard equipment to be used in the switchyard area.

Quantity Calculations
The bills of materials for civil and electrical works of transmission lines and substations are shown in Annex C. Quantities were based on the design drawings and the total cost estimate for each project was calculated based on estimated quantities and cost rates as mentioned above.

Rate Analysis
The cost estimates of the civil and electrical works were based on the prevailing basic rates of materials, equipment and labor. These rates were based on the Standard Schedule of Rates of Indian Utilities and NEA.

Abstract of Cost
The abstract of the cost of civil and electrical works included expenditures incurred to date and the provisions required for the balance work including the quantity, rates and amount of each of the items included in the estimate.

The cost estimates were prepared after route verification of the transmission line, substation transformation capacity, and BOM. The estimated environmental, social and resettlement costs of each project were also considered after obtaining inputs from other disciplines.
The cost estimate for each project includes:

- Bill of quantities of major equipment and materials for transmission lines and substations
- Design and engineering cost
- Project management costs
- Services and works contractor cost
- Material and erection components

- Provision for contingencies
- Administrative costs
- Applicable taxes
- Route correction factor
- Additional foundation cost for extended chimney works
- Tower foundation protection cost
- Conductor length Multiplier (due to Sag)
- Contingency (Foundations)

The cost estimate includes inflation adjustment costs on materials as well as the erection component of the projects. The cost estimate also provides compensation for land acquisition, damage to standing crops, and the immovable property of land owners. For more details on compensation, refer to the Volume 3, Task 3 (Resettlement) report.

For this purpose, the procedure used at NEA for estimating project costs was discussed and studied. The routes have been finalized through desktop studies and during the studies, we identified five different terrain types through which line route passes.

Accordingly, we developed a cost multiplier to observe feasibility-level routing inefficiency in each transmission line. This has been considered as a route correction factor in the preparation of estimates.

Route Correction Factors

Table 2.17 Route Correction Factors

Sr. No	Transmission line	Route Correction factor
1	New Butwal – New Damauli Line	0.75
2	New Damauli – Naubise Line	0.68
3	Naubise - New Hetauda Line	No Change
	Naubise - Lapsiphedi Line	0.8
5	Ilam- Inaruwa Line	0.85
6	Balanch – Attariya Line	NA
7	New Khimti – Likhu Hub Line	0.82
8	Tadekhani – Kusma Line	0.78
9	New Lamki - India Border Line	0.9
10	Butwal - India Border Line	0.95

According to data collected from NEA, line construction works in hilly terrains require a certain number of foundation chimney extensions. Extension are required when the largest tower's unequal leg cannot cover the difference in natural ground elevations at tower legs points. This added cost can reach 5-10%

of the line's foundation cost depending on the harshness of its terrain. The following rates have been applied to different lines for this matter.

Extended Chimney Added Cost Factor

Table 2.18 Extended Chimney Added Cost Factors

Sr. No	Transmission line	Extended Chimney Factor
1	NR3	1.08
2	T2'	1.1
3	NR1	1.06
4	NR1; New Damauli – New Butwal	1.05
5	XB1	1
6	T3	1.1
7	T8	1

Data collected from NEA also suggest that in hilly areas, transmission line foundations need to be protected by the construction of retaining walls in certain route slopes. This cost may vary from NRS 20,000 to NRS 40,000 per kilometer depending on the harshness of the terrain. The following additional costs have been considered for different transmission lines to observe this cost factor.

Extended Foundation Protection Cost

Table 2.19 Extended Foundation Protection Cost

Sr. No	Transmission line	Foundation Protection Cost (NRS/km)
1	NR3	20,000
2	T2'	35,000
3	NR1	15,000
4	NR1; New Damauli – New Butwal	13,000
5	XB1	0
6	T3	35,000
7	T8	0

Conductor Length Multiplier (Due to Sag):

This is an important consideration in the mechanical design of overhead lines. The conductor sag should be kept to a minimum in order to reduce the conductor material required and to avoid extra pole height for sufficient clearance above ground level. It is also desirable that tension in the conductor should be low to avoid the mechanical failure of conductor and to permit the use of less strong supports

In an overhead line, the sag should be so adjusted that tension in the conductors is within safe limits. The tension is governed by conductor weight, diameter and its mechanical properties such as coefficient of thermal expansion, modulus of elasticity …, effects of wind, ice loading, temperature variations and safety margins in different loading conditions which are to be applied to conductor tensioning criteria in terms of maximum allowable percentage of its ultimate tensile strength.

Conductor length is never equal to transmission line route length and is always longer than the route length by a certain percentage because of conductor sag. The conductor sag which is mainly a parameter of its tension depends also on the ground profile on which transmission line stretches. As a result conductor length is longer in mountainous and hilly terrains than in flat terrain. So the extra percentage which shall be applied to line route will be higher in mountainous and hilly terrains comparing to flat terrain. The following conductor length multipliers are applied to line routes in different projects to observe the terrain difference in different projects' route.

Project	Particulars	Conductor Length Multiplier (Due to Sag)
NR1	New Butwal – New Damauli Line	1.07
	New Damauli – Naubise Line	1.08
	Naubise - New Hetauda Line	1.09
	Naubise - Lapsiphedi Line	1.08
NR-3	Ilam- Inaruwa Line	1.07
NR-4	Balanch – Attariya Line	1.07
T-2'	New Khimti – Likhu Hub Line	1.08
T-3	Tadekhani – Kusma Line	1.08
T-8	New Lamki - India Border Line	No Change
XB-1	Butwal - India Border Line	No Change

Contingency (Foundations)

This tables shows different contingency used for Transmission lines foundation design. Due to lack of information on boreholes, additional contingency has been used in the cost estimate. These contingency includes 10% overall contingency applied to all the projects.

*For Contingency basis, please refer to Transmission Line Geo Technical Risk Assessment in Section 2.9

Project	Particulars	Contingency Foundation (%)
NR1	New Butwal – New Damauli Line	50
	New Damauli – Naubise Line	50
	Naubise - New Hetauda Line	50
	Naubise - Lapsiphedi Line	50
NR-3	Ilam- Inaruwa Line	50
NR-4	Balanch – Attariya Line	NA
T-2’	New Khimti – Likhu Hub Line	50
T-3	Tadekhani – Kusma Line	50
T-8	New Lamki - India Border Line	40
XB-1	Butwal - India Border Line	40

Inflation Calculation

It is an overall rate of inflation worked out considering component of materials supply and services as 60:40. We have considered rate of inflation at the rate of 2% per annum for materials supply and at the rate of 5 % per annum for services. Clubbing together, the annual rate of inflation would work out to (60 X 0.02) + (40 X 0.05 i.e. 61.2 + 42.0 = 103.2). Therefore rate of inflation on total contact cost is considered @ rate of 3.2 % Per Annum. Compounded over the MCC Compact period of 5 years, it will be a total of 17.06 % say 17 %.

Recommendation on Operation and Maintenance Activity Costs

Schedules of maintenance for transmission lines and substations were prepared as per standard practice implemented in Nepal and India. The effects of terrain, environment and spares availability were taken into consideration for this purpose. O&M costs were derived considering a life cycle of 50 years for transmission lines and 30 years for substations. The engineer’s input was obtained regarding the Inventory of spares to be maintained for transmission lines and substations, and the finalization of technical specifications for equipment and materials. As per engineer’s inputs, following will be additional O&M training required to maintain 400kV substations in Nepal.

Following training will be required for employees in charge of maintaining the T Line and stations with the help of material suppliers. Training will be integral part of all material supplier contractors:

- Training for 400kV and 220kV GIS
- Training on maintenance for the new 400kV equipment

We also assume that NEA already has the following elements / equipment:

- Preventive maintenance computer program. If not available in house.
- Nacelle trucks
- Thermographic testing equipment (Refer to Flir)
- RMS multi-function meter with 0.5% accuracy (Refer to Fluke). Should already be available has it is the most basic maintenance tool.
- Megohmmeter (Refer to Fluke)
- Low Resistance Ohmmeter (Refer to Megger)
- Earth Resistance Meter (Refer to Megger has some models)
- Primary injection testing system like CPC 100 from Omicron
- Power factor meter (Fluke)
- Relay test set (Doble)
- Transformer Turn-Ratio Test Set (Megger)
- Purchase of recommended spares parts for the different 400kV equipment (breakers, switches, CTs, PTs)

2.8 Project Procurement Packaging

This section describes our proposed methodology for packaging procurements for the MCC compact. MCC's compact consists of the following projects, which have been listed from the east to the west of the country.

Table 2.20 MCC Compact Projects from the East to the West of Nepal

Project Name	Voltage (kV)	GIS / AIS	MCC project title	Remarks
Ilam substation upgrade	132	AIS	NR3	Adding two line bays to existing substation
Inaruwa substation upgrade	132	AIS	NR3	Adding two line bays to existing substation
Ilam – Inaruwa transmission line	132	-	NR3	Double circuit transmission line
Likhu Hub substation	220/132	GIS	T2'	New substation beside IPP's 132 kV substation
New Khimti substation upgrade	220	AIS	T2'	Adding two line bays to existing substation

Table 2.20 MCC Compact Projects from the East to the West of Nepal

Project Name	Voltage (kV)	GIS / AIS	MCC project title	Remarks
Likhu Hub – New Khimti transmission line	220	-	T2’	Double circuit transmission line
Lapsiphedi substation	400/220	GIS	NR1	New substation beside ADB’s 220 kV substation
Naubise substation	400/220	AIS	NR1	New substation
New Hetauda substation	400/220	GIS	NR1	New substation beside WB’s 220 kV substation
New Damauli substation	400/220	GIS	NR1	New substation
New Butwal substation	400/220	AIS	NR1	New substation beside ADB’s 220 kV substation
Lapsiphedi – Naubise transmission line	400	-	NR1	Double circuit transmission line
New Hetauda – Naubise transmission line	400	-	NR1	Double circuit transmission line
Naubise - New Damauli transmission line	400	-	NR1	Double circuit transmission line
New Damauli - New Butwal transmission line	400	-	NR1	Double circuit transmission line
New Butwal – cross border transmission line	400	-	XB1	Double circuit transmission line
Tadhekani substation	220	GIS	T3	New substation
Kusma substation upgrade	220	AIS	T3	Adding two line bays to existing substation
Tadhekani – Kusma transmission line	220	-	T3	Double circuit transmission line
New Lamki substation	400/132	AIS	T8	New substation
New Lamki – cross border transmission line	400	-	T8	Double circuit transmission line
Attariya substation upgrade	132	AIS	NR4	Adding one line bay to existing substation
Balanch substation upgrade	132	AIS	NR4	Adding one line bay to existing substation
Attariya – Balanch transmission line	132	-	NR4	Adding second circuit to existing transmission line

In summary, the MCC compact includes 8 new substations, 6 substation upgrades, and 10 transmission lines from 132 kV to 220 kV and 400 kV, which are spread across the country. It is not feasible to award all of these projects to one or two contractors and it would be better to package them as subprojects. However, it is recommended that one Engineering firm be responsible for the full oversight for all packages and to coordinate all packages.

There are different ways in which procurement could be packaged:

- Method # 1 – Packages are split according to their geographical location
- Method # 2 - Groupings are based on substation size and/or transmission line length
- Method # 3 – Groupings are based on voltage levels
- Method #4 – Groupings are based on technology (e.g., AIS or GIS) or type of equipment/material
- Method #5 – Groupings are based on power system parameters (their contribution to improvements in power flow and technical losses) and economic factors (profitability and sensitivity).

Each of these methods of packaging has advantages and some of them have a number of disadvantages:

- The advantages of Method 1 are that the contractor's logistics will be worked out more efficiently, faster, and at less cost. Additionally, a sub-project with a smaller footprint will be managed more effectively than one with geographically scattered elements. Further, local resources will be better utilized by separating projects in this way.
- Large size projects require special project and construction management skills, and usually require highly experienced international contractors (especially in Nepal), while small projects can be efficiently managed by regional contractors (or even in the case of very small projects, by local contractors). By separating small from large projects, regional or local contractors will have a chance to engage in some of the packages, making small package tenders more competitive.
- For projects of different voltages, the design, procurement and construction approaches will also differ. There are some criteria and phenomenon that are critical in 400 kV infrastructures that normally do not need to be considered in 132 kV project (e.g., corona). On the other hand, not all contractors are specialized in extra high voltage projects or have EHV equipment suppliers on their active vendor list. Putting 400 kV projects in different packages from 132 and 220 kV projects enables MCC to invite more contractors to the latter group of projects; these contractors may not have the competence needed to design and construct 400 kV projects.
- Method 4 aims to take advantage of utilizing specialized contractors for certain technologies. This will result in a more efficient design and more economical procurement and construction. However, applying this method may contradict the other methods. For example, GIS substations are scattered and awarding all of contracts to one bidder will require the coverage of a geographically large area.
- Method 5 seeks to group projects with similar power system improvement ratings or similar economic characteristics in the same package. In this way, those projects that are not approved may be finally dropped and will go into the same package. Hence, removing them from the compact won't affect other packages. The disadvantages of this method, which is similar to Method 4, is that it might produce projects that are not geographically proximate, or of similar size or voltage. The disadvantages of this method are greater in construction work and outweigh

its advantages. Furthermore, if some of the projects in one package are dropped, the remaining projects can be added to another package; this will not cause insurmountable problems.

In all of above mentioned methods we have put transmission lines and substations in same package. Including both transmission lines and substations in the same package has some pros and cons however we believe that its advantages are more. List of expected benefits and disadvantages of this packaging is as per following:

Advantages:

- Ease of coordination at the interface of two infrastructures
- Ease of logistics of two projects
- Ease of transportation of material
- Geographical separation of contractors and keeping their jurisdictions exclusive
- Integration of responsibility of line and station components of a transmission project in one contractor
- On-time commissioning and energization of the facility

Disadvantages:

- Construction of substations and lines are completely different professions and one contractor might not have both skillset in-house (this is really true just for small contractors)

2.9 Risk Assessment

Please refer to Task 5 (Sustainability) for complete list of Risks.

Area	Risk	Solution	Comments
Substation	The existing station drawings downloaded from NEA website for different tender packages do not reflect consistent information.	Close coordination between MCA Engineer and NEA/other donors' consultants or PMS. MCA is to facilitate coordination by periodic coordination meetings	
SCADA	Lack of information about the design of new LDC project and also existing LDC which will have interface with MCA's substations.	MCA engineer to have close connection with design firms or EPC contractors of these project. Periodic coordination meetings with these firms will mitigate this issue.	
Transmission line civil works	Increase in cost for civil works due to possible landslide locations in the transmission line area	A detailed landslide analysis must be done and if required the alignment must be changed to avoid the landslide location.	
Substation access	There are several locations along the access routes to the substations where the water is flowing over the	A detailed investigation should be done prior to the start of the detailed design to clearly identify the hazards/deficiencies and appropriate	

	roads and landslides occurring during rainfall events.	mitigation measures shall be provided in the design.	
Geotechnical investigation and foundation cost	Geotechnical study for substations and transmission lines was not completed at the time of the material estimates during the feasibility stage. Estimated foundation quantities may fall well outside the anticipated +/- 20% range based on actual geotechnical conditions at site.	A detailed geotechnical report will need to be completed prior to the detailed design stage to gain a clear understanding of soil conditions at each site.	
Geotechnical investigation and foundation cost	A limited number of boreholes were drilled for the geotechnical investigations on site. There is a reasonable chance that soil conditions in the area could be significantly different from the results given from the borehole data.	A more extensive geotechnical investigation will be required prior to starting detailed foundation design/ civil design to gain a reasonable understanding of the soil conditions to be expected at each station location and along the transmission line route.	Further details on Geo Technical Risk are provided below.

Addition of 2 PSTs in New Butwal

During the comment phase of the draft feasibility study, OMCN stated that phase shifting transformers are required to control the power flow between New Butwal and India.

Given that the India power system model was not available, Tetra Tech was not able to study the interactions between the Nepal and India networks to determine which solution, if required, would be appropriate to prevent loop flows. As such, the PST was not added in the engineering documents.

However, Tetra Tech recommends that the addition of the phase shifting transformers be treated as a risk and incorporated in the total capital cost requirements. According to the system studies, the transfer capacity between Nepal and India would be of approximately 1800 MW divided into 2 lines. A 900 MVA phase shifting transformer would be added to each line.

Tetra Tech recommends that MCC obtain the detailed model of the Indian network in order to be able to conduct a detailed study on the power transfers between Nepal and India. This study would allow to determine if loop flows are anticipated and what the best mitigation solution is. Once the best solution is identified, a final cost estimate can be completed in order to get a full picture of the project price.

Once the detailed modeling is complete, one of the mitigation options to loop flows could be to develop standard operating procedures that would provide guidelines on how the national power control centers of both countries would coordinate in order to avoid loop flows. The example of Bhutan could be followed as it is already exporting power to India.

Addition of 2 new transformers and a 150MVAR capacitor bank in Inaruwa

System studies have revealed that the total installed transformer capacity at Inaruwa should be 480 MVA (3 x 160 MVA) and that an additional 150 MVAR capacitor bank would also be required. As of right now, the total transformer capacity in the substation is 200 MVA. Two additional 160 MVA transformers would need to be provided to meet the required capacity. This work is outside the scope of the MCC compact.

Transmission Line Geotechnical Risks

To account for the lack of soil data at this stage, a contingency factor was applied to the costs of all transmission line foundations. For transmission line foundations in hilly terrain, the soil found in the boreholes gave a reasonable level of confidence that the foundations assumed for normal dry soil and submerged loose soil would be sufficient, however, the bearing strength of the fissured rock was lower than what was assumed in the design and hard rock was not found in any of the boreholes along the transmission lines. As 80% of the foundations in hilly terrain was assumed to be hard rock or submerged fissured rock, the results from the boreholes highlights the high level of uncertainty in the soil conditions. Due to this level of uncertainty a contingency of 50% was applied to the cost of the transmission line foundations in hilly terrain.

For transmission line foundations in plains terrain, the soil found in the boreholes gave a reasonable level of confidence that the foundations assumed for normal dry soil, wet black cotton soil and normal wet soil would be sufficient, however, the bearing strength of the fissured rock was lower than what was assumed in the design and hard rock was not found in any of the boreholes along the transmission lines. As 40% of the foundations in plains terrain was assumed to be hard rock or submerged fissured rock, the results from the boreholes highlights the high level of uncertainty in the soil conditions. Due to this level of uncertainty a contingency of 40% was applied to the cost of the transmission line foundations in hilly terrain.

To reduce the level of uncertainty, a more thorough geotechnical study should be completed with a sufficient number of boreholes drilled to a suitable depth. To reduce the contingency applied, it is suggested to drill an additional borehole approximately every 5 to 10 kilometers of transmission line to a minimum depth of ten meters below grade or until suitable bearing strata is intercepted.

Due to the remote location of some of the transmission lines, it may not be feasible to carry out a detailed geotechnical study prior to the foundation design stage. In this case, it would be prudent to include a large contingency in the foundation design to cover unexpected costs encountered during foundation construction.

Substation Geo Technical Risk

Two boreholes were drilled at most substation sites to provide a general idea of the soil conditions at the substation sites. This information was used to verify the safe soil bearing pressure used for the preliminary design of foundations at site. As only limited information can be derived from two boreholes and in some cases, the soil bearing capacity found was less than what was assumed for the foundation quantities, a contingency factor was applied to the foundation costs to compensate for undersized foundations and limited geotechnical information. The table below provides a brief description of the situation found at each site and the contingency used:

Station	Soil Type found during borehole drilling	Comparison between borehole results and assumed soil conditions	Contingency
Naubise	Normal Dry Soil	Foundation size for most yard foundations is acceptable, building foundation sizes are expected to increase.	15%
Tadhekani	Normal Dry Soil underlain by Sandy Soil and Dry Fissured Rock	Soil bearing capacity is high. Foundation sizes could be reduced. If dense gravels are shallow, excavation costs could increase.	5%
New Damauli	Normal Dry Soil underlain by Sandy Soil	Foundation size for most yard foundations is acceptable, building foundation sizes are expected to increase.	20%
New Hetauda	Fissured Rock underlain by Submerged Fissured Rock	Soil bearing capacity is high. If dense gravels or rock are shallow, excavation costs could increase.	10%
Likhu Hub	Unknown	N/A	40%
New Butwal	Normal Dry Soil underlain by Wet Soil and Fully Submerged Soil	Increase in most foundation sizes will be required to accommodate low soil bearing capacity at this site.	40%
Lapsiphedi	Wet Soil and Submerged Sandy Soil	Foundation size for yard foundations is acceptable, building foundation sizes are expected to increase.	20%
New Lamki	Normal Dry Soil	Increase in most foundation sizes will be required to accommodate low soil bearing capacity at this site.	40%
New Khimti	Unknown	N/A	40%
Inaruwa	Sandy Soil underlain by Submerged Sandy Soil	Increase in foundation size will be required for gantry foundations. Yard equipment foundations should be sufficient based on borehole data.	25%
Balanch	Unknown	N/A	40%
Kusma	Unknown	N/A	40%

Attariya	Unknown	N/A	40%

3. Detailed Feasibility Assessment

The key factor in engineering assessment is the understanding of compact objectives and MCC's standard approach to implementing such compacts. Furthermore, NEA's standard line construction, and operation and maintenance must be taken in consideration. This section provides details and results of feasibility assessment of power system, substations and transmission lines.

3.1 Power System Assessment

As described in the methodology (Section 2), the main assessments were carried out using PSS®E power system simulation software:

- Load Flow Study
- Short circuit study
- Technical Power Loss Study
- Dynamic Study
- Technical benefit analysis.

The details of the studies and the results are summarized in the following sub-sections.

3.1.1 Representation of MCC Projects in Power System Studies

The MCC compact enforcement includes projects in – NR1, XB1, NR3, NR4, T2', T3 and T8 – are included in the studies. The projects were modelled in PSS®E as follows.

NR1: High-Voltage Transmission Trunk Line
The 400 kV double circuit backbone Lapsiphedi - Naubise – Hetauda – New Damauli – New Butwal is shown in Figure 3.1. The 160 MVA 400 kV/220 kV and 400 kV/220 kV transformers shown in the figure were considered initially and the exact number of transformers required at each location was later evaluated through power flow studies. It should be noted that in Lapsiphedi, there is no 220 kV station available in the power flow cases provided WSP and the 400 kV substation was connected to the existing 132 kV station using 400 kV/132 kV transformers. The same configuration was described in the WSP due diligence report.

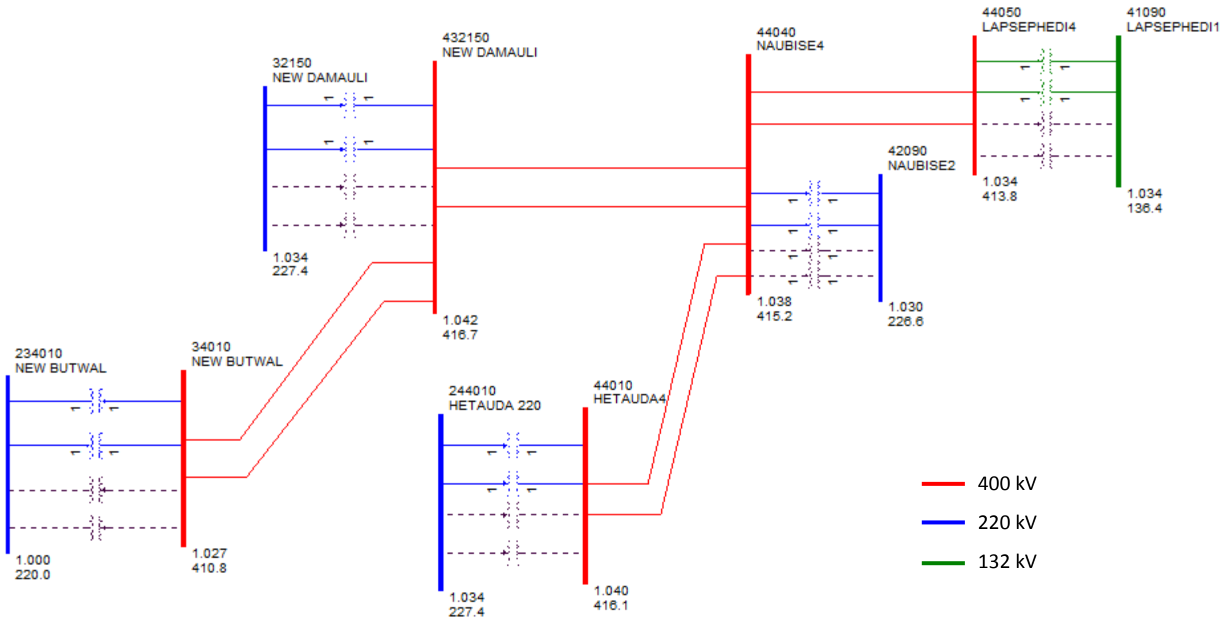


Figure 3.1 Single Line Diagram of NR1

XB1: Second Tie Line to India (from New Butwal to Gorakhpur)

A double circuit 400 kV line from New Butwal (Nepal) to Gorakhpur (India) was included in this project, as shown in Figure 3.2.

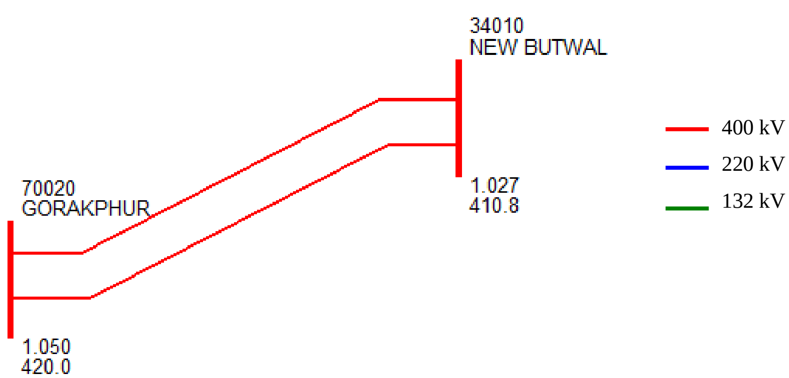


Figure 3.2 Single Line Diagram of XB1

NR3: Ilam-Inaruwa Transmission Line Project

A double circuit 132 kV transmission line from Inaruwa to Ilam was included in the project and the line was connected to the existing stations, as shown in Figure 3.3.

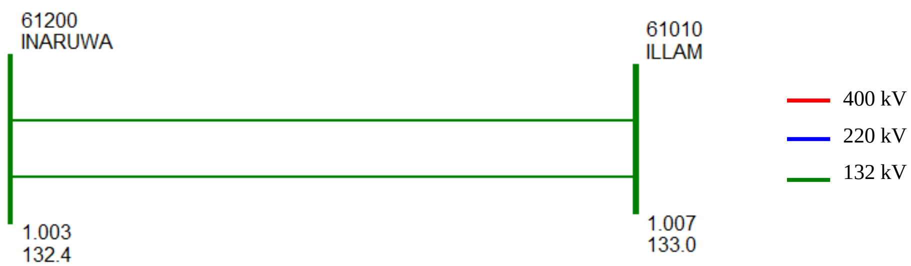


Figure 3.3 Single line diagram of NR3

NR4: Balanch-Attariya Transmission Line Project

One second circuit of the 132 kV transmission line to the existing circuit from Balanch hub to Attariya was included in the project and the line connected to the existing stations, as shown in Figure 3.4.

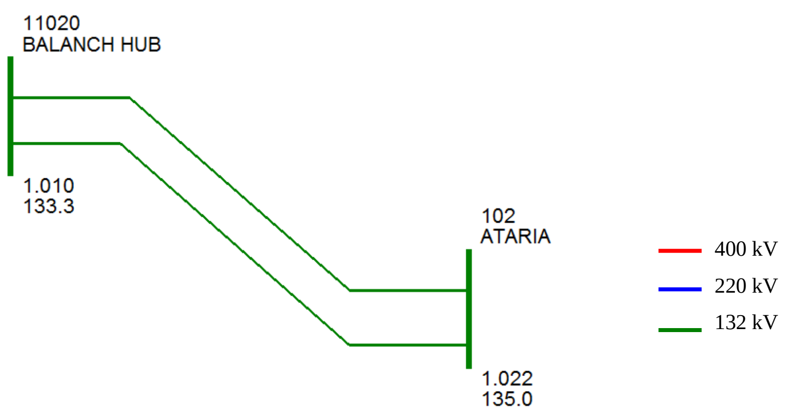


Figure 3.4 Single Line Diagram of NR4

T2': New Khimti – Likhu Hub Transmission Line Project

A double circuit 220 kV transmission line from New Khimti to Likhu hub was included in the project and the New Khimti end of the line was connected to the existing 220 kV substation; the other end of the line was connected to a new 220 kV substation at Likhu, as shown in Figure 3.5. The 220 kV/132 kV transformers at Likhu are also included in the project and the number of transformers required was determined.

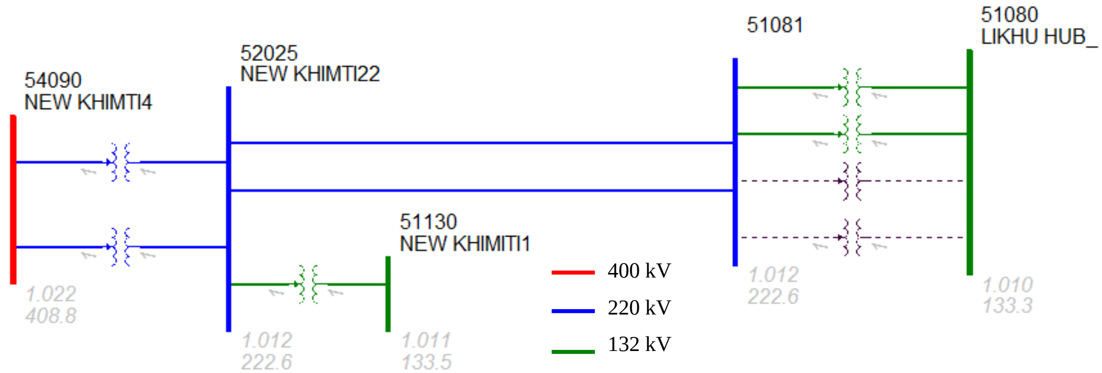


Figure 3.5 Single Line Diagram of T2'

T3: Tadhekani—Kusma Transmission Line Project

A double circuit 220 kV transmission line from Tadhekani to Kusma was included in the project and the Kusma end of the line connected to the existing 220 kV substation; the other end of the line was connected to a new 220 kV substation at Tadhekani, as shown in Figure 3.6. The 220 kV/132 kV transformers at Tadhekani are also included in the project and the number of transformers required was determined.

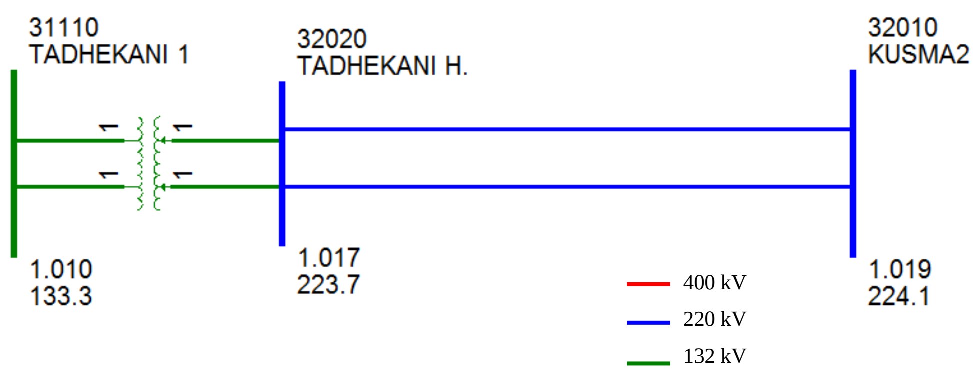


Figure 3.6 Single Line Diagram of T3

T8: New Lamki—Nepal/India Border Transmission Project

T8 is the third cross-border line added to the system. 88% of the generation in Upper Karnali is transferred to India through T8 and the remaining 12% of the power is transferred to Nepal through the existing 132 kV substation at Limki. The power transfer is regulated using a phase shifting transformer connected between the New Limki 400 kV bus and the 132 kV bus. The project is shown in Figure 3.7.

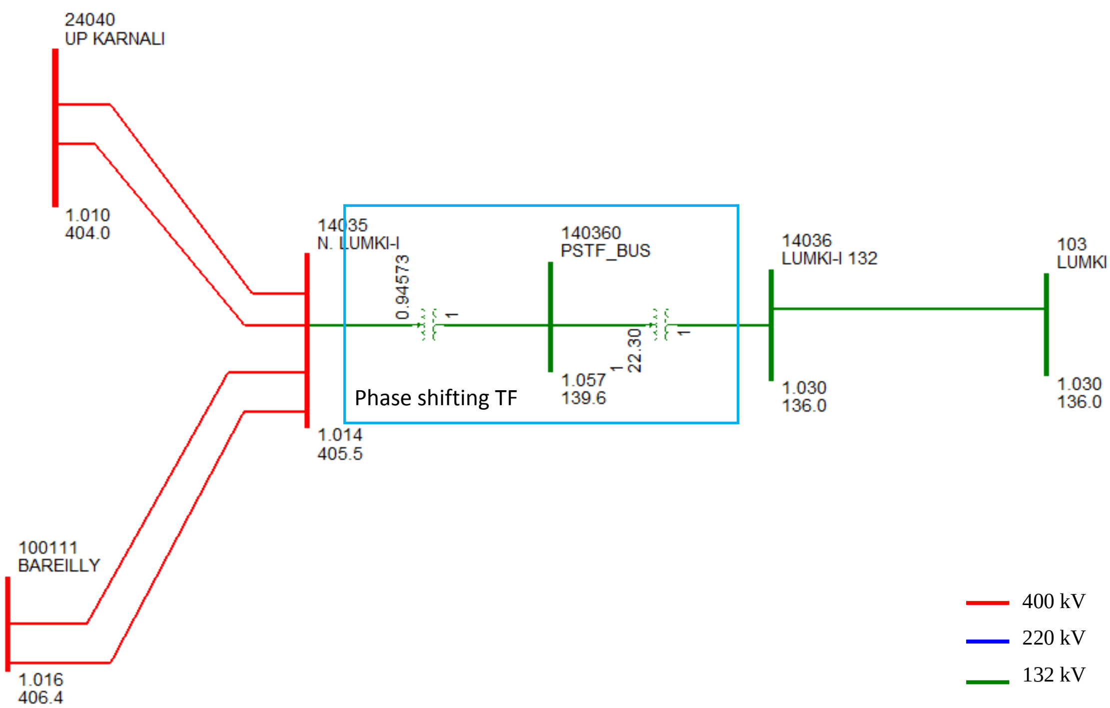


Figure 3.7 Single Line Diagram of T8

3.1.2 Assumptions and Major Considerations

One of the major considerations is the power transfer capabilities of the tie lines to India. As agreed upon, the following transfer limits were considered.

- Dhalkebar-Muzzaffarpur interconnector (1st tie line)
  - Maximum of 700 MW in 2023
  - Maximum of 1200 MW in 2030
- XB1 – second interconnector (considering 40%:60% power distribution between the first tie line and XB1)
  - Maximum of 1050 MW in 2023
  - Maximum of 1800 MW in 2030.

The following assumptions were made:

- It was assumed that the power flows provided by the due diligence team accurately represent the existing system and the system upgrades other than the MCC projects.

- It was not possible to obtain an equivalent model of the India power system. Therefore, the tie line terminals were individually modeled without considering the transfer impedances between the terminals. The power transfers were modeled as described above.

3.1.3 Technical Feasibility Studies

The studies were performed for years 2023 and 2030 considering the counterfactual base cases (CF Base Cases) and the cases with all the MCC projects included. The results are summarized below.

Additional Reactive Power Requirements under System Intact Conditions

The Nepal network (132 kV and below) needs major upgrades in order to handle the load forecast for 2030. The reactive power balancing was performed to obtain the maximum possible support from the generators. However, most of these loads are far away from the generators and needs local reactive power support. The issues reported in this section are not relevant to the MCC projects. The purpose of this section is only to highlight the areas that require addition reactive power compensation.
A detailed reactive power compensation study needs to be done at a later stage including the details of the sub-transmission and distribution system in order to determine the exact amount of reactive power requirement and locations.

The identified issues are summarized below.

(1) In 2030 dry peak scenario, the voltages in the area of Hetauda, Karame, Patha, Parwani and N. Birgunj drops significantly even under system intact conditions (i.e. no contingencies applied) as shown in Figure 29. Note that this issue is not relevant to the MCC projects and just showing the inability of existing network to supply the expected loads in 2030. It was required to add a significant amount of reactive power support in order to solve the low voltage issues. The following changes were made.

    - The capacitive range of the existing switch shunt at Patha was changed from 75 MVAR to 150 MVAR
    - The capacitive range of the existing switch shunt at Parwani was changed from 75 MVAR to 180 MVAR
    - New switch shunt of 150 MVAR was added at Hetauda 132 kV bus.
    - The capacitive reactive power capability of the Bharatpu switch shunt was changed from 75 MVAR to 150 MVAR

The resulted voltages after making the changes are shown in Figure 3.8. The voltages stayed above 0.9 pu (Power Unit).

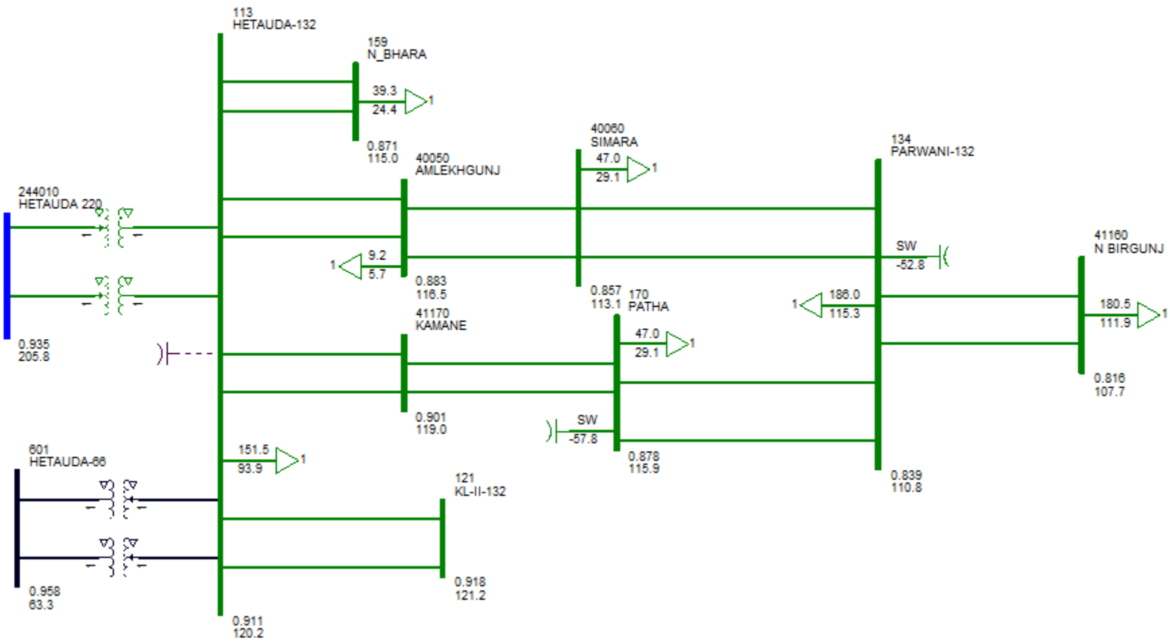


Figure 3.8 Low voltages in the area of Hetauda, Karame, Patha, Parwani and N. Birgunj in 2030 Drypeak Scenario

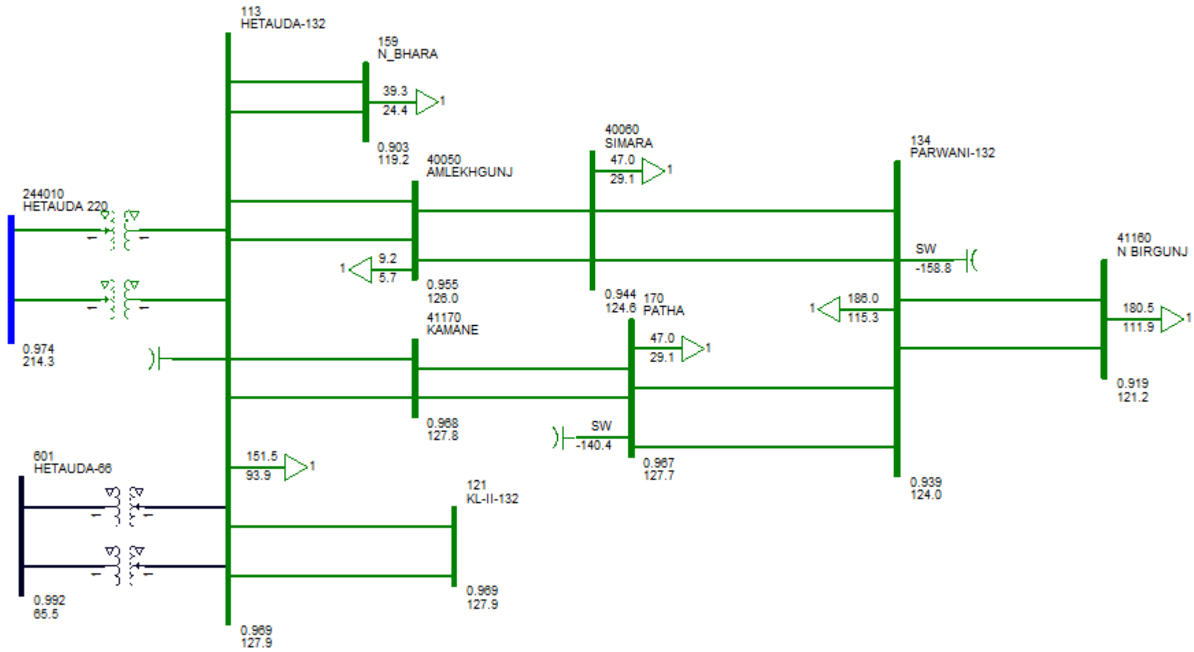


Figure 3.9 Voltage performance in the area of Hetauda, Karame, Patha, Parwani and N. Birgunj in 2030 DryPeak Scenario after adding some additional switch shunts

(2) The network around Inaruwa is heavily loaded in dry peak scenarios and having low voltage issues under system intact and contingency conditions. About 150 MVAR of additional capacitive reactive power compensation is required and the most suitable location was Inaruwa 132 kV bus (terminal of NR3). A 150 MVAR switching shunt was added to this bus. Note that there is an existing switch shunt at Inaruwa 220 kV bus and if required, this can be combined with the existing one and the tap changers (if available) of 220kV/132 kV transformers can be used to control the 132 kV bus voltage.

(3) In 2030 dry peak scenario, the 66 kV network between Siuchata (bus # 610) and N. Bhakta (Bus # 614) was heavily loaded and the power flow could not be solved even under system intact conditions. The network reinforcements in 66 kV and lower network was not considered in this project and therefore, the problem was simply solved by adding reactive power compensation at these buses. The capacitive reactive power capacity of Siuchata switch shunt was increased to 500 MVAR in order to keep the voltage near 1pu. The capacitive reactive power capacity of N. Bhakta switch shunt was increased to 150 MVAR in order to keep the voltage near 1pu. Note that this issue is also not relevant to the MCC projects and just demonstrates the inability of existing network to supply the expected loads in 2030.

3.1.4 Loss Evaluation

Table 3.1 provides a summary of losses in each zone, generation, total loads supplied, power import from India and power export to India. In the wet min scenarios, the transmission losses reduced when the MCC projects were added. For example, the transmission losses reduced from 3.3% to 2.8% in 2030 wetmin scenario.
Since the loadings in the dry peak cases with and without MCC projects are different, the losses cannot be compared each other. For example in 2030 dry peak case, the losses were changed from 79.1 MW to 176.7 MW when MCC projects are introduced. In this case, the loads supplied were almost doubled and about 3000 MW was imported for India. Most of the losses were reported in zones 3, 4 and 5.
The losses in each voltage level in these zones are compared in Table 3.2 for 2030 Drypeak scenarios. The 400 kV system losses are negligible compared to the other losses. Most of significant difference between the losses were reported in the 132 kV system and the increased loads were responsible for this.

Table 3.1 Steady State Transmission Losses

Case Name	Zone Losses (MW)								Nepal Total Loss (MW)	Nepal Generation (MW)	Loads supplied (MW)	Nepal Imports* (MW)	Nepal Exports (MW)	T8 Project		% Transmission Losses
	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7 (Two tie lines to India)	Zone 8 (Upper Karnali)						Generation (MW)	Exports to India (MW)	
CF 2023 Dry Peak	1	1.1	5.8	15.6	8.0	1.8	1.1	-	33.4	1016.6	1682.1	698.9				1.9%
MCC ALL 2023 Dry Peak	1.1	2.1	14.2	26.7	13.8	4.7	4.1	0.3	66.7	1170.6	2573.4	1469.5		270	237	2.53%
CF 2023 Wet Min	2.9	0.8	5.8	23.4	7.2	2.2	0.5	-	42.3	1814.6	1287		485.3			2.3%
MCC ALL 2023 Wet Min	3.7	1.7	9.2	11.2	6.6	1.8	5.8	2.7	42.7	2385.9	1286.7	108	1164.5	900	786	1.71%
CF 2030 Dry Peak	1.1	2.3	13.1	38.9	16.5	3.5	3.6	-	75.4	1286.7	2407.7	1196.4				3.0%
MCC ALL 2030 Dry Peak	2.6	6.7	42.5	73.3	35.5	11.7	17.4	0.3	189.7	1433.1	4273.4	3030		270	237	4.25%
CF 2030 Wet Min	14.8	2.4	20.7	46.4	14.9	7.3	2.3	-	106.5	3231.3	2137.7		987.2			3.3%
MCC ALL 2030 Wet Min	16.4	3.4	34.5	32	23.8	9.8	15.9	2.8	135.8	4735.2	2136.7	108	2570.7	900	786	2.80%

**Imports from T8 (Upper Karnali) included*

Table 3.2 Losses in Zones 3, 4 and 5 for 2030 Drypeak Scenario

Case Name	400 kV	220 kV	132 kV	66 kV
CF 2030 Drypeak (MW)	-	10.7	33.8	17.3
MCC ALL 2030 Drypeak (MW)	6.8	15	81.1	39.2

Estimation of line reactors to limit open circuit voltages

The requirement to have line reactors to limit the open circuit voltages of transmission lines was studied using the Bergeron transmission line model in PSCAD (Electromagnetic transient simulation software). The longest transmission lines of 400kV (127 km, Hetauda—Dhalke), 220kV (230 km, Kohalpur—New Butwal) and 132kV (131 Km, Balanch—Ataria) were selected for the study.

Error! Reference source not found..10 shows the open circuit voltages of the 3 transmission lines entioned above. The sending end voltages were set to 1.05 pu. The open circuit voltages observed at the open end are less than 1.1pu in all cases. Therefore, no reactors are required during line energization.

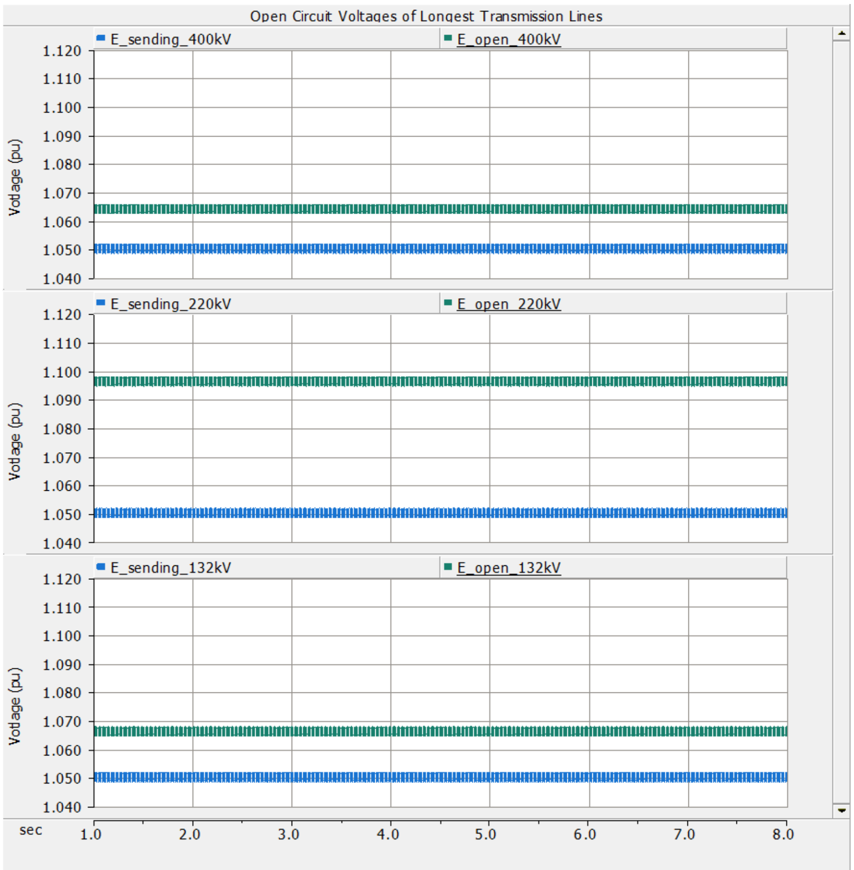


Figure 3.10 Open circuit voltages of longest transmission lines (400kV, 220kV and 132kV)

3.1.5 Steady State Contingency Analysis

The steady state contingency analysis was performed using “ACCC” utility in PSS®E for the N-1 and N-2 contingencies defined in the methodology.

Required Number of Transformers in MCC Projects

First, the study was performed with the following transformers of the MCC projects included.

Table 3.3 Initial number of transformers considered at MCC projects

Project	Station	Transformer	Rating (MVA)	Number of TFs
NR1	New Butwal	400 kV/220 kV	160	2
	New Damauli	400 kV/220 kV	160	2
	Naubise	400 kV/220 kV	160	2
	Hetauda	400 kV/220 kV	160	2
	Lapsiphedi	400 kV/220 kV	160	2
NR3	Inaruwa	220 kV/132 kV	160	2
T2'	New Khimti	400 kV/220 kV	160	2
	Likhu Hub	220 kV/132 kV	160	2
T3	Tadhekani	220 kV/132 kV	160	2
T8	New Lamki	One 400 kV/132 kV 160MVA phase shifting TF		

The MCC transformer overloads reported from the studies are given in Table 3.5. There are significant overloads reported for most of the transformers and it would be necessary to consider the following number of transformers in order to avoid the overloads. Note that for the 400 kV/220 kV transformers at New Butwal, the overloads under the N-2 contingency of New Butwal –Damauli 400 kV line were not considered. It is not possible to transfer all imports (1800 MW) into the 220 kV system and therefore, a reduction of imports /load shedding would be required under this contingency.

Table 3.4 Required number of transformers to avoid overloads

Project	Station	Transformer	Rating (MVA)	Number of TFs
NR1	New Butwal	400 kV/220 kV	160	5
	New Damauli	400 kV/220 kV	160	4
	Naubise	400 kV/220 kV	160	3
	Hetauda	400 kV/220 kV	160	3
	Lapsiphedi	400 kV/220 kV	160	3
NR3	Inaruwa	220 kV/132 kV	160	3
T2'	New Khimti	400 kV/220 kV	160	3
	Likhu Hub	220 kV/132 kV	160	3
T3	Tadhekani	220 kV/132 kV	160	2
T8	New Limki	One 400 kV/132 kV 160MVA phase shifting TF		

The steady state contingency analysis was repeated with the aforementioned modifications to the number of transformers. The results are summarized in the next sections.

Table 3.5 Overloads of Transformers of the MCC Projects (with initial number of transformers)

Project	Overloaded Transformer							Worst Contingency			No contingency Overloads (%)	MVA Rating of TF
	Bus-1			Bus-2			CKT ID					
	No	Name	Base kV	No	Name	Base kV		Powerflow	Contingency	% loading		
NR1	32150	NEW DAMAULI	220	432150	NEW DAMAULI	400	1	2030_Wetmin	(N-1): 32150-432150(2)	298.424	178.021	160.000
	32150	NEW DAMAULI	220	432150	NEW DAMAULI	400	2	2030_Wetmin	(N-1): 32150-432150(1)	298.424	178.021	160.000
	34010	NEW BUTWAL	400	234010	NEW BUTWAL	220	2	2030_Drypeak	(N-2): NR1_DAMUL_BUTWA	528.433	196.828	160.000
	34010	NEW BUTWAL	400	234010	NEW BUTWAL	220	1	2030_Drypeak	(N-2): NR1_DAMUL_BUTWA	528.433	196.828	160.000
	41090	LAPSIPHEDI1	132	44050	LAPSIPHEDI4	400	2	2030_Drypeak	(N-1): 41090-44050(1)	187.843	116.361	160.000
	41090	LAPSIPHEDI1	132	44050	LAPSIPHEDI4	400	1	2030_Drypeak	(N-1): 41090-44050(2)	187.843	116.361	160.000
	44010	HETAUDA4	400	244010	HETAUDA 220	220	2	2030_Drypeak	(N-1): 44010-244010(1)	188.109	123.244	160.000
	44010	HETAUDA4	400	244010	HETAUDA 220	220	1	2030_Drypeak	(N-1): 44010-244010(2)	188.109	123.244	160.000
	42090	NAUBISE2	220	44040	NAUBISE4	400	1	2030_Wetmin	(N-2): NR1_NAUB_LAPSE	156.332	-	160.000
	42090	NAUBISE2	220	44040	NAUBISE4	400	3	2030_Wetmin	(N-2): NR1_NAUB_LAPSE	156.332	-	160.000
NR3	61200	INARUWA	132	62020	INARUWA2	220	2	2030_Drypeak	(N-1): 61200-62020(1)	233.200	130.501	160.000
	61200	INARUWA	132	62020	INARUWA2	220	1	2030_Drypeak	(N-1): 61200-62020(2)	233.200	130.501	160.000
T2'	51080	LIKHU HUB_	132	51081	LIKHU 220	220	1	2023_Wetmin	(N-1): 51080-51081(2)	211.464	105.562	160.000
	51080	LIKHU HUB_	132	51081	LIKHU 220	220	2	2023_Wetmin	(N-1): 51080-51081(1)	211.464	105.562	160.000
	52025	NEW KHIMTI22	220	54090	NEW KHIMTI4	400	1	2023_Wetmin	(N-1): 52025-54090(2)	228.246	111.272	160.000
	52025	NEW KHIMTI22	220	54090	NEW KHIMTI4	400	2	2023_Wetmin	(N-1): 52025-54090(1)	228.246	111.272	160.000
T3	31110	TADHEKANI 1	132	32020	TADHEKANI H.	220	2	2023_Wetmin	(N-1): 31110-32020(1)	118.311	-	160.000
	31110	TADHEKANI 1	132	32020	TADHEKANI H.	220	1	2023_Wetmin	(N-1): 31110-32020(2)	118.311	-	160.000

Diverged Power flow Cases for N-1 Contingencies

During the contingency analysis procedures, three contingencies diverged for the 2030 drypeak case that could not be fixed and solved.

The first contingency that could not be fixed is the loss of the transmission line between buses 107 and 108. Figure 3.11 illustrates the system's configuration during normal operating conditions. This diagram illustrates that over half of the power required by the load at bus 107 is provided by the line between buses 107 and 108. Furthermore, this diagram illustrates that the voltage at bus 107 is already close to the lower operating limit of 0.9 pu during normal operating conditions. It was found that even though there is alternative transmission path to bus 107, there is not enough voltage support available when the system is heavily loaded. Therefore, the voltage at bus 107 quickly collapses and the power flow solution diverges.

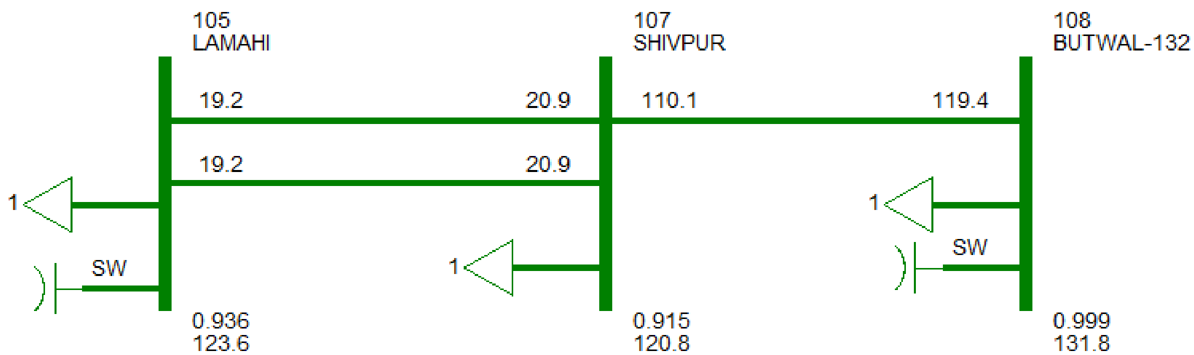


Figure 3.11 System configuration near transmission line 107-108 (1)

The second and third contingencies that could not be fixed are the loss of either one of the transmission lines connecting buses 52010 and 62020. Figure 33 illustrates the system's configuration during normal operating conditions. This diagram illustrates that the double circuit transmission path between buses 52010 and 62020 provides the majority of the power coming into bus 62020. Furthermore, the system voltages are already near the lower limit of 0.9 pu during normal operating conditions. It was found that there is not enough voltage support on the Inaruwa side of the system when a single transmission line between buses 52010 and 62020 is tripped. As the result, the system voltages collapse and the power flow solution diverges.

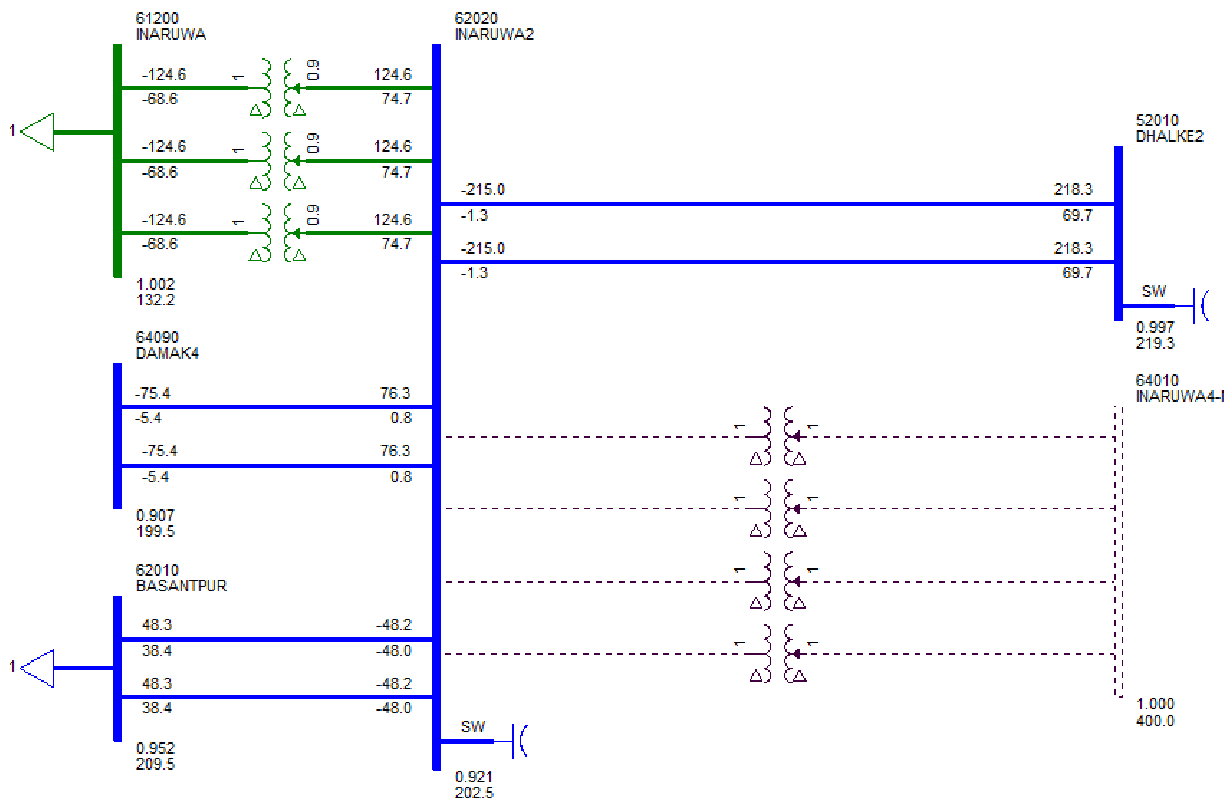


Figure 3.12 System configuration near transmission lines 52010-62020 (1) and (2)

The solution for all of these issues would be to add parallel lines to the lines tripped. Note that none of these issues are related to the MCC projects.

Transformer Loadings under N-1 Contingencies – MCC Projects

The loadings of the transformers of the MCC projects are given in Table 3.6 for N-1 contingencies. When the number of transformers are increased to the aforementioned numbers, the transformer overloads stay within 120%.

Table 3.6 Loading of Transformers of the MCC Projects for N-1 Contingencies (with the proposed of transformers)

Project	Overloaded Component							Worst Contingency			NO Contingency Overload (%)	MVA rating
	Bus 1			Bus 2			CKT ID					
	from Bus	Bus Name	kV	to Bus	Bus Name	kV		Power flow	Contingency	Loading (%)		
NR1	34010	NEW BUTWAL	400	234010	NEW BUTWAL	220	1	2030 Dry Peak	SINGLE 34010-234010(2)	100.8	0.0	160
	34010	NEW BUTWAL	400	234010	NEW BUTWAL	220	2	2030 Dry Peak	SINGLE 34010-234010(1)	100.8	0.0	160
	34010	NEW BUTWAL	400	234010	NEW BUTWAL	220	3	2030 Dry Peak	SINGLE 34010-234010(1)	100.8	0.0	160
	34010	NEW BUTWAL	400	234010	NEW BUTWAL	220	4	2030 Dry Peak	SINGLE 34010-234010(1)	100.8	0.0	160
	34010	NEW BUTWAL	400	234010	NEW BUTWAL	220	5	2030 Dry Peak	SINGLE 34010-234010(1)	100.8	0.0	160
	41090	LAPSIPHEDI1	132	44050	LAPSIPHEDI4	400	1	2030 Dry Peak	SINGLE 41090-44050(2)	85.0	0.0	160
	41090	LAPSIPHEDI1	132	44050	LAPSIPHEDI4	400	2	2030 Dry Peak	SINGLE 41090-44050(1)	85.0	0.0	160
	41090	LAPSIPHEDI1	132	44050	LAPSIPHEDI4	400	3	2030 Dry Peak	SINGLE 41090-44050(1)	85.0	0.0	160
	44010	HETAUDA4	400	244010	HETAUDA 220	220	1	2030 Dry Peak	SINGLE 44010-244010(2)	88.1	0.0	160
	44010	HETAUDA4	400	244010	HETAUDA 220	220	2	2030 Dry Peak	SINGLE 44010-244010(1)	88.1	0.0	160
	44010	HETAUDA4	400	244010	HETAUDA 220	220	3	2030 Dry Peak	SINGLE 44010-244010(1)	88.1	0.0	160
	32150	NEW DAMAULI	220	432150	NEW DAMAULI	400	1	2030 Wet Min	SINGLE 32150-432150(2)	87.9	0.0	160

Project	Overloaded Component							Worst Contingency			NO Contingency Overload (%)	MVA rating
	Bus 1			Bus 2			CKT ID					
	from Bus	Bus Name	kV	to Bus	Bus Name	kV		Power flow	Contingency	Loading (%)		
	32150	NEW DAMAULI	220	432150	NEW DAMAULI	400	2	2030 Wet Min	SINGLE 32150-432150(1)	87.9	0.0	160
	32150	NEW DAMAULI	220	432150	NEW DAMAULI	400	3	2030 Wet Min	SINGLE 32150-432150(1)	87.9	0.0	160
	32150	NEW DAMAULI	220	432150	NEW DAMAULI	400	4	2030 Wet Min	SINGLE 32150-432150(1)	87.9	0.0	160
NR3	61200	INARUWA	132	62020	INARUWA2	220	1	2030 Dry Peak	SINGLE 61200-62020(2)	100.8	0.0	160
	61200	INARUWA	132	62020	INARUWA2	220	2	2030 Dry Peak	SINGLE 61200-62020(1)	100.8	0.0	160
	61200	INARUWA	132	62020	INARUWA2	220	3	2030 Dry Peak	SINGLE 61200-62020(1)	100.8	0.0	160
T2’	51080	LIKHU HUB_	132	51081		220	1	2023 Wet Min	SINGLE 51080-51081(2)	106.1	0.0	160
	51080	LIKHU HUB_	132	51081		220	2	2023 Wet Min	SINGLE 51080-51081(1)	106.1	0.0	160
	51080	LIKHU HUB_	132	51081		220	3	2023 Wet Min	SINGLE 51080-51081(1)	106.1	0.0	160
	52025	NEW KHIMTI22	220	54090	NEW KHIMTI4	400	1	2023 Wet Min	SINGLE 52025-54090(2)	111.3	0.0	160
	52025	NEW KHIMTI22	220	54090	NEW KHIMTI4	400	2	2023 Wet Min	SINGLE 52025-54090(1)	111.3	0.0	160
	52025	NEW KHIMTI22	220	54090	NEW KHIMTI4	400	3	2023 Wet Min	SINGLE 52025-54090(1)	111.3	0.0	160
T3	31110	TADHEKANI 1	132	32020	TADHEKANI H.	220	1	2023 Wet Min	SINGLE 31110-32020(2)	118.6	0.0	160
	31110	TADHEKANI 1	132	32020	TADHEKANI H.	220	2	2023 Wet Min	SINGLE 31110-32020(1)	118.6	0.0	160

Transmission Line Loadings under N-1 Contingencies – MCC Projects

The ratings of the lines were determined based on the information given in Table 3.7. The transmission line loadings are summarized in Table 30.

Table 3.7 Specified current ratings of transmission lines

Voltage	Ampacity rating/phase
400kV	4xmoose ACSR 3143A/phase
220kV	2xBison ACSR 1285.4A/phase
132kV	NR3: 1xBison ACSR 642.7A NR4: 1xBear ACSR 567.7A/phase

There is only one overload recorded in the contingency analysis. In NR4 project, the 132 kV line get an overload of about 117% in 2030 scenarios due to the extra power generation in Balanch Hub. It is recommended to re-conductor the 1 x Bear ACSR to HTLS (High Temperature Low Sag) conductor in future when line load exceeds the 100% capacity of Bear ACSR in order to increase the power transmission capacity of the line for N-1 contingency.

In NR1 project, the 400 kV lines are lightly loaded even under N-1 conditions. Therefore, there is a possibility of using a lower rated line configuration for this project.

Table 3.8 Loading of Transmission Lines of the MCC Projects for N-1 Contingencies

MCC Project	Monitoring Branch	Voltage (kV)	Rating		Maximum Loading	
			kA	MVA	MVA	%
NR4	102 ATARIA 132.00 11020 BALANCH HUB 132.00 1	132	0.52	129.00	151.37	117.20%
	102 ATARIA 132.00 11020 BALANCH HUB 132.00 2	132	0.52	129.00	151.37	117.20%
T8	14035 N. LAMKI-I 400.00 24040 UP KARNALI 400.00 1	400	3.14	2177.53	900.08	41.34%
	14035 N. LAMKI-I 400.00 24040 UP KARNALI 400.00 2	400	3.14	2177.53	900.08	41.34%
	14035 N. LAMKI-I 400.00 100111 BAREILLY 400.00 1	400	3.14	2177.53	789.20	36.24%
	14035 N. LAMKI-I 400.00 100111 BAREILLY 400.00 2	400	3.14	2177.53	789.20	36.24%
T3	32010 KUSMA2 220.00 32020 TADHEKANI H.220.00 1	220	1.29	489.65	188.79	38.56%
	32010 KUSMA2 220.00 32020 TADHEKANI H.220.00 2	220	1.29	489.65	188.79	38.56%
XB1	34010 NEW BUTWAL 400.00 70020 GORAKPHUR 400.00 1	400	3.14	2177.53	1713.57	78.69%
	34010 NEW BUTWAL 400.00 70020 GORAKPHUR 400.00 2	400	3.14	2177.53	1713.57	78.69%
NR1	34010 NEW BUTWAL 400.00 432150 NEW DAMAULI 400.00 1	400	3.14	2177.53	829.43	38.09%
	34010 NEW BUTWAL 400.00 432150 NEW DAMAULI 400.00 2	400	3.14	2177.53	826.43	38.09%
	44010 HETAUDA4 400.00 44040 NAUBISE4 400.00 1	400	3.14	2177.53	351.21	16.13%
	44010 HETAUDA4 400.00 44040 NAUBISE4 400.00 2	400	3.14	2177.53	351.21	16.13%
	44010 HETAUDA4 400.00 54010 DHALKE4-NP 400.00 1	400	3.14	2177.53	367.30	16.87%
	44010 HETAUDA4 400.00 54010 DHALKE4-NP 400.00 2	400	3.14	2177.53	367.30	16.87%
	44040 NAUBISE4 400.00 44050 LAPSIPHEDI4 400.00 1	400	3.14	2177.53	581.50	26.70%
	44040 NAUBISE4 400.00 44050 LAPSIPHEDI4 400.00 2	400	3.14	2177.53	581.50	26.70%
	44040 NAUBISE4 400.00 432150 NEW DAMAULI 400.00 1	400	3.14	2177.53	563.89	25.90%
	44040 NAUBISE4 400.00 432150 NEW DAMAULI 400.00 2	400	3.14	2177.53	563.89	25.90%
T2'	51081 220.00 52025 NEW KHIMTI22220.00 1	220	1.29	489.65	338.33	69.10%

MCC Project	Monitoring Branch	Voltage (kV)	Rating		Maximum Loading	
			kA	MVA	MVA	%
	51081 220.00 52025 NEW KHIMTI22220.00 2	220	1.29	489.65	338.33	69.10%
Tieline1	54010 DHALKE4-NP 400.00 70010 MUZZAFA 400.00 1	400	3.14	2177.53	1202.85	55.24%
	54010 DHALKE4-NP 400.00 70010 MUZZAFA 400.00 2	400	3.14	2177.53	1202.85	55.24%
NR3	61010 ILLAM 132.00 61200 INARUWA 132.00 1	132	0.64	146.94	38.93	26.49%
	61010 ILLAM 132.00 61200 INARUWA 132.00 2	132	0.64	146.94	38.93	26.49%

Overloads in Existing System under N-1 Contingencies

The overloads of the existing system transformers are given in Table 3.9. The overloads are not significant and the maximum loading is about 115%.

The overloads of the existing system transmission lines are given in Table 3.10. The mitigation measures are further discussed in the following sections.

Table 3.9 Overloads of non- MCC project transformers for n-1 contingencies (overloads above 100%)

Overloaded Transformer							Worst Contingency			MVA Rating of TF
Bus-1			Bus-2							
No	Name	Base kV	No	Name	Base kV	CKT ID	Power flow	Contingency	% loading	
108	BUTWAL-132	132	234010	NEW BUTWAL	220	1	2030 Dry Peak	SINGLE 108-234010(2)	114.054	500
108	BUTWAL-132	132	234010	NEW BUTWAL	220	2	2030 Dry Peak	SINGLE 108-234010(1)	114.054	500
114	DHALKE-132	132	52010	DHALKE2	220	1	2030 Dry Peak	SINGLE 114-52010(2)	115.050	600
114	DHALKE-132	132	52010	DHALKE2	220	2	2030 Dry Peak	SINGLE 114-52010(1)	115.050	600
122	SIUCH	132	610	SIUCHATA	66	1	2030 Dry Peak	SINGLE 122-610(3)	112.783	200

122	SIUCH	132	610	SIUCHATA	66	2	2030 Dry Peak	SINGLE 122-610(1)	109.991	200
122	SIUCH	132	610	SIUCHATA	66	3	2030 Dry Peak	SINGLE 122-610(1)	109.102	200
130	N-BHAKTA-132	132	614	N-BHAKTA-66	66	1	2030 Dry Peak	SINGLE 130-614(2)	102.509	100
130	N-BHAKTA-132	132	614	N-BHAKTA-66	66	2	2030 Dry Peak	SINGLE 130-614(1)	102.509	100
130	N-BHAKTA-132	132	614	N-BHAKTA-66	66	3	2030 Dry Peak	SINGLE 130-614(1)	102.509	100
52010	DHALKE2	220	54010	DHALKE4-NP	400	1	2030 Dry Peak	SINGLE 52010-54010(2)	104.707	500
52010	DHALKE2	220	54010	DHALKE4-NP	400	2	2030 Dry Peak	SINGLE 52010-54010(1)	104.707	500
52010	DHALKE2	220	54010	DHALKE4-NP	400	3	2030 Dry Peak	SINGLE 52010-54010(1)	104.707	500

Table 3.10 Overloads of non-MCC project transmission lines for n-1 contingencies (overloads above 100%)

Overloaded Component							Worst Contingency			NO Contingency Overload (%)	MVA Rating	Comments
Bus 1			Bus 2			CKT ID						
from Bus	Bus Name	kV	to Bus	Bus Name	kV		Power flow	Contingency	Loading (%)			
108	BUTWAL-132	132	31190	BAIRAHAWA	132	1	2030 Dry Peak	SINGLE 108-31190(2)	121.487	-	159.130	
108	BUTWAL-132	132	31190	BAIRAHAWA	132	2	2030 Dry Peak	SINGLE 108-31190(1)	121.487	-	159.130	
112	BHARATPU-132	132	159	N_BHARA	132	1	2030 Dry Peak	SINGLE 112-159(2)	128.444	-	123.970	
112	BHARATPU-132	132	159	N_BHARA	132	2	2030 Dry Peak	SINGLE 112-159(1)	128.444	-	123.970	
113	HETAUDA-132	132	40050	AMLEKHGUNJ	132	1	2030 Dry Peak	SINGLE 113-40050(2)	123.658	-	186.000	
113	HETAUDA-132	132	40050	AMLEKHGUNJ	132	2	2030 Dry Peak	SINGLE 113-40050(1)	123.658	-	186.000	
114	DHALKE-132	132	1115	MIRCHAY	132	1	2030 Dry Peak	SINGLE 114-1115(2)	151.426	103.568	123.970	It is recommended to add another circuit. This is not relevant to MCC projects
114	DHALKE-132	132	1115	MIRCHAY	132	2	2030 Dry Peak	SINGLE 114-1115(1)	151.426	103.568	123.970	
114	DHALKE-132	132	1115	MIRCHAY	132	3	2030 Dry Peak	SINGLE 114-1115(1)	151.426	103.568	123.970	

Overloaded Component							Worst Contingency			NO Contingency Overload (%)	MVA Rating	Comments
Bus 1			Bus 2			CKT ID						
from Bus	Bus Name	kV	to Bus	Bus Name	kV		Power flow	Contingency	Loading (%)			
115	LAHAN	132	124	KUSHAHA	132	1	2030 Dry Peak	SINGLE 52010-62020(1)	108.373	-	123.970	
115	LAHAN	132	1115	MIRCHAY	132	1	2030 Dry Peak	SINGLE 115-1115(2)	125.676	-	142.000	
115	LAHAN	132	1115	MIRCHAY	132	2	2030 Dry Peak	SINGLE 115-1115(1)	125.676	-	142.000	
115	LAHAN	132	1115	MIRCHAY	132	3	2030 Dry Peak	SINGLE 115-1115(1)	125.676	-	142.000	
115	LAHAN	132	51070	RAJBIRAJ_	132	1	2023 Dry Peak	SINGLE 115-51070(2)	149.349	-	27.090	This is not relevant to MCC projects. It is recommended to add a third circuit.
115	LAHAN	132	51070	RAJBIRAJ_	132	2	2023 Dry Peak	SINGLE 115-51070(1)	149.349	-	27.090	
115	LAHAN	132	61200	INARUWA	132	1	2030 Dry Peak	SINGLE 52010-62020(2)	105.068	-	123.970	
116	DUHABI-132	132	61200	INARUWA	132	1	2030 Dry Peak	SINGLE 116-61200(2)	106.559	-	228.000	
116	DUHABI-132	132	61200	INARUWA	132	2	2030 Dry Peak	SINGLE 116-61200(1)	106.559	-	228.000	
117	ANARMANI-132	132	175	DAMAK	132	1	2030 Dry Peak	SINGLE 117-175(2)	115.748	-	123.970	
117	ANARMANI-132	132	175	DAMAK	132	2	2030 Dry Peak	SINGLE 117-175(1)	115.748	-	123.970	
118	MARSHYAN	132	159	N_BHARA	132	1	2030 Dry Peak	SINGLE 119-158(1)	113.787	100.163	180.000	
122	SIUCH	132	133	MATATRIT	132	1	2030 Dry Peak	SINGLE 122-133(3)	118.948	-	228.000	
122	SIUCH	132	133	MATATRIT	132	3	2030 Dry Peak	SINGLE 122-133(1)	118.948	-	228.000	
129	LAMOSANG	132	41100	BARABISE1	132	1	2030 Wet Min	SINGLE 129-41100(2)	123.777	-	186.000	
129	LAMOSANG	132	41100	BARABISE1	132	2	2030 Wet Min	SINGLE 129-41100(1)	123.777	-	186.000	
131	CHAPALI	132	41080	MULPANI	132	1	2030 Dry Peak	SINGLE 131-41080(2)	105.242	-	159.130	
131	CHAPALI	132	41080	MULPANI	132	2	2030 Dry Peak	SINGLE 131-41080(1)	105.242	-	159.130	
134	PARWANI-132	132	170	PATHA	132	1	2030 Dry Peak	SINGLE 134-170(2)	116.735	-	142.000	
134	PARWANI-132	132	170	PATHA	132	2	2030 Dry Peak	SINGLE 134-170(1)	116.735	-	142.000	

Overloaded Component							Worst Contingency			NO Contingency Overload (%)	MVA Rating	Comments
Bus 1			Bus 2			CKT ID						
from Bus	Bus Name	kV	to Bus	Bus Name	kV		Power flow	Contingency	Loading (%)			
134	PARWANI-132	132	40060	SIMARA	132	1	2030 Dry Peak	SINGLE 134-40060(2)	143.145	-	123.970	This overload is not a result of MCC projects. It is recommended to upgrade to a 3 CCT line.
134	PARWANI-132	132	40060	SIMARA	132	2	2030 Dry Peak	SINGLE 134-40060(1)	143.145	-	123.970	
134	PARWANI-132	132	41160	N BIRGUNJ	132	1	2030 Dry Peak	SINGLE 134-41160(2)	172.191	-	123.970	This is not relevant to MCC projects. Low voltage issues also observed in this area. Therefore it is recommended to add a third circuit.
134	PARWANI-132	132	41160	N BIRGUNJ	132	2	2030 Dry Peak	SINGLE 134-41160(1)	172.191	-	123.970	
601	HETAUDA-66	66	602	KL-I-66	66	1	2030 Dry Peak	SINGLE 601-602(2)	100.716	-	100.000	
601	HETAUDA-66	66	602	KL-I-66	66	2	2030 Dry Peak	SINGLE 601-602(1)	100.716	-	100.000	
602	KL-I-66	66	610	SIUCHATA	66	1	2030 Dry Peak	SINGLE 602-610(2)	107.511	-	77.000	
602	KL-I-66	66	610	SIUCHATA	66	2	2030 Dry Peak	SINGLE 602-610(1)	107.511	-	77.000	
610	SIUCHATA	66	611	BALAJU-66	66	1	2030 Dry Peak	SINGLE 610-611(1)	167.012	-	100.000	It is recommended to add another circuit. This is not relevant to MCC projects
610	SIUCHATA	66	611	BALAJU-66	66	2	2030 Dry Peak	SINGLE 610-611(2)	167.012	-	100.000	
610	SIUCHATA	66	616	NEW PATAN	66	1	2030 Dry Peak	SINGLE 610-616(2)	194.686	104.275	100.000	This overload is not a result of MCC projects. Outage of a single cct fom New Patan to Siuchata results in transmitting about 150 MW to serve loads in New Patan and New Baneswor. It is recommended to upgrade to a 3 CCT line. That will result in only 102% overload at the outage of a single circuit.
610	SIUCHATA	66	616	NEW PATAN	66	2	2030 Dry Peak	SINGLE 610-616(1)	194.686	104.275	100.000	
610	SIUCHATA	66	630	TEKU	66	2	2023 Dry Peak	SINGLE 610-700(1)	139.517	-	100.000	This overload is not a result of MCC projects. Under the outage of s/c line from DUMTEKU to K-3, the line from Teku to Siucha is overloaded to transmit power to the loads at K-3 and Teku. This line overload can be resolved by upgrading the line

Overloaded Component							Worst Contingency			NO Contingency Overload (%)	MVA Rating	Comments
Bus 1			Bus 2			CKT ID						
from Bus	Bus Name	kV	to Bus	Bus Name	kV		Power flow	Contingency	Loading (%)			
												from Teku to Siucha to a double circuit line.
610	SIUCHATA	66	700	DUMTEKU	66	1	2030 Dry Peak	SINGLE 610-630(2)	127.238	-	200.000	
613	CHABEL	66	619	DEVIGHAT-66	66	1	2030 Dry Peak	SINGLE 613-614(1)	159.824	-	40.000	This overload is not a result of MCC projects. The rating of this line is only about 40 MVA. This overload can be resolved if this line is reconductored to increase the rating to about 60 MVA.
614	N-BHAKTA-66	66	615	NEW BANESWOR	66	1	2023 Dry Peak	SINGLE 615-616(1)	107.197	-	100.000	
615	NEW BANESWOR	66	616	NEW PATAN	66	1	2030 Dry Peak	SINGLE 130-614(1)	152.158	-	100.000	It is recommended to add another circuit. This is not relevant to MCC projects
630	TEKU	66	631	K-3	66	1	2030 Dry Peak	SINGLE 610-630(2)	138.666	-	100.000	This overload is not a result of MCC projects. It is recommended to upgrade to a 2 CCT line.
631	K-3	66	700	DUMTEKU	66	1	2030 Dry Peak	SINGLE 610-630(2)	127.295	-	200.000	
40050	AMLEKHGUNJ	132	40060	SIMARA	132	1	2030 Dry Peak	SINGLE 40050-40060(2)	117.614	-	186.000	
40050	AMLEKHGUNJ	132	40060	SIMARA	132	2	2030 Dry Peak	SINGLE 40050-40060(1)	117.614	-	186.000	
41080	MULPANI	132	41090	LAPSIPHEDI1	132	1	2030 Dry Peak	SINGLE 41080-41090(2)	152.208	-	186.000	Transfers all the power from NR1-Lapsehphedi to Mulpani. The outage of one circuit forces to transmit over 300 MW in single circuit that results in overload. It is recommended to upgrade to a 3 CCT line.
41080	MULPANI	132	41090	LAPSIPHEDI1	132	2	2030 Dry Peak	SINGLE 41080-41090(1)	152.208	-	186.000	

Voltage Violations

No over voltage violations were identified in the steady state contingency analysis. The low voltage (<0.9 pu) given in Table 3.11 were reported for the N-1 contingencies in the system. The 66 kV and 132 kV networks in Zone 4 are the mostly stressed areas. None of these issues are related to the MCC projects. Note that the network divergence issues and overloads discussed in the above sections were also observed in the same areas. Therefore, it is expected that most of the under voltages will be solved when the required lines upgrades are done. The additional shunt compensation requirements are discussed in a later section.

Table 3.11 Low Voltage Violations for N-1 Contingencies

Bus	Worst Low Voltage		
	Case	Contingency	Voltage (pu)
64090 DAMAK4 220.00	2030_Drypeak	SINGLE 62020-64090(1)	0.881
612 LAINCHOU 66.000	2030_Drypeak	SINGLE 610-611(1)	0.871
101 MAHENDRA 132.00	2030_Drypeak	SINGLE 101-102(1)	0.863
105 LAMAHI 132.00	2030_Drypeak	SINGLE 104-135(1)	0.890
107 SHIVPUR 132.00	2030_Drypeak	SINGLE 104-135(1)	0.885
21070 GOHARI 132.00	2030_Drypeak	SINGLE 104-135(1)	0.874
135 KUSUM 132.00	2030_Drypeak	SINGLE 104-135(1)	0.875
21020 HAPURE_ 132.00	2030_Drypeak	SINGLE 104-135(1)	0.869
41160 N BIRGUNJ 132.00	2030_Drypeak	SINGLE 118-159(1)	0.880
112 BHARATPU-132132.00	2030_Drypeak	SINGLE 118-159(1)	0.805
119 DAMAULI-132 132.00	2030_Drypeak	SINGLE 118-159(1)	0.838
159 N_BHARA 132.00	2030_Drypeak	SINGLE 118-159(1)	0.809
31200 KHUDI 132.00	2030_Drypeak	SINGLE 118-159(1)	0.833
124 KUSHAHA 132.00	2030_Drypeak	SINGLE 124-61200(1)	0.876
180 KATAIYA 132.00	2030_Drypeak	SINGLE 124-61200(1)	0.865
611 BALAJU-66 66.000	2030_Drypeak	SINGLE 610-611(1)	0.883
618 TRISHULI 66.000	2030_Drypeak	SINGLE 610-611(1)	0.873
619 DEVIGHAT-66 66.000	2030_Drypeak	SINGLE 610-611(1)	0.879
632 MAILUNG 66.000	2030_Drypeak	SINGLE 610-611(1)	0.895
630 TEKU 66.000	2030_Drypeak	SINGLE 610-630(2)	0.873
631 K-3 66.000	2030_Drypeak	SINGLE 610-630(2)	0.879
700 DUMTEKU 66.000	2030_Drypeak	SINGLE 610-630(2)	0.891
61160 ITHARI_ 132.00	2030_Drypeak	SINGLE 61160-61200(1)	0.859
61170 DHARAN_ 132.00	2030_Drypeak	SINGLE 61160-61200(1)	0.843
102 ATARIA 132.00	2030_Wetmin	SINGLE 102-11020(1)	0.886
11040 DEEPAYAL 132.00	2030_Wetmin	SINGLE 102-11020(1)	0.895
11050 BAJHANG 132.00	2030_Wetmin	SINGLE 102-11020(1)	0.897

N-2 Outages

This section discusses the remedies for overloads resulting or worsened under n-2 contingencies. Wherever the generation tripping is suggested, the recommendations are based only on making an acceptable operating point and the economic aspects of tripping a particular generation unit over another is not considered.

(1) **D/C transmission line from Naubise to Lapsiphedi (MCC project: NR1)**

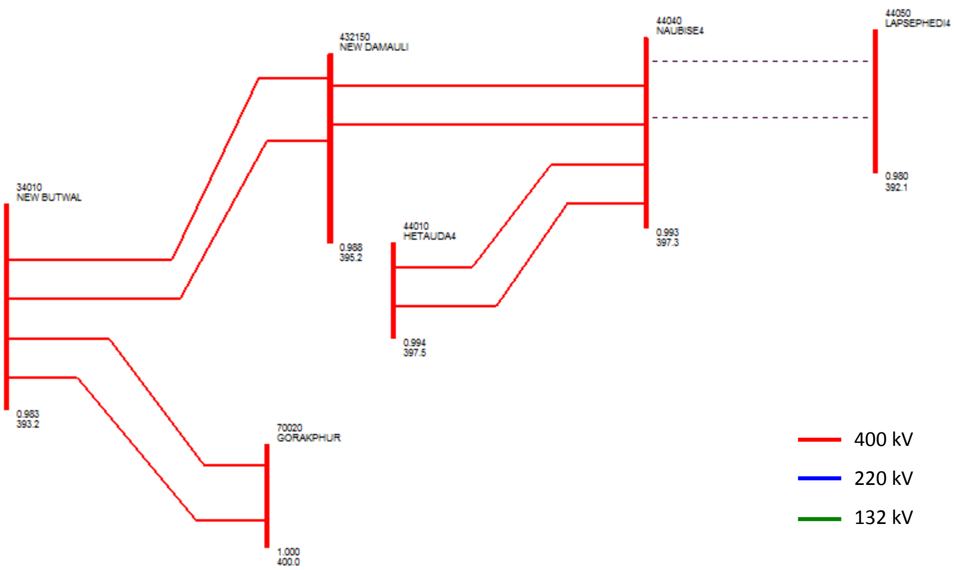


Figure 3.13 Outage of double circuit transmission line from Naubise to Lapsiphedi

The outage of Naubise to Lapsiphedi double circuit line forces the power coming from Barabise substation (power coming from T2') into the 132 kV system specially, under Wetmin conditions. In 2030 Wetmin scenario, the 132 kV line from Mulpani to Lapsiphedi gets overloaded to about 113%. Note that for N-1 contingencies, this line gets overloaded to about 152%. All other overloads are below 110%. Therefore, the outage of Naubise to Lapsiphedi double circuit line is not a concern.

(2) **D/C transmission line from New Damauli to New Butwal (MCC project: NR1)**

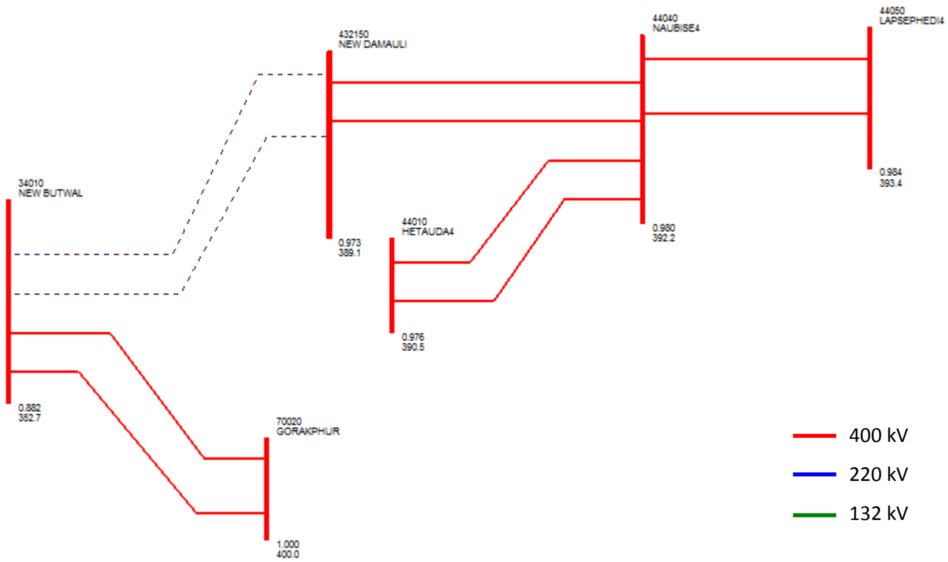


Figure 3.14 Outage of double circuit transmission line from New Butwal to New Damauli

The worst case is the outage of the double circuit line from New Butwal to New Damauli in 2030 Drypeak scenario where the imports are at its maximum using the two tie lines. The outage requires the entire import power from Gorkapur to be transmitted into the 220 kV system at New Butwal substation which is about an increment of 1000 MW. It was not possible to obtain a converged power flow under these conditions.

Recommendation:
Load shedding in order to have acceptable loading in 400kV/220kV transformers at the New Butwal substation is recommended. Shedding of about 900 MW of loads on following buses resulted in acceptable transformer loading: Bharatpu-132, Damauli-132, Butwal-132, Bairahawa, Shivpur, Hapure, Kusum and Lamhi.

(3) **D/C transmission line from Naubise to New Damauli (MCC project: NR1)**

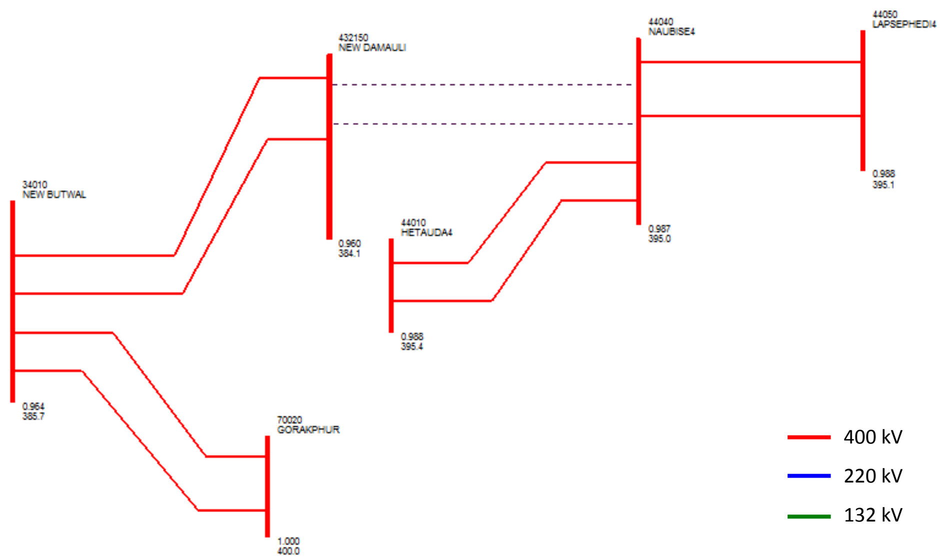


Figure 3.15 Outage of double circuit transmission line from New Damauli to Naubise

In 2030 Wetmin scenario, the loss of D/C line from new Damauli to Naubise results in transmitting about additional 300 MW of power from the 220kV system. This results in overloading the 4 X 400kV/220kV transformers at the New Damauli substation about 114%. If this overload is not acceptable, the generation at New Damauli, Lekhnath, Lower Modi can be adjusted to control the overload.

(4) **D/C transmission line from Hetauda to Naubise (MCC project: NR1)**

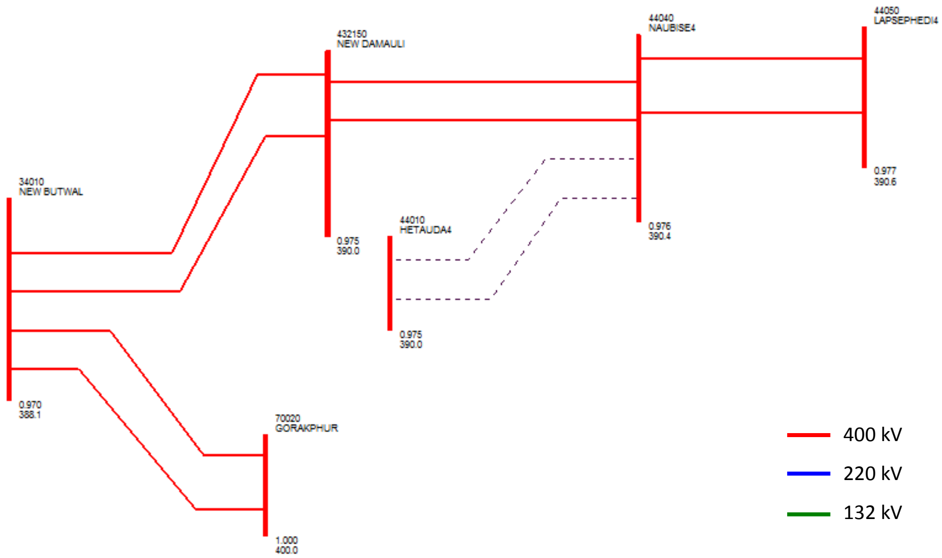


Figure 3.16 Outage of double circuit transmission line from Hetauda to Naubise

Only few overloads as shown in Table 3.12 were reported for this contingency. The overloads stay below 120%. For most of the overloaded lines, N-1 outages show much larger overloads, which needs to be mitigated. Therefore, the outage double circuit transmission line from Hetauda to Naubise is not a concern.

Table 3.12. Overloads for outage of double circuit transmission line from Hetauda to Naubise

Overloaded Component							Worst Contingency			Worst n-1 loading (%)	MVA Rating
Bus 1			Bus 2			CKT ID					
from Bus	Bus Name	kV	to Bus	Bus Name	kV		Power flow	Contingency	Loading (%)		
114	DHALKE-132	132	1115	MIRCHAY	132	1	2030 Dry Peak	(N-2): NR1_NAU_HETA	106.5	151	124
114	DHALKE-132	132	1115	MIRCHAY	132	1	2030 Dry Peak	(N-2): NR1_NAU_HETA	106.5	151	124
114	DHALKE-132	132	1115	MIRCHAY	132	1	2030 Dry Peak	(N-2): NR1_NAU_HETA	106.5	151	124
118	MARSHYAN	132	159	N_BHARA	132	5	2030 Dry Peak	(N-2): NR1_NAU_HETA	118.5	114	180
610	SIUCHATA	66	616	NEW PATAN	66	3	2030 Dry Peak	(N-2): NR1_NAU_HETA	110.7	195	100
610	SIUCHATA	66	616	NEW PATAN	66	3	2030 Dry Peak	(N-2): NR1_NAU_HETA	110.7	195	100

(5) **Tie line 1: D/C transmission line from Hetauda to Dhalkebar**

Under maximum imports – 2030 Drypeak scenario
In this scenario, the tie line 1 is importing 1200 MW. The outage of the double circuit tie line requires the load shedding of the about the same number of MWs. Loads in zone 5 and some of the loads in zone 6 were shed while keeping the maximum imports (1800 MW) in XB1. The total system loads were reduced to about 3151 MW after about 1122 MW load shedding.

Under maximum exports – 2030 Wetmin scenario
In this scenario, the tie line 1 is exporting 1034 MW. The outage of the double circuit tie line requires the generation to be tripped while ensuring the maximum exports from the second tie line. XB1 is exporting about 1540 MW whereas the maximum exports is 1800 MW.

Some generation in Zone 5 (including T2') and Zone 6 were tripped to ensure 1800 MW exports in XB1. The total generation of the system was reduced to about 3943 MW after about 792 MW of generation tripping.

2023 Drypeak scenario and 2023 Wetmin scenario also require similar strategies to keep an acceptable operating point.

(6) **XB1: D/C transmission line from New Butwal to Gorakhpur**

Under maximum imports – 2030 Drypeak scenario
In this scenario, both tie line 1 and XB1 imports are at their maximum (XB1: about 1798 MW, tie line 1: 1200 MW). The outage of XB1 forces load shedding as the imports of the tie line 1 is also at its maximum. Loads in zone 2, zone 3 and some of zone 4 were shed to resolve equipment rating violations and to limit the imports from the tie line 1.

Under maximum exports – 2030 Wetmin scenario
In this scenario, XB 1 is exporting about 1540 MW and tie line 1 is exporting about 1034 MW. At the outage of XB1, the tie line 1 exports can be increased to 1200 MW. The excess generation needs to be tripped in this situation.

The generation at Zone2, Zone 3 and zone 4 were shed to maintain an acceptable operating point.
2023 Drypeak scenario and 2023 Wetmin scenario also require similar strategies to keep an acceptable operating point.

For the outage of a tie line, it is necessary to have a special protection scheme to trip loads and generation based on the conditions. A comprehensive study including the India system would be required to determine the strategy.

(7) **D/C transmission line from New Lamki to Bareilly**

The outage of New Lamki –Bareilly tie line requires the generation cross tripping. The only supply from T8 under this contingency is the 12% power to the Nepal system. It is assumed that the 12% supply in wet season is 108 MW and for dry season is 32.4 MW.

Accordingly, in Drypeak scenario, about 237 MW of generation at Upper Karnali needs to be tripped. In Wetmin scenario, about 792 MW of generation at Upper Kanali needs to be tripped.

(8) **Mitigation of Steady State Power flow Issues**

It is found that the existing Nepal network is not capable of supplying the loads expected by 2030. Line upgrades and additional shunt compensation would be required to solve the issues identified in the above sections. The following system upgrades were considered to mitigate these violations.

- One additional parallel circuit was considered for each of the lines given in the following table. Note that only the 132 kV circuit between Mulpani and Lapsiphedi is directly relevant to the MCC projects.

Table 3.13 Additional circuits required to mitigate overloads and network divergence issues

From Bus			To Bus		
Bus No	Name	kV	Bus No	Name	kV
107	SHIVPUR	132	108	BUTWAL-132	132
114	DHALKE-132	132	1115	MIRCHAY	132
115	LAHAN	132	51070	RAJBIRAJ_	132
134	PARWANI-132	132	40060	SIMARA	132
134	PARWANI-132	132	41160	N BIRGUNJ	132
610	SIUCHATA	66	611	BALAJU-66	66
610	SIUCHATA	66	616	NEW PATAN	66
610	SIUCHATA	66	630	TEKU	66
613	CHABEL	66	619	DEVIGHAT-66	66
615	NEW BANESWOR	66	616	NEW PATAN	66
630	TEKU	66	631	K-3	66
41080	MULPANI	132	41090	LAPSIPHEDI1	132
52010	DHALKE2	220	62020	INARUWA2	220

- As described in the above sections, the following switch shunts were considered to avoid low voltages under system intact conditions.
    - A switch shunt of 150 MVAR (capacitive) at Inaruwa 132 kV bus
    - The capacitive range of the existing switch shunt at Patha was changed from 75 MVAR to 150 MVAR
    - The capacitive range of the existing switch shunt at Parwani was changed from 75 MVAR to 180 MVAR
    - New switch shunt of 150 MVAR was added at Hetauda 132 kV bus.
    - The capacitive range of the existing switch shunt at Bharatpu was changed from 75 MVAR to 150 MVAR
    - About 500 MVAR of switch shunts were required at Siuchata 66 kV bus. The capacitive reactive power capacity of N. Bhakta switch shunt was increased to 150 MVAR. Note that 66 kV and 33 kV networks were not fully modelled in the power flow cases used and therefore, this requirement needs to be re-evaluated in a later stage.

The contingency analysis was repeated after adding the aforementioned system upgrades. Table 3.14 shows the overloads obtained after adding the upgrades. There is only one line loaded to about 137 % and all other overloads stays below 125%. It is necessary to evaluate these minor overloads carefully and the low cost solutions such as re-dispatching the generators or re-conductoring can be used.

The low voltage violations in the system still remains the same. It is necessary to perform comprehensive reactive power coordination study in the sub transmission and distribution system in order to solve these issues.

Table 3.14 Remaining overloads after adding the proposed upgrades

Overloaded Component								Worst Contingency			NO Contingency Overload (%)	MVA rating
Bus 1			Bus 2			CKT ID						
from Bus	Bus Name	kV	to Bus	Bus Name	kV		Power flow	Contingency	Loading (%)			
40050	AMLEKHGUNJ	132	40060	SIMARA	132	1	2030_Drypeak	SINGLE 134-170(1)	137.0	121.3	186.0
118	MARSHYAN	132	159	N_BHARA	132	1	2030_Drypeak	SINGLE 119-158(1)	113.0	0.0	180.0
108	BUTWAL-132	132	31190	BAIRAHAWA	132	2	2030_Drypeak	SINGLE 108-31190(1)	120.8	0.0	159.1
108	BUTWAL-132	132	31190	BAIRAHAWA	132	1	2030_Drypeak	SINGLE 108-31190(2)	120.8	0.0	159.1
108	BUTWAL-132	132	234010	NEW BUTWAL	220	2	2030_Drypeak	SINGLE 108-234010(1)	114.2	0.0	500.0
108	BUTWAL-132	132	234010	NEW BUTWAL	220	1	2030_Drypeak	SINGLE 108-234010(2)	114.2	0.0	500.0
112	BHARATPU-132	132	159	N_BHARA	132	2	2030_Drypeak	SINGLE 112-159(1)	122.8	0.0	124.0
112	BHARATPU-132	132	159	N_BHARA	132	1	2030_Drypeak	SINGLE 112-159(2)	122.8	0.0	124.0
113	HETAUDA-132	132	40050	AMLEKHGUNJ	132	2	2030_Drypeak	SINGLE 113-40050(1)	114.5	0.0	186.0
113	HETAUDA-132	132	40050	AMLEKHGUNJ	132	1	2030_Drypeak	SINGLE 113-40050(2)	114.5	0.0	186.0
114	DHALKE-132	132	52010	DHALKE2	220	2	2030_Drypeak	SINGLE 114-52010(1)	102.8	0.0	600.0
114	DHALKE-132	132	52010	DHALKE2	220	1	2030_Drypeak	SINGLE 114-52010(2)	102.8	0.0	600.0
115	LAHAN	132	1115	MIRCHAY	132	2	2030_Drypeak	SINGLE 115-1115(1)	106.9	0.0	142.0
115	LAHAN	132	1115	MIRCHAY	132	3	2030_Drypeak	SINGLE 115-1115(1)	106.9	0.0	142.0
115	LAHAN	132	1115	MIRCHAY	132	1	2030_Drypeak	SINGLE 115-1115(2)	106.9	0.0	142.0
117	ANARMANI-132	132	175	DAMAK	132	2	2030_Drypeak	SINGLE 117-175(1)	115.1	0.0	124.0
117	ANARMANI-132	132	175	DAMAK	132	1	2030_Drypeak	SINGLE 117-175(2)	115.1	0.0	124.0
122	SIUCH	132	133	MATATRIT	132	3	2030_Drypeak	SINGLE 122-133(1)	116.6	0.0	228.0
122	SIUCH	132	133	MATATRIT	132	1	2030_Drypeak	SINGLE 122-133(3)	116.6	0.0	228.0
122	SIUCH	132	610	SIUCHATA	66	2	2030_Drypeak	SINGLE 122-610(1)	113.5	0.0	200.0
122	SIUCH	132	610	SIUCHATA	66	3	2030_Drypeak	SINGLE 122-610(1)	113.5	0.0	200.0

122	SIUCH	132	610	SIUCHATA	66	1	2030_Drypeak	SINGLE 122-610(2)	118.3	0.0	200.0
131	CHAPALI	132	41080	MULPANI	132	2	2030_Drypeak	SINGLE 131-41080(1)	106.2	0.0	159.1
131	CHAPALI	132	41080	MULPANI	132	1	2030_Drypeak	SINGLE 131-41080(2)	106.2	0.0	159.1
134	PARWANI-132	132	170	PATHA	132	2	2030_Drypeak	SINGLE 40050-40060(1)	157.5	0.0	142.0
134	PARWANI-132	132	170	PATHA	132	1	2030_Drypeak	SINGLE 40050-40060(1)	157.5	0.0	142.0
602	KL-I-66	66	610	SIUCHATA	66	2	2030_Drypeak	SINGLE 602-610(1)	111.8	0.0	77.0
602	KL-I-66	66	610	SIUCHATA	66	1	2030_Drypeak	SINGLE 602-610(2)	111.8	0.0	77.0
610	SIUCHATA	66	616	NEW PATAN	66	2	2030_Drypeak	SINGLE 610-616(1)	103.0	0.0	100.0
610	SIUCHATA	66	616	NEW PATAN	66	3	2030_Drypeak	SINGLE 610-616(1)	103.0	0.0	100.0
610	SIUCHATA	66	616	NEW PATAN	66	1	2030_Drypeak	SINGLE 610-616(2)	103.0	0.0	100.0
615	NEW BANESWOR	66	616	NEW PATAN	66	2	2030_Drypeak	SINGLE 615-616(1)	100.2	0.0	100.0
615	NEW BANESWOR	66	616	NEW PATAN	66	1	2030_Drypeak	SINGLE 615-616(2)	100.2	0.0	100.0
113	HETAUDA-132	132	41170	KAMANE	132	1	2030_Drypeak	SINGLE 40050-40060(1)	122.7	0.0	159.1
113	HETAUDA-132	132	41170	KAMANE	132	2	2030_Drypeak	SINGLE 40050-40060(1)	122.7	0.0	159.1
170	PATHA	132	41170	KAMANE	132	1	2030_Drypeak	SINGLE 40050-40060(1)	110.5	0.0	159.1
170	PATHA	132	41170	KAMANE	132	2	2030_Drypeak	SINGLE 40050-40060(1)	110.5	0.0	159.1
52010	DHALKE2	220	54010	DHALKE4-NP	400	2	2030_Drypeak	SINGLE 52010-54010(1)	100.3	0.0	500.0
52010	DHALKE2	220	54010	DHALKE4-NP	400	3	2030_Drypeak	SINGLE 52010-54010(1)	100.3	0.0	500.0
52010	DHALKE2	220	54010	DHALKE4-NP	400	1	2030_Drypeak	SINGLE 52010-54010(2)	100.3	0.0	500.0
102	ATARIA	132	11020	BALANCH HUB	132	2	2030_Wetmin	SINGLE 102-11020(1)	122.1	0.0	124.0
102	ATARIA	132	11020	BALANCH HUB	132	1	2030_Wetmin	SINGLE 102-11020(2)	122.1	0.0	124.0
129	LAMOSANG	132	41100	BARABISE1	132	2	2030_Wetmin	SINGLE 129-41100(1)	124.0	0.0	186.0
129	LAMOSANG	132	41100	BARABISE1	132	1	2030_Wetmin	SINGLE 129-41100(2)	124.0	0.0	186.0
31110	TADHEKANI 1	132	32020	TADHEKANI H.	220	2	2030_Wetmin	SINGLE 31110-32020(1)	118.1	0.0	160.0
31110	TADHEKANI 1	132	32020	TADHEKANI H.	220	1	2030_Wetmin	SINGLE 31110-32020(2)	118.1	0.0	160.0
51080	LIKHU HUB_	132	51081		220	2	2030_Wetmin	SINGLE 51080-51081(1)	105.8	0.0	160.0

51080	LIKHU HUB_	132	51081		220	3	2030_Wetmin	SINGLE 51080-51081(1)	105.8	0.0	160.0
51080	LIKHU HUB_	132	51081		220	1	2030_Wetmin	SINGLE 51080-51081(2)	105.8	0.0	160.0
51081		220	52025	NEW KHIMTI22	220	2	2030_Wetmin	SINGLE 51081-52025(1)	125.0	0.0	270.0
51081		220	52025	NEW KHIMTI22	220	1	2030_Wetmin	SINGLE 51081-52025(2)	125.0	0.0	270.0

Sensitivity analysis - Lapsiphedi - New Khimti line at 220 kV

For the 2023 and 2030 scenarios considered, the Lapsiphedi - New Khimti line built by another donor will be at 400 kV level. Therefore, three 160 MVA 400 kV/132 kV transformers were used at Lapsiphedi. Initially it is expected that the Lapsiphedi - New Khimti line will be energized at 220 kV. Therefore, a sensitivity analysis was carried out to determine the transformer requirements at Lapsiphedi and the studies revealed that THREE 160 MVA 400 kV/220 kV transformers would be required at Lapsiphedi.

3.1.6 Short Circuit Analysis

The short circuit calculations were done to determine the breaker rating of the stations. The calculations were done using the "ASCC" utility in PSSE. Note that only the positive sequence data is available in the PSSE power flow cases and therefore, only the three phase short circuit currents were calculated. In order to determine the worst possible fault current the following approach is used.

- It is assumed that the pre-fault voltages at all the bus bars are at the maximum steady state value (i.e. 1.1 pu).
- The short circuit contribution of India was unknown to the date on which the studies were done and therefore the calculations were done without considering the contribution of India. Since the interconnections are at 400 kV system, the largest impact would be on the 400 kV stations. The following currents were added to the calculated short circuit current based on the voltage levels.
    - 400 kV stations: 15 kA
    - 220 kV stations: 10 kA
    - 132 kV stations: 5 kA

  For example, 15 kA at 400 kV is equivalent to the short circuit current of a 2000 MVA generator. It is expected that the northern part of India is relatively weak and therefore this assumption can be considered as pessimistic.
- The calculations were done considering the Wetmin and Drypeak powerflow scenarios in 2023 and 2030. The supply scenarios in these cases were considered as reasonable. However, there is a possibility of having a higher supply and hence a larger short circuit current.
- Considering above two facts, it is necessary to consider an extra margin from the calculated values when determining the breaker ratings. A 30 % margin was assumed while determining the minimum breaker ratings in this analysis.

The maximum short circuit currents were calculated for all the stations in 132 kV and above. The results are summarized in Table 3.15. The stations relevant the MCC projects are highlighted in the following colors.

NR+XB1
NR3
NR4
T3
T8
T2'

Table 3.15 Maximum Short Circuit Currents

BusNo	Bus Name	Voltage	Short Circuit Contribution					Contribution from India*	Expected Max SC Current	Min breaker rating (with 30% margin)
			2023		2030		Max			
			MVA	kA	MVA	kA	kA	kA	kA	kA
101	MAHENDRA	132	357.7	1.6	404.5	1.8	1.8	5.0	6.8	9
102	ATARIA	132	882.8	3.9	1010.2	4.4	4.4	5.0	9.4	13
103	LAMKI	132	1794.9	7.9	1953.3	8.5	8.5	5.0	13.5	18
104	KOHALPUR	132	1492.7	6.5	1639.4	7.2	7.2	5.0	12.2	16
105	LAMAHI	132	1173.3	5.1	1310.5	5.7	5.7	5.0	10.7	14
106	JHIMRUK-132	132	805.8	3.5	891.8	3.9	3.9	5.0	8.9	12
107	SHIVPUR	132	1119.6	4.9	1260.4	5.5	5.5	5.0	10.5	14
108	BUTWAL-132	132	3788.5	16.6	4277.6	18.7	18.7	5.0	23.7	31
110	BARDGHAT	132	1482.7	6.5	1673.9	7.3	7.3	5.0	12.3	17
111	GANDAK-132	132	1047.4	4.6	1187.6	5.2	5.2	5.0	10.2	14
112	BHARATPU-132	132	2533.6	11.1	2771.9	12.1	12.1	5.0	17.1	23
113	HETAUDA-132	132	5281.7	23.1	5731.4	25.1	25.1	5.0	30.1	40
114	DHALKE-132	132	3702.4	16.2	4247.1	18.6	18.6	5.0	23.6	31
115	LAHAN	132	2052.3	9.0	2293.0	10.0	10.0	5.0	15.0	20
116	DUHABI-132	132	1878.7	8.2	2213.1	9.7	9.7	5.0	14.7	20
117	ANARMANI-132	132	1113.2	4.9	1253.4	5.5	5.5	5.0	10.5	14
118	MARSHYAN	132	3441.2	15.1	3768.3	16.5	16.5	5.0	21.5	28
119	DAMAULI-132	132	2109.9	9.2	2308.1	10.1	10.1	5.0	15.1	20
120	POKHARA	132	3258.4	14.3	3632.4	15.9	15.9	5.0	20.9	28
121	KL-II-132	132	4488.5	19.6	4886.0	21.4	21.4	5.0	26.4	35
122	SIUCH	132	5495.8	24.0	5949.2	26.0	26.0	5.0	31.0	41
123	BALAJU-132	132	4819.8	21.1	5220.6	22.8	22.8	5.0	27.8	37
124	KUSHAHA	132	1544.8	6.8	1804.6	7.9	7.9	5.0	12.9	17
125	KG-A-132	132	2494.8	10.9	2618.2	11.5	11.5	5.0	16.5	22
126	MODI-132	132	972.9	4.3	1057.4	4.6	4.6	5.0	9.6	13
127	KHIMTI-132	132	1047.4	4.6	1083.9	4.7	4.7	5.0	9.7	13
128	BHOTEKOS-132	132	1912.5	8.4	1992.7	8.7	8.7	5.0	13.7	18
129	LAMOSANG	132	3828.7	16.7	3994.6	17.5	17.5	5.0	22.5	30
130	N-BHAKTA-132	132	4766.7	20.8	5143.8	22.5	22.5	5.0	27.5	36
131	CHAPALI	132	4632.5	20.3	5020.2	22.0	22.0	5.0	27.0	36
133	MATATRIT	132	5850.2	25.6	6329.1	27.7	27.7	5.0	32.7	43
134	PARWANI-132	132	2686.3	11.7	3017.3	13.2	13.2	5.0	18.2	24
135	KUSUM	132	944.9	4.1	1058.7	4.6	4.6	5.0	9.6	13
142	MMMARS	132	2182.3	9.5	2346.7	10.3	10.3	5.0	15.3	20

BusNo	Bus Name	Voltage	Short Circuit Contribution					Contribution from India*	Expected Max SC Current	Min breaker rating (with 30% margin)
			2023		2030		Max			
			MVA	kA	MVA	kA	kA	kA	kA	kA
150	MIDMARS-132	132	2038.8	8.9	2159.8	9.4	9.4	5.0	14.4	19
151	N-MARSYA	132	3593.0	15.7	3965.9	17.3	17.3	5.0	22.3	30
157	CHANDRAN	132	2107.1	9.2	2342.4	10.2	10.2	5.0	15.2	20
158	LEKHNATH	132	3548.2	15.5	4020.0	17.6	17.6	5.0	22.6	30
159	N_BHARA	132	2647.9	11.6	2901.2	12.7	12.7	5.0	17.7	23
160	SYANGJA	132	2066.7	9.0	2241.9	9.8	9.8	5.0	14.8	20
170	PATHA	132	2800.6	12.2	3116.0	13.6	13.6	5.0	18.6	25
175	DAMAK	132	1734.8	7.6	1989.6	8.7	8.7	5.0	13.7	18
180	KATAIYA	132	1047.6	4.6	1193.1	5.2	5.2	5.0	10.2	14
181	BANSKOT	132	1962.6	8.6	2157.1	9.4	9.4	5.0	14.4	19
182	LOW_MOD	132	836.4	3.7	907.5	4.0	4.0	5.0	9.0	12
199	KAWASOTI	132	848.6	3.7	956.4	4.2	4.2	5.0	9.2	12
1115	MIRCHAY	132	2532.8	11.1	2817.9	12.3	12.3	5.0	17.3	23
1151	UDIPUR	132	1634.7	7.1	1735.7	7.6	7.6	5.0	12.6	17
2103	SINGATI	132	1790.3	7.8	1785.5	7.8	7.8	5.0	12.8	17
2104	SIPRING	132	1416.3	6.2	1425.7	6.2	6.2	5.0	11.2	15
11020	BALANCH HUB	132	742.6	3.2	1089.8	4.8	4.8	5.0	9.8	13
11040	DEEPAYAL	132	419.7	1.8	475.0	2.1	2.1	5.0	7.1	10
11050	BAJHANG	132	378.6	1.7	428.4	1.9	1.9	5.0	6.9	9
11060	BUDHI GHANGA	132	585.4	2.6	653.8	2.9	2.9	5.0	7.9	11
14030	N. LAMKI-NP	400	1764.7	2.5	1945.5	2.8	2.8	15.0	17.8	24
14035	N. LAMKI-I	400	3610.7	5.2	3685.6	5.3	5.3	15.0	20.3	27
14036	LAMKI-I 132	132	1794.9	7.9	1953.3	8.5	8.5	5.0	13.5	18
21010	NEPALGUNJ_	132	706.3	3.1	793.9	3.5	3.5	5.0	8.5	12
21020	HAPURE_	132	552.3	2.4	624.8	2.7	2.7	5.0	7.7	11
21030	SURKHET_	132	883.9	3.9	987.5	4.3	4.3	5.0	9.3	13
21040	DAILEKH_	132	574.0	2.5	645.8	2.8	2.8	5.0	7.8	11
21070	GOHARI	132	818.6	3.6	920.2	4.0	4.0	5.0	9.0	12
24010	N KOHALPUR-N	400	1879.9	2.7	2082.8	3.0	3.0	15.0	18.0	24
24040	UP KARNALI	400	4193.3	6.1	4034.1	5.8	6.1	15.0	21.1	28
31010	GULMI	132	1170.7	5.1	1269.8	5.6	5.6	5.0	10.6	14
31020	BURTIBANG	132	598.2	2.6	653.4	2.9	2.9	5.0	7.9	11
31050	KUSMA 1	132	3305.3	14.5	3528.5	15.4	15.4	5.0	20.4	27
31060	NEW MODI	132	3126.5	13.7	3367.9	14.7	14.7	5.0	19.7	26
31070	UPPER MODI A	132	2143.5	9.4	2264.7	9.9	9.9	5.0	14.9	20
31100	DANA1	132	1501.4	6.6	1680.4	7.4	7.4	5.0	12.4	17

BusNo	Bus Name	Voltage	Short Circuit Contribution 2023		2030		Max	Contribution from India*	Expected Max SC Current	Min breaker rating (with 30% margin)
			MVA	kA	MVA	kA	kA	kA	kA	kA
31110	TADHEKANI 1	132	2321.5	10.2	2336.8	10.2	10.2	5.0	15.2	20
31130	KHUDI NOR. 1	132	2197.7	9.6	2620.9	11.5	11.5	5.0	16.5	22
31150	KIRTIPUR HUB	132	1729.7	7.6	1951.8	8.5	8.5	5.0	13.5	18
31170	UP. DARRAU1	132	1371.5	6.0	1512.2	6.6	6.6	5.0	11.6	16
31190	BAIRAHAWA	132	2273.1	9.9	2559.1	11.2	11.2	5.0	16.2	22
31200	KHUDI	132	1182.0	5.2	1289.0	5.6	5.6	5.0	10.6	14
32010	KUSMA2	220	4193.4	11.0	4457.3	11.7	11.7	10.0	21.7	29
32020	TADHEKANI H.	220	3157.2	8.3	3303.2	8.7	8.7	10.0	18.7	25
32040	DANA	220	3500.9	9.2	3692.5	9.7	9.7	10.0	19.7	26
32060	BHARATPUR2	220	5031.6	13.2	5924.0	15.5	15.5	10.0	25.5	34
32070	MARSYGANDI2	220	5930.0	15.6	7468.2	19.6	19.6	10.0	29.6	39
32130	UPPER DARAU	220	3945.2	10.4	4679.1	12.3	12.3	10.0	22.3	29
32150	NEW DAMAULI	220	6303.7	16.5	7432.7	19.5	19.5	10.0	29.5	39
32160	LEKNATH2	220	3627.8	9.5	4257.3	11.2	11.2	10.0	21.2	28
34010	NEW BUTWAL	400	5653.3	8.2	7011.5	10.1	10.1	15.0	25.1	33
40050	AMLEKHGUNJ	132	3520.6	15.4	3896.1	17.0	17.0	5.0	22.0	29
40060	SIMARA	132	2899.2	12.7	3237.1	14.2	14.2	5.0	19.2	25
41010	HARSIDDHI	132	4147.2	18.1	4477.0	19.6	19.6	5.0	24.6	32
41020	CHAPAGON	132	4174.9	18.3	4507.4	19.7	19.7	5.0	24.7	33
41030	BALHEPI HUB	132	1467.2	6.4	1511.5	6.6	6.6	5.0	11.6	16
41080	MULPANI	132	5280.4	23.1	5723.6	25.0	25.0	5.0	30.0	40
41090	LAPSIPHEDI1	132	5668.8	24.8	6176.0	27.0	27.0	5.0	32.0	42
41100	BARABISE1	132	4803.3	21.0	5053.1	22.1	22.1	5.0	27.1	36
41120	TRISHULI 3B1	132	3000.5	13.1	3015.3	13.2	13.2	5.0	18.2	24
41130	SAMUDARTAR	132	1123.2	4.9	1161.4	5.1	5.1	5.0	10.1	14
41140	CHILME1	132	1560.5	6.8	1582.1	6.9	6.9	5.0	11.9	16
41160	N BIRGUNJ	132	2086.0	9.1	2346.7	10.3	10.3	5.0	15.3	20
41170	KAMANE	132	3545.9	15.5	3910.6	17.1	17.1	5.0	22.1	29
42020	MATATRIT2	220	6622.7	17.4	7168.5	18.8	18.8	10.0	28.8	38
42030	TRISHULI 3B	220	4991.2	13.1	5042.2	13.2	13.2	10.0	23.2	31
42040	CHILME HUB	220	4021.0	10.6	4045.4	10.6	10.6	10.0	20.6	27
42090	NAUBISE2	220	6862.2	18.0	7566.9	19.9	19.9	10.0	29.9	39
42100	UPTRISHULI1	220	3945.5	10.4	3950.8	10.4	10.4	10.0	20.4	27
44010	HETAUDA4	400	7030.4	10.1	7879.8	11.4	11.4	15.0	26.4	35
44040	NAUBISE4	400	7885.9	11.4	8798.1	12.7	12.7	15.0	27.7	37
44050	LAPSIPHEDI4	400	7271.6	10.5	7974.7	11.5	11.5	15.0	26.5	35

BusNo	Bus Name	Voltage	Short Circuit Contribution					Contribution from India*	Expected Max SC Current	Min breaker rating (with 30% margin)
			2023		2030		Max			
			MVA	kA	MVA	kA	kA	kA	kA	kA
44060	BARABISE4	400	6329.3	9.1	6947.7	10.0	10.0	15.0	25.0	33
51040	TINGLA HUB	132	1257.6	5.5	1234.5	5.4	5.5	5.0	10.5	14
51050	JANAKPUR_	132	1705.6	7.5	1911.3	8.4	8.4	5.0	13.4	18
51060	JALESWOR_	132	1318.6	5.8	1472.5	6.4	6.4	5.0	11.4	15
51070	RAJBIRAJ_	132	1493.2	6.5	1664.8	7.3	7.3	5.0	12.3	16
51080	LIKHU HUB_	132	2749.3	12.0	3778.9	16.5	16.5	5.0	21.5	28
51081		220	2761.4	7.2	4431.0	11.6	11.6	10.0	21.6	29
51130	NEW KHIMITI1	132	781.6	3.4	1030.6	4.5	4.5	5.0	9.5	13
52010	DHALKE2	220	4638.6	12.2	5628.2	14.8	14.8	10.0	24.8	33
52020	NEW KHIMTI21	220	3196.0	8.4	5615.4	14.7	14.7	10.0	24.7	33
52025	NEW KHIMTI22	220	2864.0	7.5	5615.1	14.7	14.7	10.0	24.7	33
52030	UPPER_TAMA	220	3296.4	8.7	4182.3	11.0	11.0	10.0	21.0	28
52040	TAMAKO-3	220	2301.6	6.0	2553.6	6.7	6.7	10.0	16.7	22
54010	DHALKE4-NP	400	4961.7	7.2	5733.0	8.3	8.3	15.0	23.3	31
54090	NEW KHIMTI4	400	4788.8	6.9	5540.4	8.0	8.0	15.0	23.0	30
61010	ILLAM	132	1699.8	7.4	1881.6	8.2	8.2	5.0	13.2	18
61020	BHADRAPUR	132	879.6	3.8	987.1	4.3	4.3	5.0	9.3	13
61025	BIRATNAGAR	132	1446.6	6.3	1664.6	7.3	7.3	5.0	12.3	16
61030	PHIDIM	132	1367.8	6.0	1440.0	6.3	6.3	5.0	11.3	15
61040	KABELI	132	1189.1	5.2	1244.5	5.4	5.4	5.0	10.4	14
61050	PINASEGAHT	132	1072.1	4.7	1113.1	4.9	4.9	5.0	9.9	13
61090	KHANDBARI	220	1404.7	3.7	2263.7	5.9	5.9	10.0	15.9	21
61160	ITHARI_	132	1145.6	5.0	1331.3	5.8	5.8	5.0	10.8	15
61170	DHARAN_	132	922.9	4.0	1057.5	4.6	4.6	5.0	9.6	13
61200	INARUWA	132	2200.1	9.6	2704.0	11.8	11.8	5.0	16.8	22
61220	BANESHWOR1	132	418.8	1.8	462.3	2.0	2.0	5.0	7.0	10
62010	BASANTPUR	220	1617.1	4.2	2396.8	6.3	6.3	10.0	16.3	22
62015	BANESHWOR	220	1471.5	3.9	2307.5	6.1	6.1	10.0	16.1	21
62020	INARUWA2	220	2451.7	6.4	3096.7	8.1	8.1	10.0	18.1	24
62050	ARUN 3 NP_	220	1221.9	3.2	2137.9	5.6	5.6	10.0	15.6	21
64090	DAMAK4	220	1857.0	4.9	2157.1	5.7	5.7	10.0	15.7	21
70010	MUZZAFA	400	3894.2	5.6	4591.7	6.6	6.6	15.0	21.6	29
70020	GORAKPHUR	400	3657.3	5.3	4957.6	7.2	7.2	15.0	22.2	29
100111	BAREILLY	400	2438.3	3.5	2835.8	4.1	4.1	15.0	19.1	25
140360	PSTF_BUS	132	1845.5	8.1	1918.2	8.4	8.4	5.0	13.4	18
234010	NEW BUTWAL	220	5496.3	14.4	6592.1	17.3	17.3	10.0	27.3	36

BusNo	Bus Name	Voltage	Short Circuit Contribution 2023		2030		Max	Contribution from India*	Expected Max SC Current	Min breaker rating (with 30% margin)
			MVA	kA	MVA	kA	kA	kA	kA	kA
234140	KHUDI 220	220	3144.8	8.3	5497.3	14.4	14.4	10.0	24.4	32
234150	MANANG 220	220	2125.2	5.6	3034.5	8.0	8.0	10.0	18.0	24
244010	HETAUDA 220	220	5968.1	15.7	6651.4	17.5	17.5	10.0	27.5	36
432150	NEW DAMAULI	400	6668.3	9.6	7895.9	11.4	11.4	15.0	26.4	35

Based on the short circuit analysis, at least 42 kA breakers are recommended for 132 kV stations of MCC projects. For the 220 kV and 400 kV levels, the breaker ratings should be at least 39 kA and 37 kA respectively. Standard breaker ratings shall be selected based on these requirements.

3.1.7 Transient stability analysis

The objective of this study is to analyze the ability of the system to maintain the synchronism and the stability after being subjected to a fault.

Methodology

The transient stability analysis were performed using PSSE dynamic simulation tools for the power flow scenarios given in Table 3.16.

Table 3.16 Operating points selected for transient stability analysis

Case	Supply/Demand	Set of MCC Projects Included in this Case
8	2023 Drypeak	Base Case + all MCC Projects
16	2023 Wetmin	Base Case + all MCC Projects
24	2030 DryPeak	Base Case + all MCC Projects
32	2030 Wetmin	Base Case + all MCC Projects

Representation of loads

The loads were represented using the constant current model for active power and constant admittance model for reactive power (default load model used in PSSE).

Dynamic representation of generators and auxiliary devices

For the existing devices (by 2016), the dynamic data provided by NEA were used in the transient stability analysis. The generators listed in Table 3.17 were identified from the NEA database. Note that the bus numbers of the NEA power flow cases and WSP provided powerflow cases were completely different and the units were identified by matching the bus names.

Table 3.17. Generators identified from NEA database

Generators in power flows			Identified from NEA dynamic data
Bus No	Station	ID	BusNo-ID
106	JHIMRUK-132 132.00	1	6003-1
111	GANDAK-132 132.00	1	1002-1
111	GANDAK-132 132.00	2	1002-2
113	HETAUDA-132 132.00	2	1005-2
118	MARSHYAN 132.00	1	1001-1
121	KL-II-132 132.00	1	6004-1
126	MODI-132 132.00	1	6006-1
127	KHIMTI-132 132.00	1	1007-1
129	LAMOSANG 132.00	1	129-1
129	LAMOSANG 132.00	2	129-2
129	LAMOSANG 132.00	3	129-3
129	LAMOSANG 132.00	4	129-4
150	MIDMARS-132 132.00	1	1001-2
601	HETAUDA-66 66.000	1	1005-1
602	KL-I-66 66.000	1	1003-1
617	SUNKOSHI-66 66.000	1	6005-1
619	DEVIGHAT-66 66.000	1	6001-1
620	CHILIME-66 66.000	1	1006-1
622	INDRAWAT-66 66.000	1	6008-1
234140	KHUDI 220 220.00	1	6012-1
234140	KHUDI 220 220.00	2	6012-2

For the other devices, the generic dynamic device data were used as mentioned below.

Generators: Salient pole generator model. PSSE model – GENSAL

It is expected that most of the new generating stations would be hydro generators. For the hydro generators (low speed & higher number of poles), the most suitable generator model is the salient pole model (GENSAL). Usually, the inertia of hydro generators vary in the range of 2s to 4s regardless of the size of the generators. As a mean value, an inertia of 3s was used and typical values were selected for the other variables. All the model parameters are listed below.

Table 3.18 Parameters used for PSSE GENSAL generator model

Constant	Value
T'_{do}	5.5 s
T''_{do}	0.036 s
T''_{qo}	0.1 s
H, Inertia	3.0 s
D, Speed damping	0.0 pu
X_d	0.63 pu
X_q	0.45 pu
X'_d	0.25 pu
$X''_d = X''_q$	0.178 pu
X_l	0.1167 pu
S (1.0)	0.09
S (1.2)	0.29

No equivalents were provided for the India system and therefore, the India system was modeled using three Thevenin sources connected at the end of three tie lines considered in the models. The short circuit contribution of each source was kept at 15 kA. These sources are modeled using GENCLS in PSSE. The PSSE models the units as voltage sources when the inertia of GENCLS model is zero.

Exciters: PSSE model – SEXS

The same exciter model with the same parameters has been used in the existing NEA database. Therefore, the same model was used for the new generating stations as well. Note that there is a great influence of the exciters on the transient stability of the system; however, at this stage it is difficult to select different models for different generators without having much insight into the generation (manufacturer, type, etc.). The generic exciter parameters are given below.

Table 3.19. Parameters used for PSSE SEXS exciter model

Constant	Value
TA/TB	0.05
TB	100 s
K	180
TE	0.5 s
EMIN	0
EMAX	4

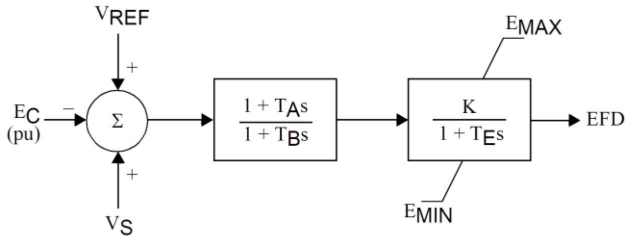


Figure 3.17. Block diagram representation of PSSE SEXS exciter model

Power System Stabilizers: PSSE model – IEEEST

The need of power system stabilizers was determined by performing the small signal stability analysis of the system. This analysis was performed using TGSSR – an in-house developed small signal stability assessment tool.

The power system stabilizers were designed to improve the damping of a local and an inter area oscillator mode of 0.9 Hz and 0.8 Hz respectively. Figure 3.18 shows the improvement of damping of the generation speed oscillations for a 5 cycle 3 phase to ground fault occurred very close to the Lapsiphedi 400 kV bus which was cleared by isolating the ckt 1 of the 400 kV transmission line from Lapsiphedi to Naubise (Contingency 10, 2030 Wetmin scenario).

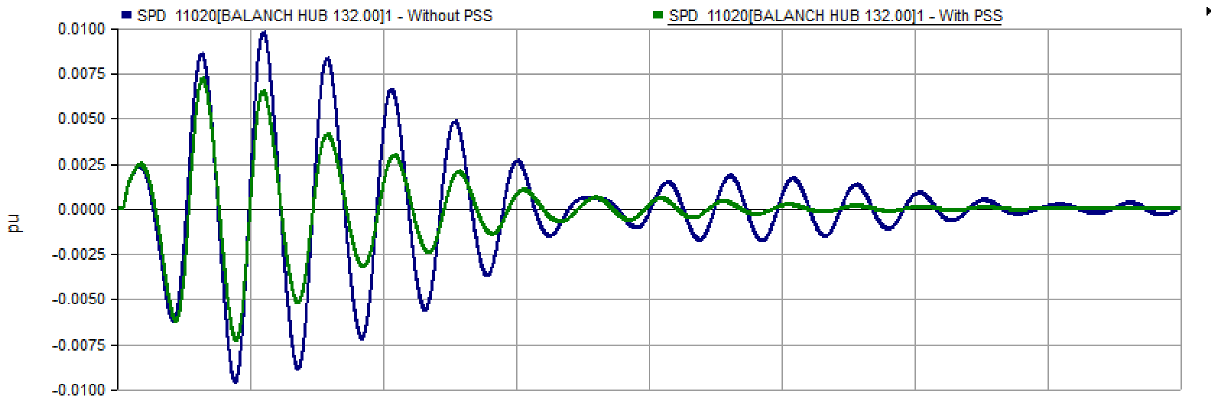


Figure 3.18 Effect of the PSS on damping of the generation oscillations for contingency 10 (2030 Wetmin scenario)

Table 3.11 lists the parameters of PSSE library model IEEEST type power system stabilizers on the generators at Bus: 11020, id: 1 and Bus: 52030, Id: 1.

Table 3.20 Parameters used for Power system stabilizers

Constant	Generators: Balanch Hub 132 kV bus (Bus #: 11020, Id '1') Upper Tama 220 kV bus (Bus #: 52030, Id '1')
A1	0.02
A2	0
A3	0
A4	0
A5	0
A6	0
T1	0.06
T2	0.4
T3	0.06
T4	0.4
T5	10
T6	10
Ks	20
Lsmax	0.2
Lsmin	-0.2
Vcu	0
Vcl	0

Turbine-Governor: PSSE model – HYGOV

A hydro governor model (HYGOV) model with the following parameters were used in the analysis.

Table 3.21 Parameters used for PSSE HYGOV turbine-governor model

Constant	Value
R, permanent droop	0.05
r, temporary droop	0.4 s
Tr, governor time constant	7
Tf, filter time constant	0.05 s
Tg, servo time constant	0.5 s
+ VELM, gate velocity limit	0.1
GMAX, maximum gate limit	1.5
GMIN, minimum gate limit	0
TW, water time constant	1
At, turbine gain	1

Dturb, turbine damping	0.0
qNL, no power flow	0.1

List of contingencies

The list of contingencies comprised of 3 phase balanced faults occurred on transmission lines and transformers close to major stations relevant to the MCC projects were considered in this analysis. The fault was cleared by tripping the relevant transmission line or transformer. The fault duration was considered to be 5 cycles (100ms). Table 3.22 shows the list of contingencies.

Table 3.22 List of contingencies used for dynamic simulation

Number	Faulted bus (fault duration: 5 cycles)	Tripped Devices
1	NewButwal 400kV	LNout: NewButwal- Gorakhpur
2	NewButwal 400kV	LNout: NewButwal-KohalpurN
3	NewButwal 400kV	2WDout: NewButwal 400-220 kV
4	NewButwal 400kV	LNout: NewButwal-NewDamauli
5	NewDamauli 400kV	LNout: NewDamauli-Naubise
6	NewDamauli 220kV	LNout: NewDamauli-Lekhnath
7	NewDaumuli 400kV	2WDout: NewDaumuli 400-220 kV
8	NewDamauli 220kV	LNout: NewDamauli-Marsygandi
9	Naubise 400kV	LNout: Naubise-Hetauda
10	Naubise 400kV	LNout: Naubise-Lapsiphedi
11	Naubise 400kV	2WDout: Naubise 400-220 kV
12	Lapsiphedi 400kV	LNout: Lapsiphedi-Barabise
13	Lapsiphedi 400kV	2WDout: Lapsiphedi 400-220 kV
14	Barabise 400kV	2WDout: Barabise 400-220 kV
15	Barabise 400kV	LNout: Barabise-NewKhimti
16	NewKhimti 400kV	2WDout: NewKhimti 400-220 kV
17	NewKhimti 220kV	LNout: NewKhimti-LikhuHub
18	NewKhimti 220kV	2WDout: NewKhimti 220 kV
19	LikhuHub 132kV	2WDout: LikhuHub 220-132 kV
21	Hetauda 400kV	LNout: Hetauda-Dhalke
22	Hetauda 400kV	2WDout: Hetauda 400-220 kV
23	Hetauda 220kV	LNout: Hetauda-Bharatpur
24	Hetauda 220kV	2WDout: Hetauda 220-132 kV
25	Hetauda 132kV	LNout: Hetauda-KL-II
26	Hetauda 132kV	LNout: Hetauda-Kamane
27	Hetauda 132kV	LNout: Hetauda-Amelekhgunj
28	Hetauda 132kV	LNout: Hetauda-NBhara
29	Dhalke 400kV	2WDout: Dhalke 400-220 kV
30	Dhalke 220kV	2WDout: Dhalke 220-132 kV

Number	Faulted bus (fault duration: 5 cycles)	Tripped Devices
31	Dhalke 220kV	LNout: Dhalke-NewKhimti
32	Dhalke 220kV	LNout: Dhalke-Inaruwa
33	Dhalke 400kV	LNout: Dhalke-Muzaffarpur
34	Inaruwa 220kV	2WDout: Inaruwa 220-132 kV
35	Inaruwa 132kV	LNout: Inaruwa-Huhabi
36	Inaruwa 132kV	LNout: Inaruwa-Ithari
37	Inaruwa 132kV	LNout: Inaruwa-Khshaha
38	Inaruwa 132kV	LNout: Inaruwa-Damak
39	Inaruwa 132kV	LNout: Inaruwa-Lahan
40	Inaruwa 220kV	LNout: Inaruwa-Basantpur
41	Inaruwa 132kV	LNout: Inaruwa-Ilam
42	Ilam 132kV	LNout: Ilam-Damak
43	Ilam 132kV	LNout: Ilam-Phidim
44	Ilam 133kV	2WDout: Ilam 133-33 kV
45	Kusma 220kV	LNout: Kusma-NewButwal
46	Kusma 220kV	2WDout: Kusma 220-132 kV
47	Kusma 220kV	LNout: Kusma-Dana
48	Kusma 220kV	LNout: Kusma-TadhekaniH
49	Tadhekani 220kV	2WDout: Tadhekani 220-132 kV
50	Ataria 132kV	LNout: Ataria-Lamki
51	Ataria 132kV	LNout: Ataria-Deepayal
52	Ataria 132kV	LNout: Ataria-Mahendra
53	Ataria 132kV	LNout: Ataria-BalanchHub
54	NLamki 400kV	LNout: NLamki-UPKarnali
55	NLamki 400kV	LNout: NLamki-Bareilly
56	NLamkiNP 400kV	2WDout: NLamkiNP 400-132 kV
57	NLamkiNP 400kV	2WDout: NKohalpurN 400-132 kV
58	NKohalpurN 400kV	LNout: NLamkiNP-KohalpurN
59	Upper Tama Gen Terminal	Upper Tama Generator
60	Khudi Gen Terminal	Khudi Generator

Dynamic Study Results

The system was transiently stable for the set of contingencies listed in Table 3.22. The detailed system responses under the list of contingencies are listed as an Annex A to the report.

Dynamic Voltage Performance

This section examines the transient recovery bus voltages of the system buses relevant to proposed MCC projects. For the dynamic voltage performance, there is no straight forward criterion defined in the Nepal grid code. The following performance criterion commonly used in North America was adapted while analyzing the results.

- Transient undervoltages after the fault clearance should remain above 0.7 pu and the voltage should recover above 0.9 pu within 2 seconds from the fault occurrence.
- Transient overvoltages should remain below 1.3 pu for first 200 ms from the fault occurrence and the voltage should recover below 1.1 pu after that.

The worst possible voltage responses observed at the stations relevant to the MCC projects are summarized below.

MCC Project: NR1: High Voltage Transmission Trunk Line
For the faults in the NR1 project, the voltage recovers well within the criteria defined above, the system performance is acceptable in the voltage stability point of view. The voltage recovery at each station is shown below.
New Hetauda substation

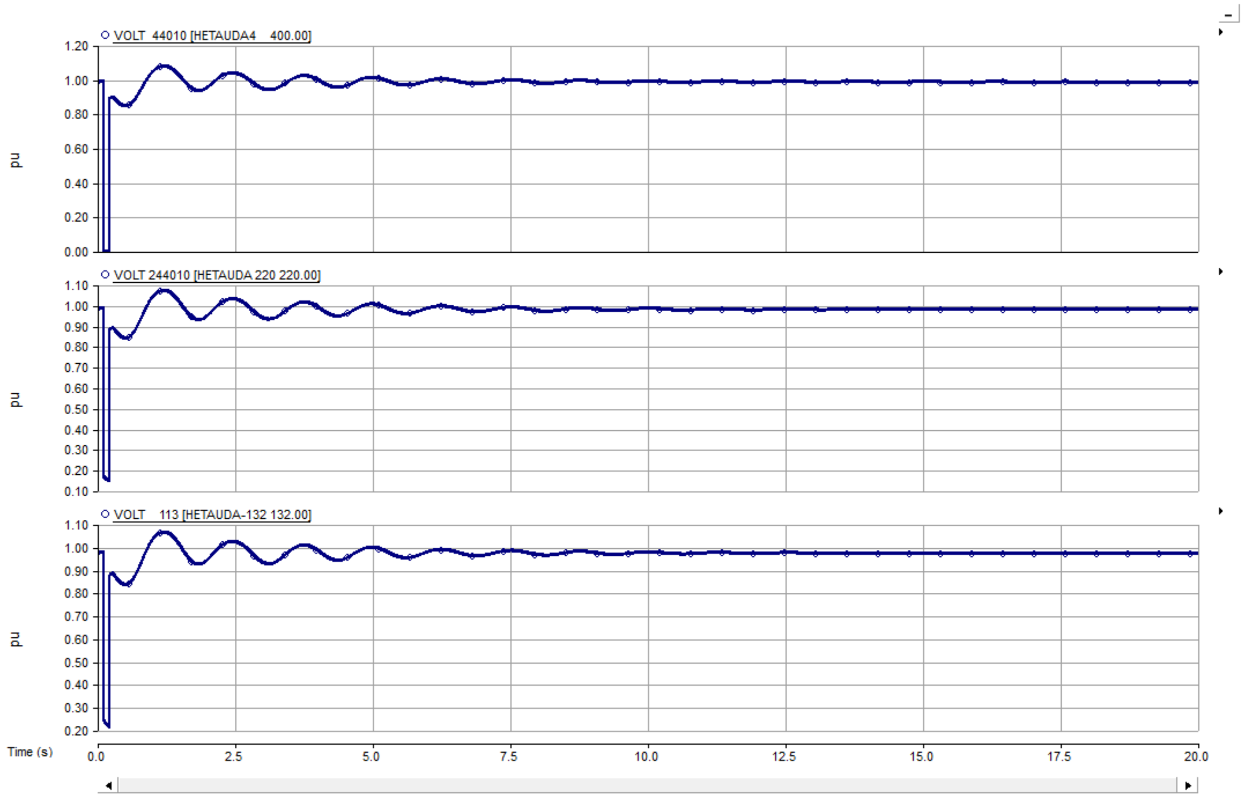


Figure 3.19 Voltage recovery after being subjected to a fault at Hetauda 400 kV bus (Contingency 21, 2030 Wetmin scenario).

New Damauli Substation

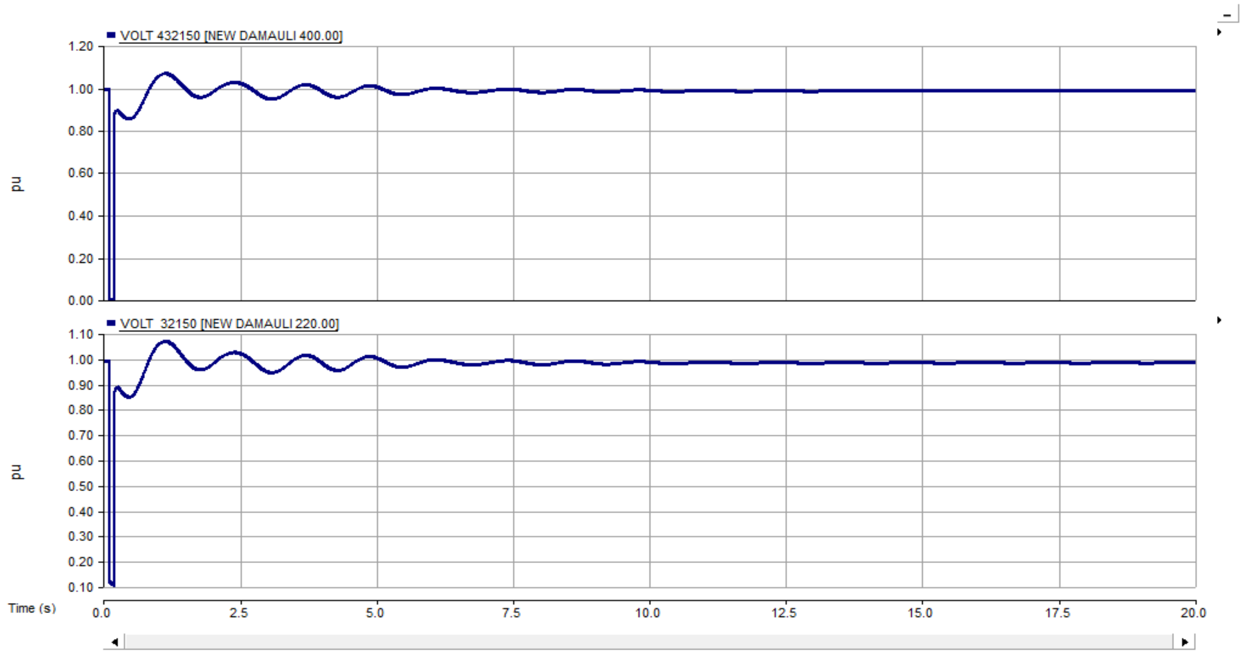


Figure 3.20 Voltage recovery after being subjected to a fault at New Damauli 400 kV bus (Contingency 5, 2030 Wetmin scenario).

Naubise Substation

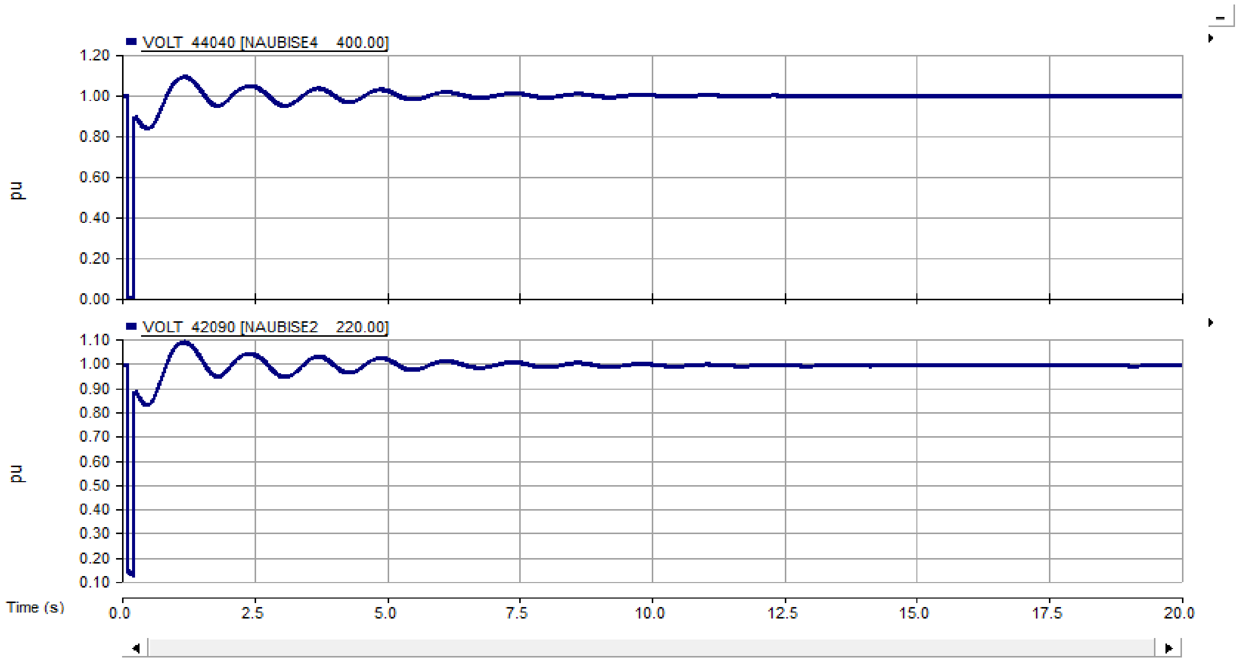


Figure 3.21 Voltage recovery after being subjected to a fault at Naubise 400 kV bus (Contingency 10, 2030 Wetmin scenario)

Lapsiphedi Substation

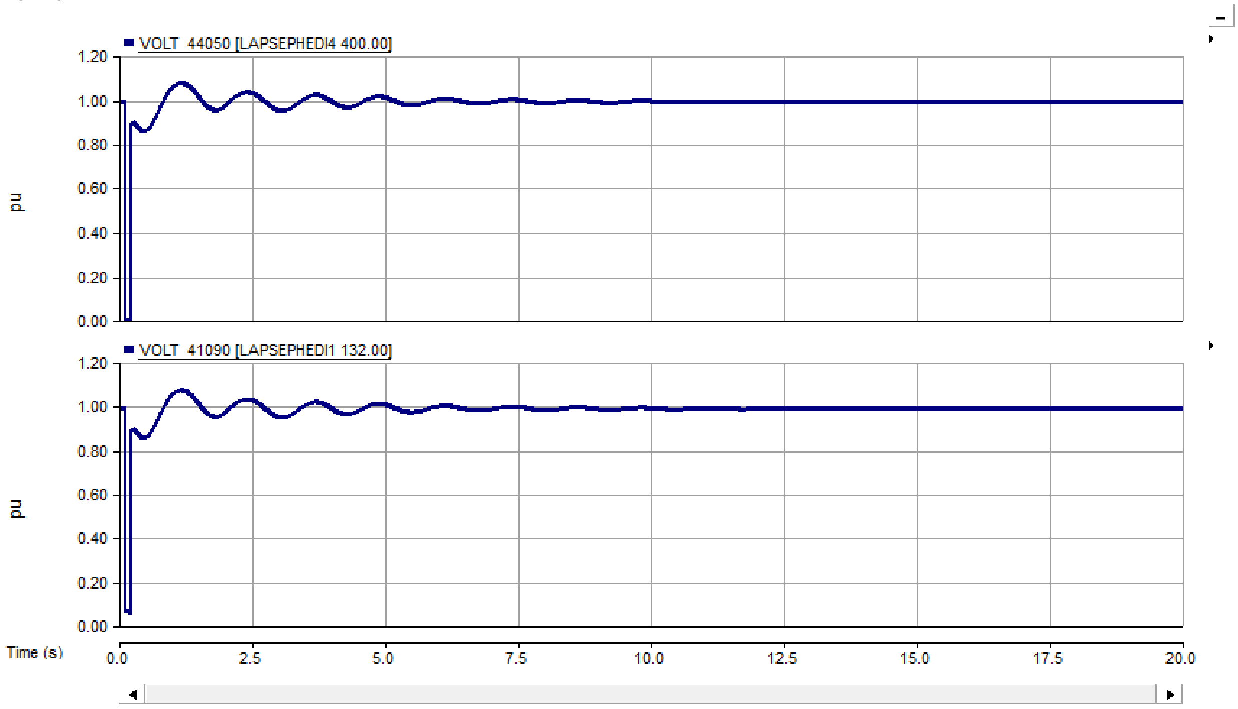


Figure 3.22 Voltage recovery after being subjected to a fault at Lapsiphedi 400 kV bus (Contingency 12, 2030 Wetmin scenario)

New Butwal Substation

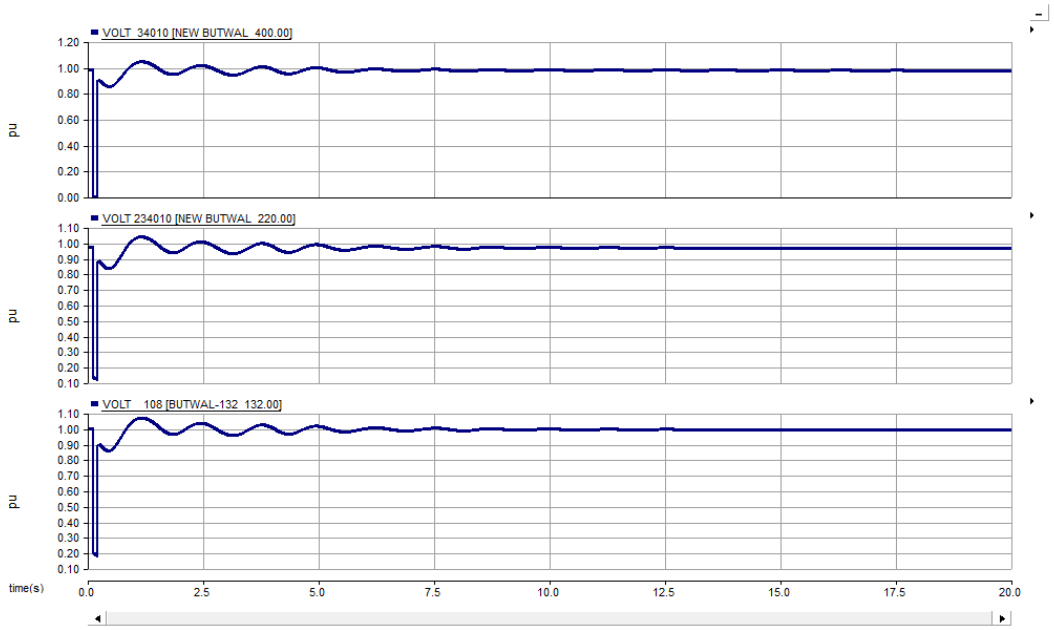


Figure 3.23 Voltage recovery after being subjected to a fault at New Butwal 400 kV bus (Contingency 4, 2030 Wetmin scenario)

MCC Project: NR3: Ilam—Inaruwa Transmission Line Project

In NR3 project, the system recovers well for the fault near Ilam. However for the fault near Inaruwa substation, the voltage drops slightly below 0.7 pu while recovering in 2030 wetmin powerflow scenario (outage of Inaruwa-Basantpur 220 kV circuit). Note that the Inaruwa-Basantpur 220 kV circuit are heavily loaded in this powerflow scenario and the network divergence issues were also observed near this area in the steady state analysis. It is expected that the slight dynamic voltage violation will disappear when the steady state voltage performance in that area is improved.

Ilam Substation

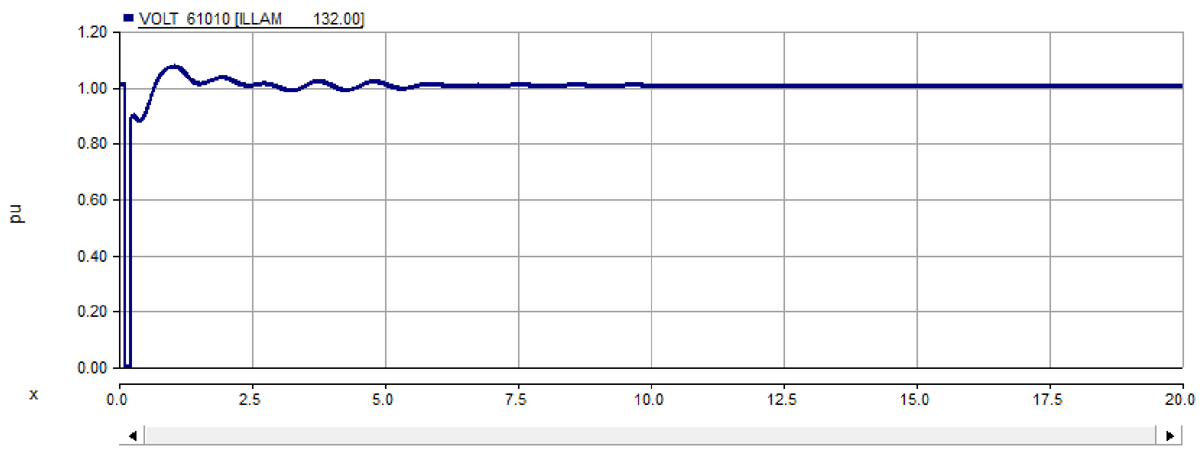


Figure 3.24 Voltage recovery after being subjected to a fault at Ilam 132 kV bus (Contingency 43, 2030 Wetmin scenario)

Inaruwa Substation

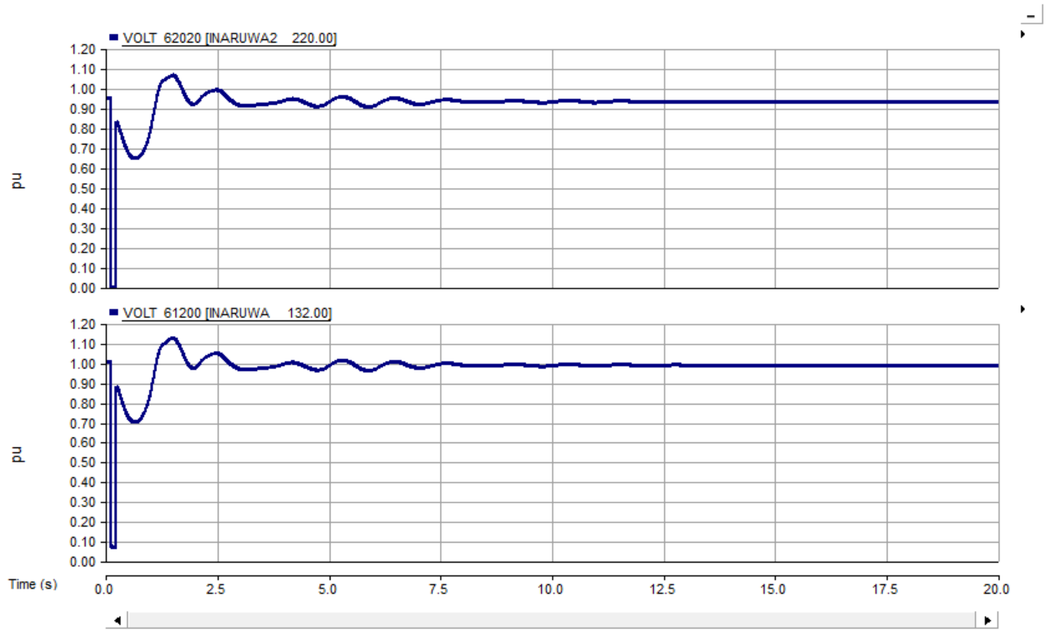


Figure 3.25 Voltage recovery after being subjected to a fault at Inaruwa 220 kV bus (Contingency 40, 2030 Wetmin scenario)

MCC project NR4: Balanch—Attaria Transmission line project

For the faults in and near the NR4 project, the system recovers well. The worst reported voltage recovery is shown below.

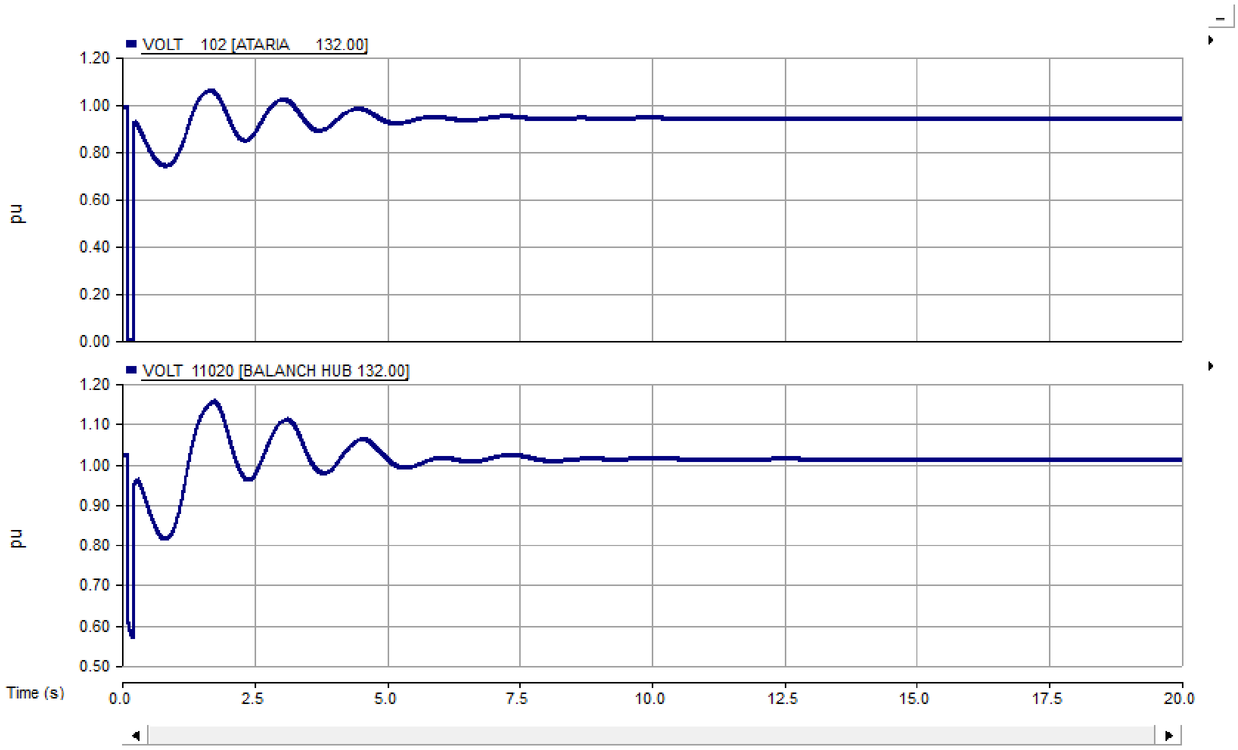


Figure 3.26 Voltage recovery after being subjected to a fault at Ataria 132 kV bus (Contingency 53, 2030 Wetmin scenario)

MCC project: T2': New Khimti – Likhu Hub Transmission Line Project

For the faults in and near the T2' project, the system recovers well. The worst reported voltage recoveries at the stations are shown below.

New Khimti Substation

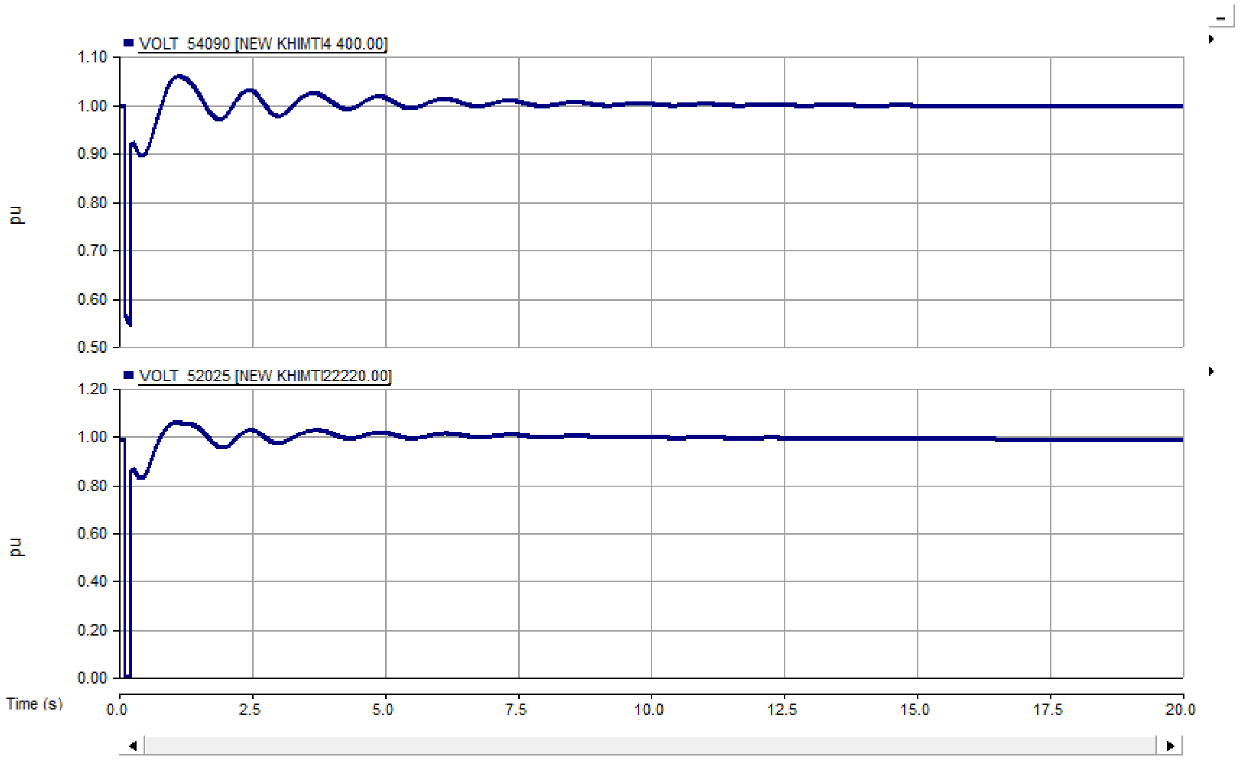


Figure 3.27 Voltage recovery after being subjected to a fault at New Khimti 220 kV bus (Contingency 17, 2030 Wetmin scenario)

Likhu Hub Substation

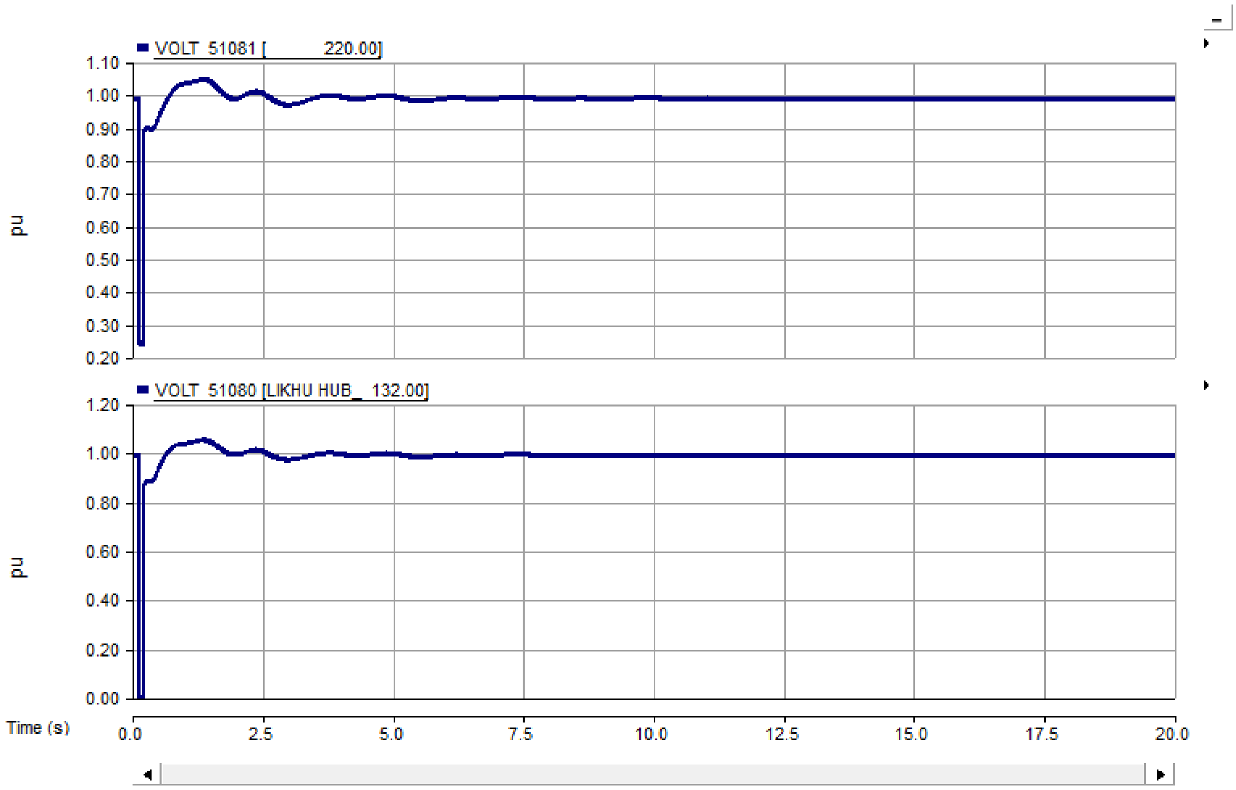


Figure 3.28 Voltage recovery after being subjected to a fault at Likhu 132 kV bus (Contingency 19, 2030 Wetmin scenario)

MCC project: T3: Tadekhani—Kusma Transmission Line Project

For the faults in and near the T3 project, the system recovers well. The worst reported voltage recovery is shown below.

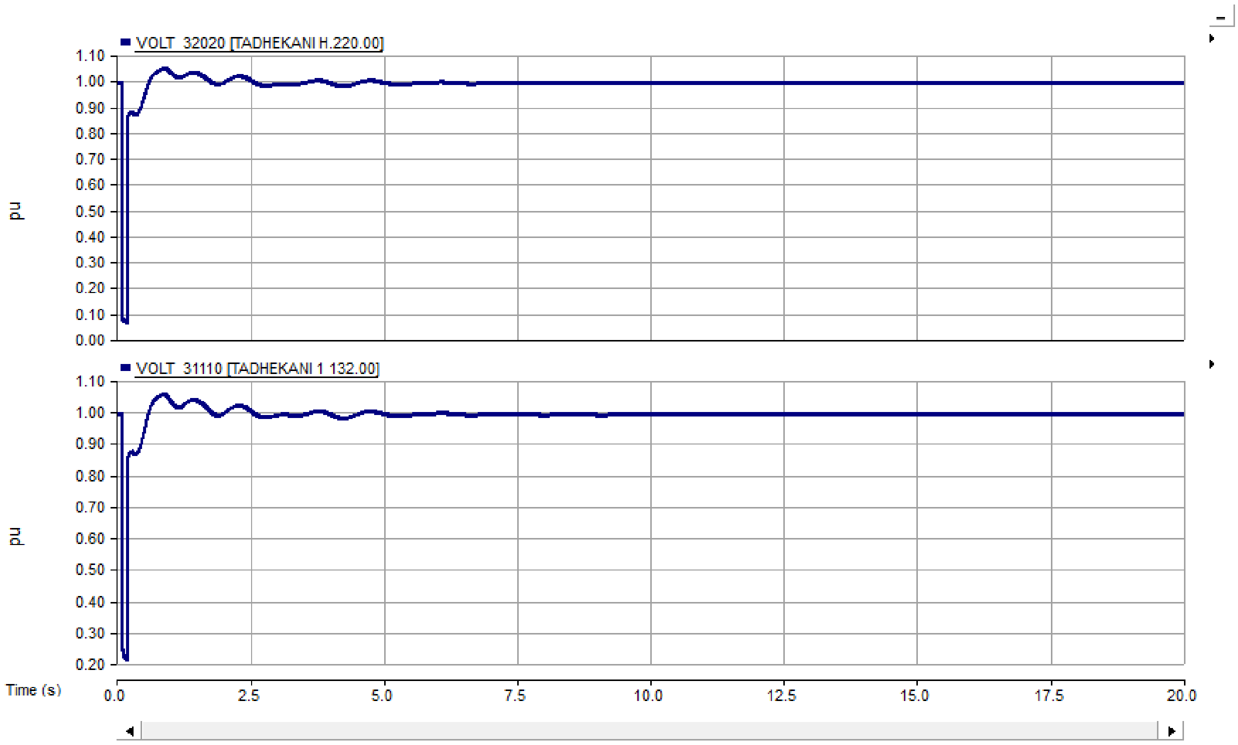


Figure 3.29 Voltage recovery after being subjected to a fault at Tadhekani 220 kV bus (Contingency 49, 2030 Wetmin scenario)

T8: New Lamki—Nepal/India Border Transmission Project
For the faults in and near the T8 project, the system recovers well. The worst reported voltage recovery is shown below.

New Lamki Substation

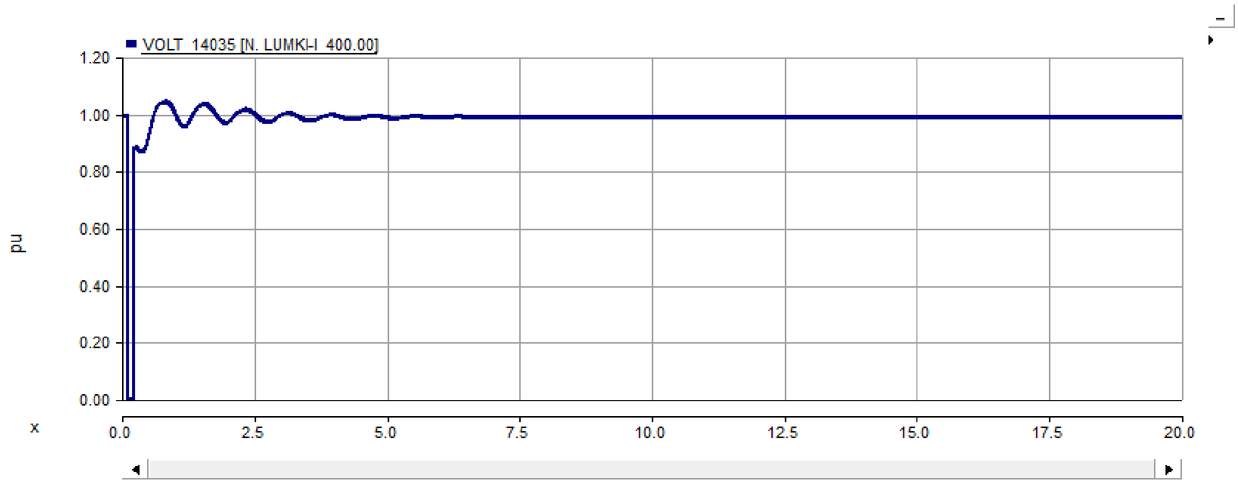


Figure 3.30 Voltage recovery after being subjected to a fault at New Lamki 400 kV bus (Contingency 54, 2030 Wetmin scenario)

Electromechanical Oscillation Damping

The electromechanical oscillations of the system was analyzed using the transient stability results as well as the small signal stability analysis. In general 3% to 5% damping is acceptable for the electromechanical oscillations. Based on the small signal stability analysis of the system intact conditions prior to the disturbances, the lowest damping of the electromechanical oscillations is about 7% and therefore, there is no concern about the damping of the oscillations. This performance was also observed in the dynamic simulations. Some of the worst case electromechanical oscillations observed in the system for the contingencies considered in the transient stability analysis are shown below. The oscillations die down within 10 seconds.

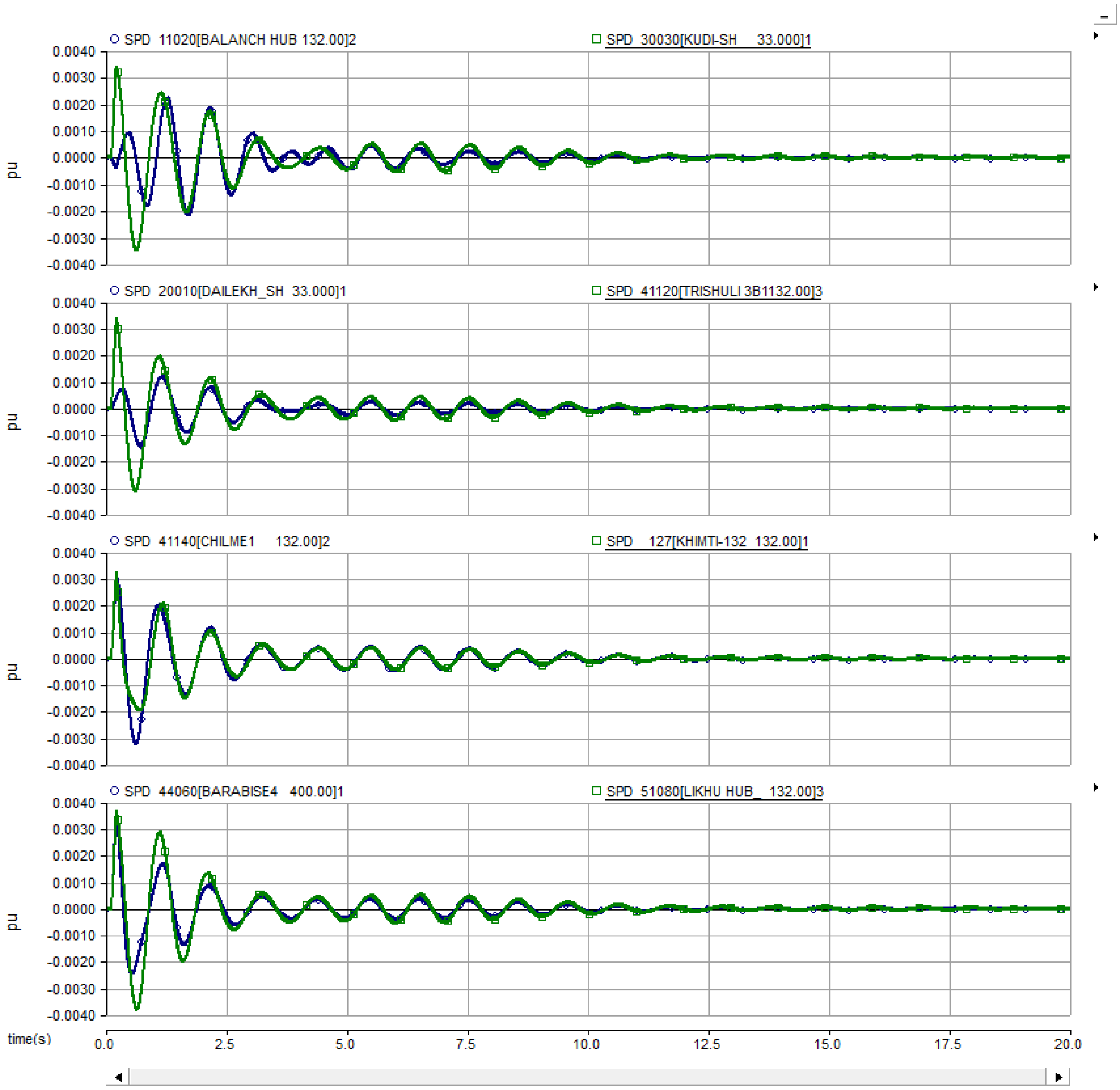


Figure 3.31 Generator speed variations under contingency9 (2030 Drypeak)

Frequency Stability

The system frequency stays within 49 Hz and 51 Hz, which is acceptable during the system disturbances. Some of the worst case frequency responses are shown below.

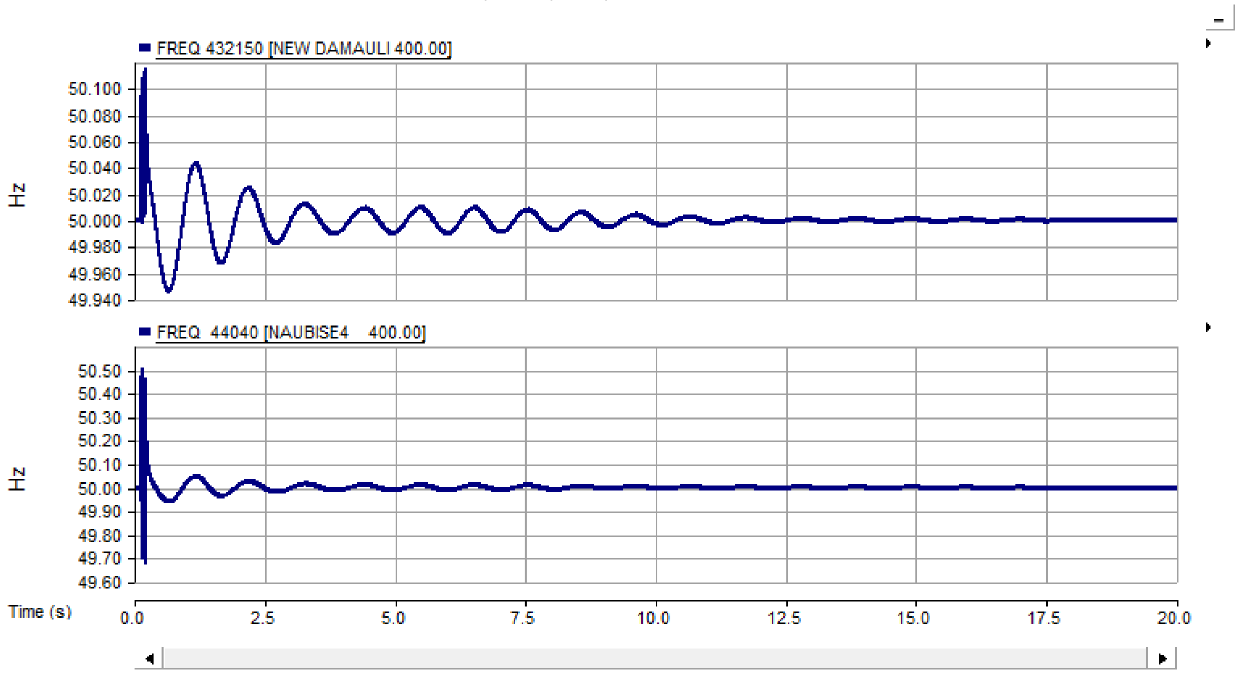


Figure 3.32 Bus frequency variation under contingency 9 (2030 Drypeak)

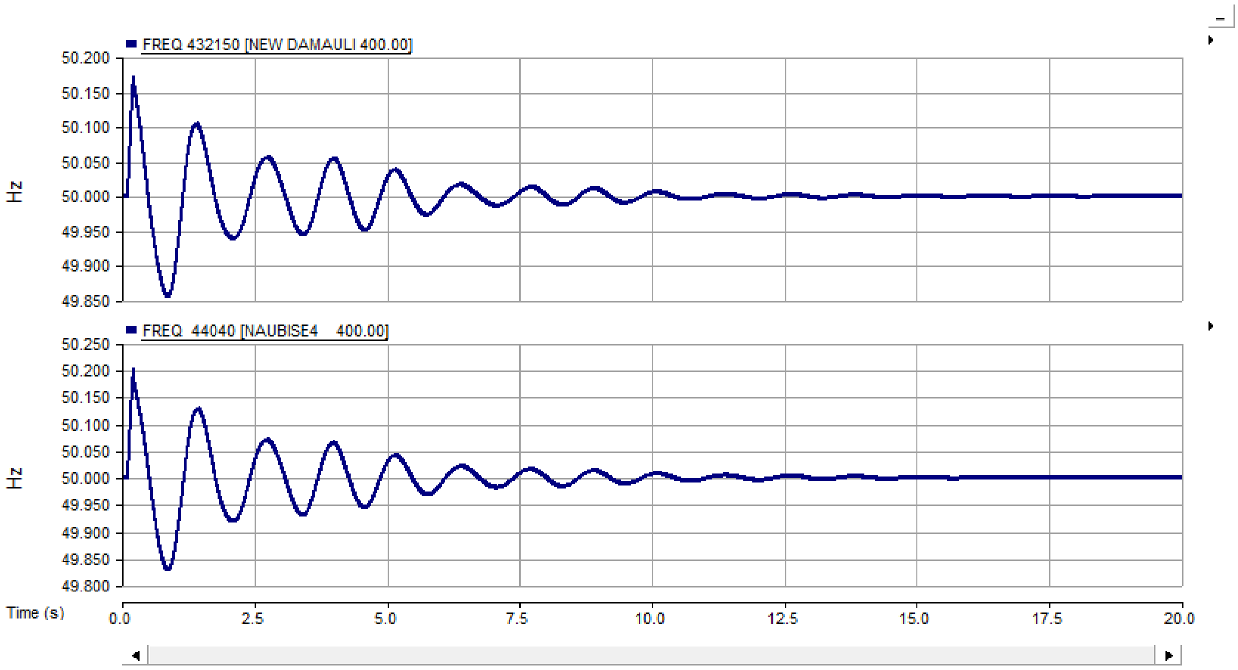


Figure 3.33 Bus frequency under contingency 5 (2030 Wetmin)

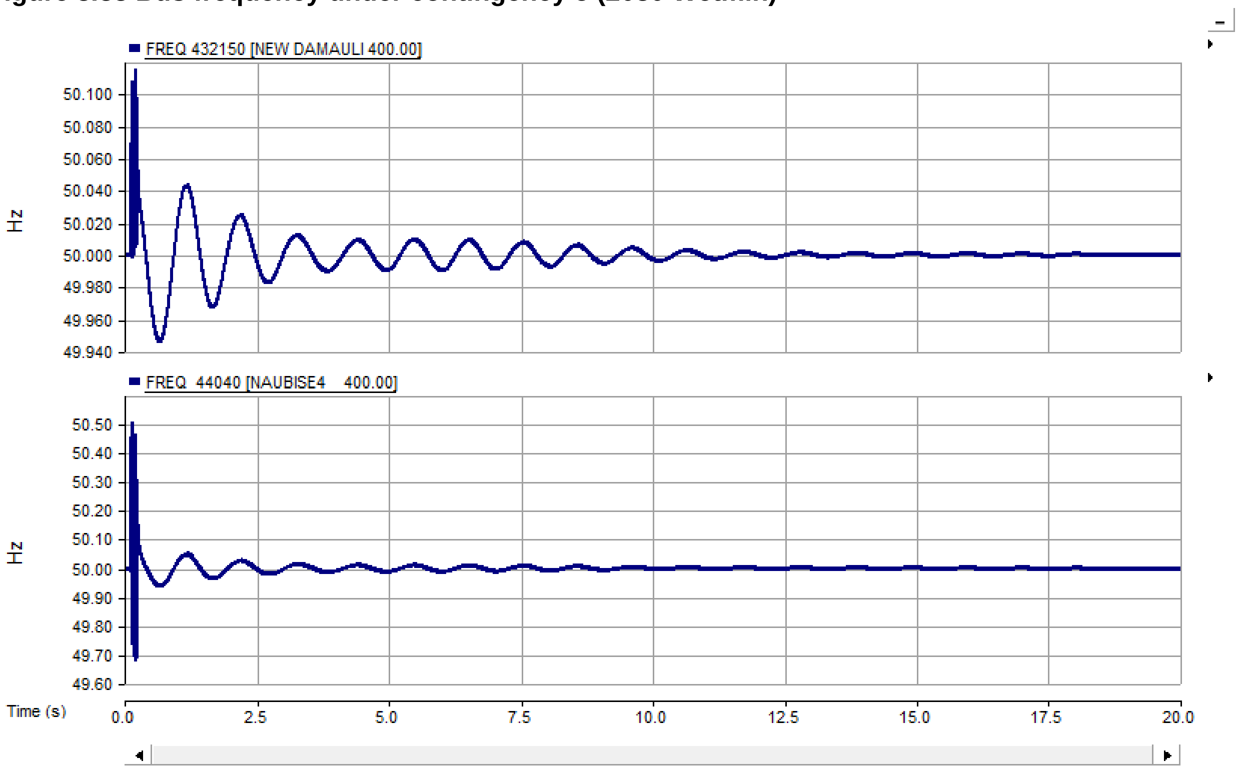


Figure 3.34 Bus frequency variation under contingency 9 (2023 Drypeak)

Largest Generator Outage in Nepal

In 2030 Drypeak scenario, the generator at Khudi is supplying about 170 MW. The tie lines flows are shown for the outage of the generator after a 3 phase fault at the terminal. The first tie line (Dhalkebar) imports were increased by about 80 MW and XB1 imports were increased by about 73 MW. Note that the tie lines provide the entire power mismatch because fixed frequency voltage sources were used to model the India system. In the real system, some power would be provided by the local generators due to governor action and the rest is provided by the tie lines. Therefore the case simulated can be considered as the worst case when considering the stresses on the tie lines and the Nepal system. The system recovers well and the voltage performance of the system is good.

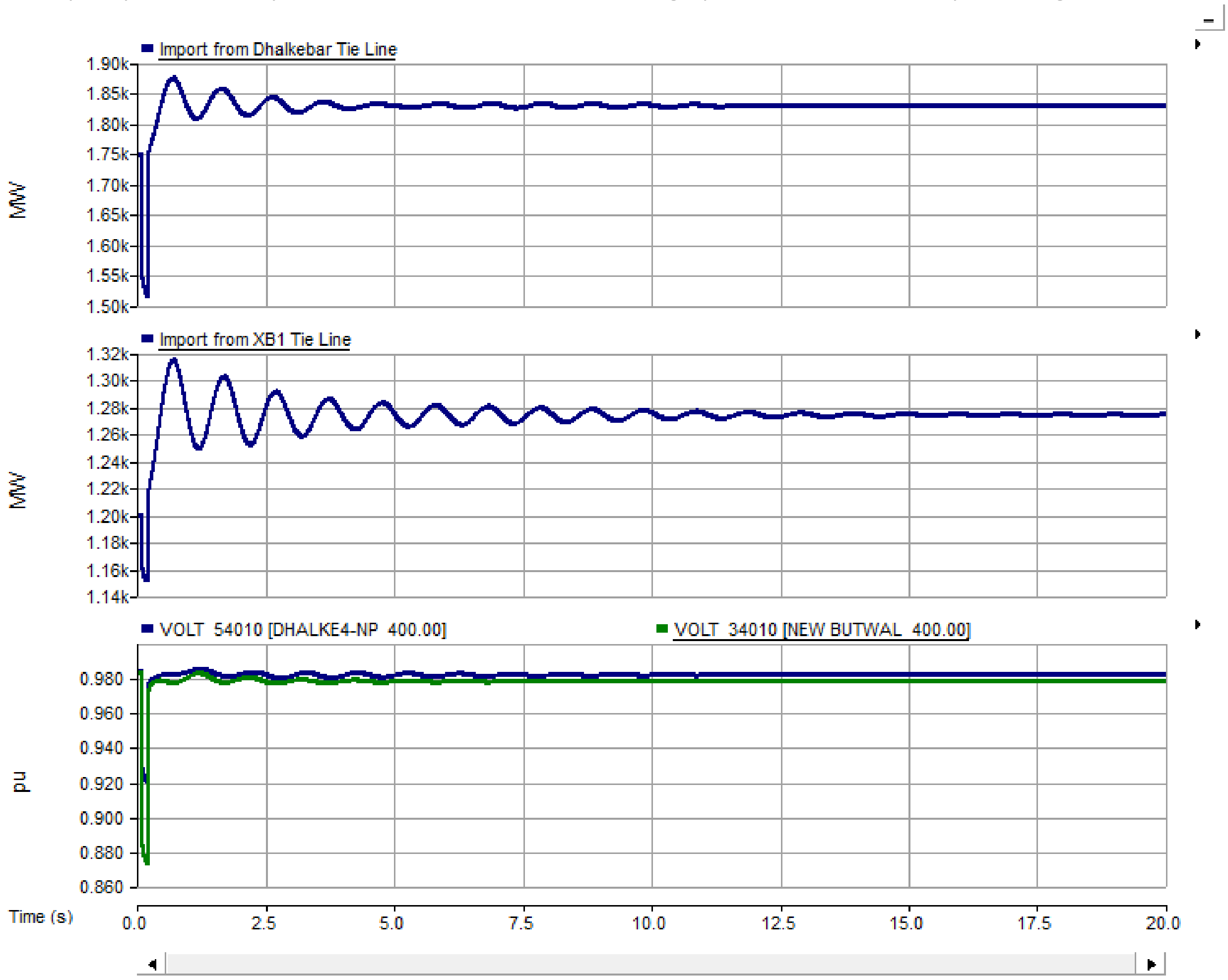


Figure 3.35 Tie line power transfers and voltages for the outage of Generator at Khudi - 2030 Dry Peak

Summary of Dynamic Analysis
The transient stability studies were performed using the dynamic data from NEA for the existing generating stations and the generic models with typical parameters for the new generating stations. All possible N-1 contingencies relevant to the MCC projects were considered in the analysis. The system recovers well after the contingencies and there is no concern related to the dynamic voltage performance, frequency stability of the electromechanically oscillations of the generators

3.1.8 Technical Benefits Study

An energy benefits study was performed to determine the benefits of eight different MCC project scenarios in terms of load shedding, generation not utilized, and losses. Furthermore, sensitivity studies were performed to determine the effects of different demand and supply forecasts along with the impacts of the tie line connecting New Butwal and Gorakhpur (XB1).

Power flow cases were created using PSS®E to evaluate the energy benefits and sensitivity of each scenario considered in this study. A power flow case was created for each scenario using different load and supply forecasts depending on the year and season. The Nepal system load and generation were balanced to ensure that the following constraints were met for each case:

- ***Transmission line limits.*** The load on each transmission line in the system was limited to 100% of its MVA rating value defined in PSS®E. Local generation was shifted to try and alleviate branch limit violations whenever possible. Generation reduction and load shedding were used in cases where branch limit violations could not be eliminated by shifting generation.
- ***Bus voltage limits.*** The voltage at each bus in the system was limited to a value between 0.9 pu and 1.1 pu. Local shunt devices and tap changing transformers were used to eliminate voltage violations whenever possible. Load shedding was used in cases where under voltage violations could not be eliminated by local voltage control devices.
- ***Interchange limits.*** Power interchange between Nepal and India was limited to 700 MW without XB1, 1750 MW with XB1 in the 2023 cases, 1200 MW without XB1, and 3000 MW with XB1 in the 2030 cases. Furthermore, it was assumed that the existing tie line between Dhalkebar and Musaffarpur carries 40% of the total interchange amount, while XB1 carries 60% of the total interchange amount in all cases where XB1 is in service.

Scenarios with MCC Projects
Tables 3.23 and 3.24 contain the annual energy figures for each MCC project scenario for 2023 and 2030, respectively. The results show that the XB1 tie line project has the greatest impact on reducing load shedding in Nepal. In general, it was found that the load supplied for Drypeak cases and total generation utilized for Wetmin cases are primarily constrained by the Nepal-India interchange limits. The system’s transmission line and bus voltage limits did not have a significant impact on load shedding and generation utilization for these power flow cases.

Table 3.23 Annual Energy Figures for Different MCC Project Scenarios for 2023

Scenario	Annual Supply (GWh)	Annual Consumption (GWh)	Annual Loss (GWh)	Annual Load Shedding (GWh)	Annual Imports (GWh)	Annual Exports (GWh)	Annual Generation Not Utilized (GWh)
Counterfactual	12219.6	12986.5	377.0	3924.8	3571.1	2427.2	8482.5
NR1	12180.1	13012.2	272.7	3899.1	3570.2	2465.4	8522.0
NR1 + XB1	12604.9	15184.9	347.4	1726.4	5823.2	2895.8	8097.2
NR1 + XB1 + T2' + T3	15577.0	15313.5	400.3	1597.9	4911.2	4774.4	5125.1
NR3	12215.1	13004.9	350.3	3906.4	3570.8	2430.7	8486.9
NR4	12217.4	12985.1	373.7	3926.2	3570.8	2429.3	8484.7
T8	17097.5	13133.5	411.4	3777.8	3501.6	7054.1	3604.5
All Projects	20702.0	15349.6	351.7	1561.7	4670.0	9670.8	0.1

Table 3.24 Annual Energy Figures for Different MCC Project Scenarios for 2030

Scenario	Annual Supply (GWh)	Annual Consumption (GWh)	Annual Loss (GWh)	Annual Load Shedding (GWh)	Annual Imports (GWh)	Annual Exports (GWh)	Annual Generation Not Utilized (GWh)
Counterfactual	19305.1	18635.9	740.2	9452.7	4462.7	4391.7	12869.9
NR1	19650.8	19915.1	660.2	8173.5	5315.8	4391.3	12524.2
NR1 + XB1	23852.8	24923.8	1072.2	3164.7	10615.9	8472.6	8322.2
NR1 + XB1 + T2' + T3	26801.9	25025.7	1155.2	3062.9	9982.6	10603.5	5373.2
NR3	19305.1	19463.2	708.2	8625.4	5267.4	4401.2	12869.9
NR4	19285.6	19418.2	757.5	8670.3	5281.4	4391.2	12889.5
T8	24036.8	19636.7	809.0	8451.9	5297.2	8888.4	8138.2
All Projects	31710.2	25138.3	946.7	2950.3	9790.5	15415.7	464.8

Based on above two tables, it reveals that the NR1 and the tie line project between New Butwal and Gorakphur (XB1) has the most significant impact on the reduction of load shedding in Nepal. The annual load shedding (GWh) will be reduced to 44% of the level comparing with the base case without the NR1 and XB1 project in 2023, and reduced to 33% of the level comparing with the base case without the NR1 and XB1 project in 2030.

T8 tie line is critical important for the 900 MW Upper Karnali HPP generation project. With T8 project, the overall generation utilization will increase to 83% from 59% in Base case in 2023, and increase to 75% from 60% in Base case in 2030. As the energy resources are distributed over the entire country in different zones. Therefore, with all proposed MCC projects, the generation utilization can be increased to 100% and 99% in 2023 and 2030 respectively.

Impact of Different Supply Scenarios

The original cases prepared for the technical benefits study include a three- and five-year lag on generation and transmission projects for 2023 and 2030, respectively. Two additional supply scenarios were considered for the counterfactual and all MCC project cases to determine the impact of changes in the supply forecast on the technical benefit results. The first supply scenario is a low supply scenario that reduces the total generation available and transmission system capacity in Nepal by applying an additional five-year lag to both base cases. The low supply cases for 2023 were created by first removing all transmission projects with a commission date of 2020 except if the project provides power to a radial load. The low supply cases for 2030 were created by simply scaling the generation profile of the corresponding 2030 cases.

The second supply scenario is a high supply scenario that increases the total generation available and transmission system capacity in Nepal by eliminating the lag associated with each case. The high supply cases for both 2023 and 2030 were created by scaling the generation profile of each base case to increase the overall system capacity. Furthermore, any out-of-service transmission system projects with commission dates of 2025 were enabled in the 2030 high supply cases. Finally, it was found that Zone 1 could not support the high supply generation figures for 2030, so an additional generator was added to Lamki's 132 kV bus to provide additional power in Zone 1.

Tables 3.25 and 3.26 contain the annual energy figures for the supply sensitivity scenarios along with the base technical benefit results for 2023 and 2030, respectively. It was found that transmission line capacity in Nepal was the primary limiting factor in both the low and high supply scenarios. In the case of low supply scenarios, the elimination of transmission line projects increases the loading on other transmission pathways in the system. In the case of high supply scenarios, the transmission system is not capable of transmitting the additional generation available. For example, during the high supply wetmin 2030 cases, there is a significant amount of generation not utilized despite the fact that there is capacity available on the Nepal-India tie lines.

A particular situation important to note is the low supply wetmin scenario for the year 2023 with all MCC projects. It was found that during peak and shoulder loads, there is some generation capacity available and not utilized despite the fact that the system is importing power. In this case, importing power to supply loads close to the tie lines is favored over using Nepal's generation, as the system's infrastructure is unable to transmit the required power. It should also be noted that this does not occur in the base or high supply cases.

Table 3.25 Annual Energy Figures for the Supply Sensitivity Study for 2023

Scenario	Annual Supply (GWh)	Annual Consumption (GWh)	Annual Loss (GWh)	Annual Load Shedding (GWh)	Annual Imports (GWh)	Annual Exports (GWh)	Annual Generation Not Utilized (GWh)
Counterfactual							
Low	5134.4	9885.2	231.5	7026.1	4982.3	0.0	8096.3
Base	12219.6	12986.5	377.0	3924.8	3571.1	2427.2	8482.5
High	13652.2	13802.6	435.8	3108.7	3145.4	2559.2	9312.5
All MCC Projects							
Low	12147.6	14984.9	524.5	1926.4	8030.1	4668.2	1083.0
Base	20702.0	15349.6	351.7	1561.7	4670.0	9670.8	0.1
High	22852.4	15532.8	404.5	1378.5	3692.2	10607.3	112.4

Table 3.26 Annual Energy Figures for the Supply Sensitivity Study for 2030

Scenario	Annual Supply (GWh)	Annual Consumption (GWh)	Annual Loss (GWh)	Annual Load Shedding (GWh)	Annual Imports (GWh)	Annual Exports (GWh)	Annual Generation Not Utilized (GWh)
Counterfactual							
Low	12178.4	17538.2	554.6	10550.4	6440.3	526.0	8096.9
Base	19305.1	18635.9	740.2	9452.7	4462.7	4391.7	12869.9
High	26610.3	24551.4	1332.6	3537.2	3698.9	4425.2	18596.7
All MCC Projects							
Low	20275.3	21929.0	592.4	6159.6	9236.1	6990.0	0.0
Base	31710.2	25138.3	946.7	2950.3	9790.5	15415.7	464.83
High	35744.6	25293.9	1138.7	2794.7	3522.2	12834.1	9462.4

Impact of Different Demand Scenarios
The original cases prepared for the technical benefits study use a constant rate of 7.5% per year to forecast the growth in Nepal's demand. Two additional demand scenarios were considered for the counterfactual and all MCC project cases to determine the impact of changes in the demand forecast on the technical benefit results. The first scenario is a low demand growth scenario that uses a constant growth rate of 5% per year. The second scenario is a high demand growth scenario that uses a constant growth rate of 10% per year.

Tables 3.27 and 3.28 contain the annual energy figures for the demand sensitivity scenarios along with the base technical benefit results for 2023 and 2030, respectively. The results from the demand sensitivity study show that load shedding increases as the demand growth rate increases. Furthermore, annual imports increase as the growth rate increases and annual exports decrease as the growth rate decreases. These results were expected because as the demand increases, more of Nepal's generation must be used to supply the increasing demand and less is available for export to India.

Table 3.27 Annual Energy Figures for the Demand Sensitivity Study for 2023

Scenario	Annual Supply (GWh)	Annual Consumption (GWh)	Annual Loss (GWh)	Annual Load Shedding (GWh)	Annual Imports (GWh)	Annual Exports (GWh)	Annual Generation Not Utilized (GWh)
Counterfactual							
Low	12086.0	12576.3	361.6	3182.4	3411.2	2559.2	8616.1
Base	12219.6	12986.5	377.0	3924.8	3571.1	2427.2	8482.5
High	12328.5	13258.6	365.1	4860.3	3570.7	2275.5	8373.5
All MCC Projects							
Low	20702.1	14449.8	330.0	1308.9	4084.1	10006.4	0.0
Base	20702.0	15349.6	351.7	1561.7	4670.0	9670.8	0.1
High	20702.1	16298.7	372.9	1820.1	5367.5	9398.0	0.0

Table 3.28 Annual Energy Figures for the Demand Sensitivity Study for 2030

Scenario	Annual Supply (GWh)	Annual Consumption (GWh)	Annual Loss (GWh)	Annual Load Shedding (GWh)	Annual Imports (GWh)	Annual Exports (GWh)	Annual Generation Not Utilized (GWh)
Counterfactual							
Base	19305.1	18635.9	740.2	9452.7	4462.7	4391.7	12869.91
High	19924.6	20690.6	826.3	10819.6	5365.2	3772.9	12250.4
All MCC Projects							
Low	31452.4	22708.0	852.8	2262.9	8293.5	16185.1	722.6
Base	31710.2	25138.3	946.7	2950.3	9790.5	15415.7	464.8
High	32074.1	27668.0	1081.4	3842.2	11255.8	14580.5	100.9

Impact of Reduced Interchange with India

The results from the MCC scenarios study indicate that the XB1 tie line project has the greatest impact on reducing load shedding in Nepal. Cases including all MCC projects were run a second time with XB1 out of service to determine the impact of XB1 on the study results.

Tables 3.29 and 3.30 contain the annual energy figures for the XB1 sensitivity scenario along with the base technical benefit results for 2023 and 2030, respectively. The results demonstrate that XB1 has a significant effect on reducing both annual load shedding and generation not utilized.

Table 3.29 Annual Energy Figures for the XB1 Sensitivity Study for 2023

Scenario	Annual Supply (GWh)	Annual Consumption (GWh)	Annual Loss (GWh)	Annual Load Shedding (GWh)	Annual Imports (GWh)	Annual Exports (GWh)	Annual Generation Not Utilized (GWh)
Counterfactual	12219.6	12986.5	377.0	3924.8	3571.1	2427.2	8482.5
All MCC Projects	20702.0	15349.6	351.7	1561.7	4670.0	9670.8	0.1
All MCC Projects Except XB1	18066.4	13687.3	276.7	3224.1	2951.3	7053.7	2635.7

Table 3.30 Annual Energy Figures for the XB1 Sensitivity Study for 2030

Scenario	Annual Supply (GWh)	Annual Consumption (GWh)	Annual Loss (GWh)	Annual Load Shedding (GWh)	Annual Imports (GWh)	Annual Exports (GWh)	Annual Generation Not Utilized (GWh)
Counterfactual	19305.1	18635.9	740.2	9452.7	4462.7	4391.7	12869.91
All MCC Projects	31710.2	25138.3	946.7	2950.3	9790.5	15415.7	464.8
All MCC Projects Except XB1	25438.2	20840.0	584.1	7248.6	5241.0	9255.1	6736.9

Based on above two tables, the study reveals that the XB1 project itself is critically important for all MCC projects. With XB1 and all other MCC projects, annual load shedding (GWh) will reduce further to 40% of the base case level compared with 82% of the base case level without XB1 in 2023, and to 31% of the base case level compared with 77% of the base case level without XB1 in 2030.

With XB1 and all other MCC projects, generation utilization will increase to 170% of the base case level compared with 148% of the base case level without XB1 in 2023, and to 164% of the base case level compared with 132% of the base case level without XB1 in 2030.

In addition, the technical benefit study was completed for NR1 +XB1 with 0.85 Power Factor. The effect of power factor on system losses are negligible since the lines are not heavily loaded.

Original results:

Scenario	Annual Supply (GWh)	Annual Consumption (GWh)	Annual Loss (GWh)	Annual Load Shedding (GWh)	Annual Imports (GWh)	Annual Exports (GWh)	Annual Generation Not Utilized (GWh)
All Projects	31710.2	25138.3	946.7	2950.3	9790.5	15415.7	464.8

Results with 0.85 power factor cases:

	Annual Supply (GWh)	Annual Consumption (GWh)	Annual Loss (GWh)	Annual Load Shedding (GWh)	Annual Imports (GWh)	Annual Exports (GWh)	Annual Generation Not Utilized (GWh)
All MCC Projects	31755.8	24327.3	1021.1	3761.3	9816.4	16223.9	419.2

3.1.9 Power System Assessment Conclusion

Table 3.31 Power System Assessment Results

Project	Study Results or Justifications
400 kV East-West Transmission Trunk Line - NR1	NR1 project is the backbone transmission network; it enhances the Nepal network's transmission capacity. It provides the transmission backbone to transfer the remote energy to load centers and import/export energy from/to India.
XB1	XB1 is critically important within all MCC projects. It doubles the energy exchange capability between Nepal and India. It greatly reduces the load shedding requirement due to the increasing import capability, and greatly increases generation utilization due to the increasing export capability.
T2', T3, NR3, and NR4	T2', T3, NR3, and NR4 are remote transmission projects. These projects enhance the remote area transmission capacities, therefore, to accommodate increasing remote generation projects.
T8	T8 is a dedicated transmission line project that will provide the transmission network for the 900 MW Upper Karnali HPP generation project in which around 12% of project capability will be excavated by NEA.

3.2 Transmission Lines and Substations – Detail Feasibility Assessment

3.2.1 NR1: Transmission Lines

The 400 kV East-West Transmission Backbone trunk line project will develop a new 270 km, 400 kV double-circuit transmission line through hilly regions in central Nepal. The route for the first section of the line is through New Hetauda – Naubise - New Damauli - New Butwal and the second section will run from Naubise to Lapsiphedi.

The lengths of each section of transmission lines are:

- New Butwal substation to New Damauli substation – 84 km
- New Damauli to Naubise substation – 98 km
- Naubise Substation to New Hetauda substation – 41 km
- Naubise substation to Lapsiphedi – 48 km.

Data Gathering Results

Data were collected from NEA managers of past and current projects, local consultants and contractors, and World Bank and ADB employees:

- 400 kV standard tower drawings
- Transmission line projects that are designed to connect to proposed substations in NR1
- Future requirements at all proposed substations in NR1
- Environmental and climatic data along the proposed transmission line and substations.

Site Visit Findings and Observations

We conducted site visits along the NR 1 route via helicopter. The proposed route goes through small villages, agricultural land and over very hilly terrain. The crops grown in this area are mainly rice and potatoes. The route also goes over some houses scattered over the hills. A section of the route passes over forest land, which varies from dense vegetation to treeless patches. There is also a possibility that the line would pass through grazing and pasture land. Nine river crossings were observed along the route. The land near New Butwal substation is dry and flat.

The routing of this transmission line was difficult because of its hilly terrain. We tried to avoid steep slopes, but they still can be found at some locations. In such situations the terrain commanded shorter spans and thus required more towers. Detail designs of these lines (and all other lines in hilly terrain) need to consider all of these problems and avoid such a harsh centerline. Line routing in the detailed design stage (unlike in the detailed feasibility stage) will start with survey data that will have to come from either a LiDAR survey or detailed land survey. Airborne LiDAR surveys have advantages such as covering a wider corridor (which greatly facilitates the upcoming desktop routing practice), fast operation and high accuracy levels, and hence is the preferred method. Furthermore, the airborne LiDAR survey is more cost effective and more economical for long spans.

Survey data in the detailed design stage should include very precise information about ground points in good density which will be suitable for detailed design. All the obstacles such as side slopes, trees and their heights, existing transmission lines, roads with an identification of their class and width, structures with type identifications, etc. will be labeled (this action is called feature coding). A desktop line routing based on this survey data can avoid many problems. Furthermore, a detailed site walk/drive down will eliminate the remaining problems. The final line route emerging from this exercise will guarantee a smooth, efficient and cost-effective line spotting.

Assessment of Utilized Material in Existing Facilities

We collected data on existing transmission lines in Nepal from NEA, local engineering consulting companies, and local contractors. This includes information on existing transmission line networks in Nepal, the structure types used on these lines, the materials used, and their performance quality:

- Conductors
- Insulators
- Overhead shield wires
- Optical fiber ground wires

- Insulator string fittings
- Structure number boards
- Aerial markers.

Material used in 400 kV East-West Transmission Trunk Line
Full specifications of the materials used in the 400 kV east-west transmission trunk line are presented in various specification documents in Annex D.

3.2.2 New Hetauda Substation

The New Hetauda 400 kV-220 kV substation is planned to be constructed adjacent to a 220 kV substation that is under construction by the World Bank.

The substation will contain the following:

- 2 x 400 kV bays for lines to Naubise
- 2 x 400 kV bays for lines to Dhalkebar
- 3 x 3 phase, 400 kV-220 kV, 160 MVA power transformers*
- Space for 2 x 3 phase, 400 kV-220 kV, 160 MVA future power transformers
- Space for 2 future 400 kV bays for lines to Budhi Gandaki.

* As per the due diligence report, 2 x 320 MVA transformers are to be provided at this station. However, based on the site access constraints, the capacity of the power transformer is recommended to be limited to 160 MVA. Also, based on the power system assessment results, only 3 x 160 MVA transformers are required to meet the design criteria requirements (N-1).

The control building at this substation needs to house the following P&C and SCADA panels:

- 18 protection panels
- 9 control/mimic panels
- 2 SCADA/RTU panels
- 3 communication/teleprotection panels
- 5 spare/dummy panels
- 1 dynamic disturbance recorder.

New Hetauda Site: Option 1
The substation layout is presented in drawing 1661550400-DWG-E0001[1]. The 400 kV switchgear is an indoor GIS type with a breaker-and-a-half scheme. The 220 kV yard is AIS with a mixed double bus-single breaker and transfer bus scheme. The new 220 kV bus bars are designed to be connected to the 220 kV bus bar of the adjacent 220 kV station. The 220 kV bus extensions are positioned for easy installation and to connect two future 400 kV-220 kV, 160 MVA transformers.

[1] These drawings are submitted as separate files owing to their large size (on average, over 250 MB).

The red polygon in Figure 3.36 shows the space reserved by NEA for the 400 kV extension. As can be seen, the space required for the 400 kV extension is larger than the reserved space. As such, in order to position the 400 kV extension immediately beside the 220 kV substation, the following work/actions need to be completed:

- Re-routing of the east/west road north of the 220 kV substation as well as the north/south road west of the 220 kV station
- Relocation of the residents within the area to be occupied by the 400 kV extension
- Demolition and relocation of the living quarters and office building already constructed in the area available for the 400 kV extension
- Relocation of the water pond and ditch located in the area available for the 400 kV extension.

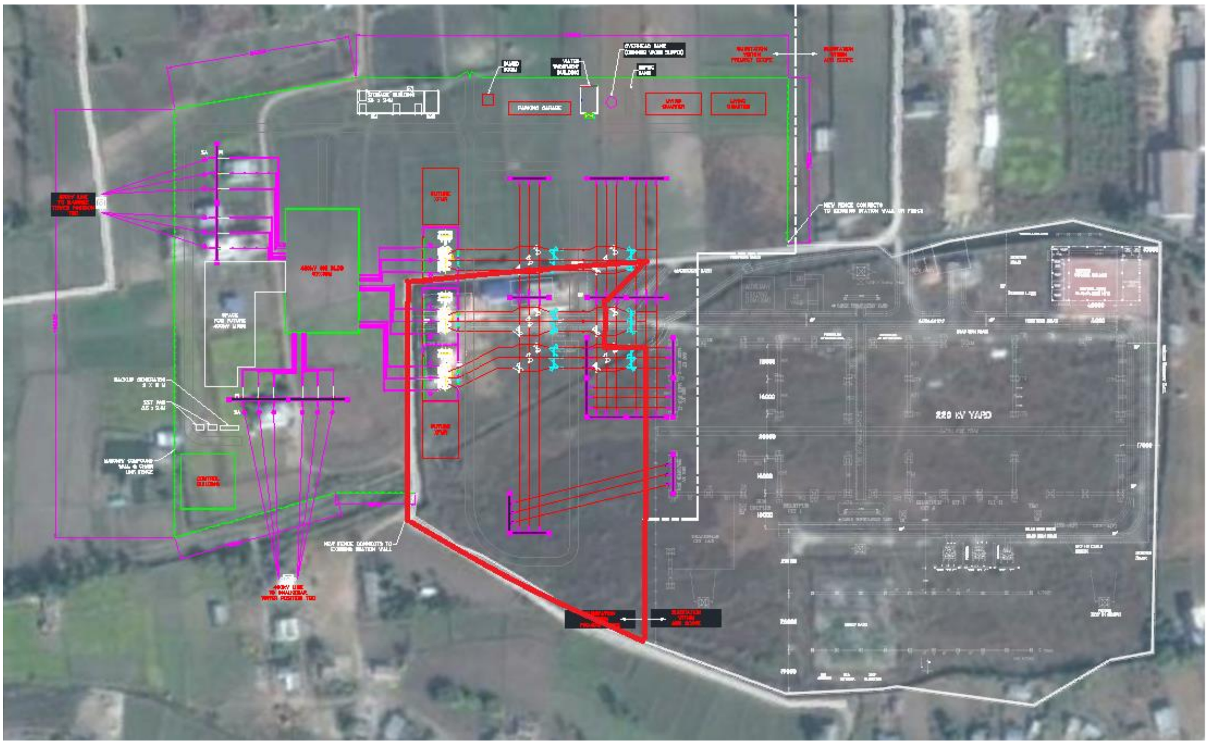


Figure 3.36 Overlay of the Available Space and the Design of the 400 kV Extension

New Hetauda Site: Option 2

Figure 3.37 presents an alternate substation placement considered in order to avoid relocation of the residents to the west of the 220 kV substation. In this option, the 400 kV substation is constructed on empty farmlands to the northwest of the 220 kV substation and the two substations are connected through a double circuit, 220 kV transmission line. The analysis of the solution reveals the following:

- Requires the purchase of additional land when considering the 220 kV interconnection buses and the transmission lines right of ways
- Purchasing the land for the transmission line right of way could potentially lead to the relocation of some of the residents on the west side of the 220 kV station

- Potential for population unrest caused by the use of additional land and the perception of poor project planning driven by the construction of two separate substations in close proximity.

Given the substantial higher financial and social impact, this option is considered less feasible and hence will not be pursued further.

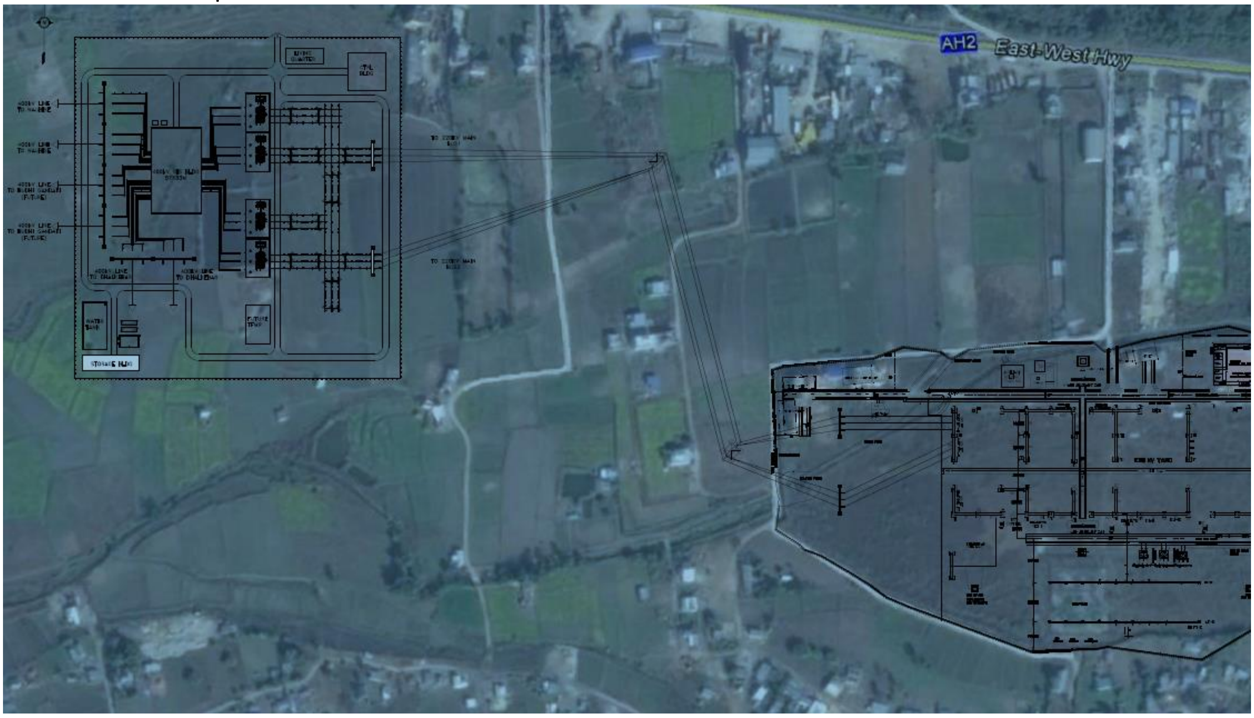


Figure 3.37 Alternate Substation Placement Explored for New Hetauda

The location as shown in option 1 above was selected as the final site location. The discussions below are specific to the selected option.

The civil work consists of realigning the irrigation ditch currently running across the site to the perimeter of the site. The new ditch will follow the substation perimeter outside the fenced area and then reconnect to the original alignment downstream to the west of the station. The topsoil (1 m deep) inside the fenced area needs to be removed and backfilled with engineered fill in order to stabilize the yard area. The top layer needs to be finished with electrical insulation stone while maintaining a slope of 2 to 3% throughout the site. The existing conditions for this site are shown in drawing 1661550400-DWG-C0001, while the final site grading and drainage plan are shown in drawing 1661550400-DWG-C0002.

The perimeter fence is composed of a compound wall with a barbed fence on top as well as one swing gate for site access. A new access road into the substation from the E-W Highway needs to be constructed and finished with sub base, base, and asphalt layers (see typical details in drawing 705-1661550400-C-703) to handle heavy truck loads. The staff quarters need be connected to a water supply system consisting of a water treatment system. The wastewater from the staff quarters is to be collected and treated in a septic tank and septic bed system.

In conclusion, the analysis above reveals that it is feasible to build the 400 kV extension beside the 220 kV station if more land is purchased. The scope of supply will consist of the construction of the 440 kV extension as well as the extension of the 220 kV bus within the existing station.

3.2.3 Naubise Substation

The new 400kV-220kV Naubise substation is considered to contain:

- 2 x 400 kV bays for lines to New Damauli
- 2 x 400 kV bays for lines to New Hetauda
- 2 x 400 kV bays for lines to Lapsiphedi
- 2 x 220 kV bays for lines to Marsyangdi
- 2 x 220 kV bays for lines to Matatirtha
- 3 x 3 phase, 400 kV-220 kV, 160 MVA power transformers*
- Space for 2 x 3 phase, 400 kV-220 kV, 160 MVA future power transformers
- Space for 4 x 220 kV bays for lines to be constructed by IPPs.

* As per the due diligence report, 2 x 315 MVA transformers are to be provided at this station. However, based on the site access constraints, the capacity of the power transformer is recommended to be limited to 160 MVA. Also, based on the power system assessment results, only 3 x 160 MVA transformers are required to meet the design criteria requirements (N-1)..

The control building at this substation needs to house the following P&C and SCADA panels:

- 34 protection panels
- 14 control/mimic panels
- 2 SCADA/RTU panels
- 3 communication/teleprotection panels
- 5 spare/dummy panels.
- 1 dynamic disturbance recorder.

The substation layout is presented on drawing 1661550400-DWG-E0100. The substation footprint is optimized using a combination of strain and rigid bus at three different elevations to achieve the breaker-and-a-half scheme. In order to further optimize the footprint use, all gantries are oriented in order for the 400 kV lines to enter from the north and for the 220 kV lines to enter from the south. As a result, only one bay of the two bay breaker-and-a-half arrangement is connected for the 400 kV New-Hetauda lines. In order to maintain a similar level of reliability to that originally planned, an additional breaker is added to connect the line bay to the second bus. This results in a double-bus double breaker connected line bay arrangement that can be expanded to a breaker-and-a-half arrangement by adding a third breaker and the associated disconnect switches.

Figure 3.38 presents the two locations considered for the Naubise station. The red polygon shows the original location selected while the green polygon shows the final substation position.

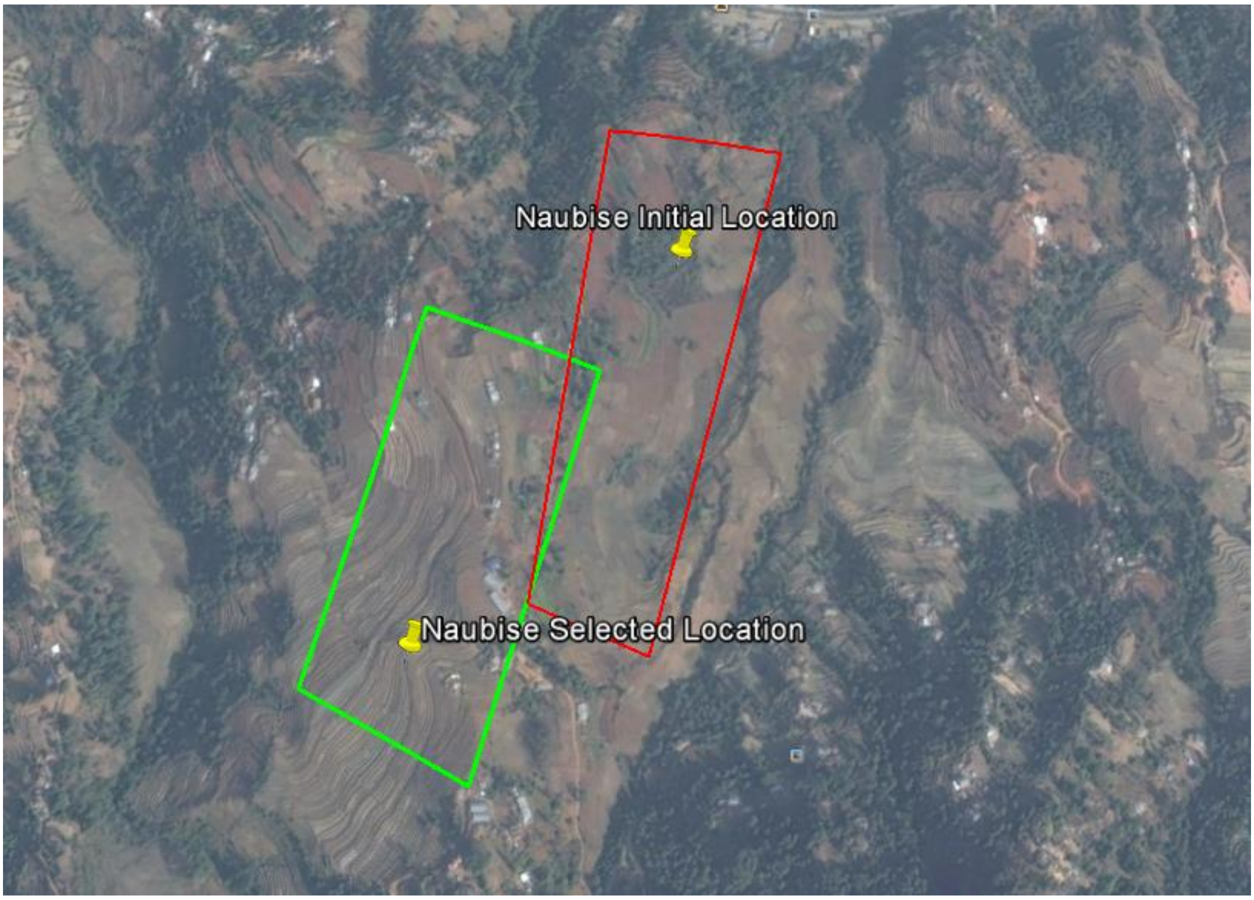


Figure 3.38 Planned Location (Red) and Selected Location (Green) for Naubise Substation – Latitude 27º44'0.12"N Longitude 85º6'59.63"E

Naubise Site Option 1 (Original Position)

The AIS substation is designed in order to allow its construction within the available land for Option 1 (207 m x 530 m).

This option was rejected following a more in-depth civil investigation. According to the civil analysis, there is an elevation difference of approximately 60 meters between the highest and lowest points of the station. A two step terrace design was studied but ruled out. In fact, the terrace design led to increase the width of the station from 200m to 400m which also increased the civil and electrical construction costs. The increased width was required in order to provide appropriate transition distances between the different flat segments. It was not feasible to simply provide a retaining wall given the 30m elevation difference between flat segments. A 3 to 1 slope was provided for slope stability as per good engineering practices.

Tetra Tech's civil engineer went to site to further investigate and determine if the substation position could be improved further. During the walkdown, the engineer was able to identify an area west of the original position that was flatter and more favorable.

Naubise Site Option 2 (Final Position)
The final site location presents manageable elevations. However, the land is not already purchased and parts of it are occupied. The land will need to be purchased and residents relocated.

There were flatter section to the north and south of the current location, so a split in the station to the north and south with an access road in the middle was considered as an option. However during the site visit it was noticed that an existing 132Kv transmission line was passing through the north section of the split which rendered expansion to the north unfeasible.

The civil design consists of installing a retaining wall (1000 m long) around the perimeter of the site in order to retain the excess backfill from the excavation at higher elevations and the new engineered fill, which will be imported to create a relatively flat site. The topsoil (1.5 m deep) inside the fenced area has to be removed and backfilled with engineered fill in order to achieve a good stable yard area. The top layer has to be finished with electrical insulation stone and the final site grading has to have a slope of 2 to 3% throughout the site. The existing conditions for this site are shown in drawing 1661550400-DWG-C0100 and the final site grading and drainage plan are shown in drawing 1661550400-DWG-C0101.

The existing access road into the station from Prithvi Highway is a mud access road that is not able to withstand the load of the heavy trucks transporting the transformers. The road will be strengthened by the addition of base and asphalt layers and by increasing its width to 6 m. The staff quarters has to be connected to a water supply system which will also consist of a water treatment system. The wastewater from the staff quarters will be collected and treated in a septic tank and septic bed system. The yard and the staff quarters will be secured by installing a masonry wall and fence on top. A perimeter fence will be installed on top of the retaining wall to restrict access into the site. 27°44'03.0"N 85°07'05.0"E

3.2.4 New Damauli Substation

The New Damauli 400 kV-220 kV substation is considered to contain:

- 2 x 400 kV bays for lines to Naubise
- 2 x 400 kV bays for lines to New Butwal
- 4 x 3 phase, 400 kV-220 kV, 160 MVA power transformers*
- Space for 2 x 3 phase, 400 kV-220 kV, 160 MVA future power transformers
- Space for 2 x 400 kV bays for future line bays
- Space for 2 future 220 kV bays for lines to Lekhnath
- Space for 4 future 220 kV bays for lines from IPPs.

* As per the due diligence report, 2 x 315 MVA transformers are to be provided at this station. However, based on the site access constraints, the capacity of the power transformer is recommended

to be limited to 160 MVA. Also, based on the power system assessment results, 4 x 160 MVA transformers are required to meet the design criteria requirements (N-1).

The control building at this substation needs to house the following P&C and SCADA panels:

- 24 protection panels
- 12 control/mimic panels
- 2 SCADA/RTU panels
- 3 communication/teleprotection panels
- 5 spare/dummy panels.
- 1 dynamic disturbance recorder.

The yellow polygon in Figure 3.39 shows the space reserved for the substation. The available space is an L-shaped area of 49 000m^2 where the flat land is adequate for building a substation.

The substation layout is presented on drawing 1661550400-DWG-E0200. The 400 kV switchgear is indoor GIS type with breaker-and-a half scheme. The 220 kV yard is AIS with breaker-and-a half scheme. All 220 kV circuits are considered as part of the project scope. As such, only two of the three breakers are provided for each breaker-and-a half diameter. The two breakers are provided in order to allow connection to both buses.

Figure 3.39 Planned Location for New Damauli Substation – Latitude 27º58’4.80”N Longitude 84º17’37.11”E

The civil work involves removing the topsoil (1.5 m deep) inside the fenced area and backfilling with engineered fill in order to achieve a good stable yard. The top layer has to be finished with electrical insulation stone and the final site grading has to have a slope of 2 to 3% throughout the site. A new 430 m access road into the substation has to be built from the Chabdi Temple Road. This road has to be finished with a sub base, base and asphalt layers (see typical details in Annex C) in order to handle heavy truck loads. The existing conditions for this site are shown in drawing 1661550400-DWG-C0200 and the final site grading and drainage plan are shown in drawing 1661550400-DWG-C0201.

The new access road crosses a 6 m wide and 1.5 m deep stream. A system of culverts has to be installed to handle the peak flows up to 1.5 m3/s where the road crosses the stream. The design plan details for this road crossing are shown in drawing 1661550400-DWG-C0202.

The staff quarters must be connected to a water supply system that will consist of a water treatment system. The wastewater from the staff quarters has to be collected and treated in a septic tank and bed system. A perimeter compound wall and fence along with an access gate also have to be installed around the substation to restrict the access to the site.

3.2.5 New Butwal Substation

The New Butwal 400 kV-220 kV substation is planned to be constructed adjacent to a 220 kV substation that is under the ADB’s scope.

The substation is considered to contain the following:

- 2 x 400 kV bays for lines to New Damauli
- 2 x 400 kV bays for lines to the Indian border
- 5 x 3 phase, 400 kV-220 kV, 160 MVA power transformers*
- Space for 2 x 3 phase, 400 kV-220 kV, 160 MVA future power transformers
- Space for 4 future 400 kV bays for lines to Kohalpur-Kaligandaki
- Space for 2 future 400 kV bays for lines to Gorakhpur India Border.

* As per the due diligence report, 2 x 315 MVA transformers are to be provided at this station. However, based on the site access constraints, the capacity of the power transformer is recommended to be limited to 160 MVA. Also, based on the power system assessment results, 5 x 160 MVA transformers are required to meet the design criteria requirements (N-1).

The control building at this substation needs to house the following P&C and SCADA panels:

- 24 protection panels
- 6 control/mimic panels
- 2 SCADA/RTU panels
- 3 communication/teleprotection panels
- 5 spare/dummy panels.
- 1 dynamic disturbance recorder.

The substation layout is presented in drawing 1661550400-DWG-E0900. The 400 kV and 220 kV distributions are achieved by AIS. A 220 kV bus is provided in order to connect ADB's 220 kV substation to the 400 kV-220 kV substation. It is recommended that, in order to reduce the cost of the station, that ADB's 220 kV substation be designed starting from the secondary of the 400 kV-220 kV transformers. This would allow removing the additional 220 kV bus that is redundant and reduces the reliability of the system. It is also possible to extend the 220 kV bus to a breaker-and-a half scheme if the appropriate breaker configuration is designed within ADB's 220 kV substation. This allows a high level of reliability to be maintained at the 220 kV side while re-using the bus that is already provided.

Upon completion of the projects under review in this study, there will be three lines interconnecting Nepal to India; the existing tie line between Dhalkebar and Muzzaffarpur , the power flow controlled dedicated tie line T8 between New Lamki and the Indian border, and XB1, the tie line proposed between New Butwal and Gorakhpur. Depending on the system conditions at the interconnection points, it is possible that one of the tie lines operates in energy export mode while another is operating in energy export mode, therefore creating a loop flow between the two countries. These loop flows are undesirable and need to be avoided. Since no detailed model is available for the Indian power network at present, it is not possible to conduct simulations that can highlight potential loop flows. It is therefore recommended that a complete model be obtained and that the potential for loop flows between Nepal and India be studied at the detailed design stage.

However, the solutions listed below should be reviewed during detail design stage:

- Phase shifting transformer
- Back-to-back HVDC
- Flexible AC Transmission Systems (FACTS) devices.

The purple polygon in Figure 3.40 shows the space reserved by NEA and already acquired by ADB for the 400 kV-220 kV substation, while the green polygon shows additional land available that has to be purchased. Given that no information is available on the ADB 220 kV substation, it his assumed that it will be constructed besides the 400-220 kV substation and that it will have an approximate dimension of 120 m x 180 m. The approximate dimension is based on other 220 kV AIS stations that have been designed as part of this project.

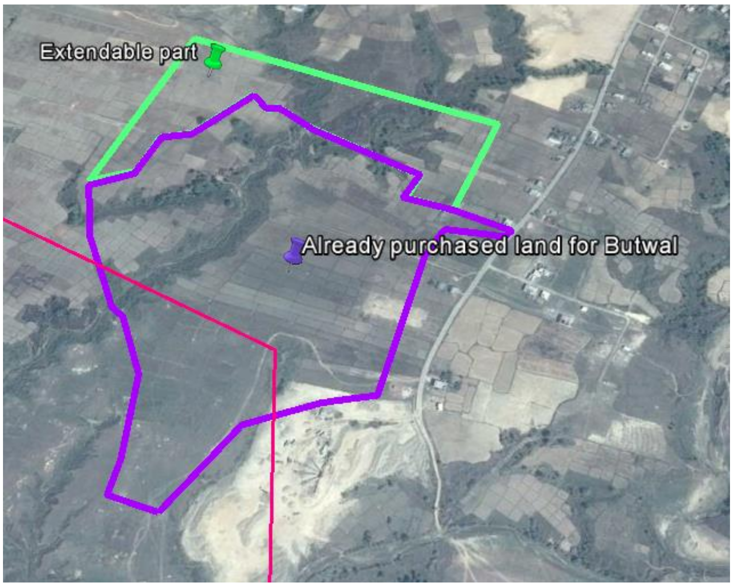


Figure 3.40 Available Land for the New Butwal Substation – Latitude 27º34'35.25"N Longitude 83º41'25.62"E

At present, a 132 kV transmission line is situated in the middle of the selected site location (see Figure 3.41). According to the local experts consulted, the line will be redirected to avoid the station. If the project goes forward, it is crucial that the relocation of the 132 kV line be completed before any work can be started on the construction of the New Butwal substation.

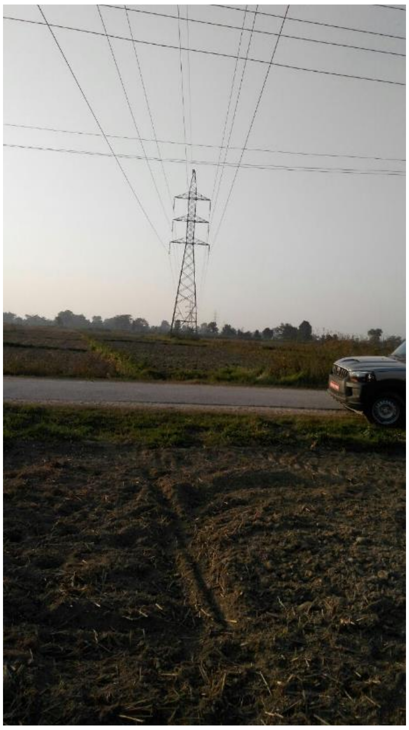


Figure 3.41 132 kV Line on Future Site for New Butwal Station

The civil design consists of excavation and backfill of the existing soil to achieve a final site grading with a slope of 2 to 3% throughout the site. The topsoil (1.5 m deep) inside the fenced area has to be removed and backfilled with engineered fill in order to achieve a good stable yard area and the top layer has to be finished with electrical insulation stone. The existing conditions for this site are shown in drawing 1661550400-DWG-C0300 and the final site grading and drainage plan are shown in drawing 1661550400-DWG-C0301. There is a stream running through the site that will be backfilled inside the substation and will be redirected to bypass the new substation.

A new access road into the substation has to be built from the E-W highway located to the north of the site, and this will be finished to handle heavy truck loads. The staff quarters have be connected to a water supply system, which also consists of a water treatment system. The wastewater from the staff quarters must be collected and treated in a septic tank and bed system. A perimeter compound wall and fence along with an access gate will also be installed around the substation to restrict the access to the site.

3.2.6 Lapsiphedi Substation

Lapsiphedi is a 400 kV-220 kV substation planned to be constructed adjacent to a 220 kV substation that is in ADB's scope.

- 2 x 400 kV bays for lines to Naubise
- 2 x 400 kV bays for lines to Barabise
- 9 x 400 kV-220 kV, 55 MVA single phase transformers*
- Space for 3 future 400 kV-220 kV, 55 MVA single phase transformers (future).

* As per the due diligence report, 2 x 275 MVA transformers are to be provided at this station. However, based on the site access constraints, the capacity of the power transformer is recommended to be limited to single phase 55 MVA. Also, based on the power system assessment results, 3 x 165 MVA transformers (3 x 55 MVA single phase transformers) are required to meet the design criteria requirements (N-1).

The control building at this substation needs to house the following P&C and SCADA panels:

- 18 protection panels
- 6 control/mimic panels
- 2 SCADA/RTU panels
- 3 communication/teleprotection panels
- 5 spare/dummy panels
- 1 dynamic disturbance recorder.

The red polygon in Figure 3.42 shows the space reserved for the substation. The available space is a rectangle at the bottom of a valley that has dimensions of 70 m by 140 m. At present, there is no information on the location of ADB's 220 kV substation. It is therefore assumed that the substation will be constructed beside the 400 kV-220 kV substation and that they will be connected via underground 220 kV cables.

Figure 3.42 Available Land for Lapsiphedi Substation – Latitude 27º44'42.44"N Longitude 85º30'33.03"E

The substation layout is presented in drawing 1661550400-DWG-E0400. The 400 kV switchgear is indoor GIS type with breaker-and-a half scheme. 220 kV cable termination structures are provided on the 220 kV side of the power transformers. The 400 kV gantries for the Barabise lines are installed on the outside of the substation fence in the inclined area in order to minimize the total substation footprint.

The civil work involves removing topsoil (1.5 m deep) inside the fenced area and then backfilling with engineered fill in order to achieve a good stable yard area. The top layer has to be finished with electrical insulation stone and the final site grading has to have a slope of 2 to 3% throughout the site. Since the site is in a valley, a retaining wall will be installed all around the perimeter of the site to protect from any potential slope failures. The existing conditions at this site are shown in drawing 1661550400-DWG-C0400 and the final site grading and drainage plan is shown in drawing 1661550400-DWG-C0401.

The existing access road to the site from Sankhu- Bhotechour road is a narrow mud road that cannot handle heavy truck loads. Therefore, the existing road from the village to the site (approximately 2.1

km) will be upgraded and expanded to a 6 m wide asphalt roads in order to carry heavy loads towards the station. The existing road plan and details is shown in drawing 1661550400-DWG-C0402.

A new access road into the substation has to be built from this upgraded road, which will also be finished to handle heavy truck loads. The staff quarters have be connected to a water supply system which also consists of a water treatment system. The wastewater from the staff quarters must be collected and treated in a septic tank and bed system. A perimeter fence has to be installed on top of the retaining wall to restrict the access into the site.

3.3 NR3: Ilam-Inaruwa 132 kV Transmission Line and Substations

3.3.1 Transmission Lines

The NR 3 Ilam substation to Inaruwa substation project is the development of a new 110 km, 132 kV double-circuit transmission line through hilly regions in eastern Nepal. The route for the first section of the line goes north of Inaruwa substation to an area called Dharan and then east towards Ilam through hilly terrain.

The due diligence report provided two proposed options for the first section of the line between Dharan and Inaruwa. As per our assessment, a hybrid route between options 1 and 2 is the most feasible route since it avoids most of the forest area on the one hand and large river of Koshi on the other.

We conducted site visits along the proposed NR 3 route, which goes through flat land between Inaruwa and Dharan, passing through small villages, agricultural land and some vegetated lands. From Dharan to Ilam, the route goes through hills and mountains at a height of approximately 2000 ft. It is observed that the main crops grown in this area are rice and tea plantations. Approximately two river crossings were observed along the route. The Ilam substation is located in a valley surrounded by huge mountains.

The routing of the 132 kV transmission line has been difficult between Dharan region and Ilam substation because of hilly and sloping terrain. Although we have avoided the steep slopes as much as possible, this problem still exists, but is expected to be avoided in detailed design stage.

Data Gathering Results

We have collected data from various sources and site visits, as well as meetings with NEA employees (managers of past and current projects, local consultants and contractors), and employees of the World Bank and Asian Development Bank. We collected the following data:

- 132 kV standard tower drawings
- Transmission line entering into the current Ilam and Inaruwa substations
- Future proposed transmission lines required to connect to these existing substations
- Environmental and climatic data along the proposed transmission line and substations.

Site Visit Findings and Observations

During the site visit, we learned that Ilam is an existing 132 kV/33 kV substation and Inaruwa, which is under construction, will be a 220 kV/ 132 kV substation.

Material used in 132 kV Ilam - Inaruwa Transmission Line

Full specifications of the material used in 132 kV Ilam - Inaruwa transmission line have been presented in various specification documents in Annex D.

3.3.2 Ilam Substation

Two 132 kV bays for new lines have to be added to the existing 132 kV/33 kV/11 kV substation. A satellite picture of the substation is presented in Figure 36. The new 132 kV line is to enter from the north of the substation.

At present, no electrical arrangement layouts are available for Ilam station. However, according to the site visit previously conducted, there is sufficient land in the northern part of the substation to add the required equipment for two additional 132 kV line bays.

Given the fact that no layout is available to create the bill of material, the required material for Ilam is estimated to be the same as for Inaruwa.

Figure 3.43 Existing Ilam Substation – Latitude 26º52'36.3"N Longitude 87º55'32.7"E

This substation expansion requires two protection panels, two control/mimic panels, modification of the busbar protection panel (if any), a new fiber patch panel to terminate the new overhead line OPGW signal cable, and modification of the existing SCADA/RTU panel to incorporate new I/O (input/output) associated with substation expansion. It is assumed that the existing control room has sufficient space for the addition of these new panels.

3.3.3 Inaruwa Substation

The construction work is in progress for this new 220 kV/132 kV substation. As a part of this project, two 132 kV line bays are to be added to this substation. Figure 3.44 shows the substation's location.

The substation layout is provided in drawing 1661550400-DWG-E2200. The layout demonstrates that it is possible to add two 132 kV line bays to the east of the existing 132 kV bus. The new bays are modelled on the existing bays to ensure homogeneity in the equipment used within the station.

Figure 3.44 Existing Inaruwa Substation – Latitude 26º36'46.5"N Longitude 87º07'16.7"E

The line bay additions requires two protection panels, two control/mimic panels, modification of the busbar protection panel (if any), a new fiber patch panel to terminate the new overhead line OPGW signal cable, and modification of the SCADA/RTU panel to incorporate the new I/O associated with the substation expansion. It is assumed that the existing control room has space for the addition of these new panels.

The structural steel and foundation quantities were determined by assuming that the new station equipment would be supported by steel structures and foundations that are similar to the existing steel structures and foundations. A significant change in material quantities is not expected as the drawings used for the steel structure and foundation bill of materials are from the existing Inaruwa station.

It was confirmed that the foundations are in general conformance with the existing geotechnical report prepared by Pashupati Drilling & Geo-Technical Services Pvt. Ltd. for the existing substation at Inaruwa identified the following geotechnical information beneath the existing station:

- Site sits upon a deposit of loose to medium dense silty sand up to six meters deep
- This site is medium risk for soil liquefaction
- The top meter of soil is loose sands or soft clay and is not suitable to support foundations
- Minimum safe bearing capacity at 3 m below grade is 54 kPa for spread footings.

3.4 NR4: Balanch-Attariya 132 kV Transmission Line and Substations

3.4.1 Transmission Line

The NR 4 Balanch substation to Attariya substation project comprises the upgrade of an existing 131 km, 132 kV double-circuit transmission line through hilly regions in western Nepal. This line is currently strung with single circuit and the MCC project will design a second circuit on the existing tower using the same single bear conductor. This new circuit will be on the east side of the transmission line.

During our site visits along the NR 4 route, we observed that the existing line goes through hilly terrain crossing small villages, agricultural land and some vegetated lands. Five river crossings were observed along the route.

There will be no deviation in design from that in the due diligence report.

Data Gathering Results
Data were collected from various sources and site visits, and meetings with NEA's managers of the design and construction of this project.

We collected the following data:
- 132 kV standard tower drawings
- Existing transmission line entering into the Attariya and Balanch substations
- Environmental and climatic data along the proposed transmission line and substations

Assessment of Materials Used in Existing Facilities
We collected data on existing transmission lines that are entering into both Attariya and Balanch substations from NEA, local engineering consulting companies, and local contractors. These data include:
- Existing 132 kV line with single circuit, composed of lattice steel towers
- There is a single conductor per phase on this line
- There is a single overhead shield wire (OPGW) cable on top of the towers
- Cap and pin type insulators are used on this line.

The line passes through hilly areas and hence the towers should be capable of taking long spans and have a good variety of body and leg extensions. The line is new and the conductor shiny, indicating that it was recently strung.

We have not seen the earthing design of the towers, but feel that the earthing must have been difficult because of the rocky terrain as observed along some parts of the route.

Towers for the Transmission Line
The existing towers on this line are double circuit self-supporting lattice type galvanized steel towers. The line contains different types from a single family of towers. These include suspension type (DA-type), angle type (DB & DC-type) and tension type (DD-type).

As per our assessment and site visit, the towers seem to be in good shape and they were recently installed. These towers have provisions to support three phases on both side of the towers and one OHGW/OPGW at the top of the tower.

The outline drawings and specifications of this towers have been prepared and presented in drawing number 705-1661550400-TS-E3061 in Annex D.

Conductors for the Transmission Line

As per our assessment, the conductor that is currently on this transmission line is a single bear conductor. The same conductor will be installed on the second circuit of this transmission line. The specifications for this conductor type are prepared in drawing number 705-1661550400-TS-E3063 in Annex D.

Insulators for the Transmission Line

As per our assessment, the insulators used on the existing circuit are porcelain type insulators. The same type of insulators will be used on the second circuit of the transmission line. Unfortunately, we were unable to find specifications for this insulator type, but general specification of such insulators are provided in document number 705-1661550400-TS-E3062 in Annex D.

3.4.2 Balanch Substations

One 132 kV line bay is to be added to the existing Balanch substation. Figure 3.45 shows the substation’s location.

The substation’s layout is shown in drawing 1661550400-DWG-E2400. The layout shows that space to add a 132 kV bay is available beside the already existing Attariya line bay. The new bay is modelled on the existing bays in order to maintain homogeneity in the equipment used in the station.

This substation expansion requires one protection panel, one control/mimic panel, modification of the busbar protection panel (if any), a new fiber patch panel to terminate the new overhead line OPGW signal cable, and modification of the SCADA/RTU panel to incorporate the new I/O associated with the substation expansion. It is assumed that the existing control room has space for the addition of these new panels.

Figure 3.45 Existing Balanch Substation – Latitude 29º41’06.5”N Longitude 80º39’00.5”E

The structural steel and foundation quantities were determined assuming that the new station equipment would be supported by the same steel structures and foundations as at the Hetauda station. A significant change in material quantities is not expected as the drawings used for the steel structure and foundation bill of materials are from the existing Inaruwa station.

3.4.3 Attariya Substations

One 132 line bay is to be added to the existing Attariya substation. Figure 3.46 shows the substation’s location.

The substation’s layout is shown in drawing 1661550400-DWG-E2600. According to information obtained from site a walk down, there is no remaining space inside the fence of the substation to add a 132 kV line bay. However, the land to the south of the station is owned by NEA and the space is available for expansion. As such, the south fence needs to be moved approximately 10 meters further south. As a result, the ground grid needs to be extended and additional civil work is required.

Figure 3.46 Existing Attariya Substation – Latitude 28º48’19.4”N Longitude 80º33’11.2”E

The existing substation will be expanded to accommodate new equipment and structures. The civil design will follow the existing grades and slopes to maintain consistency with the station. This substation expansion will require one protection panel, one control/mimic panel, modification of busbar protection panel (if any), a new fiber patch panel to terminate the new overhead line OPGW signal cable, and modification of the SCADA/RTU panel to incorporate the new I/O associated with the substation expansion. It is assumed that the existing control room has space for the addition of these new panels.

3.5 T3: Tadhekani-Kusma 220 kV Transmission Line and Substations

3.5.1 Transmission Line

The T3 Tadhekani substation to Kusma substation project is a new development of approximately 27 km, 220 kV double-circuit transmission line through hilly regions in western Nepal. This line is to connect new hydro generation plants in the surrounding area of Tadhekani substation to the national grid. Tadhekani substation's location is different from that suggested in the due diligence report, as it must be located at or close to the geographic center of the hydro power generation projects. This double circuit 220 kV line is so routed to pass near Rahughat substation (or Beni Hub). The route from Tadhekani substation goes south-east towards Kusma substation through hilly terrain.

A site visit was conducted by air together with MCC/OMCN and its new proposed location was accepted. Multi-criteria routing was conducted and the optimum route for the transmission line chosen. The proposed route was finalized (as far as feasibility-level design is concerned) after considering all environmental, social and engineering factors; the new route will pass close to the Rahughat substation (or Beni Hub).

Data Gathering Results
We collected data from various sources and site visits, and held meetings with NEA managers, local consultants and contractors:

- 220 kV standard tower drawings
- Existing transmission line entering the Kusma substations
- Information about hydro power generators near the proposed Tadhekani substation's location
- Environmental and climatic data along the proposed transmission line and substations.

Assessment of Materials Used in Existing Facilities. We collected some data on new hydropower generation near the proposed Tadhekani substation site. The substation location selected is close to the new hydro facilities.

Materials Used in 220 kV Tadhekani – Kusma Transmission Line
Full specifications of the materials used in this transmission line have been presented in various specification documents in Annex D.

3.5.2 Tadhekani Substation

The Tadhekani 220 kV-132 kV substation is planned to be constructed adjacent to a 132 kV substation under ADB's scope.

The substation is considered to contain the following:

- 2 x 220 kV bays for lines to Kusma
- 2 x, 220 kV-132 kV, 165 MVA transformers (6 x 55 MVA single phase transformers)*

- Space for one 165 MVA transformer (3 x 55 MVA single phase transformer).

* As per the due diligence report, 2 x 200 MVA transformers are to be provided at this station. However, based on the site access constraints, we recommend that the capacity of the power transformer be limited to single phase 55 MVA. Also, based on the power system assessment results, 2 x 165 MVA transformers (6 x 55 MVA single phase transformers) are required to meet the design criteria requirements (N-1).

The control building at this station needs to house the following P&C and SCADA panels:

- 14 protection panels
- 5 control/mimic panels
- 2 SCADA/RTU panels
- 3 communication/teleprotection panels
- 5 spare/dummy panels.
- 1 dynamic disturbance recorder.

The red polygon in Figure 3.47 shows the space reserved for the substation. The available space has approximate dimensions of 100 m x 250 m. According to the available information, the land remains to be acquired.

Figure 3.47 Available Land for Tadhekani Substation – Latitude 28º23’40.4”N Longitude 83º25’04.9”E

The substation layout is presented in drawing 1661550400-DWG-E0700. The 220 kV switchgear is indoor GIS type with breaker-and-a half scheme. A bus is provided on the 132 kV of the transformers in order to connect to ABB's 132 kV substation. It is recommended that the 132 kV substation designer use the 132 kV bus provided in the 220 kV-132 kV substation within the designed bus scheme. The single bus can be incorporated in the design of an appropriate double bus scheme in order to provide greater reliability.

The control building will house all protection and control, telemetry, SCADA/communication panel, RTUs, batteries, DC systems, AC systems and battery chargers, etc.

The civil design consists of removing the topsoil (1.5 m deep) inside the fenced area and backfilling with engineered fill in order to achieve a good stable yard area. The top layer has to be finished with electrical insulation stone and the final site grading has to have a slope of 2 to 3% throughout the site. The existing site conditions for this site are shown in drawing 1661550400-DWG-C0700 and the final site grading and drainage plan is shown in drawing 1661550400-DWG-C0701.

A new access road into the substation has to be built from the existing mud road to the north of the Myagdi River. This road has to be finished with a sub base, base and asphalt layers (see typical details in 1661550400-DWG-C702) to handle heavy truck loads. In addition to the new access road, a new bridge has to be constructed to cross the Myagdi River, this bridge has to have a span of 60 m and the road has to be 6m wide. The plan details for this road and bridge are shown in drawing 1661550400-DWG-C0702.

The existing road from Beni to Tadhekani substation is a mud road of 4 m wide that passes through several river bends where landslides have been observed. This 20 km road has to be upgraded to a 6 m wide asphalt road and the potential landslide locations must be strengthened to prevent landslides. The existing road plan and details are shown in drawing 1661550400-DWG-C0703.

There are several locations where small streams flow over the road and at these locations a culvert has to be added. This is required to prevent erosion of the road during major storms. The location of landslides and river crossings are identified in drawing 1661550400-DWG-C0704.

The staff quarters must be connected to a water supply system that will also consist of a water treatment system. The wastewater from the staff quarters has to be collected and treated in a septic tank and bed system. A perimeter compound wall and fence along with an access gate also need to be installed around the substation to restrict the access to the site.

3.5.3 Kusma Substation

Two 220 kV line bays have to be added to the existing Kusma station. Figure 3.48 shows the substation's location.

The substation's layout is shown in drawing 1661550400-DWG-E2500. The layout shows that space to add two 220 kV bays is available north of the existing 220 kV bus. The new bays are modelled on the existing bays in order to maintain homogeneity in the equipment used in the station.

Figure 3.48 Location of Existing Kusma Substation – Latitude 28º14'34.2"N Longitude 83º38'55.8"E

3.6 T8: Nepal-India Border Line and New Lamki Substation

3.6.1 Transmission Line

The T8 New Lamki substation to the Nepal-India border project is a new development of approximately 23 km of 400 kV double-circuit transmission line. This line is designed from New Lamki substation to the Nepal/India border to export 88% of the power generated in the Upper Karnali hydro generation plant to India and also will be used for importing power from India in dry season.

The route from New Lamki substation goes south-west towards the border. We conducted a site visit and selected the proposed New Lamki substation's location. We also reviewed GMR's line route from New Lamki substation to the border and found that this is an optimal route. However, a more detailed study has been conducted to further optimize the route. This line route meets technical, environmental and resettlement criteria, and hence has been selected as the final feasibility level design of the line.

Assessment of Existing Facilities
Lamki is a large 132 kV substation that sits on a very large piece of land that has been acquired by NEA. Currently construction work is going on in the substation to change its busbar design from single to double. The control building is just large enough for the existing 132 kV facility; there is no room for extension. Substation operators do not have the skills required to operate a transmission substation and cannot appreciate even the functions of the existing panels.

This substation's land can easily accommodate a new 400 kV substation. However, since this station is surrounded by houses and other structures, taking a double-circuit 400 kV line in and out will precipitate resettlement and is thus not feasible. Therefore, in coordination with OMCN, we have selected another location for the new Lamki 400 kV substation. This location is far from populated land and is closer to existing 132 kV and 400 kV lines. This location will be very convenient for 400 kV lines for loop-in loop-out connection as the GMR line passes near this location.

Materials Used in T8 New Lamki – Nepal/India Border 400 kV Transmission Line
Full specifications of the material used in this transmission line are presented in various specification documents in Annex D.

Data Gathering Result
We collected data from various sources and site visits, and held meetings NEA staff of existing Lamki substation, local consultants and contractors.

We collected the following data:

- 400 kV standard tower drawings
- Information on future transmission lines entering into New Lamki substation
- Coordination of the last structure before the border crossing
- Environmental and climatic data along the proposed transmission line and substations.

3.6.2 New Lamki Substation

The new 400 kV-132 kV New Lamki substation is considered to contain:

- 4 x 400 kV bays for lines to the India border
- 4 x 132 kV bays for lines
- One 400 kV-132 kV, 160 MVA phase shifting transformer*
- Space for 4 future 400 kV bays for lines to Kohalpur/Surkhet and Attariya
- Space for 2 future 400 kV bays for lines to Bareilly.

*GMR, an independent power producer, will be building a dedicated 400 kV line in order to transfer 900 MW of power from Upper Karnali to India. Twelve percent (12%) of this generation has to be evacuated to Nepal. To control the power flow of 12%, a 132 kV-132 kV phase shifting transformer will be installed.

Additional spaces for two phase shifting transformers and four 400 kV-220 kV transformers are provided in order to allow for future expansion of the station.

The control building at this station needs to house the following P&C and SCADA panels:

- 26 protection panels
- 10 control/mimic panels
- 2 SCADA/RTU panels
- 3 communication/teleprotection panels
- 5 spare/dummy panels.
- 1 dynamic disturbance recorder.

The red polygon in Figure 3.49 presents the location considered for the New Lamki substation. The selected site has sufficient flat land available to fit an AIS station.

Figure 3.49 Available Land for New Lamki Substation – Latitude 28º36’55.5”N Longitude 81º13’39.1”E

A new location for the New Lamki substation, near Pahalmanpur, has recently been proposed by the secretary of the Ministry of Energy. This new location is shown in Figure 3.50. Upon evaluation, it was determined to be unfeasible. This location is 32 km away from the original location, which means that an additional 64 km (line in/line out) of lines would be required.

Figure 3.50 Additional Proposed Location for New Lamki

The substation layout is presented in drawing 1661550400-DWG-E0800. For three of the 400 kV lines, only one line of the two-line breaker-and-a half diameter is connected. As such, the middle breaker and a disconnect switch are provided in order to allow connecting to the second bus and to maintain the reliability of the 400 kV supply. A single bus arrangement is provided for the 132 kV side. A single bus is deemed sufficient given the fact that the reliability of the link is limited by the fact that only a single phase shifting transformer is to be provided.

The civil design includes removing the topsoil (1.5 m deep) inside the fenced area and backfilling with engineered fill in order to achieve a good stable yard area. The top layer will be finished with electrical insulation stone and the final site grading will have a slope of 2 to 3% throughout the site. The existing site conditions for this site are shown in drawing 1661550400-DWG-C0800 and the final site grading and drainage plan is shown in drawing 1661550400-DWG-C0801.

A new access road into the substation from the E-W Highway situated to the south of the site has to be built and finished to handle heavy truck loads. The staff quarters must be connected to a water supply system which consists of a water treatment system. The wastewater from the staff quarters has to be collected and treated in a septic tank and bed system. The substation has to be surrounded by a compound wall and fence to restrict access into the station.

3.7 T2’: Likhu Hub-New Khimti Transmission Line and Substations

3.7.1 Transmission Line

The T2’ Likhu Hub to the New Khimti project is a new development of approximately 25 km of 220 kV double-circuit transmission line. This line has been designed to run from Likhu Hub substation to New Khimti substation. This project will help new hydro generating plants to bring energy into the national grid. As per our assessment and investigation, there are five registered Likhu hydro projects in the surrounding area. All of these plants need to connect to the national grid. Therefore, it was decided that these projects will connect to Likhu substation and will step up the voltage and connect to the New Khimti substation.

After a comprehensive desktop study, we made a site visit to possible locations for Likhu substation and the line route to New Khimti substation. As mentioned in the section on substation site selection, one of the IPPs proposed a location that is close to their power house and substation. Although the proposed land area is small, this is the only flat land on this scale in the project area, and by choosing a GIS design for the substation, the substation layout can be accommodated on this land. Based on this location, the line route was determined in the optimal corridor that was developed using multi-criteria routing. The line route developed is close to the corridor suggested by the due diligence team.

Data Gathering Results
We collected data from various sources and site visits, and held meetings with IPPs, NEA managers of past and current projects, local consultants and contractors.

We collected the following data:

- 220 kV standard tower drawings
- Information on hydro power plants that need to connect to Likhu substation
- Environmental and climatic data along the proposed transmission line and substations.

Assessment of Materials Used in Existing Facilities
We visited the proposed Likhu substation site, which is at the end of the point of the transmission line from New Khimti to Likhu Hub substation. We met with the IPP and reviewed their plan for the 132 kV substation. This IPP also has a detailed plan to upgrade the existing roads and build a new road to this location for shipping their equipment. Aside from this, there is no other facility in the area and no assessment has been conducted.

Materials Used in T2’ Likhu Hub – New Khimti 220 kV Transmission Line
Full specifications of the materials used in this transmission are presented in various specification documents in Annex D.

3.7.2 Likhu Hub Substation

The Likhu Hub 220 kV-132 kV substation is planned to be constructed adjacent to a 132 kV substation under being built by an IPP.

The substation is considered to contain the following:

- 2 x 220 kV bays for lines from New Khimti
- 3 x 220 kV-132 kV, 165 MVA transformers (9 x 55 MVA single phase transformers) *
- Space for one future, 220 kV-132 kV, 165 MVA transformer (3 x 55 MVA single phase transformers)
- 1 x 132 kV / 11 kV for local distribution / small power evacuation transformer
- Space for 4 future 220 kV bays for lines to Tingla and IPPs
- Space for 2 future 132 kV bays for lines to IPP generators.**

*Based on the site access constraints, the capacity of the power transformer is recommended to be limited to single phase 55 MVA. Also, based on the power system assessment results, 3 x 165 MVA transformers (9 x 55 MVA single phase transformers) are required to meet the design criteria requirements (N-1).

**The number of 132 kV line bays has been reduced to 2 since the IPP is already building the 132 kV bays in their substation.

The control building at this station needs to house the following P&C and SCADA panels:

- 18 protection panels
- 6 control/mimic panels
- 2 SCADA/RTU panels
- 3 communication/teleprotection panels
- 5 spare/dummy panels
- 1 dynamic disturbance recorder.

Figure 3.52 shows the space reserved for the substation based on discussions with the IPP building the 132 kV substation. The IPP has agreed to reserve space for the 220 kV-132 kV substation on the land that they have already purchased.

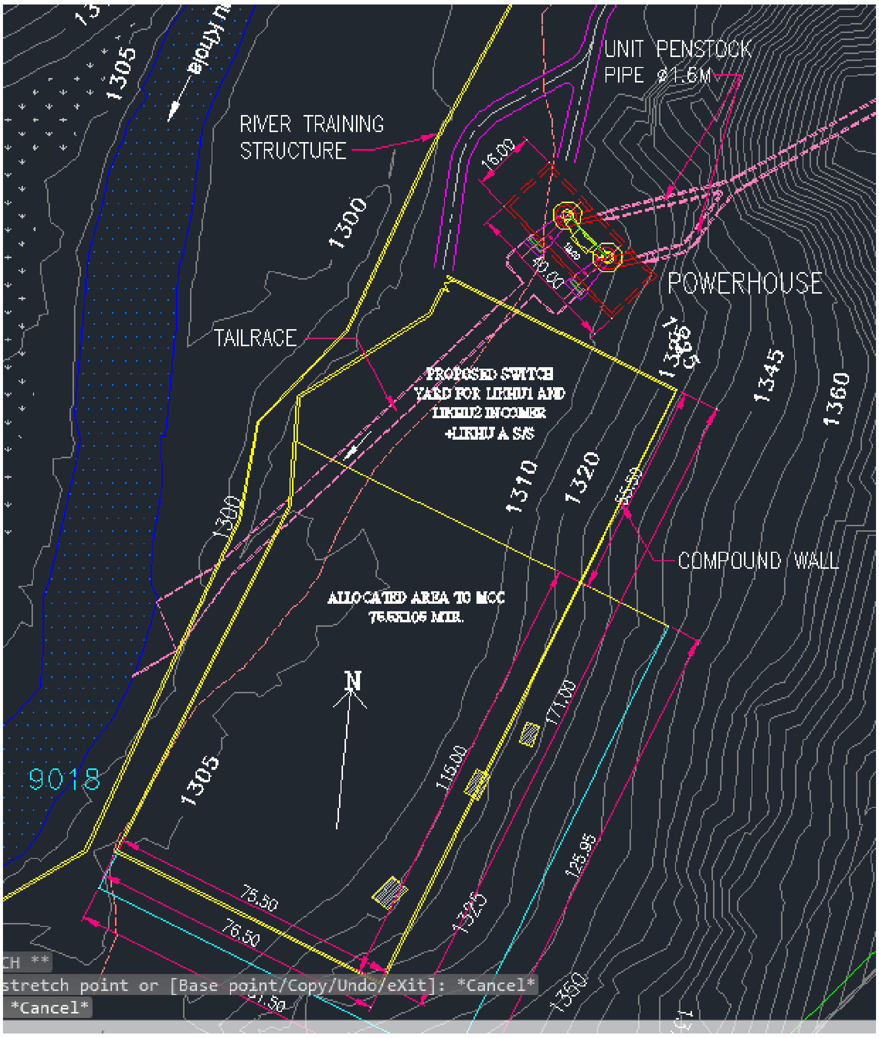


Figure 3.52 Available Land for Likhu Hub Substation after Discussions with IPP

The substation layout is presented in drawing 1661550400-DWG-E0500. The 220 kV switchgear is indoor GIS type with a breaker-and-a half scheme. The area available does not allow for the construction of living quarters and all related buildings. The land available to the north of the IPP's 132 kV substation will have to be used. The available land is surrounded by the light blue polygon in Figure 3.53.

A single 132 kV bus with two line bays is provided in the 220 kV substation in order to connect to the IPP's 132 kV substation or any other load as required. A single 132kV bus is provided because it is not possible to build two bus bars in the space provided. At the detailed design stage, it is recommended to coordinate the design of the 220 kV substation with the IPP's 132 kV substation in order to optimize the layout of both stations. With the station layout of the 132 kV station, it might be possible to extend the existing 132 kV bus in order to add a second bus and optimize the space being used.

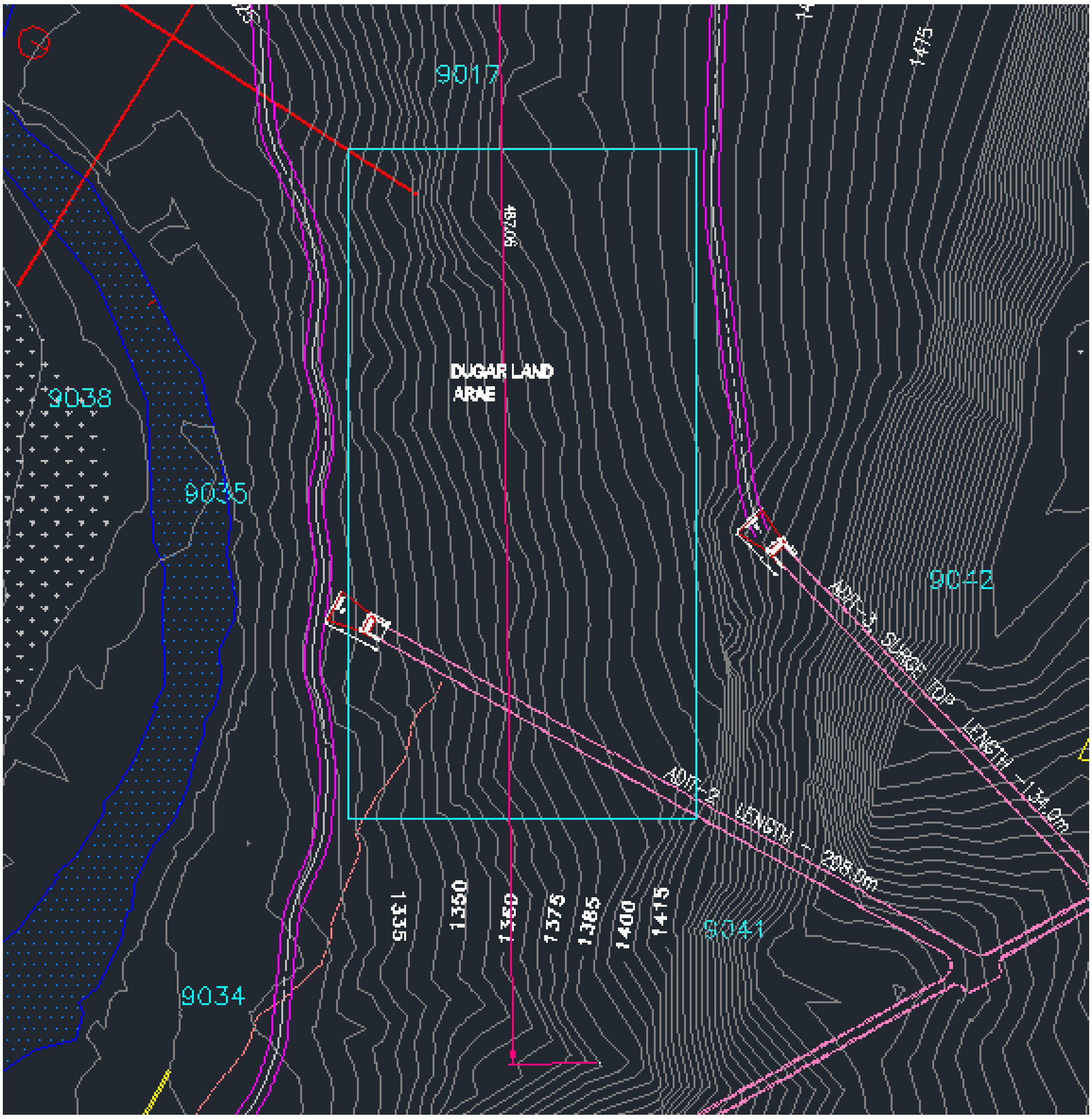


Figure 3.53 Available Land for Living Quarters at Likhu Hub

The civil design consists of removing the top layer of loose gravel and then backfilling with excavated soil from the hill to the west of the station. The top 0.5 m of the substation will be backfilled with engineered fill in order to achieve a good stable yard area. The top layer needs to be finished with electrical insulation stone and the final site grading needs to have a slope of 2 to 3% throughout the site. A retaining wall needs to be built to the west and south of the site to prevent any potential slope failure. An access road into the substation needs to be built from the 132 kV access road located to the north of the site. This road will be finished to handle heavy truck loads. The existing conditions at this site are shown in drawing 1661550400-DWG-C0500 and the final site grading and drainage plan is shown in drawing 1661550400-DWG-C0501.

The staff quarters need to be constructed to the north of the existing 132 kV station and need to be connected by a walkway to the new station. They must also be connected to a water supply system that also consists of a water treatment system. The wastewater from the staff quarters needs to be collected and treated in a septic tank and bed system. A perimeter fence needs to be installed on top of the retaining wall to the west and south and on top of a compound wall to the east and north in to restrict access into the site.

3.7.3 New Khimti Substation

Two new 220 kV line bay are to be added to the existing New Khimti substation. The 220 kV lines are to be connected to GIS breakers. Figure 3.54 shows the substation's location.

Figure 3.54 Planned Location for New Khimti – Latitude 27º29'41.7"N Longitude 86º05'54.3"E

The substation layout is shown in drawing 1661550400-DWG-E0600-SH1. Two future bays for lines are available in the original layout and are now being used for the Likhu hub line. The line will enter from the north of the station and underground cables will connect the line bays to the GIS breakers. According to the drawings obtained, the 220 kV GIS will be a double bus – single breaker with bypass arrangement.

The substation expansion will require two new protection panels, two new control/mimic panels, modification of the busbar protection panel (if any) to incorporate new line CTs, a new fiber patch panel to terminate the new overhead line OPGW signal cable, and modification of the SCADA/RTU panel to incorporate the new I/O associated with the substation's expansion. We assume that the control room will have adequate space to accommodate these new panels.

3.8 XB1: New Butwal to Nepal-India Border Transmission Line

3.8.1 Transmission Line

The XB1 New Butwal substation to the Nepal/India border is a new development of an approximately 23 km, 400 kV double-circuit transmission line. This line is to export power to India. The route from the New Butwal substation goes almost south towards the Nepal-India border.

We recently received information on the border crossing point and revised the line route to approach this point. For routing of this transmission line, we utilized multi-criteria routing and considered all environmental, social and engineering factors.

Assessment of Materials Used in Existing Facilities
This line is a new line and no existing facility is found relevant to this line.

Materials Used in XB1 New Butwal – Nepal/India Border 400 kV Transmission Line
Full specifications of the material used in this transmission line are presented in various specification documents in Annex D.

Data Gathering Results and Site Visit Findings and Observation
The 220 kV substation of New Butwal is an ADB-funded project. We met with ADB and NEA staff for this project. We understand that the land has been purchased but could not find data for the design of this substation. However, we did find a land map from NEA's manager of the 220 kV project.

We collected the following data:

- A land map showing the purchased land and its size. The substation location is not shown on the land map; however, we located it using information collected during the site visit
- 400 kV standard tower drawing
- Information about future transmission lines entering into the New Butwal substation
- Environmental and climatic data along the proposed transmission line and substation.

4. Implementation Schedule

The schedule shown in Annex F represents the proposed timeline for the MCC projects on a month-to-month basis. The timeline begins when the feasibility study is submitted and runs through to the end of the compact period (five years from the date of signing). It is assumed that a more detailed schedule will be developed once the project moves into future phases.

The schedule has been developed in Primavera P6 and Microsoft project. Also, the working file in Microsoft project is shared in the Annex F.

Please refer to Annex F for Implementation schedule.

4.1 Project Phases

The first phase – project development and planning – consists of the project definition, the compact negotiation and signing, compact implementation funding, formation of MCA entity, compact entry into force. This phase is expected to last 18-24 months.

The second phase of the project is for advanced work, which would occur approximately 3 months into the project, after the approval of MCA board. This phase is expected to take 18 months and would comprise the following activities:

- Award of engineer; will manage all the following activities
- Preparation of tender documents
- Submission and evaluation of bids.
- Award of turnkey EPC vendor(s)
- Completion of environmental and geotechnical assessments
    - Design surveys completed
    - Land acquisition
    - Permitting.
    - Preliminary and Detail Design

The first and second phases are common to all projects. The third phase, implementation, is divided into the four zones (see below) and consists of the procurement, construction, and commissioning components of the project. This phase is expected to be 60 months in duration after EIF.

4.2 Implementation Zoning

To accommodate the required timeline, Tetra Tech has proposed that the implementation phase be divided into four zones, with each being awarded to a single EPC vendor. The zones are defined as follows (their durations can be found in Annex F).

The specific projects included for each zones can be found under section 2.8 – Project Procurement Packaging.

4.3 Duration Assumptions

In order to meet the required timeline certain assumptions during the construction period have been taken into account, these assumptions are as follows:

Zone A EPC Contractor

- Transmission Line – Foundation Construction - 20 Crews (or Gangs) consisting of 15-20 workers per crew
- Transmission Line – Foundation Construction - 20 Crews (or Gangs) consisting of 15-20 workers per crew
- Transmission Line – Stringing - 2 Crews (or Gangs) consisting of 45-50 workers per crew
- Substation – 1 Substation construction crew per station, with all zone stations be constructed simultaneously

Zone B EPC Contractor

- Transmission Line – Foundation Construction - 5 Crews (or Gangs) consisting of 15-20 workers per crew
- Transmission Line – Foundation Construction - 5 Crews (or Gangs) consisting of 15-20 workers per crew
- Transmission Line – Stringing - 1 Crew (or Gang) consisting of 45-50 workers
- Substation – 1 Substation construction crew per station, with all zone stations be constructed simultaneously

Zone C EPC Contractor

- Transmission Line – Foundation Construction - 8 Crews (or Gangs) consisting of 15-20 workers per crew
- Transmission Line – Foundation Construction - 8 Crews (or Gangs) consisting of 15-20 workers per crew
- Transmission Line – Stringing - 2 Crews (or Gangs) consisting of 45-50 workers per crew
- Substation – 1 Substation construction crew per station, with all zone stations be constructed simultaneously

Zone D EPC Contractor

- Transmission Line – Foundation Construction - 15 Crews (or Gangs) consisting of 15-20 workers per crew
- Transmission Line – Foundation Construction - 15 Crews (or Gangs) consisting of 15-20 workers per crew
- Transmission Line – Stringing - 2 Crews (or Gangs) consisting of 45-50 workers per crew

- Substation – 1 Substation construction crew per station, with all zone stations be constructed simultaneously

4.4 Schedule Risk and Critical Path

We estimate that the project can be completed within a minimum of 60 months. However, this assumes that advanced funds are released to complete advanced work prior to implementation phase. There are a number of risks that may potentially impact this duration. These have been accounted for by adding additional time to the scheduled activities. Some of the identified risks are:

- Availability and reliability of existing information and studies
- Interface among stakeholders (i.e., MCA, EPC vendors, local governments)
- Availability of materials and labor
- Weather interferences, such as the monsoons.

4.5 Critical Path

The critical path is driven by the Zone A transmission line and in particular the construction of the tower foundation, the tower erection, and the stringing of the line.

4.6 Project Float

Float has been identified for each of the 4 zones. In addition to the stated float for each of the Zone, it is our understanding that for projects of this nature permission to construct may be granted during the monsoon season. Our current timeline assumes no work will occur during this time, thus allowing up to an additional 8 months of float if access was granted during all years of construction. Excluding the monsoon season the float for each of the identified zones is as follows:

- Zone A EPC Contractor - ~ 8 Months
- Zone B EPC Contractor - ~ 7 Months
- Zone C EPC Contractor - ~ 7 Months
- Zone D EPC Contractor - ~ 5 Months

** Float is calculated from the time of energization to the end of the compact period

5. Contract Procurement Packages

Section 2.8 described the methodology used for suggested procurement packages and mentions the advantages and disadvantages associated with them.

Zone A EPC Contractor
Projects include:

- NR1: Transmission line between New Damauli and Naubise
- NR1: New Damauli substation work
- NR1: Transmission line between New Damauli and New Butwal
- NR1: New Butwal 400 kV substation work (400 kV switchyard, transformers and 400 & 220 kV transformer bays) to connect to ADB's 220 kV substation
- XB1: Transmission line Between New Butwal substation and Nepal/India border
- T8: New Lamki 400 kV substation
- T8: 400 kV Transmission line between New Lamki substation and Nepal/India border

Zone B EPC Contractor
Projects include:

- T3: 220 kV Transmission line between Tadhekani and Kusma
- T3: 220 kV Tadhekani substation work
- T3: 220 kV Kusma substation upgrade work
- NR4: Adding one circuit to the existing transmission line
- NR4: Upgrading (adding one line bay) to Balanch substation
- NR4: Upgrading (adding one line bay) to Attariya substation

Zone C EPC Contractor
Projects include:

- NR1: Naubise 400 kV substation work
- NR1: 400 kV Lapsiphedi substation upgrade (400 kV switchyard, transformers and 400 & 220 kV transformer bays) to connect to ADB's 220 kV substation
- NR1: 400 kV New Hetauda substation upgrade (400 kV switchyard, transformers and 400 & 220 kV transformer bays) to connect to WB's 220 kV substation
- NR1: Transmission line between Naubise to Lapsiphedi
- NR1: Transmission line between Naubise to New Hetauda

Zone D EPC Contractor
Projects include:

- T2': 220 kV Likhu Hub substation work
- T2': 220 kV New Khimti upgrade
- T2': Likhu Hub to New Khimti 220 kV transmission line
- NR3: Upgrading (adding two line bays) to Ilam substation
- NR3: Upgrading (adding two line bays) to Inaruwa substation
- NR3: Ilam to Inaruwa 220 kV transmission line

Implementation schedule for this packaging have been provided which shows different floats for different packages depending on their size. In case more float is desired and if lower package capital cost is preferred an alternative packaging including 5 packages could be suggested. The scope of packages would be then as per below:

Zone A EPC Contractor:
Projects include:
- NR1: Naubise 400 kV substation work
- NR1: Transmission line between New Damauli and Naubise
- NR1: New Damauli substation work

Zone B EPC Contractor:
Projects include:
- T3: 220 kV Transmission line between Tadhekani and Kusma
- T3: 220 kV Tadhekani substation work
- T3: 220 kV Kusma substation upgrade work
- NR4: Adding one circuit to the existing transmission line
- NR4: Upgrading (adding one line bay) to Balanch substation
- NR4: Upgrading (adding one line bay) to Attariya substation

Zone C EPC Contractor:
Projects include:
- NR1: 400 kV Lapsiphedi substation upgrade (400 kV switchyard, transformers and 400 & 220 kV transformer bays) to connect to ADB's 220 kV substation
- NR1: 400 kV New Hetauda substation upgrade (400 kV switchyard, transformers and 400 & 220 kV transformer bays) to connect to WB's 220 kV substation
- NR1: Transmission line between Naubise to Lapsiphedi
- NR1: Transmission line between Naubise to New Hetauda

Zone D EPC Contractor:
Projects include:
- T2': 220 kV Likhu Hub substation work
- T2': 220 kV New Khimti upgrade
- T2': Likhu Hub to New Khimti 220 kV transmission line
- NR3: Upgrading (adding two line bays) to Ilam substation
- NR3: Upgrading (adding two line bays) to Inaruwa substation
- NR3: Ilam to Inaruwa 220 kV transmission line

Zone E EPC Contractor:
Projects include:
- NR1: Transmission line between New Damauli and New Butwal
- NR1: New Butwal 400 kV substation work (400 kV switchyard, transformers and 400 & 220 kV transformer bays) to connect to ADB's 220 kV substation
- XB1: Transmission line Between New Butwal substation and Nepal/India border
- T8: New Lamki 400 kV substation
- T8: 400 kV Transmission line between New Lamki substation and Nepal/India border

5.1 Execution of Packages

Data collected from NEA project managers, other donors, consultants and contractors active in Nepal's power sector yielded the following observations. The current model of NEA's execution of a project is to provide a preliminary design for transmission lines and proceed to the tendering stage with a preliminary design, select a contractor and leave the rest to the contractor. The contractor's scope in this model includes a wide range of activities from the check survey, finalization of line route, land and right of way acquisition and to project construction. This model has been more or less followed by other donors; ADB, WB etc., although some of them are changing this approach because of the problems they have experienced.

Although this model has some advantages, it results in significant changes to transmission line routes and contract values and quantities. Since the line route is finalized by the contractor, the areas affected by transmission line rights of way cannot be identified in advance of the contractor's work. So resettlement is carried out by the contractor while procurement and construction logistics are being completed. Resettlement is not easy and requires a long process of official work. Delays in resettlement introduce major problems to project construction; this is the main reason for almost all of the transmission line projects not being constructed on schedule or within budget. As a matter of fact, right of way acquisition and the procurement and construction of works are not of the same nature and cannot be managed in the same time frame.

Many of our data sources who are active players in the power sector believe that the design should be developed in more detail before assigning a contractor to the job. However, there are some concerns with this approach. Lack of confidence in this method can be summarized as:

- Although further design development will help in identifying more land owners who will be affected by line construction, an incomplete detailed design will not make a real change in project implementation.
- A long gap between the time owners are compensated and lines are constructed will not really free up the line right of way and sometimes will attract more people to come and build structures in the right of way.
- A transmission line check survey is inseparable from the contractor's construction work. So, no contractor will take responsibility for construction if the check survey is taken out of the contractor's scope.
- Contractors don't feel ownership for the detailed designs that have been provided by others and do not have much confidence in a detailed design that has been provided without being engaged in actual site conditions.
- As far we can determine, construction work goes more smoothly and faster when an EPC model is adopted.

In these circumstances, it appears that a feasible fusion of the above methods will resolve or minimize the problems listed here. The method we propose for the MCC compact projects would realistically combine the advantages of the two methods above while avoiding their disadvantages.
Details and steps of our proposed package execution are as follows:

- One engineer will be hired to provide services for all MCC compact sub-projects.
- EPC contractors will be hired for sub-projects or zones as defined above. The selection of EPC contractors should comply with the FIDIC yellow book (design-build) and hence a pre-qualification process is required.
- EPC contractors must have adequate capacity (either in-house or as a subcontractor or joint venture) to carry out the Environmental and Social Impact Assessment, Resettlement Action Plan, and Resettlement Implementation.
- EPC contractors must be capable of conducting full-scale survey works (LiDAR or land survey) and geo-technical assessments for their respective zones, either by themselves or through competent subcontractors.
- Pre-qualification of bidders will be conducted for two group of sub-projects. This pre-qualification will help determine which groups of bidders will be invited to prepare EPC bids for all the sub-projects and which groups will be invited to Zones B and D tenders only.
- The bidders can bid on multiple zones and successful bidders may be awarded more than one zone. However, Zone A and Zone C contracts will not be awarded to the same bidder.

The following points justify this set up and note its pros and cons:

- By having two EPC contractors on the design of NR1, there will be some degree of natural competition between them. Their work will be compared with each other. Innovative solutions for one package can be used in another package. If an issue arises with one EPC contractor, there is will be another one as back up. However, intensive coordination is needed between the EPC contractors in order to maintain consistency in design and remove design variety. The engineer will play a critical liaison role between the two EPC contractors.
- NR1 has four substations and approximately 280 km of transmission lines, so it is better to have two EPC contractors work on it. If MCC depends on only one, there is risk of project delay, compromise on quality and lack of resources. In other words, NR1 is a critical part of the compact and MCC shouldn't rely on one contractor. Having two EPC contractors on NR1 provides a plan B in case the first contractor encounters serious problems.
- There is also a risk of poor coordination between the two EPC contractors, which may result in unwanted design variations between two parts of NR1, XB1 and T8 in terms of different equipment, ratings and design details. In order to mitigate this risk, the engineer should provide close oversight on the designs of these two contractors, and their interface.
- Funds of the "E" part and "PC" parts will be released in two stages. "E" funds will be released (approximately 10% of total the EPC value) in the compact implementation funding (CIF) period in order to enable the EPC contractor to start working on the "E" portion of the work (preliminary and detailed design of the respective projects).
- No procurement or construction work is to be done in the CIF stage. However, all the services, including surveys, geotechnical assessments, preliminary and detailed design, vendor design, issuing shop drawings by vendors, and issued for construction (IFC) packages shall be completed by entry into force (EIF).

6. Results, Conclusions, and Recommendations

In conclusion, all projects included in MCC compact will meet the project objective of decreasing load shedding, increasing generation utilization and maximize power trade between Indian and Nepal.

The key results / recommendation of power system assessment are following:

- The technical benefit analysis reveals that the XB1 tie line project is of critical importance for Nepal because it will double the exchange capability between Nepal and India. As a result, load shedding is greatly reduced and generation utilization is increased. NR1 is also of great importance as it provides the transmission network backbone that enhances the network's transmission capacity. It provides the transmission backbone to transfer remote energy to load centers and to import/export energy from/to India. In fact, the combined effect of the NR1 and XB1 projects is a reduction of load shedding to 33% of its original value.
- Based on the short circuit analysis, at least 42 kA breakers are recommended for 132 kV stations of MCC projects. For the 220 kV and 400 kV levels, the breaker ratings should be at least 39 kA and 37 kA respectively. Standard breaker ratings shall be selected based on these requirements.
- The transient stability studies were performed using the dynamic data from NEA for the existing generating stations and the generic models with typical parameters for the new generating stations. All possible N-1 contingencies relevant to the MCC projects were considered in the analysis. The system recovers well after the contingencies and there is no concern related to the dynamic voltage performance, frequency stability of the electromechanically oscillations of the generators.
- For the outage of a tie line, it is necessary to have a special protection scheme to trip loads and generation based on the conditions. A comprehensive study including the India system would be required to determine the strategy.
- Load shedding in order to have acceptable loading in 400kV/220kV transformers at the New Butwal substation is recommended. Shedding of about 900 MW of loads on following buses resulted in acceptable transformer loading: Bharatpu-132, Damauli-132, Butwal-132, Bairahawa, Shivpur, Hapure, Kusum and Lamhi.
- The power flows provided by WSP included the transmission system (400 kV, 220kV and 132 kV) in detail. Only some parts of sub-transmission system (33kV and 66 kV) was included and the distribution system was not modelled. Furthermore, most of the loads were directly placed at the transmission levels busses. It was found that the 132 kV and 66 kV system included in the model is not capable of supplying the demand expected by 2030. There are significant number of 132 kV and 66 KV line upgrades identified from the studies. Furthermore, a significant amount of reactive power compensation at these voltages would be required. In order to determine the reactive power compensation required at each bus, a reactive power coordination study needs to be carried out considering proper distribution feeders. The 66kV and 33 kV network needs to be included and the loads should be placed at the feeders. It is also necessary to properly model the tap changing transformers with the voltage regulators. Furthermore, the generators needs to be placed at the right locations connected with their feeder lines.

- MCC projects are only in transmission and there is no significant impact on the distribution and sub-transmission systems. The distribution and sub-transmission systems should be planned such that they are capable of transferring power as well as maintaining voltage. A condition precedent to EIF could be developed to ensure a distribution master plan is developed.In the power flow studies the Indian network was not included and the studies were done considering Thevenin voltage sources at the end of each tie line. The third tie line is going to be connected for the upper Karnali generation through T8 project and there is a phase shifting transformer to regulate the 12% of power coming in to the Nepal network. Therefore, there is no concern about that tie line. However, tie line 1 and tie line 2 (XB1) are electrically coupled through both India and Nepal. Therefore, the distribution of the total power exchange between the two tie lines is a concern. The simple model used in this analysis assumed a 40:60 percent distribution between the two tie lines. The natural distribution of power can only be identified by modelling the India system in detail (at least northern part of India). The natural distribution can be controlled to some extent by changing the generation dispatch. If it is not possible, it would be required to regulate the power transfer of one of the tie lines by means of one of the followings.
    - Phase shifting transformer
    - Back to back HVDC
    - Thyristor Controlled Series Capacitors (TCSC)
- Another concern would be the interarea electromechanical oscillations between the two systems during the disturbances. These oscillations can also be controlled by some of the power regulating devices described above. The tie line power transfer capability also depends on the strength of the northern part of India at which the tie lines are connected. Therefore, it would be necessary to perform a more detailed study including the India system in order to determine the power transfer capabilities and the factors limiting them.
- It is recommended that the loop flow situation within these two tie lines be closely studied in the detailed engineering stage with details from India's network.

The key results / recommendation of Substation and Transmission Line design are following:

- The MCC compact consists of 8 new substations, upgrades of 6 existing substations, and approximately 620 km of transmission lines. The feasibility study demonstrates that difficult terrain and the size of available land are the main constraints in implementing the proposed projects. Except for the XB1, T8 and New Lamki projects, which are located in the Terai plain region, the remaining transmission lines and substations are located in mountainous areas. Because of the specific geographical features of Nepal, the terrains can become subject to landslide, seismic and flood hazards.
- There were many challenges faced during site selection process. Main challenge was to find sufficiently big and flat terrain required for a typical substation. As such, GIS option was explored to decrease the station footprint and more civil work was required to solve elevation difference in the station.
- The assessment of the substation design reveals that the infrastructure constraints Nepal will have a significant impact on the overall project cost.
- Considering the above constraints, a new, improved approach should be adopted for the implementation of MCC projects. Their design and construction will be supported by advanced

geotechnical studies.

- Further geotechnical studies will need to be completed in detail design phase. It is recommended that the borehole testing should be occur for every 5 to 10 KM of Transmission line and 3 boreholes / stations and 3+ boreholes for bigger station for detail design phase.
- A LiDAR survey will offer fast and precise survey data production for wide areas, thus guaranteeing a good transmission line routing. The design criteria provided are based on the observed land conditions as well as professional, international, modern and well developed standards aimed at organizing and harmonizing the design activities. The use of PLS-CADD adds to the accuracy of line design by eliminating all the destructive and/or eroding factors that cannot be detected without the use of finite element and non-linear analysis methods. In order to complement the design documentation, we recommend that MCC develop a comprehensive quality assurance plan for both the construction and operation phases of the projects.
- An assessment of the road conditions presented in the section 2.3, revealed that no equipment larger than a 160 MVA, 3 phase transformer can be transported to most substations, while more remote areas are limited to single phase, 55 MVA transformers. This limitation leads to an increase in the amount of transformers required, which inflates the size of substation layouts. This further compounds the space limitation problem on the selected substation sites and has the following consequences:
    - Lower power handling capacity for a given footprint
    - Lower capacity for substation expansion
    - Increased overall project cost.

The following are key results / recommendation for contract procurement packages:

- In order to meet compact end date, Tetra Tech has recommended to divide contract procurement packages in four zones. These packages should be awarded to a single EPC vendor.
- Tetra Tech recommends one Engineer entity to provide services to all MCC vendors.
- There are several resettlement risks which can impact the project schedule and these risks are further explained in Task 5.
- During construction phase, it is recommended that more than one construction crew work on transmission line routes.
- The current implementation schedule includes 8 months of float in activities and in addition there will be possible monsoon season float which can be utilized upon getting approvals from National Government.

Annex C
Conceptual Drawings and Bills of Material for Substations

The following files have been submitted as standalone documents owing to their size (over 250 MB each):

Substation	File Title	File Number
New Hetauda Substation	EA Station Layout	EA Station layout 1661550400-DWG-E0001
	Protection SLD	1661550400-DWG-E0021-SH1- 1661550400-DWG-E0021-SH2-
	Ultimate Stage	1661550400-DWG-E0023-SH1 1661550400-DWG-E0023-SH2
	P&C Communication Block Diagram	1661550400-DWG-E0022-
	Civil Drawing	1661550400-DWG-C0001-A 1661550400-DWG-C0002-A
	EA / P&C BOM	General Nepal EA/P&C BOM
	Structural BOM	1661550400-BOM-S2074-A
	Civil BOM	General BOM will be attached at the end
Naubise Substation	EA Station Layout	1661550400-DWG-E0100
	Protection SLD	1661550400-DWG-E0121-SH1 1661550400-DWG-E0121-SH2
	Ultimate Stage	1661550400-DWG-E0123-SH1 1661550400-DWG-E0123-SH2
	P&C Communication Block Diagram	1661550400-DWG-E0122
	Civil Drawing	1661550400-DWG-C0100-A 1661550400-DWG-C0101-A
	EA / P&C BOM	General Nepal EA/P&C BOM
	Structural BOM	705-1661550400-BOM-S2071-A
	Civil BOM	General BOM will be attached at the end
New Damauli	EA Station Layout	1661550400-DWG-E0200
	Protection SLD	1661550400-DWG-E0221-SH1 1661550400-DWG-E0221-SH2
	Ultimate Stage	1661550400-DWG-E0223-SH1 1661550400-DWG-E0223-SH2
	P&C Communication Block Diagram	1661550400-DWG-E0222

Substation	File Title	File Number
	Civil Drawing	1661550400-DWG-C0200-A 1661550400-DWG-C0201-A
	EA/P&C BOM	General Nepal EA/P&C BOM
	Structural BOM	705-1661550400-BOM-S2073
	Civil BOM	General BOM will be attached at the end
New Butwal	EA Station Layout	1661550400-DWG-E0900
	Protection SLD	1661550400-DWG-E0321
	Ultimate Stage	1661550400-DWG-E0323
	P&C Communication Block Diagram	1661550400-DWG-E0322
	Civil Drawing	1661550400-DWG-C0300-A 1661550400-DWG-C0301-A
	EA / P&C BOM	General Nepal EA/P&C BOM
	Structural BOM	705-1661550400-BOM-S2076-A
	Civil BOM	General BOM will be attached at the end
Lapsiphedi Substation	EA Station Layout	1661550400-DWG-E0400
	Protection SLD	1661550400-DWG-E0421
	Ultimate Stage	1661550400-DWG-E0423
	P&C Communication Block Diagram	1661550400-DWG-E0422
	Civil Drawing	1661550400-DWG-C0400-A 1661550400-DWG-C0401-A
	EA / P&C BOM	General Nepal EA/P&C BOM
	Structural BOM	705-1661550400-BOM-S2077
	Civil BOM	General BOM will be attached at the end
Ilam	EA Station Layout	N/A
	Protection SLD	N/A
	P&C Communication Block Diagram	N/A
	Civil Drawing	N/A
	EA/P&C BOM	General Nepal EA/P&C BOM
	Structural BOM	705-1661550400-BOM-S2081
	Civil BOM	General BOM will be attached at the end
Inaruwa Substation	Station Layout	1661550400-DWG-E2200
	Protection SLD	1661550400-DWG-E2221
	P&C Communication Block Diagram	N/A
	Civil Drawing	N/A
	EA / P&C BOM	General Nepal EA/P&C BOM
	Structural BOM	705-1661550400-BOM-S2080-A
	Civil BOM	General BOM will be attached at the end

Substation	File Title	File Number
Balanch	Station Layout	1661550400-DWG-E2400
	Protection SLD	N/A
	P&C Communication Block Diagram	N/A
	Civil Drawing	N/A
	EA/P&C BOM	General Nepal EA/P&C BOM
	Structural BOM	705-1661550400-BOM-S2082-A
	Civil BOM	General BOM will be attached at the end
Attariya	Station Layout	1661550400-DWG-E2600
	Protection SLD	1661550400-DWG-E2621
	P&C Communication Block Diagram	N/A
	Civil Drawing	N/A
	EA/P&C BOM	General Nepal EA BOM
	Structural BOM	705-1661550400-BOM-S2083-A
	Civil BOM	General BOM will be attached at the end
Likhu Hub	Station Layout	1661550400-DWG-E0500
	Protection SLD	1661550400-DWG-E0521
	Ultimate Stage	1661550400-DWG-E0523-SH11661550400-DWG-E0523-SH2
	P&C Communication Block Diagram	1661550400-DWG-E0522-A
	Civil Drawing	1661550400-DWG-C0500-A 1661550400-DWG-C0501-A
	EA/P&C BOM	General Nepal EA/P&C BOM-Likhu Hub Structural BOM 705-1661550400-BOM-S2075-A
	Civil BOM	General BOM will be attached at the end
New Khimti:	Station Layout	1661550400-DWG-E0600-SH1 1661550400-DWG-E0600-SH2
	Protection SLD	N/A
	P&C Communication Block Diagram	N/A
	Civil Drawing	N/A
	EA/P&C BOM	General Nepal EA/P&C BOM
	Structural BOM	705-1661550400-BOM-S2079
	Civil BOM	General BOM will be attached at the end
Tadhekani	Station Layout	1661550400-DWG-E0700-A
	Protection SLD	1661550400-DWG-E0721-A
	Ultimate Stage	1661550400-DWG-E0723-A
	P&C Communication Block Diagram	1661550400-DWG-E0722-A

Substation	File Title	File Number
	Civil Diagram	1661550400-DWG-C0700-A 1661550400-DWG-C0701
	EA/P&C BOM	General Nepal EA/P&C BOM
	Structural BOM	705-1661550400-BOM-S2072
	Civil BOM	General BOM will be attached at the end
Kusma	Station Layout	1661550400-DWG-E2500
	Protection SLD	N/A
	P&C Communication Block Diagram	N/A
	Civil Drawing	N/A
	EA/P&C BOM	General Nepal EA/P&C BOM
	Structural BOM	705-1661550400-BOM-S2082-A
	Civil BOM	General BOM will be attached at the end
New Lamki	Station Layout	1661550400-DWG-E0800
	Protection SLD	1661550400-DWG-E0821-SH1 1661550400-DWG-E0821-SH2
	Ultimate Stage	1661550400-DWG-E0823-SH11661550400-DWG-E0823-SH2
	P&C Communication Block Diagram	1661550400-DWG-E0822
	Civil Drawing	1661550400-DWG-C0800-A 1661550400-DWG-C0801-A
	EA/P&C BOM	General Nepal EA/P&C BOM
	Structural BOM	705-1661550400-BOM-S2078-A 705-1661550400-BOM-S20xx-A T8
	Civil BOM	General BOM will be attached at the end

Annex D
Conceptual Drawings and Bills of Material for Transmission Lines

The following files have been submitted as standalone documents owing to their size (over 250 MB each):

		File Number
Conceptual Design	132 kV drawings	1661550400-DWG-E9009-A-132kV
		1661550400-DWG-E9010-A-132kV
		1661550400-DWG-E9011-A-132kV
		1661550400-DWG-E9012-A-132kV
		1661550400-DWG-E9023-A-132kV
		1661550400-DWG-E9024-A-132kV
		1661550400-DWG-E9036-A-132kV
		1661550400-DWG-E9037-A-132kV
		1661550400-DWG-E9038-A-132kV
		1661550400-DWG-E9039-A-132kV
		1661550400-DWG-E9040-A-132kV
		1661550400-DWG-E9051-A-132kV
	220 kV drawings	1661550400-DWG-E9005-A-220kV
		1661550400-DWG-E9006-A-220kV
		1661550400-DWG-E9007-A-220kV
		1661550400-DWG-E9008-A-220kV
		1661550400-DWG-E9025-A-220kV
		1661550400-DWG-E9026-A-220kV
		1661550400-DWG-E9030-A-220kV
		1661550400-DWG-E9031-A-220kV
		1661550400-DWG-E9032-A-220kV
		1661550400-DWG-E9033-A-220kV
		1661550400-DWG-E9034-A-220kV
	400 kV drawings	1661550400-DWG-E9001-A-400kV
		1661550400-DWG-E9002-A-400kV
		1661550400-DWG-E9003-A-400kV
		1661550400-DWG-E9004-A-400kV
		1661550400-DWG-E9027-A-400kV
		1661550400-DWG-E9028-A-400kV
		1661550400-DWG-E9029-A-400kV
		1661550400-DWG-E9052-A-400kV
		1661550400-DWG-E9001-A-400kV

		File Number
	General drawings	1661550400-DWG-E9041-A
		1661550400-DWG-E9042-A
		1661550400-DWG-E9043-A
		1661550400-DWG-E9044-A
		1661550400-DWG-E9045-A
		1661550400-DWG-E9053-A
Transmission Line PP drawings		1661550400-DWG-E9014-A Inaruwa
		1661550400-DWG-E9015-A Tadhekani-Kusma
		1661550400-DWG-E9016-A New Khinti-Likhu Hub
		1661550400-DWG-E9017-A New Lamki
		1661550400-DWG-E9018_A_Sheets View New Butwal
		1661550400-DWG-E9019_Sheets View New Butwal-Damauli
		1661550400-DWG-E9020-A New Damauli-Naubise
		1661550400-DWG-E9021-A_Sheets View Naubise-New Hetauda
		1661550400-DWG-E9022-A Naubise-Lapsiphedi
Structure List		NR1-Damaul-Naubise_StructureList
		Structure List - Naubise to Lapsiphedi NR1
		Structure List - Nr1 New Butwal to New Damauli
		Structure List - T3 Tadhekani- Kusma sub
		Structure List - XB1 New Butwal
		Structure List NR1 Naubise to New Hetauda
		Structure List NR3 - Ilam Inaruwa
		Structure List t2 New Khimti-Likhu Hub
		T8_Structure List New Lamki
Technical Specifications		705-1661550400-DBM-E0001-A_Design Criteria Final
		705-1661550400-TS-E3061-A_TowerSpec_final
		705-1661550400-TS-E3062-A_Insulators_Final
		705-1661550400-TS-E3063-A_CondOPGWOHSW_Fina
Report		705-1661550400-REP-E3061-A - Ampacity report_Final
Transmission Line Foundation BOM		705-1661550400-BOM-S20xx-A XB1 New Butwal-India Border
		705-1661550400-BOM-S20xx-A T8 New Lamki-India Border
		705-1661550400-BOM-S20xx-A T3 Tadhekani-Kusma
		705-1661550400-BOM-S20xx-A T2’ New Khimti-Likhu Hub
		705-1661550400-BOM-S20xx-A NR3 Inaruwa-Ilam
		705-1661550400-BOM-S20xx-A NR1 New Hetauda-Naubise
		705-1661550400-BOM-S20xx-A NR1 Naubise-Lapsiphedi
		705-1661550400-BOM-S20xx-A NR1 Damauli-New Butwal
		705-1661550400-BOM-S20xx-A NR1 Damauli-Naubise
		705-1661550400-BOM-S2084-B T8 New Lamki-India Border
		705-1661550400-BOM-S2091-B T2' New Khimti-Likhu Hub

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