Journal of Advanced College of Engineering and Management, Vol. 9, 2024

STUDY OF IMPACT OF NEW BUTWAL-GORAKHPUR 400KV TRANSMISSION LINE ON THE OPERATION AND RELIABILITY OF INPS

Gopal Kumar Yadav[1], Nava Raj Karki[2], Basanta Kumar Gautam[3]

[1]M. Sc. in Power System Engineering, Department of Electrical Engineering, Pulchowk Campus, IOE, TU,

[2]Professor, Department of Electrical Engineering, Pulchowk Campus, IOE, TU, Nepal

[3]Associate Professor, Department of Electrical Engineering, Pulchowk Campus, IOE, TU, Nepal

[1]Email: yadavgopal10@gmail.com, [2]Email: nrkarki@ioe.edu.np, [3]Email: basanta.gautam@pcampus.edu.np

Abstract

In recent years, the significance and imperative of conducting impact studies on grid reliability evaluation have escalated. This thesis represents load flow analysis with a focus on improving resilience and efficiency after adding new Butwal-Gorakhpur 400KV cross border transmission line to existing power system of Nepal and simulation of 2028A.D. INPS network to find the reliability indices. The INPS is facing unprecedented challenges brought about by the increasing demand for electricity, the integration of hydropower and renewable sources, and the need for enhanced system reliability. This thesis reviews the current state of power systems and the challenges they face, including capacity constraints, energy losses. In this context, the integration of NB-G 400KV transmission line has emerged as a promising solution to address these challenges. The core of this research are used to assess the potential benefits, such as increased grid capacity, reduced transmission losses, improved power quality and reliability of the system after the integration of New Butwal-Gorakhpur (NB-G) line. Load flow analysis is carried out in DIgSILENT to find out system loss, voltage profile and reliability indices.

Keywords: *Integrated Nepal Power System(INPS), Cross Border Transmission line NB-G 400KV, Load flow, Transmission loss, Reliability, DIgSILENT.*

2 Introduction

In recent years, the significance and imperative of conducting impact studies on grid reliability evaluation have escalated. This is primarily attributed to the growing occurrence of blackout events, underscoring the need for a comprehensive assessment of their impact on the grid. The assessment of transmission system reliability in terms of quantity is crucial in a competitive electricity environment. This is because the effective functioning of electric power in a deregulated electricity market relies heavily on the management of transmission system reliability. This paper presents the study of impact of New Butwal-Gorakhpur 400 kV cross border line on the operation and reliability of Integrated Nepal Power System.

Nepal has entered a phase of power surplus during wet seasons, and this trend is expected to persist with the commissioning of additional generation projects. In the last fiscal year, the total power generation reached 2,684 MW, with 452 MW exported to India on a Day-Ahead basis through the Indian Energy Exchange (IEX). This export figure is anticipated to rise further as agreements are made to purchase more power from Nepal's hydropower sector. Over the next decade, the Government of Nepal and the Nepal Electricity Authority (NEA) have outlined a strategy to evacuate 15,000 MW of power to meet the growing demand, driven by an annual consumer increase of 7-10%, reaching a total of 5.13 million.

However, the current status of Nepal's power system is inadequate to handle this increased capacity, necessitating upgrades. The transmission line, a critical component of the power system, poses challenges due to the substantial budget required for construction and its resistance to easy replacement or modification. Notably, transmission lines like Hetauda-Pathlaiya 132kV, Damauli–Bharatpur 132 kV, Duhabi-Damak 132kV operate at full capacity, leading to issues such as power interruptions, high energy loss, voltage drops, reduced power capacity, cost inefficiency, limited hydropower integration, and diminished voltage stability.

3 Literature Review

This work examines several research papers on Nepal's power system and its transmission and distribution system planning. Below, we provide a brief summary of the papers most relevant to this thesis works:

In their paper titled 'Analysis of Load Flow and Reliability Assessment for the 220 KV Kerala Power System' [1], Dr. J. Abdul Jaleel and Shabna S.S. conducted load flow studies on the Kerala 220 KV Power system using ETAP software. The objective of their study was to facilitate future power system planning and enhance the current system's operational efficiency. Furthermore, the paper includes an assessment of various reliability indices for the system, offering valuable insights into its overall reliability.

In their work titled 'Probabilistic Reliability Assessment of 765KV Transmission Lines in KEPCO Grid Expansion Planning' [2], Trungtinh Tran et al. have demonstrated the utilization of TRELSS version 6.2, a software package developed by the Electric Research Institute, for calculating Probabilistic Reliability Evaluation indices for the KEPCO system. The paper presents findings from various case studies conducted on the KEPCO-system using the TRELSS program.

In the research conducted by Sang-Bong Choi, titled 'Evaluation of Reliability in the Distribution System of an Industrial Complex' [3], the authors elucidate methodologies for assessing EPNS (Expected Point of Non-Supply) and EENS (Expected Energy Not Supplied) at specific load points, namely the substations (S/S). These evaluations are derived from computations involving load and power flow, failure rates, and outage durations.

In their publication authored by Xiakang Xu, Feng Dong, Lengchang Huang, and Baldwin P. Lam, titled 'Modeling and Simulation of Substation-Related Outages in Power Flow Analysis' [4], a probabilistic reliability approach is detailed. This approach is designed to model and simulate the potential outages of substation-related equipment, including incoming and outgoing lines, circuit breakers, disconnect switches, and bus sections. It employs a substation reliability model to quantify the unreliability of the substation in terms of load interruption and energy unavailability.

4 Methodology

To investigate the impact of the New Butwal-Gorakhpur Cross-Border 400kV Transmission Line on the Operation and Reliability of INPS, several steps are involved: collection of appropriate research paper, data and appropriate software and then formation of simulation model for existing INPS system. The networks component data, such as information regarding generators, transmission lines, and substation loads and compensating devices within the existing INPS, was input into the simulated INPS network created using DIgSILENT. In this simulation, the Dhalkebar Bus was designated as the swing bus for assessing the load flow within the existing INPS for 2028 AD New Butwal-Gorakhpur line bus is used as slack bus and the Dhalkebar-Muzzaffarpur and Attariya-Bareli buses are used as PV bus. The load flow analysis conducted with DIgSILENT provided valuable insights, including data on line losses, instances of line overloading, and estimates of bus voltage. These results played a crucial role in estimating the amount of export/import to ensure system stability. The amount of export/import quantity was determined based on the line capacity of slack bus, load flow analyses were carried out for both dry and wet season load scenarios, considering various network configurations and different levels of power export/import. The specific cases examined in this study are detailed as follows:

4.1 Dry Season cases are:

Peak load cases:

Operation of Existing INPS at peak load (Base Case i.e. Case 1)

Operation of INPS at peak load when 25 MW power import via New Butwal-Gorakhpur line(NB-G) (i.e. Case 2)

Operation of INPS at peak load when optimum power 380.9MW import via New Butwal-Gorakhpur line(NB-G) (i.e. Case 3).

Normal load cases:

Operation of Existing INPS at normal load (Base Case I.e. Case 1)

Operation of INPS at normal load when 25 MW power import via New Butwal-Gorakhpur line(NB-G) (i.e. Case 2)

Operation of INPS at normal load when optimum power 398.5MW import via New Butwal-Gorakhpur line(NB-G) (i.e. Case 3).

Off-Peak load cases:

Operation of Existing INPS at off-peak load (Base Case i. e. Case 1)

Operation of INPS at off-peak load when 25 MW power import via New Butwal-Gorakhpur line(NB-G) (i.e. Case 2)

Operation of INPS at off-peak load when optimum power 350.6 MW import via New Butwal-Gorakhpur line(NB-G) (i.e. Case 3).

4.2 Wet Season cases are:

Peak load cases:

Operation of Existing INPS at peak load (base Case i.e. Case 1)

Operation of INPS at peak load when 25MW power export via New Butwal-Gorakhpur line(NB-G) (i.e. Case 2)

Operation of INPS at peak load when optimum power 26 MW import via New Butwal-Gorakhpur line(NB-G) (i.e. Case 3).

Normal load cases:

Operation of Existing INPS at normal load (base Case i.e. Case 1)

Operation of INPS at normal load when 25 MW power export via New Butwal-Gorakhpur line(NB-G) (i.e. Case 2)

Operation of INPS at normal load when optimum power 97 MW export via New Butwal-Gorakhpur line(NB-G) (i.e. Case 3).

Off-Peak load cases:

Operation of Existing INPS at off-peak load (base Case i.e. Case 1)

Operation of INPS at off-peak load when 25 MW power export via New Butwal-Gorakhpur line(NB-

G) (i.e. Case 2)

Operation of INPS at off-peak load when optimum power 201.7 MW export via New Butwal-Gorakhpur line(NB-G) (i.e. Case 3).

4.3 Reliability Analysis.

For reliability analysis, the following reliability indices are considered in this study:

Expected Energy Not Served (EENS): The EENS is defined as the expected amount of energy not being served to consumers by the system during the period considered due to system capacity shortages or unexpected severe power outages.

Expected Power Not Served (EPNS): The EPNS is defined as the magnitude of power (load) that has been lost due to severe outages.

Energy Index of Reliability (EIR) = 1 – EENS $_{p.u}$ where

$$\text{EENSpu} = \frac{\text{Expected Energy Not Served (EENS)}}{\text{Total Energy Demanded (TED)}}$$

Expected Cost of Energy Not Served (ECOST) or Cost of unserved Energy (CUE) = EENS * IEAR, Where IEAR is the interrupted energy assessment rate.

For Reliability analysis of the transmission system, required input data i.e. failure rate of transmission line is taken from a book "forced Outage performance of Transmission Equipment 2006", Canada Electricity Association as shown in table 1.

Table 0.1: Failure rate data of transmission line

S.N.	Description	Frequency of outage (λ)	Mean Time to Repair (MTTR)
1	66 kV lines	0.028 failure/yr./km	10.8 hr.
2	132 kV lines	0.01 failure/yr./km	9.5 hr.
3	220 kV Lines	0.0035 failure/yr./km	35.5 hr.
4	400 kV Lines	0.002 failure/yr./km	18.8 hr.

For reliability analysis of INPS, selecting standard value of annual failure rate λ (per yr.km) and mean time

to repair MTTR i.e. outage time of transmission line are taken for each line. The line flows are taken from DIgSILENT load flow result. After obtaining these data's, annual expected power not served (EPNS) is calculated by multiplying power flow in megawatt due to load in the line and failure rate of that line. Expected energy not served (EENS) is calculated by multiplying expected power not served and outage time (MTTR) in hour annually.

5.System Modeling and Simulation

The modeling of scenarios for the existing years 2023 and 2028 was conducted using DIGSilent Power Factory simulation software version 15.1.7. This software, designed for Digital Simulation and Network Calculation, incorporates functionalities such as Load Flow, the Optimal Power Flow (OPF), short circuit calculation, Harmonic analysis, Protection coordination, stability calculation and modal analysis.

To facilitate the coding necessary for the thesis, the coding platform employed was DIGSilent Programming Language (DPL). In the simulation for the year 2028, the Integrated Nepal Power System (INPS) was segmented into five zones. The total generation capacity in the existing INPS is 2700 MW, which is projected to increase to 10870 MW by the year 2028. Peak load data obtained from the NEA LDC indicates peak loads of 1900 MW and 2000 MW during the DRY and WET seasons, respectively.

According to the NEA forecast table, the expected load for the year 2022/23 is 2744.7 MW. However, the current peak load, as per data obtained from the System Operation Department of NEA, is 2000 MW. To adjust the projection for the year 2028 A.D., a multiplying factor (m.f.) has been calculated as the ratio of the current peak load to the forecasted load for 2022/23, resulting in a factor of 0.73.

Multiplying Factor (m.f.) = 2000/2744.7 = 0.73.

Projected Load for 2028 = 0.73 x table data for 2027/28 = 0.73 * 4414.5 MW = 3322.59MW.

To manage excess generation, plans have been proposed to export it to India through 400 kV transmission lines.

6 Results and Discussions

6.1.1 Simulation Results of existing INPS of 2023 A.D.

The load flow analysis and assessment of system reliability metrics for INPS during both dry and wet season operational periods are conducted. This process yields critical operational parameters, including voltage profiles, transmission losses, and system reliability indicators, for each operational scenario. Different modes of operation of INPS for dry and wet season period are categorized on the basis of different loading of the system. For the existing INPS system in year 2023, when operation in different scenario the system loss, amount of export/import are tabulated below:

Table1: Comparison of power loss under dry season mode of operation scenario

S.N.	Mode of operation: Dry-Season	Generation (MW)	Cases	Total Import (MW)	Tr.Loss (MW)	Tr.Loss (%)	Import D-M	Import NB-G	Import 132kV
1	Peak Load (1900.93MW)	1301.76	Case-1	716.36	117.18	5.81	386.36	0.00	330.00
2			Case-2	704.05	104.88	5.23	349.05	25.00	330.00
3			Case-3	696.26	97.09	4.88	328.36	367.90	0.00
4	Normal Load (1599.54MW)	858.73	Case-1	827.03	86.22	5.11	497.03	0.00	330.00
5			Case-2	817.01	76.2	4.55	462.01	25.00	330.00
6			Case-3	811.28	70.47	4.22	412.77	398.51	0.00
7	Off-Peak Load(1250.51MW)	559.73	Case-1	751.30	60.59	4.62	421.38	0.00	330.00
8			Case-2	742.93	52.15	4.00	387.93	25.00	330.00
9			Case-3	741.84	51.06	3.92	366.64	375.2	0.00

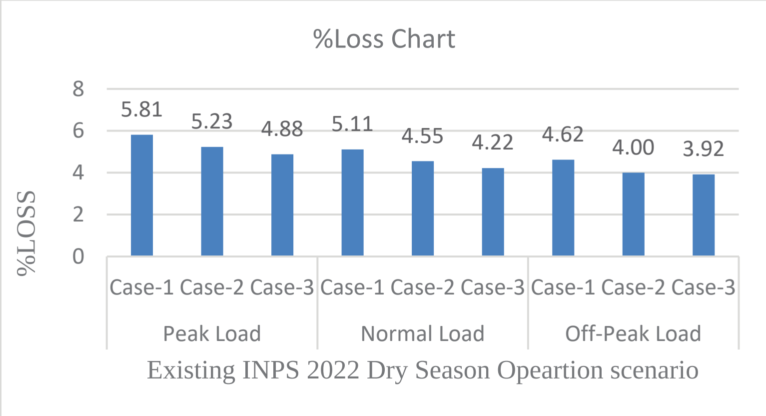


Figure1: Line loss under different mode of dry season operation scenario by 2022

From the table, it is clear that operating the INPS with addition of NB-G line, the loss of the system decreasing, in all case 3 has lowest loss then the other cases so it is recommended to operate the INPS by taking optimum import from the NB-G line.

Table 2: Comparison of power loss under wet season mode of operation scenario

S.N.	Mode of operation: Wet-Season	Generation (MW)	Cases	Total Export (MW)	Tr.Loss (MW)	Tr.Loss (%)	Export D-M	Export NB-G	Export 132kV
1	Peak Load (2000.19MW)	2500	Case-1	353.50	146.26	5.85	-353.54	0.00	0.00
2			Case-2	355.78	144.03	5.76	-330.78	-25.00	0.00
3			Case-3	361.60	138.24	5.53	-387.56	26.00	0.00
4	Normal Load (1799.68MW)	2500	Case-1	550.77	149.55	5.98	-550.77	0.00	0.00
5			Case-2	558.27	142.05	5.68	-533.27	-25.00	0.00
6			Case-3	566.30	134.02	5.36	-469.3	-97.00	0.00
7	Off-Peak Load (1600.19MW)	2500	Case-1	731.67	168.14	6.73	-731.67	0.00	0.00
8			Case-2	739.22	160.49	6.42	-714.32	-25.00	0.00
9			Case-3	766.00	133.73	5.35	-564.38	-201.7	0.00

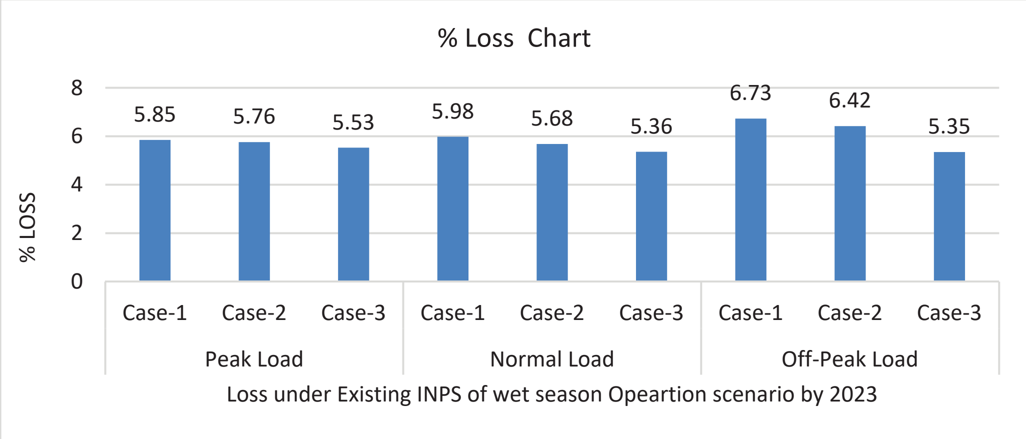


Figure2: Line loss under different mode of wet season operation scenario by 2023

From the table, it is clear that operating the INPS with addition of NB-G line, the loss of the system decreasing, in all case 3 has lowest loss then the other cases so it is recommended to operate the INPS by exporting optimum power from the NB-G line.

6.1.2 Evaluation of Reliability indices of INPS:

Calculation of EENS $_{p.u}$ and EIR $_{p.u.}$

$$\text{EENSpu} = \frac{\text{Expected Energy Not Served (EENS)}}{\text{Total Energy Demanded (TED)}}$$

Energy Index of Reliability (EIR) = 1 - EENS$_{p.u}$

Dry Season Operation

Table 3: EENS, EENSp.u. and EIRp.u. for 2022 dry season different cases.

S.N.	Mode of operation: Dry-Season	Load (MW)	Cases	EENS (MWhr)	EENSp.u	EIR = 1-EENS p.u
1	Peak Load	1900.93	Case-1	22810.74	0.00136984	0.99863016
2			Case-2	19989.02	0.00120039	0.99879961
3			Case-3	17890.00	0.00107434	0.99892566
4	Normal Load	1599.54	Case-1	20445.03	0.00145911	0.99854089
5			Case-2	19358.18	0.00138155	0.99861845
6			Case-3	18458.19	0.00131732	0.99868268
7	Off-Peak Load	1250.51	Case-1	17570.76	0.00160398	0.99839602
8			Case-2	16474.37	0.00150390	0.99849610
9			Case-3	15400.76	0.00140589	0.99859411

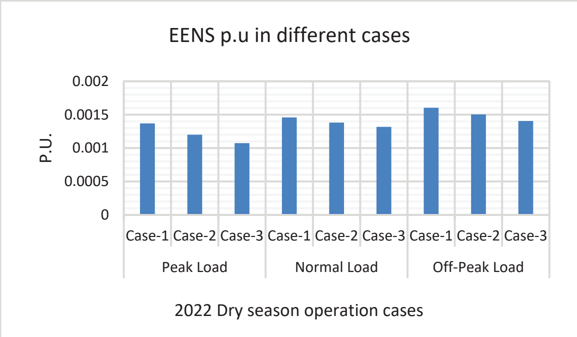


Figure 3: EENS p.u. for 2022 dry season operation of INPS.

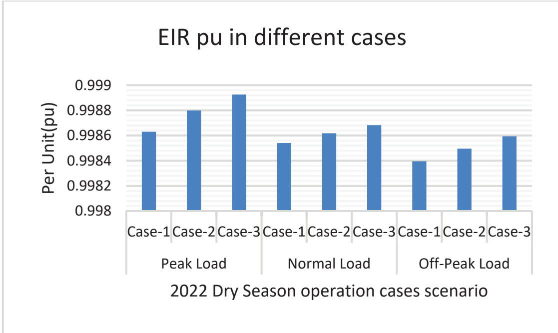


Figure 4: EIR p.u. for 2022 dry season operation of INPS.

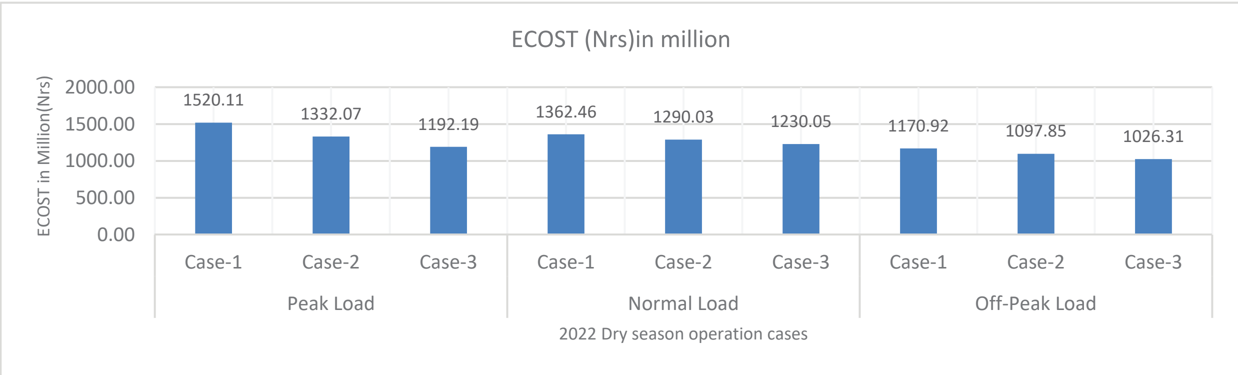


Figure5: ECOST for 2022 dry season operation cases of INPS.

Figure 4.5 provides a visual representation of the Expected Cost of Energy Not Served (ECOST) during dry season operations. Upon integrating power sourced from Gorakhpur through the NB-G 400kV transmission line into the pre-existing INPS system, a noteworthy reduction in ECOST is observed across all operational scenarios compared to the baseline setup.

For Wet Season operation:

Table 4: EENS, EENSp.u. and EIR p.u for 2023 under different cases of wet season.

S.N.	Mode of operation: Wet-Season	Load (MW)	Cases	EENS (MWhr)	EENS p.u	EIR = 1-EENS p.u
1	Peak Load	2000.19	Case-1	30252.97	0.001726604	0.998273396
2			Case-2	29696.98	0.001694872	0.998305128
3			Case-3	27629.44	0.001576873	0.998423127
4	Normal Load	1799.68	Case-1	31795.42	0.002016811	0.997983189
5			Case-2	30674.91	0.001945736	0.998054264
6			Case-3	28471.50	0.001805972	0.998194028
7	Off-Peak Load	1600.19	Case-1	33938.27	0.002421107	0.997578893
8			Case-2	33209.00	0.002369083	0.997630917
9			Case-3	30188.97	0.002153637	0.997846363

The rise in EIRp.u, the Energy Index of Reliability per unit, is linked to a simultaneous decrease in EENSp.u, Expected Energy Not Supplied per unit. This shift implies a favorable outcome – as the system imports more power from Gorakhpur, Energy Index of Reliability per unit improves due to a decrease in the expected energy not supplied per unit. This signifies a more efficient and reliable system operation.

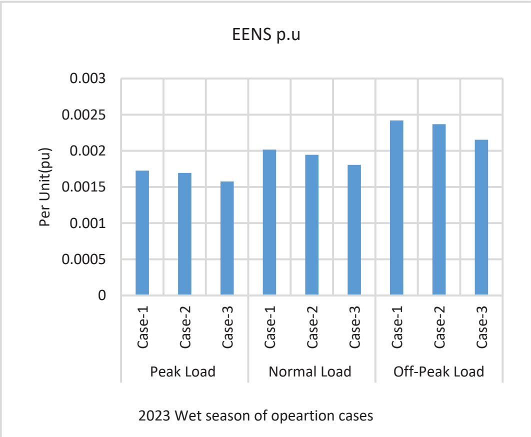


Figure 6: EENS p.u. for 2023 Wet season operation of INPS.

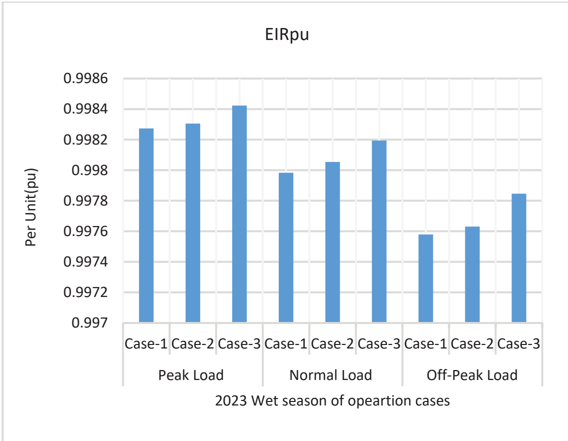


Figure 7: EIR p.u. for 2023 Wet season operation of INPS.

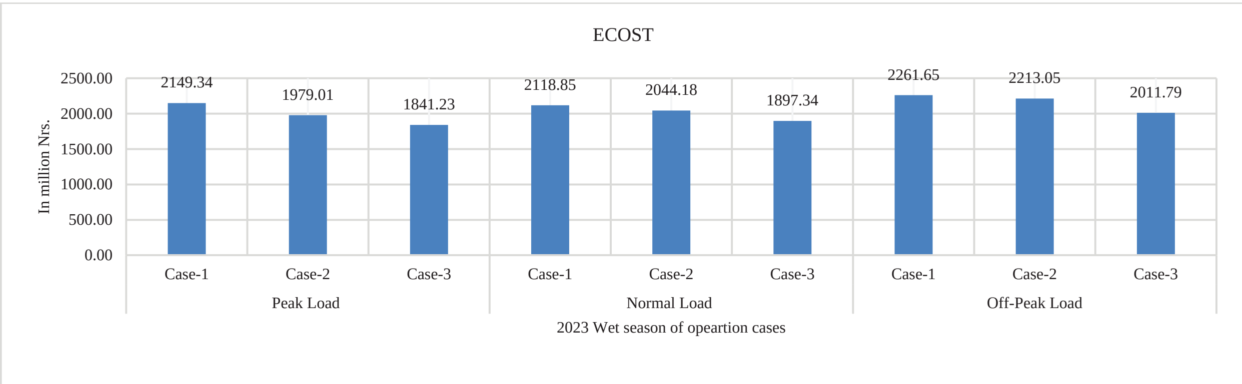


Figure 8: ECOST for 2023 wet season operation of INPS.

With the integration of power from Gorakhpur via the NB-G line into the existing system, there is a noteworthy reduction in the cost associated with the Expected Energy Not Supplied (ECOST) in all scenarios compared to the baseline mode of operation.

6.2 Modelling of 2028 A.D. Scenario

Scenario 1: Wet season - Maximum Load (Wet-Max Load) When New Butwal-Gorakhpur line is not in operation i.e. export via NB-G = 0. Attariya-Bareli bus is Slack bus(SL) and Dhalkebar-Muzzaffarpur(D-M) is assigned as PQ bus. System serves a maximum load of 3500 MW and exporting remaining power 2200.34MW via Dhalke-Muzaffarpur(D-M) and 3500MW via Attariya-Bareli line out of 9565.95 MW generation. The system's transmission loss is determined to be 331.93 MW, equivalent to 3.47 %.

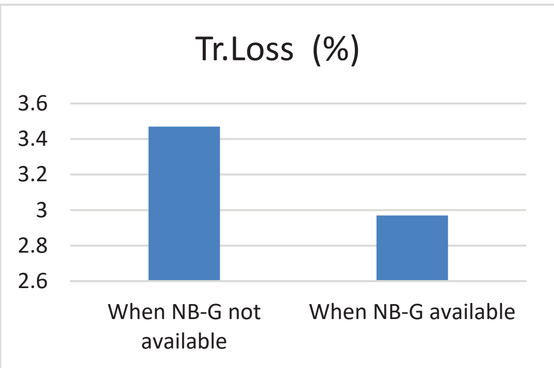
Scenario 2: Wet season - Maximum Load (Wet-Max Load) When exporting optimum power via. New Butwal-Gorakhpur(NB-G) line.

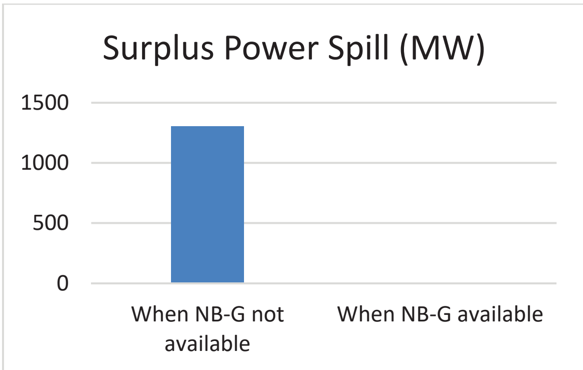
In this simulation Attariya-Bareli and Dhalkebar-Muzzaffarpur(D-M) buses are assigned as PQ bus and

New Butwal-Gorakhpur is used as Slack Bus(SL). The system serves a maximum load of 3500 MW and exporting remaining power 7047.03MW: via. Attariya-Bareli (A-B) is 2623MW and via. Dhalke-Muzaffarpur(D-M) is 2197MW and via. New Butwal-Gorakhpur is 2227.03MW, out of 10780.40 MW generation. The system's transmission loss is determined to be 323.37 MW, equivalent to 2.97 %.

Table 5: Summary of mode of scenario by 2028

S.N.	1.	2.
Mode of operation: Wet-Season	When NB-G Not Available	When NB-G Available
Generation (MW)	9565.95	10870.40
Surplus Power Spill (MW)	1302.94	0.00
Load (MW)	3500.00	3500.00
Total Export (MW)	5734.02	7047.03
Tr.Loss (MW)	331.93	323.37
Tr.Loss (%)	3.47	2.97
Export A-B (MW)	3500.00	2623.00
Export D-M (MW)	2200.34	2197.00
Export NB-G (MW)	0.00	2227.03





From the above table and graph, it is clear that when the New Butwal-Gorakhpur line is not available there is spillage of surplus power with system loss 3.47% as aforementioned line is available for operation then the power spill is zero and system loss reduced to 2.97% from 3.47%. It can be concluded that the lines have still capacity to export power because the NewButwal-Gorakhpur line is operating under the only 63.6% of loading. From the above simulation it is also clear that line must come into operation up to 2028 A.D. to export excess power to India.

7 Conclusion

The result is analyzed in two seasons, Dry and wet with different load scenario viz. peak load, normal load and off-peak load. In dry season the energy is insufficient and needs to import. In wet season, surplus energy need to export to India. From the simulation and result as seen above the analysis support to import optimum power from NB-G line in dry season and export optimum power via aforementioned line. For optimum power import/export, the loss in the system is minimum and Expected Energy Not Supplied(EENS) is also minimum so the Expected Cost of Energy Not Supplied (ECOST) is minimum. Energy Index of Reliability of system has increased. Hence findings in this research shows importance of NB-G line in the future in Integrated Nepal power system(INPS).

8 References

[1] Dr.J. Abdul Jaleel and Shabna S.S, "Load flow Analysis and Reliability Evaluation of 220 KV Kerala Power System," International Journal of Engineering and Innovative Technology, Vol.3, Issue 2, Aug. 2013.

[2] Trungtinh Tran et al., "Probabilistic Reliability Evaluation for 765KV Transmission Lines in KEPCO Grid Expansion Planning," Journal of Electrical Engineering and Technology, Vol.2, No.1, pp. 10-18, Nov. 2007.

[3] Sang-Bong Choi, "Assessment of Reliability in the distribution system of an Industrial complex," Journal of Electrical Engineering and Technology, Vol.2, No.2, pp. 201-207, March 2007.

[4] Xiakang Xu, Feng Dong, Lengchang Huang and Baldwin P. Lam IEEE, " Modelling and Simulation of Substation related outages in power flow Analysis," International Conference on Power System Technology, 2010.

[5] Rohit Kapahi, "Load Flow Analysis of 132 KV Substation using ETAP Software," International Journal of Scientific and Engineering Research, Vol.4, Issue -2, Feb.2013.

[6] Zio E., Piccinell R., Delfanti M., Olivieri V., Pozzi M. "Performance Analysis of a Power Transmission System Under Load Uncertain Conditions and Network Configuration," Summer Safety and Reliability Seminar, < hal-00721062>, pp.279-284,2010.