Analysis of Bhutan Power Systems using PSS®E Software

Kinley Jamtsho[1*], Dawa Chhoedron[2], Ugyen Chophel[3], Samten[4]

Department of Energy, Ministry of Energy and Natural Resources, Bhutan[1,2,3]
Bhutan Power System Operator, Bhutan[4]
E-mail: kjamtsho@moenr.gov.bt[1*], dchhoedron@moenr.gov.bt[2], uchophel@moenr.gov.bt[3], samten@bpso.bt[4]

Received: 14 April 2025; Revised: 9 June 2025; Accepted: 10 July 2025; Published: 17 August 2025

Abstract
Electricity demand in Bhutan has been increasing steadily ever since utility-scale power supply was introduced into the country in the 1960s and 1970s and Bhutan's first large-scale hydropower project, 336 MW Chhukha Hydropower Plant was commissioned in the 1980s. In the past three years, the rise in the demand has accelerated due to rapid growth in the industrial development. This has led to increasing stress on the power system infrastructure. Further, the country's grid is subjected to varying operating conditions brought about by seasonal variations in generation, peaking in summer, flexible operation and reaching its lowest level in winter. Additionally, the grid is connected to Indian systems via thirteen feeders at different voltage levels further increasing the risks of disturbances and influence from the larger Indian grid. Therefore, it is of paramount importance to carry out the system analysis at regular intervals to study and assess the behavior of the power systems, based on which the timely corrective measures can be implemented to ensure grid stability and efficiency. In this study, the existing power system model of Bhutan is developed in PSS®E software and simulation is carried out for summer and winter seasons. For summer, the data sets of 28th July 2024 at 20:00 hours is used while for winter, the data sets of 14th February 2024 at 15:00 hours is used corresponding to the highest generation and the lowest generation respectively. The simulation results show the overloading of Mangdechhu to Yurmo line, overloading of transformers at Gedu substations, and under voltage issues in a few substations in both the study periods. Therefore, to resolve the overloading issues, upgradation of transformers at Gedu substation and connection of a new line from Mangdechhu to Yurmo is recommended. Further, to resolve under-voltage issue, shunt capacitor of 12 MVAR is recommended in Damji substation, which has been determined based on the QV analysis.
Key Words: *peak demand, Bhutan power systems,* PSS®E, *contingency, QV curve*

1. INTRODUCTION

Electricity demand in Bhutan has been increasing at unprecedented pace in the recent years. In 2022, the peak demand was 629.61 MW, which then experienced the drastic growth of 51.76% in 2023 reaching 955.51 MW (Bhutan Power System Operator, 2024). The peak demand further increased to 1,026.44 MW in 2024 while the total generating installed capacity was 2,444 MW. However installed capacity is significantly inadequate to meet the rapidly increasing demand, especially during the winter months when the generation dwindles to 17% of installed capacity given the inherent limitations of the run-of-river hydropower plants and characteristics of hydrology that is dependent on the summer monsoons. The increase in demand, along with the varying generation patterns, exposes Bhutan's grid to various power system issues such as overloading of transformers and transmission lines, and voltage violations increasing the risk of power system outage. Globally, it has been reported that some of the prominent reasons for power system blackout are tripping and overloading of transmission lines, voltage collapse, protection and control system failures, among others (Soni & Mukherjee, 2018). Therefore, regular system analysis, especially the power flow analysis, is of paramount importance to assess the behavior of power systems under varying operating conditions, based on which the corrective measures such as grid reinforcement and optimization of reactive power and voltage controls can be implemented to ensure grid stability and efficiency.

In this study, the steady state power flow analysis is carried out using PSS®E software with the objective to assess and analyze the loading of transformers & transmission lines; check for any voltage limit violations in the busses; assess the adequacy of existing power system network under the given generation and loading scenarios during the defined period.

This paper is structured as follows: First, it describes the methodology adopted for analysis specifying how the PSS®E data inputs are considered, followed by literature review of power system operating limits. In the second half, the simulation results are presented for summer and winter seasons, following which the corrective measures are recommended at the end.

2. METHODOLOGY

This study is carried out using the PSS®E software which is a widely used simulation tools for conducting power system studies. It involves several stages: firstly, the data collection and verification, followed by detailed power system modelling of Bhutan's transmission network. Next, the load flow analysis is performed covering two scenarios i.e. a) peak generation in summer and b) lowest generation in winter. The analysis focuses on key power system parameters such as voltage profiles, transmissions and transformers loading. The following subsections explains the detailed methodology adopted for the study:

2.1 Data collection

a. Transmission line details

The parameters of the existing domestic transmission lines are as per *Power Data Book 2023* (Bhutan Power Corporation Limited, 2024). The parameters of cross-border transmission lines are as per the *National Transmission Grid Master Plan of Bhutan* (Department of Hydropower and Power Systems, 2018). The transmission map of Bhutan as of 2024 is shown **Error! Reference source not found.**:

The transmission voltage levels are 66kV, 132kV, 220kV, and 400kV.

b. Generation details

The installed capacity as of 2024 was 2,444 MW as shown in the Table *1*.

Since the simulation has to be carried out for maximum and minimum generation in a year, the monthly plant factor of 2024 is analyzed as shown in Table *2* (Bhutan Power System Operator, 2024).

Table 1: *Generating plant details as of 2024*

Sl/No	Plant name	Capacity (MW)
1	Tala (THP)	1020
2	Chhukha (CHP)	336
3	Basochhu (BHP)	64
4	Dagachhu (DHP)	126
5	Kurichhu (KHP)	60
6	Mangdechhu (MHP)	720
7	Nikachhu (NHP)	118
Total		**2,444**

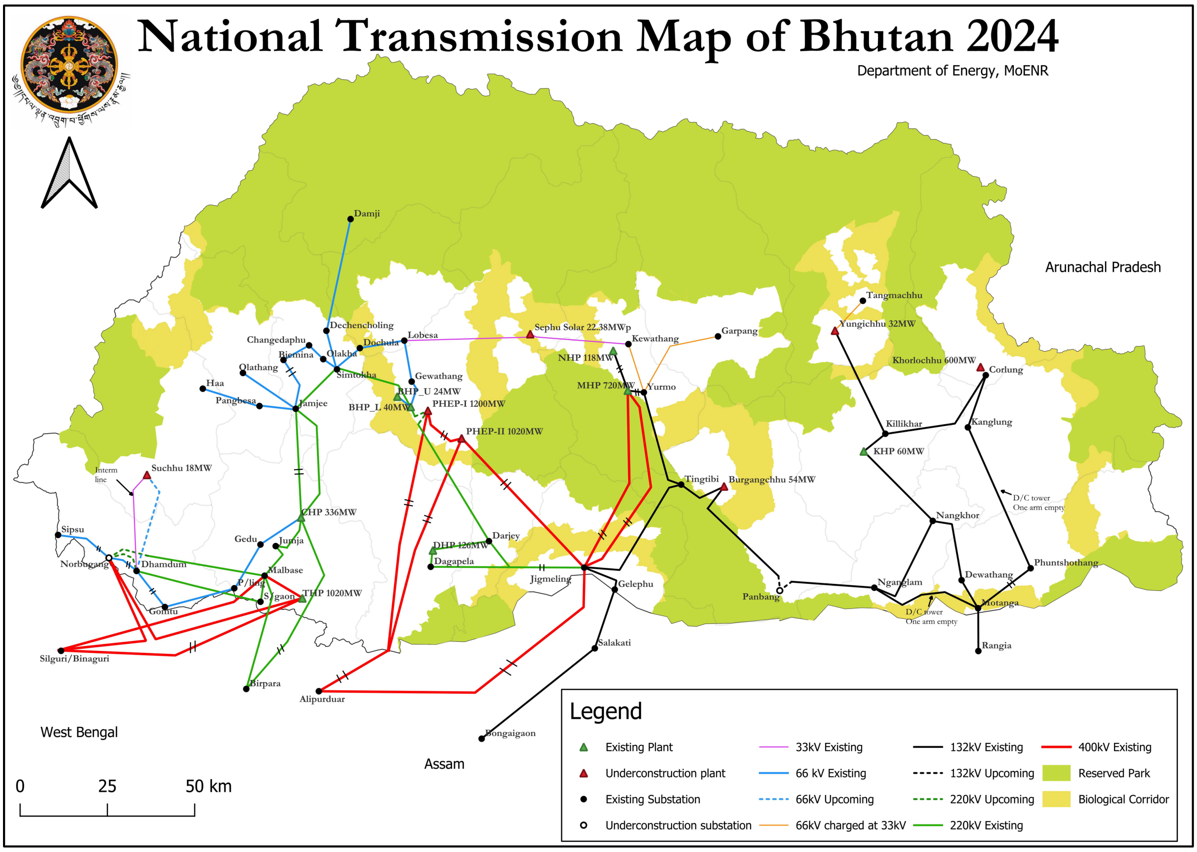

Fig 1: *Existing Transmission map of Bhutan*

Table 2: Monthly plant load factor in 2024

Month	BHP	CHP	THP	KHP	DHP	MHP	NHP	Avg.
Jan	30%	25%	18%	31%	18%	12%	3%	19.0%
Feb	25%	21%	13%	27%	13%	4%	27%	18.6%
Mar	28%	26%	17%	41%	15%	41%	15%	26.0%
April	24%	36%	25%	72%	13%	35%	21%	32.0%
May	21%	40%	26%	84%	13%	47%	28%	37.0%
June	52%	60%	53%	103%	34%	77%	59%	63.0%
July	101%	98%	106%	106%	84%	106%	107%	101.0%
Aug	87%	108%	107%	110%	81%	100%	102%	99.0%
Sep	91%	104%	100%	103%	70%	102%	100%	96.0%
Oct	36%	37%	25%	42%	23%	82%	82%	47.0%
Nov	49%	54%	37%	59%	34%	37%	39%	44.0%
Dec	36%	36%	24%	41%	23%	29%	23%	30.0%

It is observed that all the plants were operating at full capacity in July with 101% loading, while February was the minimum with only 18.6% loading. Therefore, the hourly generation data corresponding to July and February 2024 was analyzed further as shown in Fig *2* and Fig *3* below:

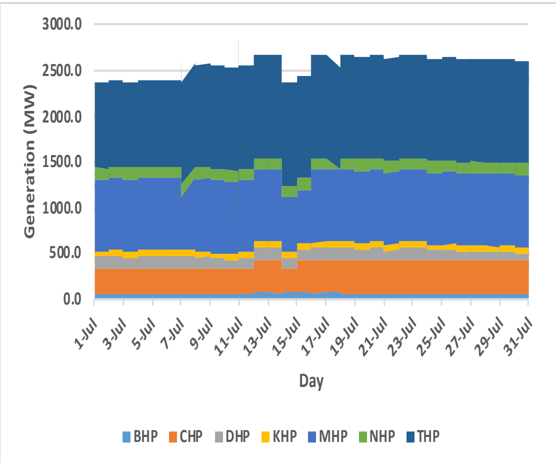

***Fig 2:** Hourly generation profile in July 2024*

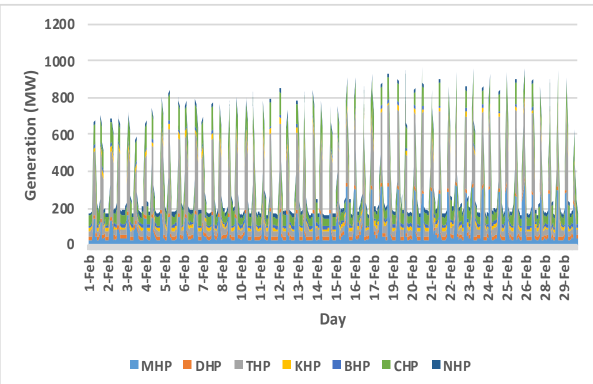

***Fig 3:**Hourly generation profile in February 2024*

In the month of July, the maximum generation was 2,615 MW recorded on 28th at 20:00 hours, while in February, the minimum generation was 164 MW recorded on 14th at 15.00 hours. The hourly generation patterns on 28th July and 14th February are shown in Fig *4* and Fig *5*.

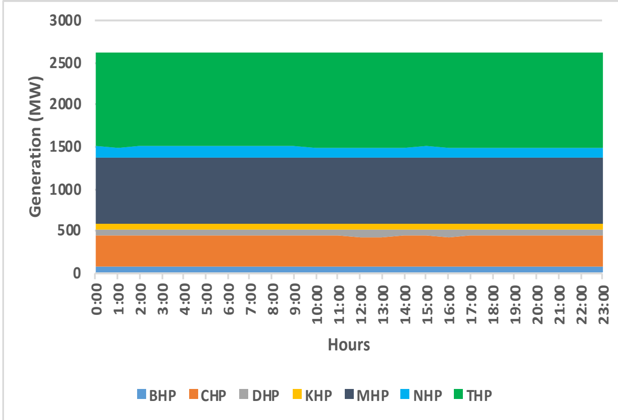

***Fig 4:** Hourly Generation profile in 28th July 2024*

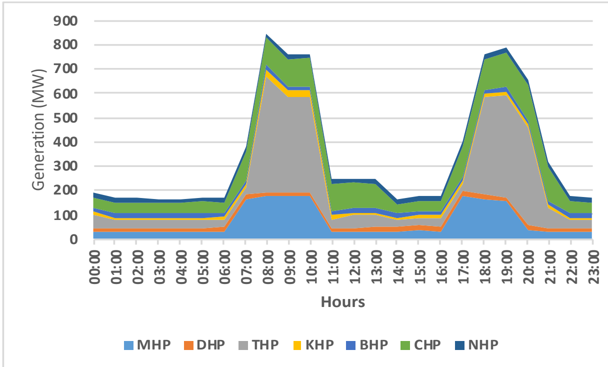

***Fig 5:** Hourly generation pattern of 14th February 2024*

The generation in July is flat for 24 hours, however, it is varying in February. This is because July month is generally rainy season and all machines are loaded to full capacity, while February is the driest month with no rainfall and machines are loaded less than half of the capacity due to low river discharge. This is the lean period where Bhutan imports power from Indian power markets to meet the power deficit. The market clearing prices in the Indian power market is usually high during the morning and evening peak hours. Therefore, the machines are operated under flexible generation modes, whereby the water is stored in the dam during off-peak hours and generate maximum power during peak hours as shown in Fig *5*.

c. Load data

There are thirty four high voltage substations within Bhutan with total capacity of 2,735.50 MVA (Bhutan Power Corporation Limited, 2023). To analyze the behavior of the grid, the simulation is carried out using the generation and load data recorded at the same instance. Therefore, the substation wise load corresponding to 28th July 2024 at 20:00 hours and 14th February 2024 at 15:00 hours was collected and analyzed. The total load in the given period was 886 MW and 821 MW respectively. The hourly load graph corresponding to the given period is shown in Fig *6* and Fig *7* below:

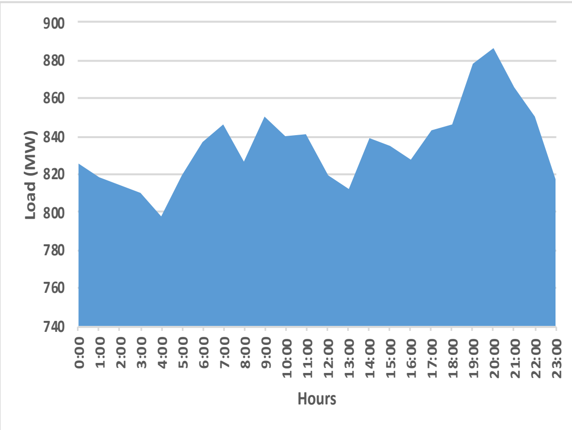

Fig 6: *Hourly load on 28th July 2024*

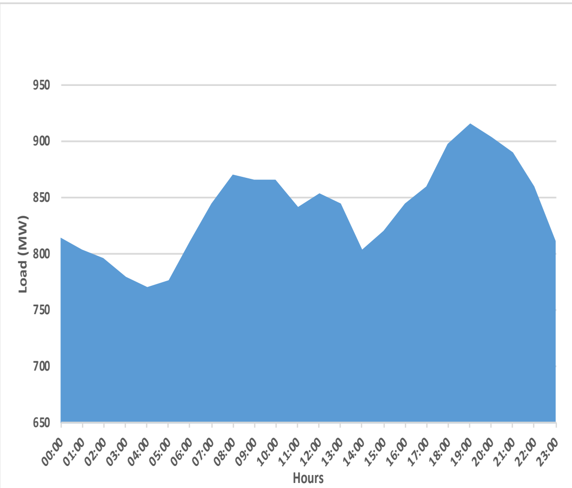

Fig 7: *Load graph on 14th February 2024*

2.2 Power System Model

The power system model of Bhutan is developed in Siemens PSS®E software version 35. For the ease of modeling, only the transmission voltage level of 66kV and above are considered. All the distribution loads are lumped in the 66kV and 33kV busses. Since the Bhutanese grid is synchronously connected with the Indian Grid, the Indian system is modelled as per *National Transmission Grid Master Plan of Bhutan* (Department of Hydropower and Power Systems, 2018). The impedance of the lines, transformers, and reactive power limits of the machines are assumed as shown in the following subsections:

a. Transmission Line Impedance

Since the actual transmission line parameters could not be obtained, the impedance value of the transmission lines are assumed as shown in Table *3* below (Central Electricity Authority, 2023).

Table 3:*Transmission line impedance*

Voltage	Positive sequence		
	R(PU) per km	***X(PU)per km***	***B(PU) per km***
400kV	1.86E-05	2.08E-04	5.55E-03
220kV	1.44E-04	8.22E-04	1.41E-03
132kV	9.31E-04	2.22E-03	5.10E-04
66kV	3.72E-03	8.86E-03	1.28E-04

b. Transformer Impedance

The transformer impedance values are as per their individual name plate ratings.

c. Reactive Power Generation Limit

The maximum and minimum reactive power generation by each plant is as per their generator capability curves.

2.3 Operating Limits

It is important for power systems to be operated within the limit for safety, reliability, better efficiency, longevity, and for regulatory compliance. Operating beyond this limits will result in cascading failures, equipment breakdown, system instability, and widespread blackout similar to the Northeast blackout in the United States (U.S.-Canada Power System Outage Task Force, 2004). The following subsections explain the operating limits that has to be maintained:

a. Transformer Loading Limit

The transformer has to be loaded optimally for better efficiency and longer lifespan. Overloading raises the winding hot-spot temperature (HST) and top-oil temperature (TOT) which compromises the transformer's insulation integrity, leading to reduced lifespan (Gao et al., 2017). According to the International Electrotechnical Commission, the winding HST should not exceed 120^0C, maintaining the TOT within 105^0C. The empirical studies have found out that the transformer overloading and increased failure rate is directly correlated. For instance, the analysis in transformer failures in Onitsha Electricity Distribution Network inferred that overloading accounted for approximately 22.5% of all transformer failures over five-year period (Amadi & Izuegbunam, 2016). In Bhutan, the transformer loading is mandated to be maintained below 90% of their capacity under normal operation (Electricity Regulatory Authority, 2024).

b. Line Loading Limit

The loading limit of transmission lines plays a significant role in power system reliability. The overloading of transmission lines causes increased line losses, voltage drops, and potential equipment failures that ultimately leads to power outages, reduced system efficiency, and increased maintenance cost (P. Kalaimani et al., 2018) Further, it results in increased wear and tear, impacting the lifespan of the lines and potentially leading to failures (Liu et al., 2017). In Bhutan, the grid codes mandate the transmission lines to be operated below 90% of the thermal limit (Electricity Regulatory Authority, 2024). The thermal rating of the transmission line is assumed as per the Table *4* (Central Electricity Authority, 2023) shown below:

Table 4: Thermal rating of Transmission lines

Voltage	35^0 C Ambient temperature		40^o C Ambient temperature	
	I (A)	*(MVA)*	*I (A)*	*(MVA)*
400kV	780	1081	707	980
220kV	805	307	626	239
132kV	455	104	424	97
66kV	295	34	270	31

c. Voltage Limit

The power system voltage stability is essential for the reliable and efficient operation of power systems (Vanishree & Ramesh, 2014).

The voltage instability results in power system blackout, equipment damage, and aging of the electrical equipment. Several ways to improve voltage stability include reactive power compensation, voltage regulation, and power electronic control such as flexible AC transmission systems (Salman et al., 2024). In Bhutan, the allowable voltage variation limit is ± 5% of the rated value during normal operation (Electricity Regulatory Authority, 2024). The transmission system is said to be in alert state when the voltage is beyond the normal limits but within ± 10% of the rated value, while it is said to be in emergency state when it is beyond ± 10% (Electricity Regulatory Authority, 2024).

Table 5: *Data validation result*

Line details		Actual flow (MW)	Simulated flow (MW)	Error (MW)	Average Error (MW)
i. 400kV					
Tala	Malbase	457.98	450.00	7.98	7.01
Tala	Silliguri	656.60	667.00	10.40	
Malbase	Silliguri	157.09	164.60	7.51	
Mangdechu	Jigmeling	849.45	846.60	2.85	
Jigmeling	Alipurduar	399.71	400.00	0.29	
Lhamizingkha	Alipurduar	266.00	279.00	13.00	
ii. 220 kV					
Chhukha	Gedu	90.26	91.60	1.34	7.29
Chhukha	Jamjee	186.93	199.53	12.60	
Chhukha	Birpara	79.94	67.80	12.14	
Malbase	Singhigaon	117.00	114.90	2.10	
Malbase	Gedu	57.00	53.79	3.21	
Malbase	Birpara	39.68	31.40	8.28	
Basoschhu	Simtokha	128.00	111.00	17.00	
Semtokha	Jamjee	24.72	15.00	9.72	
Tsirang	Basochhu	95.30	77.20	18.10	
Jigmeling	Tsirang	24.26	16.00	8.26	
Dagachhu	Tsirang	73.60	75.00	1.40	
Jigmeling	Dagapela	55.81	55.50	0.31	
Singhigaon	Dhamdum	4.98	4.64	0.34	
iii. 132kV					
Kurichhu	Killikhar	8.35	8.20	0.15	6.13
Kurichu	Nangkor	55.29	57.20	1.91	
Kilikhar	Corlung	3.72	3.50	0.22	
Corlung	Kanglung	3.24	3.10	0.14	
Nangkor	Nganglam	7.34	16.43	9.09	
Nangkor	Dewathang	46.60	39.46	7.14	
Nganglam	Motanga	40.71	29.75	10.96	
Tingtibi	Nganglam	48.00	31.55	16.45	
Dewathang	Motanga	44.06	37.79	6.27	
Motanga	P/thang	2.08	2.05	0.03	
Motanga	Rangia	54.85	37.40	17.45	
Jigmeling	Gelephu	38.84	31.40	7.44	
Gelephu	Salakti	27.80	21.20	6.60	
Jigmeling	Tingtibi	53.14	40.00	13.14	
Mangdechu	Yurmo	63.24	63.20	0.04	
Nikachhu	Mangdechu	127.15	126.06	1.09	
iv. 66kV					
Chhukha	Gedu	8.87	6.59	2.28	1.06
Jamjee	Paro	11.03	10.99	0.04	
Pangbesa	Haa	2.70	2.60	0.10	
Jamjee	Bjemina	9.75	9.84	0.09	
Semtokha	Olakha	15.22	14.99	0.23	
Olakha	Changidaphu	0.29	0.10	0.19	
Semtokha	D-choling	40.27	40.60	0.33	
Semtokha	Dochula	42.58	41.35	1.23	
D-choling	Damji	20.56	20.60	0.04	
Lobeysa	Gewathang	27.00	28.00	1.00	
Lobeysa	Dochula	18.68	19.62	0.94	
P/ling	Malbase	1.62	3.46	1.84	
P/ling	Gedu	6.19	3.70	2.49	
P-ling	Gomtu	3.27	7.38	4.11	
Samtse	Gomtu	12.23	10.24	1.99	
Jamjee	Pangbisa	3.44	3.42	0.02	
Overall Average Error					**5.37**

2.4 Simulation and Data Validation

Using the parameters explained in the above sections, the PSS®E simulation is carried out for the summer season initially and data validation is carried out to check the accuracy of the power system data used by comparing the actual recorded power flows through the transmission lines with the simulated power flow. In general, it is challenging to match the simulated power flow results with the actual flow data as the Bhutanese network is interconnected with the large Indian grid via thirteen feeders at five different locations and voltage levels. The loading conditions of the Indian network configuration have a significant influence on the power flow in Bhutan's networks. Nevertheless, the average power flow difference between the simulated and the actual is found to be only 5.37 MW and therefore, the base case is assumed to be acceptable. Subsequently, the simulation is carried out for winter season. The average power flow error for different voltage level is shown in Table 5.

3. RESULT

The simulation results showing the voltage profile, transmission lines and transformer loadings for summer and winter seasons is shown in the following subsections:

3.1 Summer Season

a. Voltage Limit Check

There were no overloading issues in the given period, however, there was under voltage issue in Damji substation, where the voltage reached emergency state as shown below:

```
BUSES WITH VOLTAGE GREATER THAN 1.0500:

 BUS#-SCT X-- NAME --X BASKV AREA  V(PU)  V(KV)      BUS#-SCT X-- NAME --X BASKV AREA  V(PU)  V(KV)

                                        * NONE *

BUSES WITH VOLTAGE LESS THAN 0.9500:

 BUS#-SCT X-- NAME --X BASKV AREA  V(PU)  V(KV)      BUS#-SCT X-- NAME --X BASKV AREA  V(PU)  V(KV)
 3306     DAMJI       33.000    6 0.9028 29.794      6607     GEDU        66.000    6 0.9390 61.976
 6626     DAMJI       66.000    6 0.9148 60.379
```

b. Line Loading Check

The transmission lines were within the permissible loading limits as shown below:

```
                         OUTPUT FOR AREA 6 [BHUTAN      ]
SUBSYSTEM LOADING CHECK (INCLUDED: LINES) (EXCLUDED: BREAKERS AND SWITCHES; TRANSFORMERS)
MVA LOADINGS ABOVE  90.0 % OF RATING SET 2:

X----------- FROM BUS ------------X X------------ TO BUS -------------X
  BUS#-SCT X-- NAME --X BASKV  AREA   BUS#-SCT X-- NAME --X BASKV  AREA CKT LOADING   RATE2 PE

                              * NONE *
```

c. Transformer Loading Check

All the transformers were within the loading limit, except at Gedu substation where it was found to be loaded to 91.4% as shown below:

```
                    OUTPUT FOR AREA 6 [BHUTAN      ]
SUBSYSTEM LOADING CHECK (INCLUDED: TRANSFORMERS) (EXCLUDED: LINES; BREAKERS AND SWITCHES)
MVA LOADINGS ABOVE  90.0 % OF RATING SET 2:

X----------- FROM BUS ------------X X------------ TO BUS -------------X
  BUS#-SCT X-- NAME --X BASKV  AREA   BUS#-SCT X-- NAME --X BASKV  AREA CKT LOADING  RATE2 PERCENT
  3315     GEDU_A      33.000    6  22013     GEDU_A      220.00*   6  1     73.1   80.0    91.4
  3317     GEDU_B      33.000    6  22014     GEDU_B      220.00*   6  1     73.1   80.0    91.4
```

3.2 Winter Season

a. Voltage Limit Check

There was no overvoltage issue during the given period, however, there were voltage dip in various substations. The Damji substation experienced the worst voltage drop of 58.266 kV against the rated voltage of 66kV, indicating a deviation of 11.7 %. The simulation result is shown below:

```
BUSES WITH VOLTAGE GREATER THAN 1.0500:

 BUS#-SCT X-- NAME --X BASKV AREA  V(PU)  V(KV)      BUS#-SCT X-- NAME --X BASKV AREA  V(PU)  V(KV)

                                        * NONE *

BUSES WITH VOLTAGE LESS THAN 0.9500:

 BUS#-SCT X-- NAME --X BASKV AREA  V(PU)  V(KV)      BUS#-SCT X-- NAME --X BASKV AREA  V(PU)  V(KV)
 1106     DOCHHULA    11.000    6 0.9481 10.429      3301     PARO        33.000    6 0.9270 30.590
 3305     D/LING      33.000    6 0.9290 30.657      3306     DAMJI       33.000    6 0.8799 29.037
 6605     PARO        66.000    6 0.9387 61.954      6611     D-CHOLING   66.000    6 0.9404 62.065
 6626     DAMJI       66.000    6 0.8912 58.821
```

b. Line Loading Check

The simulation result showed the overloading in the following lines:

```
SUBSYSTEM LOADING CHECK (INCLUDED: LINES) (EXCLUDED: BREAKERS AND SWITCHES; TRANSFORMERS)
MVA LOADINGS ABOVE  90.0 % OF RATING SET 2:

X----------- FROM BUS ------------X X------------ TO BUS -------------X
  BUS#-SCT X-- NAME --X BASKV  AREA   BUS#-SCT X-- NAME --X BASKV  AREA CKT LOADING  RATE2 PERCENT
  6610     SEMTOKHA    66.000*   6   6625     DOCHULA     66.000    6  1     55.9   60.0    93.1
 13210     YURMO       132.00    6  13212     MANGDECHU   132.00*   6  1     88.6   94.4    93.9
 22002     MALBASE     220.00*   6  22014     GEDU_B      220.00    6  1    255.5  245.0   104.3
```

c. Transformer Loading Check

The overloading of transformers in Gedu still persisted in winter season as shown below:

```
SUBSYSTEM LOADING CHECK (INCLUDED: TRANSFORMERS) (EXCLUDED: LINES; BREAKERS AND SWITCHES)
MVA LOADINGS ABOVE  90.0 % OF RATING SET 2:

X----------- FROM BUS ------------X X------------ TO BUS -------------X
  BUS#-SCT X-- NAME --X BASKV  AREA   BUS#-SCT X-- NAME --X BASKV  AREA CKT LOADING  RATE2 PERCENT
  3315     GEDU_A      33.000    6  22013     GEDU_A      220.00*   6  1     76.2   80.0    95.2
  3317     GEDU_B      33.000    6  22014     GEDU_B      220.00*   6  1     76.2   80.0    95.2
```

3.3 Field validation

To validate the simulation result, particularly the voltage profile, the site visit was carried out in Paro and Damji substations as they showed poor voltage profile. The voltage was measured at the consumer end using the HIOKI power quality analyzer, and the resulting plots are shown in Fig 8 and Fig 9. The voltage dipped below the acceptable limit of 5% threshold in the evening hours, dropping to as low as 173.5V after 5 pm, with a deviation of 24.5% from the rated voltage in Paro. Similarly, the voltage dipped below the 5% limit in morning and evening hours in Damji. Therefore, the field visits confirmed the voltage issues in both the places as indicated in the simulation results.

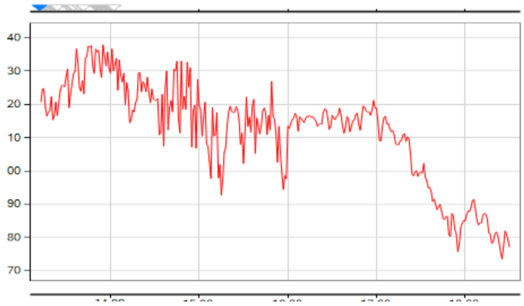

Fig 8: *Voltage profile in Paro*

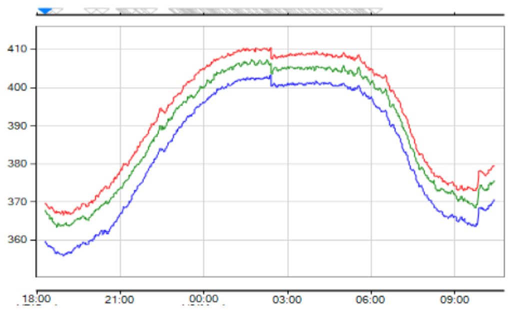

Fig 9: *Voltage profile in Damji*

4. CORRECTIVE MEASURE

The overloading of the transmission lines from Simtokha to Dochula, and Malbase to Gedu is close to the allowable limit of 90%. Therefore, it is advised to keep a close observation and take necessary measures if it persists throughout the year. For Mangdechhu to Yurmo, currently there are one double circuit 132kV lines, however, only one circuit is connected at Yurmo substation due to unavailability of bay. Therefore, it is recommended to construct additional bay and connect both the circuits to prevent the overloading issues. In terms of transformer loading, the overloading is observed at Gedu substation for both summer and winter seasons. Therefore, possibility of augmenting the transformer capacity needs to be explored.

No over voltage issue was observed, however, there were under-voltage issues in various substations in winter season. Therefore, it is imperative to take necessary measures to prevent voltage collapse. Based on the location of the substations and the severity of the voltage violations, shunt capacitor addition is found to be an ideal solution to address the under-voltage issues. The QV analysis is performed in PSS®E software to determine the ratings of the equipment and corresponding graph is shown in Fig *10* below:

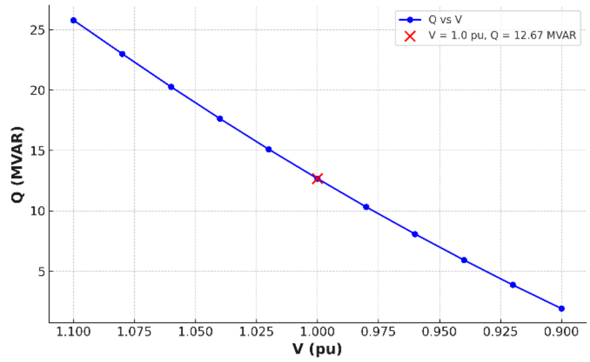

Fig 10: *QV Curve*

To maintain the voltage of 1 PU, the reactive power requirement is 12 MVAR. The simulation is run again by installing the 12 MVAR shunt capacitor in Damji substation and it is found that the voltage issue gets resolved. The SLD is shown in Fig 11 below:

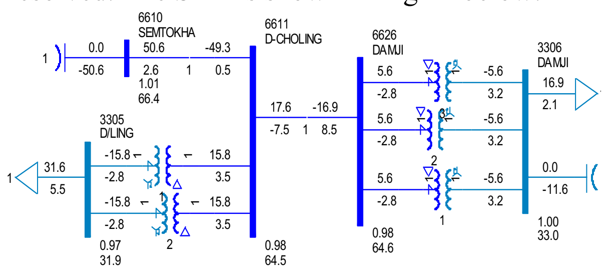

Fig 11: *Single Line Diagram with Shunt Capacitor*

5. CONCLUSION

For the summer season, the simulation study was carried out considering the data sets of 28th July 2024 at 20.00 hours. The total generation in the given period was 2,615 MW while the total domestic load was 886 MW. The system analysis showed the voltage issue in the Damji substation where voltage drop below the permissible limit of 5%. Additionally, while the transmission lines were loaded within the allowable limits, there was overloading of transformers in Gedu substation. The data sets used in the study was validated by comparing the recorded power flows and the simulated power flow, and the average error was found to 5.37 MW.

For the winter season, the simulation was carried out using the data sets of 14th February 2024 at 15:00 hours. During the given period, the total generation was 164 MW and the corresponding load was 821 MW. The system analysis showed the voltage violation in various substations. The worst voltage profile was observed in Damji substation where it deviated by -11.7%, which was attributable to the poor voltage at the source compounded by longer transmission line. The power supply to Damji substation is from Dechencholing substation via a 66kV single circuit line, with the line length of 47.23 km. The load at Damji during the study period was 20 MW. Since the source voltage at Dechencholing substation was already low at 0.92pu, a significant voltage drop occurred by the time it reached Damji substation.

6. RECOMMENDATION

To maintain voltage within permissible limit, shunt capacitor of 12 MVAR is recommended at Damji substation. Similarly, to resolve the overloading issue of Mangdechhu to Yurmo line, it is recommended to connect the existing 132 kV spare line that is kept idle at the moment. Furthermore, it is recommended to keep a close observation in the potential overloading of the transformers in Gedu substation, and transmission lines at Simtokha to Dochula, and Malbase to Gedu. If the overloading is persistence, upgrading to higher capacity is recommended.

REFERENCES

Amadi H. N., & Izuegbunam, F. I. (2016). *Analysis of Transformer Loadings and Failure Rate in Onitsha Electricity Distribution Network*.

Bhutan Power Corporation Limited. (2023). *Power Data Book*. https://www.bpc.bt/wp-content/themes/bpc/assets/downloads/Power%20Data%20Book%202023.pdf

Bhutan Power System Operator. (2024). *Annual Transmission System Performance Report for the year 2024*. https://www.bpso.bt/reports/report_preview/154

Central Electricity Authority. (2023). *Manual on Transmission Planning Criteria*. https://cea.nic.in/wp-content/uploads/psp___a_ii/2023/03/Manual_on_Transmission_Planning_Criteria_2023.pdf

Department of Hydropower and Power Systems. (2018). *National Transmission Grid Master Plan of Bhutan*. https://www.moenr.gov.bt/wp-content/uploads/2018/11/National-Transmission-Grid-Master-Plan-2018.pdf

Electricity Regulatory Authority. (2024). *Grid Code Regulation*. https://era.gov.bt/wp-content/uploads/2024/02/Final-Grid-Code-2024-modified-1.pdf

Gao, Y., Patel, B., Liu, Q., Wang, Z., & Bryson, G. (2017). Methodology to assess distribution transformer thermal capacity for uptake of low carbon technologies. *IET Generation, Transmission & Distribution*, *11*(7), 1645–1651. https://doi.org/10.1049/iet-gtd.2016.0722

Javadi, M., Wu, D., & Jiang, J. N. (2017). Approach of generation fleet voltage schedule validation for power system voltage stability. *IET Generation, Transmission & Distribution*, *11*(8), 1985–1991. https://doi.org/10.1049/iet-gtd.2016.1394

Liu, S., Cruzat, C., & Kopsidas, K. (2017). Impact of transmission line overloads on network reliability and conductor ageing. *2017 IEEE Manchester PowerTech*, 1–6. https://doi.org/10.1109/PTC.2017.7980857

P. Kalaimani, K. Mohana Sundaram, & Panimalar Engineering College, poonamallee, chennai, Tamil Nadu. (2018). Congestion Management in Power Transmission Network under line interruption condition Using TCSC. *International Journal of Engineering Research And*, *V6*(02), IJERTCON055. https://doi.org/10.17577/IJERTCON055

Salman, M. S. D., Sultan, A. J., & Bonneya, M. F. (2024). *Power system voltage stability improvement: A review*. 050031. https://doi.org/10.1063/5.0236433

Soni, N. B., & Mukherjee, D. (2018). A Review Study on Power System Blackouts. *International Journal of Scientific and Research Publications (IJSRP)*, *8*(5). https://doi.org/10.29322/IJSRP.8.5.2018.p7756

U.S.-Canada Power System Outage Task Force. (2004). *Final report on the August 14, 2003 blackout in the United States and Canada: Causes and recommendations.* https://www3.epa.gov/region1/npdes/merrimackstation/pdfs/ar/AR-1165.pdf