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Load Flow and Short Circuit Analysis in Central Part of Nepal using ETAP

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Abstract

This research focuses on conducting load flow and short-circuit analysis on a segment of central part of Nepalese power system, specifically from New Butwal substation to Dhalkebar substation. The analysis was initially carried out on a standard IEEE 5-bus system to validate the approach and methodology, followed by its application to the selected section of Nepalese power grid. Primary objective of this research was to evaluate the system's performance under various faulty conditions and identify potential vulnerabilities. Nepal's power system has been struggling with significant challenges, such as frequent outages, aging infrastructure, and a rapidly increasing electricity demand. This research applied Electrical Transient Analyzer Program software to construct and simulate the system, perform load flow studies, and analyze short-circuit scenarios on both IEEE 5 bus system and a central section of the Nepalese grid, changing faulty locations. It aimed to assess the impact of faults on different buses, identify sensitive nodes, and recommend strategies to minimize disruptions and maintain grid stability. Key findings revealed that Parwanipur 2 bus exhibited high sensitivity to faults in terms of current, while Dhalkebar bus was vulnerable in terms of voltage. These results indicated that the vulnerable system components require upgradation, such as the installation of surge protection devices, addition and upgradation of transmission lines, substations, transformers, are essential to mitigate potential risks. Overall, this research contributes to ongoing efforts to strengthen Nepal's power system by providing valuable insights that can enhance future infrastructure development and operational strategies, ultimately enhancing the grid's resilience and performance.

Keywords: *Load-flow Analysis, Nepalese Power System, Short-Circuit Analysis, ETAP software.*

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Introduction

Power system is divided into three main components: Generation, Transmission, and Distribution. Generating units produce electricity according to the demand, which is then transmitted through transmission lines (both overhead and underground) to distribution networks, ultimately delivering power to end-users. This transmission process relies on an integrated system of power lines, step-up and step-down transformers, relays, switches, fuses, and protective devices.(Shafiullah et al., 2022) During transmission, various types of faults can occur, broadly classified as symmetrical and unsymmetrical faults. Symmetrical faults affect all phases equally, maintaining system balance; an example is the Line-to-Line-to-Line-Ground (LLLG) fault. Unsymmetrical faults, however, affect one or two phases unevenly, causing potential issues such as flashover, insulation damage, or lightning strikes. These faults can severely impact power stations, leading to power outages.(Gupta, 1996)

Nepal has a long history of load shedding both scheduled and unscheduled power outages. Until 2018, Nepal experienced up to 10 to 16 hours of load shedding per day during the dry season, primarily due to poor load management, increasing demand, weak infrastructure, and low river discharge in the dry season.(Shrestha, 2011) By May 2018, measures were taken to address load-shedding issues across commercial and private sectors.(Timilsina & Steinbuks, 2021) Nepal has an estimated theoretical hydropower potential of 83,000 MW and a technical potential of 43,000 MW, with a current total installed capacity of approximately 3,063.806 MW (Government of Nepal, 2024). Despite being declared load-shedding-free, Nepal still experiences unscheduled outages due to technical issues, aging infrastructure, natural calamities, and more.

Nepal Electricity Authority (NEA) is the primary organization responsible for managing power generation, transmission, distribution, power trading, and cross-border electricity trade in Nepal. NEA actively upgrades its substations and buses to enhance the transmission capacity and reliability of the national power grid. As per the latest report, Nepal has 74 high-voltage substations, ranging from 66 kV to 400 kV, with each substation containing multiple buses (Nepal Electricity Authority, 2023). The number of buses varies based on the size and design of the substation. Load-flow analysis is conducted to ensure generation-demand balance, while short-circuit analysis helps evaluate system operation and response to faults (Power, 2023).

This research aims to investigate how faults on transmission lines affect overall system performance, focusing on voltage fluctuations, transmission line overloading, and current drops. The study initially conducts analyses on the standard IEEE 5-bus system using ETAP software. Following this, a small section of Nepal's central transmission network is analyzed, particularly from Dhalkebar to New Butwal substations with a central focus on the Bharatpur substation. This section is configured in a radial setup. Fault scenarios and their impacts on the real power system in this region are examined and discussed, providing insights into system reliability and stability under fault conditions.

Literature Review

ETAP is a kind of software that is used for the planning, designing, analyzing, and many others several reasons by researchers and engineers for the modeling and simulation of electrical network to understand and study the power system (Shertukde, 2019) In a standard IEEE 5 bus system, Aruna and her team performed load flow and short-circuit analysis in a power word simulator. Different fault conditions were simulated, and the system's behavior during the faulty condition and evaluation of such fault was done. Here, the 5-bus system consists of 5 buses, 2 generators, and 4 loads. Due to an increase in load or severe contingencies, a power system is stressed, which means it cannot have the secure operation, and such a situation leads to the overloading of lines due to voltage limit violations. System overloading can be overcome by either restructuring the power system or controlling the line parameters. While restructuring the power system, other minor or major issues like right of way, cost, environment, and enlarging the potential of the transmission system have to be addressed (Aruna, Jarapala & Maloth, 2017).

Sheila and her team conducted a study by performing short circuit and symmetrical fault analyses using MIpower software in the IEEE 14-bus system. In this research, the system's behavior when faults occur was studied. The simulation was done, and details that came out were related to the fault analysis and the importance of roles that every electric component, like relays, bus, and CB, plays for the reliable and efficient flow of electric current was crystal clear. Moreover, this research gave a clear vision in the faulty current magnitude and necessary circuit breaking rating after the supply of three phase fault in the system (Mahapatra & Singh, 2016). ETAP software was used for the analysis of short circuit in the IEEE 14-Bus system for acknowledgement of rating of protective devices based in sub-transient state which was maximum and steady-state which was minimum short circuit currents. This study analyzed 3-phase fault and single-line-to-ground fault in different-different buses which provided maximum and minimum short circuit currents. Here, ETAP was used as it is more accurate and high speed in modeling and calculation of fault current. Different fault scenarios were simulated which gives essential data that was needed for protection relay coordination and CB rating. ETAP computed different types of short circuit current like steady state, momentary and interrupting at different time intervals in the IEEE 14-Bus system. The minimum short circuit current helped in relay coordination whereas, the maximum one gave the worst-case conditions (Chilakala & Rao, 2018)

The research was performed by simulating and analyzing the IEEE 14-Buus system in the ETAP software. It focused on the load flow and short circuit analysis. Voltage, real and reactive power were determined after load flow analysis using Newton Raphson's method. This method provides detailed lights in the system's power flow, showing its quick convergence and reliable nature. The maximum and minimum fault currents were calculated during the three-phase and single-line-to-ground faults. The distribution of real and reactive power, voltage magnitude, and angle at each bus were measured by analyzing load flow in ETAP. By doing optimal power flow, the results were more filtered and processed, ultimately minimizing the losses and the operation cost of the system. The difference in standard load flow and the optimal load flow showed the significant advantage of optimal load flow in the reduction of loss in a more economical way. Short circuit analysis gave detailed information on the coordination of relays and CB by calculating the fault current at different types of faults. The outcome of this paper highlights the significance of comprehensive power system analysis in optimal design and operation (Abdulrazak, Jasim & Qahtan, 2022)

A study was performed on the roles of power transmission lines and the issues that arise during fault detection and management. This research focused on the increments of power demand and the importance of loss minimization. The paper highlighted the significance of managing reactive power and voltage deviation in long power transmission lines. This paper focuses on fault detection and swift restoration after any fault (Goh et al., 2017).

Methodology

This research was conducted through several steps, beginning from selecting an appropriate topic, then gathering and analyzing data related to the Nepalese power grid and assessing the importance of load-flow and short-circuit analysis for maintaining a secure and reliable power grid. To validate the approach, a standard IEEE 5-bus system was constructed in ETAP software, where load-flow and short-circuit assessments identified vulnerable buses by applied 3-phase faults on the different buses.

A detailed case study was then performed for a central section of Nepal's power grid, pinpointing critical transmission lines and buses. For load-flow analysis, the Newton-Raphson algorithm was employed, converging in 50 iterations. Figure 1 illustrates the methodological steps undertaken for this research.

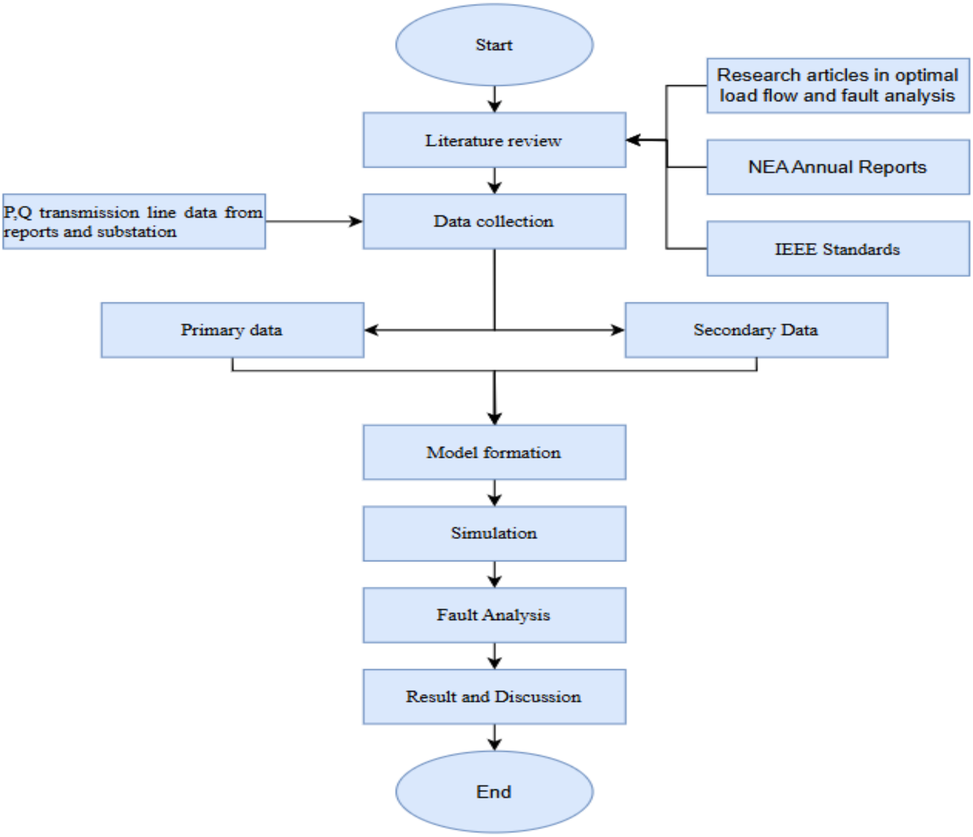

Figure 1: Flowchart of overall procedure

Load flow algorithm

The load-flow analysis provides information related to the sensitivity of the feeder with variations in power loading, conductor length, transformer capacities, and so on. They are generally used to maintain power balance (generation and demand balance) to ensure grid stability and reliability (Ikule & Ame-Oko, 2019) In our research project, Newton Raphson's algorithm is used for power flow analysis because of its great significance in load-flow studies. Newton Raphson's method originated and was formulated back in the 1970s. It was named after Sir Isaac Newton and Joseph Raphson. It is used in load flow analysis because it uses fewer number of iterations and possesses the character of quadratic convergence, which makes convergences very fast. (Niyomkitjakankul, 2024)

Following are the procedures for using the Newton-Raphson algorithm.

Step1: Read the following data

Line data

Bus data,

Tolerance for ΔP and ΔQ

Step2: Obtain Ybus matrix

Step3: Assume flat voltage profile 1+j0 or 1<0° for all buses except slack bus

Stpe4: Set iteration count, k=0

Step5: Set bus count, p=1

Step6: For load bus, calculate real power(pp) and reactive power (Qp)

Step7: Check for reactive power limit,

If QPcal<Qp,min then Qpcal =Qp,min

If QPcal>Qp,max then Qpcal =Qp,max

The bus act as PV bus

Qp,min< QPcal < Qp,max

Step8: Compute mismatch vector

Step9: Advance bus count

Set p=p+1 and go to step 6 until the bus count is n

Step10: Compute Jacobian matrix

Step11: Obtain step corrector vector

[ΔVΔδ] = [J]-1 [ΔQΔP]

Step12: Update state vector

Vnew = Vold + ΔV

δnew = δold + Δδ

Step13: Check for tolerance

If ΔPP< and ΔQp< , then go to next step, otherwise set k =k+1 and go to step 5

Step14: Calculate the following

Line flow

Slack bus power

Total line losses

Reactive power generated at PV bus

Step15: End (de Moura and de Moura, 2013)

System Description:

i. For IEEE 5 bus system

For the load flow studies, we shall consider the system of Figure 2, which has 2 generator and 3 load buses. We define bus-1 as the slack bus while taking bus-5 as the P-V bus. Buses 2, 3 and 4 are P-Q buses. Table 1 shows the initial bus voltages, power generated and load data used for the load-flow analysis of IEEE 5 bus system. The line impedances and the line charging admittances are given in Table 2.(Gouda et al., 2015)

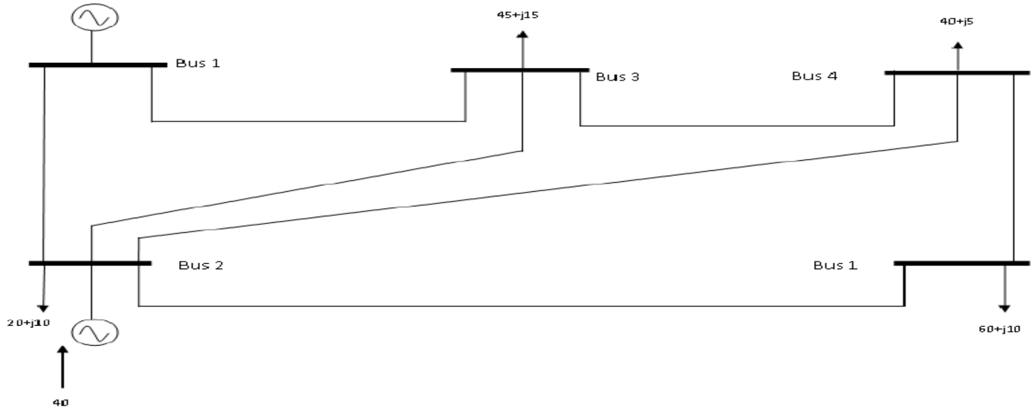

Figure 2: IEEE 5-Bus System(Gouda et al., 2015)

Table 1. Bus voltages, power generated and load- initial data

Bus Code	Assumed Bus Voltage	Generation		Load	
		Megawatts	MegaVars	Megawatts	MegaVars
1	1.06 + j0.0	0	0	0	0
2	1.0 + j0.0	40	30	20	10
3	1.0 + j0.0	0	0	45	15
4	1.0 + j0.0	0	0	40	5
5	1.0 + j0.0	0	0	60	10

Table 2. Line Impedance and Line-charging Capacitance values

Bus Code p – q	Line impedance Z_{pq}		Line charging $Y_{pq}/2$
	R per unit	X per unit	
1 - 2	0.02	0.06	X per unit
1 - 3	0.08	0.24	0.0 + j0.025
2 - 3	0.06	0.25	0.0 + 0.020
2 - 4	0.06	0.18	0.0 + j0.020
2 - 5	0.04	0.12	0.0 + j0.015
3 - 4	0.01	0.03	0.0 + j0.010
4 - 5	0.08	0.24	0.0 + j0.025

ii. Central Part of Nepal

The study area for this research includes a central section of Nepal's power grid, specifically from the Dhalkebar substation to the New Butwal substation, with a central focus on the Bharatpur substation. This study is limited to a radial configuration. Bharatpur substation, a 132/33 kV facility located in the city of Bharatpur in Chitwan district, supports two 33 kV feeders (Chanauli and Parsa) and twelve 11 kV feeders. Additionally, four 132 kV lines (Marsyangdi, Pokhara, Hetauda, and Bardhaghat) are interconnected at this substation. Figure 3 provides a power development map of the study area, sourced from the Transmission Directorate Report of the Nepal Electricity Authority. Transmission line data for simulation and modeling were collected from (Nepal Electricity Authority, 2021), with lines above 66 kV considered for analysis.

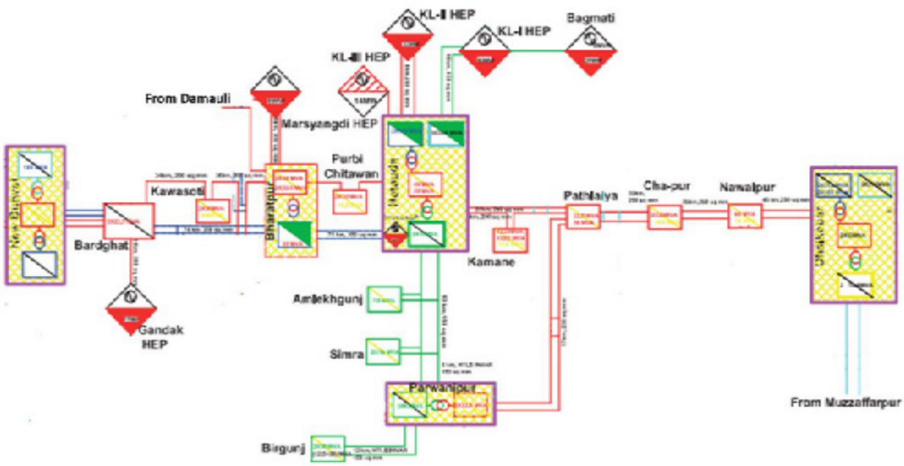

Figure 3: Central part of Nepal(Authority, 2021)

The results present the overall data, including the line length, the conductor used, and their respective capacities (see Table 3).

The overall installed capacity of the central section considered for the modelling was 892 MW(Nepal Electricity Authority, 2023), which consists of 8 generating stations with Muzaffarpur as a slack bus. The overall generation was considered to be around 562.8MW. Table 4 presents the lists of generating units with their respective installed capacity and power generation.

Table 3. Conductor length, type and capacitie

S.No.	Description	Length of Circuit(km)	Conductor Type	Nominal Aluminium Cross Section Area (Sq.mm)
A	132kV Transmission Line			
1	Duhabi-Lahan-Chandranigahapur-Pathalaiya/ Parwanipur/Pathalaiya-Hetauda	608	BEAR	250
2	Hetauda-KL2 P/S	16	BEAR	250
3	Bharatpur-Marsyangdi P/S	25	DUCK	300
4	Hetauda-Bharatpur	70	PANTHER	200
5	Bharatpur-Damauli	39	WOLF	150
6	Bharatpur-Kawasoti-Bardghat	70	PANTHER	200
7	Bardghat-Gandak P/S	28	PANTHER	200
8	Bardghat-Butwal	86	BEAR	250
B	220kV Transmission Line			
1	Dhalkebar-Muzzaffarpur 400kV	78	MOOSE	500
C	66kV Transmission Line			
2	KL1 P/S-Hetauda-Simara	104	WOLF	150
3	Simara-Parwanipur-Birgunj	40	HTLS/INVAR	150

Table 4. Generating Unit's Capacity, Generation and Power Factor

S.No.	Generating Units	Power Factor	Installed Capacity (MW)	Generation (MW)
1	Gandak HEP	0.85	15	13.5
2	Marsyangdi HEP	0.85	69	62.1
3	Kulekhani II HEP	0.85	32	28.8
4	Kulekhani III HEP	0.85	14	12.6
5	Kulekhani I HEP	0.85	60	54
6	Bagmati HEP	1	22	19.8
7	Muzaffarpur	1	600	300
8	Damauli	1	80	72

Similarly, the system consists of 18 load buses, as tabulated in Table 5. The total system demand was 561 MW (see Table 4).

Table 5. Load Bus's Rating, Power factor and Load

S.No.	Load Buses	Transformer Ratings (MVA)	Power factor	Load (MW)
1	Bardaghat	22.5	0.8	13.5
2	Kawaswoti	60	0.8	36
3	Bharatpur1	60	0.8	36
4	Bharatpur2	45	0.8	27
5	Purbi Chitwan	60	0.8	36
6	Hetauda	20	0.8	12
7	Amlekhgunj	10	0.8	6
8	Simara	30	0.8	18
9	Pathlaiya1	30	0.8	18
10	Pathlaiya2	22.5	0.8	13.5
11	Kamane	93	0.8	55.8
12	Birgunj1	42.5	0.8	25.5
13	Birgunj2	60	0.8	36
14	Parwanipur1	67.5	0.8	40.5
15	Parwanipur2	63	0.8	37.8
16	Chapur	60	0.8	36
17	Nawalpur	63	0.8	37.8
18	Dhalkebar	126	0.8	75.6

System Evaluations:

1. Five bus system

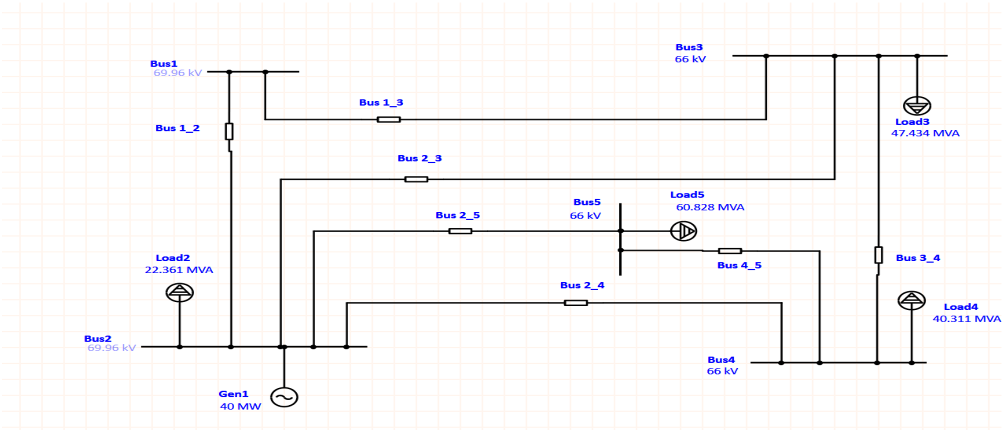

Figure 4: IEEE 5rFive-bus system modelled in ETAP

Central part of Nepal

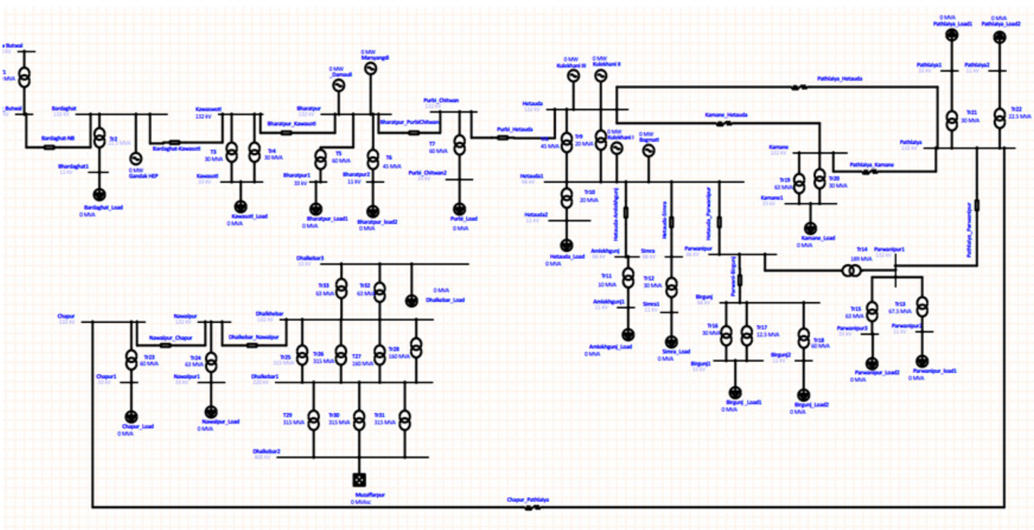

Figure 5: Central part of Nepal modelled in ETAP

Figure 4 and Figure 5 shown above represents the model of standard IEEE 5 bus system and central part of Nepal constructed using ETAP software respectively. System depicted in Figure 5 includes 38 buses from New Butwal to Dhalkebar substation, among then, 17 buses are connected to load. A power grid is connected to the Dhalkebar side which shows the power import from Muzaffarpur, India to Nepal and acts as a swing/reference bus. And a generating unit is placed at Damauli bus to indicate the power incoming from Marsyangdi side to Bharatpur substation. Both of these units were assumed to be maintained at unity p.f and remaining 6 generating units were generating at 0.85 p.f. And the load stations are maintained with the pf of 0.80.

For modelling purpose, the total generation of Nepal was considered 562.8MW where, 300MW of electricity is imported from Dhalkebar side and 72MW from Damauli side. All the other remaining 6 generator were generating 90% of power of their respective installed capacity. And for system demand, all the load buses were assumed to have 60% load of their respective substation's transformer rating. Therefore, the total system demand was 561MW. Transmission lines were modelled with the conductors (BEAR, PANTHER, MOOSE, WOLF) and their respective power transfer capability as considered by NEA.

Results and Discussion

5-Bus system:

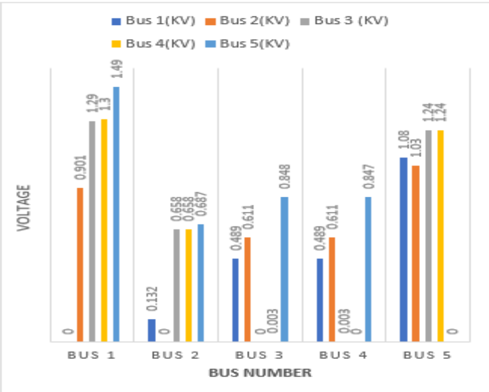

Figure 6: *Voltage in 5 Bus system*

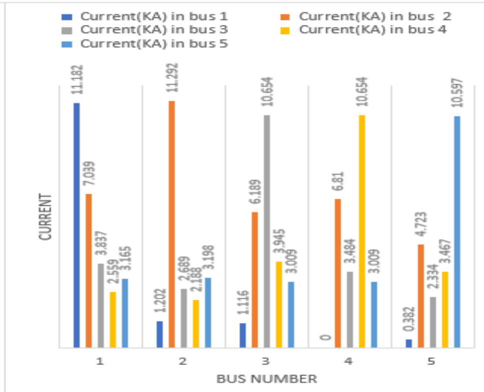

Figure 7: *Current in 5 Bus system*

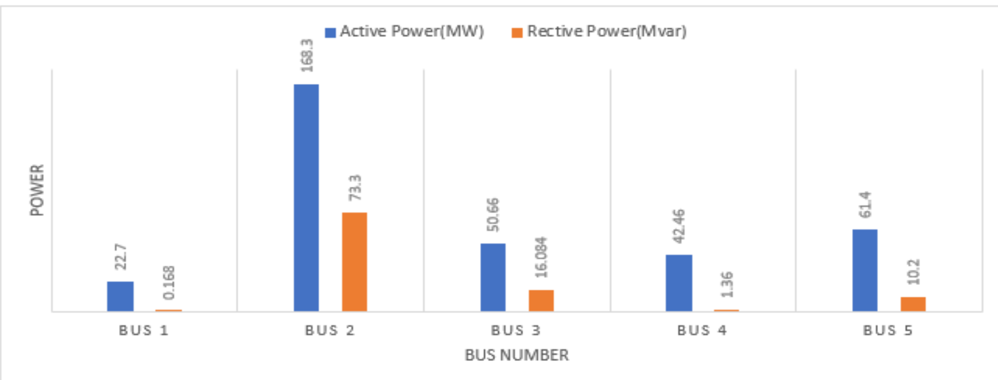

Figure 8: Power in 5 Bus system

Figure 6 and Figure 7 shows the voltage and current values obtained in each bus after short circuit analysis on IEEE 5 bus system respectively. Here, during short circuit analysis, bus 1 had the highest magnitude of current, when fault applied at bus 1. Also, bus 5 had highest voltage drop, when fault was applied at bus 1. During load flow analysis, the highest active power generation was 168.3MW at bus 2 and highest reactive power generation was 16.084MW at bus 3 as shown in Figure 8.

Central part of Nepal

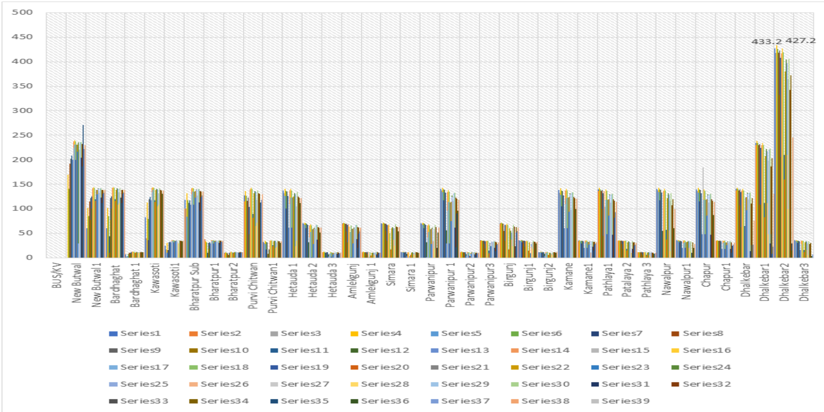

Figure 9: Voltage in Central Part of Nepal

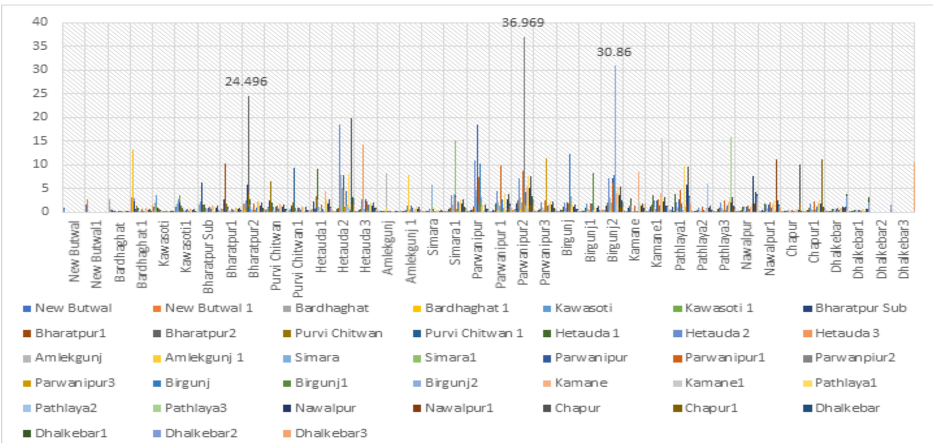

Figure 10: Current in Central Part of Nepal

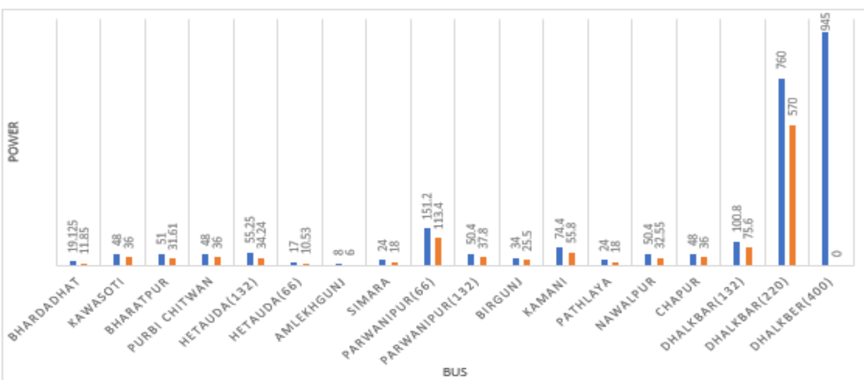

Figure 11: Power in Central Part of Nepal

Figure 9 and Figure 10 shows the status of voltage and current in each bus after performing short-circuit analysis on the central part of Nepal respectively. During Short-Circuit Analysis, Parwanipur 2 bus had highest magnitude of current, when fault applied at bus Parwanipur 2. Also, Dhalkebar 2 bus had highest voltage drop, when fault applied fault at Bhardhaghat 1 bus. During the load flow analysis, the highest active power was generated at Dhalkebar (220) and the highest reactive power was also at Dhalkebar (220). The total power generated after load-flow analysis was 562.8 MW and total demand was 561 MW with the grid losses of 1.8MW as shown in Figure 11.

For voltage

After applying short-circuit 3 phase faults at each bus, it was clear that the Dhalkebar (400) bus had highest voltage 472.2kV (fault at Amlekhgunj 1 bus).

For Current

Parwanipur 2 was the most vulnerable substation as it had highest current flow of 36.969kA through it.

Conclusion

In conclusion, after modeling and simulating the system, load flow and short-circuit analyses were conducted using ETAP software for two different cases: IEEE 5-bus system and the central region of Nepal. In IEEE 5-bus system, Bus 1 was found to be the most sensitive. For Nepal, among 38 buses, Parwanipur 2 bus was identified as highly sensitive in terms of current, while the Dhalkebar bus was found to be the most vulnerable in terms of voltage. One possible reason for Parwanipur 2's sensitivity and vulnerabilities are its status as the industrial hub of Nepal, leading to high load demands. The existing 66 kV and 132 kV transmission lines may be insufficient to accommodate this high demand due to their power transfer capability limits. Additionally, the available transformers may not have adequate capacity to manage the growing electricity demand in the Parwanipur area. For Dhalkebar, its vulnerability could be attributed to its connection with India for power exchange, where high-voltage power is transmitted from the interconnected system. To address these issues, Nepal Electricity Authority (NEA) should prioritize these vulnerable areas by upgrading and enhancing the existing power transmission lines to increase the power transfer capacity. Furthermore, the transformers at load substations should be upgraded to ensure reliable and secure electricity services for consumers. Implementing substations with high fault-tolerant design features, such as fast-responding protective devices like circuit breakers and isolators, can further protect the system from short circuits and potential system failures.

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