TRIBHUVAN UNIVERSITY

INSTITUTE OF ENGINEERING

PULCHOWK CAMPUS

THESIS NO: M-116-MSESPM-2018-2020

Operation of the Integrated Nepal Power System on Injection of the Upper Tamakoshi Hydroelectric Power Station

by

Sujan Acharya

A THESIS

SUBMITTED TO THE DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN ENERGY SYSTEM PLANNING AND MANAGEMENT

DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING

LALITPUR, NEPAL

July, 2020

COPYRIGHT

____

NawaRaj Bhattrai, PhD

Head

Department of Mechanical and Aerospace Engineering

Pulchowk Campus, Institute of Engineering

Lalitpur, Kathmandu

Nepal

TRIBHUVAN UNIVERSITY

INSTITUTE OF ENGINEERING

PULCHOWK CAMPUS

DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING

The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a thesis entitled **" Operation of the Integrated Nepal Power System on Injection of the Upper Tamakoshi Hydroelectric Power Station "** submitted by Sujan Acharya in partial fulfillment of the requirements for the degree of Master of Science in Energy System Planning and Management.

____

Supervisor, Rajendra Shrestha, PhD

Professor

Department of Mechanical and Aerospace Engineering

____

External Examinor, Er.Basanta Pancha

Senior Lecturer

Khwopa College of Engineering

____

Committee Chairperson, NawaRaj Bhattrai, PhD

Head

Department of Mechanical and Aerospace Engineering

July 31, 2020

____

Date

ABSTRACT

The goalmouth of this dissertation is to develop operating models on the injection of the Upper Tamakoshi Hydroelectric power plant within the Integrated Nepal power grid. It gives a constructive idea to assist power grid system planners. It suggests the concept of regional and sub-regional control of an Integrated Network together with addressing transmission expansion plan for the long-term operation. The possible mapping of demand and supply management for power flow study based on the current real scenario is presented by taking necessary data from the Load Dispatch Centre and System Planning Department, NEA.

Upper Tamakoshi Hydroelectric power plant, which is approximately one-third of the installed capacity of generated power, is going to operate in fiscal year 2077/078. An optimal evacuation of such a power plant of 456 MW requires a secure and reliable transmission grid for the stable operation of the integrated network. Nepalese power grid still has poor voltage supply and occasional system collapse due to insufficient and poor planning of transmission links. The proposed network of an integrated system is subjected to various analysis techniques for secure and stable operation including import and export scenarios with the optimum utilization of the generators by minimizing transmission loss. Especially, steady-state power flow analysis is conceded and simulated within the computer model to find out the most effective optimal operation. It identifies the finest optimal operating state by understanding the operation of the Integrated Nepal power grid and recommends a brand-new approach to the robust and reliable transmission line expansion plan for providing the national peak demand. Also, the integrated system can supply electrical power to the neighbouring countries.

The results obtained from the predicted model for the different scenarios shows that the voltages of all major substations and line loading of all major transmissions lines are inside the set restrictions as prescribed by the grid code. Initially, almost all the 66 kV existing transmission line conductors displayed unstable voltage supply, but later on, has a stable voltage profile when existing conductors are replaced by the BEAR conductor. Also, it is recommended that using MOOSE conductor instead of DEER conductor for the 220 kV high voltage transmission line conductors for the stable and reliable operation. Mahendranagar, Ramnagar, Raxual, Dhalkebar, and Kusaha are the

most central five, substations that are used for the cross border power exchange. About 135 MW power is exported to India through three cross borderlines. Among them, about 53 MW power through Dhalkebar 220 kV, 40 MW through Katiya, and 42 MW power through Ramnagar 132 kV substations are going to be delivering the power to Indian Grid. Kathmandu valley, Hetauda, Butwal, Duhabi Kholpur are the major load centers through which large electric power has been consumed.

The overall analysis shows that the Integrated Nepal power grid has stable operation on clustering whole integrated system into three different zones, i.e. Eastern, Central, and Western zone, which are capable of self-generation and self-consumption. The largest central zone has the load demand of approximately 1125 MVA and also the smallest western zone has a load demand capacity of 100 MVA. Also, the eastern zone incorporates a load demand of about 385 MVA. This study has concluded that after injection of Upper Tamakoshi Hydroelectric power plant provides stable operation to the integrated network on improving system voltage profile. It advises power system planners to follow regional control for the long run operation after the injection of Upper Tamakoshi onward. Due to the synchronization difficulties, and transmission line infrastructures available, sub-regional control is essential for the stable operation of the power system network. Additionally, such a power control mechanism is significant for radial power exchange in the context of cross border power trade.

ACKNOWLEDGEMENT

I would prefer to express my profound appreciation to my thesis supervisor, Professor Rajendra Shrestha, Ph.D., Assistant Dean, Department of Mechanical and Aerospace Engineering, IOE, Pulchowk Campus. He is providing endless guidance and fortitude to permit this thesis to be my work. Without his persistent help, the goal of this thesis wouldn’t have been realized.

I would wish to pay my superior honor to Associate Professor Shree Raj Shakya, Ph.D., Program Coordinator; M.Sc. in Energy System Planning and Management for his support and giving protected academic time to accomplish my thesis.

I would prefer to acknowledge Dr.NawaRaj Bhattrai, Head, Department of Mechanical, and Aerospace Engineering for major guidelines and liberal support. I am especially indebted to the dissertation committee for providing me extensive personal and professional guidance.

I wish to precise the deepest thankfulness to the professional experts who were involved within the authentication of this thesis. Especially, Anil Banjade, Load Dispatch center, and Manisha Shahi Thakuri, Grid Operation Department, who have given convincingly passionate academic time to corroborate the outcomes of my thesis.

I am very grateful to my first reader, Professor Josep M. Guerrero, Villum Investigator, Centre for Research on Microgrid- CROM, Aalborg University Denmark, and Er. Santosh Acharya, who provide me valuable help, feedback, and suggestions. Also, I would wish too many thanks to all people who are involved in my thesis writing journey directly and indirectly providing inspiration and encouragement.

Finally, my overwhelming debt is to my all family members for providing me with trustworthy care and continuous inspiration and encouragement all over my years of study. This accomplishment I have got acquired wouldn't are conceivable without their love, affection, and back support.

Thank you.

Er.Sujan Acharya

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS, SYMBOLS, AND ABBREVIATIONS

D-M 220	Dhalkebar Muzzaffarpur 220KV Transmission Line
D-M 400	Dhalkebar Muzzaffarpur 400KV Transmission Line
ETAP	Electrical Transient Analyser Program
FY	Fiscal Year
GDP	Gross Domestic Product
GoN	Government of Nepal
GWh	Giga Watt Hour
HVAC	High Voltage Alternating Current
IEEE	Institute of Electrical and Electronics Engineers
INPS	Integrated Nepal Power System
IPP	Independent power producer
kV	Kilo Volt
MW	MegaWatt
NEA	Nepal Electricity Authority
PPA	Power Purchase Agreement
RoW	Right of way
S/S	Substation
UTHEP	Upper Tamakoshi Hydropower Limited
VDC	Village Development Committee
WECS	Water and Energy Secretariat

CHAPTER ONE: INTRODUCTION

1.1 Background

Nepal is a landlocked country that lies in between the great Himalayan range of mountains, and the Mahabharat range having stepped incline towards the south. It's over 6000 southern rivers that originating within the northern chain of mountains and are very appropriate for electricity generation. It's identified that Nepal has tremendous potential for the development of the hydroelectric power station. Theoretically, the generation of 83,000 MW has been deemed possible and approximately 43,000 MW power has been estimated which seems to be economically and technically feasible(Shrestha, 1991).

Despite the large potential, less than five percent of the viable resource has been harnessed to come up with hydroelectricity. The total generation capacity is reached to 1250 MW. Even generation capacity has increased, Nepal still has an energy deficit within the dry season and about 37 percent of the overall energy consumption is imported from India. Nepal continues to be import-dependent within the power supply. The government of Nepal and therefore, the Government of India has signed Power Trade Agreement (PTA) for co-operation in cross broader power exchange, and power trading that might mutually benefit both the countries(Nepal Electricity Authority, 2019).

The total energy supplied through the NEA distribution system was 7551.23 GWh in the year 2018/019. A total of 2,548.11 GWh energy was generated from NEA operated hydropower Plant, about 2,190.05 GWh energy was generated from IPPs and 2,813.07 GWh energy was imported from India. Thee total energy consumption was 6394.38 GWh, which is an escalation of 13.89 percent over the last financial year. The rest of the energy was wasted because of system loss. The system loss has reduced to 15.32 percent from 20.456 percent and also the Annual load factor has pushed to 65.29 percent. Today, 87 percent of the population has full access to the electricity supply and on-grid supply is 78 percent. The nation's overall per capita energy consumption of electricity has reached 245 KWh. The total generation capacity is extended to 1250 MW. as generation capacity increases, Nepal still has an energy deficit within the dry season but has some surplus energy at the wet season(Nepal Electricity Authority, 2019).

The Modern digital world is nowadays mostly relying on the improvement of power system infrastructure. Electrical energy is the most sophisticated form of energy that requires a secure and reliable transmission network for the safe and sustain operation. The quantity of consumption of energy is one of the key parameters of the nation's economic and financial health. So, to grasp very high economic progression a reliable transmission network should be developed along with the event of the erection of hydropower. The development of the transmission lines requires extensive investment in terms of monetary value. Additionally trained and experienced manpower, specialized knowledge, modern technology is necessary to accomplish the targeted goal in the power sector. Land acquisition is another big issue for substations and transmission line erection. That's why related stakeholders must include an appropriate transmission development plan with a national priority for developing a reliable grid of the power system network at the state level.

The current transmission line infrastructure wouldn't hold future demand to supply reliable and quality electricity. Therefore power flow models are used to plan future transmission lines under the thermal limitation, voltage limitation, and stability limitation. Apart from the technical limitation, policy formulation is equally important for the national transmission expansion plan. The electricity demand has risen approximately ten percent per annum as economic activity has increased. Presently, we are within the state of wet season generation surplus, but still in deficit within the dry season. Within the next financial year, the generation capacity will increase with the completion of major hydropower plants like Upper Tamakoshi, Rasuwagadi, Mid-Bhotekoshi, Sanjen, etc (Rastriya Prasaran Grid Company Limited, 2018). Thus, the INPS could face reliability problems if the present transmission infrastructure is not upgraded shortly.

In this context, the Upper Tamakoshi hydroelectric powerhouse of 456 MW, located in Dolkha district, is going to be operating in the year 2020/21. It's going to be connected to the national grid via gongar - new khimti high voltage 220 kV substations. Upper Tamakoshi Hydroelectric power company Limited is a self-regulating power utility established in 2063/11/25 B.S. by Nepal Electricity Authority (NEA). This Project is fully financed by domestic commercial bodies and business companies. It is expected to end the power crisis and export surplus power, especially within the wet season (Upper Tamakoshi Hydropower Limited, 2020).

When Upper Tamakoshi Hydroelectric power plant comes to operation, it is going to be the biggest and leading hydroelectric powerhouse ever commissioned in Nepal. It's realized that the injection of such a large hydropower plant within the integrated network will have a diverse impact on voltage stability and reliability. Hence, this study is devoted to impacting - study within the countrywide grid giving a brand-new approach to transmission line expansion plan by clustering into three different sub-regional control. After injection, the Nepalese power grid will have enough power to satisfy local demand and reduces the quantity of power imports from India.

1.2 Problem Statement

Electrical energy consumption is one of the major primary indicators of nations. Economic health can be accelerated by increasing energy consumption along with the prime development of the energy sector. In Nepal, hydropower is considered as the most viable form of energy resource in terms of source availability. Therefore, the government of Nepal has foreseen developing 15 GW of hydropower plans in the upcoming 10 years and nearly 40 GW by the end of the year 2040(Rastriya Prasaran Grid Company Limited, 2018). However, only 1250 MW power is realized up to now. Nepal continues to be facing an energy deficit state and that's being fulfilled by import from India. Additionally, the evacuation of generated power for internal consumption, import & export requires a safe and reliable integrated transmission grid. So, to realize high economical and financial growth, a reliable transmission network should be developed and upgraded instantaneously along with the construction of the hydropower plant. However, insufficiency within the transmission line expansion in Nepal has got to result of unstable voltage supply and infrequent system interruptions.

The national priority project Upper Tamakoshi Hydroelectric power station goes to contribute approximately one-third of the full installed capacity across the country. Sudden injection and rejection of such an outsized powerhouse within the grid might cause instability that leads to cascading outages and huge generation loss. The modern power grid should have the flexibility to stay a continual supply system minimizing the sudden imbalance of the system. If large scale power blackout occurs the impact on the grid is catastrophic. The Nepali power grid has faced grid failure multiple times in past operations. A failure on utility supply can cause loss of service and deviation from normal voltage or frequency. System restoration is incredibly difficult if the risk assessment is not done properly. So, it's realized that it's necessary to check the constructive operation of INPS on the injection of huge power generators to avoid unnecessary power grid failure. Additionally, the regional and sub-regional control of the network is not clear for future operations. Therefore, it needs a profound study on the operation of the updated integrated system.

This study is close to addressing the above-mentioned problems to seek out the stable operation of the Integrated Nepal grid on the injection of such an outsized power plant. It identifies the concept of regional and sub-regional control of the integrated network for future operations by separating into three zones. Each zone is capable of the self-generation and accommodates power demand after the upgradation of transmission line conductors.

1.3 Research Objectives

Research objectives summarizes the accomplishments of the study that affords the direction of the study. It provides the expectations of the researchers to attain the targeted goal. This study has the following objectives:

i) Main objective

The main objective of this thesis is the study of the operational effect of the Integrated Nepal power grid on the addition of the 456 MW Upper Tamakoshi hydroelectric power station.

ii) Specific objectives

The impact has been studied by developing diverse operating conditions for the stable and reliable supply for the long run operation of an integrated network. Its subsequent specific objectives includes:

- Power flow analysis of existing INPS with identification of voltage profile of buses and calculation of transmission losses

- Power flow analysis of latest INPS system on injection of Upper Tamakoshi Hydroelectric power station with identification of voltage profile of buses, and calculation of transmission line loading and losses
- Transmission line uprating with identification of possible operating point for export case and calculation of transmission losses
- Identification of basics for regional and sub-regional grid operation and control

1.4 Limitations

Results are presented during this thesis by developing special four different cases for the best-operating conditions. In keeping with the information available from the Load Dispatch Centre and Grid Operation Department, the operating scenarios are chosen. Generation and substation load demand data are frequently changing in nature. But, during the process, steady-state power flow analysis is performed to search out the stable operation. That’s why is this study has subsequent limitations.

- Average generation data are taken for wet and dry season
- Average substation data are taken for wet and dry season
- Small generators and small loads are taken as lump sum generators and loads
- Convergence difficulties because of the numerous small generators and longer distance of transmission lines were considered

CHAPTER TWO: LITERATURE REVIEW

The analysis of the literature assessment brings the required concepts to accomplish research works to attain the targeted goal. Studying the articles and journal papers associated with the concerned work also broadens the understanding of any works or researches or studies that are put forth by scholars from the past to the present. Several works of literature are studied on power system operation and control for the integrated transmission linkages. Past research articles supported the power flow analysis are reviewed. It also includes the transmission expansion plan of Nepal conducted by various scholars. Henceforth, the goal of the study is identified, and power flow analysis practices are studied thoroughly.

2.1 Transmission Expansion Plan

The transmission directorate is one amongst the most important NEA bodies controlled by Deputy Administrator. This directorate consists of four departments, explicitly; Grid Operation Department (GOD), System Operation Department (SOD), and Grid Development Department (GDD). It is accountable for the design, operation, and maintenance of the transmission line and of high-voltage substations from 66 kV to 400 kV voltage levels. Also, it's responsible for the uprating of existing transmission lines and substations for future use. The government of Nepal has also recently shaped Rastriya Prasaran Grid Company Limited (RPGCL) in 2074 B.S. and given the responsibility of the planning, constructing, operating, and maintaining high voltage lines greater than 220 kV and more (Nepal Electricity Authority, 2019).

The present national grid has been charged up to a high voltage level of 220 kV. It is scheduled to function at a 400 kV voltage level within the following fiscal year. This transmission line directorate has the additional accountability to work integrated grid in synchronous means with Indian Grid for cross broader power exchange. It’s been illustrated that financial modalities for the expansion of the Butwal-Gorakhpur 400 kV cross-border transmission lines are in the concluding stage. Also, the detailed design of Inaruwa-Purniya and New Lumki (Dododhara)- Bareli 400kV cross borderlines are in the final stage (Transmission Directorate, 2019).

There has been little effort done by the government to develop a long-lasting plan for the expansion of the integrated transmission grid. Nepal Electricity Authority (NEA) and Joint Technical Committee (JTT) and some researchers have proposed a Transmission master plan. These master plans primarily focus on the event of the transmission linkage within the country to facilitate the export of electrical power to India. Those studies are based on the WECS report using an energy forecast is about 38 GW by the year 2040. But it's relevant to focus on national consumption by increasing the number of industries by separating the integrated system into five different zones. These reports propose an extensive plan by suggesting a 400kV East-West and North-South transmission highway. Also, they are suggested constructing a connecting bay for major river basins for the integrated connection of large-sized hydroelectric projects. Similarly, six cross-border connection points are purposed for power trade to India. Also, an extra two cross-border 400 kV connections points are purposed for power trade to China. The transmission master plan is purposed from the year 2015 to the end of the 2035 B.S. These present the clustering of hydropower to evacuate power along the river corridor in an optimal way. Also, they have purposed of a reliable transmission network that can follow N-1 contingency analysis for power export to India and China as well (Rastriya Prasaran Grid Company Limited, 2018).

The national peak demand for electricity will be approximately 18 GW by the year 2040 B.S. These energy forecasts are based upon the government of Nepal new vision for the economic development target set of 7.2 % GDP growth. (WECS, 2013). Thus, a brand-new vision of the transmission line master plan is essential that has objectives of providing reliable supply. That’s why it is essential to account for the massive modification within the generation and load demand for the country. It is because the actual scenario is different than the publication of the transmission plan.

2.2 Power System Operation and Control

(Stott, 1974) delivers the computational approach for various Power flow analysis techniques. The author presented the history of the computer software program for power flow analysis. It is explained that finding a solution was the main goal of the power-flow analysis regardless of the time of execution. The decades had been depleted within the research and development of numerical techniques to realize the most accurate solution during a very short interval of time. Before the invention of digital computers, power flow solutions were found employing a manual network analysis approach. Time had been passed and extensive research has resulted in first practical automatic digital solutions within the year 1956. Those computers were manufactured with small memory storage and were very slow and sometimes they never converged. Although they had problems with storage and execution time, the performance was found satisfactory on many power flow complications.

(Kuruganty, Thompson, & Billinton, 1983) interprets the reliability assessment employed in the interconnection benefit of the Western Canada Grid. This grid will interconnect the three Canadian provinces of Alberta, Saskatchewan, and Manitoba. A technique of compatible risk indices was employed in the grid operation. A study year was selected that had a risk level approach to the planning limit. Firstly, the standard risk indices were calculated from the system and studied load-carrying capability without considering the grid interconnection. The reliability benefits with the three grid were shown. It is because of the improvement found within the load-carrying capability during the comparison of the grid and without the grid connection. The cases were evaluated for the year 1999. It results in the accelerating capacity of the grid tap at the Saskatoon grid that provides improved reliability performance. Finally, the less reliable places are chosen that are further investigated within the reliability assessment of the Western Canada Grid. But, the result would be improved by taking standard risk indices by considering the grid interconnection.

(Zeggai & Benhamida, 2019) accomplished a simulation on advanced ETAP 16.0.0 220/63/30 kV high-voltage Algerian GHAZAOUET substation. They used the special technique to resolve problems of overloading and insignificant energized generators. The author attempts from the study to confirm reliable energy from the appropriate operation of this high voltage substation. These particular data was applied and went for ETAP simulation for the optimization. The result shows that transformers, transmission lines, and load losses were the main reason behind the voltage fluctuation problem. Therefore, the substation resulted in the degradation of energy quality. Furthermore, the analysis was accustomed to the optimal size and placement of the capacitors to resolve this problem again. Additionally, the problems were taken by the author to understand in various emergency conditions of theses 220 kV substations in overloaded lines, cables, and transformers to seek out the voltages within the acceptable limits as prescribed. Short circuits studies were also presented for the adequate size of the devices that were capable to handle the short circuit currents. Also, those studies provided information regarding the intensity of the power system, and therefore, the probable damage might be caused within the event of the short circuit. The study also helps to effective design of the protection system by Relay Co-ordination and Arc Flash.

(Jaleel & Shabna, 2013) performed load flow analysis, and finding reliability evaluation of a 220 kV grid of Kerala. The voltage profile was analyzed and showing them effective methods of optimum placement of the capacitor. Thee single line diagram was modeled using Electrical Transient Analyzer Program (ETAP). Several reliability indices like SAIFI, SAIDI, CAIDI, ASAI, and ASUI were calculated and analyzed. The optimal capacitor placements were also obtained to measure of system reliability and for voltage profile improvement. The authors also highlighted the issues and located solutions but it might be a decent result of taking exact system parameters.

(Princy, Jaseena, Sreedharan, & Sreejith, 2018) highlighted on voltage stability problems by using the Continuous Power Flow (CPF) method of Kerala grid 220KV-26 bus systems with maximum wind penetration. Small Signal Stability Analysis is used by calculating the eigenvalue of the network for the computation. The authors were doing such analysis by introducing maximum wind generation penetration in the network. The research was performed on two special purposes to pinpoint the weak buses employing CPF analysis and helpful for improving voltage stability margin. It was further extended to transmission line loadability by introducing Flexible AC transmission system (FACT) controllers. The Static Var Compensator (SVC) was employed for the analysis. Finally, the proposed methodology was validated by using the experiment outcomes of the IEEE 14 bus system.

(Tran, Kwon, Choi, Jeon, & Han, 2006) examined the probabilistic reliability evaluation of KEPCO grid expansion planning. The author tested for 765KV transmission lines and results are presented. It had been done to find out Transmission Reliability Evaluation for Large-Scale Systems (TRELSS) Version 6.2, a software package that is developed by the electric power Research Institute (EPRI). It had been implemented to determine probabilistic reliability evaluation indices and results were analyzed. The sensitivity analysis of the system introduces the addition of two 765 transmission lines into the KEPCO grid within the year 2010. It also illustrates the importance of a contingency analysis of a 765KV transmission line to study reliable electric energy to the system load.

(Patel Akash, 2016) performed optimization of Ground Grid Mesh of Extra High Voltage (750kV) Substation by using the current generated method in ETAP. Short circuit analysis had been carried out and ground grid parameters were determined using simple hand calculations. The results obtained from the modeling were verified using IEEE 80-2000 and FEM method. The result shows that increasing the area of the grid lesser the touch potential, step potential, absolute potential, and ground potential. The effect of spacing on touch and step potential is the opposite in nature. Also, there found an increase in potential voltage and drop-in touch voltage as a reduction of the spacing of conductors in 750 kV substations. It suggests the installation of more vertical rods in the substations. Also, it suggests temperature rise, mesh potential, and ground impedance to decrease. Using this FEM method, the result might be modified for the individual conductor or rod by conductor/rod editor.

(Kapahi, 2017) performed simulation of 132 kV substations located in Punjab State Transmission Corporation Limited (PSTCL). Electrical Transient Analyzer Program (ETAP) was used with detailed load flow analysis. The results were presented by taking actual data that are obtained from 132 kV substations. The substations consist of two Power Transformers, thirteen Circuit Breakers, thirteen Current Transformers, three Potential Transformers, and six isolating switches. The author attempts to seek out the problem of under-voltage at both buses. The simulation was performed taking the position of capacitor banks in shunt to the feeders. The author shows that the analysis of Demand and Losses' summary is much less than compared to the exiting designed system. Also, it was seen that there's a major improvement in the power factor of the substation that had been shown by the load flow analysis. It might be enhanced results to integrate the other state to find an optimal solution using the standard failure rate.

(Mishra, Karki & Gyawali, 2014) computed that the amount of power and energy loss reduction in the operation of the Integrated Nepal power system (INPS) as a result of the commissioning of Khimti - Dhalkebar 220kV transmission line. The test model of the integrated system had been accomplished and power flow calculation was done to determine the power loss on each branch using the Power Analysis Toolbox (PSAT) that merged in MATLAB. The result shows that 15.639MW Power loss will be saved by using this approach. The analysis also shows that there's a rise within the loadability margin by 0.8174 p.u. Furthermore, the voltage stability of the system was significantly improved. It might be a more reliable system to estimate the performance parameter of updated conditions taking import and export cases.

(Adhikari, Babu, 2016) presented an assessment of the consequence of a 400 kV transmission link between the Indian grid and also the integrated Nepalese power system taking import cases. The INPS is analyzed on different operating modes to analyze the impact on system reliability indices like Expected Energy not served, per unit value of Energy not served, per unit value of Energy Index reliability, and Expected Energy not served. The result shows that the value of Expected Energy Not Served (ECOST) reduces after the import of power through Dhalkebar – Muzzaffurpur line. But, this study is carried out by taking standard failure rate data of the transmission line. It might be practical to seek out reliability indices by considering the exact failure rate data of transmission lines, and other system components. It may be the most effective analysis if this study includes export cases with addressing regional control for the overall performance of the power system network.

CHAPTER THREE: RESEARCH METHODOLOGY

The initial study of the operation of the Integrated Nepal power grid on the addition of Upper Tamakoshi Hydropower Plant proceeds with the gathering of past literature related to the transmission line extension plan and comparative study of power flow analysis techniques. Power flow analysis is accomplished to evaluate active power losses and voltage profile of the integrated system. Implementing power flow analysis has relevance to future transmission line expansion and extension scenarios. In this study, Newton Raphson's method is employed in the simulation process in ETAP. The simulation is first applied with existing INPS with import cases taking wet and dry peak generations. The study proceeds with modifications on INPS with an injection of the Upper Tamakoshi Hydroelectric power station. Import and export cases are considered to identify stable operation through which transmission losses are minimized. Finally, the conclusion is presented by suggesting sub-regional control of the integrated Nepal grid network.

3.1 Concept of Power Flow Study

The power flow study is an extremely popular tool routinely employed in the design, control, and operations of existing power systems. By knowing the necessary data from the power utilities of adding interconnections, adding new loads, connecting new generators, connecting new transmission lines; the power flow study is performed before the installation of the power system network. The main goal of the power flow study is to obtain a complete voltage profile for every bus on the addition of a specified load and generator real power. On gathering that information, real and reactive power flow on each branch can be determined. Also, generator reactive power can be systematically determined and investigated for the overall system performance. (Grainger & William D. Stevenson, 1994).

Generally, power systems network equations show non-linear characteristics. The solution for these equations is obtained by using iterative methods. To attain an accurate solution, iterations approach to the convergence limit by replacing the previously calculated value. The iteration goes until the specified tolerance value. From the identified direct and indirect iterative methods, non-linear power flow equations are solved. The solution converges in less iteration indirect method as compared to the indirect iterative methods. Direct methods are effective for tiny power grid network problems whereas indirect methods are used for large grid networks. Among them, mostly used iterative methods today are the Gauss-Seidel and Newton Raphson method. These methods are efficient and have differences in computer storage requirements, programming methods, convergence criteria, and also the nature of test problems. However, the Newton-Raphson method is the widely used power flow tool for large load flow analysis. It is because of the calculation simplification s and fast convergence giving reliable results (Grainger & William D. Stevenson, 1994).

3.1.1 Bus Classification

A bus is one of the power system components in which one or many generators, transmission lines, substation loads, and some other electrical appliances are connected. In a power system operation and control each bus is related to four quantities: real power (P), reactive power (Q), voltage magnitude (|V|), and phase angle (δ). In a power flow solution, out of the four quantities two quantities are specified. The remaining two are required to be calculated through the converged solution of the non-linear power equations. Depending upon the quantities are specified and calculated, power system buses are categorized into three special buses solution (Lopez & Deschacht, 2004).

i) Generator bus or PV bus:

A generator bus is also called a voltage-controlled bus. This bus is connected to a generator unit in which the voltage magnitude (|V|), and real power (P_G) corresponding to the generation is specified. The output power generated on this bus can be controlled by the prime mover. But, the output voltage is controlled by adjusting the corresponding excitation system. Reactive power generation (Q_G) and the phase angle (δ) of the bus voltage is calculated by the execution of a power flow analysis solution (Lopez & Deschacht, 2004).

ii) Load bus or PQ bus

The load bus is also called the PQ bus. In this bus, it is required to calculate the voltage magnitude (|V|), and the phase angle and the phase angle (δ) by power flow method. Real power demand (P_D) and reactive power demand (Q_D) is specified. In this case, the voltage can be acceptable to vary within the tolerable limits as defined during the solution process solution (Lopez & Deschacht, 2004).

iii) Slack bus or reference bus

In a power system network solution, usually, one reference bus commonly known as the slack bus is used to meet the equilibrium of the power flow equations. Generally, load and generator buses the real power injections are specified. Now, $\sum_{i=1}^{n} P_i = P_D + P_l$ where, P_l is a real power loss, P_i is the power injection at the generation buses and P_D is the power injection at the load bus. But, the losses remain still unknown until the load flow solution is accomplished. That's why generally one of the generator buses is made a swing bus that is accountable to take the additional real and reactive power to supply transmission losses. At this bus, the voltage magnitude (|V|) and the phase angle (δ) are specified, whereas real power (P_G) and reactive power (Q_G) is obtained through the execution of power flow (Lopez & Deschacht, 2004). Table 1 below summarises the bus classification.

Table 1: Bus Classification

S.N.	Types of Buses	Variables			
		P	Q	|V|	δ
1	Generator Bus	Known	Unknown	Known	Unknown
2	Load Bus	Known	Known	Unknown	Unknown
3	Slack Bus	Unknown	Unknown	Known	Known

3.1.2 Power Flow Calculation Methods

i) Gauss Method

Gauss method is the simple and straightforward iterative method and rarely employed in the calculation of power flow equations. German mathematician Carl Friedrich Gauss and Philipp Ludwig von Seidel identified this method. It is also stated as the method of successive displacement. The solution to this method is started with an initial guess value of voltage. A new value is calculated for every bus until the stated convergence limits. However, the new voltage attained at the one bus cannot be used for the calculation of voltage at another bus until and unless the solution iteration is finished. This is often the disadvantage of the gauss method that gives the result less accurate and fewer popular(Grainger & William D. Stevenson, 1994).

ii) Gauss-Seidel Method

Gauss-Seidel method is the modified gauss method for solving a set of non-linear power equations. In this method also a starting value of voltage is predicted and a newly calculated value substitutes the initial one. When the solution converges within a defined prescribed limit, iteration is now stopped. This method has some benefits of easiness of the technique and small computer memory requirement. Likewise, it needs less computational time per iteration. However, this method is limited for only small load flow problems because of slow convergence. The major disadvantages include a large number of iterations and an increase in the number of iterations directly with the increase in the number of buses. Also, this method has disadvantages of the complexity in the calculations, highly convergence sensitive due to choice of slack buses, and initial assumed value(Grainger & William D. Stevenson, 1994).

iii) Newton-Raphson Method

Newton-Raphson Method is the most operative and common iterative method used for power flow analysis. It was named after Isaac Newton and Joseph Raphson's extensive hard work in solving non-linear equations in the late 1960s. It is the most widely used method nowadays that approaches to sets of linear simultaneous equations form a set of non-linear simultaneous by using Taylor's series expansion method. It is limited to the first approximation and does not affect much more to the selection of slack bus. The advantages of this method are fast computational technique, fast rate of convergence, and less number of iterations. But it needs higher computer memory. In this method, the convergence is reliable and guaranteed because of the fast and fine convergence. It is relatively more powerful as compared to other iterative techniques used today(Grainger & William D. Stevenson, 1994).

iv) Fast Decoupled Power Flow Method

Newton's Raphson method is later improved by introducing a series of well sustained simplifying assumptions by Stott and Alsac in 1974 and termed Fast Decoupled Power Flow Method (FDPFM). It offers simplification of calculation as in the Newton-Raphson method that results in fast convergence and gives reliable results. The power mismatch vector of both methods is identical. But, the Jacobians elements of the fast decoupled methods are voltage-independent whereas the Newton-Raphson method is voltage-dependent. That’s why the fast decoupled method significantly reduces computer storage and computing requirements. It becomes a widely used method in load flow analysis for very fast computation. But, this method has the disadvantage of not yielding an accurate solution due to limitations in the power mismatch vector(Grainger & William D. Stevenson, 1994).

3.1.3 Formation of Power Flow Equations

The power flow study is numerical under steady-state analysis for calculation of voltage magnitude and phase angle at each bus. As a by-product of this power flow calculation, real and reactive power is evaluated along with transmission losses. The input data for the power flow consists of generation data, substation bus data, transmission line data, and transformer data(Grainger & William D. Stevenson, 1994).

The power flow calculation is initiated with the formation of the bus admittance matrix Y bus. Y bus can be made from the transmission line and transformer input data provided as,

$(Y_{bus}) = \sum_{i=1, i\neq k}^{n} Y_{ik}$ Equation 3.1

The nodal current is calculated as,

$I_k = \sum_{k=1}^{n} Y_{ik} V_k$ Where, i = 1, 2, 3 ... n Equation 3.2

The complex power deliver to bus k is given by,

$$S_i = P_i + jQ_i = V_i[\sum_{k=1}^{n} Y_{ikV_k}] *$$ Equation 3.3

Taking the real and imaginary parts of equation 3.3 and power balance equations can be written as,

$P_i = V_i \sum_{k=1}^{n} Y_{ik} V_k$ Cos$(\delta_i - \partial_k - \theta_{ik})$ Equation 3.4

$Q_i = V_i \sum_{k=1}^{n} Y_{ik} V_k$ Sin$(\delta_i - \partial_k - \theta_{ik})$ Equation 3.5

We have $\Delta f = J\,\Delta X$

If $\Delta P_i = P_{i(sp)} - P_{i(cal)}$ Equation 3.6

Then i = 1, 2….n, i$\neq$ $slack, and\ if$

$\Delta Q_i = Q_{i(sp)} - Q_{i(cal)}$ Equation 3.7

Then i = 1, 2 ,…..n, i$\neq$ $slack, i = PV\ bus$

Where, the subscripts sp and cal represent the specified and calculated values, separately then the equation 3.6 can be re-written as,

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} H & N \\ M & L \end{bmatrix} \begin{bmatrix} \Delta \partial \\ \Delta V \end{bmatrix}$$ Equation 3.8

Where, $\Delta P_i < \varepsilon, \Delta Q_i < \varepsilon$

Then off-diagonal and diagonal elements of the sub-matrices H, N, M&L are calculated by difference equation 3.4 and equation 3.5 concerning $\partial \ and \ \Delta V$ (Grainger & William D. Stevenson, 1994).

3.1.4 Algorithm for Newton-Raphson (NR) method:

There are two specific techniques of solving power flow equations by using the Newton-Raphson. The first method uses rectangular coordinates for the variables while the latter uses polar coordinates. In this Power flow study, the polar coordinate is used for the analysis of the integrated network in ETAP(Grainger & William D. Stevenson, 1994).

Steps to perform the Newton-Raphson method:

Step 1: Form the nodal admittance matrix (Y_{ij}).

Step 2: Assume an initial set of bus voltage (V_i) and phase angle (δ_i) for load buses and phase angle (δ_i) for PV buses and set particular bus as the reference bus.

Step 3: Calculate the real Power $P_i \ and \ Q_i$ for each load bus using the equation (3.4) and (3.5).

Step 4: Form the Jacobian matrix.

Step 5: Find the power differences ΔP_i and ΔQ_i using equation (3.6) and (3.7).

Step 6: Choose the tolerance values.

Step 7: Stop the iteration if all ΔP_i and ΔQ_i are within the tolerance values.

Step 8: Substitute the values obtained in step 4 and step 5 then obtain the value of $\Delta\delta$ and $\Delta|V_i|$ from using the equation shown below.

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} H & N' \\ M & L' \end{bmatrix} \begin{bmatrix} \Delta \delta \\ \frac{\Delta V}{V} \end{bmatrix}$$

Step 9: Using values of $\Delta\delta$ and $\Delta|V_i|$ calculated in the above step, modify the voltage and phase angle at all the buses by the equation below.

$${}^{(r+1)}_{\ \ i}V = {}^{(r)}_{\ i}V + \Delta|{}^{(r)}_{\ i}V|$$

$$ {}^{(r+1)}_{i}\delta = {}^{(r)}_{i}\delta + \Delta {}^{(r)}_{i}\delta $$

Step 10: Start the next iteration cycle following the steps above with modified values of $\Delta\delta$ and $\Delta|V_i|$.

Step 11: Continue until scheduled errors for all the load buses are within a specified tolerance that is ${}^{(r)}_{i}\Delta P < \varepsilon$, ${}^{(r)}_{i}\Delta Q < \varepsilon$

Where ε denotes the tolerance level for the load buses. (Grainger & William D. Stevenson, 1994).

3.2 Data Collection

Data collection is the process of gathering important information for the targeted designed model to evaluate desired outcomes. Accurate data are essential to maintain the validity of the research. In this study-related data are taken from different departments of Nepal Electricity Authority, NEA. The necessary data required for the study can be presented as follows.

3.2.1 Generator Data

For the power flow study, Real Power rating of generators for wet and peak season data are taken from the Load Dispatch Center, NEA as per annex B. It includes:

- Operating Mode (Swing Control, Voltage or Power Factor Control)
- Rated kV
- %V and angle for swing control mode
- %V, MW loading, and Mvar limits for voltage control mode
- MW and Mvar loading for power factor control mode

3.2.2 Substation Load Data

Substation load data for the specified season are taken from Grid Operation Department, NEA as a lump sum load as per annex E. Those loads are taken in 66 kV and 132 kV substations which must include:

- Rated kV, MVA, power factor, and percentage motor load
- Loading category and Percentage loading

3.2.3 Transmission Line Data

Transmission line length and corresponding conductors are as per annex D and provided by Grid Operation Department, NEA. Transmission line performance parameter follows IS 398-1976 standard rule for the study and it includes:

- Conductor configuration, impedance, reactance, susceptance, spacing, etc.
- Base kV, Base MVA, tap and LTC settings

3.2.4 Capacitor Data

Existing Capacitor data are obtained from the Grid Operation Department, NEA as per annex C. It includes:

- Rated kV, Kvar per bank
- Number of the capacitor bank
- Load category and percentage loading

3.3 Computer Modelling and Simulation

Integrated Nepal power system (INPS) is the centralized controlled network consisting of generators, transmission lines, substations, and electrical loads. A robust transmission network is required for reliable and uninterruptible electrical service. Generators, transmission lines, and substation load data are desirable for this study.

Different relevant scenarios are developed as recommendations obtained from the Load Dispatch Center and Grid Operation Department (NEA) with the integrated power grid network and simulated using the electrical Transient Analyzer Program (ETAP) 16.0.0. ETAP toolbars calculate the bus voltages, branch power factor, current, and power flow through the electrical systems. It permits swing, voltage regulated, and unregulated power sources with several power grids and generator interconnections. Newton's Raphson Method is employed for the power flow analyzer in ETAP. The convergence criteria for this method is set to 0.0001 MW and 0.0001 MVar.

Existing integrated grid is employed for the study besides new 220 kV double circuit transmission lines of Lambagar - New khimti – Dhalkebar and Dhalkebar- Hetuda 220 kV substations. The generators having more than five MW capacities are used. And generators having less than five MW capacity are clustered together to make one unit in different sections. Lumped loads are taken into substations of 66 kV and above voltage level. The overall INPS is modeled as per appendix L for the existing INPS system and as per appendix M for the new INPS system. The simulation results are validated and compared to the standard report which is published by Rastriya Prasaran Grid Company Limited (RPGCL).

CHAPTER FOUR: RESULTS AND DISCUSSION

A power flow study is a vital technique for testing a power system network. The operation of the integrated power grid network is the principal means for the power system planners to identify short term and long term operation schedule. During this study, the Integrated Nepal power grid is modeled in four different cases for steady-state power flow analysis. Taking necessary data from the Nepal Electricity Authority, the system is modeled in ETAP by considering the best-case scenario for the optimal operation. The computer model on simulation finds key parameters like real and reactive power flow, voltage profile, and transmission losses. Computer analysis also includes power import and export cases. Different modes of operation are determined through dissimilar conditions like loading pattern, generation plan, transmission line expansion plan, and import duty.

3.1 First Case: Wet Peak Operation of INPS

The base case power flow is simulated with a five percentage load curtailment that is closely resembled with the current Integrated Nepal Power System (INPS). This system has been serving 1398.01 MW real power and 362.12 Mvar reactive power. A total of 551 MW power is imported through five different cross broader lines. It shows that the transmission loss of the system is 40.08 MW. Kaligandaki Hydroelectric Power Plant is taken as a swing bus generating 73.2 MW. i.e. 2.8 Percent of the total power. Parwanipur and Semera substation has appeared the highest system voltage of 67.5 kV and Patan substation has appeared the lowest voltage of 60.6 kV at 66 kV standard voltage level. Attaria Grid substations have appeared the lowest nominal voltage of 110 kV and most of the substations have a good voltage profile at 132 kV voltage level.

3.2 Second Case: Dry Peak Operation of INPS

The second case is modeled using dry peak demand and generation. This closely resembles with first case power flow study. It is operated without any load curtailment. It serves 1246.16 MW real power and 164.6 Mvar reactive power together with 424 MW power imported from India. It shows that transmission loss of the system is 33.26 MW i.e. 2.67 percent of the demand. About 94.7 MW power is generated from Kaligandaki Hydroelectric Power Station as a swing bus. Hetauda Grid substation has 73.7 kV with the highest system voltage and Patan and Banepa substations have shown the lowest voltage of 63.2 kV at 66 kV voltage level. Attaria Grid substations have shown lowest voltages and the Parwanipur substation has shown 138.2 kV at 132 kV voltage level.

3.3 Third Case: Wet Peak Operation of Modified INPS

This is the case of the modified Integrated Nepal Power System with an injection of the Upper Tamakoshi Hydroelectric Power Plant. It is performed with a minimum of 240 MW power imported from India and load curtailment is neglected but it accounts for 10 percent load growth. Hetauda – Dhalkebar – New Khimti and Trishuli 3A - Matatirtha 220 kV transmission lines have been considered. The power flow study in this setup shows that it has been serving about 1589.03 MW real power and 246 Mvar reactive powers. It accounts for about 94.8 MW (i.e. 5.27 percent) active power losses in the transmission system. Gongar and New Khimti substations are operating at 108.8 percent which is within the permissible limit. Table 2 below shows the voltage profile of the 220 kV substation in the third case.

Table 2: Voltage Profile of 220 kV Substations (Case 3)

S.N.	Bus ID	Nominal Voltage (kV)	Standard Voltage (kV)	Voltage Percentage
1	Dhalekebar	215.8	220	98.11
2	Dhalekebar 1	217.3	220	98.79
3	Gongar	239.6	220	108.89
4	Gongar1	216.0	220	98.2
5	Hetauda	215.8	220	98.1
6	Matatirtha	210.2	220	95.54
7	New Khimti	239.5	220	108.88
8	New Khimti 1	213.0	220	96.81
9	Trishuli 3A	210.2	220	95.54

3.4 Fourth Case: Wet Peak Operation of Modified INPS (Export Case)

The last case is focused on export cases after the injection of the Upper Tamakoshi Hydroelectric Power Plant on the modified Integrated Nepal Power System. Hetauda – Dhalkebar – New Khimti and Trishuli 3A- Matatirtha 220 kV transmission lines have been assumed. Power imported from India is considered about 205 MW, and five percent load curtailment is considered with 10 percent load growth taken into account.

The new system has been serving 1621.3 MW real power and 175.5 Mvar reactive power. About 53 MW power through Dhalkebar 220 kV, 40 MW through Katiya, and 42 MW power through Ramnagar 132 kV substations have been delivering to Indian Grid. It accounts for 85.6 MW active power losses which are about 5.2 Percent. The new Khimti and Gongar substations have been operating at 251 kV of the voltage level. Table 3 below shows the voltage profile of 220 kV substations in the fourth case.

Table 3: Voltage profile of 220 kV Substations (case 4)

S.N.	Bus ID	Nominal Voltage	Standard Voltage (kV)	Voltage Percentage
1	Dhalekebar	221.034	220	100.47
2	Dhalkeber 1	212.212	220	96.46
3	Gongar	251.438	220	114.29
4	Gongar1	218.878	220	99.49
5	Hetauda	221.034	220	100.47
6	Matatirtha	217.294	220	98.77
7	New Khimti	251.438	220	114.29
8	New Khimti 1	216.832	220	98.56
9	Trishuli 3A	217.294	220	98.77

The four special cases show the optimal power flow models for the operation of the Integrated Nepal Power System. Those systems are performed with power imports from India. According to the annual report of NEA about 37% of the total energy is imported in the last fiscal year. After the injection of Upper Tamakoshi hydroelectric power stations, the import case is reduced considerably. Nepal and India have signed a power trade agreement therefore it is necessary to import power to some extent. Also, it is mandatory to import power from India as the national generation could not meet domestic power demand. That’s why different cases have been considered for power flow study accounting such factors along with available technical data patterns. Table 3.4.2 below summarises the four different modes of operations.

Table 4: Operational Summary

S.N.	Generation (MW)	Generation (Mvar)	Tr. Loss (MW)	Loss (%)	Swing Bus Gen (MW)	Import (MW)	Export (MW)	Load Curtail (%)
1	1398.01	362.12	40.08	2.8	73.2	551	0	5
2	1246.17	164.6	33.26	2.67	94.7	424	0	0
3	1589.03	246.9	94.8	5.96	411.4	240	0	0
4	1621.3	175.5	85.6	5.27	418.8	205	135	2.5

Table 4 shows the comparative study of four different cases that explains the operation of the national power system based on the real scenario. It seems that the total local generation is not sufficient for national demand even generation is increased each year. The deficit power is supplied from India through the cross-border transmission line. The case first, second, and third are modeled without considering export case whereas case four is modeled for the export scenario of exporting about 135 MW power to India.

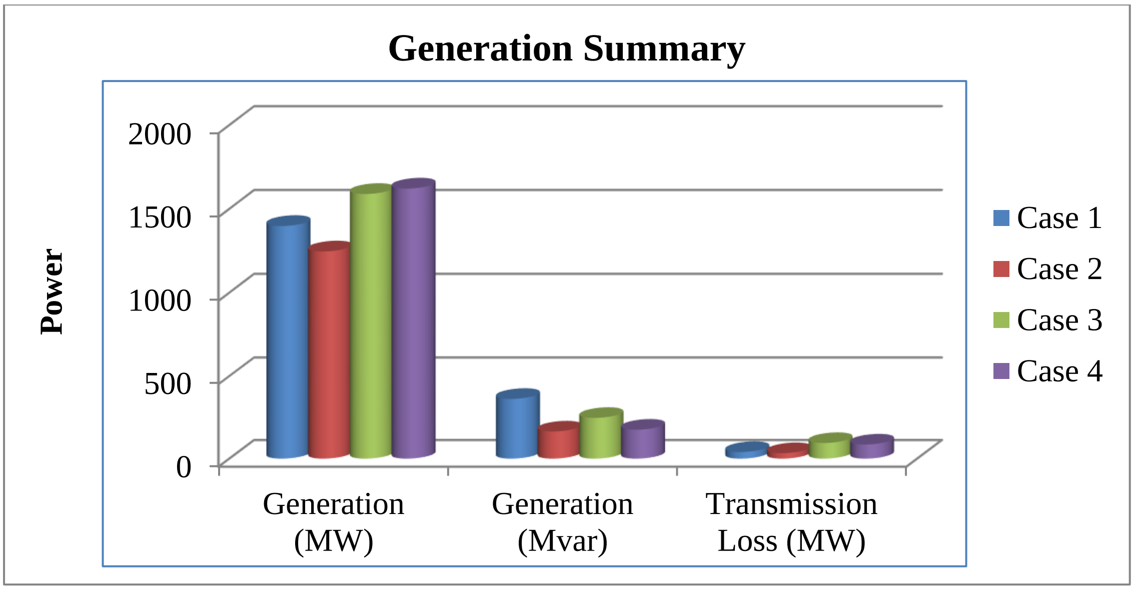


Figure 1: Generation and Loss Summary for Different Cases of Operation

3.5 Voltage Profile for Different Grid Operation Department

In electrical power stations, power is generated at a medium voltage level. This generated power is sent to the consumer through different voltage levels for a different purpose. Like power system frequency, the voltage has to be kept within the range for safe and reliable operation. During the process, a reduction in ±10 percent voltage level is the permissible limit for the transmission line (Electricity Regulation, 1993).

Therefore, voltage profile is one of the key parameters of load flow study and needs to be kept within the safe range. In this study, it is summarised that the comparative four different cases of voltage profile showing of separate seven regional grid departments of the country.

3.5.1 Voltage Distribution of Kathmandu Grid Division

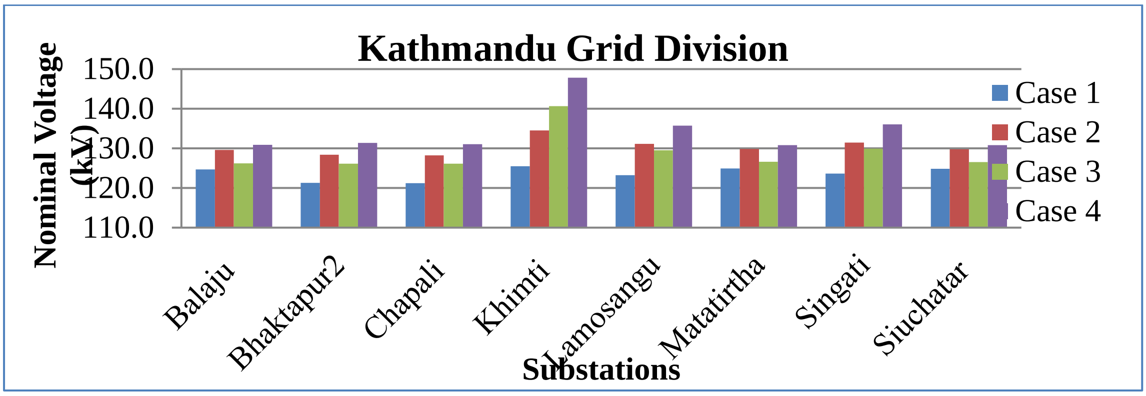


Figure 2: Voltage Distribution of Kathmandu Grid Division (132 kV)

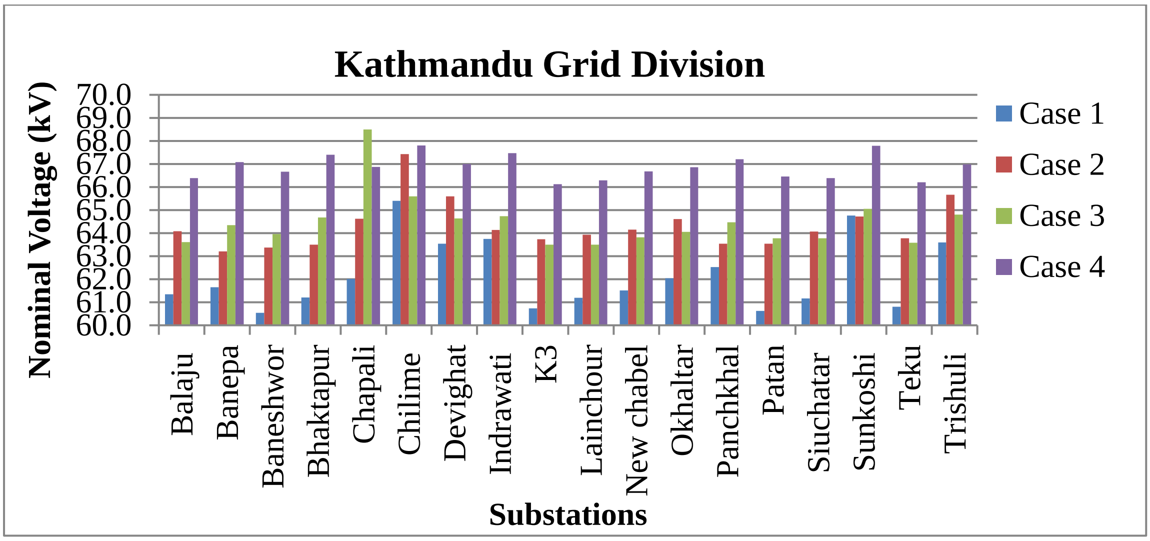


Figure 3: Voltage Profile of Kathmandu Grid (66 kV)

Figure 2 above shows the Voltage distribution of Kathmandu Grid division at 66 kV voltage level and figure 3 at 132 kV voltage level. It consists of eight 132 kV and eight 66 kV substations that control Kathmandu regional load. In third and fourth cases all the 66 kV transmission lines are replaced by BEAR conductors. That's why showing an improved voltage profile. In the first and second cases, most of the substations have low voltage profile and significantly improved in later cases after adjustment of capacitor bank and loading arrangement. Finally, all the substations show the improved voltage profile as prescribed by grid code.

3.5.2 Voltage Distribution of Hetauda Grid Division

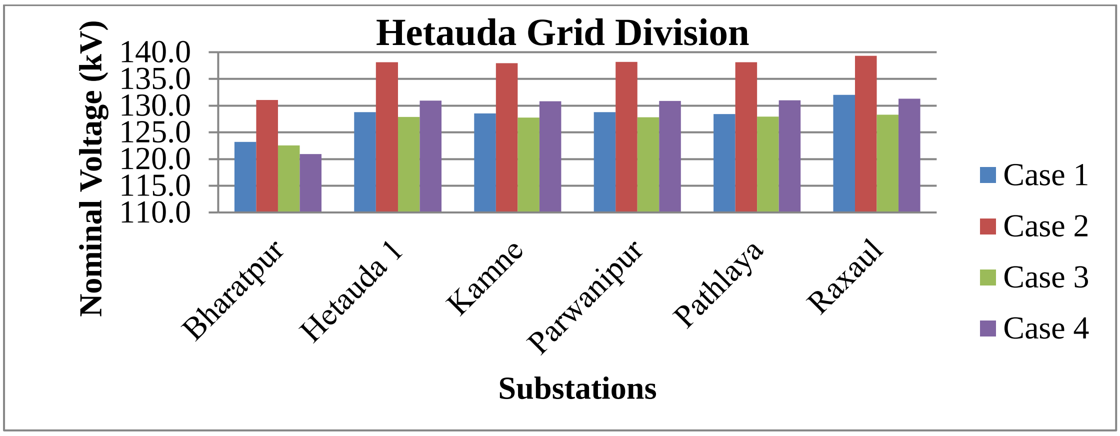


Figure 4: Voltage Profile of Hetauda Grid Division (132 kV)

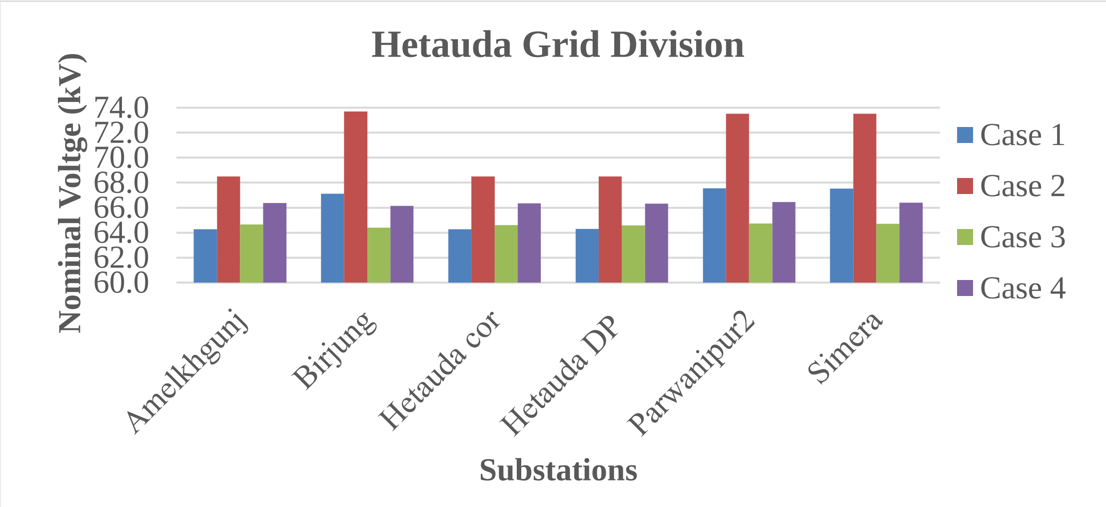


Figure 5: Voltage Profile of Hetauda Grid Division (66 kV)

Figure 4 and figure 5 above show the voltage profile for the Hetauda Grid division at 132 kV voltage level and 66 kV voltage respectively. In this case, Birgunj, Semera, and Parwanipur substations are operated at overloading conditions. But later voltage profile is improved after the replacement of DOG conductors by BEAR conductors. Raxual 132 kV substation has appeared 131.3 kV voltage at case four from which power is imported from the Indian side.

3.5.3 Voltage Distribution of Dhalkebar Grid Branch

Figure 6 below shows the voltage variation developed in the computer model of Dhalkebar Grid Branch. It consists of six major substations and the Dhalkebar substation is specially used for import and export of power from India. It is the central substation that connects the eastern and western part of Nepal. Initially 220 kV Dhalkebar substation is operated at 210.8 kV and later operated at 228.7 kV, 215.8 kV, and 221 kV respectively. Mirchaya and Chapur 132 kV substations have overloaded slightly and operated at 136.7 kV and 137.8 kV respectively. Other 132 kV substations are found to give satisfactory performance even though the voltage profile is improved in later cases within the close restrictions. Finally, all the substations have improved voltage profiles and lie within the permissible grid code.

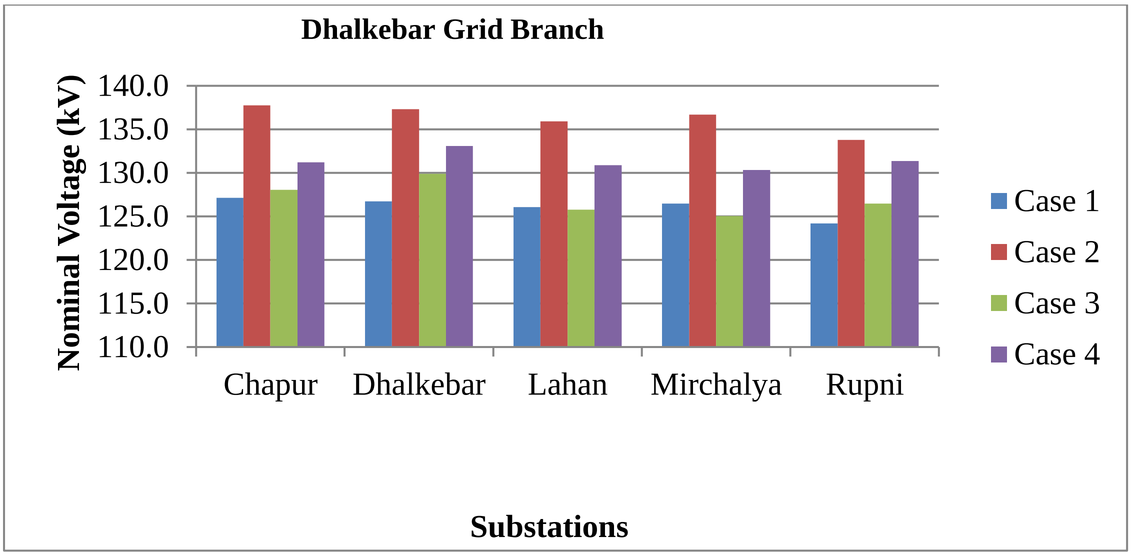


Figure 6: Voltage Profile of Dhalkebar Grid Branch

3.5.4 Voltage Distribution of Duhabi Grid Branch

Figure 7 below shows the voltage profile of the Duhabi Grid branch for four different cases. Duhabi Multiful and Maikhola substations are not operated in the first two cases but later they are operated within the restricted limits. Almost all of the 132 kV substations are operated at under load at the first case and later on, it is seen that voltage profile has improved within the specified range

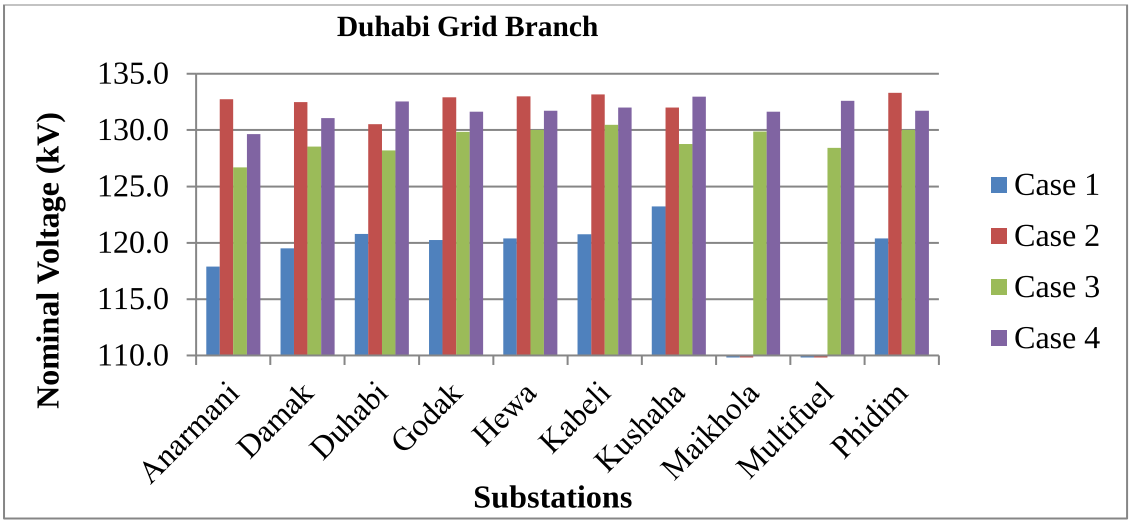


Figure 7: Voltage Profile of Duhabi Grid Branch

3.5.5 Voltage Distribution of Butwal Grid Division

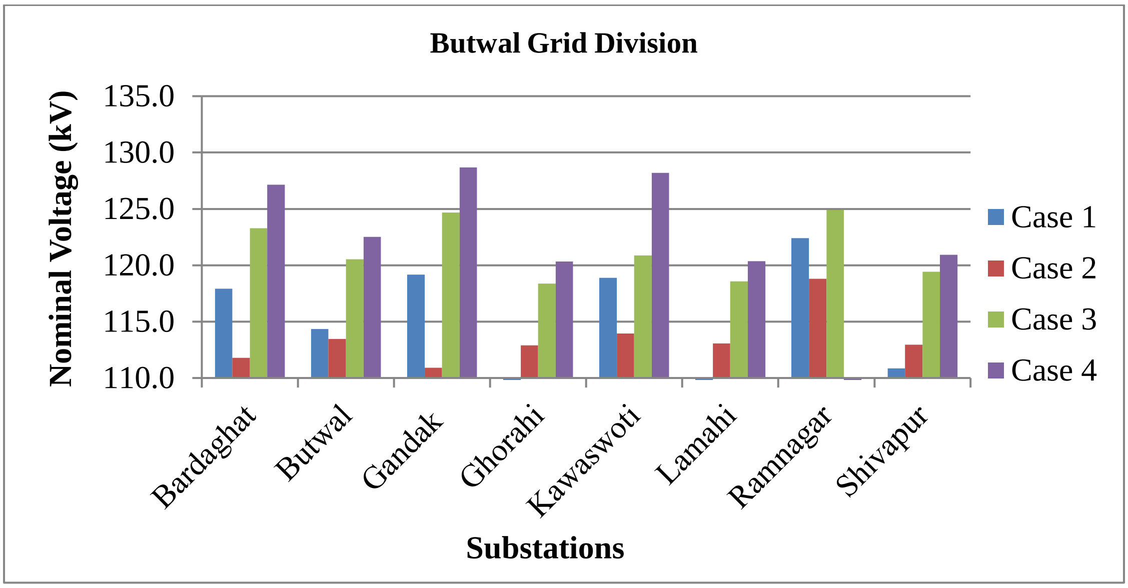


Figure 8: Voltage Profile of Butwal Grid Division

Figure 8 above shows the voltage profile of the Butwal grid Branch for four different cases at 132 kV voltage level consists of eight substations. It shows that the voltage profile is significantly improved from case one to case four. Ghorahi substation has a lower voltage of 108.3 kV and the Lamahi substation has also appeared 108.5 kV in case one. In case four all the substation has a safe voltage level and lies within the NEA guidelines. Ramnagar substation has zero voltage because in case four, import from this substation is restricted.

3.5.6 Voltage Distribution of Pokhara Grid Branch

Figure 9 below shows the voltage distribution in the Pokhara grid branch. It consists of twelve major 132 kV substations. The results show that almost all substations have a good voltage profile within the safe limit as per the grid code. Bhulbhule substation has appeared the highest voltage of 132.7 kV in case two. After adjustment of the capacitor bank, it has improved the voltage profile of 125.2 kV and 124.4 kV in case three and case four respectively.

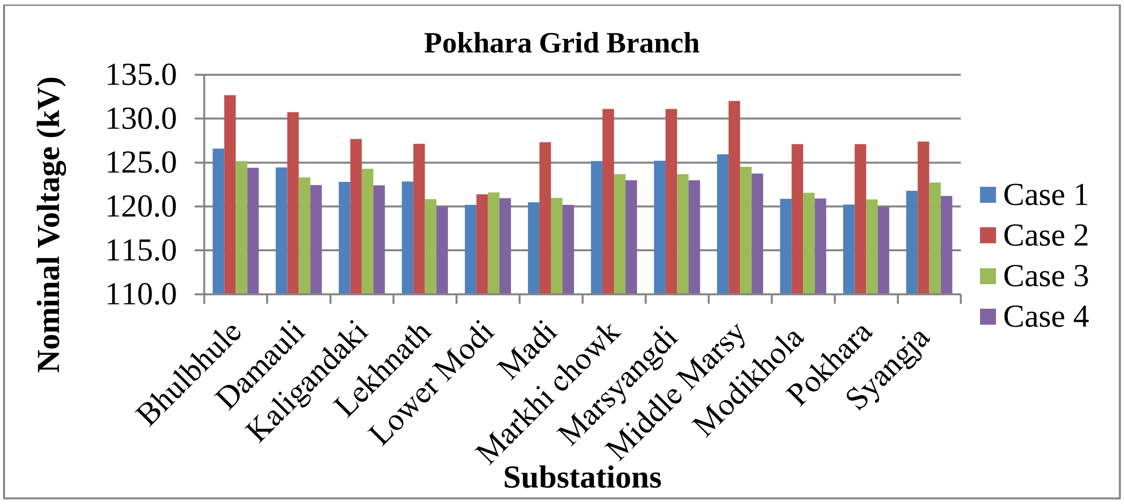


Figure 9: Voltage Profile of Pokhara Grid Branch

3.5.6 Voltage Distribution of Attaria Grid Branch

Figure 10 below shows the voltage profile of the Attaria grid branch for four major cases consists of nine 132 kV substations. Mahendranagar substation has appeared exactly 132 kV voltage from where power is imported from India radially in western Nepal. It can be seen that most of the substations in case one has appeared lower voltage at 132 kV voltage level. But in later cases, all the substations have improved voltage profile within the range of grid code.

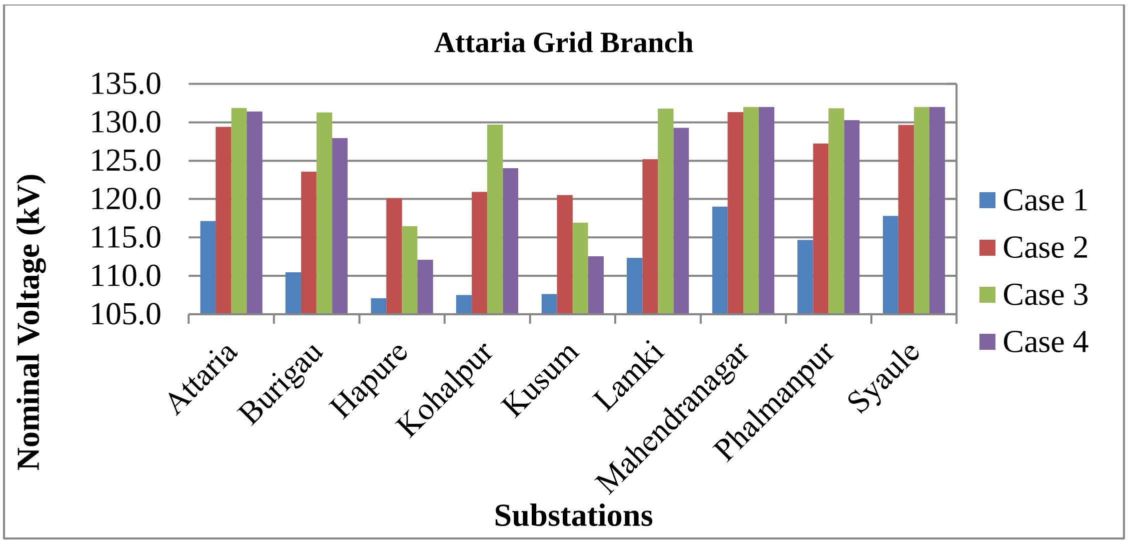


Figure 10: Voltage Profile of Attaria Grid Branch

3.6 Power Flow of 220 kV Substations

The major concern of this study is to analyze the impact of injection of the Upper Tamakoshi hydroelectric power plant which is connected in a 220 kV transmission line from Gongar to New khimti substation. Khimti - Dhalkebar 220 kV substation is constructed to evacuate power to the Terai region. It is expected to provide ease in connection with the huge load center of that region. It is the most viable route to export generated power from the Upper Tamakoshi Hydro Power Plant to Indian Grid. It shows that 268.322 MW real power is transferred to Dhalkebar station and 149.75 MW real power is transferred to the central grid through the Khimti substation. New Khimti and Gongar substation is operated at 114.29 percent of operating voltage. Matatirtha substation has the least loading of 40.63 MW real power and 2.48 Mvar reactive power. Whereas, New Khimti1 substation has the highest loading of 268.32 MW real power and 34.93 Mvar reactive power that is evacuated to the eastern region.

Table 5: Loading Summary of 220 kV Substations

S.N.	Bus ID	Nominal kV	Operating Voltage (%)	MW Loading	Mvar Loading	Amp Loading (A)
1	Dhalekebar	220	100.47	100	9.83	262.5
2	Dhalkeber 1	220	96.46	262.01	34.67	719.1
3	Gongar	220	109.29	149.76	10.78	344.8
4	Gongar1	220	99.49	272.65	21.49	721.5
5	Hetauda	220	100.47	65.5	40.38	201
6	Matatirtha	220	98.77	40.63	2.38	108.2
7	New Khimti	220	109.29	149.75	70.53	380.1
8	New Khimti 1	220	98.56	268.32	34.93	720.6
9	Trishuli 3A	220	98.77	40.64	2.65	108.2

3.7 Transmission Line Uprating

Power Flow analysis is performed in four diverse modes of operation. The case first and case second is close modeling of the Integrated Nepal Power System. The result shows that Birjung, Kulekhani, Parwanipur, and Semera substations are operated at overloading conditions. Even though most of the substations at normal operating conditions, the addition of extra load could not sustain for future use. The operation of

INPS could be consistent in two options. The formal option is to upgrade conductors and later option is to increase transmission line voltage. The study shows that upgradation of voltage level is a less reliable option than the upgradation of conductors. It would be better to replace the existing conductor by the BEAR conductor. Therefore, later two cases are modeled with the replacement of all the 66 kV conductors by BEAR conductors and the table below shows that the comparative result of before and after uprating of transmission line conductors. The final case shows that the overall systems have almost two percent voltage fluctuations suggesting improvement of voltage profile of 66 kV substations.

Table 6: Transmission Line Upratig (At 66 kV)

S.N.	Substation Name	Rating (kV)	Before Uprating		After Uprating	
			Nominal (kV)	Percent Voltage	Nominal Voltage	Percent Voltage
1	Amelkhgunj	66	68.5	103.78	66.4	100.56
2	Balaju	66	64.1	97.1	66.4	100.58
3	Banepa	66	63.2	95.76	67.1	101.63
4	Baneshwor	66	63.4	96.01	66.7	101
5	Bhaktapur	66	63.5	96.27	67.4	102.12
6	Birjung	66	73.7	111.66	66.1	100.22
7	Chapali	66	64.6	97.92	66.9	101.32
8	Chilime	66	67.4	102.17	67.8	102.74
9	Devighat	66	65.6	99.39	67.0	101.52
10	Hetauda Corri	66	68.5	103.78	66.3	100.51
11	Hetauda DP	66	68.5	103.8	66.3	100.5
12	Indrawati	66	64.1	97.17	67.5	102.23
13	K3	66	63.7	96.56	66.1	100.19
14	Kulekhani	66	69.6	105.4	66.8	101.24
15	Lainchour	66	63.9	96.87	66.3	100.44
16	New chabel	66	64.1	97.19	66.7	101.03
17	Okhaltar	66	64.6	97.89	66.9	101.3
18	Panchkhal	66	63.5	96.28	67.2	101.82
19	Parwanipur2	66	73.5	111.4	66.4	100.67
20	Patan	66	63.5	96.27	66.4	100.68
21	Simera	66	73.5	111.38	66.4	100.61
22	Siuchatar	66	64.1	97.07	66.4	100.58
23	Sunkoshi	66	64.7	98.07	67.8	102.7
24	Teku	66	63.8	96.62	66.2	100.32
25	Trishuli	66	65.7	99.5	67.0	101.5

220 kV substations and transmission lines are modeled using the DEER conductors. The simulation result shows that these lines are slightly overloaded. This is the case assumed with power export. It is seen that the overall system has better performance using the MOOSE conductor for future operations. The table 7 below shows 132 kV transmission lines that are operated at overloaded conditions. It needs to upgrade the following higher ampacity conductors to achieve stable and optimal performance.

Table 7: Transmission line Uprating (Above 66 kV)

S. N.	Transmission Line		Voltage Level (kV)	Line flow (A)	Existing Conductor	Ampacity (A)	Proposed Conductor	Ampacity (A)
	From	To						
1	Lamosangu	Bhaktapur	132	908.4	BEAR	650	MOOSE	980
2	Khimti	Lamosangu	132	836.6	BEAR	650	ZEBRA	880
3	Bharatpur	Kawaswati	132	602.8	PANTHER	560	BEAR	650
4	Kaligandaki	Butwal	132	861.1	BEAR	650	ZEBRA	880
5	Chapali	Bhaktapur	132	809.7	BEAR	650	ZEBRA	880
6	Dhalke2	Mirchalya	132	814.2	BEAR	650	ZEBRA	880
7	Mirchalya	Lahan	132	743.7	BEAR	650	ZEBRA	880
8	New Khimti	Dhalkeber	220	714.7	DEER	870	MOOSE	980
9	Gongar	New Khimti	220	721.5	DEER	870	MOOSE	980
10	Dhalkebar	Dhalkebar 1	220	847.1	DEER	870	MOOSE	980

3.8 Sub-Regional Control of INPS

The power system operation is limited to three zones based on the power handling capacity, power plants, load demand, transmission line infrastructure, and existing cross border point availability in that region. The overall INPS is divided into three zones which have at least one cross broader point. In the case of radial power export for future operation, separation of the zone is necessary for the reliable operation of the grid.

i) Eastern Region

Eastern Region is the largest region through which eightgenerators are connected. It consists of 22 buses and 22 branches. This region's power flow is controlled by Upper Tamakoshi Hydroelectric Power Station. Eastern region consists of fifteen substations out of which Dhalkebar, Gongar, and New Khimti are 220 kV substations and the rest of the substations are 132 kV substations. Kabeli, Mai Khola, and Hewa Khola are the major hydropower plant in this region. Duhabi, Dhalkebar, Anarmani are the major load centers. Dhalkebar and Katiya are the major substations used for the cross broader power exchange. Total load contributed in case three is 384.3 MVA while in case four is 274.2 MVA.

ii) Central Region

Central Region is the largest region through which 35 generators are connected. It consists of 100 buses and 120 branches. This region's power flow is controlled by the Kaligandaki Hydroelectric Power Plant. Upper Marysangdi, Maryasnagdi, Khulekhani, Trishuli, Bhotekoshi are the major hydropower plant in this region. The major load centres includes Kathmandu Valley, Hetauda, Butwal, Pokhara, Dhalkebar, etc. Dhalkebar, Ramnagar, and Raxual are the major substation used for the cross broader power exchange. Total load contributed in case three is 1125.4 MVA while in case four is 1087.9 MVA.

iii) Western Region

Western Region is the smallest region through which three generators are connected. It consists of eight buses and eleven branches. This region's power flow is controlled by Chameliya Hydroelectric Power Station. The western region consists of seven 132 kV substations. The western region generators are connected to this hub. Mahendranagar 132 kV substations are the important cross broader point through which power is imported from Tanakpur India. Kohalpur 132 kV substation is the main load center of this region. Other substations include Syaule, Altaria, Phalampur, Lamki, Burigau. Total load contributed in case three is 92.6 MVA while in case four is 98.9 MVA.

Table 3.8 shows the comparative summary of the sub-regional power control mechanism on the operation of the Integrated Nepal Power System. The overall system has been separately controlled by Upper Tamakoshi Hydroelectric Power station, Kaligandaki hydroelectric Power station, and Chameliya hydroelectric Power station. In case three, Upper Tamakoshi, Kaligandaki, and Chamelia hydroelectric power plants have been generating 285.1 MW, 108.7 MW, and 17.6 MW real power and 58.2 Mvar, 67.4 Mvar and 3.24 Mvar reactive power. Also in case, four, an Upper Tamakoshi, Kaligandaki, and Chamelia hydroelectric power plant have been generating 273.7 MW, 117.1 MW, and 28.06 MW real power and 34.9 Mvar, 83.9 Mvar and 2.03 Mvar respectively. Upper Tamakoshi hydropower plant generates high power in case three but generates low power in case four. But, Kaligandaki and Chameliya hydroelectric power plant generates low power in the case three but generates high power in the case four.

Table 8: Regional Power Control of INPS

Region	Swing generators	Swing Power Generation			
		Case 3		Case 4	
		P (MW)	Q (Mvar)	P (MW)	Q (Mvar)
Eastern	Upper Tamakoshi	285.1	58.2	273.7	34.9
Central	Kaligandaki	108.7	67.4	117.1	83.9
Western	Chameliya	17.6	3.24	28.06	2.03

The purposed controlling scheme is presented in figure 3.8 that attempts to address the stable and reliable interconnection for the operation of the Integrated Nepal Power System. The above computer model result and analysis shows that the necessity of sub-regional control as a separate entity. Eastern, Central, and Western region networks could be the three special zones that would be self- sufficient in terms of generation as per the load demand. Additionally, as per the zonal demand, bi-directional power flow would be possible between them by shifting interconnection points from one substation to another.

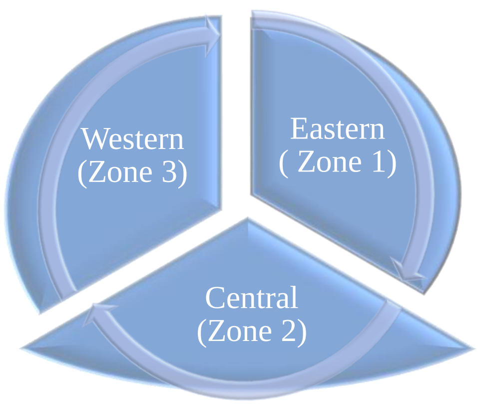


Figure 11: Purposed sub-regional INPS control model

3.9 Validation and Comparisons

The results obtained from the computer models are validated and compared with the national transmission line master plan published by Rastriya Prasaran Company Limited (RPGCL). Power flow analysis is performed by RPGCL in the computer model taking the forecasted data acquired from Water and Energy Commission Secretariat (WECS) report considering 7.2 % GDP growth. This study is performed for the study year 2020 – 2040. RPGCL purposes a 400kV East-West highway from east to west and south to north for addressing tower contingencies (Rastriya Prasaran Grid Company Limited, 2018). The table below shows the comparison of the major technical parameter between the two studies.

Table 9: Comparisons of Power flow Study

RPCL Study (2018)		**This Study (2020)**	
Year of Study	**2040**	**Year of Study**	**2021**
Zones	Five	Zones	Three
Generation	38 GW	Generation	1621 MW
Wet season peak load loss	4.03%	Dry peak loss	2.80%
Wet season min load loss	4.32%	Wet peak loss	5.96%
Dry season peak load loss	3.57%	Wet peak loss (export)	5.27%

RPGCL master plan is done by considering the expected generation is about 38 GW in 2040 whereas this study is done by considering about 1621 MW in 2021. The integrated system is separated into five different regions in the RPGCL study while this study is separated into three different regions. Each region is capable of the self-generation and fulfilling their respective demand. Budhi Gandaki Hydroelectric Power Station is the major power utility that controls the INPS. But in this study, Upper Tamakoshi Hydroelectric Power Station is the major power utility that controls the INPS. RPGCL master plan has presented with immense expectation of generation of 38 GW in the upcoming 20 years. But, it seems very difficult to implement such an expansion shortly. Therefore, based on this study it is recommended that to study separating three zones for the future addition of generation. This study reveals that the operation of the Integrated Nepal Power System will be proximity to the actual scenario for future use. Also, it is expected that this study is an economically justifiable and technically feasible model on the operation of the integrated network.

CHAPTER FIVE: CONCLUSIONS

In this dissertation, Models and cases are developed and modified to make the optimal operation of the Integrated Nepal power system on the injection of the Upper Tamakoshi Hydroelectric power station. The methodology utilized in this research has been very successful in achieving the target set forth for a power flow study in the real scenario. The Achievement of finding optimal operation, accounting import-export cases, through the implementation of the Electrical Transient Analyzer Program (ETAP) maintaining the INPS operation as suggested by Load Dispatch Center was accomplished. Different modes of operation are determined through-loading arrangement, generation plan, transmission line expansion plan, and import duties which have proven to be very effective at solving the power flow problems and suggesting regional control mechanism besides transmission line uprating plan. Simulation has been done considering base case operating mode that represents the present INPS system. Modified INPS has been simulated on the injection of Upper Tamakoshi Hydroelectric power with Hetauda – Dhalkebar – New Khimti and Trisuli 3A-Matatirtha 220 kV substations that will be the proximity to the actual operating system. The result is thus obtained are compared and validated with the national transmission line master plan published by Rastriya Prasaran Grid Company Limited (RPGCL). The following conclusions are made for the effective operation of INPS including transmission expansion Plan.

- The purposed network control scheme is within the safe limit for steady-state operation.
- The power system network has a stable operation on regional control with upgradation of 66 kV transmission lines by BEAR conductors.
- Injection of Upper Tamakoshi hydroelectric power station is modeled to end import power. Furthermore, the export case is considered to India providing a stable, and reliable operation of the power system network on the improvement of the voltage profile.
- The modified interconnected network utilizes the domestic generation and emphasizes large power reduction through import power from India.

- Mahendranagar, Ramnagar, Raxual, Dhalkebar, and Kusaha are the major five substations that are used for the cross border power exchange. About 135 MW power is exported to India through three cross borderlines. Among them, about 53 MW power through Dhalkebar 220 kV, 40 MW through Katiya, and 42 MW power through Ramnagar 132 kV substations are going to be delivering the power to Indian Grid.
- Integrated Nepal power system has stable operation on clustering whole integrated system into three different zones i.e. Eastern, Central, and Western zone, which are capable of self-generations and self-consumptions. The biggest central zone has a load capacity of approximately 1125 MVA and the smallest western zone has 100 MVA load capacity. Also, the eastern zone has the load capacity of about 385 MVA.
- This control scheme provides minimum transmission losses and mitigates the unpredictable outage of the power system network.
- Injection of the Upper Tamakoshi Hydroelectric Power Station provides stable operation to the integrated network on improving the system voltage profile of that network. It suggests power grid planners follow regional control for the long run operation after the injection of Upper Tamakoshi onwards. Because of the synchronization difficulties, and transmission line infrastructures available sub-regional control is essential for the radial power exchange for the cross border power trade.

RECOMMENDATION

An improvement would be made considering others under construction, planned, and purposed high voltage transmission lines to improve the performance of the overall integrated power system network. Additionally, this study suggests that the export of power to India through different high voltage cross borderlines. So, it is recommended to perform financial and dynamic reliability analysis of the purposed model of the integrated network power system.

REFERENCES

Adhikari, Babu, A. (2016). *Study of Impact of Dhalkebar Muzzapur 400 KV Transmission line on the Operation and Reliability of INPS*. https://doi.org/10.1192/bjp.112.483.211-a

Electricity Regulation, G. of N. (1993). ELECTRICITY REGULATION, Definition : -, *2050*.

Grainger, J. J., & William D. Stevenson, J. (1994). *POWER SYSTEM ANALYSIS*. https://doi.org/10.1299/jsmeb.43.596

Jaleel, J. A., & Shabna, S. S. (2013). Load Flow Analysis and Reliability Evaluation of 220kV Kerala Power system. *International Journal of Engineering and Innovative Technology (IJEIT)*, *3*(2), 558–563.

Kapahi, R. (2017). Load Flow Analysis of 132 kV substations using ETAP Software. *International Research Journal of Engineering and Technology (IRJET)*, *4*(2), 770–773. Retrieved from https://irjet.net/archives/V4/i2/IRJET-V4I2149.pdf

Kuruganty, P. R. S., Thompson, P. R., & Billinton, R. (1983). A reliability assessment of the western Canada grid. *IEEE Transactions on Power Apparatus and Systems*, *PAS-102*(9), 2826–2833. https://doi.org/10.1109/TPAS.1983.318169

Lopez, A., & Deschacht, D. (2004). Comparison between different data bus configurations. *Proceedings - IEEE Computer Society Annual Symposium on VLSI: Emerging Trends in VLSI Systems Design*, 69–74. https://doi.org/10.1109/ISVLSI.2004.1339510

Mishra, H. K., Karki, N. R., & Gyawali, N. (2014). Impact study of Khimti-Dhalkebar 220 kV Transmission Line on the Operation of Integrated Nepal Power System. *Proceedings of IOE Graduate Conference, 2014*, 203–208.

Nepal Electricity Authority. (2019). Yearbook of generation directorate fiscal year 2018/19, *2019*(August). Retrieved from https://nea.org.np/admin/assets/uploads/annual_publications/Generation2076.pdf

Patel Akash. (2016). *Design Analysis and Optimization of Ground Grid Mesh of Extra High Voltage Substation.*

Princy, U., Jaseena, S., Sreedharan, S., & Sreejith, S. (2018). Voltage stability analysis of power system network integrated with renewable source and SVC. *2017 Innovations in Power and Advanced Computing Technologies, i-PACT 2017*, *2017-Janua*, 1–6. https://doi.org/10.1109/IPACT.2017.8245058

Rastriya Prasaran Grid Company Limited. (2018). Transmission System Development Plan of Nepal, (July). Retrieved from http://www.aseanenergy.org/energy_sector/electricity/malaysia/tnb/transmission_system_devt.htm

Shrestha, H. M. (1991). Cadastre of Hydropower Resources. *Hydro Nepal*, (15), 87–89.

Stott, B. (1974). Review of Load-Flow Calculation Methods. *Proceedings of the IEEE*, *62*(7), 916–929. https://doi.org/10.1109/PROC.1974.9544

Tran, T., Kwon, J., Choi, J., Jeon, D., & Han, G. (2006). Probabilistic reliability evaluation for 765KV transmission lines in KEPCO grid expansion planning. *2006 9th International Conference on Probabilistic Methods Applied to Power Systems, PMAPS*, (July 2006). https://doi.org/10.1109/PMAPS.2006.360253

Transmission Directorate. (2019). Year book-fiscal year 2018/2019 of transmission project management directorate, *2019*, 1–120.

WECS. (2013). Nepal's Energy Sector Vision 2050 A.D., 149. Retrieved from http://www.wecs.gov.np/uploaded/vision-2050.pdf

Zeggai, A., & Benhamida, F. (2019). Power flow and Short circuit of 220 kV Substation using ETAP. *Proceedings of Algerian Large Electrical Network Conference, CAGRE 2019*, 158–163. https://doi.org/10.1109/CAGRE.2019.8713172

PUBLICATION

Acharya, S., & Shrestha, R. (2020). Operation of the Integrated Nepal Power System on Injection of the Upper Tamakoshi Hydroelectric Power Station. In Proceedings of IOE Graduate Conference.

APPENDIX A: Salient Features of Upper Tamakoshi Hydroelectric Power Plant

Type of Development	Peaking Run-of-River (PRoR)
Location	Lamabagar VDC, Dolakha District, Janakpur Zone, Central Development Region
Headworks Location	Lamabagar, Lamabagar VDC
Powerhouse Location	Gongar Gaon, Lamabagar VDC
Maximum Output (MW)	456
Annual Energy (GWh)	2,281
Gross Head (m)	822
Design Discharge (m^3/s)	66.0
Catchment Area (Km^2)	1,745
Min. Mean Monthly Flow(m^3/s)	14.1
Mean Annual Flow(m^3/s)	67.2
Design flood $Q_{1,000}$(m^3/s)	885.0
Diversion Dam (m^2)	22 m x 60.0 (H x L)
Live Storage (Million m^3)	1.2
Settling Basins	2 Nos. L=225 m
Headrace Tunnel	8.4 km (Cross Sectional Area = 32.14 m^2)
Penstock (Vertical Shaft and Horizontal Tunnel)	1,134.0 m
Power House (Underground)	142.0m x 13.0m x 25.0 m (L x B x H)
Number of units	6
Tailrace Tunnel	2.9 km (Cross Sectional Area = 35.0 m^2)
Access Road from Charikot of Dolakha District	68.0 km
Transmission line	220 kVA Double Circuit, 47.0 km (Gongar to Khimti Substation)
Construction Cost	NRs.35.29 Billion equivalent to US$ 441 Million (Excluding Interest During Construction)
Construction Period	6 Years

APPENDIX B: Generation Data

S.N.	Power Plant	Rating	S.N.	Power Plant	Rating
1	Adhikhola	9.4 MW	24	Kulekhani 3	17.1 MW
2	Bagmati	5 MW	25	Lower Modi	10 MW
3	Bhotekoshi	45 MW	26	Mai khola	22 MW
4	Ramechap IPP	22 MW	27	Marsyangdi	69 MW
5	Chamelia	30 MW	28	Middle Marsyangdi	70 MW
6	Chilime	22.5 MW	29	Modikhola	14 MW
7	Damauli IPP	5 MW	30	Muzzafur India	246 MW
8	Devgat	14.1 MW	31	Pokhara IPP	20 MW
9	Dhaula IPP	25 MW	32	Puwa khola	6.2 MW
10	Duhabi multifuel	39 MW	33	Raxaul import	80 MW
11	Gandak	15 MW	34	Singati khola	25 MW
12	Hetauda DP	14.4 MW	35	Sipring khola	10 MW
13	Hetauda IPP	50 MW	36	Sunkoshi	10.05 MW
14	Hewa Khola	2.4 MW	37	Syangja IPP	10 MW
15	Illam IPP	30 MW	38	Tanahu IPP	20 MW
16	Indrawati	7.5 MW	39	Tanakpur Import	80 MW
17	Jhimruk	12 MW	40	Trishuli 3A	80 MW
18	Kabeli	37 MW	41	Trisuli	24 MW
19	Kaligandaki	144 MW	42	Upper Madi	25 MW
20	Katiya Import	100 MW	43	Upper Marsyangdi	50 MW
21	Khimti	60 MW	44	Upper Tamakoshi	156 MW
22	Kulekhani 1	60 MW	45	Upper Tamakoshi	300 MW
23	Kulekhani 2	32 MW	46	Western IPP	15 MW

APPENDIX C: Capacitor Bank Data

Capacitor Bank Installation Lists					
S.N.	Substation	Capacity (Mvar)	S.N.	Substation	Capacity (Mvar)
1	Butwal	50	19	New Khimti	54
2	Bharatpur	30	20	Dhalekebar	5
3	Hetauda	100	21	Hetauda DP	10
4	Simera	10	22	Siuchatar	30
5	Birjung	30	23	Matatirtha	20
6	Pathlaya	5	24	Teku	20
7	Kohalpur	20	25	Bhaktapur	20
8	Shivapur	20	26	Chapali	20
9	Lahan	40	27	Parwanipur	30
10	Duhabi	100	28	Chapur	12.5
11	Anarmani	10	29	Mirchalya	20
12	Patan	20	30	Dhalkebar	24
13	Baneshwor	25	31	Damak	12
14	Balaju	25	32	Bardaghat	15
15	New Chabel	25	33	New Khimti	30
16	Lamki	12.5	34	Dhalkeber	30
17	Lamahi	30	35	Kusaha	50
18	Hetauda	30	36	Pokhara	15

APPENDIX D: Voltage Distribution of Different Grid Division

i) Voltage Distribution of Kathmandu Grid Division

A. Kathmandu Grid Division						
			Case 1	**Case 2**	**Case 3**	**Case 4**
S.N.	**Substation**	**Voltage ratio kV**	**kV**	**kV**	**kV**	**kV**
1	Balaju	132	124.7	129.6	126.2	130.9
2	Balaju	66	61.3	64.1	63.6	66.4
3	Banepa	66	61.7	63.2	64.3	67.1
4	Baneshwor	66	60.5	63.4	64.0	66.7
5	Bhaktapur	66	61.2	63.5	64.7	67.4
6	Bhaktapur2	132	121.3	128.4	126.2	131.4
7	Chapali	66	62.0	64.6	68.5	66.9
8	Chapali	132	121.2	128.3	126.1	131.0
9	Chilime	66	65.4	67.4	65.6	67.8
10	Devighat	66	63.5	65.6	64.6	67.0
11	Indrawati	66	63.7	64.1	64.7	67.5
12	K3	66	60.7	63.7	63.5	66.1
13	Khimti	132	125.5	134.5	140.7	147.8
14	Lainchour	66	61.2	63.9	63.5	66.3
15	Lamosangu	132	123.3	131.1	129.6	135.7
16	Matatirtha	132	124.9	129.8	126.6	130.8
17	New chabel	66	61.5	64.1	63.8	66.7
18	Okhaltar	66	62.0	64.6	64.1	66.9
19	Panchkhal	66	62.5	63.5	64.5	67.2
20	Patan	66	60.6	63.5	63.8	66.4
21	Singati	132	123.6	131.5	129.9	136.1
22	Siuchatar	132	124.9	129.8	126.5	130.8
23	Siuchatar	66	61.2	64.1	63.8	66.4
24	Sunkoshi	66	64.8	64.7	65.1	67.8
25	Teku	66	60.8	63.8	63.6	66.2
27	Trishuli	66	63.6	65.7	64.8	67.0
26	Trishuli 3A	220	124.9	129.8	210.2	217.3

ii) Voltage Distribution of Hetauda Grid Division

B. Hetauda Grid Division						
		Voltage	Case 1	Case 2	Case 3	Case 4
S.N.	Substation	ratio kV	kV	kV	kV	kV
1	Amelkhgunj	66	64.3	68.5	64.7	66.4
2	Bharatpur	132	123.2	131.1	122.6	120.9
3	Birjung	66	67.1	73.7	64.4	66.1
4	Hetauda 1	132	128.8	138.1	127.9	130.9
5	Hetauda cor	66	64.3	68.5	64.6	66.3
6	Hetauda DP	66	64.3	68.5	64.6	66.3
7	Kamne	132	128.6	137.9	127.8	130.8
8	Parwanipur	132	128.8	138.2	127.8	130.9
9	Parwanipur2	66	67.5	73.5	64.7	66.4
10	Pathlaya	132	128.4	138.1	127.9	131
11	Raxaul	66	132.0	139.3	128.3	131.3
12	Simera	66	67.5	73.5	64.7	66.4
13	Hetauda	220			215.8	221.0

iii) Voltage Distribution of Dhalkebar Grid Branch

C. Dhalkebar Grid Branch						
		Voltage	Case 1	Case 2	Case 3	Case 4
S.N.	Substation	ratio kV	kV	kV	kV	kV
1	Chapur	132	127.1	137.8	128.1	131.2
2	Dhalekebar 1	220	210.8	228.7	215.8	221.0
3	Dhalkebar	132	126.7	137.3	129.9	133.1
4	Lahan	132	126.1	135.9	125.8	130.9
5	Mirchalya	132	126.5	136.7	125.0	130.3
6	Rupni	132	124.2	133.8	126.5	131.4

iv) Voltage Distribution of Duhabi Grid Branch

D. Duhabi Grid Branch						
		Voltage	Case 1	Case 2	Case 3	Case 4
S.N.	Substation	ratio kV	kV	kV	kV	kV
1	Anarmani	132	117.9	132.7	126.7	129.7
2	Damak	132	119.5	132.5	128.5	131.1
3	Duhabi	132	120.8	130.5	128.2	132.5

D. Duhabi Grid Branch						
		Voltage	Case 1	Case 2	Case 3	Case 4
S.N.	Substation	ratio kV	kV	kV	kV	kV
4	Godak	132	120.3	132.9	129.8	131.6
5	Hewa	132	120.4	133.0	130.0	131.7
6	Kabeli	132	120.8	133.2	130.5	132.0
7	Kushaha	132	123.2	132.0	128.8	133.0
8	Maikhola	132	0.0	0.0	129.9	131.6
9	Multifuel	132	0.0	0.0	128.4	132.6
10	Phidim	132	120.4	133.3	130.0	131.7

v) Voltage Distribution of Butwal Grid Division

E. Butwal Grid Division						
		Voltage	Case 1	Case 2	Case 3	Case 4
S.N.	Substation	ratio kV	kV	kV	kV	kV
1	Bardaghat	132	117.9	111.8	123.3	127.2
2	Butwal	132	114.4	113.5	120.5	122.5
3	Gandak	132	119.2	110.9	124.7	128.7
4	Ghorahi	132	108.3	112.9	118.4	120.3
5	Kawaswoti	132	118.9	114.0	120.9	128.2
6	Lamahi	132	108.5	113.1	118.6	120.4
7	Ramnagar	132	122.4	118.8	124.9	0.0
8	Shivapur	132	110.9	113.0	119.4	120.9

vi) Voltage Distribution of Pokhara Grid Branch

F. Pokhara Grid Branch						
		Voltage	Case 1	Case 2	Case 3	Case 4
S.N.	Substation	ratio kV	kV	kV	kV	kV
1	Bhulbhule	132	126.6	132.7	125.2	124.4
2	Damauli	132	124.4	130.8	123.3	122.5
3	Kaligandaki	132	122.8	127.7	124.3	122.4
4	Lekhnath	132	122.8	127.2	120.8	120.0
5	Lower Modi	132	120.2	121.4	121.6	121.0
6	Madi	132	120.5	127.3	121.0	120.2
7	Markhi chowk	132	125.2	131.1	123.7	123.0
8	Marsyangdi	132	125.2	131.1	123.7	123.0
9	Middle Marsy	132	125.9	132.0	124.5	123.8
10	Modikhola	132	120.9	127.1	121.6	120.9
11	Pokhara	132	120.2	127.1	120.8	120.0
12	Syangja	132	121.8	127.4	122.7	121.2

vii) Voltage Distribution of Attaria Grid Branch

G. Attaria Grid Branch						
		Voltage	**Case 1**	**Case 2**	**Case 3**	**Case 4**
S.N.	**Substation**	**ratio kV**	**kV**	**kV**	**kV**	**kV**
1	Attaria	132	117.2	129.4	131.8	131.4
2	Burigau	132	110.5	123.6	131.3	127.9
3	Hapure	132	107.1	120.1	116.5	112.1
4	Kohalpur	132	107.5	120.9	129.7	124.0
5	Kusum	132	107.6	120.5	116.9	112.5
6	Lamki	132	112.3	125.2	131.8	129.3
7	Mahendranagar	132	119.0	131.3	132.0	132.0
8	Phalmanpur	132	114.7	127.2	131.8	130.3
9	Syaule	132	117.8	129.7	132.0	132.0

APPENDIX E: Wet Peak Operation of INPS (Case 1)

S.N.	From Bus	To Bus	MW Flow	Mvar Flow	Amp Flow	% V Drop	kW Losses
1	Lainchour	Balaju S/S2	13.549	7.568	146.4	0.23	18.03
2	Balaju S/S2	Siuchatar S/S2	6.624	4.962	78.11	0.26	11.92
3	Balaju S/S	Siuchatar S/S	24.258	5.501	115.2	0.15	21.06
4	Chapali	New chabel	37.246	4.038	351.6	0.74	261
5	New chabel	Lainchour	13.228	5.4	134.8	0.5	23.56
6	Teku	Siuchatar S/S2	38.799	18.454	408	0.56	112.7
7	K3	Teku	12.088	5.571	126.5	0.09	4.64
8	Siuchatar S/S2	Patan	43.104	3.457	411.8	0.83	335.4
9	Patan	Baneshwor	5.826	2.299	59.73	0.13	5.44
10	Bhaktapur	Baneshwor	22.292	-1.001	210.5	1.02	275.5
11	Lamosangu	Bhaktapur2	83.477	1.926	397.5	1.5	1253.3
12	khimti s/s	Lamosangu	57.389	-0.129	264.1	1.68	1108.7
13	Bhaktapur	Banepa	6.335	2.873	65.61	0.68	31.38
14	Banepa	Panchkhal	16.541	7.732	171	1.31	155.7
15	Indrawati s/s	Panchkhal	6.381	3.496	67.19	1.84	82.59
16	Siuchatar S/S	Matatirtha	79.812	22.436	383.3	0.05	24.29
17	Matatirtha	Kulekhani	31.873	16.543	166	1.03	157.3
18	Siuchatar S/S2	Kulekhani	44.794	15.393	447	5.1	1630.2
19	Hetauda DP S/s	Kulekhani	30.326	-10.163	286.1	0.37	368.7
20	Marsyangdi s/s	Siuchatar S/S	9.122	-2.811	44.01	0.26	49.87
21	Marsyangdi s/s	Bharatpur	88.44	-2.033	414.5	1.51	1423.3

S.N.	From Bus	To Bus	MW Flow	Mvar Flow	Amp Flow	% V Drop	kW Losses
22	Damauli	Bharatpur	41.14	-8.263	194.7	0.94	830.4
23	Bharatpur	Hetauda	6.188	29.347	140.5	4.2	403.8
24	Bharatpur	Kawaswati	70.782	8.231	346.1	3.28	1812.9
25	Bardaghat	Kawaswati	42.377	-5.526	207.5	0.74	614.9
26	Bardaghat	Butwal	87.222	23.487	456.1	2.7	1465.4
27	Shivapur	Butwal	96.234	23.759	516.2	2.63	1663.4
28	Kali	Butwal	111.558	52.445	622.4	6.42	3659
29	Lekhnath	Damauli	36.262	9.629	180	3.13	816.1
30	Lamahi	Shivapur	63.415	8.525	340.6	1.82	971.9
31	Ghorahi	Lamahi	11.733	5.683	69.52	0.15	10.09
32	Lamahi	Kusum	20.198	-1.104	107.7	0.63	179.7
33	Hapure	Kusum	9.969	4.828	59.73	0.43	23.08
34	Jhimruks/s	Lamahi	11.781	5.248	68.65	1.13	74.47
35	syangja s/s	Lekhnath	40.512	-18.495	213.7	1.09	713.7
36	Pokhara	Lekhnath	10.909	24.92	130.6	0.07	5.64
37	Modikhola s/s	Pokhara	29.064	-2.807	139.5	0.49	237.2
38	Marsyangdi s/s	Markhi chowk	33.466	-28.655	203.2	0.02	6.82
39	Trishuli s/s	Balaju S/S2	29.536	3.486	279.9	3.47	957.5
40	chilime s/s	Trishuli s/s	21.947	-2.386	194.9	2.68	835.4
41	Devighat	Trishuli s/s	7.384	-0.321	67.06	0.14	11.44
42	Devighat	Okhaltar	18.095	5.278	175.4	2.27	341.2
43	Okhaltar	Chapali	13.695	3.203	131	0.06	4.04
44	Hetauda	Kamne	1.179	-15.239	68.63	0.13	5.92

S.N.	From Bus	To Bus	MW Flow	Mvar Flow	Amp Flow	% V Drop	kW Losses
45	Hetauda	Parwanipur	13.846	34.154	165.3	0.04	4.51
46	Hetauda DP S/s	Hetauda corridor	12.318	5.938	122.9	0.04	2.49
47	Hetauda corridor	Amelkhgunj	0.508	0.246	5.068	0	0.0042
48	Parwanipur2	Simera	13.39	1.251	115	0.02	2.19
49	Parwanipur2	birjung	49.465	-1.317	423	0.66	354.9
50	Anarmani	Damak	37.635	6.263	186.8	1.23	322.4
51	sunkoshi s/s	Panchkhal	13.577	5.994	137	3.4	305.1
52	Damak	Duhabi	4.868	-10.305	55.06	0.96	37.77
53	chapali s/s	Bhaktapur2	39.25	-8.675	191.3	0.04	66.27
54	Bardaghat	Gandak s/s	60.052	37.762	347.3	0.96	276.9
55	Markhi chowk	Damauli	56.629	10.247	267	0.55	211.1
56	Middle Marsyas	Markhi chowk	86.422	-12.032	400	0.58	1052.6
57	Mahendranagar	Attaria	17.848	9.712	100.1	1.41	118.9
58	Syaule	Attaria	22.722	8.326	119.3	0.5	60.72
59	Phalmanpur	Attaria	23.246	11.912	131.5	1.87	212.3
60	Burigau	Kohalpur	16.707	11.237	108.1	2.25	185.4
61	Lamki	Burigau	17.616	10.719	107.8	1.43	123.4
62	Kusum	Kohalpur	13.751	-3.099	75.61	0.11	74.3
63	Kamne	Pathlaya	18.744	-10.194	95.94	0.14	52.16
64	Pathlaya	Chapur	67.598	-44.676	367.9	0.94	701.6
65	Parwanipur	Pathlaya	40.621	-28.061	222	0.31	135.9
66	Dhalkebar	Chapur	110.66	-32.467	525.4	0.32	3146.5
67	Dhalkebar	Mirchalya	33.283	-5.324	153.6	0.2	123.3

S.N.	From Bus	To Bus	MW Flow	Mvar Flow	Amp Flow	% V Drop	kW Losses
68	Mirchalya	Lahan	22.992	3.931	106.8	0.29	50.16
69	Rupni	Lahan	6.898	43.704	205.7	1.43	178.7
70	Kushaha	Duhabi	107.432	19.475	521.9	1.86	1345.9
71	godak-illam	Damak	63.379	-5.033	305.3	0.56	522.3
72	Phidim	godak-illam	54.156	3.549	260.6	0.1	47.14
73	Kabeli	Phidim	52.379	3.63	251.8	0.3	139.3
74	Gandak s/s	Ramnagar	75.945	36.633	408.5	0.15	55.26
75	Maikhola	Godak	21.946	-2.447	106	0.01	3.72
76	Butwal	Parasi	9.295	5.071	205.3	0.32	13.96
77	Phalmanpur	Lamki	22.418	12.171	131.1	1.77	194.9
78	Matatirtha	Trishuli 3B	59.86	-6.317	278.1	0.01	9.02
79	Hewa	Phidim	2.398	-0.0345	11.5	0	0.0438
80	Singati	Lamosangu	21.956	-1.978	102.9	0.29	71.26
81	Kushaha	Rupni	30.222	-21.601	174	0.72	198.1
82	Lekhnath	Madi	26.99	2.506	130.1	0.13	28
83	Parwanipur	Raxaul	79.151	35.568	388.9	2.42	848.8
84	Bhulbhule	Middle Mars	49.892	-4.878	228.6	0.49	432
85	Lamahi	Kusum	20.198	-1.104	107.7	0.63	179.7
86	Kusum	Kohalpur	13.749	-3.108	75.61	0.11	74.42
87	Burigau	Kohalpur	16.711	11.233	108.2	2.25	185.7
88	Lamki	Burigau	17.62	10.713	107.8	1.43	123.6
89	Phalmanpur	Lamki	21.206	11.578	124.2	1.77	184.4
90	Phalmanpur	Attaria	23.251	11.904	131.5	1.87	212.7

S.N.	From Bus	To Bus	MW Flow	Mvar Flow	Amp Flow	% V Drop	kW Losses
91	Mahendranagar	Attaria	17.851	9.706	100.1	1.41	119.1
92	syangja s/s	Kali	42.665	-22.823	229.4	0.8	431.6
93	K3	Siuchatar S/S2	13.431	6.789	143	0.66	40.59
94	khimti s/s	Dhalkebar	2.454	-6.943	33.88	0.94	18.66
95	Duhabi	Rupni	15.634	13.584	99.01	2.58	175.4
96	Middle Mars	Damauli	35.651	-1.879	163.7	1.13	513.3
97	Balaju S/S2	Balaju S/S	24.258	5.501	115.2	1.5	42.81
98	Siuchatar S/S2	Siuchatar S/S	21.535	5.855	103.2	1.91	40.89
99	Siuchatar S/S2	Siuchatar S/S	21.535	5.855	103.2	1.91	40.89
100	Siuchatar S/S2	Siuchatar S/S	21.535	5.855	103.2	1.91	40.89
101	Chapali	chapali s/s	11.906	-8.293	135.1	2.1	13.38
102	Chapali	chapali s/s	11.906	-8.293	135.1	2.1	13.38
103	Bhaktapur	Bhaktapur2	15.957	-3.874	154.9	0.85	17.59
104	Hetauda DP S/s	Hetauda	4.213	0.395	18.98	0.13	1.16
105	Hetauda DP S/s	Hetauda	4.213	0.395	18.98	0.13	1.16
106	Chamelia	Syaule	29	15.339	1820	5.37	95.36
107	Parwanipur	Parwanipur2	31.429	-26.225	349.9	4.75	70.53
108	Parwanipur	Parwanipur2	31.429	-26.225	349.9	4.75	70.53
109	Dhalkebar	Dhalekebar s/s 220	99.811	-8.504	456.4	0.17	189
110	Dhalkebar	Dhalekebar s/s 220	99.811	-8.504	456.4	0.17	189

APPENDIX F: Dry Peak Operation of INPS (Case 2)

S.N.	From Bus	To Bus	MW Flow	Mvar Flow	Amp Flow	% V Drop	kW Losses
1	Lainchour	Balaju S/S2	20.511	5.461	191.7	0.23	30.91
2	Balaju S/S2	Siuchatar S/S2	2.827	-2.802	35.87	0.04	2.46
3	Balaju S/S	Siuchatar S/S	21.713	4.092	98.41	0.12	15.37
4	Chapali	New chabel	34.502	6.923	316.7	0.73	211.7
5	New chabel	Lainchour	1.035	4.974	45.88	0.32	2.68
6	Teku	Siuchatar S/S2	32.495	15.416	325.6	0.45	71.79
7	K3	Teku	8.339	3.789	82.98	0.06	1.99
8	Siuchatar S/S2	Patan	45.053	2.607	410.1	0.79	332.6
9	Patan	Baneshwor	11.688	4.986	115.8	0.26	20.44
10	Bhaktapur	Baneshwor	16.099	-5.263	153.9	0.26	147
11	Lamosangu	Bhaktapur2	70.638	18.036	327.8	2.04	840.2
12	Khimti S/S	Lamosangu	42.929	10.912	195.1	2.59	597.9
13	Bhaktapur	Banepa	6.539	-8.78	100	0.51	72.73
14	Banepa	Panchkhal	18.015	-3.133	166.1	0.53	147.2
15	Indrawati S/S	Panchkhal	6.471	-0.37	58.35	0.89	63.48
16	Siuchatar S/S	Matatirtha	68.342	11.39	308.2	0.03	15.71
17	Matatirtha	kulekhani	34.984	3.013	156.2	0.47	144.3
20	Marsyangdi S/S	Siuchatar S/S	9.224	4.269	45.21	1.01	49.95
21	Marsyangdi S/S	Bharatpur	86.857	-20.014	392.5	0.03	1271.9
22	Damauli	Bharatpur	36.616	-17.972	180.1	0.25	702.7
23	Bharatpur	Hetauda	8.888	39.151	176.8	5.32	646.3

S.N.	From Bus	To Bus	MW Flow	Mvar Flow	Amp Flow	% V Drop	kW Losses
24	Bharatpur	Kawaswati	80.108	0.259	352.8	2.17	1888.8
25	Bardaghat	Kawaswati	64.792	-10.463	295.5	0.8	1247
26	Bardaghat	Butwal	70.454	48.955	404.3	3.52	1133.5
27	Shivapur	Butwal	68.152	6.858	327	1.19	669.1
28	Kali	Butwal	124.737	18.297	594.2	3.94	3367.3
29	Lekhnath	Damauli	46.035	3.092	209.5	2.73	1114.8
30	Lamahi	Shivapur	40.974	-6.305	197.9	0.43	325.9
31	Ghorahi	Lamahi	2.983	1.444	15.9	0.03	0.479
32	Lamahi	Kusum	12.131	-4.814	62.6	0.11	58.06
33	Hapure	Kusum	8.143	3.944	43.49	0.31	12.08
35	Syangja	Lekhnath	33.248	-10.252	158	0.17	390.1
36	Pokhara	Lekhnath	13.856	14.932	92.54	0.05	2.83
37	Modikhola	Pokhara	7.628	-2.683	36.73	0.01	15.6
38	Marsyangdi	Markhi chowk	24.894	-12.255	122.2	0.01	2.46
39	Trishuli	Balaju	28.825	-2.318	254.2	2.4	790.2
40	Chilime	Trishuli	21.95	-2.241	188.9	2.67	785
41	Devighat	Trishuli	10.309	-2.353	92.97	0.11	21.96
42	Devighat	Okhaltar	22.344	-3.675	199.3	1.5	442.5
43	Okhaltar	Chapali	17.439	-5.736	164.1	0.03	6.34
44	Hetauda	Kamne	16.263	10.079	80.08	0.12	8.28
45	Hetauda	Parwanipur	12.344	43.503	189.1	0.05	5.9
46	Hetauda DP	Hetauda corridor	7.631	3.664	71.35	0.02	0.84
47	Hetauda corridor	Amelkhgunj	0.42	0.204	3.937	0	0.0025

S.N.	From Bus	To Bus	MW Flow	Mvar Flow	Amp Flow	% V Drop	kW Losses
48	Parwanipur2	Simera	14.432	0.788	113.5	0.02	2.13
49	Parwanipur2	birjung	31.032	-16.184	274.8	0.27	149
50	Anarmani	Damak	17.698	-7.956	84.56	0.19	64.55
51	Sunkoshi	Panchkhal	15.892	-0.77	141.9	1.79	329.9
52	Damak	Duhabi	25.697	7.948	119	1.48	197.5
53	chapali s/s	Bhaktapur2	30.55	-0.51	137.4	0.11	34.32
54	Bardaghat	Gandak s/s	16.761	66.063	309.5	1.14	217.5
55	Markhi chowk	Damauli	62.677	-4.997	276.9	0.27	227.7
56	Middle Marsy	Markhi chowk	86.183	-9.444	379.2	0.68	946.7
57	Mahendranagar	Attaria	19.945	11	101.6	1.43	122.1
58	Syaule	Attaria	23.224	-0.643	103.5	0.18	45.98
59	Phalmanpur	Attaria	28.033	10.252	135.4	1.64	226.3
60	Burigau	Kohalpur	20.868	10.188	110.9	1.98	196
61	Lamki	Burigau	21.604	9.213	109.7	1.23	128.6
62	Kusum	Kohalpur	6.679	-5.465	41.34	0.32	20.22
63	Kamne	Pathlaya	9.429	2.363	40.68	0.12	9.54
64	Pathlaya	Chapur	32.641	-18.025	156.3	0.25	123.5
65	Parwanipur	Pathlaya	12.177	-7.407	59.59	0.06	9.33
66	Dhalkebar	Chapur	60.211	-23.625	271.9	0.33	821.2
67	Dhalkebar	Mirchalya	86.179	-10.532	365	0.49	701.7
68	Mirchalya	Lahan	77.544	-2.579	327.7	0.58	479.1
69	Rupni	Lahan	50.69	40.796	280.8	1.61	342.5
70	Kushaha	Duhabi	92.734	6.711	411.3	1.12	837.3

S.N.	From Bus	To Bus	MW Flow	Mvar Flow	Amp Flow	% V Drop	kW Losses
71	Godak	Damak	58.179	-8.694	255.5	0.33	364.1
72	Phidim	Godak	53.836	-5.346	234.9	0.05	38.29
73	Kabeli	Phidim	52.373	-5.958	228.5	0.14	114.5
78	Phalmanpur	Lamki	27.277	10.686	135.1	1.56	207.9
79	Matatirtha	Trishuli 3B	40.53	-7.629	183.4	0	3.92
81	Hewa	Phidim	2.399	-0.0283	10.41	0	0.0359
82	Singati	Lamosangu	21.898	2.091	96.88	0.29	63.05
83	Kushaha	Rupni	11.186	25.306	121	1.36	94.05
84	Lekhnath	Madi	13.668	7.656	71.13	0.14	8.32
85	Parwanipur	Raxaul	87.999	0.0001	364.7	0.86	749
86	Bhulbhule	Middle Marsy	50.897	-4.615	222.4	0.51	408.7
87	Lamahi	Kusum	12.131	-4.814	62.6	0.11	58.06
88	Kusum	Kohalpur	6.676	-5.471	41.35	0.32	20.25
89	Burigau	Kohalpur	20.871	10.183	110.9	1.98	196.4
90	Lamki	Burigau	21.607	9.205	109.7	1.23	128.8
91	Phalmanpur	Lamki	25.803	10.19	127.9	1.56	196.6
92	Phalmanpur	Attaria	28.036	10.242	135.4	1.64	226.6
93	Mahendranagar	Attaria	19.949	10.994	101.6	1.43	122.3
94	Syangja	Kali	33.715	-12.652	163.2	0.24	218.3
95	K3	Siuchatar	10.927	5.542	111	0.51	24.42
96	Khimti	Dhalkebar	12.753	-16.372	89.08	2.14	177.3
97	Duhabi	Rupni	26.184	11.38	126.3	2.47	295.7
98	Middle Marsy	Damauli	36.537	-3.153	160.4	0.95	491.7

S.N.	From Bus	To Bus	MW Flow	Mvar Flow	Amp Flow	% V Drop	kW Losses
99	Balaju S/S2	Balaju S/S	21.713	4.092	98.41	1.1	31.24
100	Siuchatar S/S2	Siuchatar S/S	18.612	3.908	84.6	1.25	27.49
101	Siuchatar S/S2	Siuchatar S/S	18.612	3.908	84.6	1.25	27.49
102	Siuchatar S/S2	Siuchatar S/S	18.612	3.908	84.6	1.25	27.49
103	Chapali	Chapali S/S	8.64	-3.205	82.33	0.75	4.97
104	Chapali	Chapali S/S	8.64	-3.205	82.33	0.75	4.97
105	Bhaktapur	Bhaktapur2	9.639	3.798	46.58	1.01	6.36
106	Hetauda DP	Hetauda	6.73	-3.3	31.34	0.82	3.17
107	Hetauda DP	Hetauda	6.73	-3.3	31.34	0.82	3.17
108	Parwanipur	Parwanipur2	22.733	-38.735	352.7	6.72	71.66
109	Dhalkebar	Dhalekebar S/S	89.87	-5.852	378.6	0.07	130.1

APPENDIX G: Wet Peak Operation of Modified INPS (Case 3)

S.N.	From Bus	To Bus	MW Flow	Mvar Flow	Amp Flow	% V Drop	kW Losses
1	Lainchour	Balaju 2	17.301	-13.913	201.8	0.15	26.89
2	Balaju 2	Siuchatar 2	9.459	-11.808	137.3	0.25	21.57
3	Balaju	Siuchatar	99.958	-43.638	498.8	0.23	395.3
4	Chapali	Balaju	127.539	-44.361	618.3	0.11	630.7
5	Chapali	New chabel	78.871	-5.369	712.3	0.39	418.6
6	New chabel	Lainchour	45.031	-0.483	409.4	0.47	217.9
7	Teku	Siuchatar	39.3	3.913	358.6	0.28	87.17
8	K3	Teku	12.151	9.381	139.6	0.13	5.64
9	Siuchatar 2	Patan	25.69	-8.47	244.9	0.01	69.13
10	Patan	Baneshwor	12.344	8.208	134.2	0.28	16.03
11	Bhaktapur	Baneshwor	41.257	-0.0054	368.3	1.1	492.5
12	Lamosangu	Bhaktapur2	253.148	-8.131	1129	2.57	10107.1
13	Bhotekoshi	Lamosangu	29.948	-2.32	133.3	0.44	181.8
14	Khimti	Lamosangu	195.209	-0.841	869.9	8.42	12032.5
15	Bhaktapur	Banepa	6.51	-7.416	88.54	0.51	28.16
16	Banepa	Panchkhal	16.908	-2.31	152.8	0.19	61.65
17	Indrawati	Panchkhal	6.472	-0.364	57.81	0.41	30.82
18	Siuchatar	Matatirtha	28.048	-44.463	239.9	0.04	9.5
19	Matatirtha	Kulekhani 2	56.678	-36.651	307.8	0.84	548.9
20	Kulekhani 2	Hetauda	88.169	-37.832	433.8	0.12	248.1

S.N.	From Bus	To Bus	MW Flow	Mvar Flow	Amp Flow	% V Drop	kW Losses
21	Siuchatar	Kulekhani 1	30.844	2.724	280.4	1.51	375.3
22	Hetauda DP	Kulekhani 1	45.532	-9.769	415.1	0.27	454.1
23	Marsyangdi	Siuchatar	11.816	8.361	67.56	2.15	111.4
24	Marsyangdi	Bharatpur	93.864	-8.547	439.9	0.85	1601
25	Damauli	Bharatpur	39.865	-11.279	194	0.57	822
26	Bharatpur	Hetauda	40.676	15.71	205.4	4.01	909
27	Bharatpur	Kawaswati	109.754	-16.106	522.5	1.28	4133.9
28	Bardaghat	Kawaswati	77.053	-41.272	417.5	1.81	2479.2
29	Bardaghat	Butwal	93.634	12.27	452.3	2.07	1447.7
30	Shivapur	Butwal	85.693	-5.598	411.3	0.85	1060.7
31	Kali	Butwal	120.969	3	579.5	2.86	3219.5
32	Lekhnath	Damauli	55.242	-6.846	260.6	1.88	1722.8
33	Lamahi	Shivapur	52.02	-5.541	252.9	0.65	535.7
34	Ghorahi	Lamahi	12.063	5.843	65.37	0.14	8.88
35	Lamahi	Kusum	13.675	6.731	75.25	1.24	83.91
36	Hapure	Kusum	10.796	3.548	56.32	0.33	20.61
38	Syangja	Lekhnath	62.594	-25.052	322.1	1.43	1632.9
39	Pokhara	Lekhnath	6.071	12.742	67.46	0.04	1.5
40	Modikhola	Pokhara	34.061	-2.843	162.3	0.6	321.6
41	Marsyangdi	Markhi chowk	16.502	-10.126	90.37	0.01	1.35
42	Chilime	Trishuli	21.947	-2.371	194.3	1.2	484.9
43	Devighat	Trishuli s/s	38.235	-4.675	343.2	0.25	175
44	Devighat	Okhaltar	49.128	-6.419	442.6	0.88	854.9

S.N.	From Bus	To Bus	MW Flow	Mvar Flow	Amp Flow	% V Drop	kW Losses
45	Okhaltar	Chapali	43.825	-10.507	406.2	0.03	38.94
46	Hetauda	Kamne	24.946	1.758	113	0.08	16.86
47	Hetauda	Parwanipur	68.344	-2.686	308.8	0.02	15.77
48	Simera	Amelkhgunj	30.368	-27.683	367	0.07	22.25
49	Hetauda DP	Hetauda cor	42.764	-21.596	428.3	0.03	30.31
50	Hetauda cor	Amelkhgunj	30.9	-27.394	369	0.07	22.5
51	Parwanipur2	Simera	17.184	-19.685	233.2	0.06	8.98
52	Parwanipur2	birjung	48.687	-4.316	435.9	0.52	376.7
53	Anarmani	Damak	38.764	9.562	181.9	1.39	304.9
54	Sunkoshi	Panchkhal	13.913	-0.517	123.6	0.89	146
55	Damak	Duhabi	2.835	2.482	16.97	0.25	3
56	Chapali	Bhaktapur2	179.532	-44.911	846.9	0.05	1303
57	Bardaghat	Gandak	33.839	54.561	300.7	1.07	205.8
58	Markhi chowk	Damauli	72.096	-7.702	338.4	0.28	340.2
59	Middle Marsy	Markhi chowk	84.625	-10.566	395.4	0.63	1029.3
60	Mahendranagar	Attaria	19.579	-4.423	87.8	0.12	92.69
61	Syaule	Attaria	26.226	-3.242	115.6	0.12	57.27
62	Phalmanpur	Attaria	26.57	-7.106	120.4	0.03	179.4
63	Burigau	Kohalpur	39.53	-0.737	173.9	1.19	499.9
64	Lamki	Burigau	20.622	-1.17	90.51	0.38	89.12
65	Kamne	Pathlaya	7.476	-6.703	45.37	0.12	10
66	Pathlaya	Chapur	23.928	-11.263	119.4	0.11	71.89
67	Parwanipur	Pathlaya	24.023	-10.675	118.7	0.06	38.66

S.N.	From Bus	To Bus	MW Flow	Mvar Flow	Amp Flow	% V Drop	kW Losses
68	Dhalkebar	Chapur	16.168	16.028	102.6	1.4	98.99
69	Dhalke2	Mirchalya	226.566	-62.78	1090	0.36	6261.7
70	Mirchalya	Lahan	210.229	-68.97	1022	0.55	4642.9
71	Rupni	Lahan	163.181	-58.062	795	0.51	2808.5
72	Kushaha	Duhabi	86.745	-12.089	392.7	0.43	761.7
73	Godak	Damak	62.472	8.7	283.3	0.99	448.4
74	Phidim	Godak	54.051	10.916	245.2	0.12	41.7
75	Kabeli	Phidim	52.285	9.758	236.2	0.36	122.2
76	Gandak	Ramnagar	49.962	53.164	337.8	0.17	37.78
77	Lower Modi	Modikhola	8.981	-0.38	42.67	0.03	3.01
78	Maikhola	Godak	21.95	2.346	98.16	0.02	3.19
79	Butwal1	parasi	9.305	5.138	196.1	0.31	12.74
80	Phalmanpur	Lamki	25.775	-6.753	116.7	0.04	155.6
81	Gongar	New Khimti	149.736	-11.89	362	0.01	15.28
82	Hetauda	Dhalekebar	65.82	9.217	177.8	0.01	3.69
83	Matatirtha	Trishuli 3B	40.637	-2.84	111.9	0	1.46
84	Parasi	Aadhikhola	9.317	5.185	196.1	0.31	12.73
85	Hewa	Phidim	2.398	1.171	11.85	0	0.0462
86	Singati	Lamosangu	21.896	1.948	97.96	0.29	64.55
87	Kushaha	Rupni	88.228	-54.816	474.2	1.75	1483.3
89	Lekhnath	Madi	26.991	2.539	129.5	0.13	27.77
90	Parwanipur	Raxaul	29.897	0.35	135	0.34	102.7
91	Multifuel	Duhabi	9.981	10.009	63.66	0.16	6.64

S.N.	From Bus	To Bus	MW Flow	Mvar Flow	Amp Flow	% V Drop	kW Losses
92	Bhulbhule	Middle Marsy	49.889	-4.992	231.3	0.49	442.1
93	Dhaula	Modikhola	14.933	1.333	71.2	0.48	66.71
94	Lamahi	Kusum	13.675	6.731	75.25	1.24	83.91
95	Kusum	Khol 2	13.828	10.371	86.81	1.5	95.11
96	Lamki	Burigau	20.621	-1.182	90.51	0.38	89.28
97	Phalmanpur	Lamki	24.382	-6.478	110.5	0.04	147.2
98	Phalmanpur	Attaria	26.566	-7.122	120.4	0.03	179.7
99	Mahendranagar	Attaria	19.577	-4.435	87.8	0.12	92.85
100	Syangja	Kali	60.808	-32.914	325.3	1.21	870
101	K3	Siuchatar 2	13.782	3.179	128.6	0.41	32.84
102	Duhabi	Rupni	50.891	-20.957	251.3	1.32	1192.7
103	Middle Marsy	Damauli	37.431	-3.72	174.4	0.9	581.3
104	Gongar1	New Khimti 2	283.945	-3.905	758.9	1.39	4768.2
106	Balaju 2	Balaju	26.901	-4.234	247.2	0.73	49.28
107	Siuchatar 2	Siuchatar	19.831	-3.355	182.1	0.75	31.84
108	Siuchatar 2	Siuchatar	19.831	-3.355	182.1	0.75	31.84
109	Siuchatar	Siuchatar	19.831	-3.355	182.1	0.75	31.84
110	Chapali	Chapali	17.542	-6.784	169.5	1.55	21.06
111	Chapali	Chapali	17.542	-6.784	169.5	1.55	21.06
112	Bhaktapur	Bhaktapur2	34.775	-11.85	327.9	2.43	78.84
116	Hetauda DP	Hetauda	9.397	-3.824	90.7	0.99	6.63
117	Chameliya	Syaule	17.632	0.164	925.5	0	24.67
121	Parwanipur	Parwanipur2	15.756	-6.747	152.9	1.24	13.46

S.N.	From Bus	To Bus	MW Flow	Mvar Flow	Amp Flow	% V Drop	kW Losses
122	Parwanipur	Parwanipur2	15.756	-6.747	152.9	1.24	13.46
123	Dhalkebar1	Dhalekebar	34.155	-5.112	153.5	0.31	21.37
124	Dhalke2	Dhalke 3	270.583	-41.462	1269	0.21	1460.2
142	Hetauda	Hetauda 2	32.91	19.045	101.7	1.24	20.86
143	Hetauda	Hetauda 2	32.91	19.045	101.7	1.24	20.86
144	Matatirtha	Matatirtha	20.292	-2.429	93.21	0.37	25.22
145	Matatirtha	Matatirtha	20.292	-2.429	93.21	0.37	25.22
153	khimti s/s	New Khimti	149.72	52.387	382.3	2.31	2354.5

APPENDIX H: Wet Peak Operation of Modified INPS (Case 4)

S.N.	From Bus	To Bus	MW Flow	Mvar Flow	Amp Flow	% V Drop	kW Losses
1	Lainchour	Balaju 2	5.291	6.991	76.36	0.14	3.84
2	Balaju 2	Siuchatar 2	21.581	-6.885	197	0	44.71
3	Balaju	Siuchatar	94.86	-18.188	426.1	0.07	288.6
4	Chapali	Balaju	119.191	-22.409	534.4	0.12	471.6
5	Chapali	New chabel	55.505	-2.54	479.7	0.29	189.8
6	New chabel	Lainchour	21.827	6.142	197.5	0.59	50.62
7	Teku	Siuchatar 2	39.915	2.951	349	0.26	82.55
8	K3	Teku	12.334	9.785	137.5	0.13	5.47
9	Siuchatar 2	Patan	28.353	-12.819	270.6	0.1	84.37
10	Patan	Baneshwor	10.312	11.286	132.8	0.32	15.7
11	Bhaktapur	Baneshwor	39.198	-0.222	339.5	1.11	418.6
12	Lamosangu	Bhaktapur2	253.979	4.854	908.4	3.26	9277.5
13	Bhotekoshi	Lamosangu	29.954	-2.114	127.2	0.45	165.7
14	Khimti	Lamosangu	196.308	11.319	836.6	9.17	11121.2
15	Bhaktapur	Banepa	6.311	-7.319	83.18	0.49	24.83
16	Banepa	Panchkhal	16.876	-2.157	146.2	0.19	56.38
17	Indrawati	Panchkhal	6.474	-0.335	55.47	0.41	28.39
18	Siuchatar	Matatirtha	29.752	-29.993	186.5	0.02	5.74
19	Matatirtha	Kulekhani 2	58.24	-20.642	272.7	0.13	434.5
20	Kulekhani 2	Hetauda	89.848	-21.077	406.8	0.04	218.5
21	Siuchatar 2	Kulekhani 1	27.752	-2.979	241.2	0.66	277.5

S.N.	From Bus	To Bus	MW Flow	Mvar Flow	Amp Flow	% V Drop	kW Losses
22	Hetauda DP	Kulekhani 1	49.007	-3.289	424.4	0.74	475.2
23	Marsyangdi	Siuchatar	9.216	26.037	129.7	5.89	415.2
24	Marsyangdi	Bharatpur	100.388	0.806	471.3	1.56	1839.3
25	Damauli	Bharatpur	45.954	-8.102	220	1.16	1062.3
26	Bharatpur	Hetauda	42.857	40.122	280.3	7.57	1681.4
27	Bharatpur	Kawaswati	118.855	5.25	602.8	5.29	5509
28	Bardaghat	Kawaswati	90.843	-8.317	462.2	1.63	3056.9
29	Bardaghat	Butwal	21.345	-29.308	187.2	1.25	232.1
30	Shivapur	Butwal	69.915	-12.146	361.1	0.37	814.1
31	Kali	Butwal	165.618	34.683	861.1	6.76	7075.1
32	Lekhnath	Damauli	40.136	-1.838	189.4	1.85	912.2
33	Lamahi	Shivapur	37.073	-13.011	200.8	0.08	329.8
34	Ghorahi	Lamahi	11.881	5.754	67.52	0.15	9.5
35	Lamahi	Kusum	6.633	2.082	35.66	0.41	18.67
36	Hapure	Kusum	10.665	3.506	57.83	0.34	21.76
38	Syangja	Lekhnath	58.201	-20.133	296.3	0.9	1382
39	Pokhara	Lekhnath	3.797	-14.665	72.9	0.04	1.76
40	Modikhola	Pokhara	44.043	-3.772	211.1	0.72	544.2
41	Marsyangdi	Markhi chowk	25.634	-18.36	148	0.01	3.62
42	Trishuli	Balaju 2	35.179	-2.791	304.1	0.92	441.8
43	Chilime	Trishuli	21.951	-2.217	187.8	1.24	453.3
44	Devighat	Trishuli	3.093	-1.51	29.66	0.02	1.3
45	Devighat	Okhaltar	14.149	-2.625	124	0.23	66.6

S.N.	From Bus	To Bus	MW Flow	Mvar Flow	Amp Flow	% V Drop	kW Losses
46	Okhaltar	Chapali	9.559	-4.222	90.24	0.03	1.92
47	Hetauda	Kamne	25.158	1.231	111.2	0.07	16.32
48	Hetauda	Parwanipur	67.627	-6.656	299.7	0.01	14.85
49	Simera	Amelkhgunj	32.362	-23.403	347.4	0.05	19.94
50	Hetauda DP	Hetauda cor	44.883	-17.268	418.6	0.01	28.96
51	Hetauda cor	Amelkhgunj	32.896	-23.12	349.9	0.05	20.23
52	Parwanipur2	Simera	19.043	-19.753	238.6	0.05	9.4
53	Parwanipur2	birjung	49.188	-5.691	430.3	0.45	367
54	Anarmani	Damak	34.014	6.827	154.5	1.07	219.8
55	Sunkoshi	Panchkhal	13.919	-0.477	118.6	0.88	134.6
56	Damak	Duhabi	13.648	-14.907	89.04	1.12	105
57	Chapali	Bhaktapur2	182.193	-27.548	809.7	0.27	1191.6
58	Bardaghat	Gandak	57.553	19.493	316.3	0.66	230.4
59	Markhi chowk	Damauli	63.892	-0.527	300	0.39	267.9
60	Middle Marsy	Markhi chowk	85.56	-11.462	402.7	0.6	1067.3
61	Mahendranagar	Attaria	19.788	-0.785	86.62	0.45	91.64
62	Syaule	Attaria	41.058	3.626	181.1	0.45	140.8
63	Phalmanpur	Attaria	33.947	0.412	150.4	0.84	284.3
64	Burigau	Kohalpur	53.325	8.167	251.1	2.96	1036.7
65	Lamki	Burigau	27.941	5.403	128.4	1.02	178.3
66	Kamne	Pathlaya	7.527	-7.308	46.3	0.14	10.26
67	Pathlaya	Chapur	24.163	-12.611	120.1	0.16	72.4
68	Parwanipur	Pathlaya	24.277	-11.867	119.2	0.08	38.85

S.N.	From Bus	To Bus	MW Flow	Mvar Flow	Amp Flow	% V Drop	kW Losses
69	Dhalkebar	Chapur	16.312	16.822	103.1	1.42	98.97
70	Dhalke2	Mirchalya	172.226	-60.696	814.2	0.63	3487.7
71	Mirchalya	Lahan	158.503	-55.33	743.7	0.43	2456.8
72	Rupni	Lahan	113.888	-42.403	536.1	0.35	1273.1
73	Kushaha	Duhabi	65.029	-9.287	285.2	0.33	401.1
74	Godak	Damak	72.774	-9.98	322.2	0.43	580.2
75	Phidim	Godak	64.029	-3.031	281	0.07	54.81
76	Kabeli	Phidim	62.388	-3.86	273.4	0.21	164.2
77	Gandak	Ramnagar	42.341	20.506	245.1	0.09	19.9
78	Lower Modi	Modikhola	8.982	-0.385	42.91	0.03	3.05
79	Maikhola	Godak	21.955	-0.851	96.36	0.01	3.08
80	Butwal1	Parasi	9.294	5.061	206.7	0.33	14.15
81	Phalmanpur	Lamki	33.293	0.467	148.7	0.77	256.3
82	Gongar	New Khimti	149.765	-10.785	344.8	0.01	13.86
83	Hetauda 1	Dhalekebar 1	65.502	10.105	173.1	0.01	3.49
84	Matatirtha	Trishuli 3B	40.64	-2.656	108.2	0	1.37
85	Parasi	Aadhikhola	9.308	5.113	206.7	0.33	14.15
86	Hewa	Phidim	2.399	0.329	10.61	0	0.0372
87	Singati	Lamosangu	21.905	2.512	93.81	0.3	58.91
88	Kushaha	Rupni	56.244	-38.991	300.8	1.23	594.9
89	New Khimti 2	Dhalkeber 2	268.352	-5.794	714.7	2.1	6334.2
90	Lekhnath	Madi	26.99	2.486	130.4	0.13	28.14
91	Parwanipur	Raxaul	29.901	0.404	131.9	0.33	97.93

S.N.	From Bus	To Bus	MW Flow	Mvar Flow	Amp Flow	% V Drop	kW Losses
92	Multifuel	Duhabi	19.977	-1.032	87.1	0.05	12.56
93	Bhulbhule	Middle Marsy	49.886	-5.054	232.7	0.49	447.5
94	Kushma2	Modikhola	24.906	0.424	118.9	0.36	93.69
95	Lamahi	Kusum	6.633	2.082	35.66	0.41	18.67
96	Lamki	Burigau	27.942	5.394	128.4	1.02	178.6
97	Phalmanpur	Lamki	31.493	0.529	140.7	0.77	242.4
98	Phalmanpur	Attaria	33.946	0.4	150.4	0.84	284.8
99	Mahendranagar	Attaria	19.787	-0.798	86.62	0.45	91.79
100	Syangja	Kali	56.698	-27.046	299.2	0.89	736.6
101	K3	Siuchatar 2	14.011	2.974	125.1	0.39	31.05
102	Duhabi	Rupni	34.805	-15.621	167.7	0.9	525.4
103	Middle Marsy	Damauli	36.483	-3.027	170.8	0.98	557.9
104	Gongar1	New Khimti 2	272.658	-21.488	721.5	0.93	4306.2
105	Balaju 2	Balaju	23.822	-6.553	214.9	1.44	37.24
106	Siuchatar 2	Siuchatar	18.368	-5.573	166.9	1.51	26.76
107	Siuchatar2	Siuchatar	18.368	-5.573	166.9	1.51	26.76
108	Siuchatar 2	Siuchatar	18.368	-5.573	166.9	1.51	26.76
109	Chapali	Chapali	22.974	-9.464	214.5	2.06	33.74
110	Chapali	Chapali	22.974	-9.464	214.5	2.06	33.74
111	Bhaktapur	Bhaktapur2	33.331	-12.605	305.3	2.59	68.31
114	Hetauda DP	Hetauda	8.868	-5.08	88.96	1.32	6.38
115	Hetauda DP	Hetauda	8.868	-5.08	88.96	1.32	6.38
116	Chameliya	Syaule	28.061	0.784	1473	0	62.53

S.N.	From Bus	To Bus	MW Flow	Mvar Flow	Amp Flow	% V Drop	kW Losses
120	Parwanipur	Parwanipur2	15.077	-8.17	149	1.5	12.79
121	Parwanipur	Parwanipur2	15.077	-8.17	149	1.5	12.79
122	Dhalkebar	Dhalekebar 2	34.47	-5.727	151.6	0.35	20.85
123	Dhalke2	Dhalkeber 2	207.955	-43.392	947.1	1.64	813.9
128	Hetauda	Hetauda 2	32.751	20.192	100.5	1.28	20.37
129	Hetauda	Hetauda 2	32.751	20.192	100.5	1.28	20.37
130	Matatirtha	Matatirtha	20.296	-2.255	90.14	0.32	23.59
131	Matatirtha	Matatirtha	20.296	-2.255	90.14	0.32	23.59
132	Khimti s/s	New Khimti	149.75	60.044	370.5	2.32	2211

APPENDIX I: Transmission Line Data

S.N.	Substaion	To Bus	Voltage (kV)	Length	Conductor	Rpu	Xpu	R0	X0
1	Anarmani	Damak	132	28	Bear	0.01746	0.06386	3.04195	11.1261
2	Anarmani	Puwa	33	40	Dog	1.0072	1.4848	10.9684	16.1695
3	Askstell-1	Trivspinmill	66	7	Wolf	0.02913	0.06124	1.2691	2.66752
4	Askstell-1	Suryanepal	66	1.5	Wolf	0.00624	0.01312	0.27195	0.57161
5	Askstell-2	Himal-Iron	66	8	Wolf	0.0333	0.06999	1.4504	3.0486
6	Ataria	Lumki	132	73	Bear	0.04552	0.16648	7.93079	29.0074
7	Balaju	Chapali	132	10	Bear	0.00624	0.02281	1.08641	3.97361
8	Balaju	Trishuli	66	29	Dog	0.18265	0.292	7.95637	12.7196
9	Balaju	Trishuli	66	29	Dog	0.18265	0.292	7.95637	12.7196
11	Balaju	Lainchour	66	2.3	Panther	0.00716	0.0218	0.31184	0.94978
12	Bardghat	Gandak	132	14	Panther	0.01089	0.13272	1.89819	23.1251
13	Bardghat	Kawasoti	132	42	Panther	0.03268	0.39816	5.69456	69.3754
14	Bhaktapur	Chapali	132	12	Bear	0.00748	0.02737	1.30369	4.76834
15	Bharatpur	Hetauda	132	67	Panther	0.05214	0.63516	9.08418	110.67
16	Bharatpur	Kawasoti	132	28	Panther	0.02179	0.26544	3.79637	46.2503
17	Bharatpur	Damauli	132	39	Wolf	0.04058	0.09446	7.07057	16.4584
18	Bhotekoshi	Lamosangu	132	30	Bear	0.01871	0.06842	3.25923	11.9208
19	Birgunj	Tr.Sp.Yn	66	5	Wolf	0.02081	0.04374	0.9065	1.90537
20	Butwal	Bardghat	132	43	Bear	0.02681	0.09806	4.67156	17.0865

S.N.	Substaion	To Bus	Voltage (kV)	Length	Conductor	Rpu	Xpu	R0	X0
21	Butwal	Kg-A	132	40	Duck	0.02179	0.09301	3.79669	16.2061
22	Chabel	Devighat	66	31	Dog	0.19525	0.31214	8.50509	13.5968
23	Chandran	Patha	132	17	Bear	0.0106	0.03877	1.8469	6.75514
24	Chilime	Mailung	66	14.1	Wolf	0.05869	0.12335	2.55633	5.37316
25	Damauli	Lekhnath	132	40	Wolf	0.04162	0.09688	7.25187	16.8804
26	Dhalke	Chandran	132	60	Bear	0.03741	0.13683	6.51846	23.8417
27	Dhalke	Mirchay	132	32	Bear	0.01995	0.07298	3.47651	12.7156
28	Duhabi	Damak	132	48	Bear	0.02993	0.10947	5.21477	19.0733
29	Hamasteel	Amlekh-2	66	9.5	Wolf	0.03954	0.08311	1.72235	3.62021
30	Hamasteel	Simra-2	66	0.5	Wolf	0.00208	0.00437	0.09065	0.19054
31	Hetauda	Kl-Ii	132	8	Bear	0.00499	0.01824	0.86913	3.17889
32	Hetauda	Patha	132	37	Bear	0.02307	0.08438	4.01972	14.7024
33	Hetauda	Kl-I	66	16	Wolf	0.06659	0.13997	2.9008	6.0972
34	Hetauda	Htcem-1	66	1	Wolf	0.00416	0.00875	0.1813	0.38107
35	Himal-Iron	Jyotispining	66	0.5	Wolf	0.00208	0.00437	0.09065	0.19054
36	Him-Iron	Parwani	66	1	Wolf	0.00416	0.00875	0.1813	0.38107
37	Htcem-1	Amlekh-1	66	13	Wolf	0.05411	0.11373	2.3569	4.95397
38	Htcem-2	Amlekh-2	66	13	Wolf	0.05411	0.11373	2.3569	4.95397
39	Hulastll	Jagdamba	66	0.7	Wolf	0.00291	0.00612	0.12691	0.26675
40	Hulastll	Amlekh-1	66	8.7	Wolf	0.03621	0.07611	1.57731	3.31535
41	Kg-A	Syangja	132	23	Duck	0.01253	0.05348	2.1831	9.31849

S.N.	Substaion	To Bus	Voltage (kV)	Length	Conductor	Rpu	Xpu	R0	X0
42	Khimti1	Lamosang	132	46	Bear	0.02868	0.1049	4.99749	18.2786
43	Khudi	Damauli	33	46	Dog	1.15828	1.70752	12.6137	18.5949
44	Kl-I	Siuchatar	66	29	Wolf	0.1207	0.2537	5.25769	11.0512
45	Kl-Ii	Matatritha	132	30.6	Bear	0.01908	0.06978	3.32441	12.1593
46	Kohalpur	Lamahi	132	96	Bear	0.05986	0.21893	10.4295	38.1467
47	Lahan	Mirchay	132	28	Bear	0.01746	0.06386	3.04195	11.1261
48	Lahan	N-Duhabi	132	81	Bear	0.0505	0.18472	8.79992	32.1863
49	Lamahi	Jhimruk	132	50	Bear	0.03118	0.11403	5.43205	19.8681
50	Lamahi	Shivpur	132	51	Bear	0.0318	0.11631	5.54069	20.2654
51	Lamosang	Bhaktapur	132	48.2	Bear	0.03005	0.10992	5.2365	19.1528
52	Lamosang	Singati	132	41	Bear	0.02556	0.0935	4.45428	16.2918
53	Lekhnath	Syangja	132	42	Duck	0.02288	0.09766	3.98652	17.0164
54	Low_Mod	New Modi	132	5	Bear	0.00312	0.0114	0.5432	1.98681
55	Lumki	Kohalpur	132	80	Bear	0.04988	0.18244	8.69128	31.7889
56	Mahendra	Ataria	132	37	Bear	0.02307	0.08438	4.01972	14.7024
57	Marshyan	Siuchatar	132	84	Duck	0.04576	0.19532	7.97305	34.0327
58	Marshyan	N-Marsya	132	7	Duck	0.00381	0.01628	0.66442	2.83606
59	Marshyan	N-Marsya	132	7	Duck	0.00381	0.01628	0.66442	2.83606
60	Marshyan	N_Bhara	132	22	Duck	0.01198	0.05116	2.08818	8.91333
61	Midmars	N-Marsya	132	37	Cardinal	0.01295	0.0629	2.25641	10.9597
62	Modi	Banskot	132	30	Bear	0.01871	0.06842	3.25923	11.9208

S.N.	Substaion	To Bus	Voltage (kV)	Length	Conductor	Rpu	Xpu	R0	X0
63	Modi	New Modi	132	1	Bear	0.00062	0.00228	0.10864	0.39736
64	Multifl	Duhabi	33	5	Dog	0.1259	0.1856	1.37105	2.02118
66	Parwani	Patha	132	17	Bear	0.0106	0.03877	1.8469	6.75514
67	Parwani	Birgunj	66	9	Wolf	0.03746	0.07873	1.6317	3.42967
68	Parwani	Tr.Sp.Yn	66	4	Wolf	0.01665	0.03499	0.7252	1.5243
69	Parwani	Himal-Iron	66	1	Wolf	0.00416	0.00875	0.1813	0.38107
70	Parwani	Jyoti	66	0.5	Wolf	0.00208	0.00437	0.09065	0.19054
71	Pokhara	Banskot	132	10	Bear	0.00624	0.02281	1.08641	3.97361
72	Pokhara	Lekhnath	132	6	Wolf	0.00624	0.01453	1.08778	2.53206
73	Shivpur	Butwal	132	61	Bear	0.03803	0.13911	6.6271	24.239
74	Simra-1	Suryanepal	66	0.5	Wolf	0.00208	0.00437	0.09065	0.19054
75	Simra-2	Askstell-2	66	2	Wolf	0.00832	0.0175	0.3626	0.76215
76	Singati	Sipring	132	7	Wolf	0.00728	0.01695	1.26908	2.95406
77	Siuchatar	Balaju	132	7	Bear	0.00436	0.01596	0.76049	2.78153
78	Siuchatar	Matatritha	132	3.4	Bear	0.00212	0.00775	0.36938	1.35103
79	Siuchatar	Balaju	66	7	Wolf	0.02913	0.06124	1.2691	2.66752
80	Siuchatar	Balaju	66	7	Wolf	0.02913	0.06124	1.2691	2.66752
81	Siuchatar	Patan	66	2	Wolf	0.00832	0.0175	0.3626	0.76215
82	Siuchatar	Patan	66	2	Wolf	0.00832	0.0175	0.3626	0.76215
83	Tr.Spinn	Him-Iron	66	1	Wolf	0.00416	0.00875	0.1813	0.38107
84	Trishuli	Devighat	66	5	Wolf	0.02081	0.04374	0.9065	1.90537

APPENDIX J: Substation Load Data

POWER TRANSFORMER LOADING STATUS(FY 076/077)											
S.No	**Substation**	**Voltage**	**Nos**	**Capacity**	**Total**			**Max Load**	**Forecasted Load**		
		Ratio, kV			Capacity	Bhadra	Mangsir	MVA	Bhadra	Mansir	Max
		kV		MVA	MVA	MVA	MVA		MVA	MVA	MVA
A	**Kathmandu Grid Division**										
1	Balaju	132/66	1	45	45	43.43856	41.1523	43.43856	46.914	44.445	46.914
		66/11	2	22.5	45	20.0046	18.2899	20.0046	21.605	19.753	21.605
		66/11		22.5		20.0046	18.2899	20.57616	21.605	19.753	22.222
2	Siuchatar	132/66	3	37.8	113.4	27.43488	27.4349	29.72112	29.63	29.63	32.099
		132/66		37.8		27.43488	27.4349	29.72112	29.63	29.63	32.099
		132/66		37.8		29.26387	28.1208	29.263872	31.605	30.37	31.605
		66/11	2	18	36	12.00276	12.0028	16.57524	12.963	12.963	17.901
		66/11		18		12.00276	11.4312	16.57524	12.963	12.346	17.901
3	New Chabahil	66/11	3	22.5	67.5	12.46001	12.9173	12.917256	13.457	13.951	13.951
		66/11		22.5		12.46001	12.9173	12.917256	13.457	13.951	13.951
		66/11		22.5		12.23138	11.7741	12.231384	13.21	12.716	13.21
4	Lainchour	66/11	2	22.5	45	16.00368	12.3457	16.00368	17.284	13.333	17.284
		66/11		22.5		16.00368	12.3457	16.00368	17.284	13.333	17.284
5	New Patan	66/11	4	18	72	13.83175	12.2314	13.831752	14.938	13.21	14.938
		66/11		18		14.289	12.46	14.631936	15.432	13.457	15.802
		66/11		18		14.63194		16.460928	15.802	0	17.778

POWER TRANSFORMER LOADING STATUS(FY 076/077)											
S.No	**Substation**	**Voltage**	**Nos**	**Capacity**	**Total**			**Max Load**	**Forecasted Load**		
		Ratio, kV			Capacity	Bhadra	Mangsir	MVA	Bhadra	Mansir	Max
		kV		MVA	MVA	MVA	MVA		MVA	MVA	MVA
		66/11		18		0	13.1459	14.174688	0	14.198	15.309
6	Teku	66/11	2	22.5	45	15.31781	13.6031	15.317808	16.543	14.691	16.543
		66/11		22.5		15.31781	13.6031	15.317808	16.543	14.691	16.543
7	K3	66/11	2	22.5	45	14.74625	11.6598	14.746248	15.926	12.593	15.926
		66/11		22.5		14.51762	10.1738	14.517624	15.679	10.988	15.679
8	Baneswor	66/11	2	18	36	15.08918	14.4033	15.089184	16.296	15.556	16.296
		66/11		18		14.86056	16.8039	16.803864	16.049	18.148	18.148
9	Bhaktapur	132/66	1	49.5	49.5	41.15232	32.0074	41.15232	44.445	34.568	44.445
		132/11	2	22.5	45	16.91818	17.604	17.604048	18.272	19.012	19.012
		132/11		22.5		15.54643	16.6896	16.689552	16.79	18.025	18.025
10	Banepa	66/11	2	22.5	45	0	0	3.657984	0	0	3.9506
		66/11		22.5		11.65982	12.8029	12.802944	12.593	13.827	13.827
11	Panchkhal	66/11	1	10	10	3.772296	4.45817	12.117072	4.0741	4.8148	13.086
12	Lamosanghu	132/33	1	30	30	17.60405	17.1239	17.604048	19.012	18.494	19.012
13	Matatirtha	132/11	1	22.5	22.5	13.48882	8.00184	14.631936	14.568	8.642	15.802
14	Chapali	132/66	2	49.5	99	24.46277	22.6338	24.462768	26.42	24.444	26.42
		132/66		49.5		24.69139	23.5483	24.691392	26.667	25.432	26.667
		132/11	1	30	30	17.60405	14.8606	17.604048	19.012	16.049	19.012
B	**Hetauda Grid Division**										
15	Hetauda	132/66	2	45	90	30.17837	32.4646	35.43672	32.593	35.062	38.272
		132/66		45		29.94974	32.6932	32.693232	32.346	35.309	35.309

POWER TRANSFORMER LOADING STATUS(FY 076/077)											
S.No	**Substation**	**Voltage**	**Nos**	**Capacity**	**Total**			**Max Load**	**Forecasted Load**		
		Ratio, kV			Capacity	Bhadra	Mangsir	MVA	Bhadra	Mansir	Max
		kV		MVA	MVA	MVA	MVA		MVA	MVA	MVA
		66/11	2	10	20	13.26019	7.88753	13.260192	14.321	8.5185	14.321
		66/11		10		13.26019	7.88753	13.260192	14.321	8.5185	14.321
16	Bharatpur	132/33	2	30	60	17.37542	12.5743	17.375424	18.765	13.58	18.765
		132/33		30		17.37542	12.1171	21.490656	18.765	13.086	23.21
		132/11	1	22.5	52.5	21.26203	12.3457	21.262032	22.963	13.333	22.963
		132/11	1	30		19.20442	18.9758	20.57616	20.741	20.494	22.222
17	Birgunj	66/33	2	12.5	25	7.887528	4.00092	11.888448	8.5185	4.321	12.84
		66/33		12.5		12.80294	7.77322	14.403312	13.827	8.3951	15.556
		66/11	2	30	60	16.68955	10.0595	16.689552	18.025	10.864	18.025
		66/11		30		16.68955	10.0595	16.689552	18.025	10.864	18.025
18	Parwanipur	132/11	3	22.5	67.5	16.00368	15.0892	16.00368	17.284	16.296	17.284
		132/11		22.5		16.00368	15.0892	16.00368	17.284	16.296	17.284
		132/11		22.5		16.00368	15.0892	45.953424	17.284	16.296	49.63
		132/66	2	63	126	48.92554	29.0352	48.925536	52.84	31.358	52.84
		132/66		63		48.92554	29.0352	48.925536	52.84	31.358	52.84
19	Simra	66/11	2	15	30	5.372664	7.54459	8.459088	5.8025	8.1482	9.1358
		66/11		15		9.373584	7.88753	1.562264	10.123	8.5185	1.6872
20	Amlekhgunj	66/11	1	7.5	7.5	0.57156	0.45725	3.543672	0.6173	0.4938	3.8272
21	Pathalaiya	132/11	1	22.5	22.5	8.459088	11.8884	21.033408	9.1358	12.84	22.716
22	Kamane	132/33	1	30	30	19.66166	21.0334	21.033408	21.235	22.716	22.716
C	**Duhabi Grid Branch**										

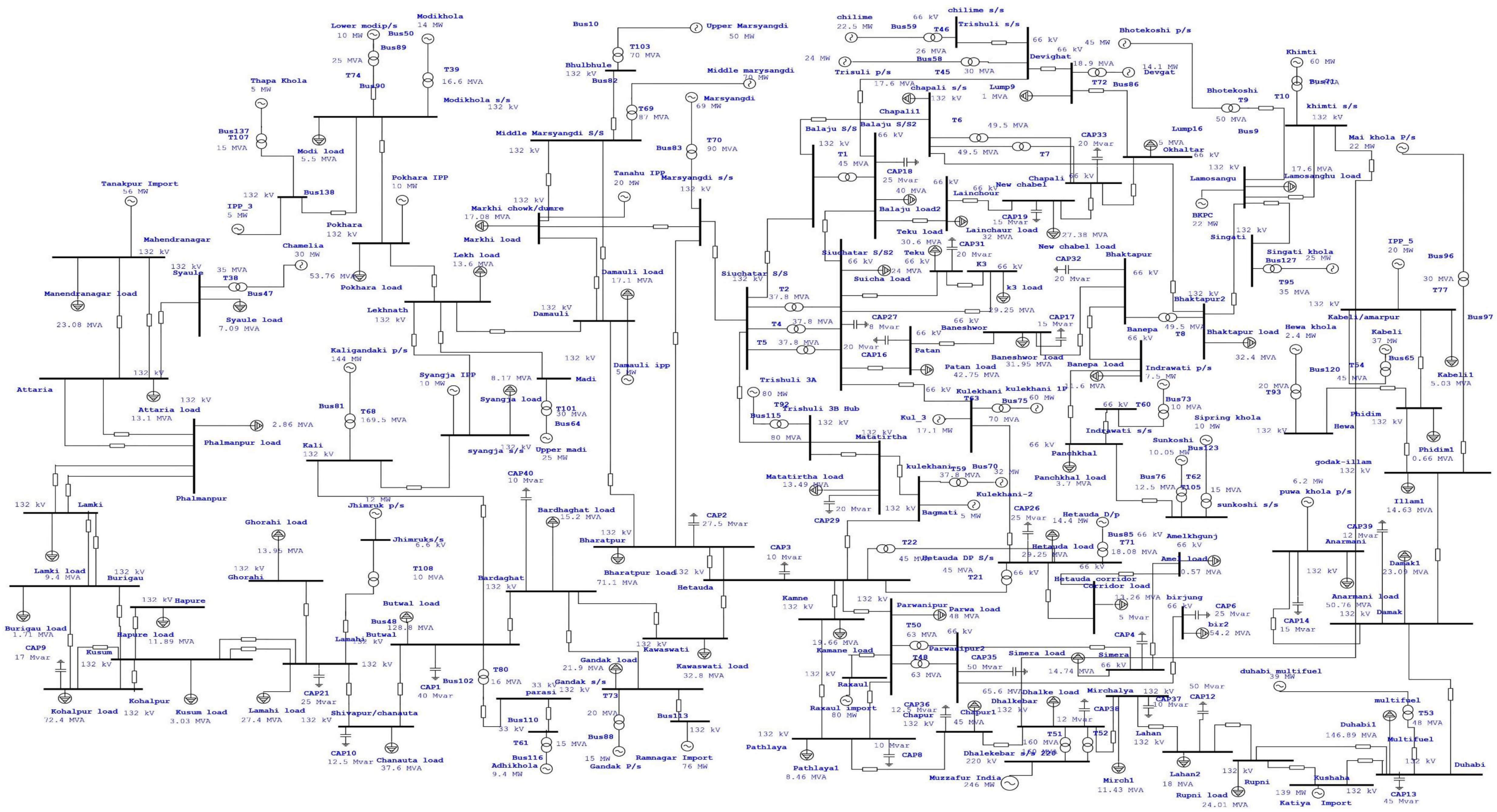
POWER TRANSFORMER LOADING STATUS(FY 076/077)											
S.No	**Substation**	**Voltage**	**Nos**	**Capacity**	**Total**			**Max Load**	**Forecasted Load**		
		Ratio, kV			Capacity	Bhadra	Mangsir	MVA	Bhadra	Mansir	Max
		kV		MVA	MVA	MVA	MVA		MVA	MVA	MVA
23	Duhabi	132/33	3	63	189	55.78426	55.0984	56.698752	60.247	59.506	61.235
		132/33		63		53.04077	53.7266	53.72664	57.284	58.025	58.025
		132/33		63		58.0705	52.5835	58.070496	62.716	56.79	62.716
24	Anarmani	132/33	2	30	60	23.54827	16.4609	23.548272	25.432	17.778	25.432
		132/33		30		27.20626	19.433	27.43488	29.383	20.988	29.63
25	Damak	132/33	1	30	30	23.09102	15.7751	26.749008	24.938	17.037	28.889
26	Godak	132/33	1	63	63	14.63194	7.31597	14.631936	15.802	7.9012	15.802
27	Pidhim	132/33	1	20	20	0.66301	0.9145	0.914496	0.7161	0.9877	0.9877
28	Amarpur	132/33	1	30		0	5.02973	55.784256	0	5.4321	60.247
D	**Dhalkebar Grid Branch**										
28	Lahan	132/33	1	63	63	48.01104	28.578	48.01104	51.852	30.864	51.852
29	Mirchaiya	132/33	1	30	30	11.4312	8.68771	21.033408	12.346	9.3827	22.716
30	Dhalkebar	132/33	1	30	93	26.52038	23.5483	36.57984	28.642	25.432	39.506
		132/33	1	63		39.0947	26.5204	39.094704	42.222	28.642	42.222
31	Chapur	132/33	2	30	60	29.72112	18.0613	29.72112	32.099	19.506	32.099
		132/33		30		14.86056	11.2026	14.86056	16.049	12.099	16.049
32	Rupani	132/33	1	63	63	26.29176	14.289	43.895808	28.395	15.432	47.407
E	**Butwal Grid Division**										
32	Butwal	132/33	3	63	189	52.58352	57.156	57.156	56.79	61.728	61.728
		132/33		63		54.86976	44.8103	61.271232	59.259	48.395	66.173
		132/33		63		51.4404	53.0408	53.955264	55.556	57.284	58.272
33	Bardghat	132/11	1	22.5	30	10.97395	9.83083	11.888448	11.852	10.617	12.84

POWER TRANSFORMER LOADING STATUS(FY 076/077)											
S.No	**Substation**	**Voltage**	**Nos**	**Capacity**	**Total**			**Max Load**	**Forecasted Load**		
		Ratio, kV			Capacity	Bhadra	Mangsir	MVA	Bhadra	Mansir	Max
		kV		MVA	MVA	MVA	MVA		MVA	MVA	MVA
		132/11	1	7.5		4.343856	0	8.535296	4.6914	0	9.2181
34	Chanauta	132/33	1	30	42.5	28.578	23.7769	28.578	30.864	25.679	30.864
		132/33	1	12.5		9.14496	7.77322	23.776896	9.8766	8.3951	25.679
35	Lamahi	132/33	1	30	93	8.230464	6.40147	19.43304	8.8889	6.9136	20.988
		132/33	1	63		19.20442	22.6338	33.379104	20.741	24.444	36.049
36	Kawasoti	132/33	1	30	30	22.8624	15.0892	22.8624	24.691	16.296	24.691
37	Ghorahi	132/33	1	30	30	13.94606	3.42936		15.062	3.7037	0
38	Gandak	132/33	1	30	30	21.9479	4.91542		23.704	5.3086	0
F	**Pokhara Grid Branch**										
37	Damauli	132/33	2	30	60	10.5167	5.94422	10.516704	11.358	6.4198	11.358
		132/33		30		6.630096	12.1171	12.117072	7.1605	13.086	13.086
38	Pokhara	132/11	2	30	60	24.50849	24.4628	24.508493	26.469	26.42	26.469
		132/11		30		29.26387	7.54459	29.263872	31.605	8.1482	31.605
39	Lekhnath	132/11	1	22.5	22.5	13.59627	14.257	26.063136	14.684	15.398	28.148
		132/33	1	30	30			26.520384	0	0	28.642
40	Syangja	132/33	1	30	30	8.173308	6.91588	6.687252	8.8272	7.4691	7.2222
41	Markichowk	132/33	1	30	30	17.07821	19.6754		18.444	21.249	0
G	**Attaria Grid Branch**										
41	Attaria	132/33	2	30	60	10.74533	5.80705	10.745328	11.605	6.2716	11.605
		132/33		30		2.423414	1.48606	20.873371	2.6173	1.6049	22.543
42	Kohalpur	132/33	2	63	93	43.43856	43.6672	43.667184	46.914	47.161	47.161
		132/33		30		29.03525	19.6617	29.035248	31.358	21.235	31.358

POWER TRANSFORMER LOADING STATUS(FY 076/077)											
S.No	**Substation**	**Voltage**	**Nos**	**Capacity**	**Total**			**Max Load**	**Forecasted Load**		
		Ratio, kV			Capacity	Bhadra	Mangsir	MVA	Bhadra	Mansir	Max
		kV		MVA	MVA	MVA	MVA		MVA	MVA	MVA
43	Lamki	132/33	2	15	30	5.349802	5.3498	8.230464	5.7778	5.7778	8.8889
		132/33		15		9.14496	5.39553	9.14496	9.8766	5.8272	9.8766
44	Mahendranagar	132/33	2	15	30	12.80294	9.37358	12.802944	13.827	10.123	13.827
		132/33		15		10.28808	7.38456	10.28808	11.111	7.9753	11.111
45	Kusum	132/11	1	12.5	12.5	0	0	5.944224	0	0	6.4198
46	Syaule	132/33	1	30	30	7.315968	7.54459	7.544592	7.9012	8.1482	8.1482
47	Hapure	132/33	1	30	30	11.88845	9.37358	15.317808	12.84	10.123	16.543
48	Pahalmanpur	132/33	1	30	30	2.8578	2.40055	2.8578	3.0864	2.5926	3.0864
49	Bhurigaun	132/33	1	30	30	1.71468	1.23457	1.771836	1.8519	1.3333	1.9136

APPENDIX K: Plagiarism Report

APPENDIX L: Single line diagram for Existing INPS



APPENDIX M: Single line diagram for New INPS