Ph.D Dissertation

Run-of-River カスケード 水力発電計画および過酷環境を考慮した運用

Planning and Operation of Run-of-River Cascade Hydro Power Considering Extreme Conditions

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Abstract

Increasing consumption of power and economic growth in Nepal implies that the demand for electric power will be increasing rapidly in the upcoming years. Nepal has a tremendous amount of hydroelectricity potential; however, currently installed hydro power plants are less compared to the total potential of hydro power in Nepal. The Himalayan nation Nepal has approximately 6,000 rivers in Nepal and from these rivers, approximately more than 42,000 MW of hydroelectricity is considered to be economically feasible. Currently, the grid-connected electricity coverage is 58% of the total population of Nepal. All the residents of Nepal do not have access to grid-connected electricity, and there is a power shortage and load shedding problems in Nepal.

The electricity grid is limited to urban areas and almost all rural areas are isolated from the grid-connected energy supplies systems. Therefore, most of the rural communities, villages are fulfilled their energy requirements by kerosene lamps, firewood flames, biogas and so on. Therefore, energy consumptions are dominated by traditional energy sources. Micro-hydro power also a major energy supply sources for rural areas. In Nepal, the residential sector is the most electric energy consuming sector and the primary source of the electric supply system is not reliable and secure. Most of the power deficit in dry season compared to the wet season. However, to fulfill the peak demand across the country, Nepal government import a massive amount of electricity from India.

In this dissertation, some methods are presented for addressing the problems of extreme electricity condition and power systems in emergencies cases. There is not enough research to solve the electricity problems and balance the power supply and demand of Nepal. So far, in Nepal Run-of-River (ROR) cascade hydro power techniques are not applied to most of the rivers. There are a great needs for introducing the multiple cascade hydro power plants in the same river rather than a single dam. Applying the cascade hydro power systems we can generate a huge amount of electricity.

There are basically three main objectives of this study; first, design and analyze the planning and operation of the grid-connected existing and proposed cascade hydro power plants; for this reason, in this dissertation, after the existing hydro power plants, we consider a Run-of-River cascade hydro power plants in the downstream of the river to generate the hydroelectricity. This study focuses on clean energy sources, namely Run-

of-River cascade hydroelectricity and presents an intelligent technique for the generation of hydro power. The proposed cascade hydro power plants are medium heads (Head < 50 m) with different installed capacities. Considering the installed capacity for Case 1 is 30 MW and for Case 2 is 40 MW. The study area region has a complex geographical shape formed by high Hills and Mountains together. Based on the hydrology and geology point of view a medium head hydro power plants (HPPs) could consider in the mainstream of Trishuli river after the existing Devighat hydro power plant.

The proposed site is one of the grid-connected area and has massive potential for electricity. The study area for the proposed cascade HPPs, components parameters and expected output power of existing hydro power plants and proposed power plants are analyzed and described. A Power System Computer Aided Design (PSCAD) simulator is introduced to design and analyze the dynamic performance of the existing and proposed cascade hydro power plants. The generated output power of existing and proposed power plants are connected to the 66 kV grid system. All simulation results are analyzed in the PSCAD environment. The expected hydro power generation for all existing and proposed models simulation results are nearly close to considered real value. As it is reported that, the large-scale HPPs are connected to the 66 kV grid with minimum system loses.

As for interconnection of large-scale hydro power plants to the main grid, it should be noted that the system loss in the designed model is less. Therefore, from the designed model generated electric energies are flowing from power plants to system grid is more reliable and secure. The simulation can be observed in real time graphical environment.
However, the design of civil components of the cascade hydro power plants are not mention this study. The exploitable potential of hydroelectric resources requires further analysis for economically, technically and environmentally.

Second, the location of the proposed cascade hydro power plants and river flow characteristics of a different period of years are identified. Run-of-River flow prediction model is designed in a Radial Basis Function Network (RBFN). Moreover, in this study, short-term river flow characteristics are predicted to identify the hydroelectric potential in extreme cases. Based on the predicted river flow value, identified the technical potential of hydro power to solve the power crisis problem in extreme cases such as an earthquake. The study for short-term prediction hydroelectricity will significantly help to reduce the power shortage in local communities as well as across the country.

Finally, the Economic Load Dispatch (ELD) and Optimal Power Flow (OPF) for the existing and proposed HPPs are identified and analyzed. In this study, considering the two different cases for design and operation for the large-scale grid-connected power systems. For Case 1, considering emergency situation occurs during the hydroelectricity maximum generation seasons and for Case 2, considering the emergency situation occur during the hydroelectric minimum generation season. The existing and proposed models for large-scale power systems are designed in Power World simulator environment. The designed, proposed model balance the system load and significantly reduce the import power from India. The obtained simulation results show the proposed system is more reliable and secure compared to the existing system.

The designed model address the power systems in emergencies conditions. Most importantly, in the proposed model, there is surplus power in the system and that surplus power is export to India with low-cost compared to Indian import cost. The surplus power management system also considered in the proposed model. This kind of study is a milestone and a window to begin to find out the real solution of large-scale grid-connected systems for researchers. To minimize the power uncertainties in Nepal, this study is most important and necessary for the improvement and development of the power system. Based on the finding results, we believe that this study will be useful, in the schedule of a real-time power solution technique and also, minimize the power shortage problem in the local community and urban areas of Nepal.

Besides this, the study in implementation and development of Run-of-River cascade HPPs scheme, an intelligent prediction method for river flow characteristics and power systems in emergencies cases would be useful for providing clean and sustainable energy reliably and securely. The practical implementation of this study will help to develop the nation and make Nepalese people life better and more comfortable.

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List of Abbreviations

MW	Mega Watt
ROR	Run-of-River
PSCAD	Power System Computer Aided Design
kV	Kilo Volt
HPPs	Hydro Power Plants
RBFN	Radial Basis Function Network
ELD	Economic Load Dispatch
OPF	Optimal Power Flow
M	Meter
IEA	International Energy Agency
TWh/yr	Tera Watt Hour per Year
GW	Giga Watt
Mtoe/yr	Million Tonnes of Oil Equivalent per Year
WEC	World Energy Council
GWh	Giga Watt Hour
NEA	Nepal Electricity Authority
MHP	Micro Hydro Power
IPPs	Independent Power Producers
PV	Photovoltaic
kWh	Kilo Watt Hour
BCM	Billion Cubic Meters
Sec	Second
Km	Kilometer
GUI	Graphical User Interface
EMTDC	Electromagnetics Transients Including DC
MVAR	Mega Volt Ampere Reactive
RMS	Root Mean Square

MVA	Mega Volt Ampere
Hz	Hertz
INPS	Integrated Nepal Power System
kA	Kilo Ampere
Rad	Radian
ANN	Artificial Neural Network
LMS	Least Mean Square
SFCV	S-Fold Cross-Validation Procedure
MAE	Mean Absolute Error
RMSE	Root Mean Square Error
MAPE	Mean Absolute Percentage Error
DHM	Department of Hydrology and Meteorology
TSP	Time Series Plot
SOD	Standard of Deviation
COV	Coefficient of Variation
GA	Genetic Algorithm
PSO	Particle Swarm Optimization
SCOPF	Security-Constrained Optimal Power Flow
PSAT	Power System Analysis Toolbox
ACG	Automatic Control Generation
O&M	Operating and Maintenance

Chapter 1
Introduction

1.1 General Remarks

The federal democratic republic of Nepal is a landlocked country located in South Asia and bordered by China in the North and by India in the South, East and West. Home to approximately 29.30 million people [1]. The surface area is more than 147 km^2 and rich in culture and geography. Kathmandu is the capital city of Nepal which is the largest urban area in the country. Nepal territory is divided into three regions; the high Himalayas, the high hills, and the plains. The landscape elevation varies significantly from the highest level on Earth, the Mount Everest at 8,848 meters to the flat Tarai, only 70 meters above the sea level [2]. Eight of the world`s ten highest Himalayas are lies in Nepal. Nepal is one of the least developed countries in the world having economic growth approximately 4% per year over the past one decade.

Nepal is a developing country with an enormous potential of hydro power. Beside this there is another major kind of renewable energies also exist such as solar, wind, biomass, and so on. In Nepal, until now, there is no any utility-scale grid-connected wind power generation project in the country. Nepal has an average 300 sunny days in a year and has a minimum of 3.6 to maximum 6.2 kWh of solar radiation per square across the country [3]. According to Department of Electricity Development, Nepal, they have reported many renewable energies projects On-grid and Off-grid power supply systems in the entire country. Those projects implementations are like micro and mini-hydro power, solar, wind, and biomass energies generations.

The majority of micro and mini hydro power projects are under below 1 MW to above 1 MW. There are approximately 6,000 rivers are in Nepal and rivers more than three times water flow in the monsoon season compared to the non-monsoon season. The rivers mostly flow from north to south direction passing through different regions. Nepal is gifted with a huge potential of hydro power approximately 83,000 MW, out of which 42,000 MW is considered to be economically feasible, however, the present situation is that Nepal has developed only approximately 960.6 MW [4]. This implies that the country is facing both challenges and huge opportunities for the development of hydro power.

More than 90% of electricity is generating from hydro power. Moreover, Nepal produces a low level of CO_2 compared to the world, almost CO_2 emissions (metric tons per capita) is 0.30 in 2017 [1].

The electricity demand has been increasing in Nepal by about 7-9% per year [4], and only about 40% of the population has access to electricity through the grid and Off-grid system. Nepalese people faces the power shortage and about 25% of the population have no access to electricity. In Nepal, the electrification rate in 2014 was 76% and people without access to electricity was 7 million [5]. Nepal was declared an energy crisis state in early 2008. Still, to fulfill the peak demand across the country, Nepal import huge amounts of electricity from India [4].

In this dissertation, we considered to explore the hydro power potential and designed to address the power shortage problem by developing the Run-of-River (ROR) cascade hydro power systems with multiple dams on the same river. In Nepal, reliable supply of electricity is the most challenging part. This problem is not only the planning but also the operation issues which is done for the first time in Nepal. In operation phase, to minimize this problem we considered the Economic Load Dispatch (ELD) and Optimal Power Flow (OPF) techniques to achieve the utilization of a more significant part of cascade hydro power potential. The main purpose of this study in planning phase is to investigate and establish more hydro dams to increase the hydro power potential of Run-of-River in Nepal.

In this study, we proposed establishing new dams with two hydro power plants (HPPs) in the Trishuli river after existing power plants and studied the potential, designed the model and analyzed the power generation. A simulator known as the "Power System Computer Aided Design (PSCAD)" has been used based on the developed hydro components. Our study focuses on cascade hydro power development, model designing and output results of the designed models. The power demand inside the country and its neighboring nations (India and Bangladesh) are increasing, it is expected that Nepal will be an important exporter of hydroelectricity in south Asia in the years to come.

This indicates that there will be a significant development in Nepal`s hydro power sector in the coming years. Development of cascade hydro power, in coming years, Nepal`s power sector is expected to bloom tremendously. Hydro power can be developed any part of the country that ranges from pico to micro or mini to large. It should be a major source of electricity across the country. Economic barriers and structure designed of civil components of the proposed cascade HPPs have been excluded.

1.2 Hydro Power Systems

Hydro power is a clean, sustainable green energy. The HPP converts the kinetic energy into mechanical energy, and then store the energy as electrical energy in the generator. In recent years, the efficiency of the hydro turbine is more than 90%. There is energy loss in HPPs, which is also known as friction losses or head losses. The following mathematical expression (1.1) can describe the actual power that can be generated from the HPP relationship [6].

$$P = \rho . g . H . Q . \eta \tag{1.1}$$

Where,

$P = \ Electrical\ or\ mechanical\ power\ produced\ [W]$,

$\rho = \ Density\ of\ water\ [kg/m^3]$,

$g = \ Acceleration\ due\ to\ gravity\ [m/s^2]$,

$H = \ Elevation\ head\ of\ water\ [m]$,

$Q = \ Flow\ rate\ of\ water\ [m^3/s]$,

$\eta = \ Overall\ efficiency\ of\ the\ hydropower\ plant.$

There are generally three different types of HPPs [7]. Storage hydro power, pump storage hydro power and Run-of-River hydro power. In Nepal, most of the HPPs are Run-of-River type hydro power.

1.2.1 Storage Hydro Power

The storage hydro power commonly consists of a large-scale dam to store water. This type of hydro power operates when the demand for electricity is increased.

1.2.2 Pump Storage Hydro Power

The storage type and pump storage type hydro power works in the same way, however, when the demand is low or there is surplus power in the power system, this power is used to pump up the water back into the storage dam.

1.2.3 Run-of-River

Run-of-River hydro power is the common type of hydro power in Nepal. Based on the river flow rate the electric power is generated. Almost HPPs are ROR systems. This type of HPP systems are more flexible and provide a continuous supply of electric power. However, ROR hydro power potential depends on weather and seasonal variation. Therefore there is an imbalance in the power generation. In this study, we used ROR cascade HPPs for planning and operation of hydroelectric power plants.

1.3 Run-of-River Cascade Hydro Power Plants

ROR cascade hydro power concept is an important technique for contribution to supply the power to meet the baseload electricity requirements in the power system technology. Fig. 1.1 shows the Run-of-River cascade hydro power plants.

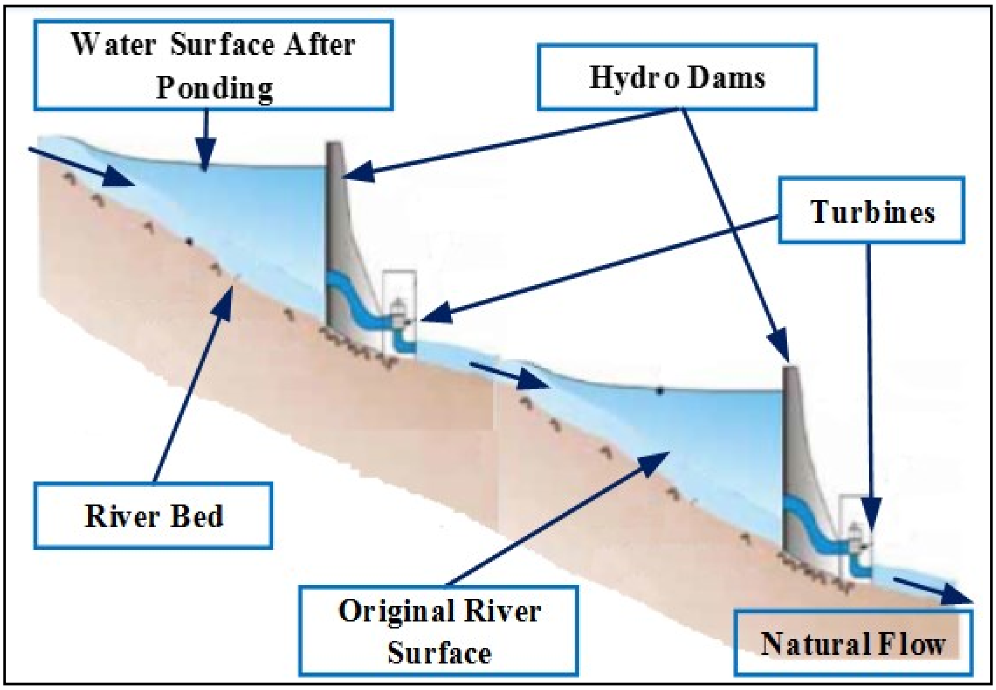

Figure 1.1: Run-of-River cascade hydro power plants.

ROR hydro power schemes do not require a large amount of water and dam to generate the electricity. However, generation could be possible where there is a little amount of water storage is provided. Therefore, the generation of electric power may vary due to the seasonal water flow of the river.

In this study, we considered a medium type of ROR hydro power plants. We consider constructing more than one hydro power plant in the same river. In Nepal, more than one dam such as cascade hydro power concept is applicable because Nepal`s river has a massive potential for water. The main objective of this study is to design and analyze the potential of ROR cascade HPPs and verify the power supplied by cascade hydro power dams rather than a single dam to the grid-connected power system.

1.3.1 Scope and Benefits of Cascade Hydro Power

- Clean renewable energy
- Increase the generation of hydroelectricity rather than a single dam
- Simple proven technology
- Low operating cost
- Reduce the emission of greenhouse gases

1.4 Hydro Power Technologies

Currently, there are two different types of hydro power turbine technologies. These hydro turbines operate at very high efficiency, more than 90% based on structure and type of the turbines. The various types of hydro turbines are as follows:

- **Impulse turbine**
  - This type of turbine is usually used high head HPPs. Impulse turbines are also divided into three different types.
    - Pelton turbine (most commonly used in Nepal)
    - Cross flow turbine
    - Turgo turbine

- **Reaction turbine**
  - In reaction turbines, the turbine runner rotor is fully submerged in the water to generate the electricity and has a high operating pressure. The

different types of reaction turbines are as follows:

- Propeller turbine
- Francis turbine
- Kinetic turbine

In this study, we considered the Francis turbine to design the HPP models. In Francis turbine, the minimum admissible flow is considered to be 40% of design flow. If the water flow falls decrease below the minimum level, the power plant is not capable to generate the hydroelectricity due to heavy vibration of the power system [6]. This turbine is originally designed for a medium head HPP which is shown in Fig. 1.2. Provides the greater runner speed and higher efficiency for the power systems. We considered, the proposed cascade HPPs head is less than 50 m. The designed details and components parameters of proposed HPPs are explained in later stage.

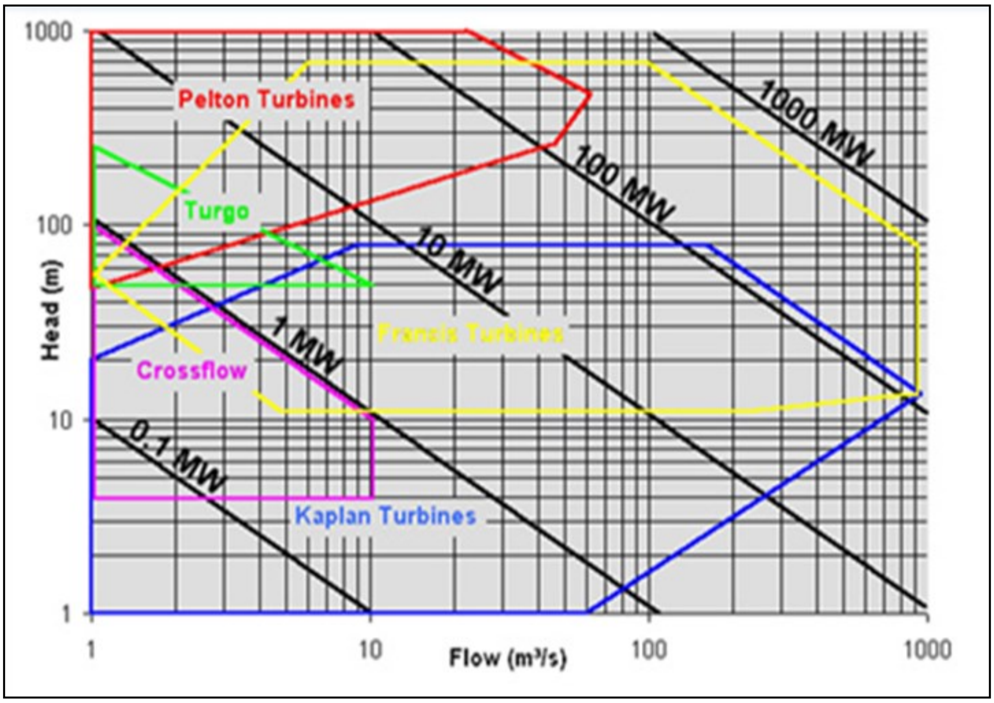

Figure 1.2: Types and application of hydro turbines.

1.5 Hydro Power Systems and their Classifications

In Nepal, HPPs are different categories depending upon the generation capacity. The classification of hydro power based on the ability to generate power is shown in Table 1.1. According to Alternative Energy Promotion Center Nepal, the total number of installed small-scale of hydro power station during this ten years periods were approximately 22,849 hydro power projects [8]. The small-scale HPPs are dominated by the power supply in remote communities of Nepal. Table 1.1 shows the classification of hydro power in Nepal [8].

Table 1.1: Classification of hydro power in Nepal.

Power generation capacity	**Types of hydro power plant**
[< 1] MW	Micro
[1-25] MW	Small
[25-100] MW	Medium
[> 100] MW	Large

1.6 Global Hydro Power Potential

Hydro power is the clean and green renewable energy source for electricity generation. Globally it is supplying 71% of renewable electricity [9]. According to International Energy Agency (IEA) currently, the world generates approximately 1831.31 TWh/yr of hydroelectricity, which amounts to 16.6% of the world's total electricity generations [10]. The installed hydroelectricity capacities have been growing in recent decades at an average of 24.2 GW each year. At the end of 2016, it has found 1,246 GW including pump storage hydro power [11].

Various scenarios for the future development of hydro power indicating, by 2050 the total installed hydro power potential will be 2000-2050 GW [12]. Table 1.2 shows the global hydro power installed capacity by region. The hydro power potential, regarding installed capacity, China (96.9 Million tonnes of oil equivalent per year, Mtoe/yr) leads followed by Brazil (32.9 Mtoe/yr) and Canada (32.3 Mtoe/yr) [12]. In the coming years, the major new hydro power developments regions are Asia, Africa, and South America [13].

Table 1.2: Hydro power installed capacity by region.

Region	Hydro power installed capacity [GW]	Hydro power installed capacity [%]
East Asia	381.0	31.6
Europe	293.0	24.4
North America	193.0	16.1
Latin America & The Caribbean	159.0	13.2
South & Central Asia	72.3	6.0
South East Asia & Pacific	57.8	4.8
Africa	25.3	2.1
Middle East & North Africa	20.6	1.7

Source: World Energy Council 2016 [12].

1.7 Hydro Power in Nepal

Nepal has a huge potential of hydro power and most of the HPPs in Nepal are Run-of-River types, hydro power generation potential varies due to the seasonal river water flow. More than 90% of electricity generated from hydro power, therefore Nepal electricity is dominated by hydroelectricity. According to World Energy Council (WEC), Nepal`s total potential of hydro power is 209,338 GWh/year and undeveloped hydro power is 205,777 GWh/year. However, current utilization of hydro power is only 2% [12]. Currently, Nepal has an installed capacity of 956.1 MW (excluding micro hydro power plant), which is not feasible to connect the grid system.

1.8 Power System of Nepal

According to NEA, the total installed capacity of hydro power is 960.6 MW, including Off-grid installed power stations and micro-hydro power. In Nepal, the thermal power plants installed capacity is 53.4 MW. However, in fiscal year of 2017 only 0.28 GWh of electricity was produced from the thermal power plants. The total ROR and storage hydro power installed capacity is 902.7 MW. The ROR hydro power generation divided into two. They are known as NEA (381 MW) and IPP (429.7 MW). The existing power generation is not sufficient to balance the peak demand across the country. Therefore, to minimize the power shortage Nepal import a vast amount of power from India. The grid-connected existing power system of Nepal, including import power, are shown in Fig. 1.3.

The On-grid and Off-grid installed power capacity are shown in Fig. 1.4.

The peak electricity demand of Nepal is nearly 1444.06 MW; the demand is imbalance during the monsoon and non-monsoon season. Most of the power deficit in the non-monsoon season, because the hydro power generation decreases very sharply during this season. Every year the import power from India is increasing to minimize the power shortage. In Nepal, the grid-connected electricity coverage only 58% of the population [4]. For the remote communities, MHP also plays a vital role to supply the electricity. Nepal government and private sector utilities are considering to increase the potential of hydro power by developing new HPPs across the country to solve the electricity problems.

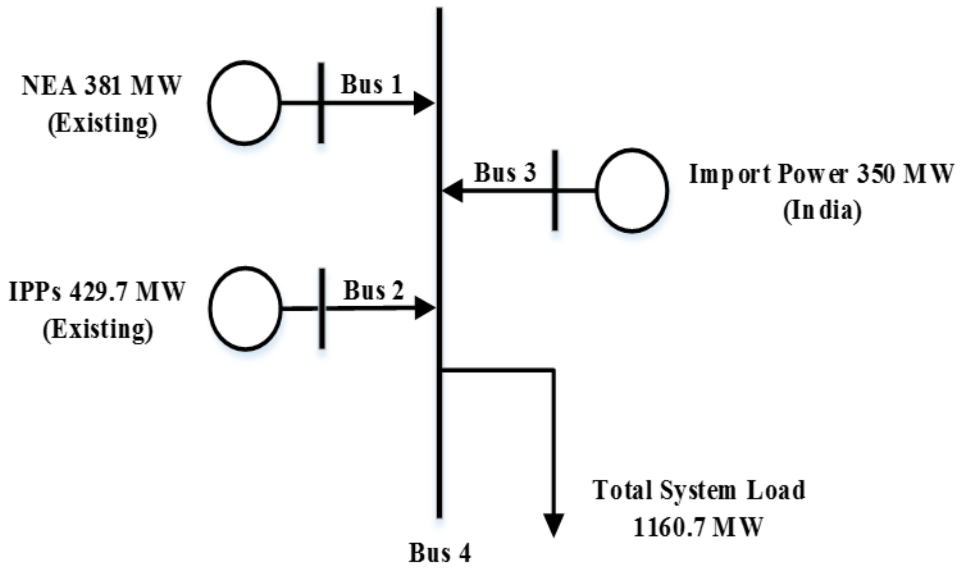

Figure 1.3: Grid-connected existing power system with import power.

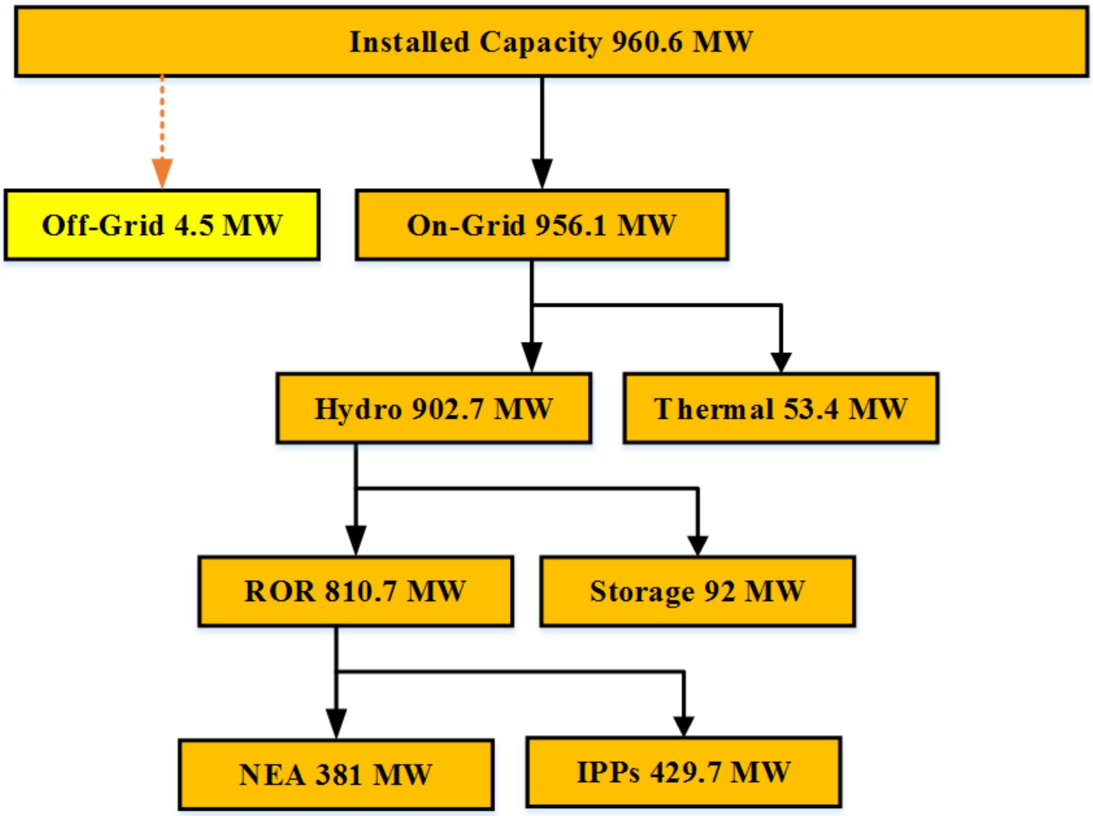

Figure 1.4: On-grid and Off-grid power system of Nepal [4].

1.9 General Status of Energy Situation in Nepal

In Nepal, the energy sources have been categories into three different types. First traditional, second commercial and third renewable. The traditional energy sources include biomass such as agriculture residues, firewood, and animal dungs and so on. Commercial sources of energy include coal, petroleum and renewable energy sources include solar, wind, and hydro power including mini and micro. In rural areas, the energy consumptions are dominated by traditional energy sources because there is a lack of commercial energy sources.

The most electric energy-consuming sector is the residential sector. However, the demand for electricity is increasing every year and balancing the peak demand nationwide Nepal government has to an emphasis on the development of hydro power projects. Therefore, by the end of the year 2027, Nepal government has committed 4,000 MW of electricity will be generated across the nationwide including mini and micro HPPs. Fig. 1.5 shows the total primary energy sources of Nepal [14].

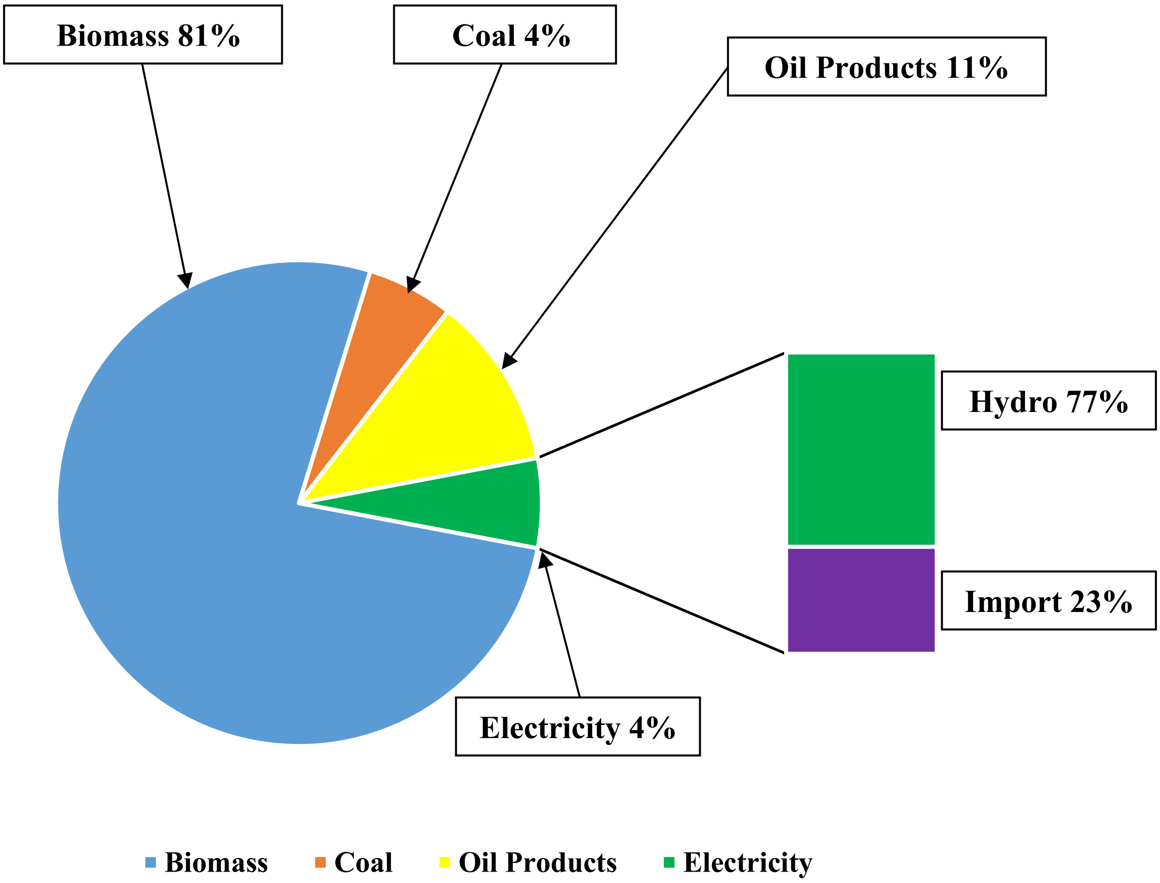

Figure 1.5: Total primary energy sources of Nepal [14].

The general status of the energy situation in Nepal is different from the rest of the world. The domestic installed hydro power potential is only 2%, despite having a huge amount of generation capacity. According to IEA, more than 80% of energy sources in Nepal is biomass. These cause the rapid deforestation to fulfill the population energy needs. Therefore, Nepal`s deforestation rate is significantly increasing by 1.23% every year a total of approximately 24.5%. Petroleum products contribute 12% of the total energy consumption and each year the imported power is gradually increasing. Fig. 1.6 shows the sector-wise energy consumption of Nepal [15]. Almost 84% of total energy has been consumed by the residential sector whereas the transport sector consumed 7% and industrial sector 6%. The energy consumed by the agriculture sector is only about 1%. Thus, the residential sector consumed a massive amount of energy in Nepal.

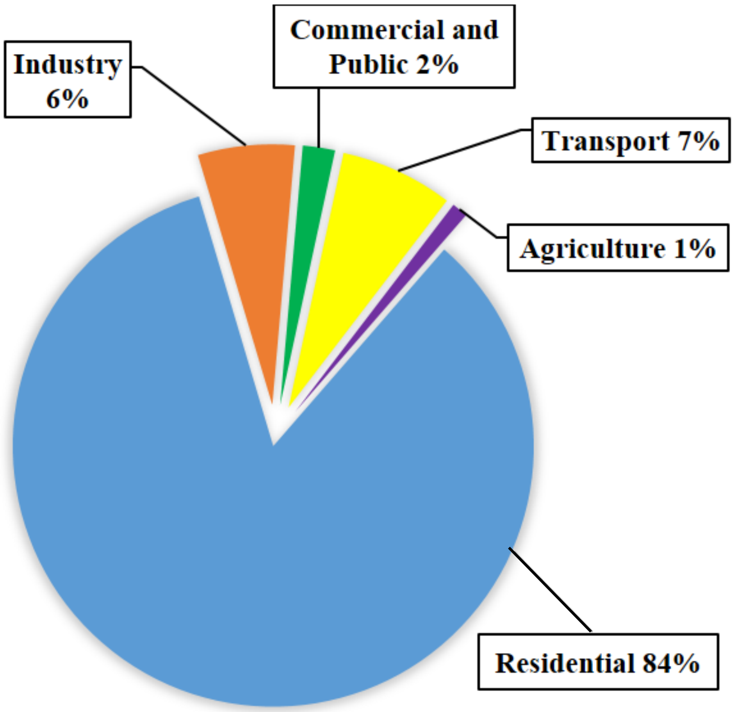

Figure 1.6: Energy consumption mix of Nepal [15].

1.10 Available Energy and Peak Demand in Nepal

According to NEA, in the fiscal year 2017, the maximum peak demand of electricity in Nepal was 1444.10 MW. Fig. 1.7 shows the generation mix and peak demand of Nepal. The peak demand growth is increasing each year. Moreover, the transmission and distribution losses are also a major problem for power systems. During the dry season, the power shortage rate is high even though the imported power also not sufficient to fulfill the peak demand. In the coming years, Nepal needs entirely reliable and quality of power supply to balance the power systems.

Environment-friendly renewable energies such as biomass, micro-hydro, and solar PV systems are also helping to reduce the ruler communities electrifications. However, according to the World Bank, the electric power consumption per capita was 139.1 kWh in 2017. The annual urban population growth is increasing by 3.2%. Grid-connected electricity to rural communities are challenging in Nepal, because of geographical locations, smaller community, low power demand, low-income consumers, and high cost for grid extension. In Nepal government own utility NEA has produced 2,168.5 GWh

(29.6%) of power from hydro and IPPs produced 1,173.1 GWh (16.0%), whereas electricity produced from thermal power is 0.1 GWh (0.001%). To minimize the power shortage problem; 1,758.4 GWh (30.4%) of electricity was imported from India. However, the imported power was not sufficient to fulfill the electricity demand across the country. Therefore 2,228.8 GWh (30.4%) of power was insufficient to balance the system load of Nepal.

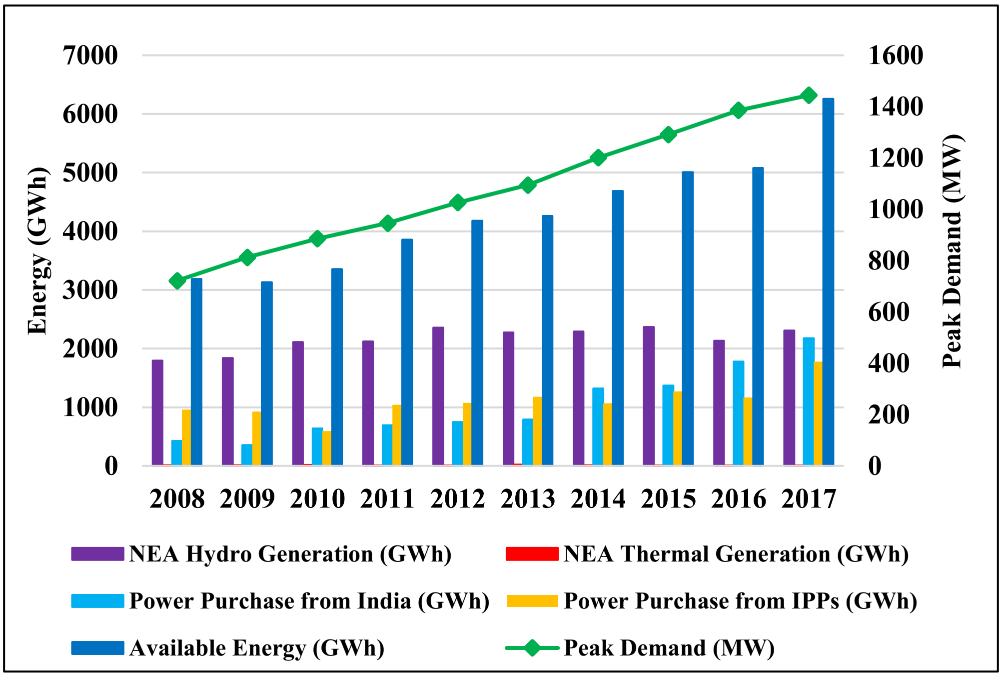

Figure 1.7: Total energy available and peak demand in Nepal [4].

In Nepal, both government and private utility companies are involved to develop the hydro power sector. As we can see in Fig. 1.7, Nepal power system has not met the peak demand in urban areas. Fig. 1.8 shows the availability of electric energy in Nepal. However, especially in isolated rural communities around 25% of the population have no electricity. Every non-monsoon season when the river water flow is less than normal flow, the hydroelectricity generation decrease, this is a major problem for load shedding in Nepal. Moreover, transmission and distribution losses also cause more power consumption in the power system. Besides, sometimes overloaded in the system also the main reason for power shortage.

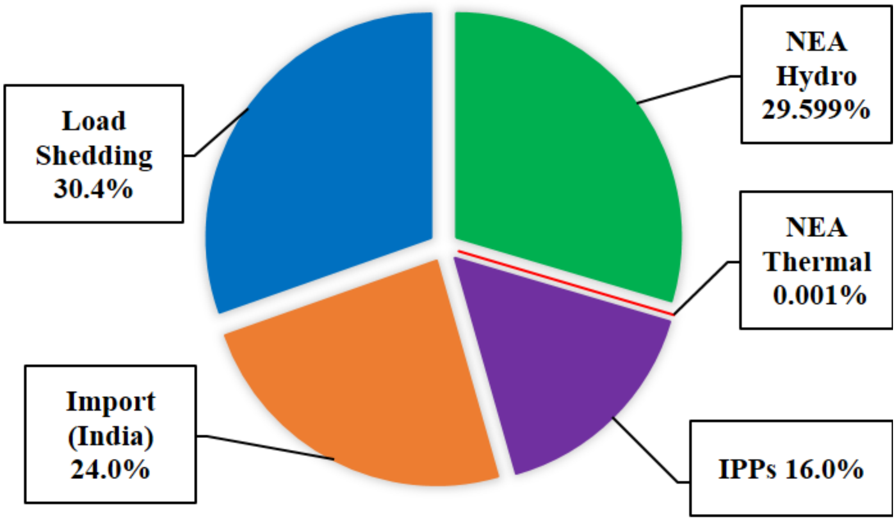

Figure 1.8: Availability of electric energy in Nepal [4].

1.11 Load Forecast of Nepal

The electric energy and peak demand forecast until fiscal year 2032/2033 are shown in Fig. 1.9. The demand for electricity is predicted to increase rapidly in the coming years. For the reliable power supply, currently Nepal need more electricity in power system and almost required electricity is imported from India.

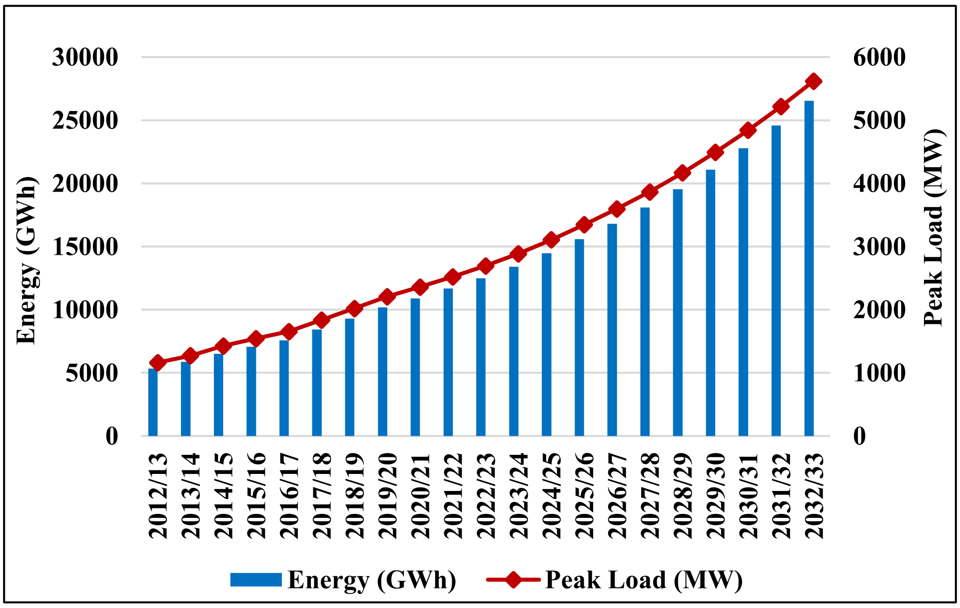

Figure 1.9: Peak load demand and electric energy forecast of Nepal [16].

Despite the insufficient electricity of Nepal power system, the import power from India will not completely minimize until next few couples of years. According to the World Bank, the electric power consumption per capita in Nepal is one of the lowest (139.1 kWh) compared to Japan (7,819.7 kWh). The peak demand for electricity of Nepal is 1444.10 MW, which is higher compared to the current installed On-grid generation of 956.1 MW. The difference between the supply and demand of electricity is reducing by importing power from neighboring country India.

Nepal imports approximately 23% of electricity from the different transmission lines (11, 33, and 132 kV). According to NEA, the electricity demand is increasing by 7-8% per year and expected to reach close to 5,500 MW of peak demand by the end of the year 2033. Predicted that the demand is increasing rapidly in the coming years [17]. Adding more hydroelectricity is the grid network will reduce the peak demand as well as minimize the import power from India.

1.12 Literature Review and Motivation of Dissertation

Electricity energy is a basic need of life support system and development purpose. There is vast hydro power resource in Nepal. However, despite having a huge potential for hydro power generation, the hydroelectricity contribute only a few percentages of power in the total primary energy sources of Nepal [14]. Due to the lack of commercial energy sources, especially in rural communities which are isolated from the national grid-connection heavily relies on traditional energy such as firewood. There are many remote villages without grid-connected electricity. However, the electricity demand is increasing rapidly. Nepal is a country having different geology areas and altitude varies from the high Himalayas to low regions.

In Nepal, there is an excellent hydro power potential in monsoon season and it is estimated that there is 42,000 MW of installed capacity of hydro power. So far, there were only a few studies regarding the renewable energies of Nepal. For rural communities biomass resources such as biogas technology application are used to generate electric energy [18]. For urban areas existing generation of grid-connected electric power is not sufficient to balance the load demand. In recent years, growing hydro power installed capacity helping to reduce the thermal and nuclear power plants across the world. In hydro power scheme, the cascade hydro power is one of the successful technique to increase the potential of hydro power and provides the consumers with multiple benefits, for example, make their life more batter and easier, creates jobs, developed the society, and so on.

In Nepal, in one river there is almost one dam and this dissertation investigates the development of cascade hydro power plants potential in the same river of Nepal. The main priority of this study is to developed model and analyze the simulation results to increase the hydroelectricity is the main objectives of this study. The significant amount of electricity is imported from neighboring country India [16]. Which is expensive, insecure and not reliable with domestic generation. The majority of Nepalese population lives in the rural areas, which is isolated from the national electric grid system. There is a vital need for electric grid system all over the country and generated sustainable and clean energy will be transmitted through that grid system.

The cost of renewable energies are cheaper and country populations also take benefits from that [16]. Nepal Electricity Authority (NEA) has also suggested consumptions of renewable energies, particularly for rural areas. Currently, around 12% of the population has access to rural renewable energies [18]. However, this 12% access to renewable energies in rural areas is deficient concerning the country massive amount of renewable resources [18]. Development of renewable energy, hydro power resources need knowledge of their implementation. Also, requires the site selection, environmental issues, social aspects, land use, and investment cost. The main motivation of this dissertation are as follows:

- The implementable potential of hydroelectric energies for individual rivers are not determined.
- There are not enough research for model, design and interconnection of multiple HPPs.
- There are not enough research regarding the seasonal potential and generation of cascade HPPs.
- There are not enough research for site selection criteria and prospect areas for HPPs installation.
- There are not enough research for grid-connected large-scale hydro power systems under emergencies conditions.
- There are not enough research for Run-of-River (ROR) water flow forecast for

extreme electricity conditions.

- There are not enough research for Economic Load Dispatch (ELD) and Optimal Power Flow (OPF) for grid-connected cascade HPPs.
- There are not enough study on power systems in emergencies situations and extreme conditions based on the natural disaster such as earthquake, flooding and so on. These issues are considered in this study.

There are many activities for research to develop the hydro power energies resources [19]. It is possible to establish the cascade hydro dams for hydroelectricity considering the river water flow value, geographical location, elevation slop, access road, and transmission lines based on the site selection. Moreover, also required to apply economic, environmental and safety factors to determine the cascade hydro power electricity potential and implementation. Utilization of river water to hydro power energy can make a huge benefit for Nepal as well as neighboring countries India and Bangladesh.

To achieve the above goals, using the PSCAD the best simulator tool for hydroelectric plant model designing and analyzing the simulation results. Besides, the PSCAD simulator is also used for interconnection to developed grid-connected large-scale cascade HPPs. The determination of proposed locations, hydro power parameters, generation potential, are the most prospect study for further development of cascade hydro power for Nepal. To predict the river flow forecast we used the Radial Basis Function Network (RBFN) to observe the results. The Power World simulator tool is used to analyze the Economic Load Dispatch (ELD) problem and Optimal Power Flow (OPF) for grid-connected large-scale power systems under extreme conditions.

1.13 Contribution of Dissertation

Recently, there are many kinds of researches are being concluded in hydro power improvement and development systems [20]. The main function of the grid-connected system is to supply the electric energy to all customers economically and reliably. Due to natural disasters such as an earthquake, flooding, and failures of power system equipment causes the power system not secured and reliable supply of electricity. Reliable electric power systems serve without interruptions in supply and demand site. In this study, the main focus has been on the development of cascade hydro power model and supply the electric power at a secured and reliable way to meet the demand across the country.

In this study, we considered two cases for planning and operation for the proposed hydro power plants. On-peak and Off-peak demand for maximum and minimum generation seasons were identified and minimize the power shortage during that period. The cascade hydro power systems ELD and OPF analysis has been done to optimize the power generation at a possible lower cost. To reduce the generation cost for power plants an advanced power generation forecast will be an essential factor in the decision process. The main contribution of this dissertation is the investigation and development of cascade HPPs, increase the hydroelectricity potential to reduce the power shortage across the country.

We believe this study, explained about the existing and proposed HPPs, determined the generation potential of cascade HPPs, which will be helpful for designing the project of hydro power in the near future. More importantly, we studied the power systems in emergencies situations considered a scenario that in extreme conditions, the existing power plants generation capacity reduced by 30% in the monsoon and non-monsoon seasons. The main accomplishments of this dissertation were listed as follows:

- Designed and analyzed the existing HPPs.
- Introduced the location of the proposed area based on geology and hydrology.
- Identified two proposed cascade HPPs potential on downstream of river based on the river water flow value.
- Designed proposed cascade HPPs models with dedicated hydro parameters and analyzed the dynamic power plant operation results in PSCAD Simulink environment.
- Determined the grid-connected large-scale cascade HPPs operations.
- Designed an intelligent prediction system to determine the seasonal river flow value to identify the potential of cascade HPPs.
- ELD and OPF techniques are applied to determine the hydroelectric power generation and supply at secure, reliable, and economical way to meet the peak demand.
- Designed a proposed system which completely reduced the load shedding.
- Import power from India could reduce significantly.

- Determined power wheeling techniques with India and exchange power for the summer-winter season or vice-versa to overcome the power shortage problem.
- Determined the power systems in extreme situations and minimize the power shortage problem as well as import power from India.

1.14 Outline of the Dissertation

This dissertation consists of six chapters and organized as follows:

In **Chapter 1,** an introduction and background of hydro power are described. Besides, the general status of electricity, hydro power potential, On-grid and Off-grid hydro power status, scope and benefits of ROR cascade HPPs are explained. Motivation and contribution of this dissertations are also included for the specific objectives of this research.

In **Chapter 2,** focuses on the study area and site selection of proposed HPPs, designing the existing hydro power models, introduces the main components of HPPs, simulation model and operation as well as power generating system performance. Describes the river flow rate and discharge of Trishuli river in different seasons. The expected generation power from the developed model of a grid-connected system is analyzed.

In **Chapter 3,** the geographical features of the proposed HPPs location and case studies of proposed, developed models are described. Analyzed results of grid-connected HPPs, which are designed for PSCAD environment. This chapter also explains the component parameters and expected generation power of proposed models with system losses.

In **Chapter 4,** the designed architecture of RBFN model to predict river flow forecast is described. The statistical performance and correlation analysis of inputs and target are also identified. Employing RBFN method for forecasting of river flow and observed less than 8% of error of test data for one-week. It has been analyzed that river flow rate prediction helps to reduce the peak demand for electric power and increase generation of HPPs. This chapter analyzes the river flow prediction and technical potential of electricity generation of the HPPs.

In **Chapter 5,** the analysis of Economic Load Dispatch (ELD) and Optimal Power Flow (OPF) of existing and proposed power systems are identified. The proposed model is designed for Power World simulator environment. The optimal generation and scheduling for all four seasons of On-peak and Off-peak system peak loads are identified. In this chapter, we considered two cases for extreme electricity conditions. The details of these cases are explained in the later stage of this chapter.

In **Chapter 6**, the main work of this research is summarized, provides the concluding remarks of this research and some recommendations for the future study.

Chapter 2
Simulation Model and Operation of Run-of-River Hydro Power Plants

2.1 Introduction

Nepal is one of the rich inland water resources countries. The surface water available in Nepal estimated about 225 billion cubic meters (BCM) per year, out of which approximately 15 BCM per year in use [21]. 0.30% of 15 BCM has been used for industry, 3.80% for domestic purpose, and 95.90% for agriculture. The rivers water flow in Nepal depends on the seasonal fluctuation of water flow. The rivers flow are maximum in July to August and decline to the minimum from January to February. The hydrology projects provide the foundation for the development of the nation. In this study, we considered the Trishuli river for this research because this river has become an essential corridor for hydro power in the future.

The river has a huge potential for hydroelectricity in Nepal. The origin of this river is the high Himalayas and flows from north to south direction. This river has a tremendous potential of hydro power and a major tributary of Narayani river, Gandaki basin in central Nepal. More than 60% of the total drainage area of the Trishili river lies in the high Himalayas and 9% covered by snow and glaciers. The basin area range of this river is about 142-4,000 km^2. Based on the basin water availability, annual natural flow is 82.70 liter/sec/km^2 and available water flow in this river is 78.89 liter/sec/km^2 [21]. In the Trishuli watershed, more additional cascade hydro power will require for hydro power development in the near future. In Nepal, hydro power has high potential; however, there are not enough power plants to fulfill the demand.

According to NEA, the power production has declined by almost 40% in the winter season because in high Himalayas region the temperature has been rapidly declined. In this river basin number of HPPs installed capacity would be possible, in upstream of this river, some power plants projects are constructing and some are under-studies. However, in the downstream after the existing the Trishuli HPP there are no any HPPs in the mainstream of this river. Therefore, this river has been considered an essential river for hydroelectricity generation and becoming the hydro power corridor.

2.2 The Study Area

In this study, the study area consists of mountainous and high hill regions. The study area is located near Kathmandu, the capital city of Nepal. The considered river is an important water source for the economic activities in the region. The river flow data were collected from the Betrawati station [22]. In Nepal, based on the Nepal climatic zone as classified by the Nepal meteorological department there are four seasons, between March to May spring season, between June to August summer season, between September to November autumn season and between December to February winter season [22]. In the summer season (between June-August) the river flow rate has been increased because of rainfall and snowmelt in the high Himalayan region, whereas the winter season (between December-February) has been found to be decreasing.

The minimum and maximum river flow rates are observed in February and August respectively. The maximum and minimum flow for the four seasons are the most important periods for snowmelt in the Himalayas region. However, snowmelt and steady river flow also affect the hydro power generation. The seasonal difference in river flow rate creates difficulties in balancing the electric power. The approximate location of this study area is shown in Fig. 2. 1.

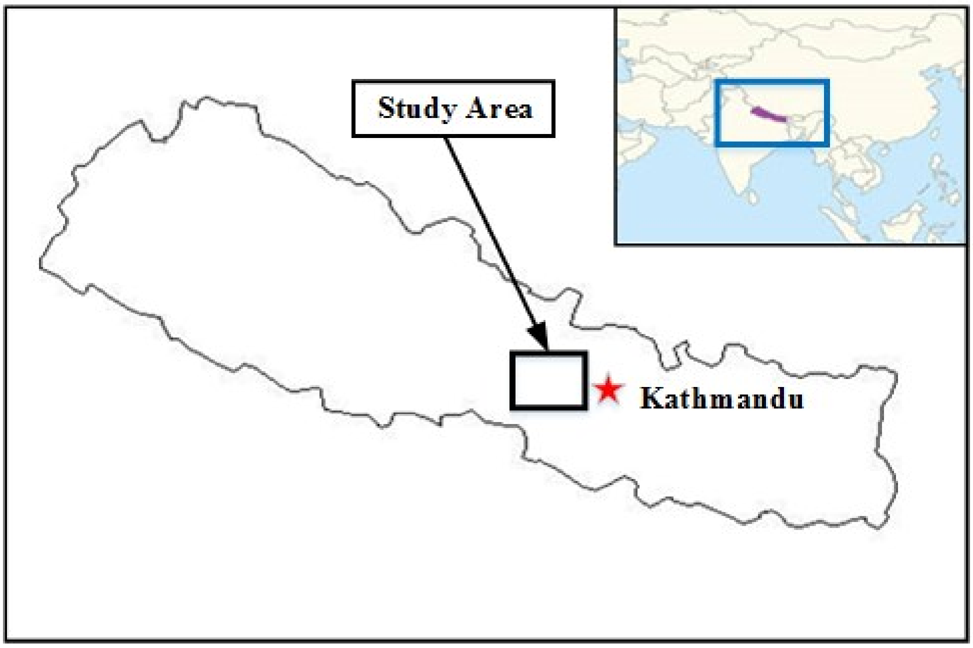

Figure 2.1: Location of the study area in Nepal [Google Map].

To determine the intake river flow value and discharge of the Run-of-River HPPs the catchment area method is a most well-known technique. This method can calculate the intake discharge of a specific proposed site. The given equation (2.1) is used to calculate the intake discharge of the HPPs [23].

$$Q_{Intake} = Q_{Gauginstation}\left(\frac{Area_{Intake}}{Area_{Gauginstation}}\right) \tag{2.1}$$

Where,

Q_{Intake}: $The\ estimated\ discharge\ at\ the\ intake\ in$ $[m^3/s]$,

$Q_{Gauginstation}$: $The\ discharge\ at\ the\ next\ gauging\ station\ in$ $[m^3/s]$,

$Area_{Intake}$: $The\ catchment\ area\ at\ the\ intake\ of\ the\ respective\ HPP\ in$ $[km^2]$,

$Area_{Gauginstation}$: $The\ catchment\ area\ of\ the\ next\ gauging\ station\ in$ $[km^2]$.

The HPPs planning and designing requires more details about the river flow characteristics of the different period of years. These provides the specific study of river flow value for a specified location to find out the potential of HPPs. First of all, the river flow value should be identified, before the development and construction of HPPs. The river flow data for specific catchment area should be available for more than 15 years of the different period [23].

2.3 River Flow Characteristics

The river flow data used in this study were taken from the Department of Hydrology and Meteorology, Nepal. With the analysis of the available data during the different periods of 1977-2012, the river flow rate is increasing every year in the summer season. However, during the winter season, it has been found to be decreasing. This study provides information about an average condition and general condition of water flow of this river. The monsoon flow pattern is entirely different from the pattern of non-monsoon season. The river flow rate for all different seasons is unregulated flow because of the function of the ecology.

The river flow regime depends on the sedimentation process, temperature and water quality of the river [24]. However, in the context of Nepal, production of hydro power drop to one-third of installed capacity [25]. Fig. 2.2 represents the observed results during the different periods of Trishili river. During the winter season, melt rate of snow and glacier in high Himalaya`s declines resulting in reduced water flow in the main rivers. In the past years, the Trishuli river saw reduced water flow rate during the winter season as well as the flow variation shows there is no contribution of snowmelt is winter season. Fig. 2.3 indicates that the flows are minimum in the winter season.

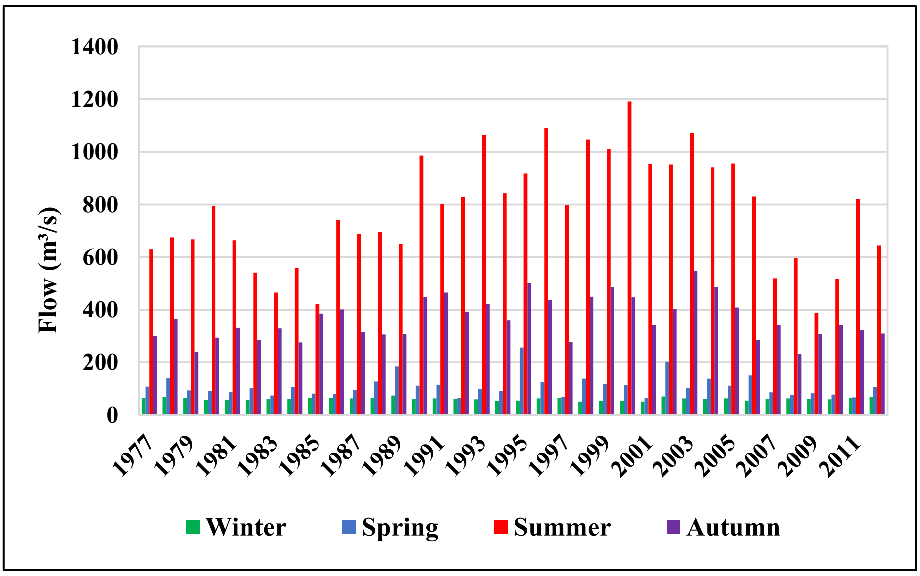

Figure 2.2: Maximum water flow of Trishuli river.

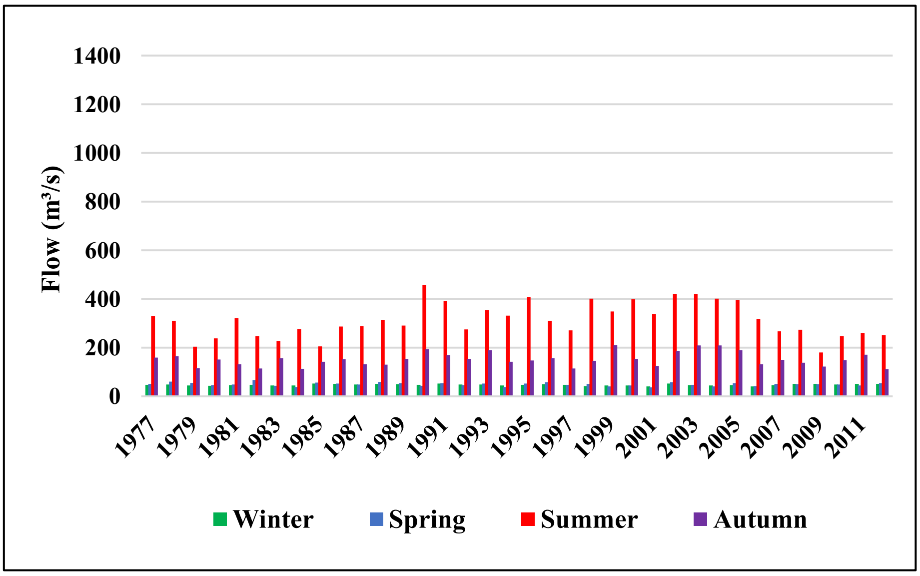

Figure 2.3: Minimum water flow of Trishuli river.

The purpose of the river flow characteristics study is to analyze and design the parameters for the system. The river flow analysis has been done based on the data during different periods of 1977-2012. More details about the river flow forecasting for a short-term period of all four seasons, discussed in the next chapter. From the predicted river flow forecast also analyzed the potential of hydro power generation of this river.

2.4 Design Discharge of Hydro Power Plant

The design discharge of Run-of-River HPP is depended on the hydrology, geology, design head and penstock diameter of the designed HPPs. The Run-of-River characteristics depend on the hydrology. The flow characteristics of different periods indicate that the maximum river flow occurs in the monsoon season and minimum in non-monsoon season. Therefore, the design discharge of Run-of-River HPP is widely depended on the flow duration curve of hydrological data. The Run-of-River flow characteristics is determined by the given equation (2.2) [23].

$$f_a = \frac{Q_d}{Q_{av}} \tag{2.2}$$

Where,

f_a: *The level of use,*

Q_d: *The design discharge* $[m^3/s]$,

Q_{av}: *The average discharge* $[m^3/s]$.

Depending upon the river flow characteristics, power generation potential the storage type large-scale reservoirs generation regulation capacity is identified by the given equation (2.3) [23].

$$f_s = \frac{V_{reservoir}}{V_{in}} \tag{2.3}$$

Where,

f_s: *The level of use,*

$V_{reservoir}$: $Useable\ storage\ volume\ of\ the\ reservior\ [m^3/s]$,
V_{in}: $The\ volume\ of\ water\ flowing\ into\ the\ reservior\ during\ one\ year\ [m^3/s]$.

2.5 Power System Computer Aided Design (PSCAD)

In this study, Power System Computer Aided Design (PSCAD) simulator is used to design and analyze the model of cascade hydro power plants. The PSCAD is well-known simulator tool, considered model can be a developed with flexible Graphical User Interface (GUI) and another main important is it works on the EMTDC (Electromagnetics Transients Including DC). The simulator consists of a default master library which consists of lots of electrical components, large power system module, transmission networks and many more. In PSCAD, the user schematically designed a model, run a simulation, and analyze the results with the graphical environment [26]. In this study, all simulation models are developed in the PSCAD environment.

2.6 Simulation Model and Operation of Existing Hydro Power Plants

In this chapter, first of all, we explain the existing HPPs which are situated downstream of this river. We have designed and analyzed two existing HPPs; Trishuli HPP and Devighat HPP. Complete model, including synchronous generator, exciter, hydro governor, hydro turbine and transformer are developed in PSCAD simulator. Based on the available data, we designed the models and observed its simulation results.

In this study, after existing HPPs, we proposed cascade HPPs in the downstream of this river because there is an abundant supply of water. This study focuses on designing of hydro power systems rather than the other factors such as financial and environmental implication. This study provides information about the system components and to explain how the hydro power system works in an interconnected grid network. All the parameters and components were chosen for normal operation and simulation results were observed until five seconds.

This result shows the output power of HPPs under normal operation. The system frequency of the model is considered as 50 Hz and current varies with the active power generation of the HPP. The active power generations are slightly lower than the actual values because of losses in the transformer and transmission line.

2.6.1 Trishuli Hydro Power Plant (Existing)

Trishuli HPP is a peaking run of river hydro power, located at Trishuli, Nuwakot, Nepal. The initial installed capacity of Trishuli hydro power station is 21 MW. It consists of 7 units of 3 MW capacity each. The annual design generation of 163 GWh. It has generated 125.97 GWh in fiscal year 2016/17, with an increase of 0.75% as compared to the previous year [27]. The net head of this HPP is 51.4 meter and rated discharge is about 14.3 m^3/s.

It consists of a step-up transformer having the capacity of 6.6/66 kV. The design parameters of the Trishuli HPP is shown in Table 2.1. Fig. 2.4 shows the single hydro generating unit of the Trishuli HPP connected to 66 kV grid and Fig. 2.5 represents the complete model of the Trishuli HPP.

2.6.2 Design Parameters of Trishuli Hydro Power Plant

Table 2.1: Parameters of Trishuli hydro power plant.

Type	**Peaking Run-of-River**
Location	Trishuli, Nuwakot, Nepal
Installed capacity	24 MW [Peaking capacity 21 MW]
Maximum gross head/Net head	51.4 m
Catchment area	2,600 km^2
Average annual flow	45.66 m^3/s
Dam	139.6 m length
Total length of water ways	4,792 m
Penstock	71.66 m long, ϕ 2.3 m, 3 Nos., steel lined 89 m long, ϕ 1.5 m, 1 No., steel lined
Turbine Number and type Rated discharge	 7, Francis 7.8 m^3/s

Source: Nepal Electricity Authority (NEA) [27].

2.6.3 Simulation Model of First unit of Trishuli Hydro Power Plant

Fig. 2.4 illustrates the single hydro generating unit of Trishuli HPP. This HPP consists of seven number of Francis turbine of each 3 MW of capacity. Each hydro generating unit consists of an exciter, synchronous generator, hydro governor, hydro turbine and transformer. Electrical power is produced by the hydro turbine, which is equipped with a turbine governor to control the speed and the output power of the system [26].

An exciter provides the field current to produce the magnetic field inside the synchronous machine. Ea, Eb, and Ec are the three-phase grid voltage. P_Grid is total active power and Q_Grid is the total reactive power of the designed system.

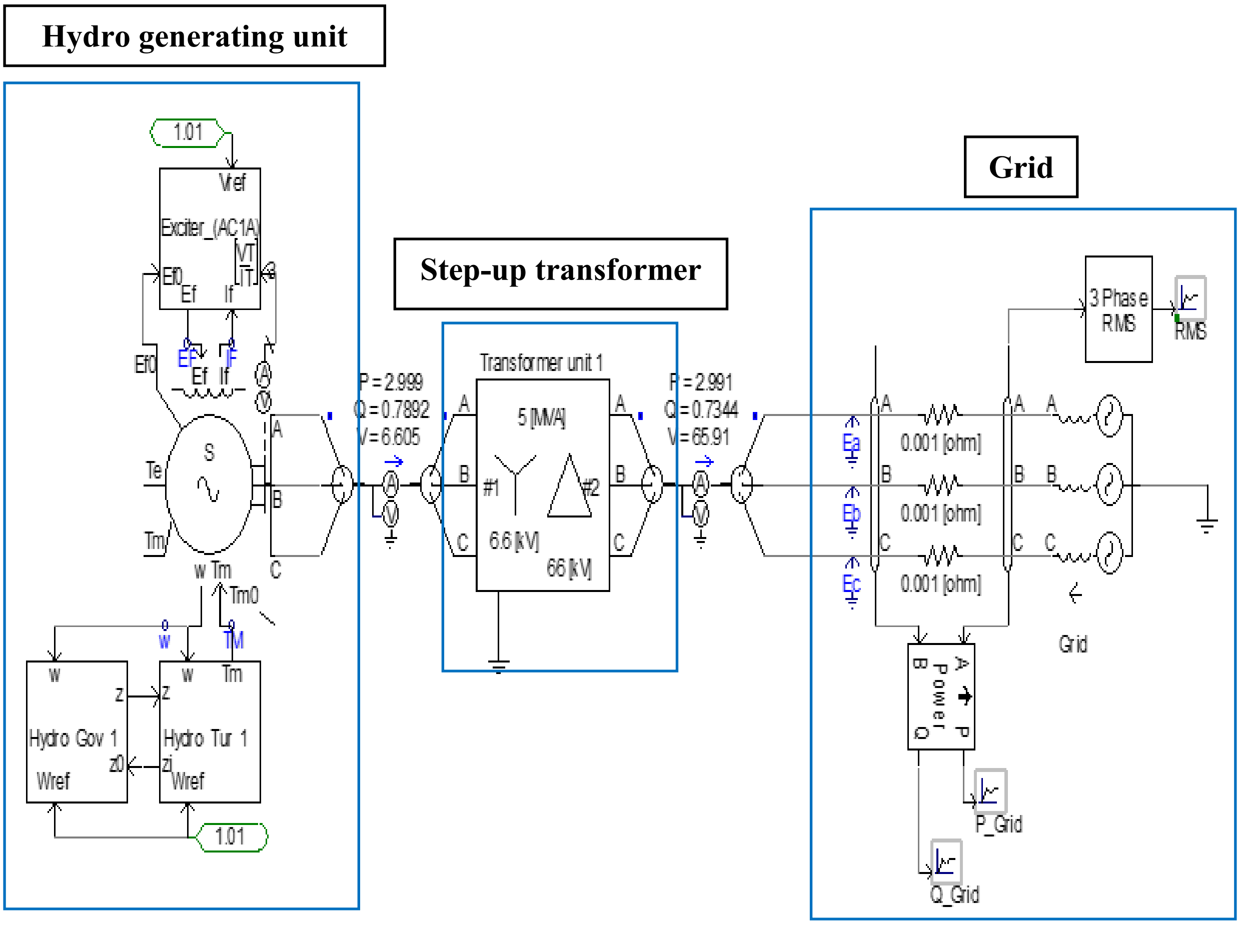

Figure 2.4: Simulation model of single hydro generating unit of Trishuli HPP.

2.6.4 Complete Model of Trishuli Hydro Power Plant

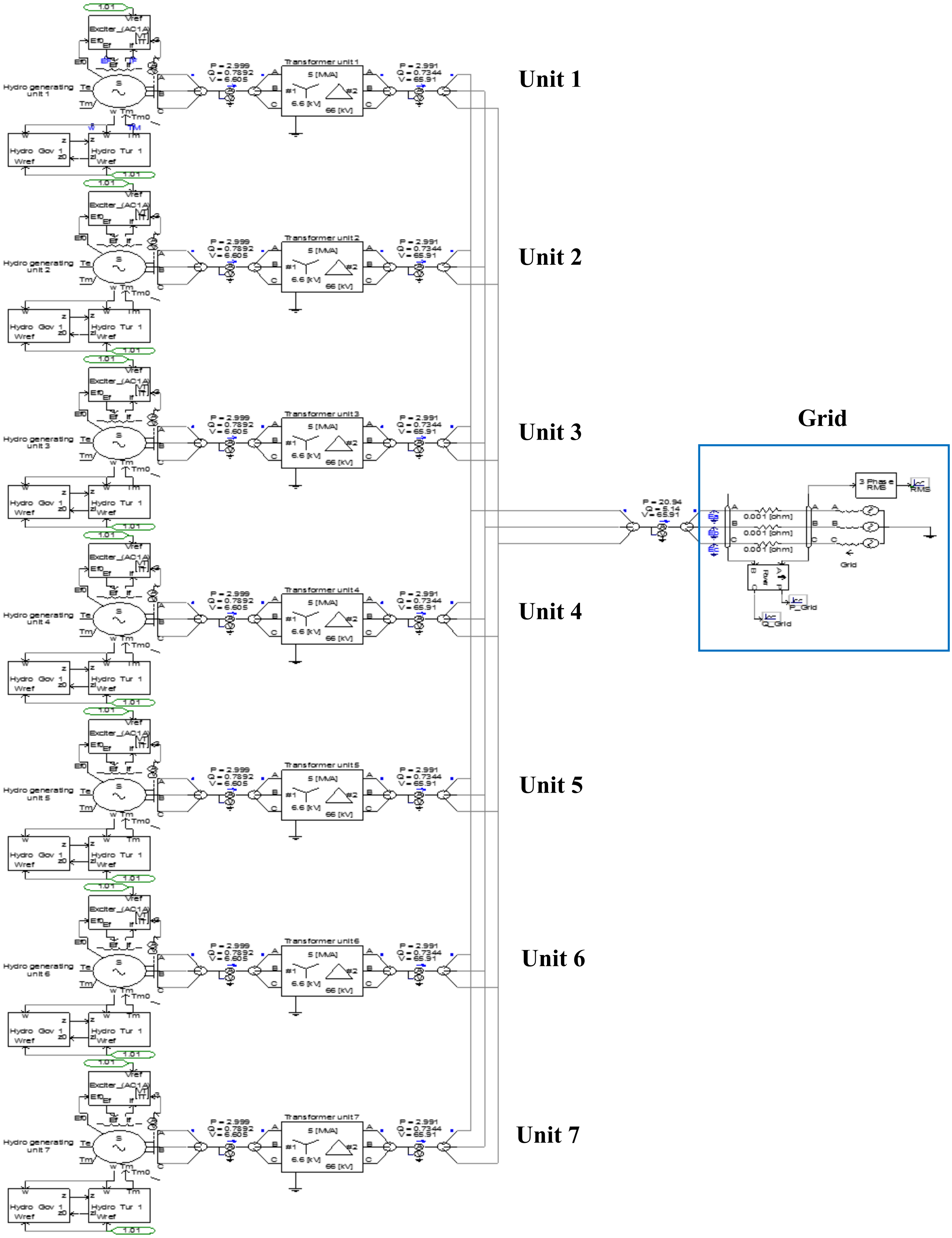

Figure 2.5: Simulation model of entire Trishuli HPP (7 units).

2.6.5 Component Parameters of Trishuli Hydro Power Plant

The selection of all components is important for the stable operation of the hydro power power system. For simulation purpose parameters used to design a hydro model is shown in Table 2.2.

Table 2.2: Component parameters of Trishuli hydro power plant.

Name	Parameter	Value
Generator	Voltage	6.60 [kV]
	Angular frequency	314.15 [rad/s]
	Inertia constant	3.11 [s]
	Mechanical friction and winding	1.00 [pu]
	Armature resistance [Ra]	1.00 [pu]
	Unsaturated reactance [Xd]	1.01 [pu]
	Unsaturated reactance [Xq]	1.00 [pu]
AC exciter	Load compensation resistance [Rc]	0.01 [pu]
	Load compensation reactance [Xc]	0.01 [pu]
	Transducer time constant [TR]	0.10 [s]
Hydro governor	Maximum gate position [Gmax]	1.00 [pu]
	Minimum gate position [Gmin]	0.00 [pu]
Hydro turbine	Head at rated conditions	0.10 [pu]
	Output power at rated conditions	0.10 [pu]
	Gate position at rated conditions	1.00 [pu]
	Penstock head loss coefficient [fp]	0.02 [pu]
	Turbine damping constant [D]	0.50 [pu]
Transformer	Three phase transformer	5.00 [MVA]
	Base operation frequency	50.00 [Hz]
	Winding 1 line voltage [RMS]	6.60 [kV]
	Winding 2 line voltage [RMS]	66.00 [kV]
	Connection	Y/Δ
Grid	Voltage	66.00 [kV]

2.7 Simulation Results

Using the PSCAD simulator, the model of Trishuli HPP is designed. We observed the active power of the single hydro generating unit is 2.99 MW and reactive power is 0.78 MVAR which is shown in Fig. 2.6. From the rest of the other units also observed the same results. The total active power (20.94 MW) and reactive power (5.14 MVAR) that could be generated by this model is shown in Fig. 2.7. The designed three-phase transformer controls the active and reactive power flows, given by an input parameter [26]. The higher active power, more reactive power consumes by transformer and grid. The developed existing hydro power model show nearly the same behavior as the real power plants. The simulation results depend on the torque, inertia and excitation of the system.

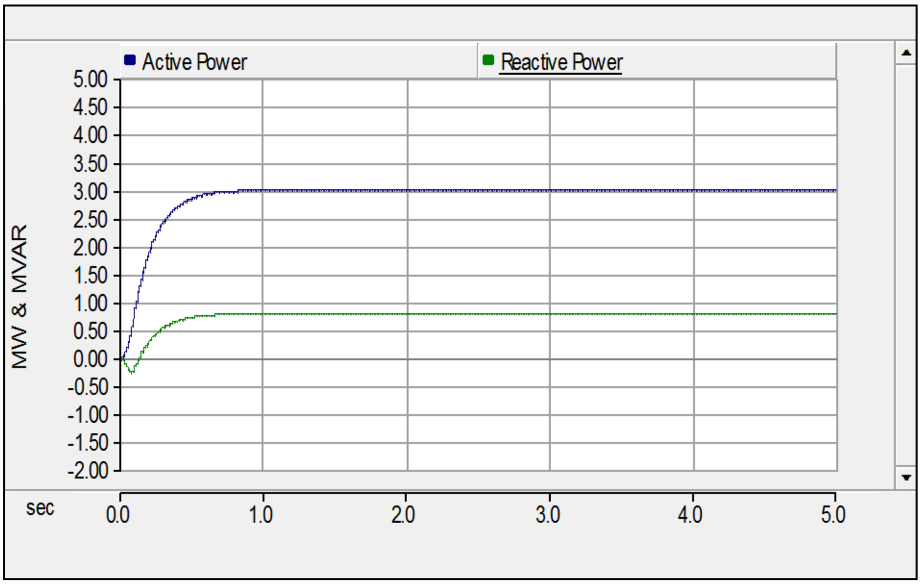

Figure 2.6: Active and reactive power of single hydro unit of Trishuli HPP.

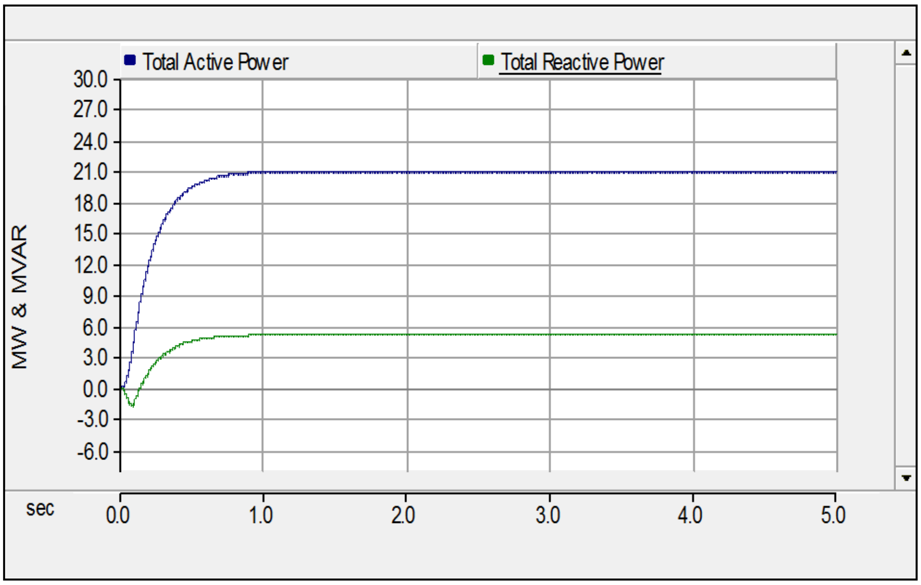

Figure 2.7: Total active power and reactive power of Trishuli HPP (7 units).

2.8 Devighat Hydro Power Plant (Existing)

Devighat HPP is located at Nuwakot, Nepal with an installed capacity of 15 MW. The output water of the Trishuli HPP is used by this hydro power station. This power station does not situate in the mainstream of the river. This power plant consists of 3 units of 5 MW capacity each. All three units operational capacities depend on the availability of released water from the upstream of Trishuli HPP. The distance between Trishuli HPP and this power plant is approximately 4.5 km. The net head of this HPP is 39 m.

This power plant consists of three vertical Francis turbine and 6.3 MVA of the power transformer. System frequency is considered as 50 Hz and generated power is transmitted through 66 kV grid to Kathmandu, the capital city of Nepal. The rated voltage and current parameters are calculated as system requirements. Design parameters of this hydro power plant are shown in Table 2.3.

2.9 Design Parameters of the Devighat Hydro Power Plant

The designed parameters of the Devighat HPP is shown in Table 2.3.

Table 2.3: Parameters of Devighat hydro power plant.

Type	Cascade of Trishuli hydro power plant
Location	Nuwakot, Nepal
Installed capacity	15 MW
Maximum gross head/Net head	40.5 m, 39 m
Catchment area	4,150 km^2 [Up to Trishuli diversion]
Average annual flow	45.3 m^3/s
Total length of water ways	4.5 km from Trishuli HPP tailrace to Devighat HPP forebay
Penstock	3 Nos., ϕ 2.5 m, steel lined
Turbine Number and type Rated discharge	 3, vertical Francis 14.3 m^3/s
Power transformer	6.3 MVA, 6.6/66 kV, 3 phase
Transmission line	66 kV

Source: Nepal Electricity Authority (NEA) [27].

2.10 Complete Model of Devighat Hydro Power Plant

The active power produced from each hydro generating unit of this hydro power plant is 4.98 MW and the reactive power is 1.16 MVAR. The total output active power of the system which is connected to the grid side is 14.96 MW and reactive power is 3.49 MVAR. Fig. 2.8 represents the complete model of this HPP. Step-up transformer of 6.3 MVA is used and system frequency is set-up 50 Hz. This HPP consists of three number of vertical Francis turbine of each 5 MW of capacity. Ea, Eb, and Ec are the three phase grid voltage. The output power is connected to the 66 kV grid. The total active power P_grid and total reactive power Q_grid are measured from the grid.

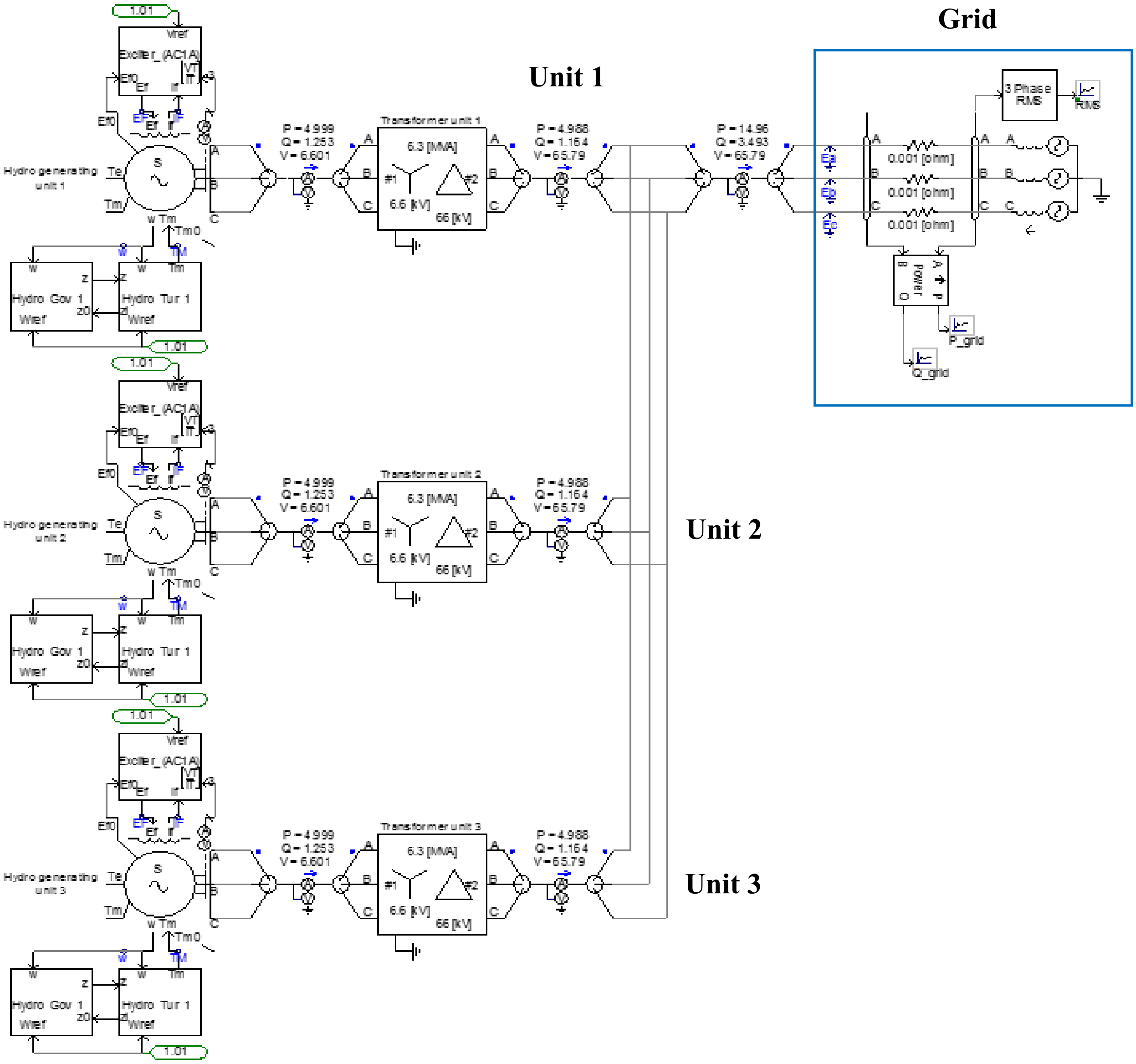

Figure 2.8: Simulation model of Devighat HPP (3 units).

In this study, the main purpose of the simulations is to show the operation of the designed system and analyzed the results. Therefore, designed each hydro unit is generating 4.98 MW of power which is shown in Fig. 2.9. Fig. 2.10 shows the total output power of this model is 15 MW. However, the obtained simulation result is 14.96 MW.

2.11 Simulation Results

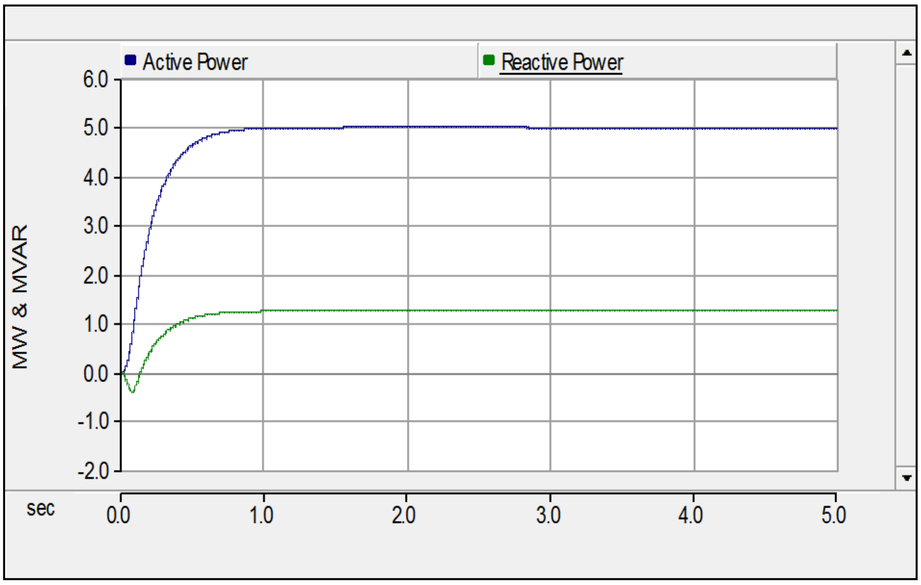

Figure 2.9: Active and reactive power of single hydro unit of Devighat HPP.

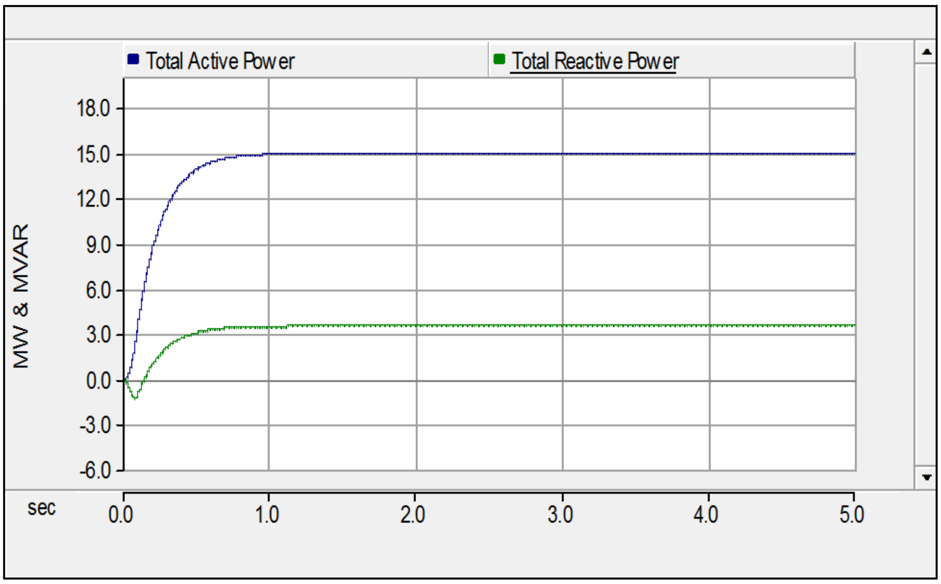

Figure 2.10: Total active and reactive power of Devighat HPP (3 units).

2.12 Conclusion

In this study, the simulation model of existing HPPs are designed and analyzed. The main objective of this study is to carry out the detailed of the existing hydro power generation. Using the PSCAD simulator, the existing HPPs models can be designed to operate and analyzed the power system. Considering the active and reactive power producing from each hydro generating model is different. Also, it is observed that the simulation time is five seconds for each power plants, the whole simulation process takes to reach an efficient solution to obtain the results.

The existing site is grid-connected area and this study focused on feasibility and potential of renewable energy sources to contribute to balance the power system. As long as when the river flow varies during the year of monsoon and non-monsoon seasons, the potential generation of HPP also varies. However, in the non-monsoon season, the power production decrease almost 40% of installed capacity. Therefore, there is high flexibility for power production.

Cost estimation, civil work design and component parameters such as penstock diameter, head loss of designed HPPs are not studied. Various aspects of HPP modeling and analyzing are discussed to obtain better results. Moreover, the existing hydro models are capable of producing efficient power. Generation from the existing HPPs has contributed almost 8% of the total energy in the Integrated Nepal Power System (INPS).

Chapter 3
Interconnection and Operation of Proposed Cascade Hydro Power Plants

3.1 Introduction

Nepal has huge resources of water for hydroelectric. However, significantly fewer power plants are in Nepal. In this study, first of all, we proposed and designed two HPPs generation models; 30 MW (Case 1) and 40 MW (Case 2). The study area located in the lesser Himalaya area and regions are examined to propose two new HPPs with different capacity in this river. Hydrology and geology point of view a medium head (Head < 50 m) HPPs could be considered in mainstream of Trishuli river after the existing Devighat hydro power plant. The proposed site is one of the grid-connected area and has a vast potential for electricity [28]. Trishuli river basin is located at a sloped surface along the direction from north to south. There are many small village and town along the riverbanks and mountainous area. Generally, this region has a complex geographical shape formed by high Hills and Mountains together.

The primary geographical condition and proposed location of Run-of-River HPPs are shown in Fig. 3.1 [29]. Considering the potential of proposed HPPs for Case 1, for 30 MW and Case 2 for 40 MW. The water flow characteristics of this river depended on the seasonal water flow rate and snowmelt in the high Himalayas. In the monsoon season, between June to August the volume of the river flow rate massively increase whereas the non-monsoon season, between December to February decreased very sharply. In the monsoon season, the river flow volume is increased by more than three times compared to the non-monsoon season.

Based on the river water flow rate and elevation of the catchment location, we proposed the ROR cascade HPPs and analyzed simulation results of the proposed cascade HPPs. The proposed models are designed in PSCAD environment. The obtained simulation results shows the nearly close to the considered potential value. Therefore, this river has a massive potential of hydroelectricity during the monsoon season compared to non-monsoon season. The generated hydroelectric power will be help to reduce the peak load and minimize the import power from India.

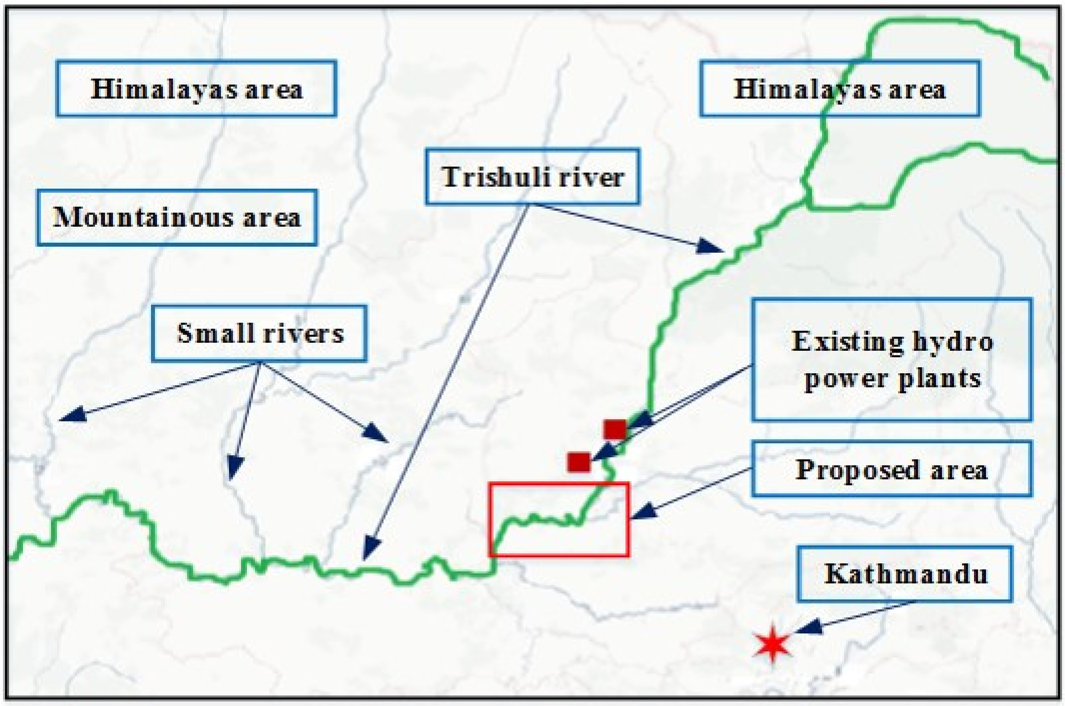

Figure 3.1: Geographical features and proposed hydro power location of Trishuli river.

3.1.1 Case Study 1

In Nepal, almost all rivers are flowing from north to south direction, high elevation to low elevation zone. In this study, we considered that the Case 1 (30 MW) is located at the downstream of the Trishuli river. In Trishuli river after the existing Devighat HPP (14.10 MW), we proposed a medium head (Head < 50 m) HPP installed capacity of 30 MW. The distance between the last existing power plant and the proposed power plant (Case 1) is approximately 3-5 km. The proposed power plant site locates significantly high hills and mountainous areas and discharge of river flow rate is high.

3.1.2 Case Study 2

For Case 2, we considered as an installed capacity of 40 MW. The distance between the two proposed HPPs is approximately 2-7 km. In downstream, after the existing HPPs, the water level and flow discharge are increased because many other small rivers join to this main river stream. Therefore, this river has a huge potential for hydro power. However, the cascade hydro power generation is dependent on the river water flow rate and discharge. Based on the available data, the river flow rate of a different period of year`s could be known.

Moreover, the generated electricity could be supply to local communities or connect to the main grid. From the two proposed cascade HPPs, we could generate at least 70 MW of electricity and helps to reduce the power shortage as well as import power from India. The details of these case studies including a skand so onh of approximate site locations of the existing and proposed HPPs are shown in Fig. 3.2.

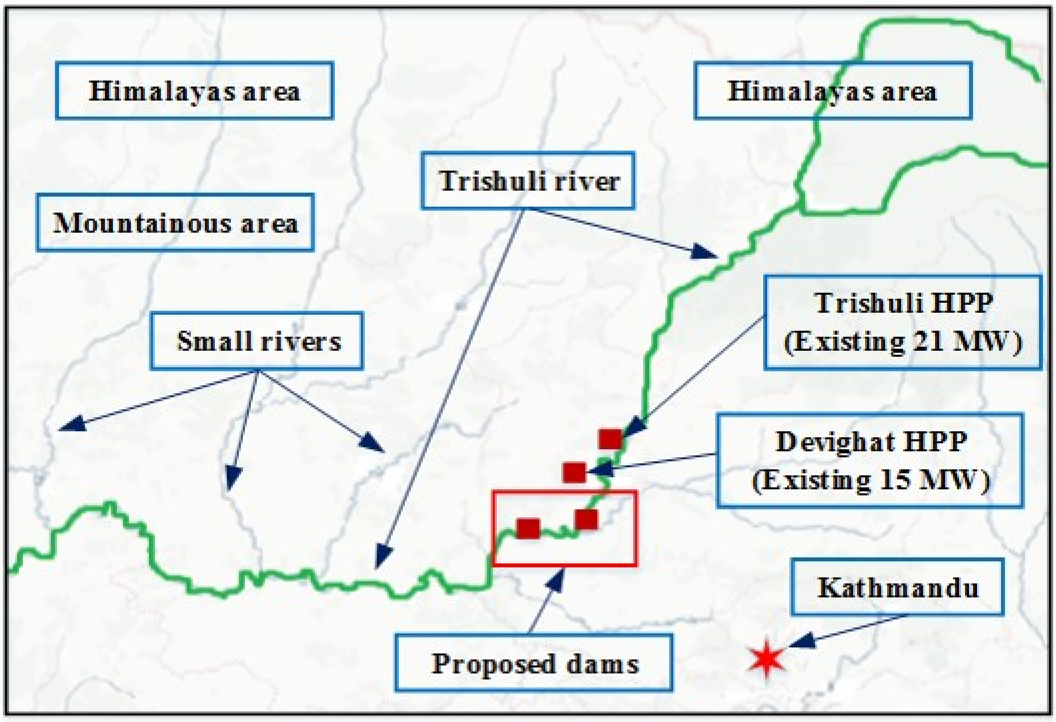

Figure 3.2: Sketch of existing and proposed hydro dams in Trishuli river.

3.2 Assumptions and Procedures

The assumptions and procedures that applied in this study are as follows:

- Considered the cascade hydro power located in downstream of the river.
- Based on the river flow data and elevation of the catchment location proposed medium head HPPs.
- According to the climatological and hydrological facts, the proposed location is suitable for HPPs.
- Based on the existing data, the existing hydro power models are designed.
- For the proposed models, the system parameters are selected as required.
- The system is considered as a grid-connected network.

3.3 Simulation Model and Operation of Proposed Hydro Power Plants

In this study, the simulation model of proposed HPPs for Case 1 consists of 3 hydro generating units and for Case 2, consists of 4 units of each 10 MW. The hydro generating units are connected to step up transformer (11 kV/66 kV) of 15 MVA. The efficiency of the hydro turbine is considered 90% and the losses in the turbines and transformers has considered as system losses. The excitation system which is connected to hydro generation unit operates the generator with reactive power from the network [30]. The voltage and frequency are constant throughout the designed system.

The generator rated voltage is 11 kV and the grid voltage is 66 kV. The design of a grid-connected cascade hydro power based on the PSCAD simulator is used to designed and analyzed. The output power of each hydro system is depended on the generating unit connected to the system. Therefore, the hydro power with different potential may have different outputs. The assumption parameters used to design both Case 1 and Case 2 and model of the proposed power plant for Case 1 are shown in Table 3.1 and Fig. 3.3.

3.4 Design Parameters for Proposed Hydro Power Plants

The proposed hydro power designed parameters are shown in Table 3.1.

Table 3.1: Design parameters of proposed hydro power plants.

Type	**Run-of-River**
Location	Trishuli, Nepal
Proposed installation capacity Case 1 Case 2	 30 MW 40 MW
Maximum net head for Case 1 Maximum net head for Case 2	30-40 m [Approximate] 23-37 m [Approximate]
Distance between two dams	2-7 km [Approximate]
Average flow rate	45.66 m^3/s
Turbines Number and type Number and type	 3, Francis [Case 1] 4, Francis [Case 2]

3.5 Simulation Model (Case 1)

In this model, the active power generating from every hydro generating unit is 9.98 MW and reactive power is 2.65 MVAR. The total active power of the proposed system which is shown on the grid side is 29.95 MW and reactive power is 7.97 MVAR. In a hydro system, the power which operates is determined by the demanded power of the system [31]. The simulation model of proposed HPP for Case 1 is shown in Fig. 3.3.

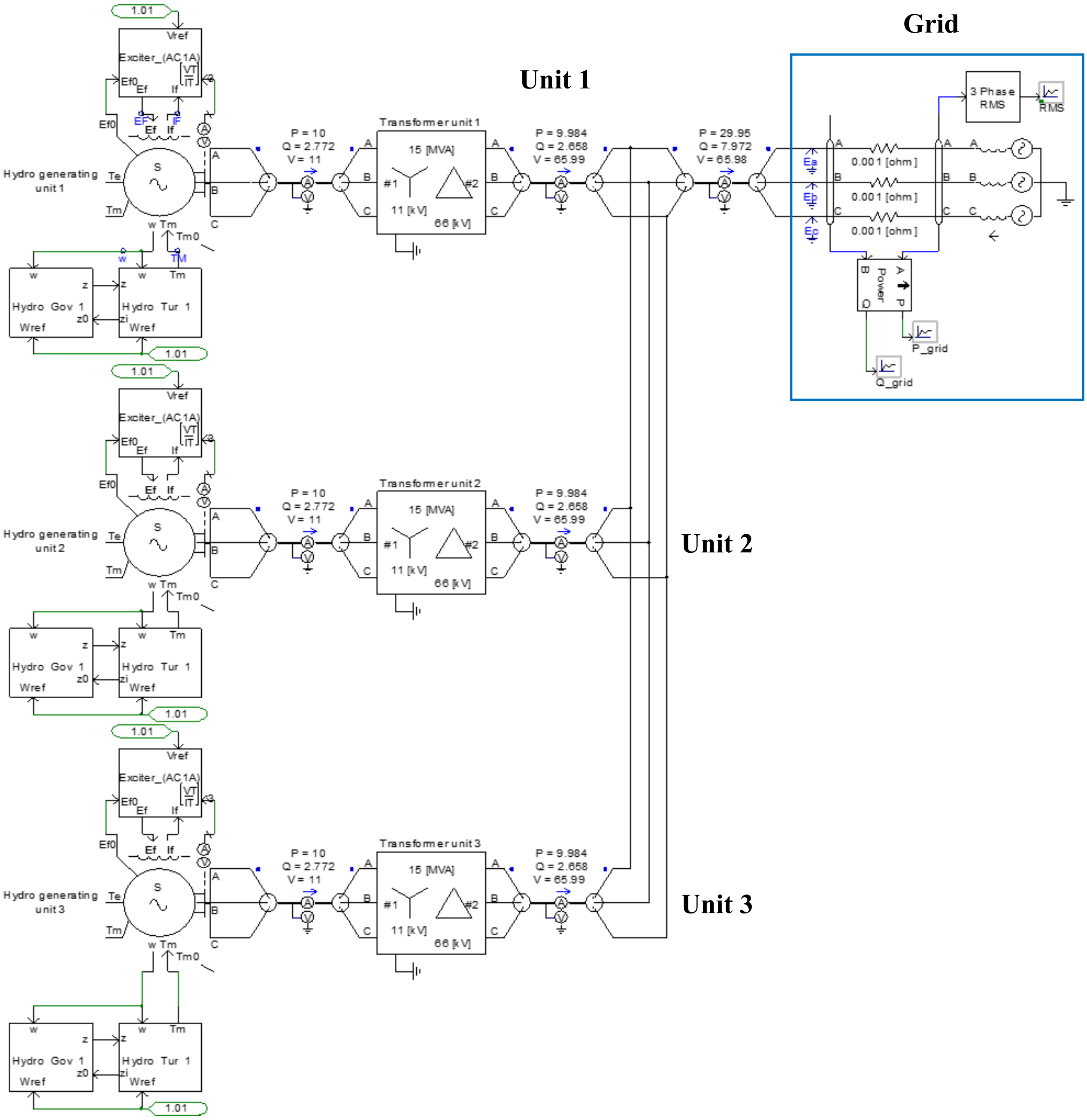

Figure 3.3: Simulation model of proposed HPP for Case 1.

3.6 Component Parameters of Proposed Hydro Power Plants

The parameters used for to design proposed hydro power model are shown in Table 3.2.

Table 3.2: Component parameters of proposed HPPs models.

Name	Parameter	Value
Generator	Voltage	11.00 [kV]
	Angular frequency	314.15 [rad/s]
	Inertia constant	3.11 [s]
	Mechanical friction and winding	0.10 [pu]
	Armature resistance [Ra]	1.00 [pu]
	Unsaturated reactance [Xd]	1.01 [pu]
	Unsaturated reactance [Xq]	1.00 [pu]
AC exciter	Load compensation resistance (Rc)	0.01 [pu]
	Load compensation reactance (Xc)	0.10 [pu]
	Transducer time constant (TR)	0.10 [s]
Hydro governor	Maximum gate position (Gmax)	1.00 [pu]
	Minimum gate position (Gmin)	0.00 [pu]
Hydro turbine	Head at rated conditions	0.10 [pu]
	Output power at rated conditions	0.10 [pu]
	Gate position at rated conditions	1.00 [pu]
	Penstock head loss coefficient (fp)	0.02 [pu]
	Turbine damping constant (D)	0.50 [pu]
Transformer	Three phase transformer	15.00 [MVA]
	Base operation frequency	50.00 [Hz]
	Winding 1 line voltage (RMS)	11.00 [kV]
	Winding 2 line voltage (RMS)	66.00 [kV]
	Connection	Y/Δ
Grid	Voltage	66.00 [kV]

3.7 Simulation Results (Case 1)

In this study, the observed active power for the single hydro generating unit is 9.98 MW and reactive power is 2.65 MVAR which are shown in Fig. 3.4. The total active power (29.95 MW) and reactive power (7.97 MVAR) are shown in Fig. 3.5.

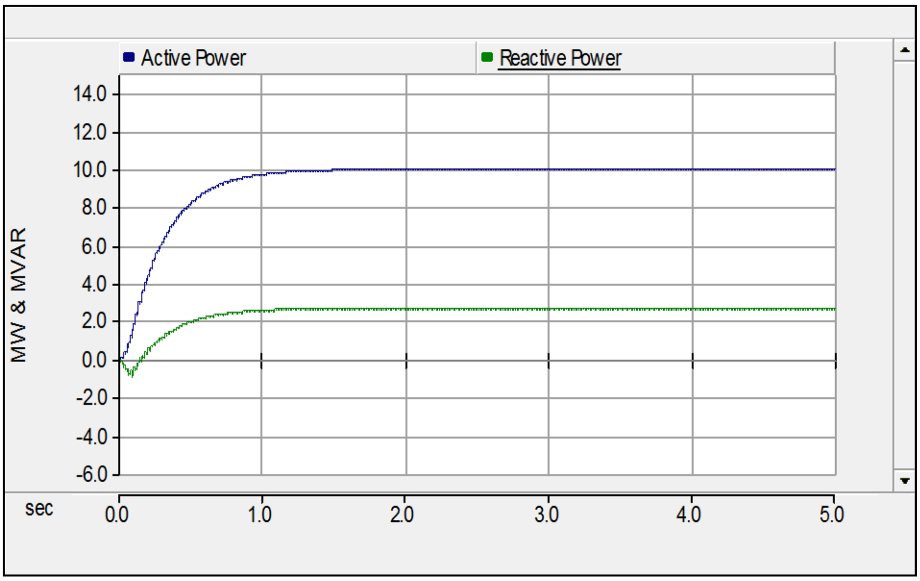

Figure 3.4: Active and reactive power of single hydro unit of proposed HPP (Case 1).

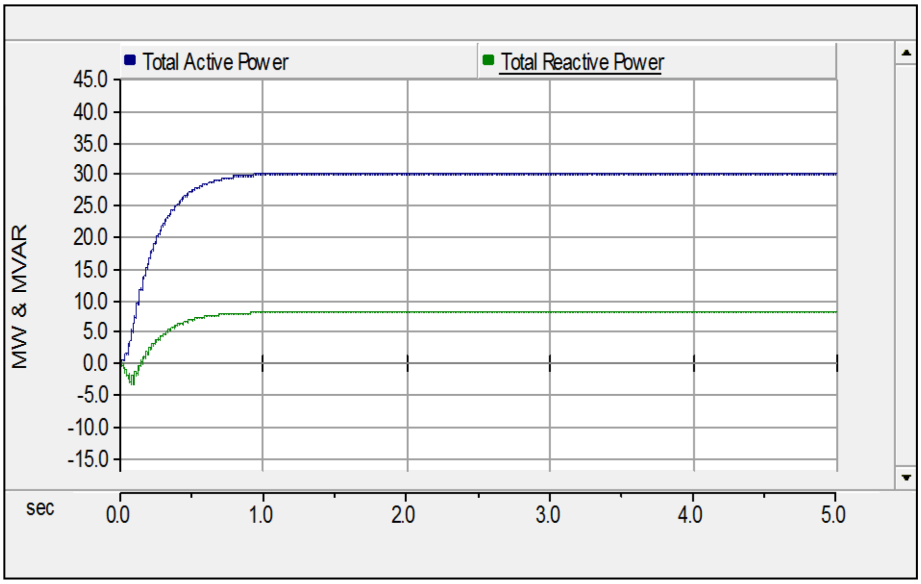

Figure 3.5: Total active and reactive power of proposed HPP (Case 1).

3.8 Simulation Model (Case 2)

In this model, the active power generating from every hydro generating unit is 9.98 MW and reactive power is 2.65 MVAR. The total active power of the proposed system which is shown on the grid side is 39.93 MW and reactive power is 10.63 MVAR. The simulation model of proposed HPP for Case 2 is shown in Fig. 3.6.

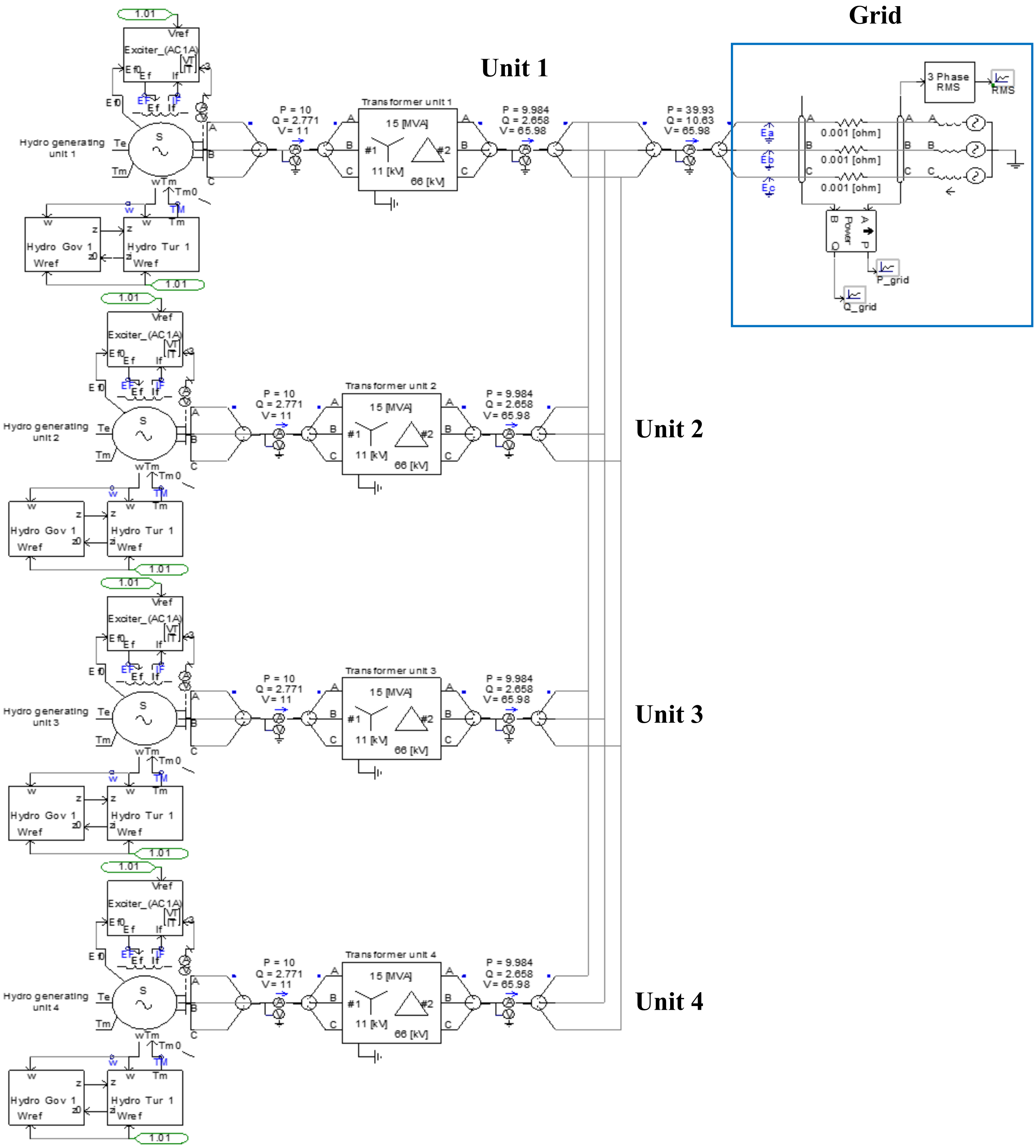

Figure 3.6: Simulation model of proposed HPP for Case 2.

3.9 Simulation Results (Case 2)

The obtained active power for the single hydro generating unit for proposed Case 2 is 9.98 MW and reactive power is 2.65 MVAR. The observed results are shown in Fig. 3.7. The observed total active power (39.93 MW) and reactive power (10.63 MVAR) are shown in Fig. 3.8.

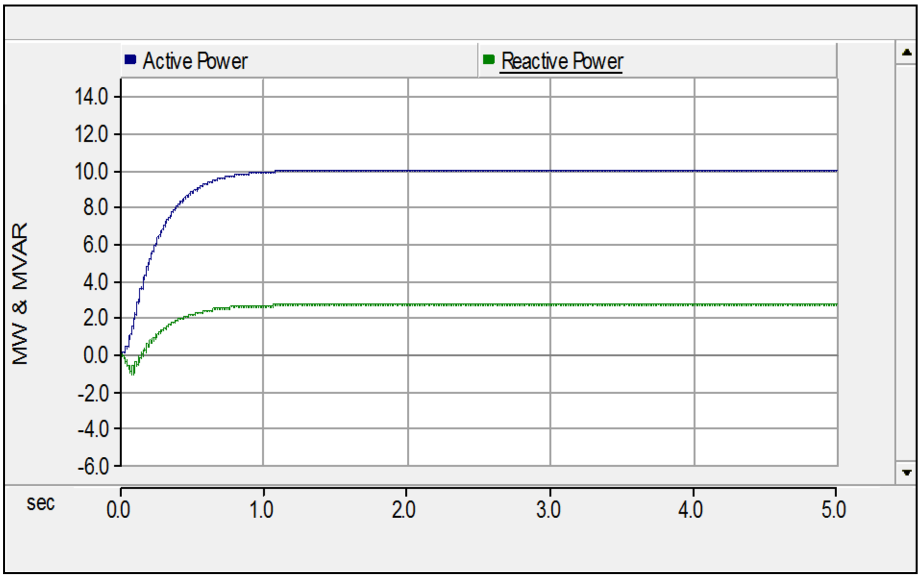

Figure 3.7: Active and reactive power of first hydro unit of proposed HPP (Case 2).

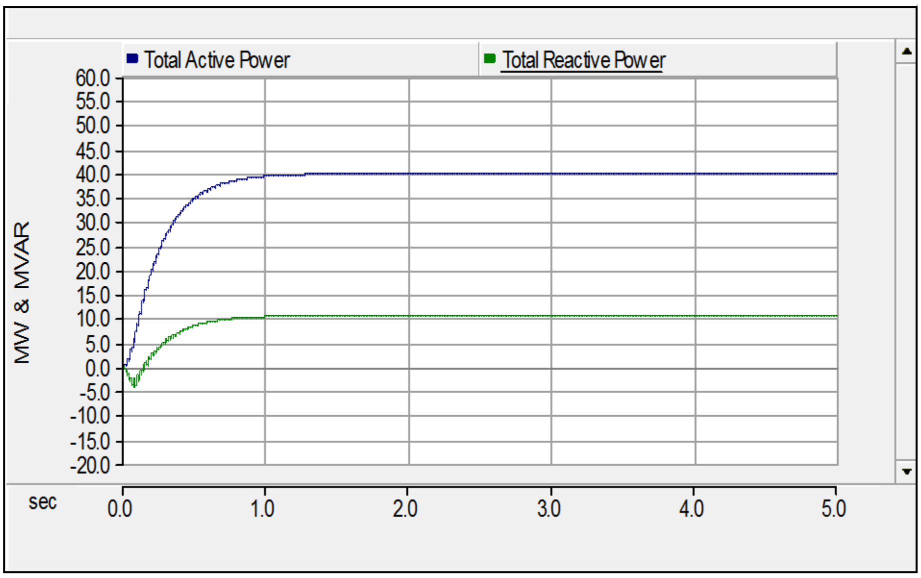

Figure 3.8: Total active and reactive power of proposed hydro power plant (Case 2).

3.10 Interconnection of Cascade Hydro Power Plants to Grid

As mentioned earlier, the main objective of this study is to design and analyze the cascade hydro power generation systems, connect all HPPs with the same grid to balance the supply and demand of Nepal. For this reason, considering all four cascade hydro powers are connected to 66 kV grid. In this chapter, we designed and analyzed the interconnection of existing and proposed HPPs. First of all, connected all four (two existing and two proposed) HPPs with the same grid of 66 kV and analyzed the performance of real power flow considering with grid-connected power systems.

3.11 Simulation Model and System Design

In this chapter, all four hydro power (two existing and two proposed) models are connected to the 66 kV grid. The output results of the HPPs are different. The capacity of each hydro generating unit of all four HPPs are shown in Fig. 3.9 and the arrows indicate that the generation power of each power plants are flowing through the grid. The output results of grid-connected HPPs are analyzed with the graphical environment. In this study, all hydroelectric plants consist of a hydro generating unit, exciter, hydro turbine, hydro governor, and step-up transformer (11 kV to 66 kV) and so on. The obtained three-phase voltage has a clean sinusoidal waveform, the real power and current are proportional due to constant grid voltage in the system.

In this study, considering the cascade HPPs are situated in Trishuli river, Nepal and will be helpful to balance the lack of power through power generation. We could successfully design the hydro power models and interconnected all HPPs to 66 kV grid. The grid-connected cascade hydro power simulation results are analyzed. The benefits of using the PSCAD simulator is; it consists of various components such as generating units, exciter, hydro turbine, hydro governor, transformer, and many other components that can be combined easily and freely. Using this model, it can be analyzed that the power generation and interconnection of power plants to the grid.

Also, possible to observe the detail power system of each hydro power plants. Moreover, active power, reactive power, frequency, and three phase grid voltage can be measured for all HPPs. It should be noted, that the total expected installed power for this model is 106.00 MW. However, the designed existing and proposed hydro power plants have with total actual power potential is 105.55 MW, whereas 0.45 MW is

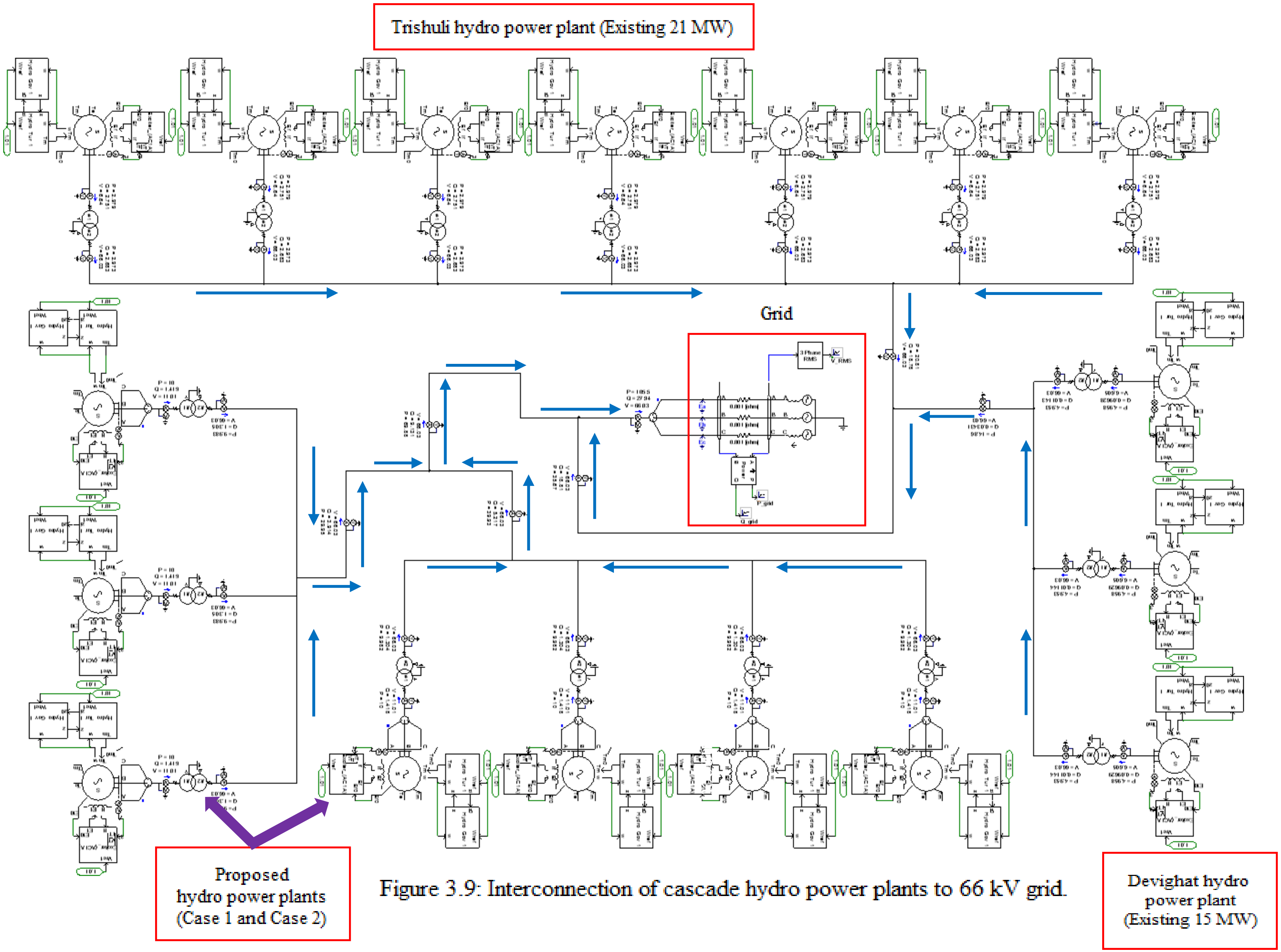

Figure 3.9: Interconnection of cascade hydro power plants to 66 kV grid.

total loss occurred in the designed system. By performing the simulation, the output results are close to the actual power of the system. The grid-connected system consists of a cascade HPPs driven by a synchronous machine that can be run either as a machine or generator. The output of the power plants is connected to 66 kV grid via set-up transformers.

In this designed system, all HPPs are operated at their highest output power. Hydro power systems have a tremendous impact on the power flow, frequency, system voltage, and system reliability at the distribution. Recently, large-scale hydro power generation has enormous impact when it is connected to the power grid. A combination of large-scale hydro power generation has a significant influence on the demand side load system. An imbalance between the power generation and demand causes the frequency varies in the power system [32]. The three-phase grid voltage parameters for this system is determined by the following Fig. 3.10. The simulation has done considering the RMS voltage is 66 kV and frequency is set as 50 Hz. The obtained results of this system using three phase voltage parameters along with the overall simulation results are shown in this section.

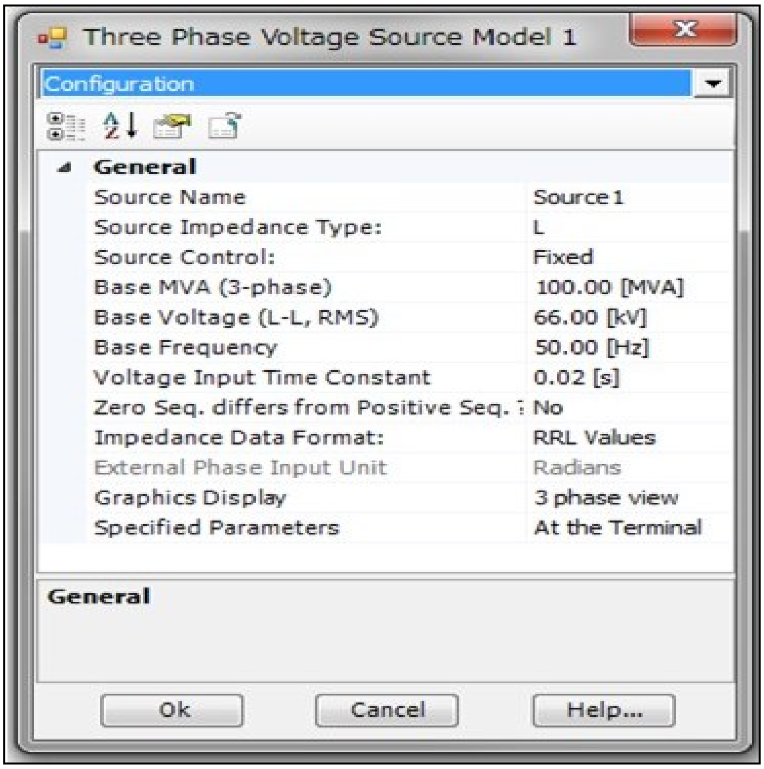

Figure. 3.10: Three phase grid voltage parameter in PSCAD.

The main aim of the designed model is to balance the different power generation, improve the active or real power performance, and control the grid voltage. However, balancing the power generation and demand through grid-connected transmission systems are becoming increasingly important. In the context of Nepal, renewable energy such as hydro power, it represents the large share of total production. The results of interconnection of cascade HPPs are shown in Table 3.3.

Table 3.3: Expected generation power of proposed cascade HPPs with system losses.

Power plant	**Expected generation power [MW]**	**Actual generation power [MW]**	**Actual reactive power [MVAR]**	**System loss [MW]**
Trishuli hydro power [Existing]	21.00	20.81	18.78	0.19
Devighat hydro power [Existing]	15.00	14.86	0.03	0.14
Proposed hydro power [Case 1]	30.00	29.95	3.91	0.05
Proposed hydro power [Case 2]	40.00	39.93	5.21	0.07
Total	106.00	105.55	27.93	0.45

3.12 Simulation Results of Grid-Connected Hydro Power Plants

The expected maximum hydro power generation from the existing and proposed power plants considering with cascade HPPs results are analyzed. The total active power and reactive power of grid-connected cascade hydro power are shown in Fig. 3.11. Similarly, three phase voltage (Fig. 3.12), grid-connected RMS voltage (Fig. 3.13), and system frequency (Fig. 3.14) respectively. In this study, we proposed two HPPs at some distance of a capacity of 30 MW for Case 1 and 40 MW for Case 2. The generated electric power is transmitted through 66 kV grid. The proposed site is one of the grid-connected area and has a huge potential of hydro power.

This research is focused on the feasibility and potential of Trishuli river. Also, with the new cascade hydro plants, generate more electric power. It will help to reduce the power shortage in the local community as well as urban areas of Nepal. Furthermore, the proposed hydro models are capable of producing efficient power and the system losses are very low. The generation, interconnection, and transmission have a significant impact on grid-connected hydro power systems.

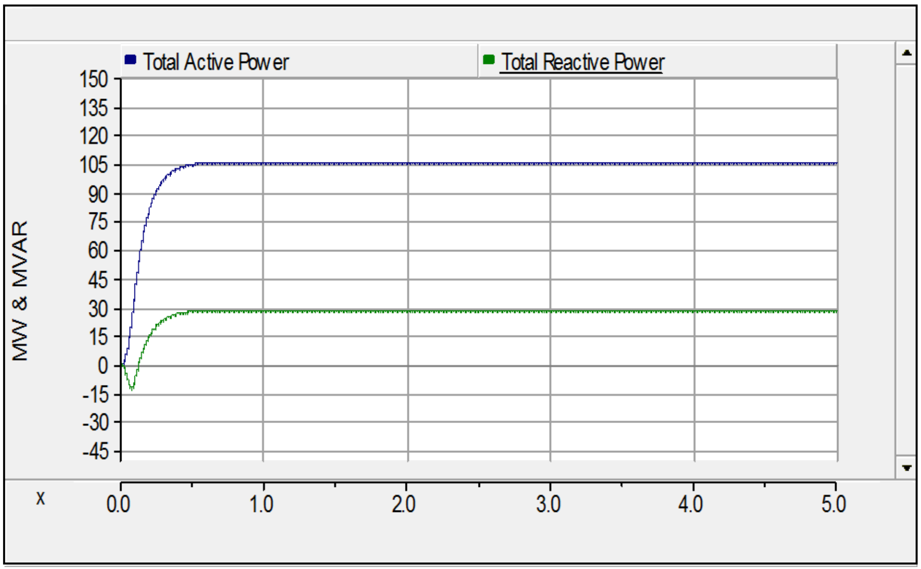

Figure 3.11: Total active and reactive power of grid-connected cascade HPPs.

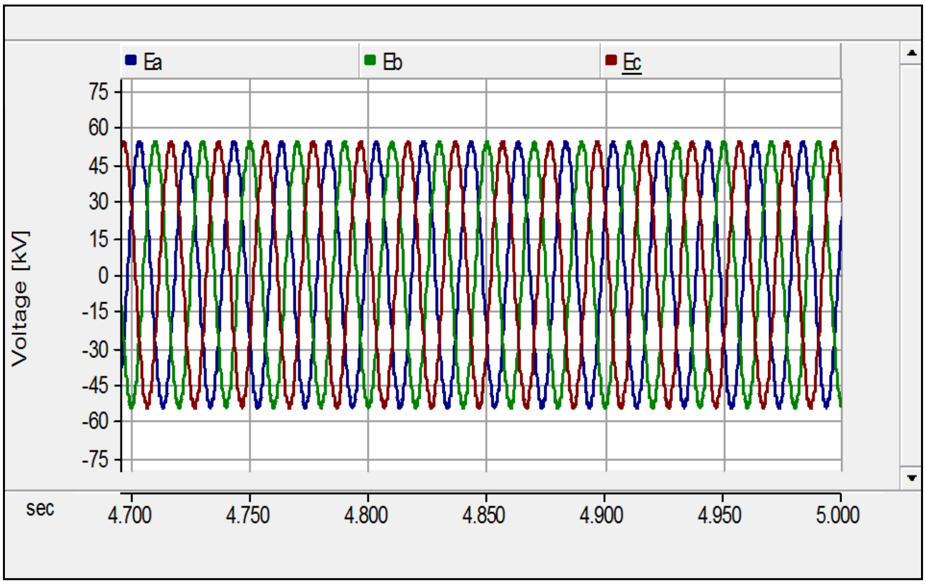

Figure 3.12: Three phase voltage of grid-connected cascade HPPs.

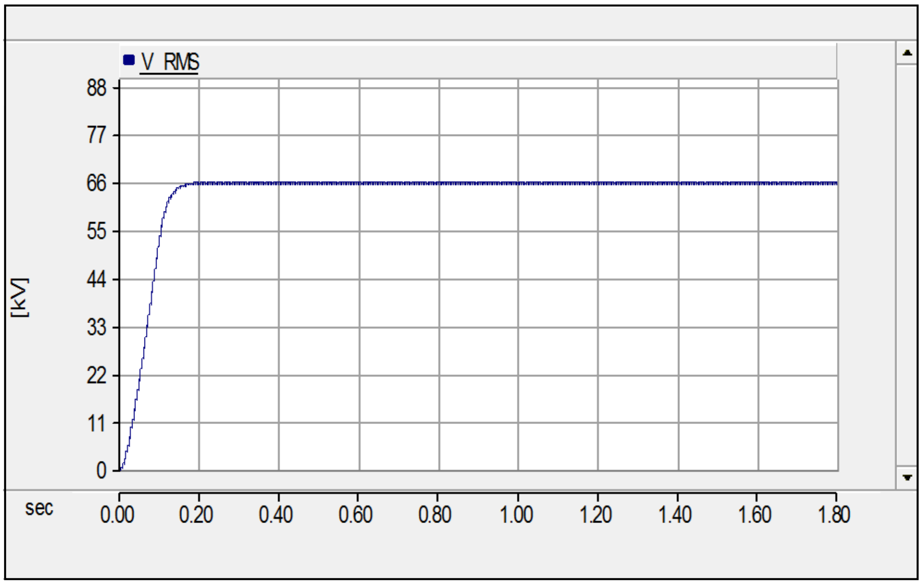

Figure 3.13: RMS voltage of grid-connected cascade HPPs.

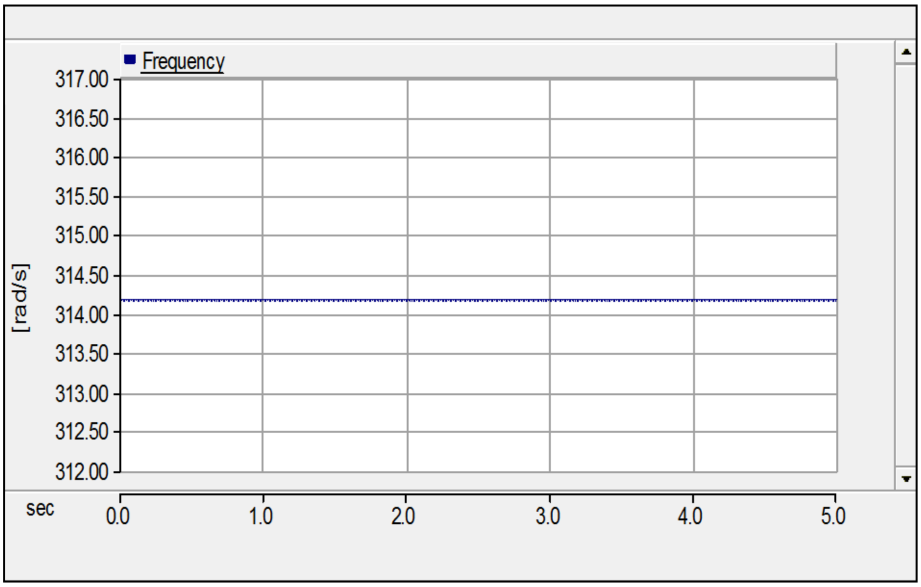

Figure 3.14: System frequency of grid-connected cascade HPPs.

3.13 Concluding Remarks

3.13.1 Environmental Impact of Grid-Connected HPPs

Nepal has huge water resources for hydro power generation. Hydro power development is most essential for the economic growth of Nepal. The power utility sector of Nepal is mainly dependent on the seasonal river flow rate. Nepal government has taken the plan to overcome the power shortage problem and reduce the import power, promoting to install HPPs across the country. The obtained results of this section show that it will be feasible to install cascade HPPs in this river. However, cascade hydro power development makes either to decrease the river flow rate or change the river flow pattern. Also, affected and reduce the water environmental dramatically.

This turns in results, change of the river water quality for both upstream and downstream of the proposed HPPs. The river will look like a series of small ponds or lakes. Moreover, changes the sediment and hydraulic transport characteristics due to the creation of cascade dams in the river. Besides, development of cascade HPPs affects the marine systems and ecosystems.

3.13.2 Outcomes for Cascade Hydro Power Developments

The cascade hydro power establishment could contribute to developing those areas by the establishment of new highways, infrastructure, health care centers and so on. Moreover, the new outcomes such as jobs creation, low-cost energy, and reduce the greenhouse gas emissions. Cascade hydro power developments have brought many opportunities in the new areas.

Chapter 4
Intelligent Prediction Model for Extreme Electricity Conditions

4.1 Introduction

The traditional artificial Intelligence method prediction has been applied for a various approach to forecast because of its ability to learn non-linear relationships. Forecasting is an essential method for day-to-day scheduling and operations of a power system. Two methods are beneficial in forecasting; statistical method and artificial intelligence method. Statistical methodologies, an approach using regression analysis methods are mentioned in [33-34]. At present, an Artificial Neural Network (ANN) is very famous for its robustness because of its generalization techniques [35]. An Artificial Neural Network (ANN) is a parallel-distributed system with a large number of processing elements capable of working in parallel described by D.E. Rumelhart, J.L. McClelland, and the PDP Research Group, 1986 [36].

Most of the research on ANN deals with short-term and long-term load forecasting [37], weather forecasting [38] and reservoir inflow [39]. In this study, Radial Basis Function Network (RBFN) is used to predict the one-week ahead river flow forecast at a different season to determine the maximum generation of electricity to minimize the power shortage in Nepal. An advantage of river flow forecast will benefit the generation of clean, green energy and scheduling the load to overcome the peak demand.

4.2 The Radial Basis Function Network (RBFN)

There are various types of network models in Artificial Neural Networks (ANNs). Among them, the reason behind using the RBFN in this study are described as; hybrid learning neural network, radial basis functions are good at modeling the data, a combination of best-fitting non-linear functions and this network can produce the output in shorter time. RBFN is the modeling tool that is used to classify the pattern or predict outputs from a given input value.

In this study, the Gaussian function as the non-linearity for the hidden layer to find the suitably hidden neurons was implied. The architecture of the RBFN model is shown in

Fig. 4.1. The RBFN model has three layers known as the input layer, hidden layer, and an output layer. An input layer which performs no computation whereas the hidden layer corresponds the number of the hidden neurons in the network.

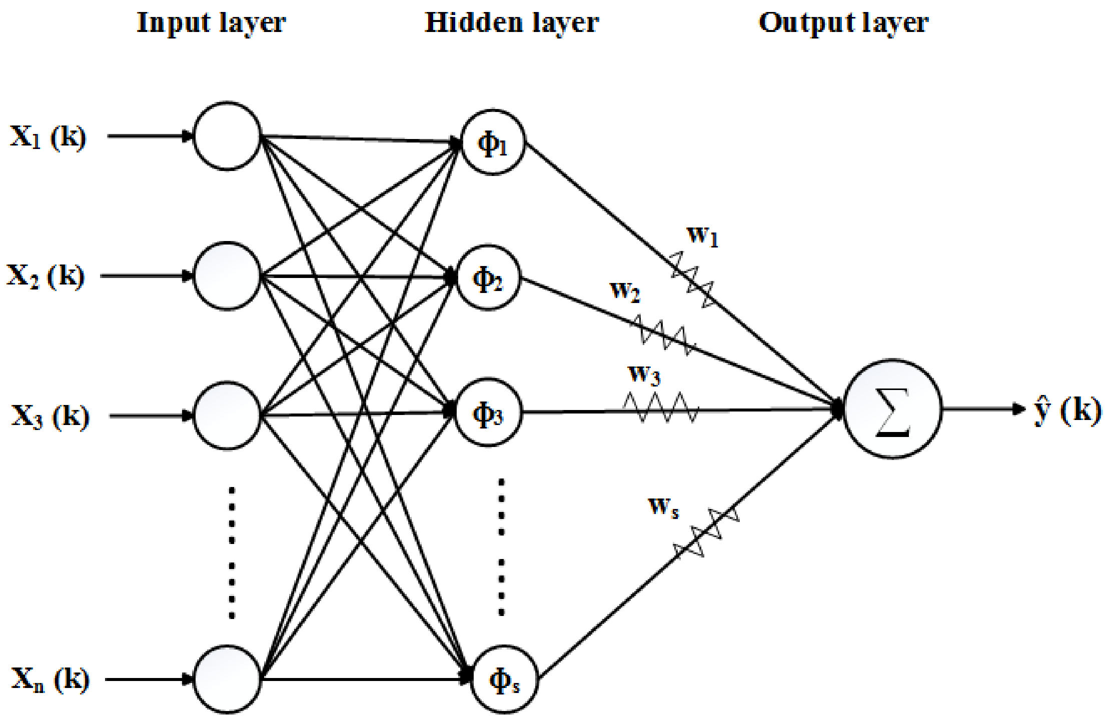

Figure 4.1: The architecture of RBFN model.

The hidden neuron *i* with pattern *s* can be determined by the following equation (4.1) [40].

$$\phi_s(i) = exp\left(-\frac{\|s - c_i\|}{2\sigma_i^2}\right) \quad (4.1)$$

The nature and scope of each hidden unit have a value width which is denoted by "σ" and defines the nature and scope of the respective field units. The output layer is parameterized by the weights, *w* between the hidden layer and output layers. The following equation (4.2) calculates the predicted output.

$$O_k(s) = \sum_{j=1} w_{jk} \times \emptyset_s(j) \quad (4.2)$$

Where, for the output k of record s as $O_k(s)$, j denotes the hidden neuron of the architecture network. The weights are denoted by w_{jk} and are initialized to small random values. After that, to calculate each iteration t Least Mean Square (LMS) method is applied to supervise.

$$w_{jk}(t) = w_{jk}(t-1) + \Delta\, w_{jk}(t) \tag{4.3}$$

Where,

$$\Delta w_{jk}(t) = \eta \times e_k \times \phi_s + \alpha \Delta\, w_{jk}(t-1) \tag{4.4}$$

Where,

$w_{jk}(t)$: $The\ weight\ of\ the\ hidden\ unit,$

$\Delta w_{jk}(t)$: $The\ weight\ adjustment,$

η: $Trail - independent\ learning\ rate,$

α: $Constant\ (between\ 0\ and\ 1),$

e_k: $Prediction\ error.$

4.3 Modes of Operation

In this research, the ANN model based on RBFN algorithm is operated in three modes, i.e. training, validation, and testing. In the training mode, a training data set is used to adjust the weight of the network. Once the weight has been determined, the network is said to be trained. RBFN has an internal representation of hidden processing. During the training, the neural network has been evaluating the performance of the network. If the network is trained too long or over train, the network loses the ability to generalize the data. In the neural network system, to monitor the performance of the network, the validation mode is needed to train the data. This is done because in RBFN network is overtraining which cause the network performance not reliable and secure. However, the trained network is activated by the test data.

4.4 The Learning Method

In the learning method, two parameters the momentum coefficient (μ) and the learning coefficient (α) are used to weights change and adjustments for the network. The network uses the Gaussian function for both the hidden layer and output layer for activation purpose. Gaussian function easily implementation the network to determine the hidden neurons. During the learning period, the output layer of the network is derived by the Gaussian mixture techniques. The design parameters of the RBFN can be easily determined by using a method called the "S-Fold Cross-Validation Procedure" (SFCV) [41]. The learning strategy of RBFN and neural network flowchart is shown in Fig. 4.2 [40].

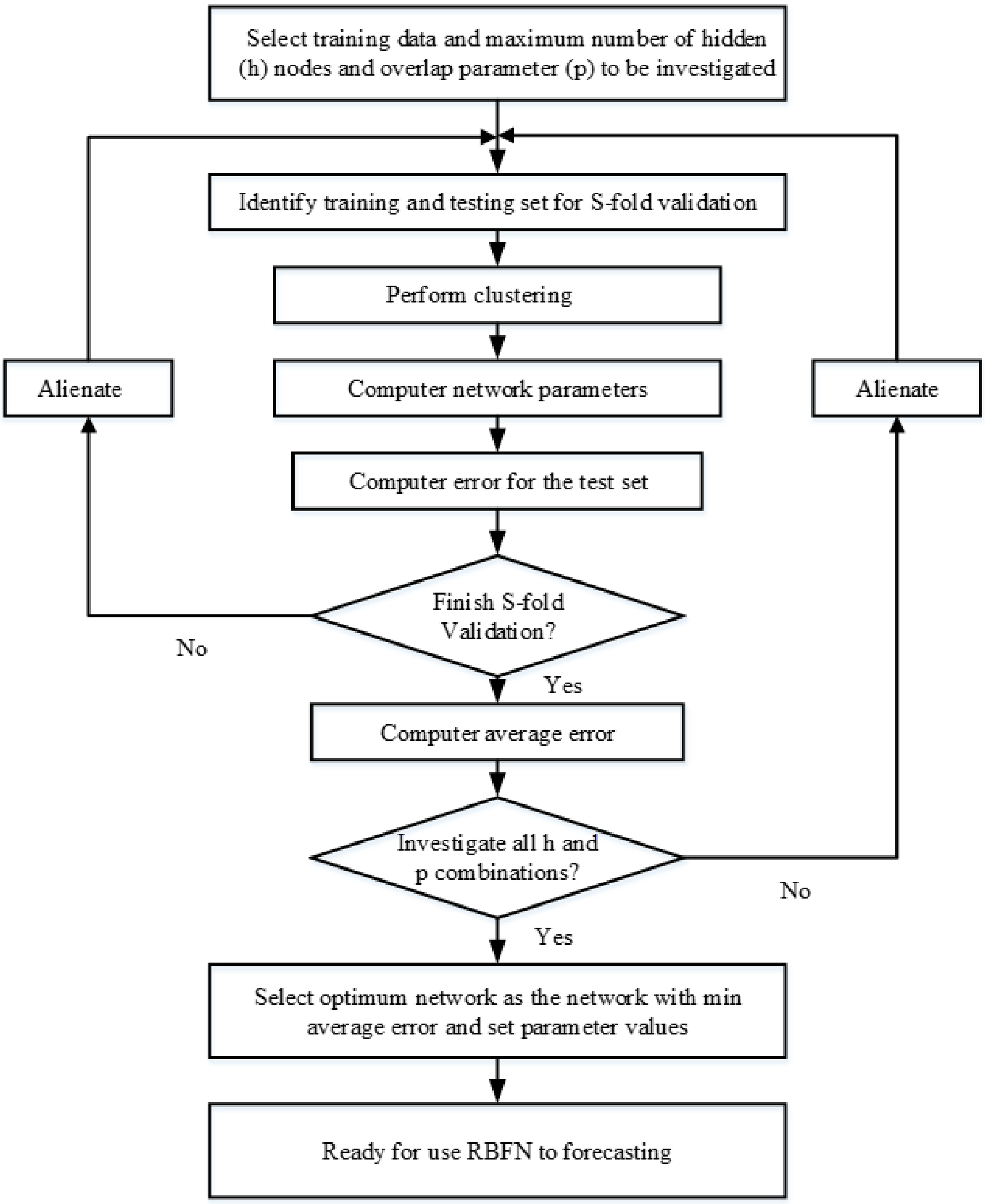

Figure 4.2: Flowchart of the learning strategy of RBFN.

4.5 Model Used in this Study

In Nepal, based on the Nepal climatic zone as classified by the Nepal meteorological department there are four seasons, between March to May spring season, between June to August summer season, between September to November autumn season, and between December to February winter season [42]. In the summer season, the river flow rate has been increasing because of rainfall and snowmelt in the Himalayan region, whereas the winter season has been found to be decreasing. The maximum and minimum flow for the four seasons are the most important periods for snow melt. However, snowmelt and steady river flow also affect the hydro power generation. The seasonal difference in river flow rate creates difficulties in balancing the electric power. However, in the context of Nepal, production of hydro power drop to one-third of installed capacity in the winter season [43].

The ANNs are becoming a standard analysis of hydrology and water resources development, management, modeling, and prediction systems. Many kinds of ANN models have emerged in the last decades for solving the various problem. For example, river flow prediction using artificial neural networks [44-45], neural network based water inflow forecasting [46-48] flood forecasting and prediction capabilities [49]. Nepal is a developing country with rich in water resources, the electricity demand is very high, but generation is deficient. In Nepal, the river flow rate plays an increasingly important role in electricity generation. To minimize the power shortage in a local community, prediction of river flow is most necessary for the Run-of-River HPPs in Nepal. In this research, the river flow forecasting model based on the ANNs was developed using the Neural Connection simulator [50].

In this study, the RBFN model for river flow forecasting consists of 4 input units; temperature, rainfall, cloud, and humidity. The output layer contains 1 unit which represents the river flow value. Finally, the architecture of the RBFN model was constructed. All internal parameters of the RBFN model were selected as required. The designed network supervised the input and target data for positive output results. The output result depends on the input parameters. In the prediction of the river flow rate with the number of inputs, the RBFN trained faster and gave the better results for forecasting short-term flow rate as well as total energy production forecasting. The architecture of the RBFN model used in this study is shown in Fig. 4.1. Table 4.1 shows the number of neurons in the input, hidden, and output layers of the model.

Table 4.1: Artificial Neural Network`s layer data.

ANN for river flow forecasting model	
Input neurons	4
Hidden neurons	8
Output neuron	1

4.6 Statistical Performance

In this study, the statistical performance is adapted to find the desired output of the model. To evaluate the model performance, Mean Absolute Error (MAE), Root Mean Square Error (RMSE), and Mean Absolute Percentage Error (MAPE), statistical criteria are used in this model. In Neural Network, the error has calculated the difference between actual and predicted values. As the obtained result is close to zero, the better will be the network performance.

The MAE is defined as the sum of the absolute value of the difference between the actual and predicted value and divided by the total number of input data. The equation (4.5) is given by;

$$MAE = \frac{\sum_{i=0}^{N} |A_i - P_i|}{N} \tag{4.5}$$

RMSE is the square root of the mean square error. The RMSE is calculated by the following equation (4.6).

$$RMSE = \sqrt{\frac{\sum_{i=0}^{N} [A_i - P_i]^2}{N}} \tag{4.6}$$

The MAPE is used to determine the relative error between the actual and predicted value.

The MAPE is denoted by the given equation (4.7).

$$MAPE = \frac{\sum_{i=0}^{N} \frac{|A_i - P_i|}{A_i} * 100}{N} \tag{4.7}$$

Where,

A_i: *The actual value,*

P_i: *The predicted value,*

N: *Total number of data points.*

The input data, target data, and test data sets are firstly normalized in the range of 0 to 1 [44]. The normalization is done by using the following equation (4.8).

$$\overline{X} = \frac{X - X_{min}}{X_{max} - X_{min}} \tag{4.8}$$

Where,

$\overline{X}$: *The standardized value of the input,*

X_{min}: *Minimum of actual value,*

X_{max}: *Maximum of actual value,*

X: *Original value.*

The predicted normalized value of this study is de-normalized by the following equation (4.9) [51].

$$\overline{B} = \overline{A} * (A_{max} - A_{min}) + A_{min} \tag{4.9}$$

Where,

$\overline{B}$: *The original value,*

$\overline{A}$: *The normalized value,*

A_{max}: *The maximum value of the input data sets,*

A_{min}: *The minimum value of the input data sets.*

4.7 Data Process

The hydrological and downstream data used for this simulation study were obtained from the Government of Nepal, Department of Hydrology and Meteorology (DHM), Kathmandu, Nepal. The weather forecast data input parameters were collected from the World Weather Online website [52]. The collected actual daily river flow data of Trishuli river for 2013 were divided into four different seasons to obtain a hydro power potential. Every season was used to train the network and one-week data was used for the testing phase. Four inputs and one output were set for the network model. The output is one i.e. one-week river flow prediction. In this study, the actual minimum and maximum river flow rates are observed in March 36.10 m^3/s and in July 841 m^3/s respectively.

4.8 Correlation Analysis of Inputs and Target

In this study, the correlation analysis is carried out to measure the strength of a relationship between the input and target data sets. The coefficient of correlation varies between the values 0 to 1, the value close to 1 indicates the perfect correlation. Table 4.2 data sets shows a positive correlation.

Table 4.2: Correlation analysis of inputs and target.

	Temperature	**Rain**	**Cloud**	**Humidity**	**Flow**
Temperature	1				
Rainfall	0.407	1			
Cloud	0.324	0.746	1		
Humidity	0.183	0.567	0.623	1	
Flow	0.516	0.703	0.658	0.626	1

4.9 RBFN Configuration Used for Simulation

In this study, we used the Neural Connection simulator tool [50] to build the model for short-term river flow forecasting to determine the potential of hydro power. Fig. 4.3 shows the architecture of RBFN used for this simulation. The simulation is held to predict the short-term river flow forecast for all four seasons. The multiple inputs of designed

RBFN model provide the one output. In Time Series Plot (TSP), we can see the output results after the simulation.

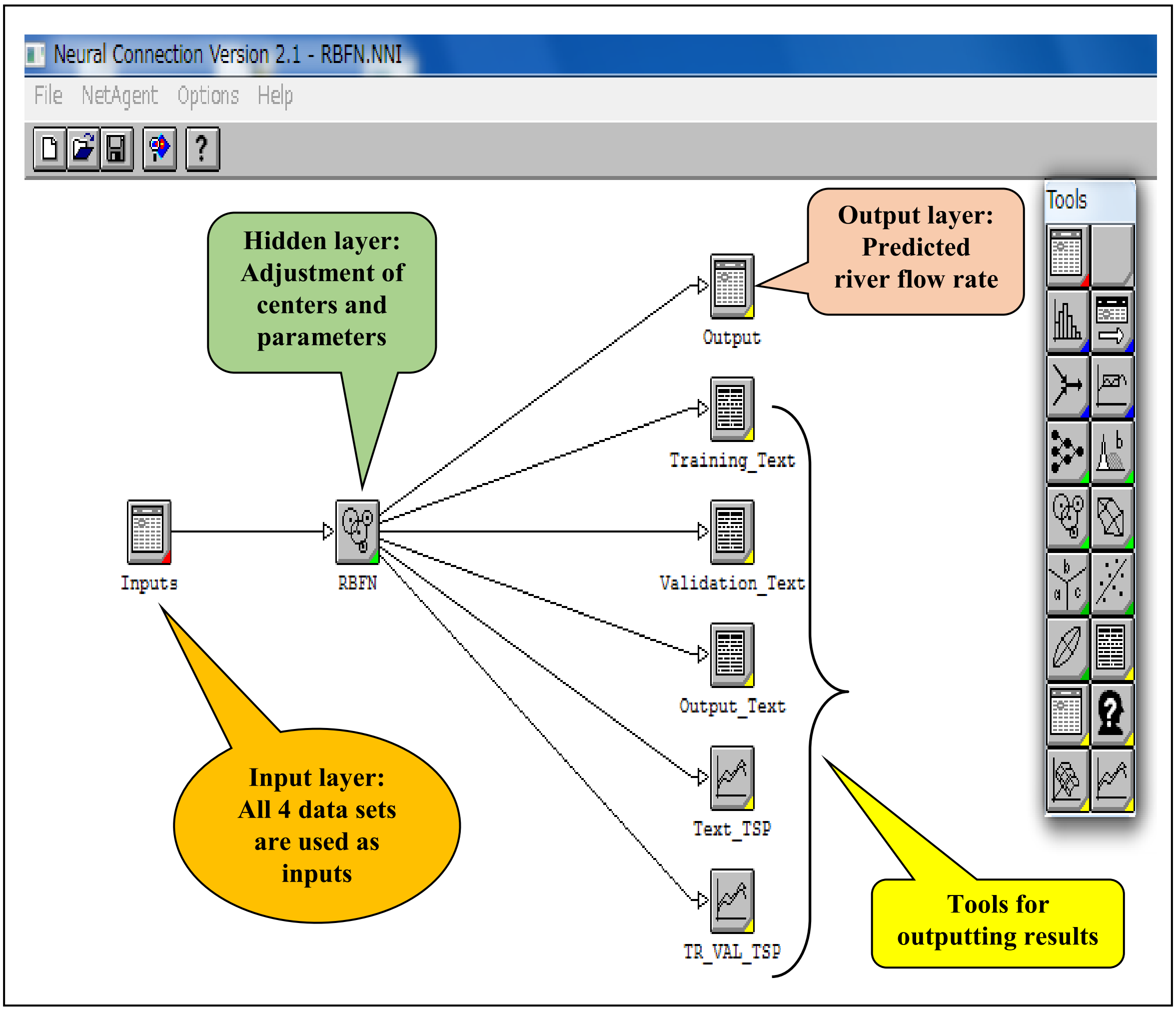

Figure 4.3: RBFN architecture for simulation in this study.

Fig. 4.4 shows the RBFN model input dialog box used in this study. The dialog box shows the actual function, parameters, and centers for the simulation. The inputs and out data sets are first normalized and the centers are taken randomly. In this study, the multiple outputs of the RBFN architecture are used to analyze the results. RBFN architecture method gives a better solution for prediction. Therefore, the predicted short-term river flow later used to determine the hydroelectric potential.

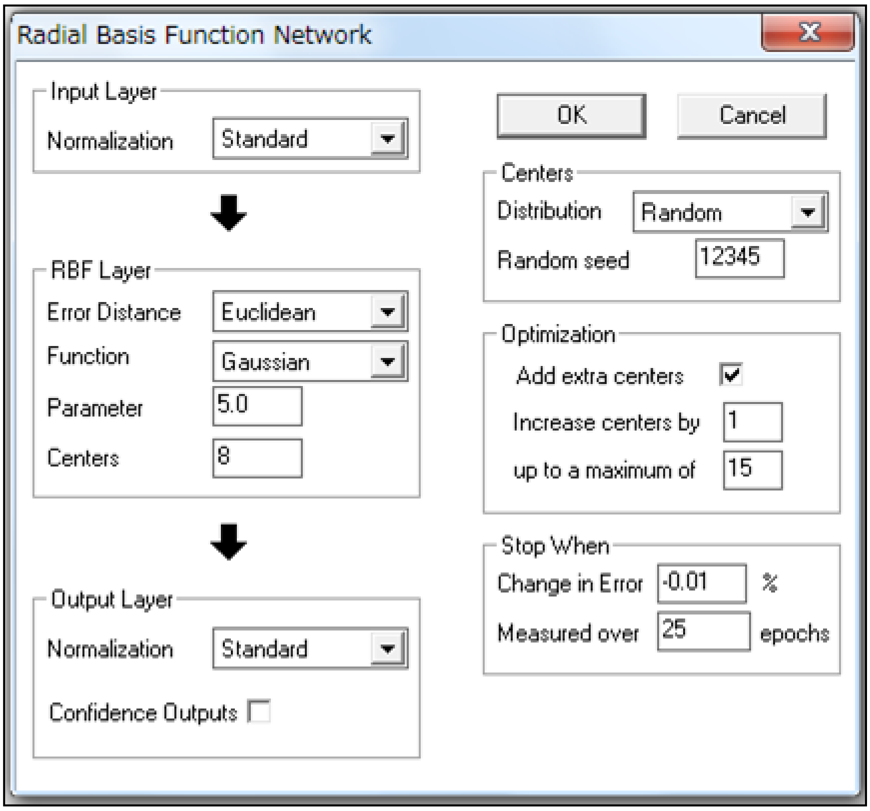

Figure 4.4: Selection of RBFN parameters and centers for simulation in this study.

4.10 Simulation Results

The performance of the developed model based on the results of this research, prediction of river flow was observed. Employing Radial Basis Function Network (RBFN) method for forecasting of river flow and observed less than 8% of error of test data for one-week. However, the noise level in the hydrology dataset is usually ranging between 5% and 15% [53]. One-week of flow prediction, hydro power generation potential, and peak demand of the Kathmandu, the capital city of Nepal has been identified.

The model can be used in predicting one-week flow forecasting of four seasons by providing the past successive yearly flow of the same week. In this study, to identify the number of hidden neurons in the RBFN model, we applied trial and error method to determine the number of hidden layer neuron of our model. For that purpose, we tried up to 20 hidden neurons, however for our model the number of hidden neurons 8 is very appropriate with MAPE 3.86% which is shown in Fig. 4.5. The river flow rate of Trishuli river, used in this study is shown in Fig. 4.6. The minimum and maximum river flow rates are observed in March 36.10 m^3/s and in July 841 m^3/s respectively. The RBFN network which consists of 365 days data taken from the one year period of 2013. The 20 days river flow and 15 days only high flow value which is randomly chosen in the one-year period. The input data sets are used to feed into the RBFN network. A test result that is predicted flow discharge is then compared to the desired discharge value. The RBFN technique that was used in the forecasting gave a MAPE of less than 8%.

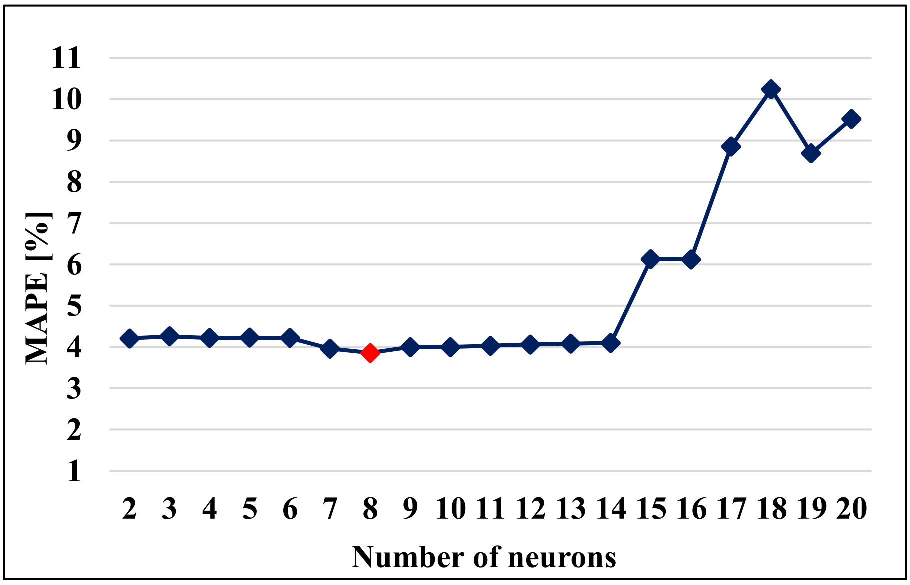

Figure 4.5: The number of neurons in the hidden layer and MAPE.

Figure 4.6: Monthly water flow rate of Trishili river.

Fig. 4.7 and Fig. 4.8 shows the test results for 20 randomly selected value and 15 randomly selected high flow value from one year datasets of 2013.

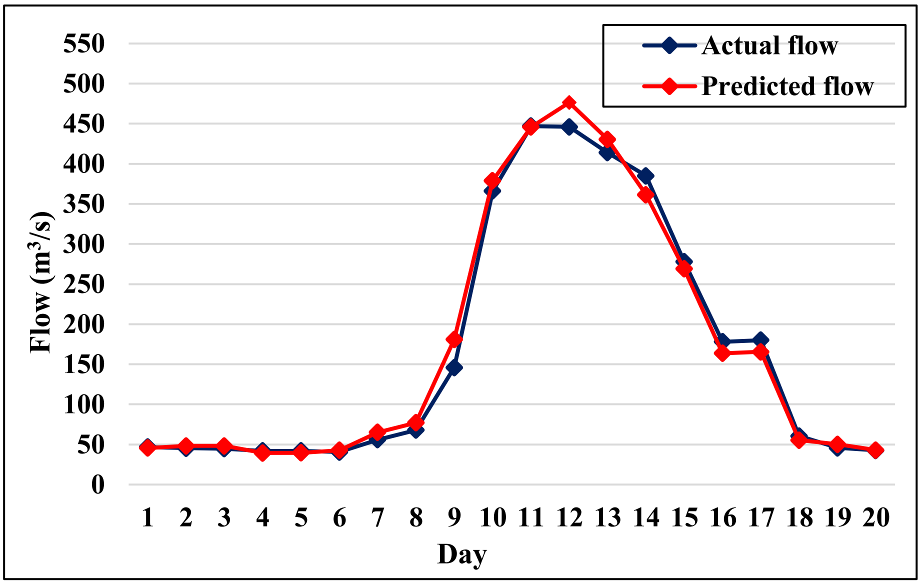

Figure 4.7: Test result for 20 randomly selected days of one year.

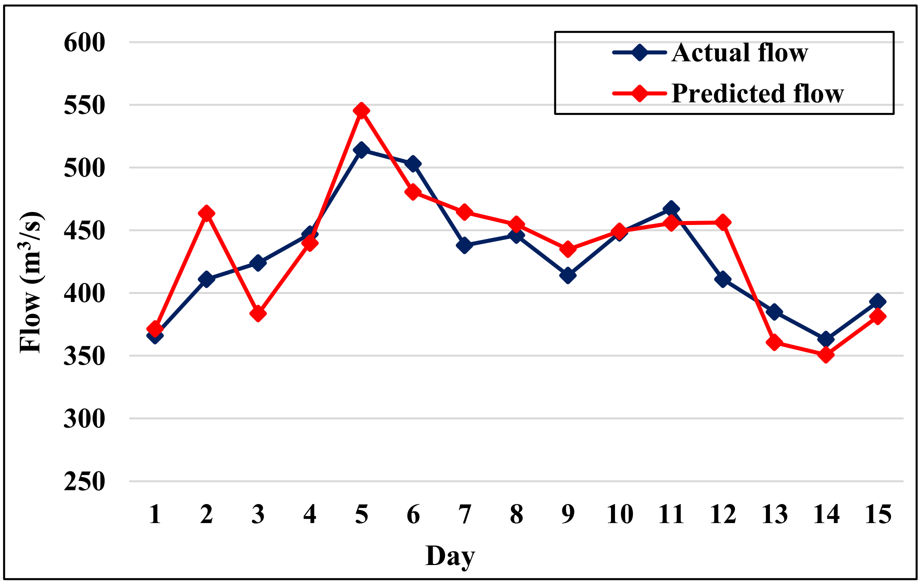

Figure 4.8: Test result for 15 high flow randomly selected days of one year.

As can be seen from results, RBFN was able to learn in predicting the river flow rate. The learning ability demonstrated as shown by a less than 8% error as shown in Table 4.3. Standard of Deviation (SOD) and Coefficient of Variation (COV) were identified during that period.

Table 4.3: Statistical parameters of the test phase.

Test result	SOD [m^3/s]	COV [m^3/s]	MAPE [%]
20 data set	160.03	0.93	7.25
15 data set	53.14	0.12	5.02

In this study, using the RBFN technique to forecast the river water discharge for one-week ahead of all four seasons. This is an indication that RBFN based neural network can still be used to predict river flow rate up to one-week ahead. In this architecture, the summer season forecasted error is high in compared to other corresponding seasons. This is due to the drastic change of river flow in the summer season. Test results that are the forecasted discharge are then compared to the desired discharge.

The RBFN based river flow forecasted values are not significantly different. The actual versus predicted flow value of the test phase for all four seasons are shown in the following Figs. (Figs. 4.9-4.12).

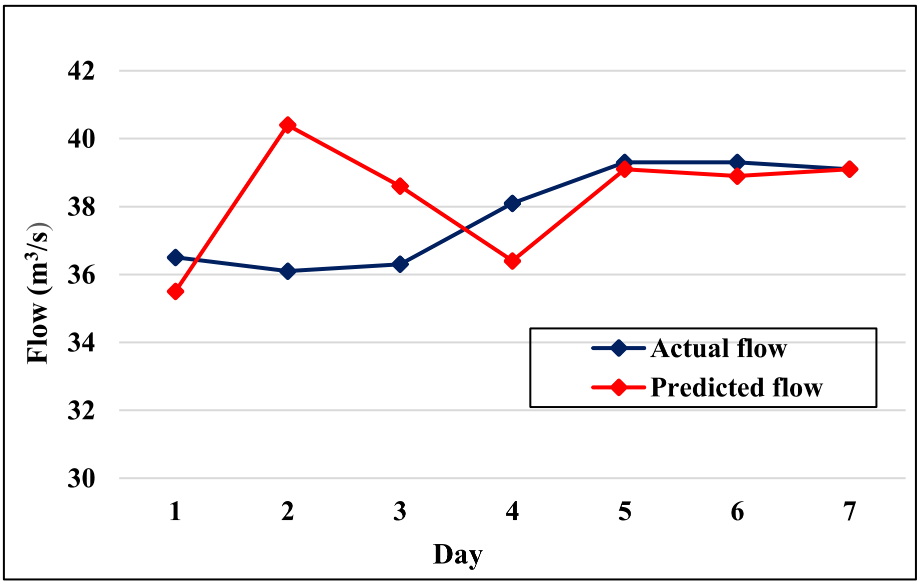

Figure 4.9: The actual versus predicted flow value for the spring season.

The network is trying to recognize the test data as the original value. However, the obtained values are reliable as compared to actual values and forecasting errors are less than 8%.

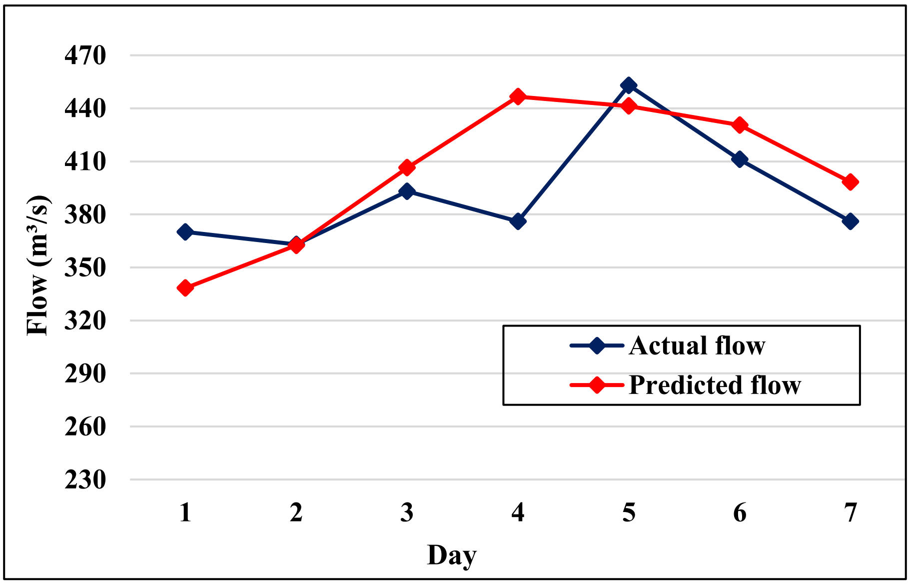

Figure 4.10: The actual versus predicted flow value for the summer season.

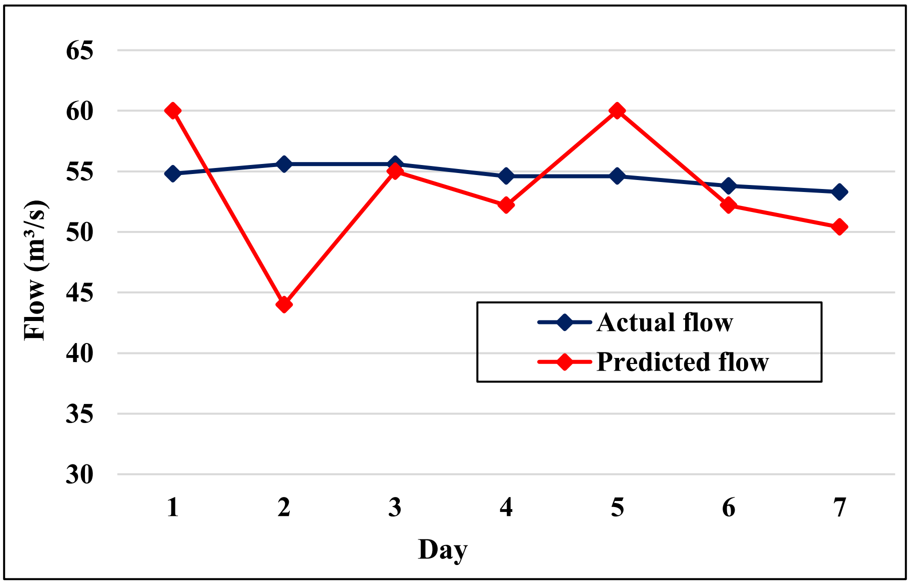

Figure 4.11: The actual versus predicted flow value for the autumn season.

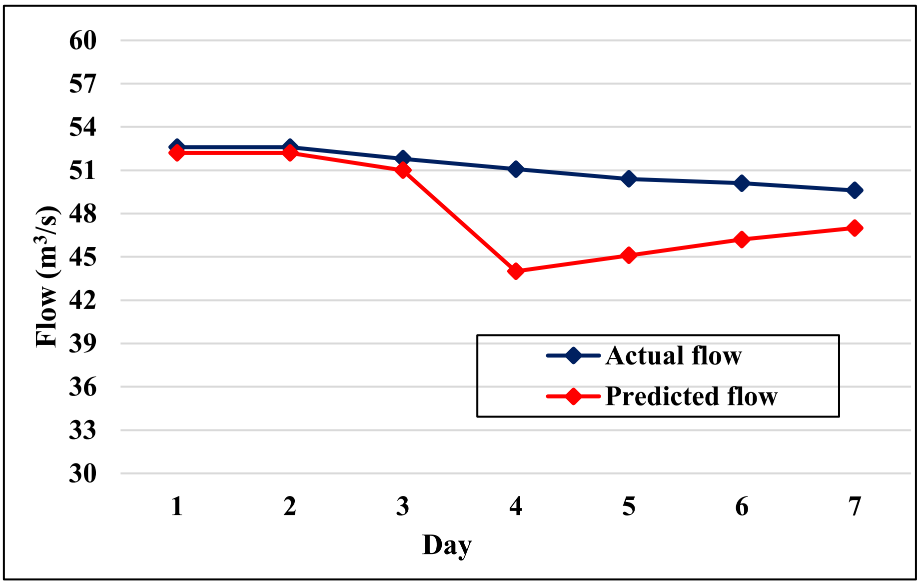

Figure 4.12: The actual versus predicted flow value for the winter season.

As we can see from the results, RBFN was able to learn and predict the river flow rate. Fig. 4.9 and Fig. 4.10 shows the one-week test result of the spring and summer seasons. In the spring season, it demonstrated that the network error is less than 4% for the one-week test result. However, in the summer season, the network error is relatively high in comparison to spring season due to high river flow. The river flow varies from minimum 134 m^3/s to maximum 841 m^3/s. In the autumn season, the river flow rate starts to decrease and becomes very low in the spring and winter seasons. The one-week test result of autumn and winter seasons are shown in Fig. 4.11 and Fig. 4.12.

The statistical parameters of actual and predicted of river flow are shown in Table 4.4. Furthermore, MAPE increases as summer and autumn seasons. Increasing the test data error for more than one-week will increase the MAPE. Therefore the predicted values of river flow will be significantly different. As shown in Table 4.4, illustrates the differences between the predicted river flow rates of Trishuli river at different seasons. The predicted average lowest and highest river flow rates are 37.80 m^3/s and 403.39 m^3/s in spring and summer seasons.

The maximum error is 7.71% and the minimum is 3.71% for one-week. Also, to predict the river flow rate from the RBFN method could be applied for its better performance. In this study, besides the normal operation of the power system, considering for one-week of the spring season river flow data for extreme condition.

Table 4.4: Statistical parameters of the predicted flow of one-week for the test phase.

Test result	**Spring**	**Summer**	**Autumn**	**Winter**
Average actual flow [m^3/s]	37.80	391.71	54.60	51.20
Average predicted flow [m^3/s]	38.29	403.39	53.40	48.20
Coefficient of variation [Actual]	0.03	0.08	0.01	0.02
Coefficient of variation [Predicted]	0.04	0.10	0.10	0.07
MAPE [%]	3.71	6.30	7.71	5.71

In Nepal, the electricity demand is very high compared to generation, due to multiple reasons, for example seasonally the river flow rate increase and decrease drastically, natural disasters such as an earthquake, flooding and so on. For that reason, to overcome the power shortage problem for a short-term period, first of all, we predicted the river flow forecast for one-week ahead of the spring season, calculated the technical potential of hydro power from the daily river flow value, hydro power head design and assumptions of other physical parameters.

The assumption of design discharge for the technical potential of hydro power generation, theoretical potential, and peak demand for electricity until one-week ahead is identified. The river flow is not uniform for this reason the predicted power generation of one-week is different. We consider the statistical parameter of predicted flow of one-week predicted result to simulate the model. From Table 4.5, one-week ahead predicted the amount of electricity generation could be determined by; 't', 't+1', 't+2', 't+3', 't+4', 't+5', 't+6' from date 3/08/2013 to 3/14/2013.

The one-week prediction of river flow value and its potential generation of electric power will not suffice to solve the power crisis because the demand for Kathmandu, the capital city of Nepal is very high, however, it will help to supply of electric power for a couple of days to overcome the power outage across the Kathmandu valley. Similarly, Table 4.6 shows the actual and predicted of maximum and minimum river flow value and its electricity generation potential for the spring season.

Table 4.5: Predictions for electricity generation, potential and peak demand for the spring season.

Prediction [Day ahead]	River flow [m^3/s]	Design discharge [m^3/s] [Approx.]	Theoretical potential [MW]	Technical potential [MW]	Peak demand [MW] [Approx.]
Day [t]	41.46	29.02	16.47	11.52	295-335
Day [t+1]	42.32	29.62	16.81	11.76	300-350
Day [t+2]	41.09	28.76	16.32	11.42	295-330
Day [t+3]	45.45	31.81	18.05	12.63	290-325
Day [t+4]	41.97	29.37	16.67	11.66	305-330
Day [t+5]	36.86	25.80	14.64	10.25	300-325
Day [t+6]	39.07	27.34	15.52	10.86	310-340

Table 4.6: Actual and predicted parameters for electricity generation and peak demand for the spring season.

Season	Spring [Actual]	Spring [Predicted]
Maximum river flow [m^3/s]	209	209.55
Minimum river flow [m^3/s]	36.1	42.50
Maximum theoretical potential [MW]	83.03	83.25
Minimum theoretical potential [MW]	14.34	16.88
Maximum technical potential [MW]	58.06	58.17
Minimum technical potential [MW]	10.02	11.80
Maximum demand [MW] [Approximate]	270-350	275-360
Minimum demand [MW] [Approximate]	260-350	270-355

The predicted one-week ahead of river flow forecasting result is shown in Fig. 4.13. The prediction result is obtained less than 6% error. In this study, based on Radial Basis Function Network (RBFN) model was developed for simulating the hydrological behavior of river flow. The model was constructed to predict seasonal river flow. The

RBFN model provided improved weekly forecast during the testing phase. Based on the predicted river flow data, we calculated the potential of electricity and identified the potential of electricity for one-week for the spring season.

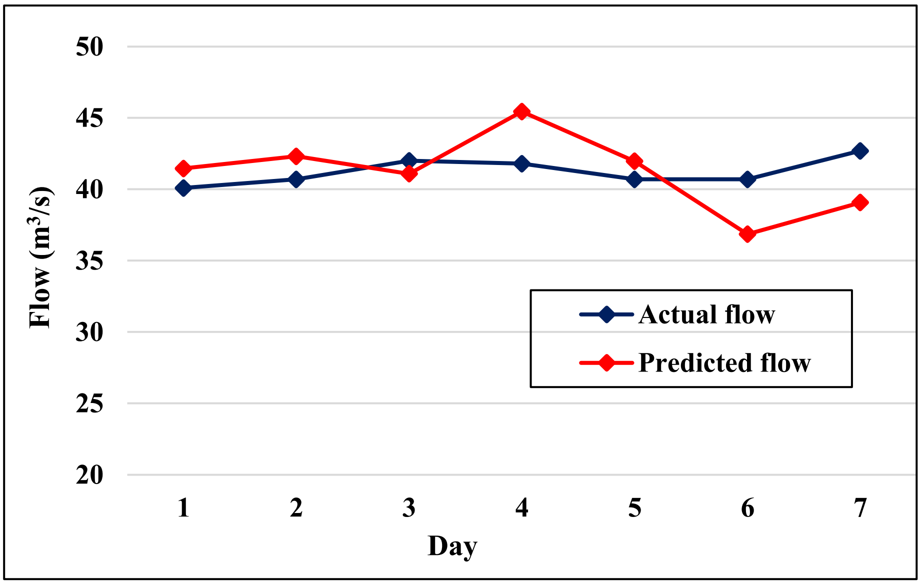

Figure 4.13: The test result for one-week ahead of the spring season.

4.11 Conclusion

The obtained research results from the artificial neural network indicate that the RBFN network model is more capable of predicting river flow. The performance of river flow model depends on the input parameters, selection of training and testing data and has a strong relationship with climate elements of that area. River flow prediction models are essential tools in hydro power development and water resources management. This research was mainly focused on the prediction of river flow at different seasons. However, we considered the minimum, maximum, and one-week river flow condition of the spring season to predict the river flow value and potential of electricity.

It has been analyzed that river flow rate prediction helps to reduce the demand for electric power. The prediction method optimizes and plans for the future system. This research analyzed the river flow prediction and technical potential of electricity generation of the hydro power plant in Trishuli river in Nepal. To reduce the power shortage in a local community and urban areas for a short-term period, this kind of research is most important and necessary. Therefore, this research will more useful to lead the efficient operation, planning, and development of hydro power plants, development of water resources management system and early warning system in flood forecasting system.

Chapter 5
Analysis of Economic Load Dispatch and Optimal Power Flow

5.1 Introduction

In the past decades, renewable power companies are overgrowing with the development of civilization. From a historical perspective, reliable energy is one important key to make a prosperous society. The electricity is improving the quality of human life and driving economic prosperity into a right path. The concept of Economic Load Dispatch (ELD) and Optimal Power Flow (OPF) techniques are widely used for solving the power system problems [54-55]. Today, these techniques were used to solve the problems regarding the system stability. In order to become the system more efficient, reliable and secured.

The increasing power system poses a more significant challenge in demand and control management system for reliable and secure system. Sudden changes of demand or generation are resulting imbalance between the systems [56]. In order to balance the system more efficiently, a thorough understanding of economic load dispatch and optimal power flow solutions are necessary.

5.1.1 Economic Load Dispatch (ELD)

As we know that, the economic load dispatch is basically used to solve the system load with minimum cost. As the energy requirements are rising rapidly, the number of power plants supply the electricity to meet the system load. Generally, the traditional methods were used to solve the economic load dispatch problem such as the Lambda-Iteration method, Gradient method, Newton`s method and so on [57-60]. Recently, the advanced optimization techniques are developed to replace the traditional concepts.

The Genetic Algorithm (GA) and fuzzy based hybrid Particle Swarm Optimization (PSO) [61-64] are the advanced methods to solve the economic load dispatch problems. The following equations (5.1-5.4) determine the economic load dispatch problem considering the network with and without losses [57].

5.1.1.1. Economic Load Dispatch (Without Losses)

The energy balance equation can be represented by the following equation (5.1).

$$\sum_{i=1}^{N} P_i - P_D = 0 \tag{5.1}$$

The inequality constraint is represented by the following equation (5.2).

$$P_{imin} \leq P_i \leq P_{imax} \qquad i = 1,2,3, \dots \dots \dots \dots, N \tag{5.2}$$

Where,

P_i: $The\ power\ output\ of\ the\ i_{th}\ generating\ unit,$

P_D: $The\ real\ demand,$

N: $The\ number\ of\ generation\ plants,$

P_{imin}: $The\ minimum\ output\ of\ the\ i_{th}\ generating\ unit`s,$

P_{imax}: $The\ maximum\ output\ of\ the\ i_{th}\ generating\ unit`s,$

$F_i(P_i)$: $The\ operating\ fuel\ cost\ of\ i_{th}\ plant.$

The cost function is calculated by the given quadratic equation (5.3).

$$F_i(P_i) = a_i^2 + b_i P_i + c_i \tag{5.3}$$

5.1.1.2. Economic Load Dispatch (With Losses)

The energy balance equation can be written by the given equation (5.4).

$$P_{load} + P_{loss} - \sum_{i=1}^{N} P_i = 0 \tag{5.4}$$

Where,

P_{load}: $The\ load\ demand,$

P_{loss}: $The\ transmission\ losses,$

N: $The\ number\ of\ generation\ plant,$

$$\sum_{i=1}^{N} P_i : The\ generation\ of\ i_{th}\ plant.$$

5.1.2 Optimal Power Flow (OPF)

The Optimal Power Flow (OPF) of a power system, involves much consideration such as power reliability, system security, economic operation and so on. The optimal power flow methods could be applied in the power system to supply the real power at various stations with minimum generation cost and balance the entire power flow of the system. The optimal power flow calculated the maximum power that can safely be transferred from one area to another. In the power system, the particular type of optimal power flow is known as "Security-Constrained Optimal Power Flow," (SCOPF).

5.2 Power World Simulator

The Power World simulator is a computer-based simulator tool for analyzing and solving the power flow, economic dispatch problem, contingency, fault analysis and transmission system and so on [65-67]. The simulator tool, which provided the graphical user interface (GUI) to draw the power system network and analyze the power flow on a typical large power system. Several studies were done in the past to comprehend stable and secured power flow in the system. In this study, for the optimal power flow management, we used the Power World simulator to design and analysis of the existing and proposed power systems for optimal power management. Power World which is a unique simulator tool in comparison with many other technologies; Power System Analysis Toolbox (PSAT), MATPOWER [68] and so on.

5.3 The Current Status of Electric Power Industry in Nepal

In Nepal, the development of electric power productions is firmly increasing because of the demand for electrical energy. In the early years of the power system developments, this increase was prolonged. However, developed countries, doubling their energy consumption every 20 years. Power consumption in developing and emerging countries like Nepal is expected to more than double, whereas industrialized and developed countries like Japan, US, UK and so on, will increase only for about 35% to 40%. However, because of a lack of investments in the hydro power projects and transmission systems in Nepal, there is a vast gap between the electricity generations and load demand. In Nepal, still, 22% of the population has no access to grid electricity. To minimize the peak load demand across the country, Nepal power system heavily depends on Indian power utilities. Therefore, the transmission lines are heavily loaded due to an increasing power exchange at the peak load duration.

First of all, we are going to give a brief outline of the electric power industry in Nepal. Nepal`s power industry is dominated by the Nepal Electricity Authority (NEA) and Independent Power Producers (IPPs). NEA performs the full range of generation, transmission, and distribution of electric power under the supervision of the government of Nepal. Whereas, the IPPs only performs the generation. Table 5.1 shows the relative ranking of these three utilities. As it can be seen, NEA is the first largest electric utility in Nepal. Among the total available energy in 2017, 36.84% was generated by NEA [69].

Table 5.1: Data of electric power utilities in Nepal.

Particulars	Generation [GWh]	Contribution [%]
NEA	2305.45	36.84
IPPs	1777.24	28.40
Import power from India	2175.04	34.76

From Table 5.1, it can be comprehended easily that how much power is necessary for Nepal to balance the system load. In this chapter, the obtained results may help to contribute the power shortage during the On-peak and Off-peak time.

5.4 Analysis of the 5 Bus Multi-Area System

In Nepal, two major grid-connected power utilities; NEA generates electric power by Run-of-River, storage hydro power, and thermal which is under the supervision of the government of Nepal, and independent power producers (IPPs). The existing generations are not sufficient to fulfill the demand. The Nepal government import almost half of its electricity from neighboring country India [69]. In this study, considering five bus system model including proposed on the Power World simulator to analyze the power system of Nepal. The design model consists of five 132 kV buses, five generators and buses, (generator on bus 1 represents the power produced by NEA, generator on bus 2 represents the power produced by IPPs and similarly, generator on bus 3 represents the power production from proposed cascade hydro power plants from the Trishuli river. The generator on bus 5 represents the import power from India), four transmission lines, one system load, bus 5 is considering as a slack bus with Automatic Control Generation (ACG) “ON” for import power.

The actual power flows from generators, through the transmission lines, and in this model, the total system load is connected to bus 4. The proposed model of this study is shown in Fig. 5.1. Considering the proposed hydro power plants generation maximum potential for upstream is 550 MW (including existing plants) and for downstream 70 MW of Trishuli river, in Nepal. We already proposed the cascade hydro power plants in downstream of this river [70]. The production of electricity depends on the river flow rate. The river flow rate is not steady which effects hydro power generation and creates difficulties in balancing the system load.

The hydro power generation is generally depended on the river flow rate and the rainfall. However, hydro power generations are not the same at all seasons. Therefore, generation outputs are different. For this reason, extreme power shortage problem may happen. The contribution of the power supply system in Nepal is shown in Table 5.2. The seasonally Off-peak and On-peak existing generations, import power, load shedding and system load of Nepal is explained in this chapter.

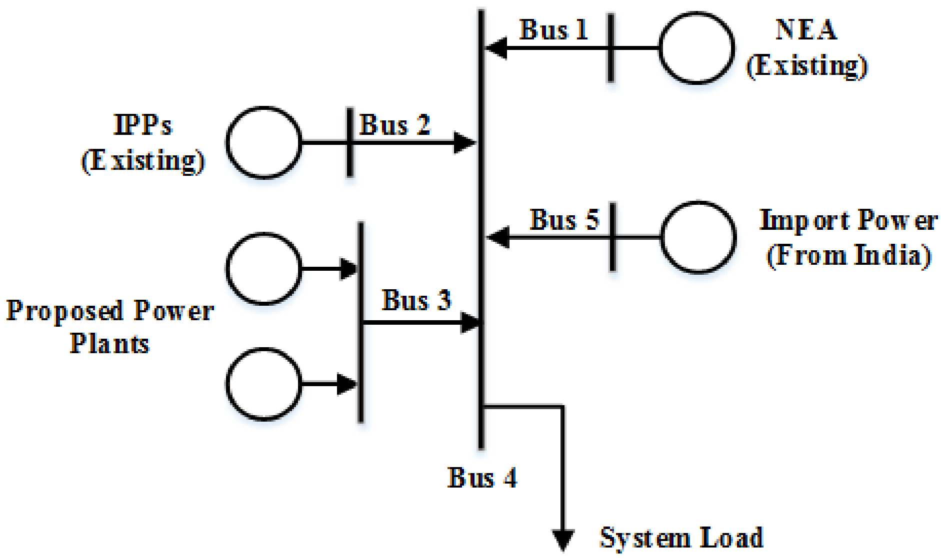

Figure 5.1: The proposed model for this study.

The daily and seasonally power generation and system load data is used to analyzed the proposed model. The system maximum peak demand of electricity in Nepal is 1444.06 MW. According to NEA, the peak demand in 2030 is predicted 10,092 MW [71].

Table 5.2: Supply and contribution of the power system in Nepal.

Supply option	Contribution [MW]
NEA hydro [Run-of-River]	272.56
NEA hydro [Storage]	89.70
IPP hydro	147.95
Import power from India	385.07
Total	**895.28**
Peak demand	1280.28
Deficit	385.00

In Nepal, the maximum peak demands are around 7:00 to 8:00 and 19:00 to 21:00. The peak demand is very high in comparison to existing and import power. There is a huge amount of power shortage during that period. Therefore, in order to overcome these problems, optimal power flow system is designed. The proposed power plants generations are added to the system. In this chapter, first, we describe the one-line diagram of the existing and proposed model together to identify the power flow of the system, which are designed in the Power World simulator.

The expected power generation from the proposed power plants considering the cascade hydro power in all four seasons is discussed in this chapter. Finally, the ELD and OPF of the 5 bus multi-area systems are identified. Fig. 5.2 shows an hourly power generation and load pattern of Nepal.

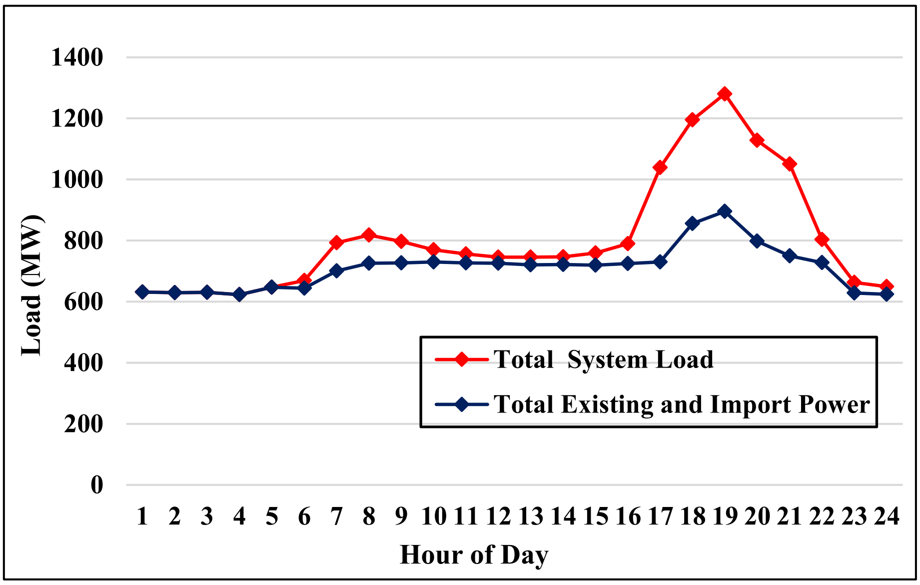

Figure 5.2: Hourly load variation pattern of Nepal.

5.5 One-Line Diagram of the Existing Power Systems

In this study, with the development of the animated simulation tool, we designed and analyzed results of the existing model to identify the economic load dispatch and optimal power flow for Off-peak load and On-peak load for all four seasons. The generator connected to bus 3 is considering as a slack bus with Automatic Generation Control (AGC) "ON." The actual power flows from generators, through the transmission lines, and in this model system load is connected to bus 4. Each generator connected to the bus has with different parameters. The real output active power is displayed for each generator. Considering all transmission lines are lossless and have the same impedance. The animated small green arrows show the direction of the power flowing through the system [65].

The rating of each generator is considered as required by our system. In this model, there are a red squares circuit breakers, the main function of this device is to open and close a model. The pie chart represents the percentage loading of each transmission lines. Fig. 5.3 shows the simulation results of the optimal power flow of the existing power systems. In Nepal, the tariff of import electricity is based on the capacity of the transmission line. According to NEA, the tariff of electricity is quite low for high capacity 132 kV transmission line, compared to 11 kV. The power production cost of NEA, IPPs, and power purchase rate from India is shown in Table 5. 3 [69]. At the time of this writing, in this system, the import power purchase rate is considered as 82.01 MWh/$.

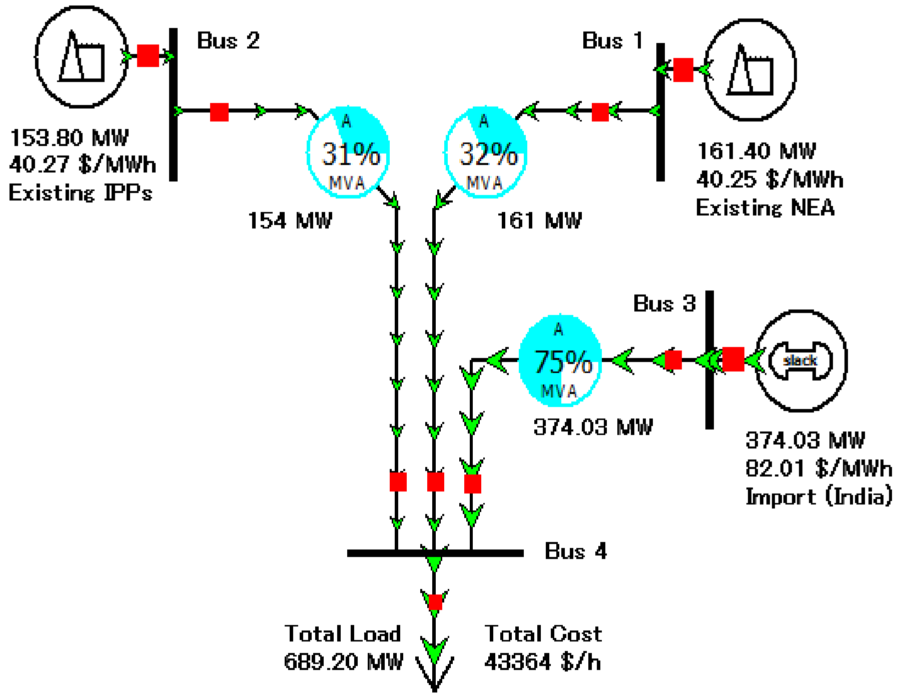

Figure 5.3: One-line diagram of the existing power systems.

Table 5.3: Generation and import tariff of electricity in Nepal.

Source	**Spring [$/MWh]**	**Summer [$/MWh]**	**Autumn [$/MWh]**	**Winter [$/MWh]**
NEA	40.25	40.25	40.25	70.46
IPPs	40.27	40.27	40.27	70.48
Proposed	40.26	40.26	40.26	70.47
Import [From 132 kV]	75.94	75.94	75.94	75.94
Import [From 33 kV]	82.01	82.01	82.01	82.01
Import [From 11 kV]	88.21	88.21	88.21	88.21

In Nepal, the electricity purchase rate by NEA from IPPs during in three spring, summer and autumn seasons known as eight wet months (mid-April to mid-December) is 40.27 $/MWh and for the four dry months, winter season (mid-December to mid-April) is 70.48 $/MWh [69]. However, the average consumer retail price is 0.07216 $/kWh. In this study, for proposed generations, we considered 40.26 $/MWh and for NEA 40.25 $/MWh. In this chapter, the generator power limits are shown in Table 5.4 and the generator operating cost is modeled using a cubic cost function. The obtained results of all four seasons, Off-peak and On-peak generation, demand, and load shedding are shown in Table 5.5.

Table 5.4: Generators power limits.

Bus No.	P_{min} **[MW]**	P_{max} **[MW]**
1	122.40	365.00
2	137.30	331.00
3	300.00	395.00
5	14.00	385.07

In this study, the output cost of the generator unit is $/MWh. Therefore, the output cost of each generator is determined by the following equation (5.5) [72].

$$C_i(P_{gi}) = F_i + (A_i + B_i P_{gi} + C_i P_{gi}^2 + D_i P_{gi}^3) * Fc + V_{OM} P_{gi} \quad (5.5)$$

Where,

C_i: *The cost of the generating unit,*

P_{gi}: *The power of the generating unit,*

F_i: *The fuel cost independent value of the generating unit,*

A_i: *The fuel cost dependent value of the generating unit,*

B_i, C_i and D_i: *The coefficients of the generating unit,*

Fc: *The fuel cost of generating unit,*

V_{OM}: *The variable O&M of generating unit.*

Table 5.5: Optimal generation and scheduling for the existing system.

Source	Spring [Off-peak]	Spring [On-peak]	Summer [Off-peak]	Summer [On-peak]	Autumn [Off-peak]	Autumn [On-peak]	Winter [Off-peak]	Winter [On-peak]
Existing NEA [MW]	161.40	365.00	309.20	250.60	284.10	457.23	122.40	362.26
Existing IPPs [MW]	153.80	155.80	236.20	331.00	247.90	247.93	137.30	147.95
Import [MW]	374.00	352.10	167.53	253.70	14.00	253.90	363.25	385.07
Load shedding [MW]	0.00	400.00	0.00	510.00	0.00	485.00	0.00	385.00
Total load [MW]	689.20	1272.90	712.93	1345.30	546.00	1444.06	622.95	1280.28
Total cost [$/MWh]	43361.62	82645.04	35696.21	86047.06	22566.10	88984.84	48091.34	99105.80

5.6 One-Line Diagram of Proposed Power System

In the proposed model, considering the 5 bus system including the bus load. The five generators are connected to bus 1 (NEA), bus 2 (IPPs), bus 3 (proposed), and bus 5 (import) respectively. The optimal generation scheduling is performed according to the generation limits and input parameters such as bus voltage, MVA rating are selected as system requirements. The best results are found when both proposed generators connected to bus 3 are added to the system. Finally, in order to make a large scale power network system, the proposed power plants should be added in the existing system as shown in Fig. 5.4. The proposed generators supply maximum power with low-cost to balance the system load.

The proposed system reduced the import power during the Off-peak of the spring season. The simulation results of the power flow of the proposed model are shown in Fig. 5.4. In the proposed model, the economic load dispatch problem and the power flow in the system are improved, compared to the existing system. In all four seasons, Off-peak load and On-peak load effects and generation variations on the developed model are shown in Table 5.6.

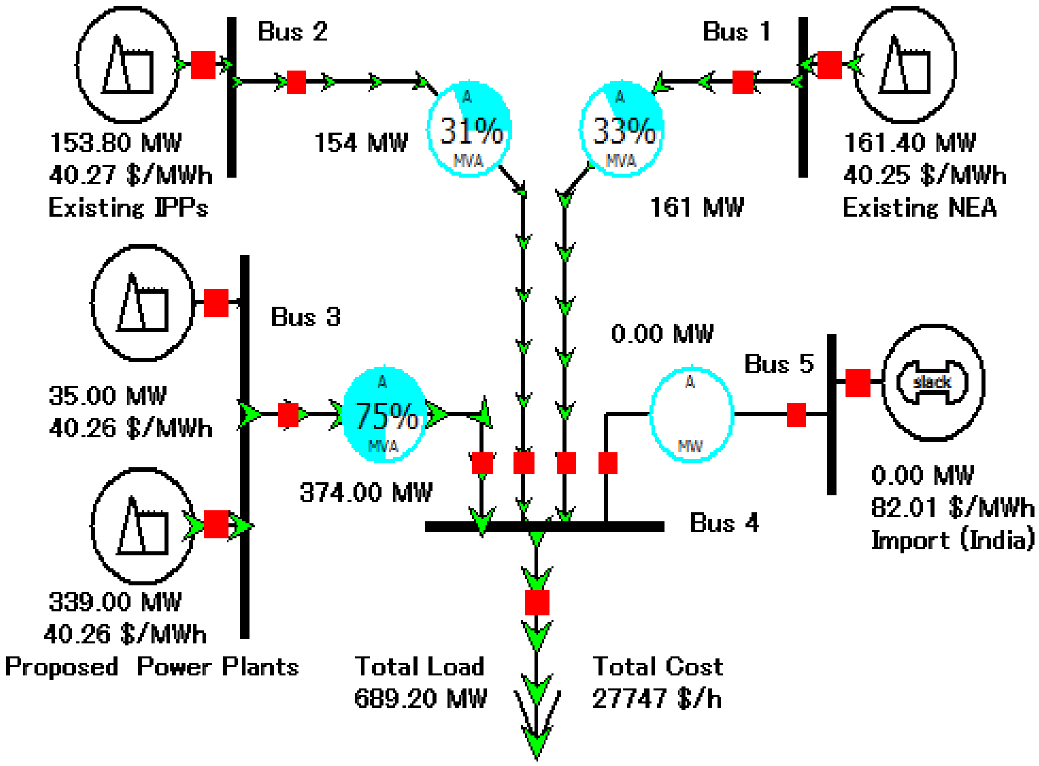

Figure 5.4: Simulation results of the proposed with import power systems.

When we open the transmission line between bus three and four the proposed model, the model automatically resolves the new power flow and shows the power flow direction. In the developed model, there is no power flowing through the transmission line from bus 5 to bus 4. Besides this, in Off-peak periods there is a surplus power which is shown in Table 5.6. Based on the available load data, the magnitude and per unit value of the power flowing on each bus also identified and the power flow in the developed model is stable, reliable and determine the best way to operate a power system. Generally, in power system networks, the load flow problem and an electrical power transmission system mentioned three types of buses. These buses are classified as follows: a load bus, a generator bus and a slack bus or system reference bus [73].

Table 5.6: Optimal operation and generation cost for proposed system.

Source	Spring [Off-peak]	Spring [On-peak]	Summer [Off-peak]	Summer [On-peak]	Autumn [Off-peak]	Autumn [On-peak]	Winter [Off-peak]	Winter [On-peak]
Existing NEA [MW]	161.40	365.00	309.20	250.60	284.10	457.23	122.40	362.26
Existing IPPs [MW]	153.80	155.80	236.20	331.00	247.90	247.93	137.30	147.95
Proposed [MW]	395.00	395.00	395.00	395.00	395.00	395.00	395.00	395.00
Import [MW]	0.00	357.10	0.00	368.70	0.00	343.90	0.00	385.07
Load shedding [MW]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Surplus power [MW]	21.00	0.00	227.47	0.00	381.00	0.00	31.75	0.00
Total load [MW]	689.20	1272.90	712.93	1345.30	546.00	1444.06	622.95	1280.28
Total cost [$/MWh]	28592.58	66153.79	37859.77	69555.81	37320.66	72493.59	46136.86	94547.50

5.6.1 Power Management in Emergencies Cases

In Nepal, after the devastating earthquake in 2015, damaged 14 existing hydro power dams and more than 30% of power was insufficient [74]. Based on that scenario, in this study, we considered two cases in power systems in an emergency situation. Case 1 for the power systems in emergencies for maximum and Case 2 for minimum generation periods. For that reason, the existing generators connected to bus 1 (NEA) and a generator connected to bus 2 (IPPs) drop production by 30%. However, the proposed generations connected to bus 3 and import power connected to bus 5 are supposed to be operating in normal conditions.

Therefore, two different cases are considered for power management in emergencies. First, we consider if an emergency occurs in a maximum power generation period and the hydro power production drops by 30% and second as well as in the minimum generation period. It is necessary to predict the power generation to minimize the power shortage during the emergency period. The simulations are done based on the On-peak and Off-peak data of the maximum and minimum generation seasons.

5.6.1.1. Power Systems in Emergency Situation for Case 1

Based on the energy data of Nepal [74], the autumn season is the maximum power generation whereas winter season is the low power generation season. In this case, considering the emergency occurred during the maximum generation of On-peak period (Situation A) and minimum generation of the Off-peak period (Situation B) of the autumn season. The existing generators connected to bus 1 and bus 2 drop production by 30%.

Case 1 **(Emergency Situation)**

Situation A: Emergency occurred during On-peak period of the autumn season (Fig. 5.5).

Location: Bus 1 and bus 2.

- Considering bus 1 and bus 2 drop generation power by 30% (211.55 MW) due to earthquake.
- Also, there were already 33.58% (485 MW) of power is insufficient due to load-shedding in the system.

Total insufficient power: 63.58% (696.55 MW).

Countermeasure:

- Keep proposed generators connected to bus 3 at maximum (395 MW).
- Increase import power by 20.88% (301.55 MW).

We designed and analyzed the proposed model to overcome the power shortage during an emergency of On-peak period for the autumn season. The simulation results for Case 1 are shown in Fig. 5.5. When the optimal operation is done with the environment of Case 1. The proposed generators connected to bus 3 supplies maximum power. However, the system load is very high compared to the existing and proposed generations. Therefore, to fulfill the system peak demand generator connected to bus 5 supplies required power to balance the system. In Fig. 5.5, to balance the system peak demand the bus 1 (NEA), bus 2 (IPPs), bus 3 (proposed), and bus 5 import (India) contributes 22.16%, 12.02%, 27.35%, and 38.47% respectively of the total demand. In the existing power system peak load is the major problem to balance the power system. However, the proposed model minimized the power crisis problems of Nepal.

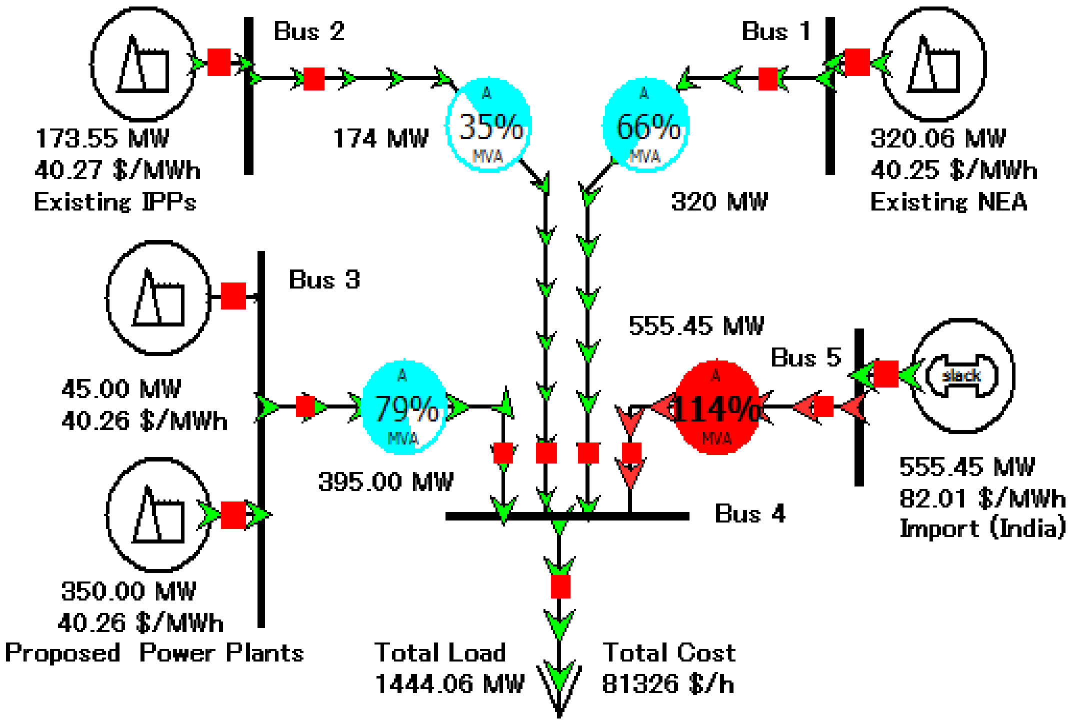

Figure 5.5: Simulation results of On-peak period for Case 1.

Moreover, the proposed generations connected to bus 3 and import power which is connected to bus 5 are supposed to be operating in normal conditions. For that purpose, keep proposed power at maximum and increased import power. To balance the peak system load during the On-peak period, the system heavily depends on bus 5 therefore, the power flowing from bus 5 to bus 4 is high.

Case 1 **(Emergency Situation)**

Situation B: Emergency occurred during Off-peak period of the autumn season (Fig. 5.6).

Location: Bus 1 and bus 2.

- Considering bus 1 and bus 2 drop generation power by 30% (159.60 MW) due to earthquake.
- Also, there were no load-shedding in the system during Off-peak period.

Total insufficient power: 30% (159.60 MW).

Countermeasure:

- Keep proposed generators connected to bus 3 at maximum (395.00 MW).
- Decrease import power by 100.00% (14.00 MW).

Surplus power: 221.40 MW (export to India with low-cost).

To fulfill the peak demand in the system during the Off-peak period, the bus 1, bus 2, bus 3 and bus contributes 36.43%, 31.78%, and 31.79% respectively of the total demand. However, in the Off-peak period, the demand is low compared to On-peak. In the Off-peak period, there is surplus power in the proposed system. In order to transfer the surplus power to India, in the proposed model a load is connected to bus 5. During this period, considering that surplus power is exported to India via the same transmission line which Nepal import power from India, for that purpose a new load is considered connected to bus 5.

Nepal energy price is low compared to the Indian electricity price. India also needs a massive amount of renewable energy to reduce thermal power plants [75]. The simulation results are shown in Fig. 5.6. An optimal way to minimize the power crisis by power wheeling with India and exchange the power for autumn-winter and vice-versa. Once if the proposed power plants added to the system, in future we do not need to import power from India.

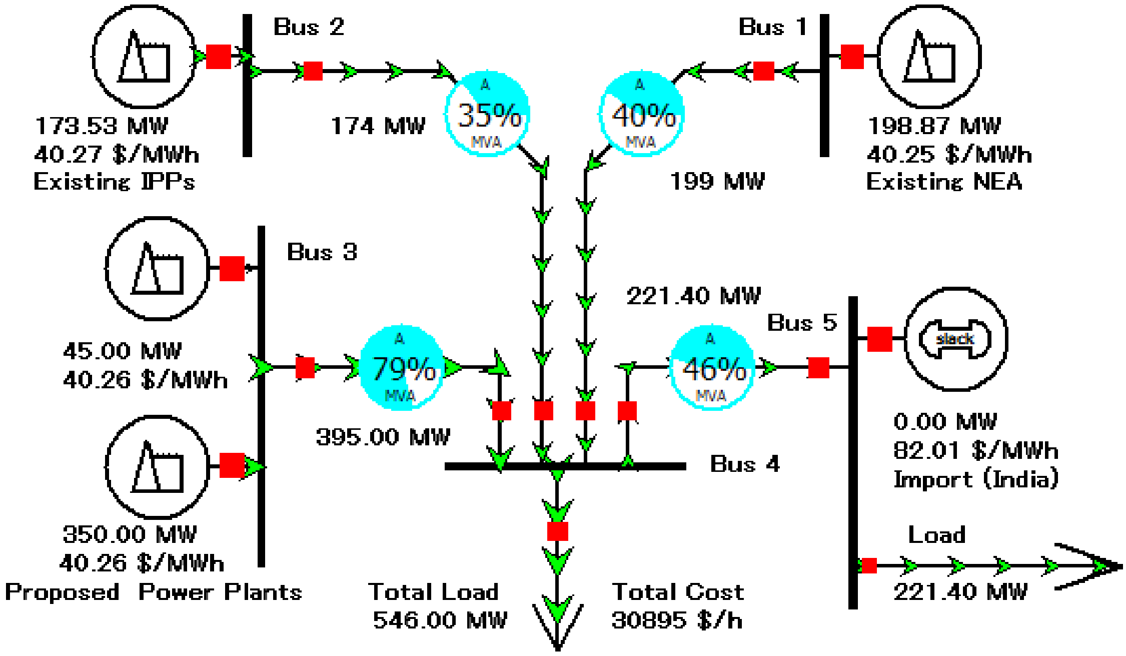

Figure 5.6: Simulation results of the Off-peak period for Case 1.

5.6.1.2. Power Systems in Emergency Situation for Case 2

In Case 2, considering the existing generations of bus 1 and bus 2 are drop power generation by 30% down, during the On-peak period (Situation A) and Off-peak period (Situation B) in minimum generation duration of the winter season.

Case 2 **(Emergency Situation)**

Situation A: Emergency occurred during On-peak period of the winter season (Fig. 5.7).

Location: Bus 1 and bus 2

- Considering bus 1 and bus 2 drop generation power by 30% (153.06 MW) due to earthquake.
- Also, there were already 30.07% (385.07 MW) of power is insufficient due to load-shedding in the system.

Total insufficient power: 60.07% (538.06 MW).

Countermeasure:

- Keep proposed generators connected to bus 3 at maximum (395.00 MW).
- Increase import power by 11.17% (143.06 MW).

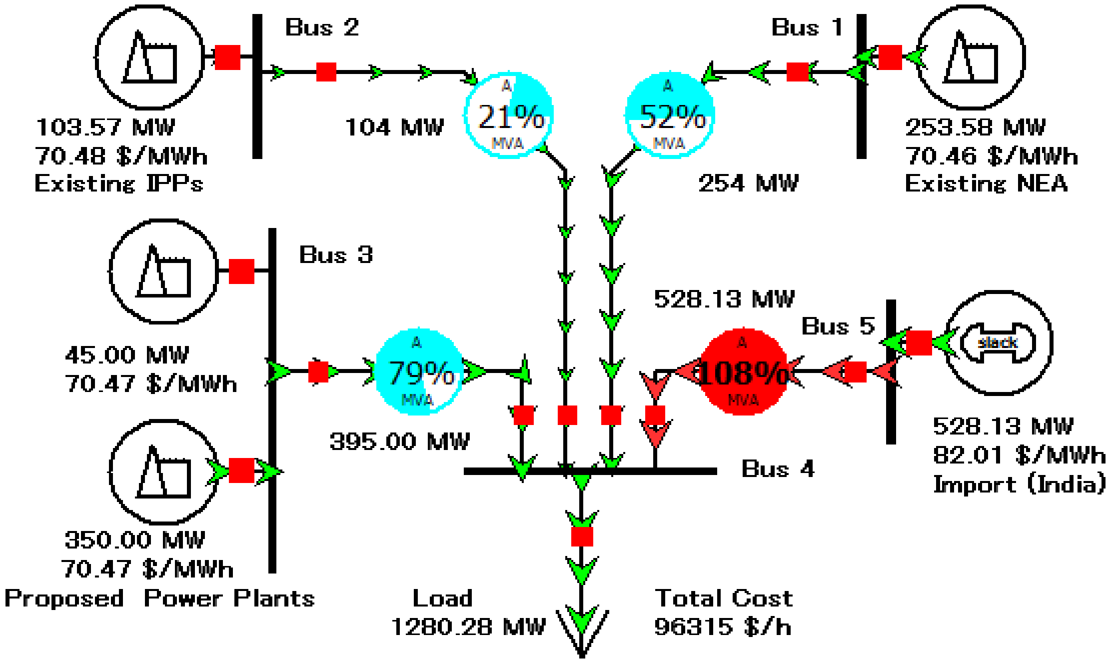

Figure 5.7: Simulation results of On-peak period for Case 2.

With the available generation and peak load data, we analyzed optimal power flow and calculated the economic load dispatch of the proposed system. The designed model and obtained simulation results for the On-peak period is shown in Fig. 5.7. To balance the peak load demand, the worst-case scenario would be to import more power from India. Therefore, the power flowing from bus 5 to bus 4 is very high.

Case 2 **(Emergency Situation)**

Situation B: Emergency occurred during Off-peak period of winter season (Fig. 5.8).

Location: Bus 1 and bus 2

- Considering bus 1 and bus 2 drop generation power by 30% (77.91 MW) due to earthquake.
- There was no load-shedding in the system during Off-peak period.

Total insufficient power: 30% (77.91 MW)

Countermeasure:

- Keep proposed generators connected to bus 3 at maximum (395.00 MW).
- Decrease import power by 92.60% (317.09 MW).

In the winter season, during the Off-peak duration when the existing power drop by 30% (77.91 MW). The existing and proposed systems are not sufficient to balance the peak demand. Therefore, 7.40% (46.16 MW) of power is needed to balance the system load. The power flowing from bus 5 to bus 4 is deficient compared to the On-peak season for Case 2. In the winter season, the power generation cost in Nepal is relatively high with compared to other three seasons, spring, summer, and autumn. The proposed system minimize the load shedding to zero and also significantly, reduced the import power in Off-peak periods of autumn and winter seasons.

The analyzed simulation results of the Off-peak period in the winter season are shown in Fig. 5.8. In emergencies, from the existing and the proposed power plants are highly capable of fulfilling the peak demand. The results show that at least we have to import 7.40% in Off-peak season and 41.25% in the On-peak season. Therefore, Indian power companies play a vital role in balancing Nepal`s power system.

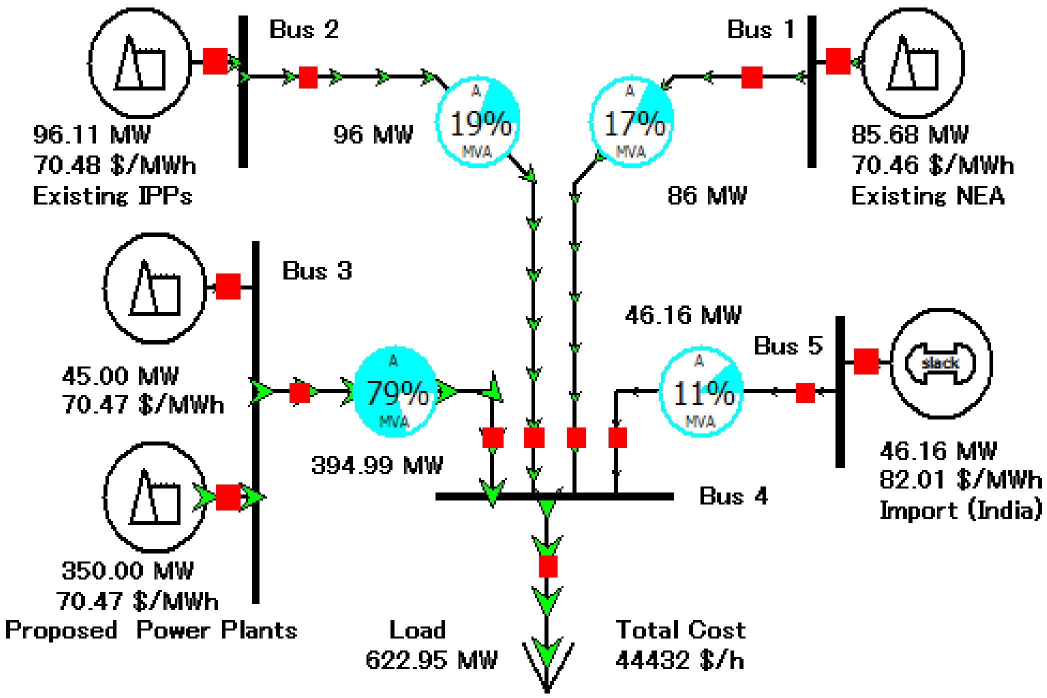

Figure 5.8: Simulation results of Off-peak period for Case 2.

In this study, basically, two cases have been considered for optimal power flow in emergencies. In the first case, considering the existing power generations are drop by 30% in maximum power generation season. So for the second case existing power generations are drop by 30% in minimum power generation season. The expected generation cost of existing generations proposed generations and import power for On-peak and Off-peak demands be calculated and compared together with the economic point of view. As the obtained results of Table 5.7, in emergencies cases, the power flowing in the system is secured.

As it reported that when a cascade hydro power plants are connected to the power system reducing the load shedding as well as import power. Moreover, the proposed power generations connected to the system to avoid instability in the system. Usually, optimal power flow is the dominant technique in understanding the dynamic behavior of large-scale power networks. Determine if the system is in significant disturbances such as system faults, sudden changes in loads, and loss of generations of the entire system.

The power grid of Nepal has posed more significant challenge in the secured and reliable operation of the system. Because of sudden changes of demand or generation resulting imbalance between the whole system. For a more secure and reliable system, it should have enough power to operate in average condition and should be capable of withstanding system disturbances.

Table 5.7: On-peak and Off-peak results of the proposed model for Case 1 and Case 2.

Source	**Autumn [On-peak]**	**Autumn [Off-peak]**	**Winter [On-peak]**	**Winter [Off-peak]**
Existing NEA [MW]	320.06	198.87	253.58	85.68
Existing IPPs [MW]	173.55	173.53	103.57	96.11
Proposed [MW]	395.00	395.00	395.00	395.00
Import [MW]	555.45	0.00	528.13	46.16
Load shedding [MW]	0.00	0.00	0.00	0.00
Surplus power [MW]	0.00	221.40	0.00	0.00
Total load [MW]	1444.06	546	1280.28	622.95
Total cost [$/MWh]	81326.00	30895.00	96315.00	44432.00

5.7 Conclusion

In this study, the economic load dispatch and optimal power flow considering the proposed generations are done with the help of a well-known Power World simulator. We could analyze the power flow with a real-time solution. Considering cascade hydro power in the same river to generate the maximum clean energy with low-cost (proposed cost is lower than import cost), reduce the power shortage problem and the amount of import power as well. The proposed model identified to solve the On-peak and Off-peak load during emergencies cases. Besides this, the simulation results show that during the Off-peak seasons of spring, summer, autumn, and winter the load shedding is completely ended and there is surplus power in the system during the Off-peak season.

However, in On-peak of all four seasons accepts emergencies cases, significantly reduced import power as well as the insufficient power in the system compared to existing system; 1.25% (5.00 MW), 22.55% (115.00 MW), and 18.55% (90.00 MW) power are insufficient in On-peak of spring, summer, and autumn season. The proposed system will be capable of balancing the system load with efficient power flow, generate more power with fewer price, save more money and it is friendly to the environment.

The OPF of this system calculated the maximum power that can safely be transferred from one area to another. To minimize the power uncertainties in Nepal, the proposed model will be a milestone for improvement and development of the power system. Based on the findings and results, we believe that this research will help in the schedule of a real-time solution, reduce the power shortage problem in the local community and urban areas of Nepal.

Chapter 6
Concluding Remarks

In this dissertation, the current status of hydroelectricity energies situation, the power system of Nepal, seasonal installed capacity and potential of hydro power in Nepal is described. In Nepal generally, there are two types of HPPs; the first type is Run-of-River and the second type is storage hydro power. The existing hydro power generation is not sufficient to fulfill the electric energy, for this reason, we proposed the Run-of-River cascade HPPs to balance the load, reliable power flow and secure the grid power system across the country. From the proposed, developed models, we reduced the power shortage problem and also minimize the imported electric energy from India. Designed models and simulation results for different cases were conducted and analyzed their effectiveness.

In **Chapter 2,** the river flow rate and discharge characteristics of different seasons of Trishuli river were studied. According to the obtained results of this river, we identified the electric power production at different seasons. In the monsoon season, there is an abundant supply of water whereas, in the non-monsoon season, the river flow value decreased very sharply. Therefore, in the monsoon season the hydroelectricity generating potential is very high, however, in the non-monsoon season, the generation potential decreased by approximately 40% of installed capacity.

The PSCAD simulator is used to develop the existing hydro power plants models and observed simulation results were introduced. The existing and proposed hydro power plants site selection and locations, components parameters as well as generating performance of the designed models were described. The total hydroelectric power produced from existing HPPs were connected to 66 kV grid voltage with minimum losses. The simulation process is an efficient technique to obtain the results. The total generation of existing HPPs has contributed approximately 8% of the total hydroelectricity energy of Nepal.

In **Chapter 3,** Run-of-River cascade HPPs was proposed to overcome the power shortage problem and minimize the import power from India. Considering the proposed

HPPs after the existing hydro power plants in the downstream of this river. Based on the river flow rate and elevation of the catchment area, we proposed medium head hydro power plants. Hydro power generation potential, components parameters and expected generation power were described and analyzed. The proposed HPPs simulation models for Case 1 (30 MW) and Case 2 (40 MW) were described and analyzed the output results with graphical environment. The output power of each hydro generating is connected to the step-up transformer (11 kV to 66 kV) and then connected to 66 kV grid system.

The obtained three phase voltage output results have a clean sinusoidal waveform. The observed simulation results of active power and system frequency of proposed hydro power plants were close to the actual power of the system. In this chapter, we interconnect the existing and proposed HPPs in the same 66 kV grid system. The total expected installed power for our model is 106.00 MW. However, the PSCAD based designed model has with total maximum hydroelectric generation power is 105.55 MW, whereas the 0.45 MW is loss occurred in our designed model. The maximum power is delivered to the grid with high efficiency and minimum losses.

In the designed model, all existing and proposed HPPs were operated at their highest level. Proposed large-scale HPPs has a significant influence on the demand side of the system. The grid-connected large-scale hydro power delivered smoothly to the 66 kV grid. The designed, proposed models of our system could handle a massive amount of hydroelectric power without any difficulties in the grid system. We consider that our designed grid-connected hydro power models will help to play a vital role to address the power shortage problem.

In **Chapter 4,** we predicted the Run-of-River flow forecast by developed RBFN network. The model is constructed to predict the hydrological behavior of river flow for different periods. We predicted the river flow value of different seasons to identify the hydro power potential. The prediction of river flow value is the most essential for hydro power development and water resources development systems. Designed Neural Connection RBFN model forecasted the randomly selected values and seasonal values of all four seasons. We forecasted the maximum and minimum flow and one-week ahead of river flow. Based on the predicted river flow results, we identified the technical potential of hydroelectric power for proposed cascade HPPs.

In this study, the minimum network error is found in the spring season (5.14%) and maximum in the autumn season (7.71%) respectively. The predicted hydro power possible help to reduce the power shortage in local communities as well as urban areas of Nepal. This kind of research will be a milestone for hydro power development and extreme electricity conditions.

In **Chapter 5,** we analyzed the economic load dispatch and optimal power flow of the existing and proposed models. The optimal generation and scheduling for On-peak and Off-peak system loads for the proposed models are identified and analyzed the results. In this chapter, we considered the two cases for analysis of economic load dispatch and optimal power flow for Nepal power system. The existing and proposed models are designed in Power World simulator environment. Designed proposed model to balance the system load as well as reducing the import power from India. We studied the power management in electricity extreme conditions and emergencies cases.

In emergencies cases, On-peak and Off-peak of power generation and peak load for both existing and proposed power plants were identified. The output simulation results of the proposed model show that the system is more reliable and secure compared to the existing system. Despite the power uncertainties, the developed model is more efficient to generate and supply the electric power in low-cost compared to the existing model. The proposed model to reduce the system load and balance the whole system across the country without any failure and uncertainties.

This study will address some topics, which are recommended for **future study**. As for the future study, the civil components of hydro power plants and power market future development and proposed hydro power plants cost estimation should be carried out and investigate. Regarding the turbine and generator efficiency should be further investigate and implement for hydroelectric power flows. The interconnection of existing and proposed hydro power plants in the high voltage grid system, power losses of the system and technical challenges of the power systems will be studied and investigated to minimize the system losses.

This research will suggest some recommendation for the development of the hydro power sector in Nepal.

- Modeling and designing the grid control system for securing and improving the reliability of the grid system.
- More cascade hydro power plants need to be installed in Nepal`s river, which has a massive hydro power potential to reduce the power shortage problem across the country.
- The transmission loss in Nepal`s power system is very high and it should be studied and investigated.

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[1] Raju Rai, Ken Nagasaka, "Modeling and Development of Run-of-River Cascade Hydro power Plants in Nepal", 2017 7th International Conference on Future Environment and Energy (ICFEE 2017), No. B0009, pp. 21-26, Penang, Malaysia, January 8-10, 2017. (Excellent Paper Award & Best Oral Presentation)（本論文との関連：第 2&3 章）

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