# Modeling and Development of Run-of-River Cascade Hydropower Plants in Nepal

Raju Rai and Ken Nagasaka

***Abstract*—Nepal is a developing country rich in water resources, with an enormous potential of hydropower having more than 6000 rivers. Hydropower plays an increasingly important role in electricity generation in Nepal. To serve Nepal's economy and reduce the power shortage, cascade hydropower plants are the most promising available renewable energy sources in Nepal. In this paper, we propose a model for a cascade of hydro power plants using multiple dams systems in Trishuli river of Nepal to increase the potential of hydropower and to solve the needs of demand in the country. The output power of proposed cascade hydropower plants are connected to a 66 kV grid. As we know, Nepal is a small country which needs more power and demand is obviously high. In Nepal, Trishuli river is one of the famous rivers having high economic importance and potential water resources. If we construct more cascade hydropower plants in this river, it will enable access to electrification in rural areas as well as reduce the power shortage in local community. Also, it helps to reduce the $CO_2$ emission. This research provides a way to assess the operation of cascade hydropower plants as well as design power plants and verify the potential of electric energy supplied by multi dams rather than a single dam. Grid connected cascade hydropower is implemented for a Kathmandu valley, Nepal. It has been analyzed that the power generated helps reduce the demand for electric power. The developed model is simulated using the Power Systems Computer Aided Design (PSCAD) software. Finally, the simulation models of existing and proposed hydropower plants and its interconnection system are analyzed.**

***Index Terms*—Renewable energy, cascade hydropower, run-of-river, power generation, PSCAD, Nepal.**

## I. Introduction

Nepal has potential to generate a large amount of hydroelectricity from thousands of its rivers running down from high hills and mountains. The current electricity demand of Nepal is more than 1200 megawatts (MW) whereas installed capacity is less than 850 megawatts (MW) [1]. The generation capacity becomes less than half of its installed capacity in winter season (Dec-Feb) because of the low river flow rate. In Nepal, more than 90% of country's grid electricity is supplied through hydropower plants. The grid connected consumers are heavily affected by long hour power shortage. More than 70% of Nepal's population is suffering from load shedding. To develop the cascade hydropower, the best idea's to overcome these type of situations across the country. Demand of electricity is rapidly increasing each and every year. In 2020 the electricity demand is expected to increase above 4000 MW [1]. Hydropower plants are not well developed and heavily dependent on fossil fuel and coal to meet the energy demand across the country. The topography changes very sharply from an elevation of 8,848 m to less than 100 m. The rivers mostly flow from high Himalaya north to south direction passing through higher to lower level. Nepal has a huge hydro-power potential of 83 GW, out of which 42 GW is considered to be economically feasible but the present situation is that Nepal has developed only approximately 730.47 MW [1]. The electricity demand has been increasing in Nepal by 7-9% per year, and more than 40% of the population has access to electricity through the grid and off grid system. In Kathmandu, capital of Nepal, there is daily 7-8 hours load shedding. To overcome the power shortage we propose the cascade hydropower in Trishuli river in Nepal. In this paper, we studied the hydropower potential of the Trishuli River in different seasons. Based on the water flow rate we identified the potential of hydropower. In Trishuli river after Devighat hydropower plant (14.1 MW) there are no other existing power plants. Based on the water flow rate, discharge and geology of the Trishuli river we proposed two hydropower plants of 30 MW (case 1) and 40 MW (case 2). Considering the output of both hydropower plants are connected to the same grid. We propose a cascade hydropower plants to increase the hydropower potential of Nepal. Although Nepal's water resources are very rich, we still face power shortages. However, having a large potential, the present installed capacity of hydropower in Nepal is still very small. In order to meet the increasing power demand there is a best opportunity to promote hydropower projects. This river is near to Kathmandu. Thus, these cascade hydropower schemes will have an important role in providing more electricity supply to Kathmandu valley to reduce the load shedding.

## II. The Study Area

Trishuli River is one of the major and famous river in Nepal. The origin of this river is high Himalayas and flows from north to south direction. The Fig. 1 shows the location of proposed hydropower plants in Trishuli river in Nepal. In this paper, initially we have studied two existing hydropower plants Trishuli hydropower and Devighat hydropower station located in Nepal. These hydropower plants are situated in the same river. The installed capacity of Trishuli hydropower station is 21 MW. It consists of 7 units of 3 MW capacity each. The output water of the Trishuli hydropower plant is used by Devighat hydropower station. This is a cascade power station.

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It has a capacity of 14.1 MW and consists of 3 units of 5 MW capacity each [2]. The output of both hydropower stations are connected to the same grid. The developed existing hydropower model shows nearly the same behaviour as the real power plants.

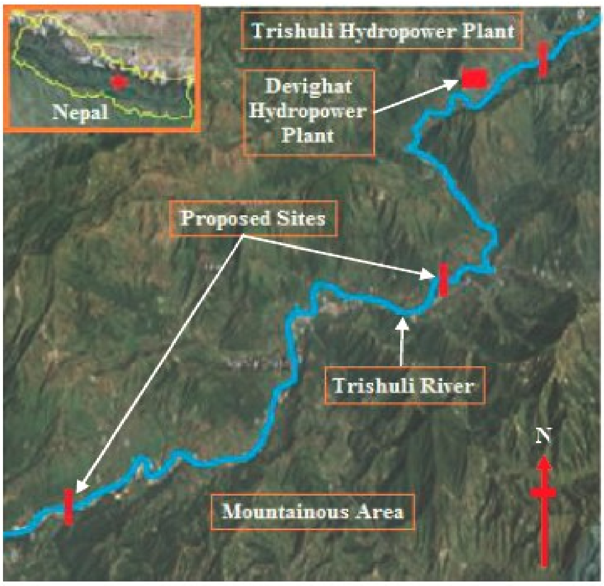


Fig. 1. Geographical condition of Trishuli river and proposed locations to establish hydro dams [Google earth].

In this paper our objectives are to design such a system and to generate a huge amount of electricity from one river. Because water level and volume increases from small rivers flowing into the main river. A large scale hydro power plant is feasible when there is an abundant supply of water [3]. In Trishuli river there are some small rivers joining the main river. For this reason, after Devighat hydropower plant we propose a cascade hydropower plant of 30 MW at a distance of 10-13 km and second hydropower plant of 40 MW at a distance of 20-25 km from the first proposed dam. Only using 70% of river water we can generate this amount of electricity. Both power plant areas have good geology and the power plant will be able to generate at full capacity of electricity.

## III. Trishuli River and Its Flow Characteristics

Fig. 2 and Fig. 3 show the maximum and minimum flow rate of Trishuli river during the different periods of 1977-2012 [4]. In summer season (May-Jul) the river flow has been increasing, whereas the winter season has been found to be decreasing. Demand for electricity in Nepal is the highest during the winter season because the flow of the river falls to a minimum, however, during the summer season the run-of-river type hydropower plants can produce more electricity. The required hydrological and downstream river data were collected from the Department of Hydrology and Meteorology (DHM) from the Betrawati gauging station, Nepal. The plots of maximum and minimum flows are the most important periods for snow melt. In the natural flow regime, the minimum monthly flow for the all four seasons is more than 30 $m^3/s$. However, the flow rates in all seasons are unregulated flow because of the function of ecology. The flow regime depends on sedimentation process, temperature and water quality of the river [5].

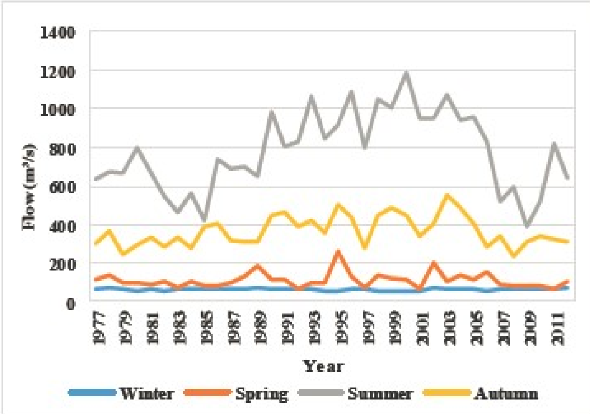


Fig. 2. Maximum flow of Trishuli river.

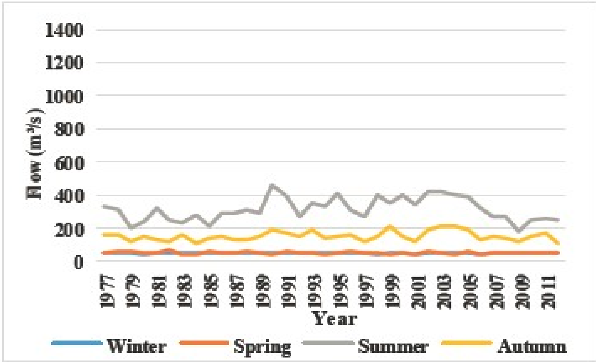


Fig. 3. Minimum flow of Trishuli river.

The Fig. 4 shows the monthly energy generation of existing hydropower plants (Trishuli hydropower plant and Devighat hydropower plant).

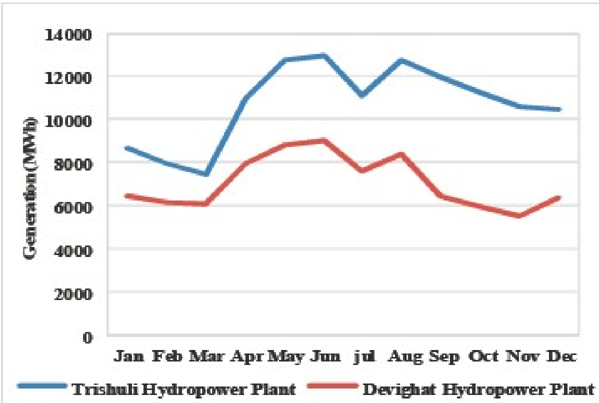


Fig. 4. Energy generation of existing power plants (2010).

These two power plants generation electricity is connected to the same grid (66 kV) and supply to the Kathmandu valley. Besides this there are other power supplies also but, those power supplies are not sufficient for the demand.

## IV. Energy and Peak Demand of Nepal

In Nepal, most of the remote communities, villages are isolated from the energy supplies and basic energy requirements are fulfilled by kerosene lamps and firewood flames in the remote areas. Hydropower has high potential but there are not enough power plants to fulfil the demand, Nepal buys each and every year some power from its neighbouring country India. In recent years, the electrical energy crisis became very high, at least 11 hour/day countrywide load shedding. The peak demand in 2013/2014 was 1200.98 MW, relatively high in comparison to supply and also system lose was 26.43%. For those reasons Nepal is still facing the power crisis.

## V. Energy Demand of Kathmandu Valley, Nepal

Kathmandu valley is the capital city of Nepal. It has many small and medium sized of industries and the population density is also high in comparison to other cities. Power demand is increasing every year but the supply in not sufficient. Therefore, Nepal still faces energy crisis every time. There are 12 sub-stations, each sub-station supply electric power to fulfil the demand of Kathmandu valley. The demand of electricity of Kathmandu valley is approximately 350-400 MW [6]. The Fig. 5 shows the one week demand of electricity for one of the sub-stations known as Siuchatar sub-station.

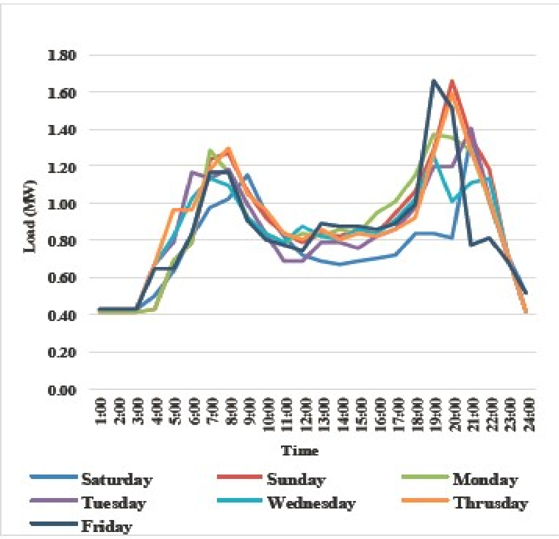


Fig. 5. Electric load of Siuchatar sub-station (July, 2010).

The cyclic pattern as seen in Fig. 5 shows a week load of each hour. Every day there is the maximum load around 8:00 and 20:00 and the minimum load reaches lowest level of the peak load. The load demands had a significant impact on the generation of hydropower plants among power grids [7]. To fulfil the peak demand across the country, the government buys huge amounts of electricity from our neighboring country India.

## VI. Measuring Head, Power and Design Parameters

The actual power that can be generated from the run-of-river water is defined by the following equation: [8]

$$P = \rho . g . H . Q . \eta \quad (1)$$

where,

$P$: Electrical 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)

$\eta$: Efficiency of hydropower plant

The electricity generation of each plant is determined upon the demanded total generated electricity in the system [9].

Parameter used for to design proposed hydropower model in this research is given in Table I.

TABLE I: Design Parameters of Proposed Hydropower Plants

| Type | Run-of-river |
|---|---|
| location | Trishuli, Nepal |
| Proposed installation capacity<br>Case 1<br>Case 2 | <br>30 MW<br>40 MW |
| Distance between two dams | 15-20 km<br>(Approximately) |
| Average annual flow | 45.66 m$^3$/s |
| Turbine<br>Number and type<br>Rated output<br>Rated speed | <br>3, 4 Francis<br>10,200 kW<br>500 rpm |
| Generator<br>Rated output<br><br>Rated voltage<br>Rated frequency<br>Power factor | <br>10,800 kVA<br>(single unit)<br>11 kV<br>50 Hz<br>0.90 |
| Power Transformer | 15 MVA, 11/66 kV |
| Transmission line | 66 V, double circuit |

## VII. Modeling and Operation of Cascade Hydropower Plants

In this research, the simulation model of both proposed hydropower plants considers each hydro generating unit produces 10 MW of electricity and each transformer is 15 MVA. Considering the step-up transformer of 11-66 kV. A complete modeling of one unit of proposed hydropower plant is shown in Fig. 6.

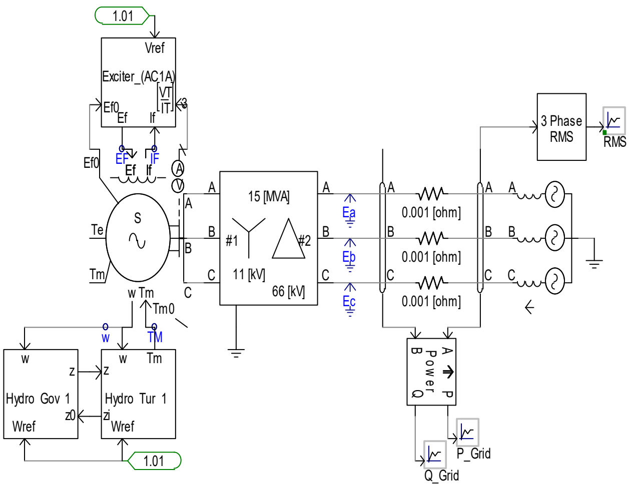


Fig. 6. Modeling of one unit of proposed hydropower plant.

## VIII. Simulation Methods

To simulate the existing and proposed hydropower plants we used the Power Systems Computer Aided Design (PSCAD) software. This is a powerful software for design of power systems. First, we designed the existing two hydropower plants models and then two proposed models with calculation parameters. Simulations were done until 5 seconds. Complete model of proposed (30 MW) of hydropower plant is shown in Fig. 7. The electrical part of the generator and the excitation system are identified using the active and reactive power as inputs and analyze the results as graphical environment [10], [11].

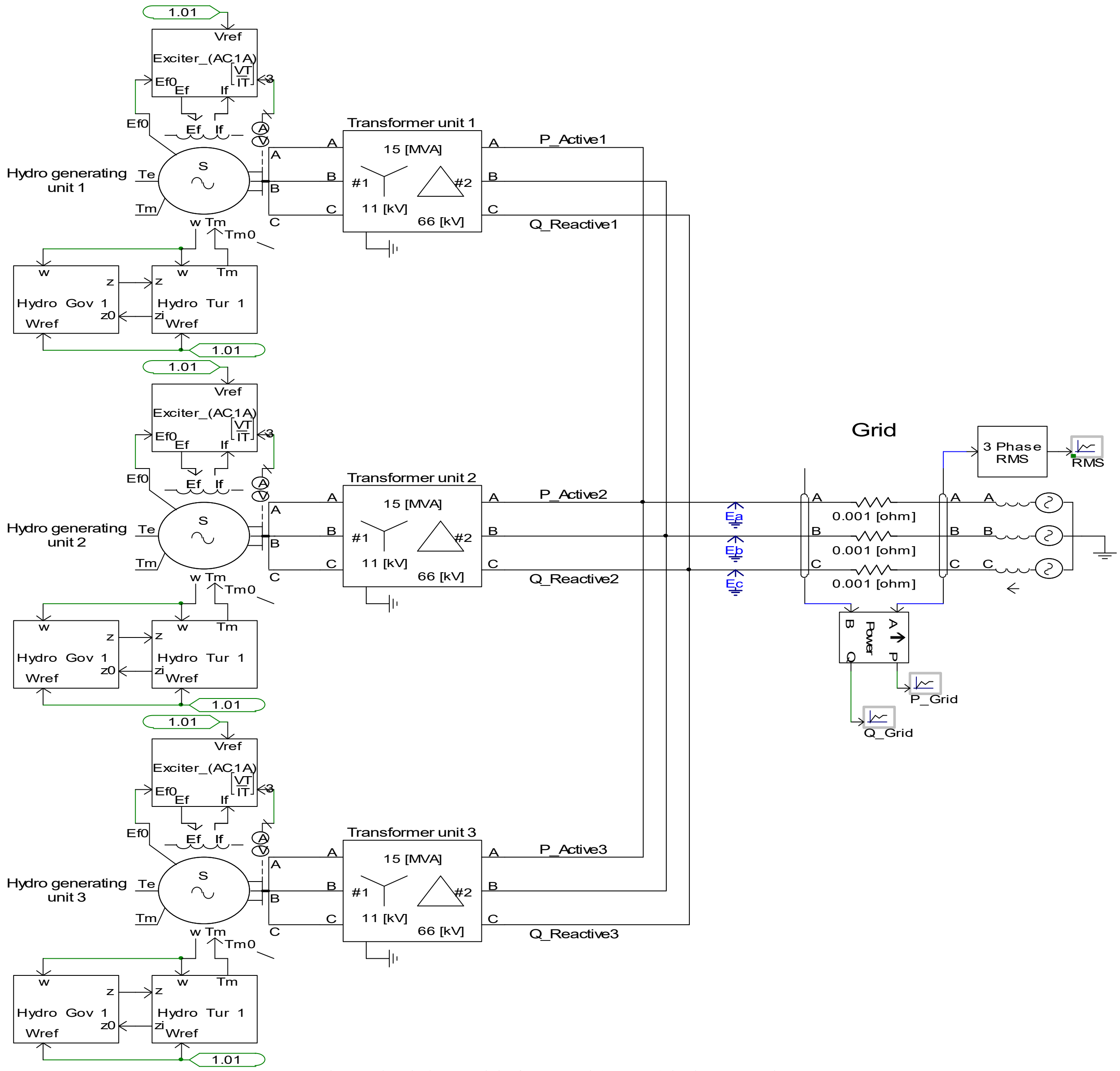


Fig. 7. Simulation model of proposed (30 MW) hydropower plant.

In this model, we consider the capacity of each hydro generating unit is 10 MW. Case 1 consists of three units of 10 MW capacity each and case 2 four units of 10 MW capacity each. The voltage was step up to 66 kV to interconnect the grid.

where,

*P*_Active1: Active power of 1st hydro generating unit

*Q*_Reactive1: Reactive power of 1st hydro generating unit

*P*_grid: Total active power of grid

*Q*_grid: Total reactive power of grid

*Ea*, *Eb* & *Ec* are the grid voltage

## IX. Simulation Results

All simulation results of existing and proposed hydropower plants are identified. The output power of each and every hydro generating unit and grid power are also shown for both cases.

Trishuli hydropower plant and Devighat hydropower plant have seven 3 MW and three 5 MW hydro generating units respectively. Fig. 8 and Fig. 9 shows the active power of each hydro generating unit and the total active power of both hydropower plants are shown in Fig. 10. Active power of the 1st hydro generating unit and total power of proposed hydropower plants are shown in Fig. 11 (Case 1) and Fig. 12 (Case 2).

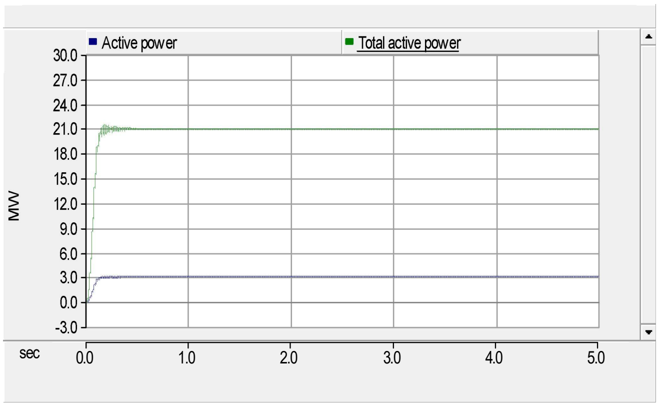


Fig. 8. Active power of 1st hydro generating unit and total active power of Trishuli hydropower plant.

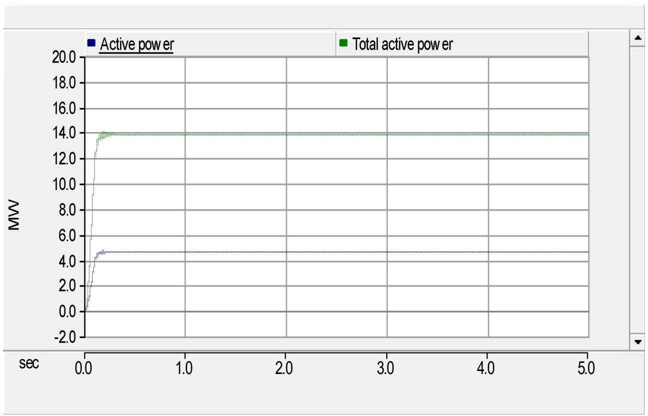


Fig. 9. Active power of 1st hydro generating unit and total active power of Devighat hydropower plant.

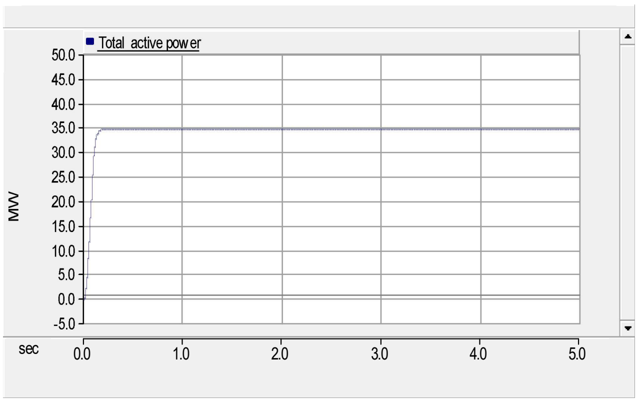


Fig. 10. Total active power of Trishuli and Devighat hydropower plants.

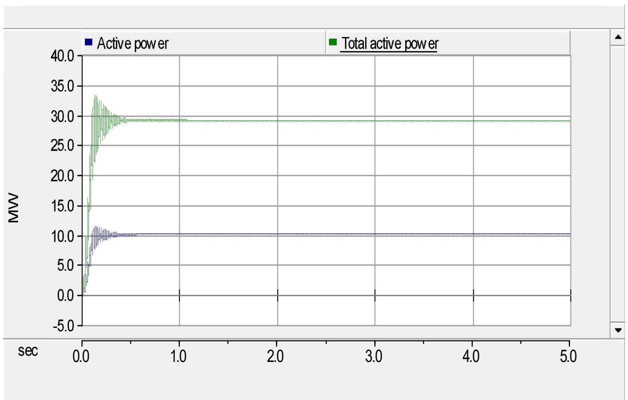


Fig. 11. Active power of 1st hydro generating unit and total active power of case 1 (30 MW).

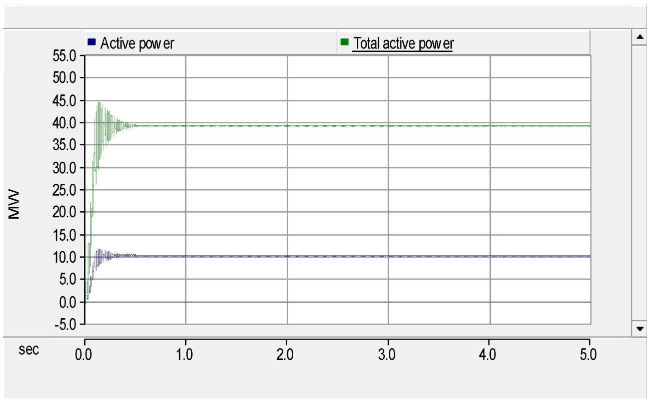


Fig. 12. Active power of 1st hydro generating unit and total active power of case 2 (40 MW).

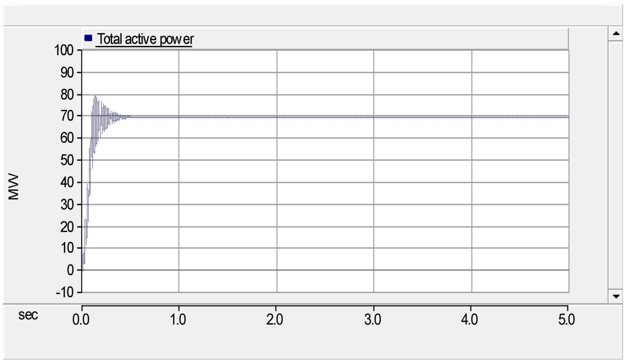


Fig. 13. Total active power of proposed hydropower plants (case 1 & case 2).

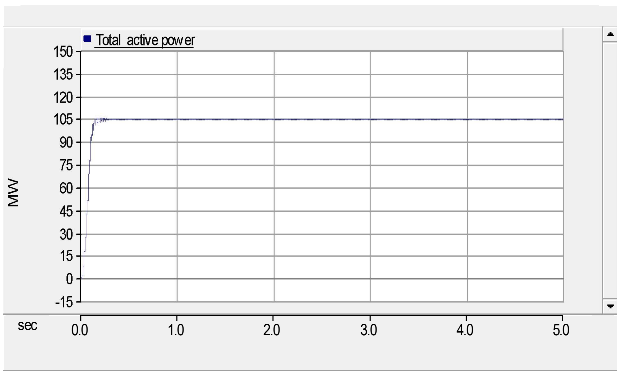


Fig. 14. Total active power of existing and proposed hydropower power plants.

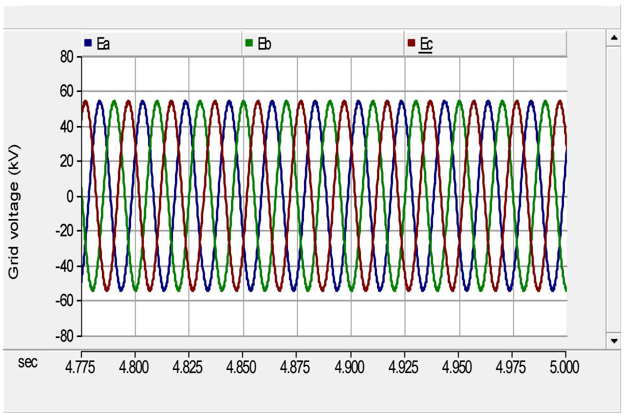


Fig. 15. Three phase grid voltage of existing and proposed hydropower plants.

Fig. 13 shows the total active power of proposed hydropower plants (Case 1 and Case 2). Generation of electric power from all hydropower plants (existing and proposed) are shown in Fig. 14. Similarly, the three phase grid voltage, frequency and three phase RMS of existing and proposed hydropower plants are shown in Fig. 15-Fig. 17 respectively.

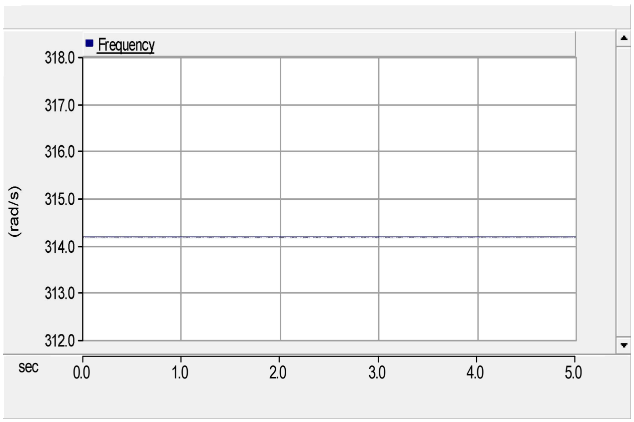

Fig. 16. Frequency of existing and proposed hydropower plants.

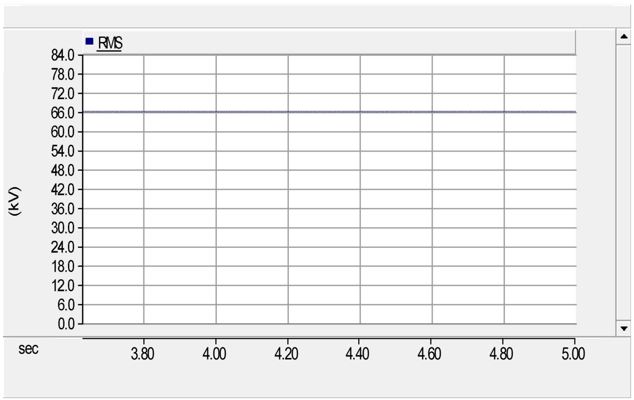

Fig. 17. Three phase RMS of existing and proposed hydropower plants.

## X. Conclusion

This research paper presented the method of modeling and generation of cascade hydropower plant in the same river based on the PSCAD software. We proposed two hydropower plants at some distance of a capacity of 30 and 40 MW. Selection of electro-mechanical equipments were designed and output results of both proposed hydropower plants were identified. The generated electric power is transmitted through 66 kV grid. Based on the water flow data we observed that in summer season the electric potential is high in comparison to winter season. The proposed site is one of the grid connected area and has a huge potential to produce electricity. This research was focused on feasibility and potential of Trishuli river. With the new cascade hydro models, we can generate more electric power. It will helps to reduce the power shortage in local community and urban areas of Nepal. Furthermore, the proposed hydro models is capable of producing efficient power. Besides this, the power losses and decision support system was not included in this paper. The impact of the generation, distribution, transmission losses and its control system will be the future works of our research.

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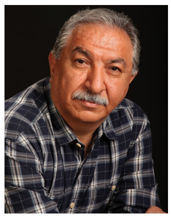

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