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Operation of Integrated Nepal Power System on Injection of Upper Tamakoshi Hydroelectric Power Plant

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Abstract
The goal of the research work is to develop operating models to help power system planners with addressing transmission expansion plan with addition of Upper Tamakoshi hydroelectric power station in an integrated Nepal power system. It advocates the possible mapping of demand and supply management in coordination with integrated network based on current real scenario. Upper Tamakoshi hydro electric power station is going to operate in fiscal year 2077/078. Optimal evacuation of such power plant of 456 MW requires secure and reliable transmission network. Nepalese power system still fallouts poor voltage supply and infrequent system downfall because of insufficient and poor planning of transmission links. The proposed network of integrated system is subjected to various analysis techniques for secure and reliable operation including import and export belongings with optimum utilization of the generators by minimizing transmission loss. Specially, steady state power flow analysis is carried out and simulated in computer model to find out best optimal operation.The results obtained from the predicted model for the different scenarios indicates that the voltages of all major substations and line loadings of all major transmission lines are within safe limits. It identifies the finest optimal operating state by understanding the operation of integrated national power system and recommends a new approach to the robust and reliable transmission line expansion plan for supplying the national peak load demand and catering to the power export to the India. Finally, it is concluded by providing essence of the regional and sub-regional control of the integrated system for the future operation.

Keywords
National Grid, Power Flow, Import, Export, Stability, Voltage limit, Blackout, Power crisis

1. Introduction

Nepal is a land locked country that lies in between the great Himalayan mountain range and Mahabharat range having steep incline towards the south. It has more than 6000 southern rivers that originating in the northern mountain range and flowing down to the lowlands in the south and are very suitable for hydropower generation. It has identified that Nepal has tremendous potential for the development of hydroelectric power plant. Theoretically, generation of 83,000 MW has been deemed possible and approximately 43,000 MW power has been estimated which seems to be economically and technically feasible [1].

Despite the enormous potential, less than five percent of the viable resource has been harnessed to generate hydroelectricity. Total generation capacity is reached to 1250 MW. Even generation capacity has increased, Nepal still has energy deficit at dry season and about 37 percent of the total energy consumption is imported from India [2]. Nepal is still import dependent in electrical power supply. Government of Nepal and Government of India have signed Power Trade Agreement (PTA) for co-operation in cross broader power exchange and power trading that would mutually benefit both the countries.

The current transmission line infrastructure could not hold the future demand in order to provide reliable and quality electricity. Therefore power flow models are used to plan future transmission lines under the thermal limitation, voltage limitation and stability limitation. Apart from the technical limitation, policy formulation is equally important for the national transmission expansion plan. The electricity demand has rose up approximately by ten percent per Annam as economic activity has increased. Presently, we are in the state of wet season generation surplus but still in deficit in dry season. In next fiscal year the generation capacity will increases with the completion of major hydro power plants such as Upper Tamakoshi, Rasuwagadi, Mid-Bhotekoshi, Sanjen etc [3]. Thus, the INPS could lead to reliability problems if the current transmission infrastructure is not upgraded in near future.

In this context, Upper Tamakoshi hydroelectric power plant of 456 MW, located in Dolkha district, is going to be in operation in coming fiscal year. It is going to be connected to the national grid via Gongar - New Khimti high voltage 220 kV substations. Nepal Electricity Authority (NEA) has established an autonomous company Upper Tamakoshi Hydroelectric Power Company Limited in 2063/11/25 B.S.with purpose of ending power crisis and exporting surplus power especially in wet season. When it comes to operation, it will be the largest hydroelectric power plant ever commissioned in Nepal. The Project is totally financed domestically through Nepali financial institutions and public enterprises. It is realised that injection of such large hydro power plant in the integrated network will have diverse impact in terms of voltage stability and reliability. Hence, this study is dedicated to impact - study in the country wide grid giving new approach of transmission line expansion plan by clustering into three different sub - regional control. After injection, Nepalese power system will have enough power to meet local demand by reducing import from India and have stable operation.

2. Problem Statement

The economic growth of the country can be accelerated with the optimum development of hydropower resources. Therefore, GoN has foreseen developing 15 GW of hydropower in 10 years and around 40 GW by the year 2040 [4]. However, only 1250 MW power is realised till date. Nepal is still facing energy deficit problem which is being fulfilled by import from India. Additionally, for the evacuation of generated power for domestic consumption as well as import & export, requires secure and reliable transmission network. So, to achieve high economic growth with the development of hydropower, reliable transmission network should be developed and upgraded simultaneously. However, insufficiency in the transmission line expansion in Nepal has lead unstable voltage supply and unusual system breakdown.

The national priority project Upper Tamakoshi Hydroelectric Power Plant is going to contribute approximately one third of the total installed capacity across the country. Sudden injection and rejection of such large power plant in the grid might cause instability that results cascading outages and huge generation loss. Modern power system should have ability to keep continuous supply system minimizing sudden imbalance of the system. If large scale power blackout occurs the impact on grid is catastrophic. Nepali power system has faced grid failure multiple times in past operation. A failure on utility supply can cause loss of service and deviation from normal voltage or frequency. System restoration is very difficult if risk assessment is not done properly. So, it is realised that it is necessary to study constructively operation of INPS on injection of large power generators to avoid from unnecessary power system failure. Additionally, the regional and sub regional control of the network is not clear for the future operation. Therefore, it needs the profound study on the operation of the updated integrated system. The study about above problems is needed to address and compensate on ending import dependency by the evaluation of optimal operation of INPS after the upgradation of voltage level and transmission line conductors.

3. Methodology

The initial study of the operation of Integrated Nepal power system on addition of Upper Tamakoshi Hydropower Plant proceeds with the collection of past literature associated to the transmission lines extension plan and comparative study of power flow examination tools. Power flow analysis has been accomplished to evaluate active power losses and voltage profile of the integrated system. Implementing power flow analysis is relevant to future transmission line expansion and extension schemes. Among the different power flow methods, Newton Raphson's algorithm is used in the simulation process in ETAP. The simulation is first carried out with existing INPS with import cases taking wet and dry peak generations. The study proceeds with modifications on INPS with an injection of Upper Tamakoshi Hydroelectric power plant. Import and export cases are considered to identify optimal operation through which transmission losses are minimized. Finally, conclusion is reached by suggesting sub regional control of the integrated power system network.

3.1 Data Requirement

The bus voltage profile, line losses,active and reactive power flow through lines are evaluated from the input data. The generation MW rating of generators, substation load data for dry and wet season, transmission line data and existing capacitor data are taken from Load Dispatch Centre, and System Planning Department of NEA.

3.2 Power Flow Study

The power flow study is a very popular tool routinely used in planning, control, and operations of existing electric power systems. The successful operation of power systems depends upon knowing the effects of adding interconnections, adding new loads, connecting new generators or connecting new transmission line before it is installed. The goal of a power flow study is to obtain complete voltage angle and magnitude information for each bus in a power system for specified load and generator real power and voltage conditions [5]. Once this information is known, real and reactive power flow on each branch as well as generator reactive power can be analytically determined.

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

The nodal current is calculated as,

$$I_k = \sum_{i=1, i\neq k}^{n} Y_{ik} V_k \quad \text{where, } i = 1, 2, 3, \ldots, n \tag{2}$$

The complex power deliver to bus k is given by,

$$S_i = P_i + j_{Qi} = {}_{Vi}[\sum_{k=1} Y_{ik} V_k]^* \tag{3}$$

Taking the real and imaginary parts of 3 and power balance equations can be written as,

$$P_i = V_i \sum_{j=1}^{n} \cos(\delta_i - \delta_j - \theta_{ik}) \tag{4}$$

$$P_i = V_i \sum_{j=1}^{n} \sin(\delta_i - \delta_j - \theta_{ik}) \tag{5}$$

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

$$\Delta P_i = P_{i(sp)} - P_{i(cal)} \tag{6}$$

Then i=1, 2, . . . , n, i ± slack, and if

$$\Delta Q_i = Q_{i(sp)} - Q_{i(cal)} \tag{7}$$

Then i=1, 2, . . . , n, i ± slack, i = PV bus

where, the subscripts sp and cal denote the specified and calculated values, respectively, then the equation 6 can be written as,

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} \begin{bmatrix} H & N \\ M & L \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \Delta V \end{bmatrix} \tag{8}$$

Then off diagonal and diagonal elements of the sub matrices H, N, M & L are determined by difference equation 4 and 5 with respect to δ and ΔV [6].

3.3 Computer Modelling and Simulation

Integrated Nepal Power System (INPS) is the centralized power system network consisting generators, transmission lines, substations and electrical loads. Existing integrated grid is used for the study in addition with new 220 kV double circuit transmission lines of Lambagar - New Khimti – Dhalkebar and Dhalkebar - Hetuda 220 kV are considered. The generators having more than 5 MW capacities have been used and generators having less than 5 MW are clustered together to form a single unit in different sections. Lumped loads are taken account into 66 kV and above voltage level substations.

The various scenario have been developed with integrated power system network and simulated using Electrical Transient Analyzer Program (ETAP) 16.0.0. ETAP toolbars calculates the bus voltages, branch power factors, current and power flows through the electrical systems. It allows swing, voltage regulated and unregulated power sources with multiple power grids and generator connections and is capable of performing analysis on both radial and loop systems. The study follows IS 398-1976 standard for the conductor selection and conductor configuration. The Newton-Raphson Method is used for the power flow analyzer in ETAP. The convergence criteria for this method are set to 0.0001 MW and 0.0001 Mvar.

4. Result and Discussion

Power flow study is the vital tool for testing power system network. Operation of integrated power system network is the principle means for the power system planners. In this study, Integrated Nepal Power System is modeled in four different cases. Taking necessary data from the Nepal Electricity Authority, the overall system is modeled in ETAP by considering best case scenario for the optimal analysis. The simulation finds key parameters such as real and reactive power flow, voltage profile, and transmission losses. The analysis also includes power import and export cases. Different modes of operation are determined through dissimilar conditions such as loading pattern, generation plan, transmission line expansion plan, and import duty.

4.1 Wet Peak operation (Case 1)

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

4.2 Dry Peak operation (Case 2)

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

4.3 Wet Peak operation of modified INPS (Case 3)

This is the case of the modified Integrated Nepal Power System with an injection of the Upper Tamakoshi Hydroelectric Power Plant. It is performed with a minimum of 240 MW power imported from India and load curtailment is neglected but it accounts 10 percent load growth. Hetauda – Dhalkebar – New Khimti and Trishuli 3A - Matatirtha 220 kV transmission lines have been considered. The overall integrated system is operated on basis of three sub-regional controls. Eastern, Central and Western region network is controlled by Upper Tamakoshi, Kaligandaki and Chameliya Hydroelectric Power Station respectively. The power flow study in this setup shows that it has been serving about 1589.03 MW real power and 246 Mvar reactive powers. It accounts for about 94.8 MW (i.e. 5.27 percent) active power losses in the transmission system. Gongar and New Khimti substations are operating at 108.8 percent which is within the permissible limit.

4.4 Wet Peak operation of modified INPS (Case 4)

The last case is focused on export cases after the injection of Upper Tamakoshi Hydroelectric Power Plant on the modified Integrated Nepal Power System. Hetauda – Dhalkebar – New Khimti and Trishuli 3A-Matatirtha 220 kV transmission lines have been considered and operated in separate three sub-regions. Eastern region is controlled by Upper Tamakoshi Hydroelectric Power Plant, The Central region is controlled by Kaligandaki Hydroelectric Power Plant and the Western region is controlled by Chameliya hydroelectric Power Plant as swing bus and generating 273.7 MW, 117.1 MW, and 28.06 MW respectively. Power imported from India is considered about 205 MW, and five percent load curtailment is considered with 10 percent load growth taken into account. The new system has been serving 1621.3 MW real power and 175.5 Mvar reactive power. About 53 MW power through Dhalkebar 220 kV, 40 MW through Katiya, and 42 MW power through Ramnagar 132 kV substations have been delivering to Indian Grid. It accounts for 85.6 MW active power losses which is about 5.2 Percent. The new Khimti and Gongar substations has been operating at 251 kV of the voltage level.

The computer model, developed in four different cases shows the active and reactive power generation summary with transmission line losses.

Table 1: Power Flow Summary

S.N.	MW Gen	MVar Gen	Tr. Loss (MW)	Loss (%)
1	1398.01	362.12	40.08	2.8
2	1246.17	164.6	33.26	2.67
3	1589.03	246.9	94.8	5.96
4	1621.3	175.5	85.6	5.27

Four different cases shows the actual scenario of the national power system operation. It seems that total generation is not sufficient for national demand even as generation is increased each year. Transmission loss is observed to be increased in fourth case. It is due to the higher generation and distant power flow.

Table 2: Import Export summary

S.N.	Swing (MW)	Import (MW)	Export (MW)	Load Curtail(%)
1	73.2	551	0	5
2	94.7	424	0	0
3	411.4	240	0	0
4	418.8	205	135	2.5

Case four shows the export scenario and accounting 1621.3 MW power. Mvar generation is also reduced in fourth case because of the suitable placement of the capacitor bank.

4.5 Voltage Profile of Regional Grid Division

In electrical power stations, power is generated at a medium voltage level. This generated power is sent to the consumers through different voltage levels for a different purpose. Like power system frequency, the voltage has to be kept within the range for safe and reliable operation. During the process, a reduction in ±10 percent voltage level is the permissible limit for the transmission line (Electricity Regulation, 1993). That's why voltage profile is one of the key parameters of load flow study and needs to be kept within the safe range. In this study, it is summarised that the comparative four different cases of voltage profile showing of separate seven regional grid department of the country.

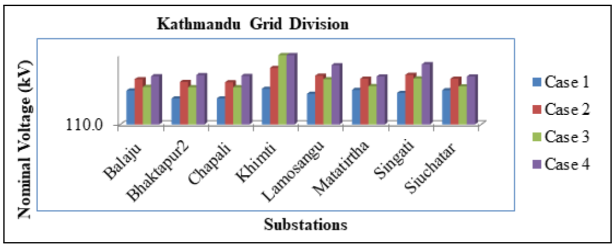

Figure 1: Voltage profile of Kathmandu grid substation

Figure 1 shows the Voltage distribution of Kathmadu Grid division at 132 kV voltage level. It consists of eight substations that control Kathmandu regional load. In first and second cases most of the substations have low voltage profile and significantly improved in later cases after adjustment of capacitor bank and loading arrangement. finally, all the substations shows the the improved voltage profile as prescribed by grid code.

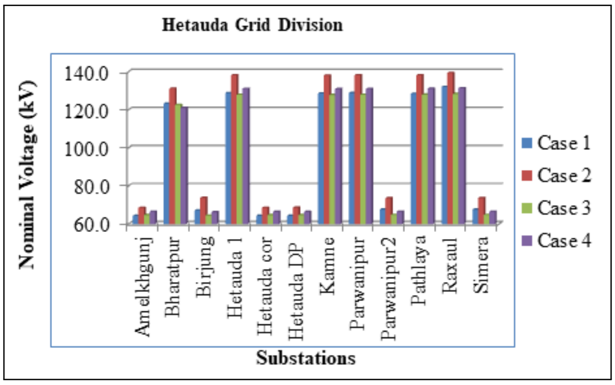

Figure 2: Voltage profile of Hetauda grid substation

Figure 2 shows the voltage profile for the Hetauda Grid division. In this case, Birgunj, Semera and Parwanipur substations are operated at overloading condition. But later voltage profile is improved after replacement of DOG conductors by BEAR conductors. Hetauda 220 kV substation is considered in later two cases and operated at 215.8 kV and 221.0 kV respectively. Raxual 132 kV substation has appeared 131.3 kV voltage at case four from which power is imported from Indian side.

Figure 3 shows the voltage variation developed in the computer model of Dhalkebar Grid Branch. It is one of the major substations of Nepal for import and export of power. It is the central substation that connects eastern and western part of Nepal. Initially 220 kV Dhalkebar substation is operated at 210.8 kV and later operated at 228.7 kV, 215.8 kV and 221 kV respectively. Mirchaya and Chapur 132 kV substation have overloaded slightly

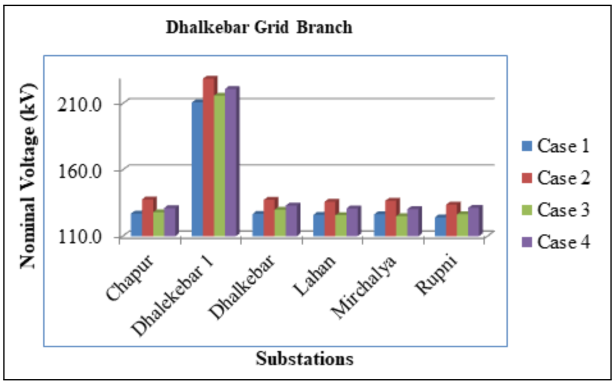

Figure 3: Voltage profile of Dhalkebar grid substation

and operated at 136.7 kV and 137.8 kV respectively. Other 132 kV substations are found to give satisfactory performance even though voltage profile is improved in later cases within the close restrictions. Finally, all the substations have improved voltage profile and lies within the permissiblee grid code.

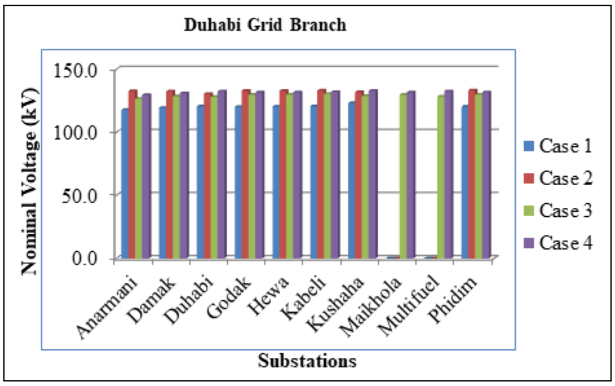

Figure 4: Voltage profile of Duhabi grid substation

Figure 4 shows the voltage profile of Duhabi Grid branch for four different cases. Duhabi Multiful and Maikhola substations are not operated in first two cases But later cases operated at within the restricted limits. Almost all of the 132 kV substations are operated at under load at first case and later on it is seen that voltage profile has improved within the specified range.

Figure 5 shows the voltage profile of Butwal grid Branch for four different cases at 132 kV voltage level. It shows that voltage profile is significantly improved from case one to case four. Ghorahi substation has lower voltage of 108.3 kV and Lamahi substation has also appeared 108.5 kV in case one. In case four all the substation has the safe voltage level and lies within the NEA guidelines. Ramnagar substation has zero voltage because in case four, import from this substation is restricted.

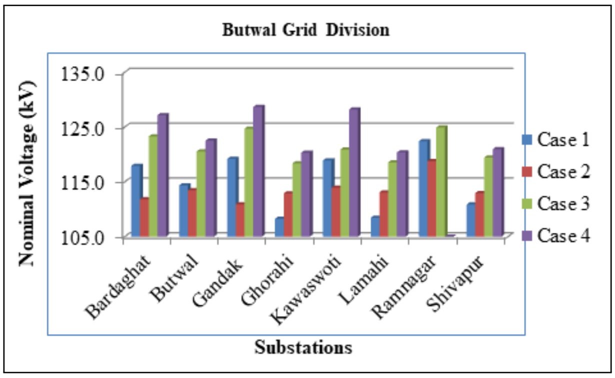

Figure 5: Voltage profile of Butwal grid substation

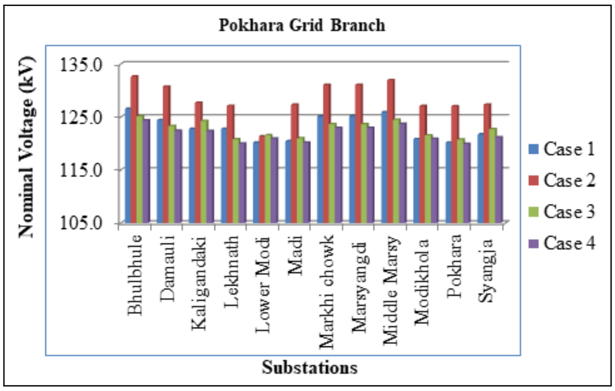

Figure 6: Voltage profile of Pokhara grid substation

Figure 6 shows the voltage distribution in pokhara grid branch. It consists of twelve major 132 kV substations. The results shows that almost all substations has good voltage profile within the safe limit as per the grid code. Bhulbhule substation has appeared highest voltage of 132.7 kV in case two. After adjustment of capacitor bank, it has improved voltage profile of 125.2 kV and 124.4 kV in case three and case four respectively.

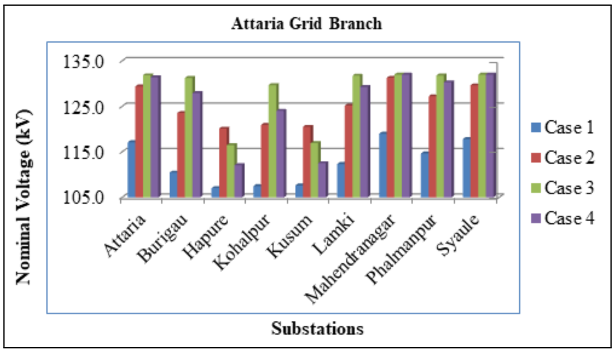

Figure 7: Voltage profile of Attaria grid substation

Figure 7 shows the voltage profile of Attaria grid branch for four major cases. It can be seen that most of the substations in case one has appeared lower voltage in 132 kV voltage level. But in later cases all the substations have improved voltage profile within the range of grid code. Mahendranagar substation has appeared exactly 132 kV voltage from where power is imported from India radially in western Nepal.

4.6 Loading Summary of 220 kV Substations

Major concern of this study is to analyse impact of injection of Upper Tamakoshi hydroelectric power plant which is connected in 220 kV transmission line from Gongar to New khimti substation. It shows that 286.32 MW real power is transferred to Dhalkebar station and 149.75 MW real power is transferred to central grid through khimti substation. Khimti - Dhalkebar 220 kV substation is constructed to evacuate power to Terai region. It is expected to provide ease in connection with huge load center of that region. It is most viable route to export generated power from the Upper Tamakoshi Hydro Power Plant to Indian Grid.

4.7 Transmission Line Upgradation

The computer model shows that almost all existing 66 kV transmission lines having poor performance and severe voltage fluctuation problem. Kathmandu and Hetauda Grid division of 66 kV substations are highly overloaded and, are replaced by BEAR conductors. Also, result shows that Gongar and Khimti substations seem to operate in overload condition in some extent. It is upgraded with MOOSE conductor instead of DEER conductor and improved voltage profile has improved. Overall, the transmission lines and substations have better performance and resulting in more secure and reliable integrated Nepal power system.

4.8 Sub Regional Control of INPS

Figure 8 shows the pictorial view of sub regional control mechanism on operation of integrated Nepal power system. The computer model result and analysis shows the necessity of sub regional- Eastern, Central, and Western region networks as a separate entity and controlled by Upper Tamakoshi Hydroelectric Power station, Kaligandaki Hydroelectric Power station, and Chameliya hydroelectric Power station respectively. All the three zones are self- sufficient in terms of generation as per the load demand. As per the zonal demand,bi directional power flow is possible between them by shifting interconnection point. The purposed controlling scheme address the interconnection for the reliable and stable operation.

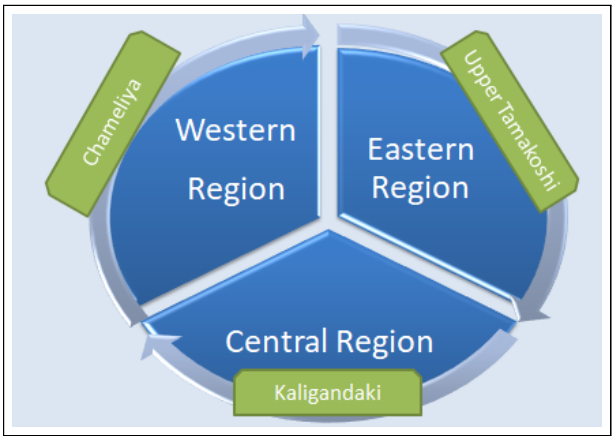

Figure 8: Regional Control of Integrated Nepal Power System

5. Conclusions

In this research, models and cases are developed and modified to make the optimal operation of the Integrated Nepal Power System on the injection of the Upper Tamakoshi Hydroelectric Power Plant. The methodology used in this research has been very successful in achieving the goals set forth for a power flow study. The purposed network control schemes are within the safe limit for steady state operation. The power system networks have stable operation on regional control with upgradation of 66 kV transmission lines by BEAR conductors. Hence, Research has been done to conclude that the best operation has been achieved through Eastern, Central, and Western region networks control. Also, it shows reliable and stable operation with synchronizing Indian Grid to ensure import-export of power. Additionally, such control provides minimum transmission losses and mitigate unpredictable outage of the power system network. Injection of Upper Tamakoshi hydroelectric power station is predicted to end import scenario and adding export scenarios to the neighboring countries providing stable and reliable operation of the power system network on the improvement of voltage profile. The modified interconnected network utilizes domestic generation and gives emphasis to large power curtailment from import power.

6. Recommendations

An improvement would be made considering other 400 kV under construction transmission lines to improve the performance of the overall integrated power system network. Additionally, this study suggest that export of power is possible. So,it is recommended to study short circuit analysis and dynamic reliability of the purposed network system.

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