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Analysis of ELD and OPF for a Large-Scale Power System under Emergencies

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Abstract- Renewable energy is one of the cleanest power sources in the world. Renewable energy such as hydropower plays one of the essential roles in power generation in Nepal. Nepal is a developing country with an enormous potential of hydropower having more than 6,000 rivers and more than 90% of electricity is producing from Run-of-River hydropower. However, the existing power generation is not sufficient to fulfill the demand and every day importing a massive amount of electricity from neighboring country India. To reduce the power shortage and to serve Nepal's economy, cascade hydropower (multi-dam) are the most promising available renewable energy sources. In this paper, the economic load dispatch (ELD) and optimal power flow (OPF) analysis model has been developed. The designed model was used to identify the optimal scheduling and to predict the extreme electricity conditions such as an emergency, earthquake disaster period. The main objective of this research is to determine an optimal technique to overcome the power shortage and identify the optimal power flow. It has been analyzed the optimal power flow and determined the optimal solution to balance the power system. Besides this, the proposed model determined the approach to reduce the imported power and balance the system.

Keywords: Hydropower, Multi-Dams, Power Shortage, Economic Load Dispatch (ELD), Optimal Power Flow (OPF), Nepal.

1. Introduction

The landlocked and Himalayan nation of Nepal has an enormous potential of Run-of-River hydropower plants, more than 90% of electricity is generating from hydropower. The potential of hydropower in Nepal is 83 GW, out of which 42 GW is economically feasible, however; currently, less than 1200 MW is installed [1]. The existing generation is not sufficient to fulfill the electricity demand across the country, Nepal is importing more than half of its electricity from its neighboring country India [2]. Most of the remote communities and villages are isolated from the power supply, suffering from power shortage. Firewood flames and kerosene lamps fulfill their basic power requirements. The electricity demand has been increasing in Nepal by to 7 to 9% per year. During the great earthquake of magnitude 7.8 in April 2015, the power outage was the worst hit, reducing domestic power production by 35%, and 600,000 households were affected and lack of power supply for several weeks [3]. Since April 2015, the Nepalese government agreed to purchase a vast amount of electricity to fulfill the lack of generation. In Nepal, the dominant power utilities are Nepal Electricity Authority (NEA) and Independent Power Producers (IPPs). Based on the energy data of 2017 [4], the generation of electricity from NEA was 36.48% and from the IPPs was 28.40%. In Nepal, only 65-70% populations are access to grid-connected energy supplies system. However, the rural villages and communities are isolated. The existing power generation is low compared to demand recently, 956.10 MW is the current existing generation and demand is more than 1450 MW [4]. Nepal power system heavily depends on Indian power utilities [4]. Power supplies were very tight until now and sudden changes of demand or generation resulting imbalance between the systems [5].

The price is about 82.01 $/MWh for which Nepal pays to the Indian for 1 MWh, which is expensive compared to domestic power generations (40.25 to 40.27 $/MWh approximately). Because of the imported power, consumers are affected by electricity price. The electricity consumption per household is very low in case of Nepal and the ranking list it lies lowest top ten countries all over the world. According to the World Energy Council, energy efficiency indicators the average electricity consumption per electrified household in 2014 was 331 kWh/household [6]. To minimize the power crisis problems, we proposed cascade hydropower plants (multi-dams) downstream of the Trishuli river after the existing hydropower known as Trishuli hydropower plant. A Power World simulator version 20 has been used to design and analyzed the results [7].

In this paper, we considered two different cases for analysis of ELD and OPF for Nepal`s power system. For case 1 and case 2; considering emergency occurred during On-peak and Off-peak period of the maximum and minimum hydroelectricity generation autumn and winter seasons. In emergencies cases, the existing power plants were dropped power generation by 30% in that situation; the proposed power plants overcome the power shortage by supplying the maximum amount of power to the system. The reliable and secure power flow in the system is the main focus of this study because the lack of generation power is a great challenging part for balance the system load. Based on the river flow rate for all seasons, we consider the river upstream hydro generation potential is 350 MW including existing and for downstream is 45 MW. The units are scheduled according to the existing model. The economic load dispatch and optimal power flow solution for the entire system is identified with considering the proposed model. In such a way, planning and operation of hydropower and energy management system is determined [8-13]. Recently, some techniques used for optimization, such as genetic algorithms (GA), particle swarm optimization (PSO) [14-17]. However, they are a good approximate solution [18-21]. Therefore, as our problems need exact solutions, for this reason, we applied ELD and OPF techniques based on Power World simulator, considering an emergency case for Nepal.

The location of the proposed cascade hydropower study area lies in the high mountains and hills zone, the drain area is 4110 km^2 and located near Kathmandu, the capital city of Nepal [22]. We consider this river for our research because Kathmandu alone will require at least more than 1500 MW of electricity within the next decade. The proposed site is one of the grid-connected areas and has tremendous potential for electricity which is shown in Figure 1. In Nepal, there are four seasons spring, summer, autumn, and winter. The production of electricity depends on the river flow. In the summer season, snowmelt in the high Himalayas and huge rainfall, whereas in the winter season the river flow rate has been found to be decreasing. The maximum and minimum river flow rates are the most important period for snow melt. The river flow rate is not steady which affects hydropower generation and creates difficulties in balancing the load. However, in the context of Nepal, in the winter season, the production of hydropower drop to one-third of installed capacity. The river flow rate of Trishuli river, used for this study is shown in Figure 2 [12]. The demand for electricity

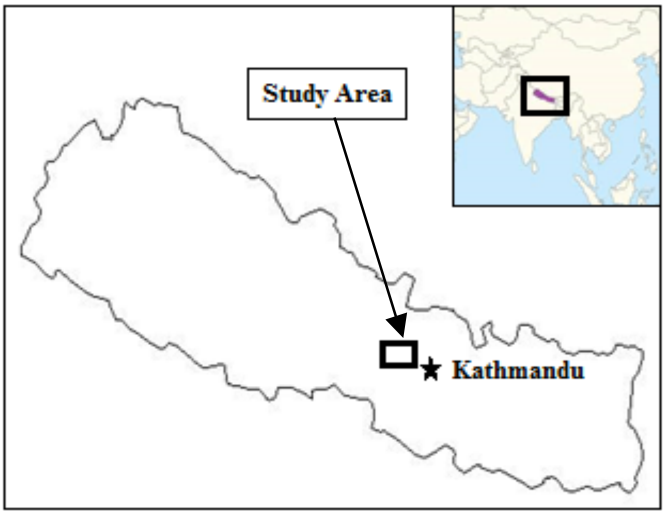

Fig.1. Location of the study area in Nepal [Google Map].

Fig.2. Monthly water flow rate of Trishili river.

in Nepal is approximately 1450 MW. According to Nepal electricity authority (NEA), the peak demand will be about 10,092 MW in 2030 [23]. Table 1 shows the supply option and contribution of existing and import power of Nepal. The existing and import power is not sufficient to fulfill the peak demand.

Therefore, there is a vast amount of power shortage across the country. Figure 3 shows hourly generation and load patterns of a typical day. Every day, the maximum peak load appears around 7:00 to 8:00 and 19:00 to 21:00 and the minimum load reaches the lowest level of the peak load. To fulfill the peak demand, the imported power from India also not sufficient to balance the peak load. In this study, we have done various analysis according to electricity generation, demand and economic point of view. To find a way to decrease the amount of imported power and also considering the situation in extreme condition. These analyses are presented in the next sections.

Table 1. Supply and contribution of power system in Nepal.

Supply Option	Contribution (MW)
NEA Hydro (Run-of-River)	272.56
NEA Hydro (Storage)	89.70
IPPs Hydro	147.95
Import (India)	385.07
Total	895.28
Peak Demand	1280.28
Deficit Power	385.00

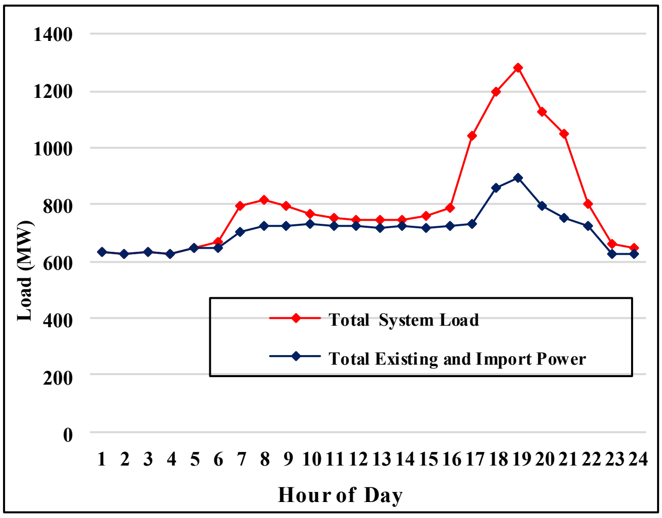

Fig.3. Hourly load variation pattern of Nepal.

2. The One Line Diagram of Proposed Power System

In this research, we designed and analyzed the existing and proposed models using an animated simulator. Figure 4, shows a one-line diagram of existing, proposed and import powers for a three-phase power system and the marginal cost of each generator respectively. The designed model consists of five 132 kV buses, five generators, (generator on bus 1 represents the power produced by Nepal electricity authority (NEA), generator on bus 2 represents the power produced by independent power producers (IPPs) and similarly, generator on bus 3 represents the power produced from proposed cascade hydropower plants from Trishuli river. The generator on bus 5 represents the import power from India), four transmission lines, one system load, and fourteen circuit breakers. Besides this, bus 5 is considering as a slack bus with automatic generation control "ON" for imported power from India. The actual power flows from generators, through the transmission lines, and in this model system load is connected to bus 4. 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 [7]. 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. The execution time for solving a case takes only about a couple of seconds.

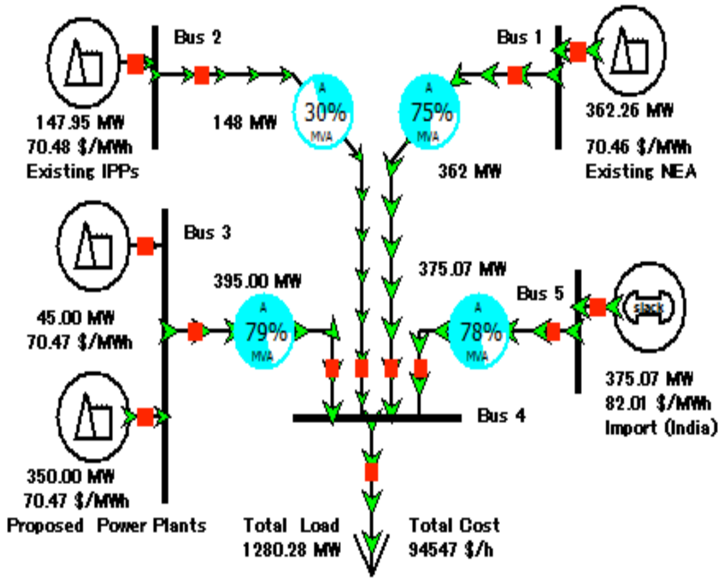

Fig.4. One line diagram of existing, proposed and import power systems.

3. Economic Load Dispatch and Optimal Power Flow Analysis

The economic load dispatch (ELD) is an important analysis to satisfied system load with minimum cost [24]. Generally, conventional economic load dispatch and optimal power flow (OPF) problem subject to the energy balance methods such as the Lambda-Iteration method, Gradient method, Newton`s method, and Linear programming method were developed for solving the OPF problem [25-29]. In this study, the generator operating cost is modeled using a cubic cost function. The output cost of each generator is calculated by the equation (1) [30].

[illegible] (1)

Where,
[illegible]: The cost of the generating unit,
[illegible]: The power of the generating unit,
[illegible]: The fuel cost independent value of the generating unit,
[illegible]: The fuel cost dependent value of the generating unit,
[illegible] and [illegible]: The coefficients of the generating unit,
[illegible]: The fuel cost of generating unit,
[illegible]: The variable O&M of generating unit.

However, in recent years, more advanced simulation tools have been developed to solve this kind of problems [31-32]. In this study, we determine the most efficient, low cost and reliable operation model of the power system. Based on the daily load data we calculated the economic load dispatch and identified the optimal power flow of our model. In this manner, with an available Off-peak and On-peak demand and economic load dispatch of all four seasons over a specified period can be identified. As the time of this writing, the approximate generator real power limits and production cost of electricity per megawatt hour are shown in Table.2 respectively.

Table 2. Generator power limits and generation cost.

Bus No.	P_{min} (MW)	P_{max} (MW)	Wet season cost ($/MWh)	Dry season cost ($/MWh)
1	122.40	365.00	40.25	70.46
2	137.30	331.00	40.27	70.48
3	300.00	395.00	40.26	70.47
5	14.00	385.07	82.01	82.01

4. Results and Discussion

In this study, an economic load dispatch and optimal power flow are performed in 4 bus system with three generators for the existing and import systems (Fig. 5) and 5 bus system with five generators for the proposed, existing, and import systems (Fig. 6). The five generators are connected to bus 1, bus 2, bus 3, and bus 5 respectively. The optimal generation scheduling is performed according to the generation limits. The minimum and maximum Off-peak and On-peak load demand of the system for all four seasons are shown in Table 3. The minimum Off-peak load demand is 622.95 MW in the winter season and On-peak load demand is 1444.06 MW in the autumn season. When the load is above 850 MW, run all five bus generators; between 622.95 MW to 712.93 MW, run bus generators 1, 2 and 3.

All simulation results of existing and proposed models are identified. The output results of economic load dispatch of each generating unit and optimal power flow are shown for both cases in Table 3 for the existing system and in Table 4 for the proposed system. The input parameters such as bus voltage, MVA rating are given a requirement of the system. In the proposed model, the optimal solution is found when both proposed generators connected to bus 3 are added to the system. The proposed generators supply maximum power with low-cost to balance the system. The effect of load and generation variation on the developed model is shown in Table 4. The power flow of existing and developed models are shown in Figure 5 and Figure 6 respectively. In this study, the results of the proposed model presented in Table 4, reduced import power significantly during Off-peak of the spring season. Economic load dispatch problem and optimal power flow solution are identified for both existing and proposed models.

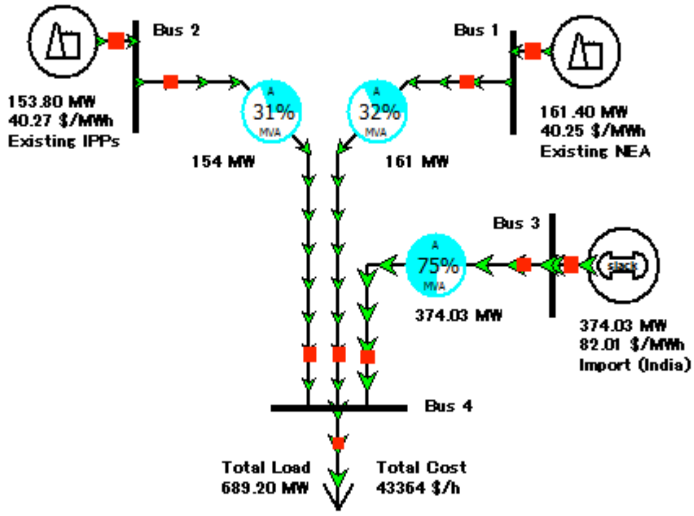

Fig.5. Simulation results of the existing with import systems.

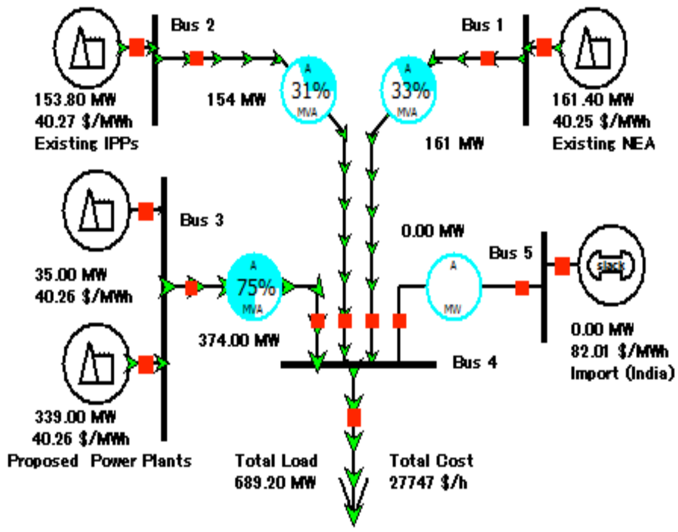

Fig.6. Simulation results of the proposed with import systems.

Table 3. Optimal generation and scheduling for existing system (including load-shedding).

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

Table 4. Optimal generation and scheduling for proposed system (including surplus power).

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	10.00
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	95367.60

When we open the transmission line between bus three and four the model automatically resolve the new power flow and also shows the power flow direction which is shown in Figure 6. In the developed model, there is no power flowing through the transmission line from bus 5 to bus 4. Besides this, in the Off-peak period, there is surplus power which is shown in Table 4. 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 an optimal way to operate a power system. In Nepal, after the devastating earthquake in 2015, damaged 14 existing hydropower dams and more than 30% of power was insufficient. Based on that scenario, in this study, we considered two cases in power systems in an emergency situation.

4.1. Power Systems in Emergency Situation (Case1).

Based on the energy data of Nepal [4], 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 (situation A) and minimum generation of the Off-peak (situation B) period of the autumn season. The existing generators connected to bus 1 and bus 2 drop production by 30%. We designed and analyzed the proposed model to

Case 1 **Emergency Situation**

Situation A: Emergency occurred during On-peak period of the autumn season. (Fig. 7)
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% (485.00 MW) of power 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 (395.00MW).
Increase import power by 20.88% (301.55 MW).

Situation B: Emergency occurred during Off-peak period of the autumn season. (Fig. 8)
Location: Bus 1 and bus 2.
Considering bus 1 and bus 2 drop generation power by 30% (159.60 MW) due to earthquake.
There were no load-shedding in the system during Off-peak.
Total insufficient power: 30.00% (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).

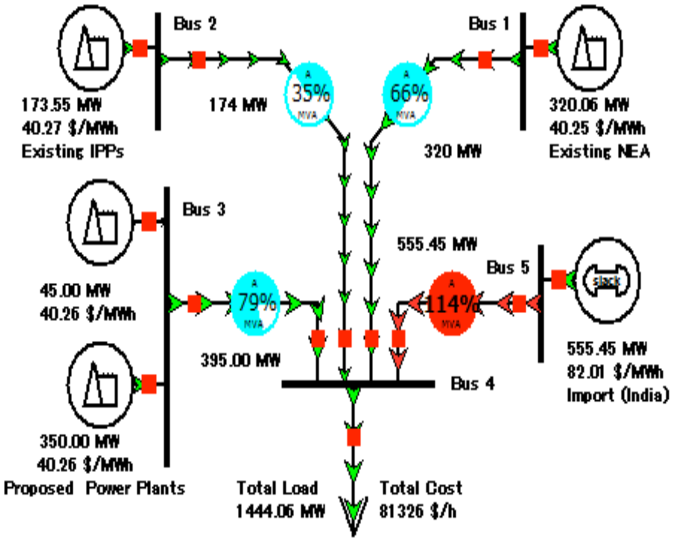

Fig.7. Simulation results of On-peak period for case 1.

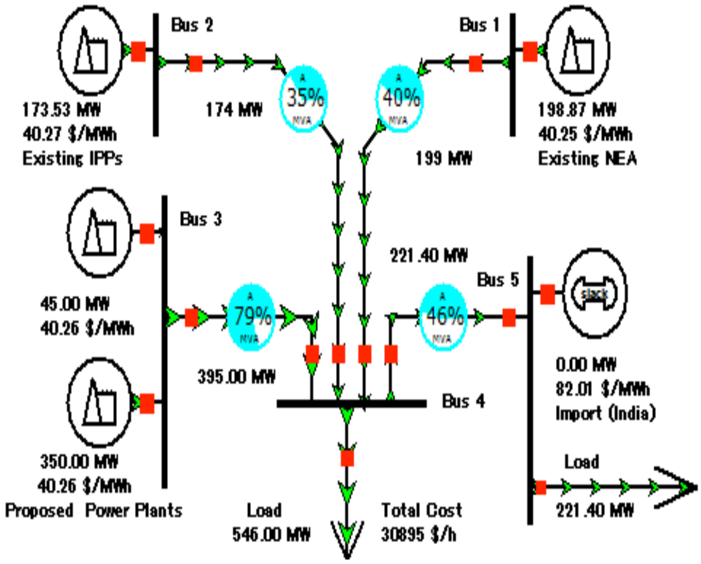

Fig.8. Simulation results of the Off-peak period for case 1.

overcome the power shortage during an emergency of On-peak period. The results are shown in Figure 7. 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.

5.2. Power Systems in Emergency Situation (Case 2).

In case 2, considering the existing generations of bus 1 and bus 2 are drop power generation by 30%, during the On-peak and Off-peak periods of autumn and winter seasons.

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. 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. The simulation results are shown in Figure 8. An optimal way to minimize the power crisis by power wheeling with India and exchange the power for autumn-winter and vice-versa. The ELD and OPF techniques applied in this study to achieve the utilization of electric energy more reliably to balancing the system load.

Case 2 **Emergency Situation**

Situation A: Emergency occurred during Off-peak period of the winter season. (Fig. 9)
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 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 (395.00MW).
Increase import power by 11.17% (143.06 MW).

Situation B: Emergency occurred during Off-peak period of the winter season. (Fig. 10)
Location: Bus 1 and bus 2.
Considering bus 1 and bus 2 drop generation power by 30% (77.91 MW) due to earthquake.
There were no load-shedding in the system during Off-peak.
Total insufficient power: 30.00% (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).

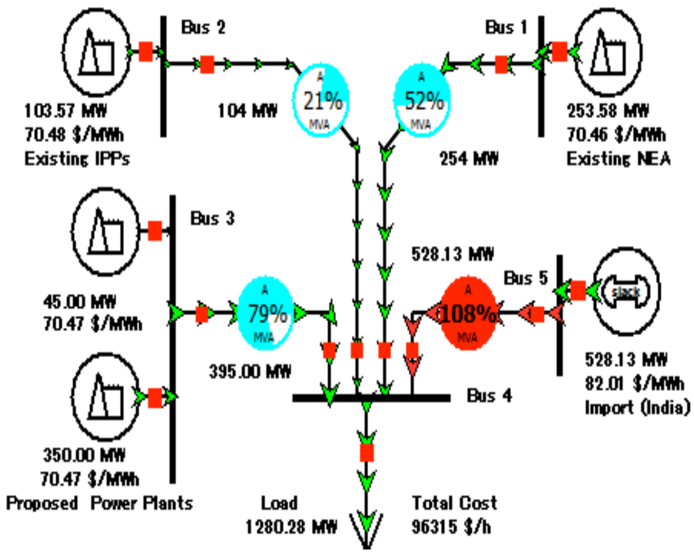

Fig.9. Simulation results of On-peak period for case 2.

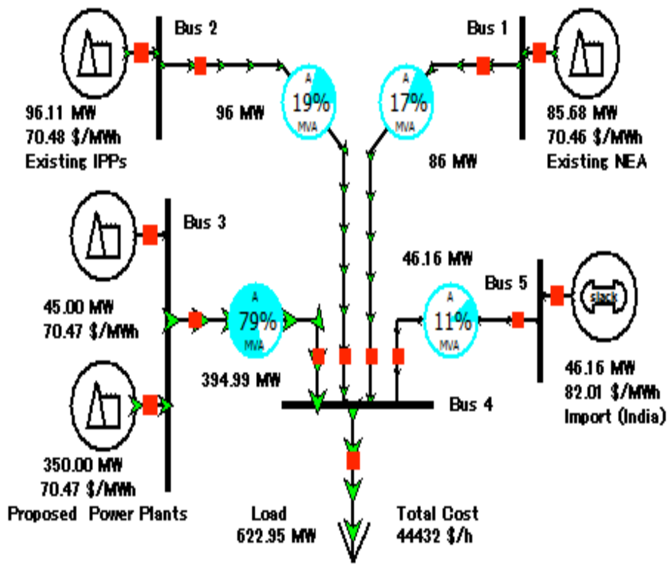

Fig.10. Simulation results of the Off-peak period for case 2.

The simulation results for the On-peak period is shown in Figure 9. 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. 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 very low 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 approximate generation cost ($/MWh) for On-peak period and Off-peak periods are shown in Table 5.

Table 5. On-peak and Off-peak load results of case 1 and 2.

Source (MW)	Autumn (On-peak)	Autumn (Off-peak)	Winter (On-peak)	Winter (Off-peak)
Existing NEA	320.06	198.87	253.58	85.68
Existing IPPs	173.55	173.53	103.57	96.11
Proposed	395.00	395.00	395.00	395.00
Import	555.45	0.00	528.13	46.16
Load Shedding	0.00	0.00	0.00	0.00
Surplus Power	0.00	221.40	0.00	0.00
Total Load	1444.06	546.00	1280.28	622.95
Total Cost ($/MWh)	81326.00	30895.00	96315.00	44432.00

The analyzed simulation results of the Off-peak period in the winter season are shown in Figure 10. The proposed system minimize the load-shedding and also significantly, reduced the import power during the Off-peak periods of autumn and winter seasons. However, during the On-peak periods of the spring, summer, and autumn seasons only 1.25% (5.00 MW), 22.55% (115.00 MW), and 18.55% (90.00 MW) power are insufficient compared to the existing system. Therefore, the proposed power generations connected to the system to avoid instability in the system. In this study, we only used this Power World simulator for five bus system; however, it can solve even higher large-scale bus systems. OPF is the dominant technique in understanding the dynamic behavior of large-scale power systems. The power grid of Nepal has posed a more significant challenge in the secured and reliable operation of the system. it should have enough power to operate in average condition and should be capable of withstanding system disturbances.

5. Conclusion

In this study, the economic load dispatch and optimal power flow considering the proposed generation has been presented to overcome the power shortage and minimize the import and consumption electricity cost in Nepal. A large-scale grid-connected power system model was designed and analyzed the results in order to meet the electric energy peak demand for Nepal. By implementing the ELD and OPF approach in our proposed power system model, the electricity generation, transmission and distribution would be identified. Therefore, it is possible to reduce the import power and the load shedding is completely ended.

To minimize the power uncertainties in Nepal, the proposed model identified the optimal operation to solve the On-peak and Off-peak load during the emergencies cases. Based on the finding results, it has been shown that the implementation of this study has a huge impact on electricity consumers would benefit from reducing the energy cost. In an emergency case, On-peak and Off-peak of power generation and peak load for both existing and proposed power plants were identified. The 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 without any failure and uncertainties. In our proposed technique, we do not consider control changes such as generator reactive limits and voltage limits

This paper has presented the development and efficient management techniques that would be useful for providing electric energy reliably and securely for balancing the system load with efficient power flow. This implemented ELD and OPF approach is the best solution for scheduling real-time power supply and demand more technically and economically. This kind of research is essential and necessary for the improvement and performance of Nepal`s power system.

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