Proceedings of IOE Graduate Conference, 2015
pp. 180–185

Impact Analysis of Wind Power System Installation in Kathmandu Valley Network

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Abstract
With recent advances in technology, utilities expect to see increasing amounts of wind power generation on the system. Addition of generation from wind power is a new challenge for conventional electric power systems due to its intermittent nature. Power injections from wind power can change network power flows, modify energy losses and voltage profile of the system. Proper location and size of wind power plant in power systems are extremely important in order to obtain maximum potential benefits. This paper evaluates the study of impact of installing Wind Turbine Generator (WTG) in Kathmandu valley on Integrated Nepal Power System (INPS). The output of the study is measured by objectively verifiable indicators, like voltage profile, system loss, and the reliability indices. Power loss minimization and voltage profile improvement are paramount technical benefits achieved with wind integrated system. Various case studies are performed and analyzed to see the impact of adding generation from wind power. This paper aims to compute the amount of power and energy loss reduction as well as improvement in load point reliability indices as a result of adding wind power generation. After data collection from Nepal Electricity Authority (NEA) and literature review, a test model is developed and power flow and reliability analysis is done in Electrical Transient Analyzer Program. The result shows that after addition of WTG at two locations, power loss and EENS are reduced significantly; likewise voltage profile is also improved to significant level.

Keywords
Load Flow – Reliability – INPS – ETAP – WTG

1. Introduction

Electrical power system provides a vital service to the society. It should be operated with the goal of achieving minimum system loss, highest reliability standards and less environmental impacts. Continuous growth in electricity demand is forcing to expand the electrical power system which includes generation, transmission and distribution system. Nepal has been experiencing severe power shortage for the last many years. Resultantly, the country is facing repeated and astonishing blackouts. It is due to the fact that installed generation capacity in Nepal has been growing at steady pace. In this current crisis of electricity, addition of wind power, in hybrid model, could be best alternative. It would really act as a back-up and help in reducing energy crisis problem of our country to some extent.

Kathmandu centric urbanization result in deficiencies of urban services. Among many urban services like water supply and sanitation, electricity is a major need of the people. Even a momentary interruption in electricity supply causes a huge monetary loss to the economy from household level to the national level. All the socio-economic factors in this globalization age, like literacy, health, finance, industry, agriculture,various occupational services are based on the electric supply. The threshold capacity of Kathmandu valley cannot cater the increasing need of electric supply. Nepal's power supply-demand scenario states that the rising gap between electricity demand and domestic supply has resulted in electricity deficit of about 1.278 GWh in FY 2014[1]. This demand and supply gap leads to load curtailment and increased dependence of our country on India and overseas in importing electricity.

The present trend of generating electricity from hydropower cannot fulfill the urgent needs of electric supply. The various factors prevailing in conventional system like huge civil infrastructure, bulk investment, congestion in transmission line hinder the continuous and reliable supply of electricity to meet the urgent present demand in time. Alternative measures are hence required to be considered so as to keep the availability of electricity as per demand so that it does not affect our daily schedule due to lack of power supply. One of the viable option may be incorporating wind power in existing conventional system as wind power plant can be built relatively quickly, even in large scale. Various parts of the country have fair or good wind profile to be considered for installation of WTGs. Researcher mapped the wind system in various parts of Kathmandu valley and about 20 MW power generation has been found feasible and stated its potential sites as Makwanpur, Lakuri Bhanjyaang, Naagdhunga, Bhimdhunga, Nagarkot, Godavari and Phulchowki.

There can be no better place than the major load centres for installing these WTGs if wind profile indicates toward techno-economical viability of such projects. In this context, it is very pertinent to explore the possibility of installing WTGs in Kathmandu valley which accounts to almost half of the total electricity demand of the country. This paper is an attempt to determine the capacity benefit in terms of system reliability indices and savings in power and energy which are very scarce in Nepal's power system these days[1].

2. Methodology

To determine the impact of installing Wind Turbine Generator in Kathmandu valley on the operation of existing power system network, following steps were followed during the paper works.

A. Data Collection

Datas related to Kathmandu valley power network were collected and necessary calculations were done.

B. Modeling

The appropriate models were developed in ETAP to represent Kathmandu valley power network for doing detailed analysis so as to meet the aim of research paper.

C. Load Flow Analysis

Load flow analysis is probably the most important of all network calculations since it concerns the network performance in its normal operating conditions. It is performed to investigate the magnitude and phase angle of the voltage at each bus and the real and reactive power flows in the system components. Load flow analysis has a great importance in future expansion planning, in stability studies and in determining the best economical operation for existing systems. It is helpful in determining the best location as well as optimal capacity of proposed generating station, substation and new lines.In order to perform a load flow study, full data must be provided about the studied system, such as connection diagram, parameters of transformers and lines, rated values of each equipment, and the assumed values of real and reactive power for each load.

Generally, load flow studies are limited to the transmission system, which involves bulk power transmission. The load at the buses is assumed to be known. Load flow studies are required for deciding the economic operation of the power system. Thus the load flow problem consists of finding the power flows (real and reactive) and voltages of a network for given bus conditions. It determines the voltage of the each bus so that voltage level at the certain buses can be kept within the closed tolerances.

At each bus, there are four quantities of interest to be known for further analysis: the real and reactive power, the voltage magnitude and its phase angle. Because of the non linearity of the algebraic equations, describing the given power system, their solutions are obviously based on the iterative methods only. In this study, load flow analysis is used to determine the power loss on each branches and also to find the optimal size and location of WTG subjected to minimum power loss using ETAP simultion software.

The complex power S_{ij} from bus i to j and S_{ji} from j to i are:

$$S_{ij} = V_i I_{ij}^* \tag{1}$$

$$S_{ji} = V_j I_{ji}^* \tag{2}$$

The power loss in the line from i to j is the algebraic sum of the line power flows:

$$S_{Tloss} = S_{ij} + S_{ji} \tag{3}$$

D. Reliability Assessment

The basic function of an electric power system is to satisfy the system load and energy requirements as economically as possible and with a reasonable assurance of continuity and quality [2]. Modern society, because of its pattern of social and working habits, has come to expect the power supply to be continuously available as per demand. But this is not possible due to the occurrence of various failures in the system. There is always a direct conflict between the two aspects which is low cost electrical energy at a high level of reliability. At present, this is an important problem in determining an appropriate generating reserve capacity margin. An excessive investment yields overly reliable system, while a low cost system gives poor service continuity.

In order to provide a quantitative evaluation about the reliability of an electrical system, it is necessary to have indices which can express system failure events on a frequency and probability basis. The following three reliability indices also called load point indices are : failure rate(λ), average outage duration (r), annual outage time (U) and EENS. These indices help to assess the measure of reliability at each load point of any meshed or parallel system. These indices help to assess the measure of reliability at each load point and allow subsidiary indices. But according to [3], these indices are notable to differentiate between the interruption of large and small loads and also not able to recognize the effect of load growth by existing customers or additional new loads. These deficiencies could be accounted for thorough evaluation of the expected energy not supplied in kWh.

Average Failure Rate at Load Point λ_i,f/yr

$$\lambda_i = \sum_{j\varepsilon N_e} \lambda_{e,j} \tag{4}$$

where $\lambda_{e,j}$is the failure rate of element j; Ne is the total number of the element whose fault will interrupt load point i.

Annual Outage Time at Load Point i, U_i(h/yr)

$$U_i = \sum_{j\varepsilon N_e} \lambda_{e,j} r_{ij} \tag{5}$$

where r_{ij} is the failure duration at load point i due to failed element j.

Average Outage Duration at load Point i, r_i(h)

$$r_i = \frac{U_i}{\lambda_i} \tag{6}$$

Expected Energy Not Supplied at Load Point i, $EENS_i$(MWh/yr)

$$EENS_i = U_i[P_i - P_{ir}] \tag{7}$$

where P_{ir} and P_i are the power flow at load point i with and without renewable power generation.

E. Software and Tool

As power system become increasingly complex, there is a critical need to make available improved tools for analyzing the power system. In addition, it gives guidance to the entry of new working professional into the power system with at least a basic understanding of power system operation. ETAP is the most comprehensive analysis platform for the design, simulation, operation, control, and optimization, automation of generation, transmission, distribution and industrial power systems. ETAP offers a suite of fully integrated software solutions including arc flash, load flow, short circuit, relay coordination, cable capacity, transient stability, optimal power flow, and more. Its modular functionality can be tailored to fit the needs of any company from small to large power systems. Typical information for all equipment (Generator, Transformer, Shunt equipment) is readily available which reduces the considerable time of the user. ETAP provides error report and highlight the mistake to the user in a brief report.

3. Case Studies

Case 1: INPS Base Case without WTG

Case study first was applied for developed network consisting 38 buses, 66 branches, 34 generators and 13 loads as depicted in Figure 1. The power demand and generation scenario of 2071/72 during peak load was considered. Voltage profile and system active power loss were obtained from load flow solution and Expected Energy Not Served (EENS)and Energy Index Reliability (EIR) from reliability assessment.

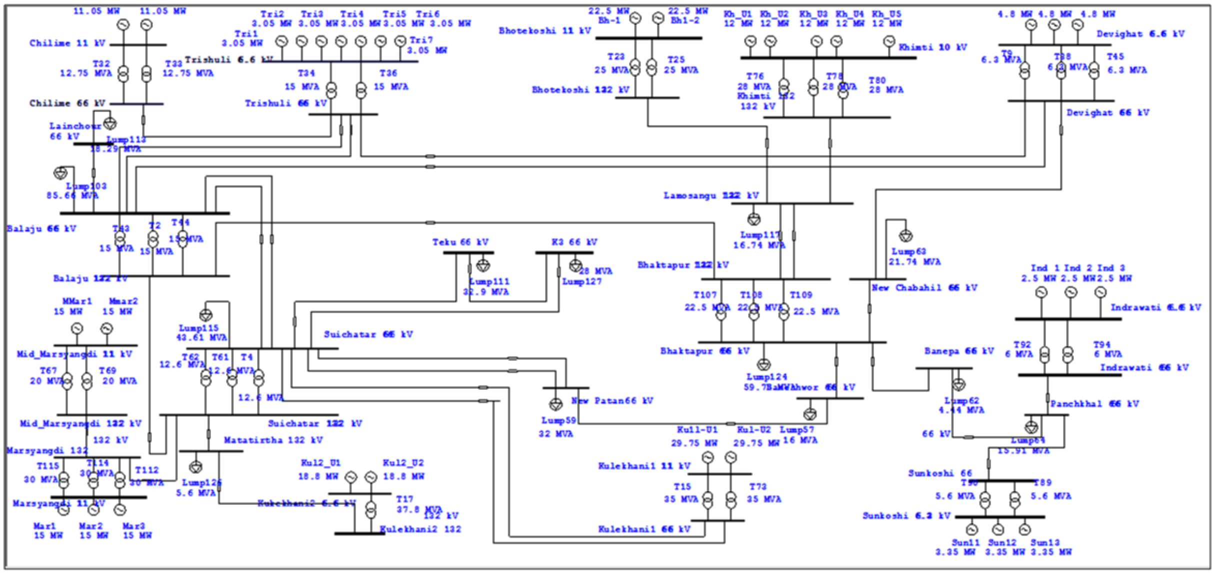

Figure 1: Kathmandu Valley Power System Network without WTG

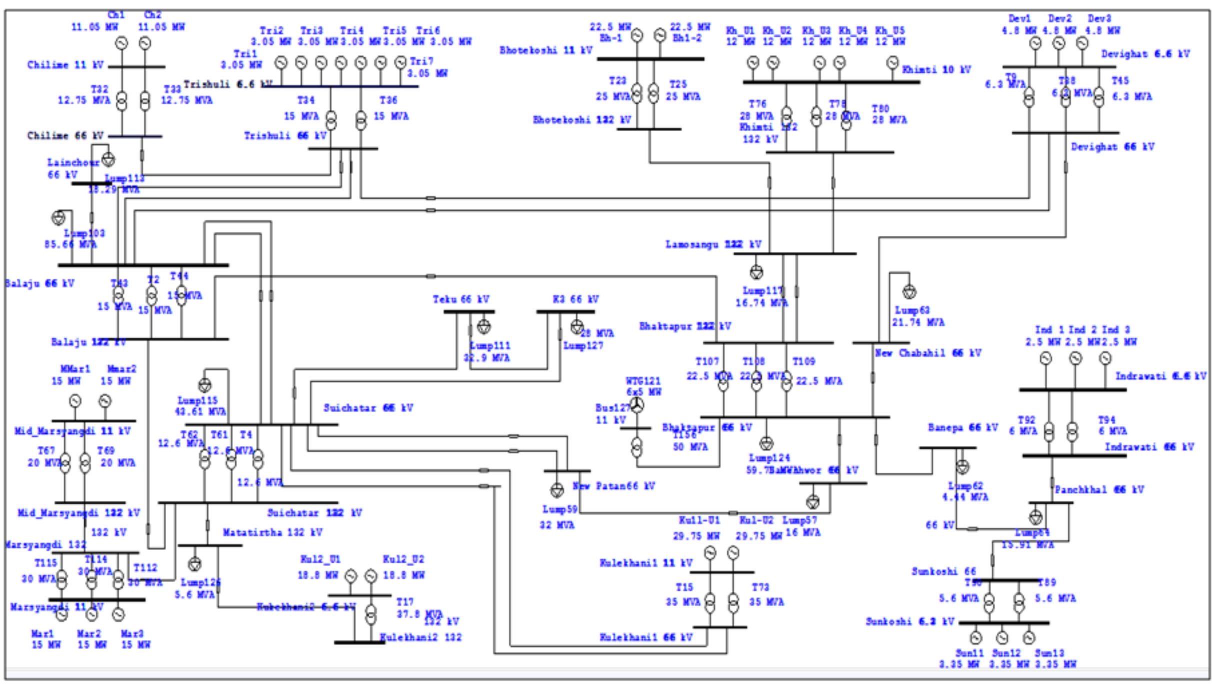

Figure 2: Kathmandu Valley Power System Network with WTG at Bhaktapur

Case 2: INPS Base Case with WTG at Bhaktapur

Case study second was applied for developed network with the addition of WTG at Bhaktapur as depicted in Figure 2. In this case, WTG was placed at Bhaktapur S/S, gradually increasing its capacity upto the level at which system active loss was minimum. It was the required optimum capacity of WTG for that location. The same procedure was followed considering the impacts of all indices as mentioned in the previous case for the optimal size of WTG.

Case 3: INPS Base Case with WTG at Patan

Case study third was applied for developed network with the addition of WTG at Patan. In this case WTG was placed at Patan S/S, gradually increasing its capacity upto the level at which system active loss was minimum. It was the required optimum capacity of WTG for that location. The same procedure was followed considering the impacts of all indices as mentioned in the previous case for the optimal size of WTG.

Case 4: INPS Base Case with WTG at both Patan and Bhaktapur

Case study fourth was applied for developed network with the addition WTGs at both Patan and Bhaktapur. In this case WTGs were placed at both substations, gradually increasing its capacity one bus at a time upto the level at which system active loss was minimum. This was the optimum capacity of WTG for that location. The same procedure was followed considering the impacts of all indices as mentioned in the previous case for the optimal size of WTG.

4. Result and Discussion

When the collected information was processed and fed as input data to the developed model, it was successful in searching the required solution.

A. Result for Base Case without WTG

Load flow analysis without WTG was done using ETAP simulation software. System active loss was found 14.78 MW out of total generation 353.29 MW and EENS was found 8166 MWh/yr. Result obtained from load flow and reliability analysis is shown in Table 1 and Table 2.

Table 1: Summary of Load Flow Analysis

Details	MW	MVAR
Source (Swing bus)	60.29	72.23
Source(Non- Swing bus)	293.00	100.11
Total Demand	353.29	172.34
Total Motor Load	157.44	51.74
Total Static Load	181.06	59.51
Total Loss	14.78	61.08

Table 2: Summary of Reliability Analysis

Details	Indices
Average Interrupting rate	31.30 failure/yr
Annual Outage Duration	353.16 h/yr
Expected Energy Not Supplied	8166 MWh/yr
Energy Index Reliability	0.9974

B. Result for Base Case with WTG at Bhaktapur

Adding WTG at Bhaktapur, load flow has been run using ETAP simulation software. System loss in this case was found 14.05 MW out of total generation 357.89 MW and EENS was 6381 MWh/yr at optimal capacity of 30 MW WTG. Power loss was decreased significantly with same load scenario. Result obtained from power flow and reliability assessment in this case is shown in Table 1 and Table 2.

Table 3: Summary of Load Flow Analysis

Details	5*5MW WTG	6*5MW WTG	7*5MW WTG
Source (Swing)	39.08	34.73	30.37
Source (Non-Swing)	318.00	323.00	328.00
Total Demand	357.44	357.73	358.37
Total Motor Load	157.44	157.44	157.44
Total Static Load	185.57	186.23	186.85
Total Loss	14.06	14.05	14.08

Table 4: Summary of Reliability Analysis

Details	5*5MW WTG	6*5MW WTG	7*5MW WTG
Outage Duration (h/yr)	355.17	355.56	355.97
Failure rate (f/yr)	31.409	31.429	31.44
EENS (MWh/yr)	6608	6381	6172
EIR	0.9979	0.9979	0.9980

C. Result for Base Case with WTG at Patan

Adding WTG at Patan, load flow has been run using ETAP simulation software. System loss in this case was found 12.85 MW out of total generation 357.89 MW and EENS was 4805 MWh/yr at optimal capacity of 55 MW WTG. Power loss is decreased significantly with same load scenario. Result obtained from power flow in this case is shown in Table 5 and Table 6.

Table 5: Summary of Load Flow Analysis

Details	10*5MW WTG	11*5MW WTG	12*5MW WTG
Source (Swing)	16.91	12.50	8.10
Source (Non-Swing)	343.00	348.50	353.10
Total Demand	359.91	360.50	361.10
Total Motor Load	157.44	157.44	157.44
Total Static Load	189.48	190.09	190.68
Total Loss	12.985	12.96	12.97

Table 6: Summary of Reliability Analysis

Details	10*5MW WTG	11*5MW WTG	12*5MW WTG
Outage Duration (h/yr)	357.16	357.57	357.96
Failure rate (f/yr)	31.50	31.52	31.54
EENS (MWh/yr)	5249	5036	4832
EIR	0.9983	0.9984	0.9984

D. Result for Base Case with WTG at Patan and Bhaktapur

Adding WTG at both substations, i.e Patan and Bhaktapur, load flow has been run using ETAP simulation software. System loss in this case was found 12.94 MW out of total generation 357.89 MW and EENS was 4754 MWh/yr at optimal capacity of 55 MW WTG at Patan and 5 MW at Bhaktapur. Power loss is decreased significantly with same load scenario. Result obtained from power flow in this case is shown in Table 7 and Table 8.

Table 7: Summary of Load Flow Analysis and Reliability Assessment

WTG at Patan	WTG at Bhaktapur	Loss MW	EENS	EIR
9*5	2*5	12.97	4914	0.9984
10*5	2*5	12.95	4754	0.9984
11*5	1*5	12.94	4696	0.9985
11*5	2*5	12.97	4223	0.9986

5. Cost Analysis

Total cost of wind power installation at Bhaktapur without considering carbon credit is found NRs 10500 million taking total WTG installation cost of USD 3500 per kW. There is reduction in system power loss of about 1.97 MW by adding WTGs at both Patan and Bhaktapur in INPS. Cost of energy saving due to addition of 30 MW WTG at Bhaktapur is NRs 48.35 million per year.This will be the income for NEA from consumer. When 55MW WTG is placed at Patan, cost of energy saving is NRs 54.00 million. Likewise, when WTGs placed in distributed way at more than one location, i.e., Patan and Bhaktapur, cost of energy saving by adding 55 MW WTG at Patan and 5 MW WTG at Bhaktapur is NRs 120.88 million per year. Likewise, impact of adding WTG on unserved energy cost is shown in Figure 3.

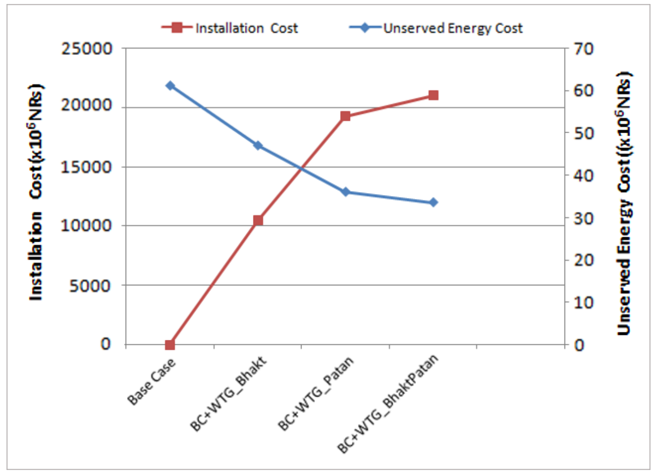

Figure 3: Impact of adding WTG on Unserved Energy Cost

6. Conclusion

Analysis carried out in this research shows that there is a reduction in system power loss and significant improvement in voltage profile of the substations. At the same time overall reliability of the system is also found improved by adding WTG in the existing system. Optimal capacity of WTG at different location is determined based on minimum system loss and found 30 MW in Bhaktapur and 55 MW in Patan. When WTGs are placed at both the location i.e., in Patan and Bhaktapur, optimal capacity of WTG at Patan is found 55 MW and 5 MW in Bhaktapur and in that case power loss is found only 12.94 MW. Analysis shows that optimal capacity from system loss perspectives is found sensitive to the location of WTG. Installation of WTGs at more than one places in a distributed way is found more improvement in the active loss reduction and reliability due to less dependence on transmission line constraints. Hence it can be concluded that, wind power locally available in Kathmandu valley should be utilized as soon as possible to get benefitted overall.

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