Proceedings of 12th IOE Graduate Conference
Peer Reviewed
ISSN: 2350-8914 (Online), 2350-8906 (Print)
Year: 2022 Month: October Volume: 12

Grid Impact Analysis of Distribution System before and after Injection of Distributed Energy Resources (DERs) : A Case Study of Standard IEEE 10 Bus System

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Abstract

The Radial Distribution System (RDS) has a voltage drop that is highest at the transmitting end and gradually decreases as it approaches the feeding ends. Techniques such as injection of the capacitors, Distributed Energy Resources (DERs) such as grid connected wind and solar power plants, in the feeder can reduce power loss and improve the voltage profile of the system. Utilizing a standard IEEE 10 bus system, grid impact analysis of the penetration of the grid connected wind and solar power plants into the feeder system is used to improve the performance of the distribution system. Analysis is done on the system's performance both prior to and after the injection of DERs. In both cases, i.e., prior to and after DERs compensation and injection, bus voltages at each nodes, power loss, voltage control, and voltage profile are compared. The voltage profile is improved and power losses is decreased after the penetration of DERs in the distribution feeder. Voltage regulation of the system is also found to be improved.

Keywords

Radial Distribution System (RDS), Distributed Energy Resources (DERs), Voltage Profile, Voltage Regulation, IEEE 10 bus system

1. Introduction

Usually, production, transmission and the distribution of electrical energy are the major components of the integrated power system. Our country has a major challenge in delivering electrical energy with the best achievable efficiency and the minimal losses. The system losses have been lowered by Nepal Electricity Authority (NEA) from 17.18% in fiscal year 2020/21 to 15.38% in fiscal year 2021/22 [1]. It is crucial for distribution systems to deliver high-quality power to consumers with great reliability and efficiency. Demand Side Management must be implemented properly, which improves voltage regulation, power factor, power losses and voltage sag. Therefore, compensating approaches can be used to minimize such losses if the loss is significant in Distribution System Feeders. Additional DERs, such as grid-connected solar energy and wind power plants, can be added to the distribution system's feeder to improve overall performance.

The Nepalese government must put local power consumption ahead of exporting excess production to the world market as more energy resources are added to the country's integrated energy system. Hence, for this purpose, the power quality needs to be improved with good voltage profile and minimum power losses[2]. With an increase in number of consumers, the energy consumption rises. Thus, increasing line losses result from increased energy usage. The line current increases as a result of this. Further voltage drops, power factor becomes poor with poor voltage regulation, and voltage profile also declines as a result from this. Losses in the system consequently rise [3]. Consumers must receive dependable, high-quality electricity with minimal losses and a high power factor. This can be achieved by pentration of the Distributed Energy Resources in the feeder or by meeting the reactive power demand by positioning the capacitor banks in the best possible location.

The greatest challenge to the responsible authorities is delivering electrical power from distribution stations to consumers for use with minimal loss, minimal voltage drop, good voltage regulation, good quality, high reliability, and high power factor. A variety of strategies can be used to reduce distribution losses, improve power factor, and improve voltage profile. Some of these techniques include upgrading conductors, reconfiguring feeders or distribution systems, selecting and placing optimal capacitor banks, use of the distributed generation, addition of Distributed Energy Resources, or combining the aforementioned techniques [4].

Voltage regulation on the grid shouldn't deviate from its nominal value during normal operation by more than 10% [5]. However, the Standard IEEE 10 bus system has poor voltage regulation and does not comply to the NEA Grid Code Standard. Therefore, in in addition to minimizing power losses, further strategies may be used to maintain voltage regulation and improve voltage profile in terms of power losses, efficiency, voltage drop, voltage regulation, and voltage profile. The research analyzes the grid impact study caused by the injection of DERs in the system feeder. Since the system must maintain proper voltage regulation in accordance with the NEA Grid Code of 2011, the Standard IEEE 10 bus system is modeled as the study bus for system performance enhancement in terms of Voltage Profile, Voltage Regulation, and power loss.

The main aim of this research work is to carry out the impact study of the grid through the penetration of DERs i.e. wind energy and solar energy in the system feeders for the Standard IEEE 10 bus system.

2. Literature review

Distribution Systems usually consist of feeders, distributors and the service mains [6]. Feeder connects the area to be supplied by the system with the substations. The distribution system may be primary or secondary. Usually, in context of Nepal, 3.3 kV, 6.6 kV or 11 kV falls under primary distribution system while 230 V or 400 V falls under secondary distribution system.

Distribution System is classified into Radial System, Ring Main System and Inter-connected System based on the connection schemes [7]. Radial Distribution System (RDS) connects Substation and the feeder along the single path. Loop circuit makes loop throughout the areas to be served and finally is connected to the substation from which the feeder line starts. Interconnected system is interconnected by two or more stations in the feeder ring [8].

In Nepal, almost all the distribution systems are radial in nature. There is a single path for the connection between Distributor and Substation. Another form of Distribution System is Ring Main Distribution System where feeder is in form of ring and is not common form of feeder system in case of Nepal although voltage fluctuations is minimal in such systems [9]. Distribution System is classified into DC and AC distribution systems based on the nature of current. AC Distribution System is the most common and widely used system used due to its simplicity and economic condition. Distribution Systems may be overhead or underground depending on the type of construction. Overhead system is economical when compared with the underground system. However, there is more chance of faults on Overhead Systems than Underground Systems. Moreover, overhead systems also degrade the aesthetic beauty when compared with the underground systems [10].

In order to reduce the power losses and boost the voltage profile of the distribution system feeder, [11] examined the ideal placement for Distributed System Generation Units Sizing and Sitting utilizing the IEEE 33-bus radial Distribution System.. The load flow was carried out using NEPLAN 360 and proposed decision making algorithm was applied in MATLAB. The obtained results were compared with those of earlier studies carried out.

[12] analysed installation of both capacitors and PV Systems in Distribution System Feeder to reduce the active power loss for Radial Sytems even by consideration of Geography Location Constraints. Study was carried out by varying the number of capacitors for the installation of PV. The analysis was carried using Stochastic Fractal Search Optimization Algorithm (SFSOA) and tested in 33 and 69 bus systems.

[13] used Electrical Transient Analyzer Program (ETAP) for the load flow of IEEE 4 and 33 bus system and implemented GA for optimization of the distribution system for line loss reduction and improvement of voltage profile. The enhancement of power factor of the system was observed as well due to which finally the net profit was found to have increased.

Distributed Energy Resources (DERs) usually vary from 3 kW to 50 MW and are penetrated in order to improve the performance characteristics of the feeder. The voltage profile of the distribution system will be improved due to the penetration of Distribution Energy Resources in the feeder. Power Losses will also be minimized, that enables the rise of efficiency of the distribution system due to DERs injection in the system [14].

From the above literature works, the performance of distribution systems is improved by compensation through capacitor banks, D-STATCOM, conductor upgradation or placement of Distributed Generation Units considering various technical and financial aspects. In case of Standard IEEE 10 bus system, voltage regulation does not meet the NEA Grid Code Standard, 2011. DERs can be selected according the suitability of the geographical location of the feeder, where compensation seems fruitful. Hence, impacts of the penetration of DERs in the system can be analysed.

Tilt angle is the angle made by the PV module with reference to the horizontal surface. Azimuth angle is the direction shown by the compass that shows the direction of sunlight approaching the panel. Inverters convert dc current to ac current for injection of power to the grid. Performance ratio shows the ratio of measured output with reference to the expected output. Global horizontal irradiation shows the radiation received by horizontal surface from sunlight. The radiation that reaches the surface per unit area but does not follow the sun's direct path is known as diffuse horizontal irradiation. The global incident in coll. plane is determined from global horizontal irradiation and diffuse horizontal irradiation in hourly values. Wind speed of a certain area shows the rate of flow of air at that area. Wind turbine is driven through the speed of the wind. This mechanical form of energy is transferred to the Wind turbine Generator (WTG) through gearbox for the production of electrical energy.

3. Research Methodology

The study technique is primarily focused on the detailed or careful examination of technical parameters or components such as Feeder Loss Reduction, Voltage Regulation, and Voltage Profile Enhancement of the Standard IEEE 10 bus system. Analysis is conducted on the distribution system's performance both prior to and after the injection of DERs. Analysis is done on the impacts of grid-connected solar and wind power plants on the IEEE 10 bus system. The first step in the methodology is to do a scholarly or detailed investigation of the topic at the issues or the contexts that is closely related in order to conduct the meticulous analysis. The collection of data for the IEEE 10 bus system follows subsequently then after. The load flow is then carried out in order to determine each bus voltage in the distribution system. The nodal bus voltages are then obtained by executing and simulating the load flow. Then, both prior to and after compensation, the technical parameters or characteristics such as power loss and voltage profile are examined.

The literature review for the revelant works are analysed in detail and the research gap has been determined. Thenafter, the data is collected and the simulation is carried out for various scenarios after performing the load flow analysis. Figure 1 elucidates general methodology while carrying out the research works.

The line data and load data of the Standard IEEE 10 bus system is taken for analysis. The losses and voltages at each bus and line is thoroughly observed and analysed prior to and after penetration of the DERs into the distribution system feeder, the losses and voltage at each bus and line are examined. After that, a grid impact analysis is done to determine how the introduction of DERs into the distribution system would affect technical factors like voltage regulation, voltage profile, and power loss. Hence, technical aspects of the system after injection of DERs are analyzed.

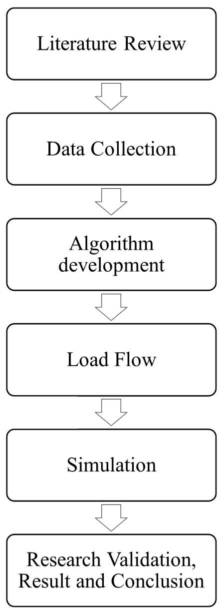

Figure 1: Methodology of the research work

Table 1: Bus Voltage of Standard IEEE 10 bus system without compensation

Bus Number	Bus Voltage in percentage
Bus 1	100.00%
Bus 2	99.31%
Bus 3	98.78%
Bus 4	96.47%
Bus 5	95.00%
Bus 6	92.07%
Bus 7	91.12%
Bus 8	89.41%
Bus 9	86.57%
Bus 10	84.60%

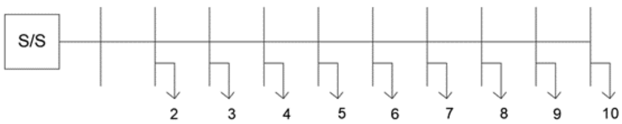

Figure 2: Single Line Diagram of Standard IEEE 10 bus system

4. Results and Discussion

After carrying out the load flow of the the Standard IEEE 10 bus system, we obtain bus voltage at each nodes. The voltage across the bus without any compensation after simulation of the Standard IEEE 10 bus system has been tabulated in Table 1.

Figure 3 shows the load flow of Standard IEEE 10 bus system during normal case without any compensation.

According to the Voltage Profile, it is observed that bus voltages drop from the grid toward the feeder from the transmitting end to the receiving end as shown in Table 1. At the feeder's ends, the substantial voltage sag is noticeable. The losses gradually increase from the substation's initial point to the feeder's end. Voltage at the sending end is 1 pu and is decreased to 0.846 pu at the receiving end that clearly shows 15.4% voltage drop.

The bus voltages are observed to drop from the grid

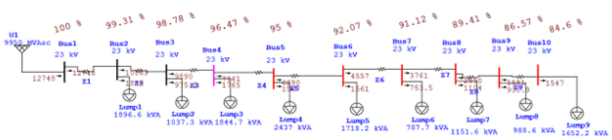

Figure 3: Load flow of Standard IEEE 10 bus system

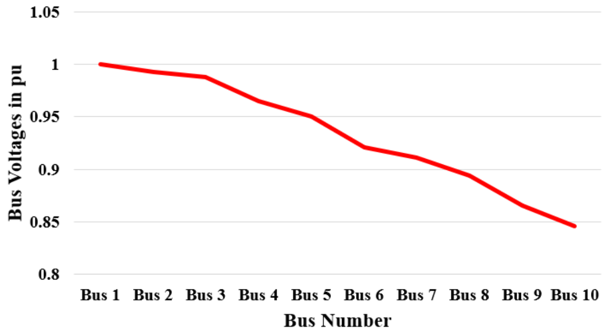

Figure 4: Voltage Profile of Standard IEEE 10 bus system

towards the feeder from the transmitting end to the receiving end based on the load flow. At the feeder's ends, the extreme voltage sag is observable. According to the Voltage Profile in Figure 4, the voltage steadily decreases from the beginning point of the substation to the end of the feeder.

Combination of different units of 450 kW grid connected solar panel and 100 kW grid connected wind power plant is selected for injection into Standard IEEE 10 bus system. Consider at receiving end of Distribution System Feeder, i.e. at bus 10, Distributed Energy Resources (DERs) is injected to analyse the system parameters prior to and after injection. DERs are injected into the feeder at the receiving end of the radial distribution feeder that comprises of about 15% of the total load. For the purpose of analyzing the effects of injecting DERs into the Distribution System Feeder while taking various factors into account, numerous cases are analyzed with injection of 100 kW wind, 450 kW solar, 450 kW solar and 100 kW wind, 900 kW solar, 900 kW solar and 100 kW wind, 1350 kW solar, 1350 kW solar and 100 kW wind, 1800 kW solar and 1800 kW solar and 100 kW wind respectively.

4.1 Impact of DERs injection on Voltage Profile of the system

It has been found that adding DERs to the system improves the distribution system's voltage profile. The Voltage Profile of the Distribution System is enhanced as DER capacity rises. The voltage across each bus in each of the cases is shown in 5.

Figure 6 illustrates the voltage profile through the injection of various grid-connected solar and wind power plant ratings for the IEEE 10 bus standard. The figure depicts that the bus voltages are found to be

	Without compensation	With 100 kW wind	With 450 kW solar	With 450 kW solar and 100 kW wind	With 900 kW solar	With 900 kW solar and 100 kW wind	With 1350 kW solar	With 1350 kW solar and 100 kw wind	With 1800 kW solar	With 1800 kW solar and 100 kW wind
Bus1	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Bus2	0.993	0.993	0.993	0.993	0.994	0.994	0.994	0.994	0.994	0.994
Bus3	0.988	0.988	0.998	0.988	0.989	0.988	0.989	0.989	0.989	0.989
Bus4	0.965	0.965	0.966	0.966	0.967	0.967	0.969	0.969	0.970	0.970
Bus5	0.950	0.950	0.952	0.952	0.954	0.954	0.956	0.956	0.958	0.958
Bus6	0.921	0.921	0.925	0.926	0.929	0.930	0.933	0.934	0.937	0.937
Bus7	0.911	0.912	0.917	0.917	0.922	0.922	0.927	0.927	0.932	0.932
Bus8	0.894	0.895	0.902	0.903	0.909	0.910	0.916	0.917	0.923	0.923
Bus9	0.866	0.867	0.879	0.880	0.891	0.892	0.903	0.904	0.914	0.915
Bus10	0.846	0.849	0.865	0.867	0.882	0.884	0.899	0.901	0.915	0.917

Figure 5: Voltage Profile of Standard IEEE 10 bus system after injection of DERs in the system in pu

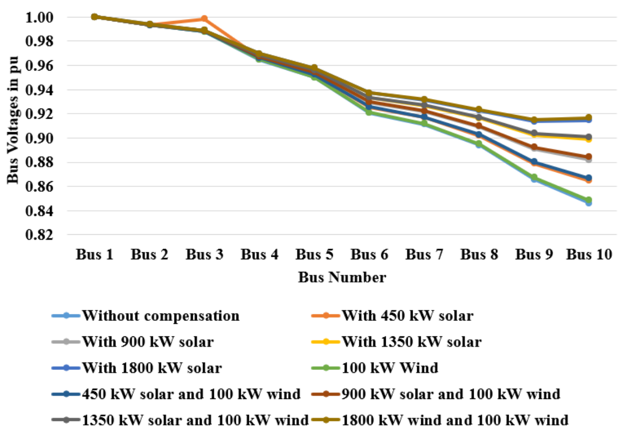

Figure 6: Voltage Profile of Standard IEEE 10 bus system after injection of DERs in the system

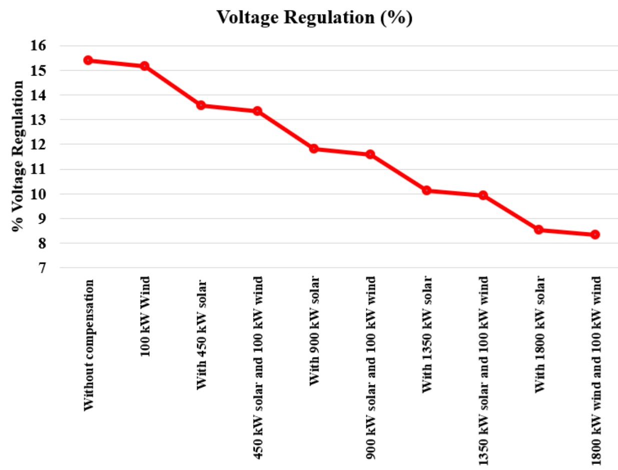

Figure 7: Voltage Regulation of Standard IEEE 10 bus system after injection of DERs in the system

Table 2: Voltage Regulation of Standard IEEE 10 bus system after injection of DERs in the system in percentage

Without compensation	15.4000
100 kW wind	15.1500
450 kW solar	13.5500
450 kW solar and 100 kW wind	13.3200
900 kW solar	11.8000
900 kW solar and 100 kW wind	11.5800
1350 kW solar	10.1300
1350 kW solar and 100 kW wind	9.9200
1800 kW solar	8.5300
1800 kW solar and 100 kW wind	8.3400

enhanced and the voltage profile is found to be improved after the injection of DERs in the system. Thus, it can be shown that an increase in DER capacity immediately correlates with an increase in voltage profile.

4.2 Impact of DERs injection on Voltage Regulation of the system

The voltage profile is analysed for the system through the penetration of the different cases with various scenarios such as 100 kW wind, 450 kW solar, 450 kW solar and 100 kW wind, 900 kW solar, 900 kW solar and 100 kW wind, 1350 kW solar, 1350 kW solar and 100 kW wind, 1800 kW solar and 1800 kW solar and 100 kW wind respectively.

It is observed that the injection of Distributed Energy Resources (DERs) in the distribution system causes improvement in voltage regulation. As the capacity of the injected DERs in the distribution system feeder increases, voltage regulation of the distribution system is improved. The graph elucidated in Figure 7 depicts the different values of voltage regulation for different cases through the injection of different ratings of solar and wind power plants. After penetrating the suitable ratings of DERs in the system, voltage regulation is found to be improved. The improvement in voltage regulation seems to be directly proportional as per the increment of capacity of DERs.

4.3 Impact of DERs injection on Power Losses of the system

The power losses for the system is analysed with different scenarios such as 100 kW wind, 450 kW solar, 450 kW solar and 100 kW wind, 900 kW solar, 900 kW solar and 100 kW wind, 1350 kW solar, 1350 kW solar and 100 kW wind, 1800 kW solar and 1800 kW solar and 100 kW wind respectively.

Voltage control has been found to improve with the addition of DERs to the distribution system. Voltage regulation of the distribution system is enhanced as

Table 3: Power Losses of Standard IEEE 10 bus system after injection of DERs in the system in kW

Without compensation	709.9000
100 kW wind	682.9000
450 kW solar	579.5000
450 kW solar and 100 kW wind	557.8000
900 kW solar	473.6000
900 kW solar and 100 kW wind	456.6000
1350 kW solar	389.1000
1350 kW solar and 100 kW wind	376.4000
1800 kW solar	323.6000
1800 kW solar and 100 kW wind	314.8000

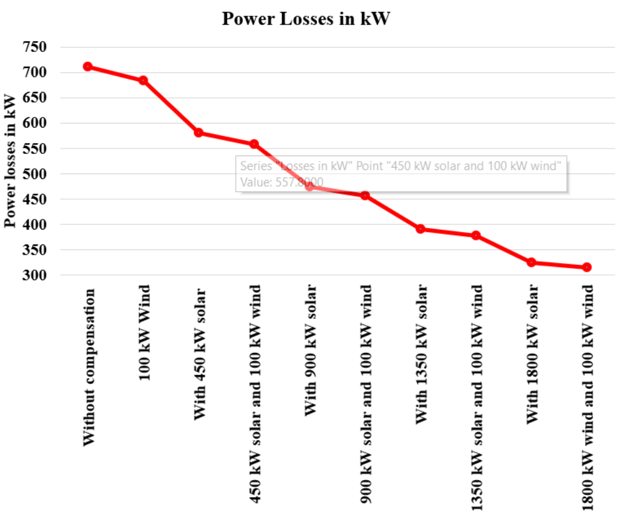

Figure 8: Power Losses of Standard IEEE 10 bus system after injection of DERs in the system in kW

the capacity of the injected DERs in the feeder increases. The graph shown in Figure 8 illustrates the various voltage regulation values for various scenarios through the injection of various Grid Connected Solar and Wind Power Plant ratings. Voltage regulation has been proven to be better after the addition of DERs to the system. The increase in DERs' capacity is directly correlated with the improvement in voltage regulation.

5. Conclusion

The bus voltages of the Standard IEEE 10 bus system are calculated using the load flow, and it is observed that the Voltage Profile of the Distribution System is improved after compensation. For the Standard IEEE 10 bus system, Grid Connected Solar Power Plants of various ratings are chosen, and Grid Connected Wind Power Plants with the appropriate capacity are chosen for the corresponding site. After the introduction of DERs, a grid impact study is conducted. Voltage Regulation and Voltage Profile for the Standard IEEE 10 bus system are found to be improved after the addition of Distributed Energy Resources. With the Standard IEEE 10 bus, there have been considerable reductions in power losses. Power losses have been severely reduced in case of the Standard IEEE 10 bus system after the injection of DERs in the system.

6. Recommendations

Further study on no-load condition that may arise due to load rejection or disturbances in the feeder can be studied in detail. Reliability Assessment of the system can further be done for the Standard IEEE 10 bus system. The study can further be carried out considering load growth patterns and load models. Feeder reconfiguration can also help in reduction of losses in addition to injecting DERs in the system. The detailed analysis on harmonics of Standard IEEE 10 bus system before and after compensation and DERs injection can be further carried out. Provision of storage of solar and wind power plant can be implemented for more reliability of the system. However, storage may not be an economical option for grid connected DERs in such remote areas with unforeseen problems in repair and maintenance as well.

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