

MAXIMUM HOSTING CAPACITY ASSESSMENT OF DISTRIBUTION SYSTEMS WITH MULTITYPE DISTRIBUTED ENERGY RESOURCES

Lokesh Karna^{1*}, Menaka Karki¹

¹ Department of Electrical Engineering, Paschimanchal Campus, IOE, TU, Pokhara, Nepal

Abstract

Renewable energy resources are frequently integrated into the power systems to support load growth, reduce transmission and distribution losses, allow cost effective grid expansion, improve voltage profile and power quality. Hence, it is also necessary to determine the maximum capacity of distributed energy resources (DERs) that can be integrated into the distribution systems. In this study, the maximum capacity of distributed generations that can be integrated into the distribution systems has been assessed by a new DERs' hosting capacity (DERHC) assessment method known as analytical optimal power flow method. The process is divided into two stages. In the first stage, the optimal location for the placement of single and multiple multitype renewable resources is found, and in the next stage, the maximum size of distributed generations is calculated, which satisfies operational constraints. This method for finding the maximum hosting capacity requires less computational time and is reliable for complex distribution networks. Moreover, battery storage devices have also been used to enhance the hosting capacity of the distribution systems. The simulations are performed using MATLAB coding and MATPOWER tool for the IEEE-33 bus radial distribution system and practical feeders of Nepal.

Keywords: Hosting capacity, Distributed generations, Battery storage device

1. Introduction

The integration of distributed generations has been increasing rapidly to reduce transmission and distribution losses, support change in local demand, improve reliability and utilize the local renewable resources efficiently. This problem is being considered when the power is transmitted over a longer distance. However, the excess integration of the renewable sources into the power system can cause several problems such as overvoltage, undervoltage, thermal overload, power quality deterioration, excessive line losses and protection failure. Hence, the concept of hosting capacity assessment arises and needs to be performed to protect the system from aforementioned issues.

DERHC can be defined as the amount of distributed generations that can be integrated into the power system without violating operational constraints. Different methods that can be used to assess hosting capacity of distribution systems. They are iterative, stochastic, streamlined and heuristic methods (Ismael et al., 2019; Taheri et al., 2021;

Abad and Ma, 2021; Ding and Mather, 2017; Alturki et al., 2018). The iterative method is a time-consuming method. The stochastic method is faster than iterative method, but the accuracy depends upon the computational resources. This method simulates uncertainties of the system and depends on probabilistic models, which may not provide global optimum solution. Similarly, the streamlined method is simple and has accuracy problems in complex systems. Heuristic methods are based on random variables without mathematical certainty and approximation errors. This method relies on single search mechanism that necessitates manual configuration of population position update parameters (Hassan et al., 2021). Analytical methods are more efficient since they can solve several optimization problems with various objective functions (Hung et al., 2010; Mahmoud and Lehtonen, 2021). The same method has been implemented to assess the hosting capacity of the distribution systems. This method has been illustrated in detail for this study. The analytical optimal power flow method uses two algorithms. In the first algorithm, the optimal location of the distributed generations is found based on the power flow analysis of the system with the integration of the DGs. In the second algorithm,

*Corresponding author: Lokesh Karna

Department of Electrical Engineering, Paschimanchal Campus, TU
Email: karnalokesh2@gmail.com
<https://doi.org/10.3126/jsce.v12i2.91418>

the maximum hosting capacity is determined based on iteration over the different sizes of the renewable energy resources, followed by the performance of power flow analysis considering the limiting factors for the operational constraints. The implemented method is primarily based on the power flow analysis of the distribution systems which is necessary as when the distributed generations are integrated, they inject powers and the voltage, current, active and reactive powers at each bus changes which can only be monitored when we perform power flow analysis using standard power flow analysis methods such as Newton-Raphson, fast decoupled methods. These methods are used because they are the standard methods to perform power flow analysis. The other methods to calculate the active and reactive power injected by the DERs are not useful when the networks become complicated. The method considers the issues that can arise after the integration of distributed generations using power flow analysis. This analyzes on the correct parameters and gives global optimum solution for calculating maximum hosting capacity of the system. The analytical optimal power flow method has been implemented on the IEEE-33 bus radial distribution system.

2. Assessment of DERHC

In this section, the hosting capacity assessment method is being discussed. The analytical method of assessing hosting capacity is the implemented method. This method is the improved form of the conventional iterative method. These two methods have been discussed. The methods have been explained based upon the flow diagrams.

2.1. OPF Iterative Method

This method has been conventionally used for the assessment of hosting capacity. In this method, the distributed generations are placed on all possible buses within the feeder. After the distributed generations are placed on all buses, the individual hosting capacity assessment is performed separately on all buses, considering the operational constraints. At each bus, the hosting capacity is determined, in which the capacity of the DG is increased in step size. The hosting capacity analysis is performed for all the capacities, starting from the minimum to maximum value. After the simulation is complete, the result will be printed for the maximum capacity that does not violate the operational constraints. The operational constraints are formulated in the form of objective functions. The load flow is carried out to check the limits of these operational constraints. When more than one DGs are used, the DGs are placed on all buses and at each bus, all possible combinations of the capacities of two DGs are formed, starting from minimum to maximum. The capacity combinations are placed on all buses of the

feeder, and power flow is performed considering operational constraints. After the simulation for all possible capacity combinations has been finished, the combination which total or sum is maximum and that stays within the limits of operational constraints will be printed as the maximum hosting capacity.

2.2. Implemented Method of DERHC Assessment

The implemented method of hosting capacity assessment is the analytical optimal power flow method. The detailed explanation of this method has been discussed in the Section III. The method is different from the conventional iterative method in the way that the optimal location of the distributed generations is found first, and then the hosting capacity analysis is performed based on the method that has been discussed in the OPF iterative method. The method is fast, saves time and is based upon the mathematical certainty. It also provides global optimum solution.

3. Analytical Optimal Power Flow Method

The method has been divided into two sections. These are the analytical stage in which the optimal location of the DG is determined, and the next stage is the optimal power flow, in which the maximum DERHC is determined. The enhancement of maximum hosting capacity has also been discussed. For enhancement purposes, the battery storage devices are used.

The types of DGs that are to be integrated into the system are categorized as Type 1 and Type 2.

Type 1 DERs: Type 1 DGs have a unity power factor and are considered as a negative load during simulation. These types of distributed generations are capable of injecting only active power into the distribution systems. The most common example for Type 1 DER is a photovoltaic array with a static power converter (Hassan et al., 2021).

Type 2 DERs: Type 2 renewable resources have zero power factor and are taken as a negative load during simulation. These renewable resources are capable of injecting only reactive power but no active power into the distribution systems. An example of Type 2 DERs is a wind turbine with a squirrel cage induction machine (Hassan et al., 2021).

Type 3 DERs: These renewable energy resources are capable of injecting both active and reactive powers into the distribution systems with an unspecified power factor. The power factor can fluctuate between some ranges. The examples for Type 3 DERs are small and micro hydro power plants, gas turbine plants, etc. (Hassan et al., 2021).

The Type 3 DERs are not taken into consideration for this study because the prime focus is on the practical feasibility on how the distributed generations are integrated into the distribution systems. The integration of Type 3 DERs is not considered. The integration of Type 3 DERs does not affect

the overall methodology because the objective function is to maximize the apparent power. So, we can use the apparent power step sizes to find the hosting capacity of the feeder at a bus that meets the voltage, current and power loss constraints. Also, the optimal locations can be found based on the DG capability to inject maximum of active and reactive power at a particular bus. The power injections by a DER can be found using Equation (1) and Equation (2). To understand the effects of injecting active and reactive powers separately, Type 1 and Type 2 DERs are taken for integration as DGs in this study, but Type 3 DERs can also be taken in further studies. For simplicity and to meet the objective, the two types of DGs are taken.

The equations for active and reactive power injections by the distributed generations are as shown (Hassan et al., 2022).

$$P = \sum |V_i||V_k|(G_{ik} \cos \theta_{ik} + B_{ik} \sin \theta_{ik}) \quad (1)$$

$$Q = \sum |V_i||V_k|(G_{ik} \sin \theta_{ik} - B_{ik} \cos \theta_{ik}) \quad (2)$$

The summation of the equation is performed for the variable k=1 to n.

The objective functions are also formed to ensure that the operational constraints are within the limits. The operational constraints are formed on the fact to maximize the apparent power of the system, and the voltage, current and power loss constraints should be within the specified limits. The voltage limits are based on the minimum and maximum values of the voltage of the feeder under normal condition. These are generally taken between 0.95 p.u. and 1.05 p.u. Similarly, the maximum limit for current is taken as 120 amps since most of the current values for the IEEE-33 and practical feeder buses are below 50 ampere value (Chen et al., 2015). Similarly, the power loss limit is taken as 5 %.

3.1. Analytical Stage

The steps for the analytical stage to find the optimal distributed generation location are as shown below.

- 1) Read the line and load data, number and type of distributed generations.
- 2) Run power flow analysis and calculate the power injected by the DGs.
- 3) Obtain the optimal location based on the maximum value of the power injected.

3.2. OPF Stage

The steps for the optimal power flow stage have been discussed in the following points.

- 1) Import optimal location from the first stage.
- 2) Create possible combinations of the DG capacities
- 3) Run power flow analysis

4) Save the combinations that are within the operational constraints

5) Select the combination that has maximum value as the maximum hosting capacity. The feeders that have been taken for the simulation purposes are the IEEE-33 bus distribution system, Feeder 1 and Feeder 2. Feeder 1 and Feeder 2 are the practical distribution feeders of Nepal. Feeder 1 has comparatively less load than Feeder 2. The feeders are shown in Figure 1, Figure 2 and Figure 3 (Kwangaew et al., 2022).

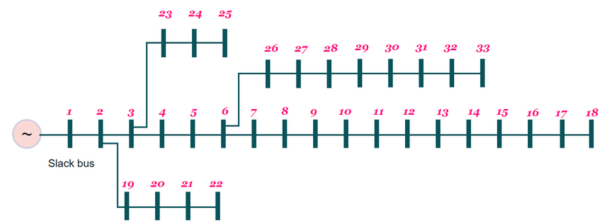


Figure 1. Single line diagram of IEEE-33 bus system

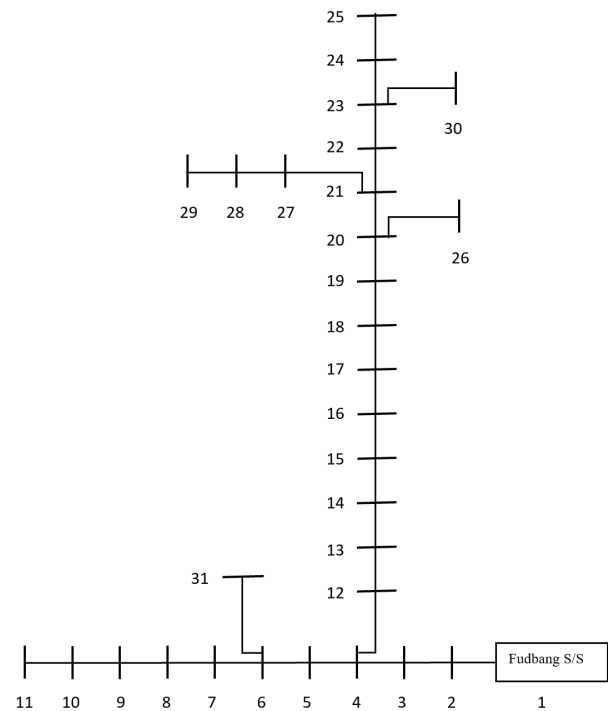


Figure 2. Single line diagram of Feeder 1

4. Enhancement of Hosting Capacity

The enhancement of the hosting capacity can be achieved by using a battery storage device. The battery storage device can be used in charging mode. When the battery is in charging mode, the battery can be modelled as a positive load during simulation. The batteries are integrated by

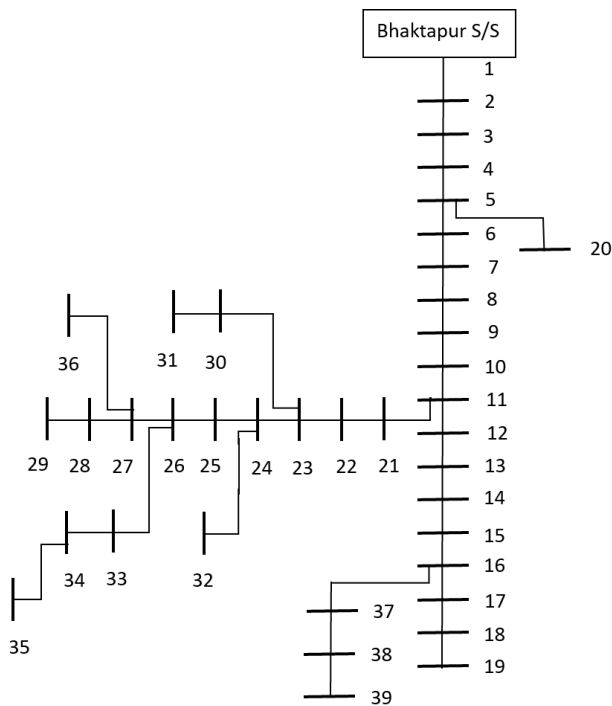


Figure 3. Single line diagram of Feeder 2

obtaining the optimal location of the battery and finding its optimal size. For determining the optimal location, the batteries are placed on those buses where the voltage is maximum or near the maximum specified limits for the voltage. The optimal battery size is the minimum battery size after which increasing the battery size will not show any significant change in the hosting capacity.

Some assumptions have been made for the battery storage device. The battery is charging at a C rate of 0.5 and the charging efficiency is 0.97.

The battery has not been simulated as a discharging device for the enhancement of hosting capacity. This is because when the battery discharges with the same amount of load in the system, the battery increases the voltage and current in the feeder. This decreases the power loss limits and limits of other operational constraints. Hence, the hosting capacity remains same and may decrease if the size of battery goes on increasing when used in discharging mode. But the hosting capacity is increased if we discharge a charged battery in the distribution system by the amount of the power rating of the battery itself, because the battery storage device is a type of distributed generation.

If we want to model the battery in dynamic charging and discharging mode, first, the format of the current methodology has to be changed. This format does not allow dynamic charging and discharging simultaneous but the study has the capability to identify that the mode of battery whether charging or discharging can increase the HC

of the feeder.

So, if we want to model the BESS in dynamic charging and discharging mode, the current format has to be changed into the time series format where we do simulations for the 24 hours of a day. This can allow dynamic operation of BESS. The code handles the dynamic charging and discharging which are formulated to enhance the hosting capacity of the feeder.

5. Results and Discussions

The results showing the hosting capacity assessment for the IEEE-33 bus radial distribution system is as shown in Figure 4. The maximum hosting capacities that have been obtained for single, two and three type 1 DERs are 3000 KVA, 4600 KVA and 5300 KVA, respectively. Similarly, the results for hosting capacity calculations for single, two and three Type 2 DERs are 3400 KVA, 3500 KVA and 3300 KVA, respectively. The reason why the hosting capacities are exceeding the total load of the system arises here. For IEEE-33 bus system modelling, the reference generation has been providing a 10 MW of active power and the reactive power is modelled between the range of -10 MVAR and +10 MVAR. The modelling suggests that the reference generator can produce and absorb reactive power. This also tells us that the system is not completely isolated, but it is connected to a grid. The reference generation allows the flow of excess power towards the upper stream through reverse power flow. This allows more hosting capacity values for both Type 1 and Type 2 DERs' active and reactive power injections. Modern world transformers are also able to regulate the voltage with the help of on-load tap changers. The excess of reactive power production by the DGs is not limited for use at the bus where they are connected, but the power can flow to other buses, improving the voltage profile of the weak buses also. The maximum time taken for the finding the hosting capacity is 156 seconds, which is very less in comparison to the conventional iterative method.

Figure 5 shows the line graph showing the maximum DERHC results for Feeder 1. The maximum hosting capacities that have been obtained for single, two and three type 1 DERs are 3000 KVA, 3100 KVA and 3300 KVA, respectively. Similarly, the results for hosting capacity calculations for single, two and three Type 2 DERs are 2600 KVA, 2700 KVA and 3300 KVA, respectively. The reason for the increased hosting capacities values is due to the system modelling in which the reference generation has been modelled to produce and absorb reactive power, similar to the IEEE-33 bus system, which is also true for practical systems, as the Feeder-1 is not an isolated system but a grid connected part. The total load on this feeder is 1.15 MVA. The maximum active and reactive power production from the reference point is 15.68 MW and ± 3.18 MVAR.

The load on the Feeder-1 is less. The limits for voltage,

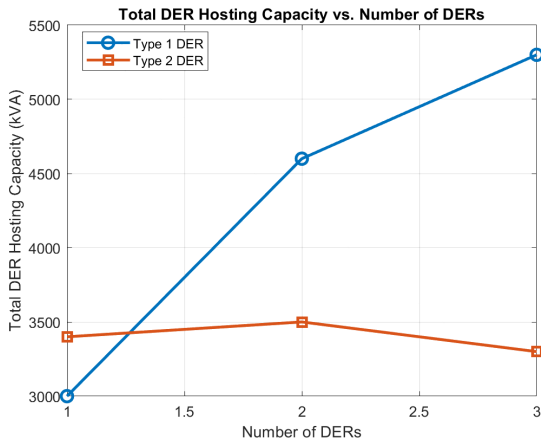


Figure 4. Maximum hosting capacity for multitype DGs

current and power loss is not being violated easily, allowing more capacities of DGs for increasing number of distributed generations. The maximum time taken for finding the hosting capacity of the feeder is 158 seconds.

Figure 6. shows the line graph for maximum DERHC results for Feeder 2. The total load on this feeder is 3.07 MVA. The reference generator can produce maximum power of 44.55 MW and ± 6.35 MVAR. This feeder has also been assessed for maximum hosting capacity, as the load on this feeder is higher, giving a different scenario for the study. The maximum hosting capacities that have been obtained for single, two and three type 1 DERs are 4500 KVA, 4600 KVA and 2300 KVA, respectively. Similarly, the results for hosting capacity calculations for single, two and three Type 2 DERs are 5000 KVA, 6500 KVA and 5400 KVA, respectively. The reason for increased hosting capacity in comparison to the Feeder-1 is due to the fact that the system is loaded heavily, and as we move further from the reference generation, the voltage profile gets weaker. This is allowing more hosting capacity when single or two DGs are used. But as the DGs are increasing, the voltage, current and power loss limits are getting violated due to the injections of more active or reactive power at different bus locations.

Figure 7. shows the line graph for the comparison of the maximum hosting capacity with and without the integration of the battery storage device for the IEEE-33 bus distribution system. After battery integration, the maximum hosting capacities obtained for single, two and three Type 1 DERs are 3100 KVA, 4700 KVA and 5500 KVA, respectively. For Type 2 DERs, the maximum DERHC are 3500 KVA, 3600 KVA and 3300 KVA for single, two and three DERs, respectively.

The reason for the increment of DERHC after the integration of battery storage system is primarily due to the fact that battery has been used at the locations where the voltage is near to the maximum limits, which is suitable

for charging. The battery has been used as a load at this position. The battery increases the overall loading of the system, causing more usage of power and decreases the voltage profile, which increases the power loss limits to a lower value, allowing a little more DG capacity at the specified buses.

In the graph, it is clear that the hosting capacity has been enhanced by using the battery. A maximum increment of 3.77 % can be obtained.

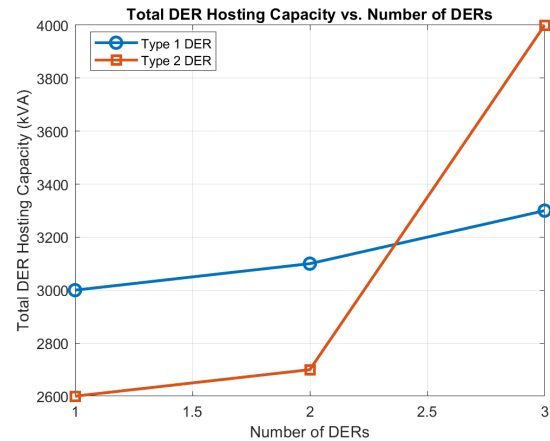


Figure 5. Maximum hosting capacity for feeder 1

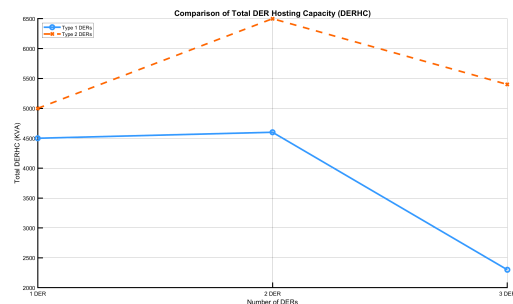


Figure 6. Maximum hosting capacity for feeder 2

Figure 8. shows the line graph for comparison of the maximum DERHC for Feeder 1 when the battery is integrated into the system. After battery integration, the maximum hosting capacities obtained for single, two and three Type 1 DERs are 3100 KVA, 3200 KVA and 4000 KVA, respectively. For Type 2 DERs, the maximum DERHCs are 3100 KVA, 3200 KVA and 7500 KVA for single, two and three DERs, respectively. A maximum of 87.5 % increment can be obtained.

Figure 9. shows the graph for comparison of the maximum DERHC for Feeder 2 with the integration of a battery. After battery integration, the maximum hosting capacities obtained for single, two and three Type 1 DERs are 4600 KVA, 4600 KVA and 4500 KVA, respectively.

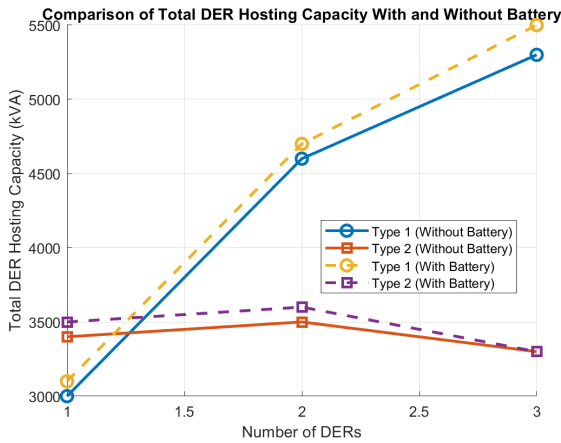


Figure 7. Comparison of DERHC for IEEE-33 bus system

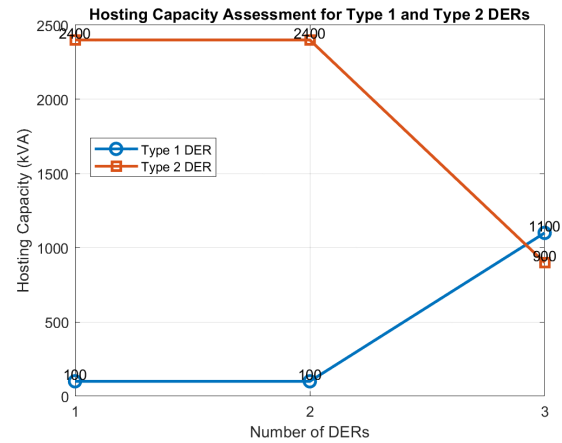


Figure 10. Hosting capacity results for three DERs for IEEE-69 bus system

For Type 2 DERs, the maximum DERHCs are 6000 KVA, 6600 KVA and 6500 KVA for single, two and three DERs, respectively. A maximum of 95 % increment can be obtained.

Figure 10. shows the graph for three DERs of Type 1 and Type 2 for the IEEE-69 bus system. For this case only, the results have been deduced as shown in the graph. The time taken for the hosting capacity assessment is very less, which is less than few minutes.

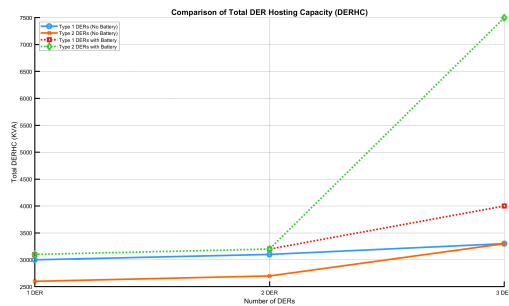


Figure 8. Comparison of DERHC for feeder 1

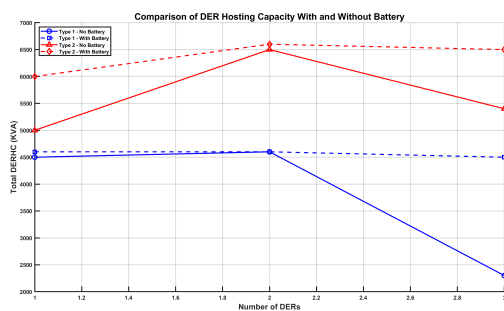


Figure 9. Comparison of DERHC for feeder 2

6. Conclusion

The analytical method is used for the assessment of hosting capacity. The algorithms for the iterative method have not been performed. But we can know that the time taken for the simulation of feeders using the iterative method is more than the analytical method by a factor of 32, if the feeder has 33 buses. This method provides mathematical certainty considering constraints to maintain system reliability. The method provides high accuracy while finding optimal locations for DG placement. The method can handle multiple DERs for integration. Different types of DERs can be integrated at simultaneously, which shows a greater scalability capacity of the implemented method. The method can be used for higher bus system easily, as it has been performed for the IEEE-69 bus system, as shown in Figure 10. The method uses optimal power flow analysis method to find the hosting capacity, which takes very less time for computation, providing more computational efficiency than other existing methods. This method is fast and easy to implement.

From this study, we can understand that the DERHC is a location-dependent process. The enhancement has also been performed using battery storage devices. A maximum of 95

The future work could be extending the study for using a battery with automation, so that what impact it generates when the battery can be removed automatically when the battery is required, either as charging and discharging device. The enhancement should also be studied using smart inverters.

Acknowledgments

I would also like to express my deepest sense of gratitude and sincere respect to M.Sc. Program Coordinator Asst.

Prof. Sandeep Dhama for his continuous advice and encouragement throughout this research work.

I would also like to express my gratitude to Head of Department Asst. Prof. Suraj Shrestha and Assoc. Prof. Bhriku Raj Bhattarai for their support and guidance.

At last, I am very much thankful to all staffs of department of electrical engineering, Paschimanchal campus, IOE, Nepal Electricity Authority, all respondents, my colleagues, my family and all those people who directly or indirectly contributed their parts in completing this research work.

References

- Abad, M. S. S., & Ma, J. (2021). Photovoltaic hosting capacity sensitivity to active distribution network management. *IEEE Transactions on Power Systems*, 36, 107117–107118. <https://doi.org/10.1109/TPWRS.2020.3007997>
- Alturki, M., Khodaei, A., Paaso, A., & Bahramirad, S. (2018). Optimization based distribution grid hosting capacity calculations. *Applied Energy*, 219, 350–360. <https://doi.org/10.1016/j.apenergy.2017.10.127>
- Chen, K., Zhang, W., Wu, B., & Sun, H. (2015). Robust restoration decision making model for distribution networks based on information gap decision theory. *IEEE Transactions on Smart Grid*, 6, 587–597. <https://doi.org/10.1109/TSG.2014.2363100>
- Ding, F., & Mather, B. (2017). On distributed PV hosting capacity estimation, sensitivity study, and improvement. *IEEE Transactions on Sustainable Energy*, 8, 1010–1020. <https://doi.org/10.1109/TSTE.2016.2640239>
- Hassan, S. J. U., Gush, T., & Kim, C.-H. (2022). Maximum hosting capacity assessment of distribution systems with multitype DERs using analytical OPF method. *IEEE Access*, 10, 100668–100669. <https://doi.org/10.1109/ACCESS.2022.3207069>
- Hassan, S. J. U., Haider, W., Mehdi, A., Gush, T., Song, J.-S., & Kim, C.-H. (2021). Optimal placement and sizing of multi-type distributed generation considering voltage profile improvement and power loss minimization. *Transactions of the Korean Institute of Electrical Engineers*, 70(4), 561–567. <https://doi.org/10.5370/KIEE.2021.70.4.561>
- Hung, D. Q., Mithulananthan, N., & Bansal, R. C. (2010). Analytical expressions for DG allocation in primary distribution networks. *IEEE Transactions on Energy Conversion*, 25, 814820–814822. <https://doi.org/10.1109/TEC.2010.2044414>
- Ismael, S. M., Aleem, S. H. E. A., Abdelaziz, A. Y., & Zobaa, A. F. (2019). State-of-the-art of hosting capacity in modern power systems with distributed generation. *Renewable Energy*, 130, 1002–1020. <https://doi.org/10.1016/j.renene.2018.07.008>
- Kwangkaew, A., Javaid, S., Charoenlarnnoppa, C., & Kaneko, M. (2022). Optimal location and sizing of renewable distributed generators for improving voltage stability and security considering reactive power compensation. *Energies*, 15, 23–24. <https://doi.org/10.3390/en15062126>
- Mahmoud, K., & Lehtonen, M. (2021). Comprehensive analytical expressions for assessing and maximizing technical benefits of photovoltaics to distribution systems. *IEEE Transactions on Smart Grid*, 12, 4938–4949. <https://doi.org/10.1109/TSG.2021.3097508>
- Taheri, S., Jalali, M., Kekatos, V., & Tong, L. (2021). Fast probabilistic hosting capacity analysis for active distribution systems. *IEEE Transactions on Smart Grid*, 12, 2000–2012. <https://doi.org/10.1109/TSG.2020.3038651>

This work is licensed under a Creative Commons “Attribution-NonCommercial-NoDerivatives 4.0 International” license.



This page is intentionally left blank.