Maximizing Hosting Capacity of Photovoltaic Sources in Radial Distribution Networks

Salah Kamel[1], Abdel-Raheem Youssef[2], Asmaa H. Ali[3] ,A. A. Ibrahim[4]

[1]Dept. of Electrical Engineering, Faculty of Engineering, Aswan University, Aswan, Egypt
[2]Dept. of Electrical Engineering Faculty of Engineering, South Valley University, Egypt
[3]Dept. of Electrical Engineering Faculty of Engineering, South Valley University, Egypt
[4]Dept. of Electrical Engineering, Faculty of Engineering, Aswan University, Aswan, Egypt

Article History: Received: 11 January 2021; Revised: 12 February 2021; Accepted: 27 March 2021; Published online: 23 May 2021

Abstract: The aim of this paper is to explore and calculate the hosting capacity in power system to determine the maximum renewable energy resources that will be spread. After the distributed generation (DG) is connected to the distribution systems, the performance indicator of the distribution system will get better or deteriorate. The point that between acceptable degradation and unacceptable degradation is the hosting capacity. This paper is exactly concerned with the influence of maximizing DG on the performance index in radial distribution networks (RDN) and else finding the maximum point of the suitable deterioration. Hosting capacity is the total amount of distribution generation that will be added to the radial distributed network without the need for other upgrades in the networks. This paper introduces a new proposed algorithm to calculate the hosting capacity and determine the quantities of DG that can be added to distributed networks before the voltage at the bus, the current through cables or the power fed back to the substation or quality or system reliability for consumers override their maximum allowed value . The two main boundaries for finding the hosting capacity are overload and overvoltage. The objective function is studied for finding the maximum hosting capacity (MHC). by inserting maximum hosting capacity of distribution generation (DG) on the 33 IEEE- standard networks taking into consideration the over voltage and thermal limit. in this study the DG is Photovoltaic (PV) for different load level

Keywords: DG, RDN, Photovoltaic (PV), power flow, Hosting Capacity, Different Load Level

1. Introduction

In the late nineteenth century have seen a surpassing growth of distribution energy resources (DER) on the whole of the world. Recently electrical power systems turn into ganglion complex, designing, management, operation, quality and control of such systems using classic attempts confront increasing problems. Most of radial distribution networks suffer from large inductive loads that cause lower voltage levels, higher currents and loss of energy, So researchers turned to solve the problems of the network by adding fixed capacitors or renewable energy to restore the network capacity to work continuously. As well as, because the power system is very large, complex and geographically more distributed. The most widely used sources of renewable energy are solar energy and wind energy because they are a clean energy that is not harmful to the surrounding environment where the total capacity energy produced by solar energy in the United States at the end of 2016 is 36 GW [1], while 25.6 GW in 2015 and 18.3 GW in 2014. Despite the growing interest of customers to implement a renewable energy techniques whether on a small scale (off grid) or on a large scale (on grid) in order to provide the network with power, it has the effects and disadvantages of multiple on radial distribution networks(RDN) .

The evolution of renewable DG's techniques were driven by social, economic , policies, technical and environmental objectives [2-7]. However, excessive DG installation can adversely affect system performance, it may lead to critical overvoltage problems, and thermal overload network equipment, increasing the risk of bypass equipment Short circuit capacity and poor protection equipment operation [8-13].

One of the early studies known for its quality and efficient radial distribution networks(RDN) is the hosting capability(HC) . Suggested hosting capacity for distribution networks is generally to the level of a breakthrough DG so the network can bear without exceeding one or more performance indicators . look at Figure 1.

The hosting capacity of the distribution system (DS) is defined with respect to performance indicators. In the condition of growing levels of PV power injected into a distribution system (DS), there are two essential specifications for technical constraints on the radial distribution network's hosting capacity [14]:

- Voltage constraints are represented by the bus voltage compared to the nominal value.
- Current constraints is represented by Permissible loading or thermal limit of cables and transformers.

The study of the hosting capacity (HC) shed light on the role, importance and damage of the DG installation to the network distribution without the occurrence any fatigue network, as it gives critical values in kilowatts(kW), preferably not exceeding. The hosting capacity is an initial planning for the planners to gain insight into how to build the network and develop it in a cheaper, more greener, stronger, more reliability and sustainable way. There has been a lot of research in increasing the hosting capacity (HC) on DER to limit the problems that are produced by DG installation , a HC optimization technique is Suggested to specify the optimal location and size of distributed generation(DG) by using on-load tap changer (OLTC) and static Var compensation (SVC). The volt/Var control trouble depended on maximizing HC is planned as a single objective optimizer trouble in [15,16]. As well as studying the effect of increasing solar energy in residential neighborhoods is being investigated and the HC is acquired in system ranging from weak voltage to moderate voltage through a stochastic analytical frameworks in [17] . In[18] linearized power flow for calculation the maximum hosting capacity(MHC) to radial distribution system . In[19]estimation of HC by considering that uncertainties associated with PV, wind turbine(WT) and loads. In[20] salp swarm optimization is used to select optimal of several types and sizes of conductors by hosting capacity . In[21]maximizing the distribution network's HC for WT and decrease the energy procurement costs in a wind inserted power system . The method of analysis of the local sensitivity for distribution feeders is presented in[22] estimating the hosting capacity(HC) to the networks by showing the effect of adding DG to the voltage deviations in the feeding contracts. There are similar studies in [23] but focusing on photovoltaic(PV) integration in distribution networks. In [24] The proposed model estimates the Impacts of harmonic deformation limits on HC according to different active network management systems, and in [25] authors search the impacts of nondispatchable DG on the harmonic deformation, and as on grid hosting capacity. Different studies have been conducted for optimal size and site of wind power or generally RES, optimal power Flow (OPF) -HC based approaches are available for wind power [26] and DG [27] in distribution system. Sun [28] estimated the hosting capacity of electrical networks and its enhancement techniques. Alamat [29] made a simple assessment for the HC problem in Jordan. In[30], presented New hosting capacity terminologies.

The goal of this paper is to create the maximum hosting capacity for DER through the calculation of the hosting capacity (HC). The desired objective will be to increase the hosting capacity of the installation DG to the radial distribution network (RDN) without adversely affecting the network performance . There are two performance measures voltage buses is selected as the first indicator of performance for the purposes of this study. The HC will be measured as the maximum limit for the amount of the DG before it exceeds the voltage of the bus 1.05 per unit , and the second indicator of performance is the current through cables HC will be measured as the maximum limit for the amount of the DG before it exceeds thermal limit .This limit is particularly important because overloading(OL) will lead to depreciation and failure to distribution system(DS) . The target of this paper is to determine the maximum size of PV units as renewable sources in RDNs with different locations for total active power loss decreasing ,Taking into account the limits of the over voltage and thermal limit of the overall distribution system (DS). We will take in this paper, one kind acts as an active power (KW) source, with unity power factor. Simulation studying carried out in 33-bus RDN.

The rest of the paper is organized as following: Section 2 gives the problem formulation, Section 3 gives the location of HC, Section 4 presents the results and discussion ,Section 5 presents the conclusion, and Section 6 presents the reference .

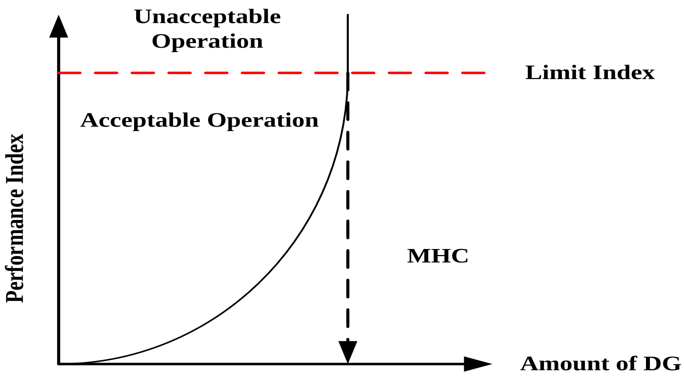


Figure 1. The definition of maximum hosting capacity

2. Problem Formulation

(1) Load Flow.

The applied load flow technique in this paper is Forward /Backward Sweep FBS [31] as it is a strong significantly applied technique in the distribution system.

(2) Hosting Capacity Calculation .

The goal of calculating maximization hosting capacity (MHC) is to increase the total quantity of DG capacity that may be installed in the distribution network with maintaining the rigidity, safety, efficiency of network operation. The equation which calculated the hosting capacity is shown in equ(1).The total installed capacity DG is the DG power installation assembly in all buses .

$$\mathrm{MHC} = \quad P_{DG}(k) = \sum_{k=1}^{N_{DG}} P_{DG}(k) \tag{1}$$

Where $P_{DG}(k)$ is the total active power injected at K-th bus, and N_{DG} is the number of DG. Single objective function(OF) is considered here, it finds the maximum hosting capacity with minimization of total active power loss. So the objective function is equivalent to the HC maximization, it is necessary to increase the active power injections from PV units without any negative impact on the distribution system . In another words, the proposed algorithm used to calculate the maximum of HC ,taking into account the thermal limit at permissible loading and the voltage value does not exceed or equal to 1.05 p.u and not less than 0.9 p.u or equal to 0.9 p.u . MHC value is equal to the lowest value either over voltage(Ov) calculation or over loading(OL) calculation .

(1) Constraints .

i. Power Balance Constraints .

The balance of active power in equ. (2) includes the generation from installed DG from PV plus the generation from substation in each bus m will be equal to the total load demand plus the total loss, where total active power loss in equ(3). Since the PV is generating active power(KW) so the equation(4) is changed to equation(5) ,it is only it can be applied to the active power , But the reactive power is fed from main grid only .

$$P_S + \sum_{k=1}^{N_{DG}} P_{DG}(k) = \sum_{i=1}^{n} P_{Loads}(i) + \sum_{j=1}^{m} P_{Loss}(j) \tag{2}$$

$$P_{T\,loss} = \sum_{j=1}^{m} P_{Loss}(j) = \sum_{j=1}^{m} I_j^2 R_j \tag{3}$$

$$Q_S + \sum_{k=1}^{N_{DG}} Q_{DG}(k) = \sum_{i=1}^{n} Q_{Loads}(i) + \sum_{j=1}^{m} Q_{Loss}(j) \tag{4}$$

$$Q_S = \sum_{i=1}^{n} Q_{Loads}(i) + \sum_{j=1}^{m} Q_{Loss}(j) \tag{5}$$

Where P_S , Q_S are the active and reactive powers are supplied to the RDS by the swing bus, $P_{DG}(k), Q_{DG}(k)$ are active and reactive output components of DG unit number, N_{DG} is the number of DG unit installation, $P_{Loads}, Q_{Loads}(i)$ are active and reactive components of the load at bus number i , $P_{Loss}(j)$ is active power loss on the feeder j of m feeders system. I_j and R_j are the currents and resistances of feeder j .

ii. Voltage Level Constraint.

The maximum value of voltage V_{max} at each buses i should be lesser than or equal 1.05 p.u but the minimum value of voltage V_{min} at each buses i should be lesser than or equal 0.9 p.u, as shown in (6)

$$V_{min} \le V_i \le V_{max} \tag{6}$$

iii. Branch Thermal Capacity Constrains .

Current limitations, represented by allowable loading of cables. To avoid overloading(OL) and over current problems, the value of a branch current must be less than or equal its thermal limit capacity I_{max} as in (7), the maximum thermal limit on feeders are available in[32], I_{max} is the maximum line current limit in ampere .

$$\text{Branch current} \le I_{max} \tag{7}$$

3. Results and Discussion

The IEEE 33-bus radial distribution system is used to display the performance of the proposed algorithm based on maximizing hosting capacity(HC) method. The system includes 32 branches, 33 buses and no presenting DG see Figure 3. The total load of the RDS is 3715 kW+ j2300 kVAr at base voltage 12.66kV. The code of the program is written using Matlab 2015 software and carried out on core i3 processor personal computer with 4-GB (RAM). The data of the IEEE 33-bus radial distribution system is shown in [38].

The hosting capacity is a site-based concept, i.e. hosting new DG may be agreed in some allocations, but not elsewhere. The voltage profile along the feeders plays an essential and an active role in determining the Location of HC[33]. In the corresponding Figure 2. shows the voltage profile for base load without compensation, so the high voltage buses are 2,19,20 buses and low voltage buses are 14,15,16,17,18.The high and low voltage buses were selected to know the extent of its hosting capacity. And also through Figure 3. The single line diagram of IEEE 33-bus network the, end buses was selected to know the extent of its hosting capacity.

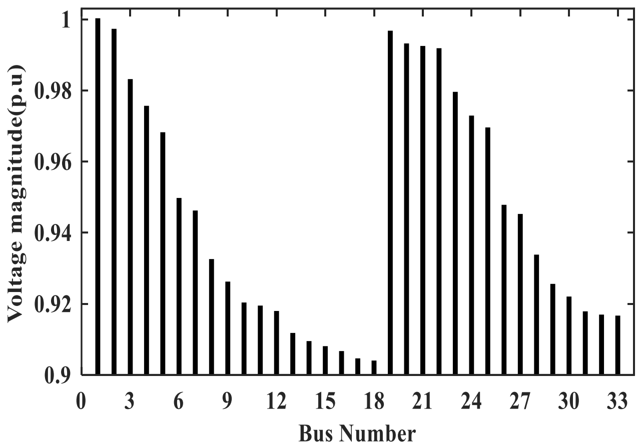


Figure 2. voltage profile for base load without compensation.

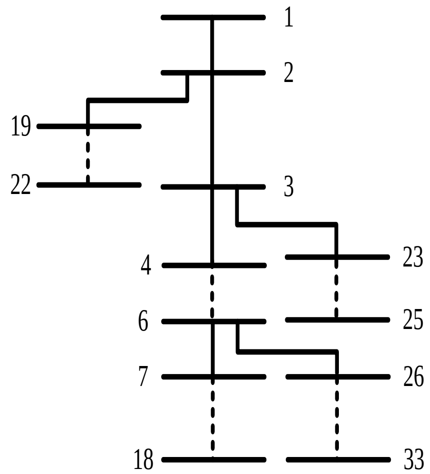


Figure 3. The single line diagram of IEEE 33-bus network

- **Loss Sensitivity Factor**

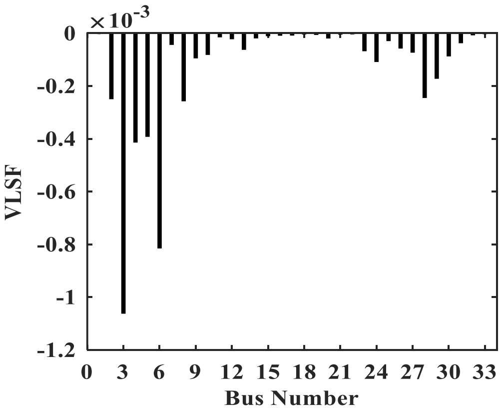
Loss Sensitivity Factor(LSF) [34,37] can be able to predict the bus that will receive the greatest loss minimization when placing a DG. LSF is used to reduce the search agents for optimization techniques , software simulation time and hosting capacity. The Loss Sensitivity Factor is selected in two known ways: One of them is (VLSF). VLSF Can be calculated by applying equ(8).And the other loss sensitivity factor is QLSF.QLSF Can be calculated by applying equ(9).

$$VLSF = \frac{\partial P_{loss}(i, i+1)}{\partial |V_i|} = R_{i,i+1} \times \frac{-2 * (P_{i,i+1}^2 + Q_{i,i+1}^2)}{|V_i|^3} \tag{8}$$

$$QLSF = \frac{\partial P_{loss}(i, i+1)}{\partial Q_{i,i+1}} = R_{i,i+1} \times \frac{2 * Q_{i,i+1}}{|V_i|^2} \tag{9}$$

- **Candidate buses of incorporated DG using sensitivity indices**

The proposed algorithm is used to find candidate buses obtained by VLSF and QLSF as given in Table 1. in Figure 4. shows VLSF profile and in Figure 5. shows QLSF profile for IEEE 33 bus test system. So the top sixteen candidate buses for insertion DG are 2,3,4,5,6,8,9,10,13,24,26,27,28,29,30 and 31. These sites have been used to calculate the extent of its maximum hosting capacity.



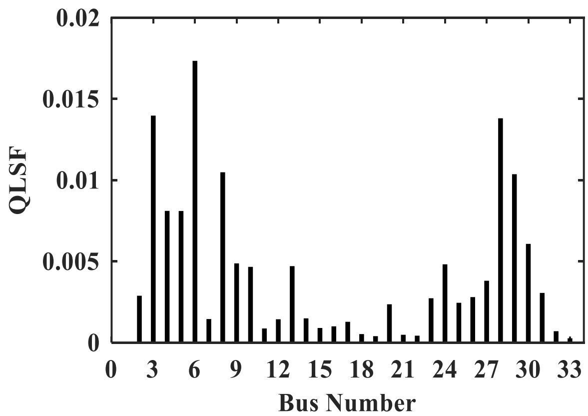


Figure 4.VLSF profile for IEEE 33bus RDN.

Figure 5.QLSF profile for IEEE 33bus RDN.

Table 1. Ranking of load buses based on VLSF and QLSF for IEEE 33 bus test system.

VLSF		QLSF	
Buses	value	Buses	value
3	-0.00106	6	0.017274
6	-0.00081	3	0.013904
4	-0.00041	28	0.01374
5	-0.00039	8	0.010418
8	-0.00025	29	0.010299
2	-0.00025	4	0.008041
28	-0.00024	5	0.008036
29	-0.00017	30	0.006011
24	-0.00011	9	0.004811
9	$-9.21*10^{-5}$	24	0.004754
30	$-8.46*10^{-5}$	13	0.004641
10	$-7.90*10^{-5}$	10	0.004597
27	$-7.05*10^{-5}$	27	0.003741
23	$-6.50*10^{-5}$	31	0.002993
13	$-5.97*10^{-5}$	2	0.002819
26	$-5.49*10^{-5}$	26	0.002735
7	$-4.11*10^{-5}$	23	0.002665
31	$-3.47*10^{-5}$	25	0.002386
25	$-2.66*10^{-5}$	20	0.002294
12	$-1.96*10^{-5}$	14	0.001427
20	$-1.68*10^{-5}$	7	0.001385
14	$-1.64*10^{-5}$	12	0.001372
11	$-1.23*10^{-5}$	17	0.001216
15	$-8.03*10^{-6}$	16	0.000936
16	$-6.34*10^{-6}$	15	0.000835
17	$-5.68*10^{-6}$	11	0.000807
32	$-4.65*10^{-6}$	32	0.000637
19	$-3.23*10^{-6}$	18	0.000459
21	$-2.03*10^{-6}$	21	0.000417
18	$-1.20*10^{-6}$	22	0.000361
22	$-8.80*10^{-7}$	19	0.000332
33	$-2.88*10^{-7}$	33	0.000201
1	0	1	0

The proposed algorithm is used to find the maximum of hosting capacity with three case studies :

(1) Case 1: Grid level hosting capacity calculation for light load (50%) .

(2) Case 2: Grid level hosting capacity calculation for base load (100%) .

(3) Case 3: Grid level hosting capacity calculation for peak load (160%) .

Three cases are studied under four Scenarios, Figure 6. summarized the scenarios and cases studied :

- Scenario 1: DG installation is allowed at buses 14,15,16,17 and 18 (low voltage buses) .
- Scenario 2: DG installation is allowed at candidate buses (16 location) .
- Scenario 3: DG installation is allowed at buses 2 , 19 and 20 (high voltage buses) .
- Scenario 4: DG installation is allowed at end buses only (buses 18, 22, 25 and 33).

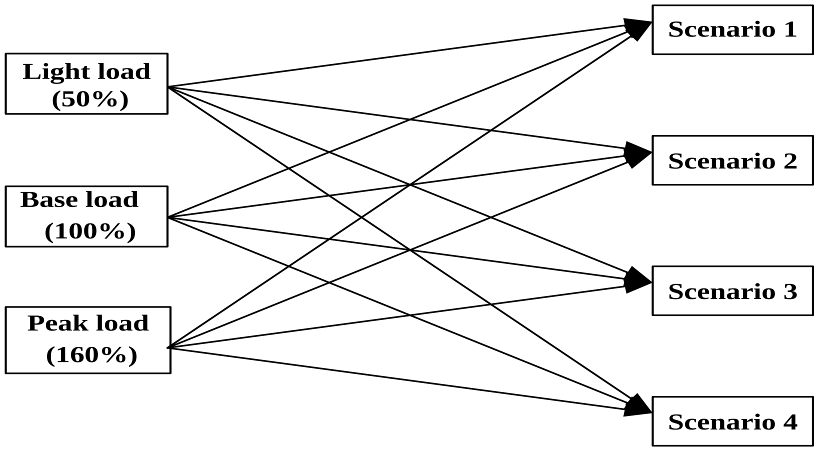


Figure 6.Summary of the studied scenarios and cases

(1) Case 1: Grid level hosting capacity calculation for light load (50%) .

In this case, the grid level hosting capacity is specified using the light load for the four considered scenarios.

- **For scenario 1**, In this scenario, the selection and calculation of the maximum hosting capacity(MHC) is limited by over voltage and not the over current, where the total maximum value of hosting capacity is calculated as 1757 kW with DG is installed in buses 14, 15,16,17 and 18 with hosting capacities of 1357 kW,100 kW ,100 kW,100 kW and 100kW respectively this buses is known as low voltage buses, in low voltage buses can't install large DG so it's low hosting capacity.
- **For scenario 2**, where DG can be installed at candidate buses, the grid level of maximum hosting capacity results in building at buses 2, 3,4,5,6,8,9,10,13,24,26,27,28,29,30 and 31 buses with hosting capacities of 3655 kW, 437 kW, 17 kW,223 kW,117 kW,1 kW,43 kW,14 kW,380 kW,979 kW,4 kW,571 kW,24 kW,70 kW,61 kW and 237 kW, respectively, for the total hosting capacity is 6833 kW.
- **In scenario 3**, the grid hosting capacity is when DG are built at buses 2, 19, and 20 with hosting capacities of 6098 kW, 44 kW, and 711 kW, respectively, so the maximum of hosting capacity is 6853 kW.
- **In scenario 4**, where DG can be installed at end buses, the grid level of maximum hosting capacity results in building at buses 18, 22, 25 and 33 with hosting capacities of 726 kW, 2203 kW, 2704 kW, and 1363 kW, respectively, for the total hosting capacity is 6996 kW.

While in the scenario 2, the scenario 3,and the scenario 4 on case 1 the selection and calculation of the maximum hosting capacity(MHC) were selected and calculated according to the over current . But in the scenario 1,MHC is calculated according to the over voltage because it is the safest. The results of four scenarios are shown in Table 2 . In Figure 7. shows the voltage profiles of maximum hosting capacity in four scenarios, and in Figure 8. represents the actual currents of maximum hosting capacity in four scenarios with thermal limit.

(2) Case 2: Grid level hosting capacity calculation for base load (100%).

In this case, the grid level hosting capacity is specified using the base load for the four scenarios.

- **For scenario 1**, MHC is calculated according to the over voltage(OV) and not over current(OC) the total maximum value of hosting capacity is calculated as 2659 kW with DG is installed in buses 14, 15,16,17 and 18 with hosting capacities of 2207kW,142kW,108kW,102kW and 100kW these buses is known as low voltage buses.
- **For scenario 2**, where DG can be installed at candidate buses, the grid level of maximum hosting capacity results in building at buses 2, 3,4,5,6,8,9,10,13,24,26,27,28,29,30 and 31 buses with hosting capacities of 3383 kW, 100 kW, 886kW,164kW,100kW,100kW,278kW,107kW,750kW,629kW,521kW,118kW,100kW,238kw,100kW, and 726kW kW, respectively, for the total hosting capacity is 8300 kW.
- **In scenario 3**, the grid hosting capacity is when DG are built at buses 2, 19, and 20 with hosting capacities of 7790 kW, 70 kW, and 510 kW, respectively, so the maximum of hosting capacity of 8370 kW.
- **In scenario 4**, where DG can be installed at end buses, the grid level of maximum hosting capacity results in building at buses 18, 22, 25 and 33 with hosting capacities of 1281 kW, 1769 kW, 3004 kW, and 2375 kW, respectively, for the total hosting capacity is 8429 kW.

While in the scenario 2, the scenario 3,and the scenario 4 on case 2 the selection and calculation of the maximum hosting capacity(MHC) is calculated according to the over current .But in the scenario 1,MHC is calculated according to the over voltage because it is the safest. The results of four scenarios are shown in Table 3 .In Figure 9. shows the voltage profiles of maximum hosting capacity in four scenarios, and in Figure 10. represents the actual currents of maximum hosting capacity in four scenarios with thermal limit.

(3) Case 3: Grid level hosting capacity calculation for peak load (160%) .

In this case, the grid level hosting capacity is specified using the peak load for the four scenarios.

- **For scenario 1**, the selection and calculation of the (MHC) was based on the over current and not the over voltage the total maximum value of hosting capacity is calculated as 3234 kW with DG is installed in buses 14, 15,16,17 and 18 with hosting capacities of 2482kW,100kW,100kW,100kW and 452kW these buses is known as low voltage buses.
- **For scenario 2**, the MHC is calculated based on the over current, where DG can be installed at candidate buses, the grid level of maximum hosting capacity results in building at buses 2, 3,4,5,6,8,9,10,13,24,26,27,28,29,30 and 31 buses with hosting capacities of 4537 kW, 300 kW, 113 kW,151 kW,457 kW,665 kW,113 kW,128 kW,738 kW,907 kW,262 kW,103 kW,232 kW,449 kW,115 kW, and 200 kW, respectively, for the total hosting capacity is 9470 kW.
- **In scenario 3**, DG installation is allowed at buses 2 , 19 and 20 (high voltage buses) we can't apply this Scenario on peak load; because of putting the DG in high voltage locations will negatively effects on the radial distribution network(RDN) where the branch currents on feeders are increasing negatively.
- **In scenario 4**, the MHC is selected based on the over current where DG can be installed at end buses, the grid level of maximum hosting capacity results in building at buses 18, 22, 25 and 33 with hosting capacities of 1113 kW, 2735 kW, 3239 kW, and 2192 kW, respectively, for the total maximum hosting capacity is 9279 kW.

The results of four scenarios are shown in Table 4. In Figure 11. . shows the voltage profiles of maximum hosting capacity in four scenarios, and in Figure 12. represents the actual currents of maximum hosting capacity in four scenarios with thermal limit.

Figure 13. presents the Combined results of the maximum hosting capacity(MHC) with various load level whether light load(50%)or base load(100%) or peak load in scenario 1. Recalling that MHC depends on the performance indicators of interest, such as the overvoltage limit as the performance indicator and thermal limit or over current on branch current as the other performance indicator . In other words, for excessive DG penetration into distribution networks, respective bus voltage values of bus voltage increase with maximum sensitivity the bus voltage value does not exceed 1.05p.u, respective current limit values of feeders increase with maximum sensitivity the branch current value does not exceed thermal limit, thus, MHC at each load level is selected as a representation of the worst case result. When applying scenario 1 on different load level we find that the MHC without any problems in the quality of the network is 1757 kW This value represents approximately 47% of the base network loads. Figure 14. presents the Combined results of MHC with different cases whether case 1 (50%)or case 2 (100%) or case 3 (160%) in scenario 2. Recalling that MHC depends on the performance indicators of interest, such as the overvoltage limit as the performance indicator and thermal limit or over current on branch current as the other performance indicator . In other words, for excessive DG penetration into distribution networks, respective bus voltage values of bus voltage increase with maximum sensitivity the bus voltage value does not exceed 1.05p.u, respective current limit values of feeders increase with maximum sensitivity the branch current value does not exceed thermal limit, thus, MHC at each load level is selected as a representation of the worst case result. When applying scenario 2 on different load level we find that the MHC without any problems in the quality of the network is 6833 kW This value represents approximately 183% of the base network loads. Figure 15. presents the Combined results of MHC with various load level whether light load(50%)or base load(100%) in scenario 3. Recalling that MHC depends on the performance indicators of interest, such as the overvoltage limit as the performance indicator and thermal limit or over current on branch current as the other performance indicator . In other words, for excessive DG penetration into distribution networks, respective bus voltage values of bus voltage increase with maximum sensitivity the bus voltage value does not exceed 1.05p.u, respective current limit values of feeders increase with maximum sensitivity the branch current value does not exceed thermal limit, thus, MHC at each load level is selected as a representation of the worst case result. When applying scenario 3 on different load level we find that the MHC without any problems in the quality of the network is 6853kW This value represents approximately 184% of the base network loads. Figure 16. presents the Combined results of MHC with various load level whether light load(50%)or base load(100%) or peak load(160%) in scenario 4. Recalling that MHC depends on the performance indicators of interest, such as the overvoltage limit as the performance indicator and thermal limit or over current on branch current as the other performance indicator . In other words, for excessive DG penetration into distribution networks, respective bus voltage values of bus voltage increase with maximum sensitivity the bus voltage value does not exceed 1.05p.u, respective current limit values of feeders increase with maximum sensitivity the branch current value does not exceed thermal limit, thus, MHC at each load level is selected as a representation of the worst case result. When applying scenario 4on different load level we find that the MHC without any problems in the quality of the network is 6833 kW This value represents approximately 188% of the base network loads.

It should be illustrated that the MHC constraints for the RDS is selected as the lowest values of the MHC results that are obtained by calculations using the two performance indicators to ensure safety and reliability operation of the system [39-43] .

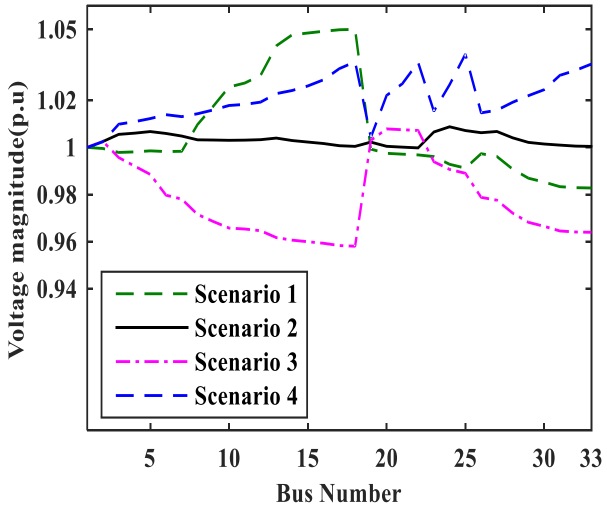


Figure 7. Voltage profile for MHC on case 1

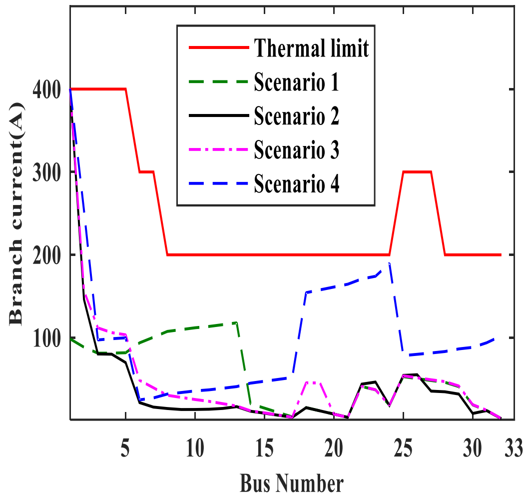


Figure 8. Actual currents for MHC with thermal limit on case 1

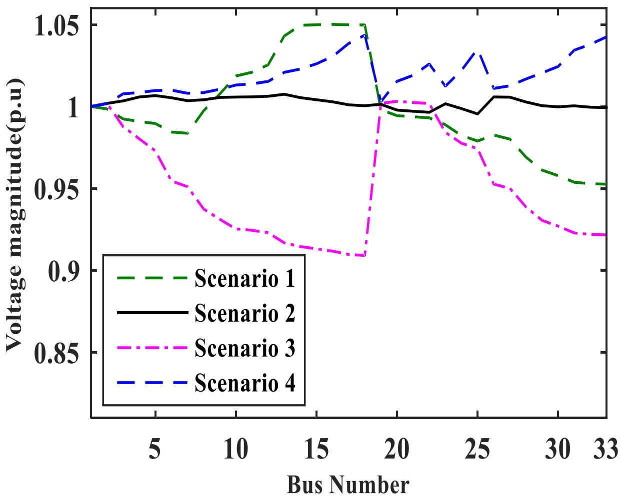


Figure 9. Voltage profiles for MHC on case 2

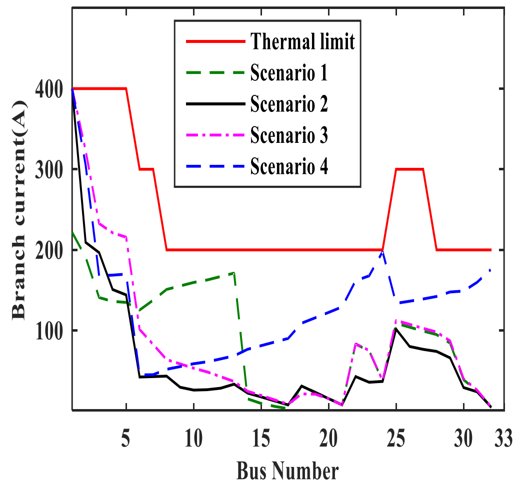
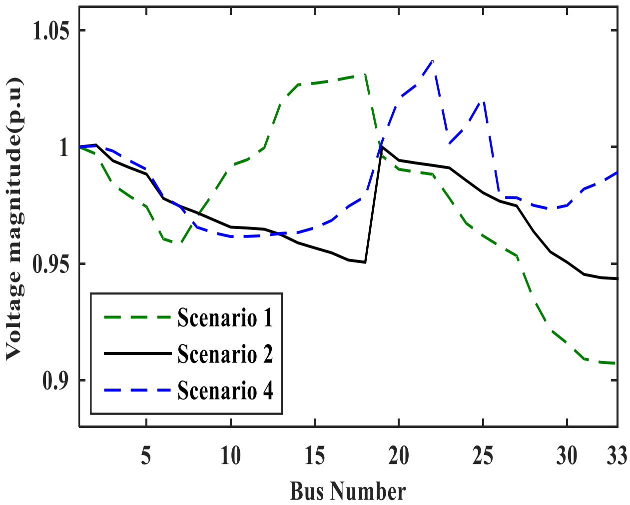


Figure 10. Actual currents for MHC with thermal limit on case 2



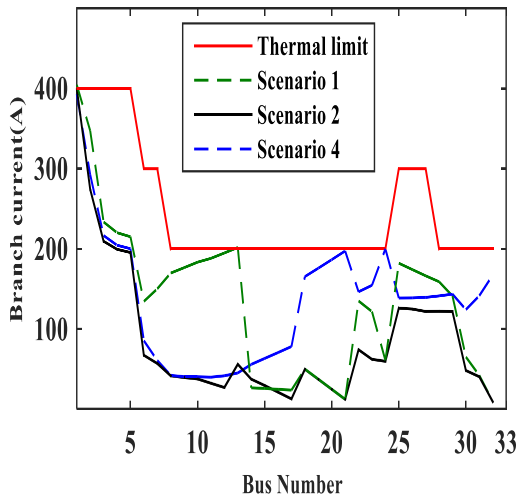
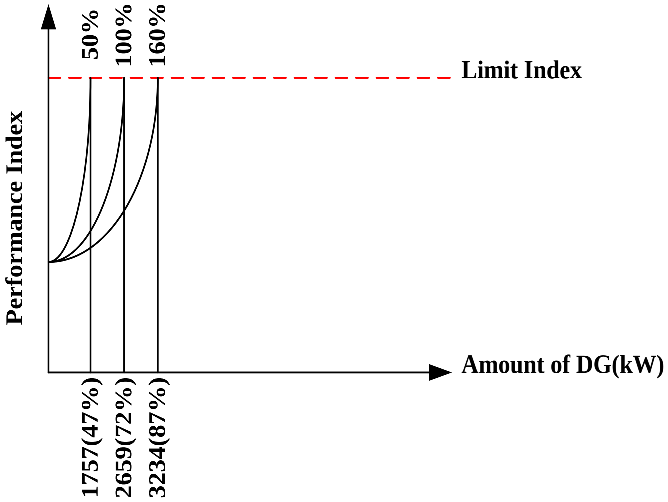


Figure 11. Voltage profiles for MHC on case 3

Figure 12. Actual currents for MHC with thermal limit on case 3



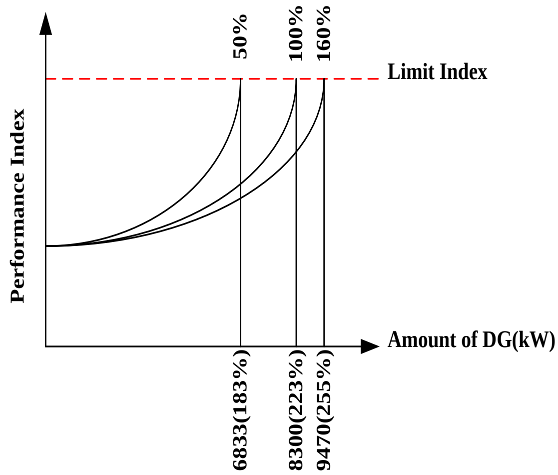
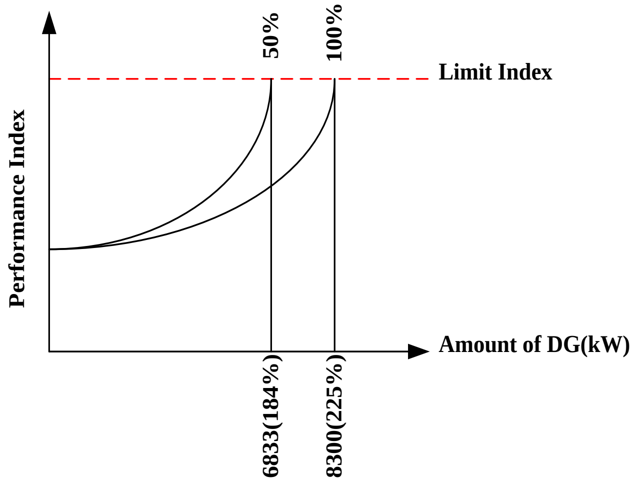


Figure 13. MHC assessment under varying load level(50% -100% -160%) in scenario 1

Figure 14. MHC assessment under varying load level(50% -100% -160%) in scenario 2



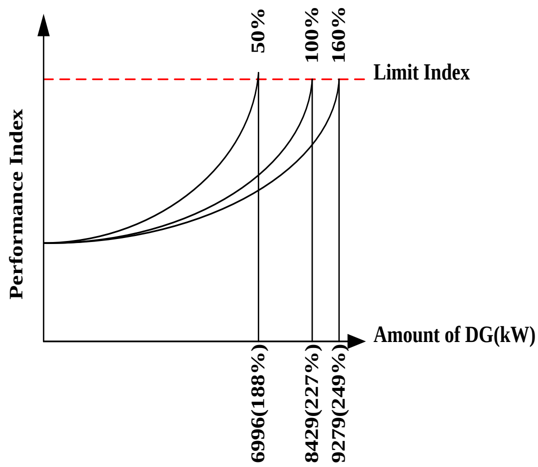


Figure 15. MHC assessment under varying load level(50% -100%) in scenario 3

Figure 16. MHC assessment under varying load level(50% -100% -160%) in scenario 4

Table 2. Case 1: light load hosting capacity results(kW).

Scenario	locations	DG size (kW)		Maximum Hosting Capacity (MHC) (kW)
		Over load	Over voltage	
Scenario 1 Low voltage buses	14	1228	1357	1357
	15	165	100	100
	16	100	100	100
	17	101	100	100
	18	1417	100	100
	Total DG(kW)	3011	1757	1757
	Total active losses(kW)	331.4543	102.9356	102.9356
	Maximum voltage(p.u)	1.1258	1.05	1.05

Scenario 2 candidate buses	2	3655	2371	3655
	3	437	9992	437
	4	17	1737	17
	5	223	223	223
	6	117	117	117
	8	1	1	1
	9	43	105	43
	10	14	1	14
	13	380	380	380
	24	979	979	979
	26	4	43	4
	27	571	571	571
	28	24	24	24
	29	70	3	70
	30	61	146	61
	31	237	237	237
	Total DG(kW)	6833	16930	6833
	Total active losses(kW)	43.6247	623.8898	43.6247
	Maximum voltage(p.u)	1.00874	1.05	1.00874
Scenario 3 high voltages	2	6098	1695	6098
	19	44	227	44
	20	711	5079	711
	Total DG(kW)	6853	7001	6853
	Total active losses(kW)	63.5125	292.5069	63.5125
	Maximum voltage(p.u)	1.00784	1.05	1.00784
Scenario 4 end buses	18	726	726	726
	22	2203	3069	2203
	25	2704	3335	2704
	33	1363	1363	1363
	Total DG(kW)	6996	8493	6996
	Total active losses(kW)	254.4737	383.5234	254.4737
	Maximum voltage(p.u)	1.03953	1.05	1.03953

Table 3. Case 2: base load hosting capacity results(kW).

Scenario	locations	DG size (kW)		Maximum Hosting Capacity(MHC) (kW)
		Over load	Over voltage	
Scenario 1 Low voltage buses	14	1381	2207	2207
	15	100	142	142
	16	100	108	108
	17	100	102	102
	18	1435	100	100
	Total DG(kW)	3116	2659	2659
	Total active losses(kW)	350.6098	246.8228	246.8228
	Maximum voltage(p.u)	1.09168	1.05	1.05
	2	3383	1413	3383
	3	100	9953	100

Scenario 2 candidate buses	4	886	1886	886
	5	164	164	164
	6	100	100	100
	8	100	100	100
	9	278	278	278
	10	107	107	107
	13	750	750	750
	24	629	1629	629
	26	521	521	521
	27	118	118	118
	28	100	100	100
	29	238	238	238
	30	100	169	100
	31	726	726	726
	Total DG(kW)	8300	18252	8300
	Total active losses(kW)	107.2226	724.3185	107.2226
	Maximum voltage(p.u)	1.00747	1.05	1.00747
Scenario 3 high voltages	2	7790	3380	7790
	19	70	100	70
	20	510	5450	510
	Total DG(kW)	8370	8930	8370
	Total active losses(kW)	211.0398	465.6043	211.0398
	Maximum voltage(p.u)	1.00314	1.05	1.00314
Scenario 4 end buses	18	1281	1281	1281
	22	1769	1769	1769
	25	3004	3950	3004
	33	2375	2375	2375
	Total DG(kW)	8429	9375	8429
	Total active losses(kW)	359.1548	447.2533	359.1548
	Maximum voltage(p.u)	1.04354	1.05	1.04354

Table 4. Case 3: peak load hosting capacity results(kW).

Scenario	locations	DG size (kW)		Maximum Hosting Capacity (MHC) (kW)
		Over load	Over voltage	
Scenario 1 Low voltage buses	14	2482	3285	2482
	15	100	142	100
	16	100	112	100
	17	100	104	100
	18	452	128	452
	Total DG(kW)	3234	3771	3234
	Total active losses(kW)	463.0055	544.8962	463.0055
	Maximum voltage(p.u)	1.03085	1.05	1.03085
	2	4537	187	4537
	3	300	7913	300
	4	113	614	113
	5	151	151	151

Scenario 2 candidate buses	6	457	457	457
	8	665	1665	665
	9	113	100	113
	10	128	213	128
	13	738	838	738
	24	907	2581	907
	26	262	262	262
	27	103	123	103
	28	232	232	232
	29	449	449	449
	30	115	1415	115
	31	200	200	200
	Total DG(kW)	9470	17400	9470
	Total active losses(kW)	188.0062	735.3050	188.0062
	Maximum voltage(p.u)	1.00081	1.05	1.00081
Scenario 4 end buses	18	1113	1113	1113
	22	2735	2735	2735
	25	3239	5050	3239
	33	2192	2192	2192
	Total DG(kW)	9279	11090	9279
	Total active losses(kW)	401.7171	564.3165	401.71771
	Maximum voltage(p.u)	1.03692	1.05	1.03692

Conclusion

Distribution generation system plays a necessary role in distribution power system because of their environmental, technical, social, and economic advantages. However, if not exactly installed, excessive DG penetration level(over loading) will cause several operational risks in the distribution system. In this paper, the MHC is investigated by using a proposed algorithm with applied load flow technique is Forwared /Backward Sweep FBS on the 33 IEEE- standard networks .The maximum hosting capacity of the DG units (PV) calculated by regarding bus voltage (over voltage)and the current carrying capacity of the feeders(thermal limit). In this paper, proposed algorithm is used to calculate the MHC for different locations with different load level at light load 50% ,base load 100% and peak load160% . In order to calculate the maximum hosting capacity, a study was carried out by selecting different locations and through them it became clear that: First , case 1 (light load) at low voltage locations (14,15,16,17and18 buses) the total MHC is 1757 kW, while at candidate buses(16 location) the total MHC is 6833 kW, but at high voltages(2,19and 20 buses) the total MHC is 6853 kW, and at end buses(18,22,25and 33 buses) the total MHC is 6996 kW . so at end buses have high hosting capacity. Second , case 2 (base load) at low voltage locations (14,15,16,17and18 buses) the total MHC is 2659 kW, while at candidate buses(16 location) the total MHC is 8300 kW, but at high voltages(2,19and 20 buses) the total MHC is 8370 kW, and at end buses(18,22,25and 33 buses) the total MHC is 8429 kW . so at end buses have high hosting capacity on case 1and case 2. Third , case 3 (peak load) at low voltage location(14,15,16,17and18 buses) the total MHC is 3234 kW, while at candidate buses(16 location) the total MHC is 9470 kW, but at high voltages(2,19and 20 buses) It's a mistake to add DG in these locations Because that did not work well on the electrical grid, and at end buses(18,22,25and 33 buses) the total MHC is 9274 kW . So at end buses have high hosting capacity for light and base load but candidate buses have high hosting capacity for peak load . Low voltage locations have low hosting capacity for different load level .

References

1. Beiter P, Tian T. 2015 renewable energy data book. Golden, CO (United States): NREL (National Renewable Energy Laboratory (NREL); 2016.
2. P.N. Vovos, A.E. Kiprakis, A.R. Wallace, G.P. Harrison, Centralized and distributed voltage control: impact on distributed generation penetration, IEEE Trans. Power Syst. 22 (2007) 476e483, https://doi.org/10.1109/ TPWRS.2006.888982.

3. J.A.P. Lopes, N. Hatziargyriou, J. Mutale, P. Djapic, N. Jenkins, Integrating distributed generation into electric power systems: a review of drivers, challenges and opportunities, Elec. Power Syst. Res. 77 (2007) 1189e1203, https://doi.org/10.1016/j.epsr.2006.08.016.
4. S. Stanfield, et al., Optimizing the Grid a Regulator's Guide to Hosting Capacity Analyses for Distributed Energy Resources, IREC, USA, 2017. https:// irecusa.org/publications. (Accessed 6 March 2018).
5. H. Pezeshki, P.J. Wolfs, G. Ledwich, Impact of high PV penetration on distribution transformer insulation life, IEEE Trans. Power Deliv. 29 (2014) 1212e1220, https://doi.org/10.1109/TPWRD.2013.2287002.
6. D. Chattopadhyay, T. Alpcan, Capacity and energy-only markets under high renewable penetration, IEEE Trans. Power Syst. 31 (2016) 1692e1702, https://doi.org/10.1109/TPWRS.2015.2461675.
7. N. Hatziargyriou, E. Karfopoulos, A. Tsitsimelis, D. Koukoula, M. Rossi, V. Giacomo, On the DER hosting capacity of distribution feeders, in: 23rd Int. Conf. Electr. Distrib, CIRED, Lyon, Paris, 2015.
8. M. Ebad, W.M. Grady, An approach for assessing high-penetration PV impact on distribution feeders, Elec. Power Syst. Res. 133 (2016) 347e354, https:// doi.org/10.1016/j.epsr.2015.12.026.
9. T. Adefarati, R.C. Bansal, Integration of renewable distributed generators into the distribution system: a review, IET Renew. Power Gener. 10 (2016) 873e884, https://doi.org/10.1049/iet-rpg.2015.0378.
10. M. Karimi, H. Mokhlis, K. Naidu, S. Uddin, A.H.A. Bakar, Photovoltaic penetration issues and impacts in distribution network - a review, Renew. Sustain. Energy Rev. 53 (2016) 594e605, https://doi.org/10.1016/ j.rser.2015.08.042.
11. V. Silva, M. Lopez-Botet-Zulueta, Y. Wang, Impact of high penetration of variable renewable generation on frequency dynamics in the continental Europe interconnected system, IET Renew. Power Gener. 10 (2016) 10e16, https://doi.org/10.1049/iet-rpg.2015.0141.
12. P. Mohammadi, S. Mehraeen, Challenges of PV integration in low-voltage secondary networks, IEEE Trans. Power Deliv. 32 (2017) 525e535, https:// doi.org/10.1109/TPWRD.2016.2556692.
13. C.T. Gaunt, E. Namanya, R. Herman, Voltage modelling of LV feeders with dispersed generation: limits of penetration of randomly connected photovoltaic generation, Elec. Power Syst. Res. 143 (2017) 1e6, https://doi.org/ 10.1016/j.epsr.2016.08.042.
14. T. Stetz, "Autonomous Voltage Control Strategies in Distribution Grids with Photovoltaic Systems - Technical and Economic Assessment," 2013.
15. Hung DQ, Mithulananthan N, Bansal RC. Analytical strategies for renewable distributedgeneration integration considering energy loss minimization. Appl Energy 2013;105:75–85.
16. Seuss J, Reno MJ, Broderick RJ, Grijalva S. Improving distribution network PV hosting capacity via smart inverter reactive power support. 2015 IEEE power & energy society general meeting. 2015. p. 1–5.
17. Dubey A, Santoso S, Maitra A. Understanding photovoltaic hosting capacity of distribution circuits. 2015 IEEE power & energy society general meeting. 2015. p. 1–5.
18. Alturki, M., Khodaei, A., Paaso, A., & Bahramirad, S. (2018). Optimization-based distribution grid hosting capacity calculations. Applied Energy, 219, 350-360.
19. Al-Saadi, Hassan, Rastko Zivanovic, and Said F. Al-Sarawi. "Probabilistic hosting capacity for active distribution networks." IEEE Transactions on Industrial Informatics 13.5 (2017): 2519-2532.
20. Ismael, Sherif M., et al. "Practical considerations for optimal conductor reinforcement andhosting capacity enhancement in radial distribution systems." IEEE Access 6 (2018): 27268-27277.
21. Rabiee, Abbas, and Seyed Masoud Mohseni-Bonab. "Maximizing hosting capacity of renewable energy sources in distribution networks: A multi-objective and scenario-based approach." Energy 120 (2017): 417-430.
22. Zillman M, Apostolopoulou D, Paaso EA, Avendano-Mora M. Locational impact of distributed generation on feeders. In: 2016 grid of the future symposium
23. Rylander M, Smith J, Sunderman W. Streamlined method for determining distribution system hosting capacity; 2015. p. 3–9.

24. Sun W, Harrison GP, Djokic SZ. Incorporating harmonic limits into assessment of the hostingcapacity of active networks. Integration of renewables into the distribution grid, CIRED 2012 workshop. 2012. p. 1–4.
25. Santos IN, Ćuk V, Almeida PM, Bollen MHJ, Ribeiro PF. Considerations on hosting capacity for harmonic distortions on transmission and distribution systems. Electr Power Syst Res 2015;119:199–206.
26. Harrison GP, Piccolo A, Siano P, Wallace AR. Hybrid GA and OPF evaluation of network capacity for distributed generation connections. Electr Power Syst Res 2008;78(3):392e8.
27. Harrison G, Wallace A. Optimal power flow evaluation of distribution network capacity for the connection of distributed generation. Gener Transm Distrib IEE Proc IET 2005:115e22.
28. W. Sun, Maximizing Renewable Hosting Capacity in Electricity Networks, The Universityof Edinburgh, Edinburgh, Scotland, 2015. Ph.D. thesis.
29. F. AlAlamat, Increasing the Hosting Capacity of Radial Distribution Grids in Jordan, Uppsala University, Uppsala, Sweden, 2015. B.Sc. thesis.
30. N. Etherden, M.H.J. Bollen, S. Ackeby, O. Lennerhag, The transparant hostingcapacity approach e overview, applications and developments, in: 23 Rd Int. Conf. Electr. Distrib., 2015, pp. 1e5.
31. J. A. Michline Ruba and S. Ganesh "Power Flow Analysis for Radial Distribution Systems using Backward/Forward Sweep Method" Vol 8, No.10, PP 1621 – 1625, 2014.
32. Aman, M. M., Jasmon, G. B., Bakar, A. H. A., and Mokhlis, H., "A new approach for optimum simultaneous multi-DG distributed generation units placement and sizing based on maximization of system loadability using HPSO (hybrid particle swarm optimization) algorithm," Energy, Vol. 66, pp. 202–215, 2014.
33. B. Palmintier, R. Broderick, B. Mather, M. Coddington, K. Baker, F. Ding, M. Reno, M. Lave, A. Bharatkumar, On the Path to SunShot: Emerging Issues and Challenges in Integrating Solar with the Distribution System, 2016. NREL/TP-5D00-6533, SAND2016-2524 R, NREL/TP-5D00-65331; SAND2016- 2524R.
34. Abdel-mawgoud, Hussein, et al. "Optimal allocation of renewable dg sources in distribution networks considering load growth." 2017 Nineteenth International Middle East Power Systems Conference (MEPCON). IEEE, 2017.
35. Abdel-Raheem Youssef, et al. "Optimal Capacitor Allocation in Radial Distribution Networks Using a Combined Optimization Approach." Electric Power Components and Systems (2018): 1-19.
36. Shahzad, Mohsin, et al. "Load concentration factor based analytical method for optimal placement of multiple distribution generators for loss minimization and voltage profile improvement." energies 9.4 (2016): 287.
37. El-Fergany, Attia A. "Optimal capacitor allocations using evolutionary algorithms." IET Generation, Transmission & Distribution 7.6 (2013): 593-601.
38. Venkatesh B, Ranjan R, Gooi HB. Optimal reconfiguration of radial distribution systems to maximize loadability. IEEE Trans Power Syst 2004;19(1):260–6.
39. M. H. Bollen and F. Hassan, Integration of Distributed Generation in the Power System. Hoboken, NJ, USA: Wiley, 2011, doi: 10.1002/9781118029039.
40. N. Etherden, M. Bollen, S. Ackeby, and O. Lennerhag, ''The transparent hosting-capacity approach—Overview, applications and developments,'' in Proc. 23rd Int. Conf. Exhib. Electr. Distrib., Lyon, France. 2015, pp. 1–5.
41. S. Sakar, M. E. Balci, S. H. E. A. Aleem, and A. F. Zobaa, ''Increasing PV hosting capacity in distorted distribution systems using passive harmonic filtering,'' Electr. Power Syst. Res., vol. 148, pp. 74–86, Jul. 2017, doi: 10.1016/j.epsr.2017.03.020.
42. S. Sakar, M. E. Balci, S. H. E. A. Aleem, and A. F. Zobaa, ''Increasing PV hosting capacity in distorted distribution systems using passive harmonic filtering,'' Electr. Power Syst. Res., vol. 148, pp. 74–86, Jul. 2017, doi: 10.1016/j.epsr.2017.03.020.
43. G. S. Elbasuony, S. H. E. A. Aleem, A. M. Ibrahim, and A. M. Sharaf, ''A unified index for power quality evaluation in distributed generation systems,'' Energy, vol. 149, pp. 607–622, Apr. 2018.