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Confidence Interval-A statistical Approach for DER Integration in Distribution System to Enhance Energy Harvesting

Prem Prakash [a*],Rakesh Chandra Jha [b]

[a*] Assistant Professor Department of Electrical and Electronics Engineering Birla Institute of Technology Mesra, Ranchi Jharkhand-835215
[b] Director, Birla Institute of Technology Deoghar Off Campus Jharkhand-815142

Abstract

Recent advents in electrical power supply and distribution networks have paved the way for Dis-tributed Energy Resources (DERs). DERs play a vital role in system stability, reliability, and power quality. Integration of DERs enhances the well-being of the distribution system, providing service during peak load and as backup power during grid failure, ensuring a reliable power supply to consumers. It also releases pressure on the generating stations and power transmission lines. However, on the integration of DERs in the system, Locational Hosting Capacity (LHC) and distribution system reliability have been the primary concern for quality in the electrical power system, depending on DER location. The distribution system reliability and LHC with the DER in the distribution system have been analyzed in the present work. Reliability is enhanced after integrating DERs in the distribution system. Roy Billinton test system was used to verify the improvement in reliability. The hosting capacity depends on the site of integration in the feeders. The location of DER with the highest hosting capacity and most improved reliability indices location differs in some feeders. Confidence interval (CI), a statistical method, is proposed to select the location for DER integration considering both maximum Hosting Capacity (HC) and the most improved reliability indices. On selecting the location of DER integration by CI method, the deviation in reliability index or hosting capacity is less than 3% from their maximum values. The efficacy of this work validates the positive impacts of DERs on distribution system reliability for the secure and efficient operation of electrical power distribution system with optimal location of DER with higher hosting capacity and reli-ability of the system. The proper place of DERs based on confidence interval leads to the maximum harvesting of the DERs with reliability.

Keywords: Confidence Interval; Distribution System; Distributed Energy Resources; Energy Harvesting; Locational Hosting Capacity; Reliability; Smart-Grid; Locations of Distributed Generations; Well-being

1. Introduction

Traditional electrical networks are undergoing a transition to smart grid. The essential component of the Smart grid is Distributed Energy Resources (DERs). DERs play a crucial role in minimizing emission, implementing demand-side management (DSM), and energy problems encountered on the supply-side & load side [1-2]. DERs are a facility of low capacity to generate power less than 100 MW and connected at any point in the distribution network at distribution level voltage [3-4]. The distribution system is the electrical power system subjected to comparatively lower voltage and delivers power to loads through a distribution network. The performance and operation of a distribution system depend on its design and network configuration. Radial distribution systems are economical and straightforward, yet these are most vulnerable to outages compared to meshed distribution systems. Failure of any component in the radial system results in power interruption to all loads downstream from the point of component failure. Despite the facts, the distribution system has localized effects; statistics show that distribution system failures affect the system as much as 85% towards unavailability of supply to a load than a failure of other parts of the system [5]. Forced outages cause momentary or sustained interruptions, and the well-being of the distribution system worsens. Recent research reveals that DER location in distribution networks plays a vital role in the distribution systems reliability. Renewable energy has been used in distribution systems for improved reliable supply to customers [6-7].

DERs have the edge over centralized generations regarding losses, interruption time, time for installation, and availability in small modular units. The main motive of integrating DERs into the distribution network is about policies, cost, sustainability, energy security, power quality, and transition from traditional to smart grid. The suitable location of DERs contributes towards the policy of adopting non-wire technology by serving the loads from the nearest bus with DER connected. It also serves as non-wire alternatives to capacity expansion by managing peak load to avoid or delay traditional expansion projects. When the demand reaches the system capacity, the conventional solution is to expand generation capacity, install more wires or reinforce the existing system [8-10]. Enhancing the DER Capacity based on suitable location in the system contributes more towards sustainable resources. Thus, an appropriate site of DERs in the power system is essential for maximum harvesting of distributed energy sources [11]. The other positive impacts of DERs are significant improvements in power flow and quality for customers and utility. DERs provide system support benefits in voltage, reactive power support, loss reduction, and reliability enhancement using available assets. However, the excessive penetration of DERs into the distribution system may lead to operational limit violations such as over-voltage, excessive line losses, feeders overloading, protection failure, and high harmonic distortion level [12-14]. Now DERs and electric vehicles (EVs) are widely used; however, the power flow of the distribution system is affected by the uncertainty and randomness of DERs and EVs, which increases the difficulty in reactive power optimization of the distribution network [15-17]. Properly utilizing DER resources as an additional supply, the sustained interruption time reduced, leading to improved system and load point reliability indices. The restoration capability of feeders can be improved using DER [18]. Both conventional and modern techniques of modeling DER in the distribution system are used to model DERs [19-21].

The system locational hosting capacity (LHC) needs to be estimated to avoid excessive penetration of DERs. Hosting capacity is total DER capacity that can accommodate a given feeder without adversely impacting voltage, protection, and power quality without feeder upgrade or modification [22] and beyond which the system performance becomes unacceptable [23-24]. The DER capacity to be integrated depends on the Locational hosting capacity (LHC) at the connecting point [25]. Higher hosting capacity is obtained if DER interconnection locations are of shorter distance and low impedance [22]. DER penetration level depends on feeder length, regulation, DER location, operating practices. The DER size is affected more by thermal limits rather than voltage limits at some places [26]. Other factors for maximum hosting capacity of the system are decided based on performance limits like overvoltage, overloading, power quality, losses, and protection problem [21].

Reliability assessments of power distribution networks and customers have been done in conjunction with micro-grid. Reliability can be evaluated in many ways using logical and matrix operations or some other methods [7, 27-29]. In recent works, the application of DERs as a backup source for improving reliability with different DER sizes has been made [30]. However, the integration of DERs will enhance the reliability, and integration at proper locations will lead to more worthy improvement.

1.1. Motivation

The distribution system must be reliable and should supply quality power to the customers. There is a change in the traditional distribution system to cope up with the current demand. Now DERs are integrated into the distribution network. The integration of DERs in the distribution system can make a visible impact on power flow and quality, thus, directly affect distribution system reliability. In addition, the well-being of the system improves with an increase in the amount of energy supplied since the integration of distributed generations will add extra power for regular operation and captive power supply using storage devices [12, 18, 31]. Energy storage and DERs are non-wire alternatives to resolve distribution issues while providing valuable services to the grid and energy customers. One such use is to defer distribution capacity investment needed due to load enhancement and DER growth [32].

Keeping the above aspects in view, the motivation of this work is to figure out the location for DER integration incorporating reliability aspects for maximizing harvesting of renewable energy and hosting capacity of the system.

1.2. Unique Contributions

For selecting the DER location in the distribution system confidence interval, a statistical method proposed considering the following points:

1. Locational hosting capacity (LHC) of the distribution system
2. Impact on reliability indices of the system after DER integration

The DERs location selected with maximum hosting capacity and maximum improvement in reliability indices like Electrical Energy Not Supplied (EENS). A case study is carried out to validate the proposed confidence interval method for selecting DER location based on reliable locational hosting capacity (RLHC) for maximum energy harvesting.

2. Impact of Location of DERs on Hosting Capacity (HC)

There is an impact of DER location on the hosting capacity in the distribution network in addition to the other DERs connected in the system and their locations [33-34]. The impact of DER in a network is quantified by using a set of performance indicators such as power quality parameters like voltage magnitude, voltage dips, and the risk of overload. Excessive DER integration in electrical distribution networks leads to many problems and operational limit violations, such as over and under voltage, increased line losses, overloading of transformers and feeders, protection failure, and high harmonic distortion. The maximum capacity of DER that is interconnected at a location before performance indices limit violation take is the locational hosting capacity. The performance indices of the system reach their limits at the different ratings of DER at other locations of the system. Performance indices are used to figure out the hosting capacity. Hence, LHC assessment and enhancement have become a requirement for distribution system operators and DER providers [21]. If the applied DERs are consumer-owned, utilities do not have control over locations; they can encourage consumers as per the location-based criterion for installing DERs and future utility plans. Variation of one performance index of the distribution system with the DER capacity is shown in Figure 1 for three distinct locations. As the DER capacity increases, the performance index starts deteriorating from the current level of the performance index. The DER capacity at which the performance index becomes unacceptable is the locational hosting capacity at that particular location. The hosting ability at location 1 is HC1 which is different from locations 2 and 3, as shown in Figure1.

In some cases, we have seen that the performance indices may improve initially and then goes beyond the limit. An extensive process used to step through all considered locations, storing data from the power flow solution for each scenario to examine the impact of DER installation on the performance indices of the feeder. The set of scenarios include a significant range of DER sizes and locations. The basic idea is to place DER at a location on the feeder and increase the DER size until any problem occurs; the flowchart shows the process in Figure 2. Using the steps shown in Figure 2, hosting capacity at all the possible locations of the system is estimated. The place where we get maximum locational hosting capacity is considered for DER integration considering all constraints.

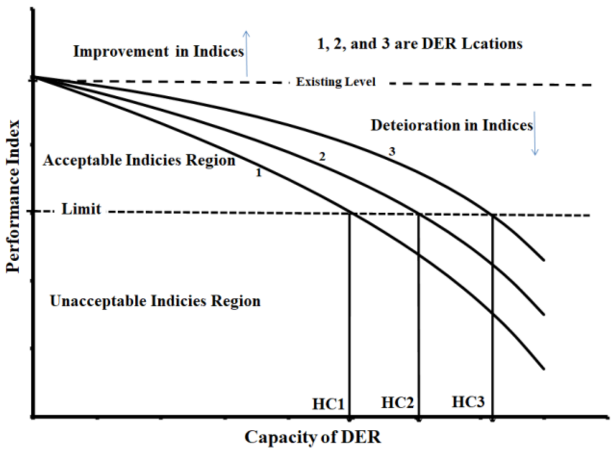

Figure 1. Variation of performance indices with DER capacity at three distinct locations.

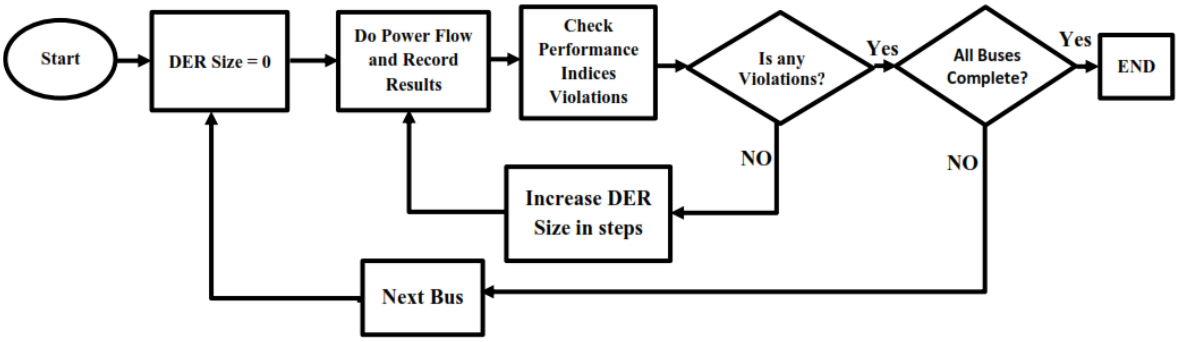

Figure 2. Flow chart for estimation of locational hosting capacity at buses of a distribution system.

The hosting capacity at any bus can be enhanced by reactive power control, adjustments of transformer tap changer, reconfiguration of feeder, and energy storage [35, 36]. The excess power generated at any location returned to the system. Thus, an increase in voltage may be there at the load points and overloading of the feeder. The conductor capacity also limits DER penetration. Hosting capacity at any location can be estimated by equation 1 in the system [37].

$$P_{DERx} = 2P_{loadx} + (1 - S_{loadx}) \quad (1)$$

Where P_{DERx} – Locational Hosting Capacity at location x (MW)

P_{loadx} –Active power demand at location x (MW)

S_{loadx} – Apparent power demand at location x (MVA)

The estimated LHC from equation-1 was used to check the violation of the performance indices. Load flow analysis is used for checking some performance index violations. The voltage changes in the network are shown in Figure 3 after connecting the DER of estimated capacity. Since there is no voltage violation, we can connect the DER of estimated capacity limited by other performance indices.

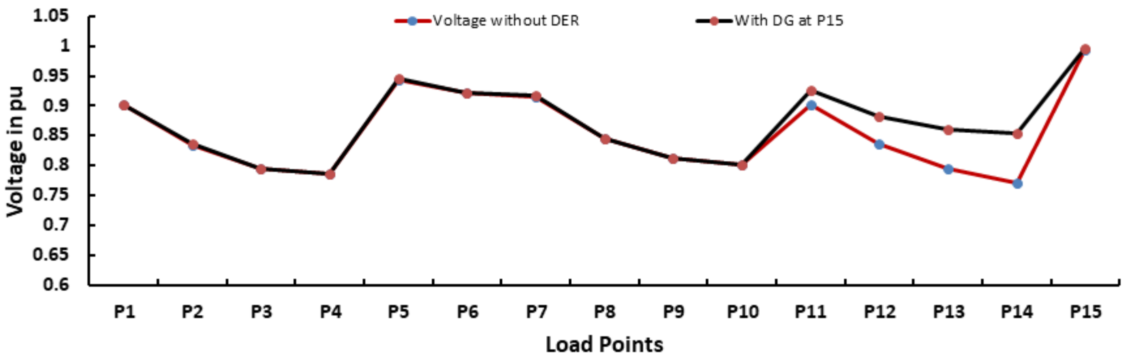

Figure 3 Change in the load point voltage after DER integration

3. An Overview on Distribution System Reliability with DER Integration

Reliability indices SAIFI, SAIDI, CAIDI, ASAI, ASUI, EENS, AENS, ECOST, and IEAR were considered to evaluate the impact of DER on the reliability of the distribution system [38-39]. Three primary failure data used for reliability evaluation are average failure rate (λ_s), average outage time (r_s) and annual outage time (U_s). For LHC based on the reliability, following reliability indices we have considered:

a) $$EENS = \sum_{x=1}^{N_P} EENS_x = \sum_{x=1}^{N_P} L_x \sum_{y=1}^{N_e} \lambda_{xy}\, r_{xy} \quad (2)$$

or

$$EENS = \sum \mathrm{L}_{\mathrm{a(x)}} \times \mathrm{U}_{\mathrm{x}} \quad (3)$$

Subjected to $EENS_{DERx} < EENS_0$

Where: $EENS_{DERx} - EENS\ after\ conecting\ DER\ at\ location\ x$

$EENS_0 - EENS\ before\ DER\ connection,$

x - location of a load point, L_x- Average load at location x

λ_{xy}- Failure rate of y element at x location, r_{xy}- Average outage time

b) AENS (average energy not supplied) or ASCI (Average system curtailment Index)

$$AENS = \frac{\sum L_{a(x)} \times U_x}{\sum N_x} \quad (4)$$

Subjected to $AENS_{DERx} < AENS_0$

Where: $AENS_{DERx} - AENS\ after\ conecting\ DER\ at\ location\ x$

$AENS_0 - AENS\ before\ DER\ connection$, $\mathbf{L_{a(x)}}$ -Average load connected to x^{th} load point, $\mathbf{U_x}$ - Annual outage time at x^{th} load point, $\mathbf{N_x}$ - Total number of customers at x^{th} load point

(c) ECOST: Expected Interruption Cost is dependent on composite customer damage function (CCDF). It depends on the type of load is being fed, viz. agricultural, industrial, commercial.

$$ECOST = \sum_{x=1}^{N_P} ECOST_x = \sum_{x=1}^{N_P} L_x \sum_{y=1}^{N_e} \lambda_{xy}\ C_{xy} \quad (5)$$

Where, Cxy - per unit (kW) interruption cost, NP -Total number of' load points in the system

Ne - Total number of elements in the distribution system

(d) IEAR: Interrupted Energy Assessment Rate is used in the managerial assessment of reliability worth and in any consideration of assigning customer tariffs for different reliability levels. IEAR is the ratio of EENS to ECOST.

$$IEAR = \frac{\sum_{x=1}^{N_P} L_x \sum_{y=1}^{N_e} \lambda_{xy} r_{xy}}{\sum_{x=1}^{N_P} L_x \sum_{y=1}^{N_e} \lambda_{xy} C_{xy}} \quad (6)$$

These customer and load point indices have been handy for assessing the system performance by evaluating the severity of system failures in the future. Furthermore, these reliability indices evaluations are essential for the following reasons too:

1. These evaluations establish the changes in the system performance and identification of weak areas and the need for reinforcement.
2. The assessed indices can provide acceptable limits of reliability assessment indices.
3. With these evaluations, we achieve reliability-based optimized use of resources.

Reliability indices have been evaluated before and after the integration of the DER at all the load points. The improvement in the reliability indices of the system depends on the location of the DER integration. When multiple DERs are integrated, the reliability indices are better than the single DER integration.

Figure 4 shows the process of selecting the location of DER integrated based on reliability indices. The location for DER integration selected, which has the maximum hosting capacity and improved reliability indices subjected to the constraints of minimum improvement in reliability indices. If locations of the highest LHC and most improved Reliability indices were different, we must use some method to select the location for DER integration. For such situations, we have proposed the Confidence Interval method to decide the location of DER integration. A case study is done on Roy Billinton Test System (RBTS) bus2 to validate the proposed method.

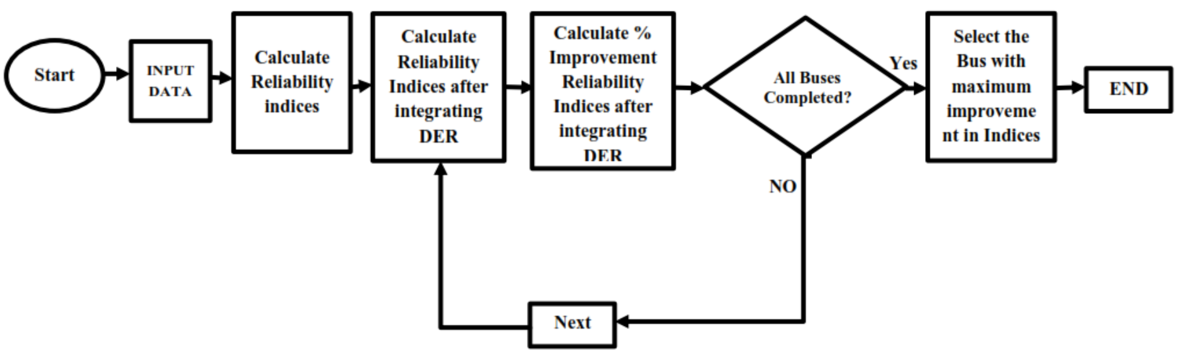

Figure 4. Process for estimation of reliability indices with DER for the best location of DER.

4. Case Study

To validate the proposed method for selecting DER location in the distribution network based on LHC and reliability indices in the presented article, the system considered is Roy Billinton Test System (RBTS) [40-41]. The single-line representation of RBTS Bus2 is shown in Figure 5. The generation and transmission system of RBTS is assumed 100 % reliable for the distribution system reliability analysis. Bus 2 of RBTS with all the load points is shown in Figure 6a. Bus 2 consists of 4 feeders with 14 load points and 22 lumped loads at these load points. Two case studies are considered; base case, i.e., without DER and when DER is connected (Figure 6). The DER used here is a wind turbine generator (WTG) of 1MW capacity with a failure rate of 2 failures/year, repair time of 80 hours (about three and a half days) and switching time of 1 hour. For reliability assessment, the tool used is Electrical Transient Analyzer Program (ETAP) version 6.0, a fully integrated AC and DC electrical power system analysis tool [42].

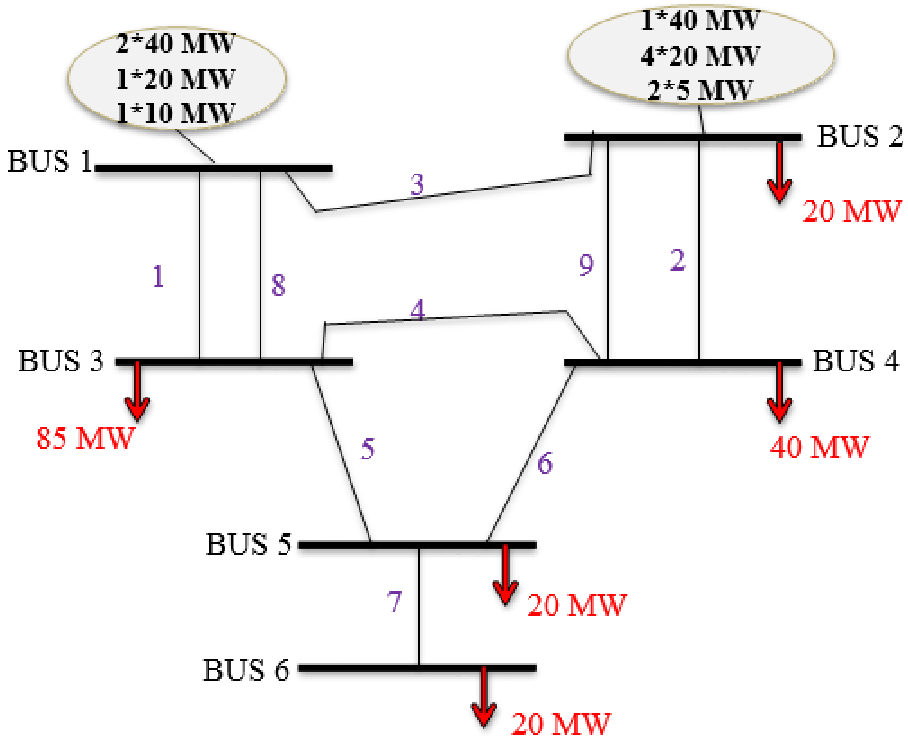

Figure 5. Single Line Diagram Representation of RBTS.

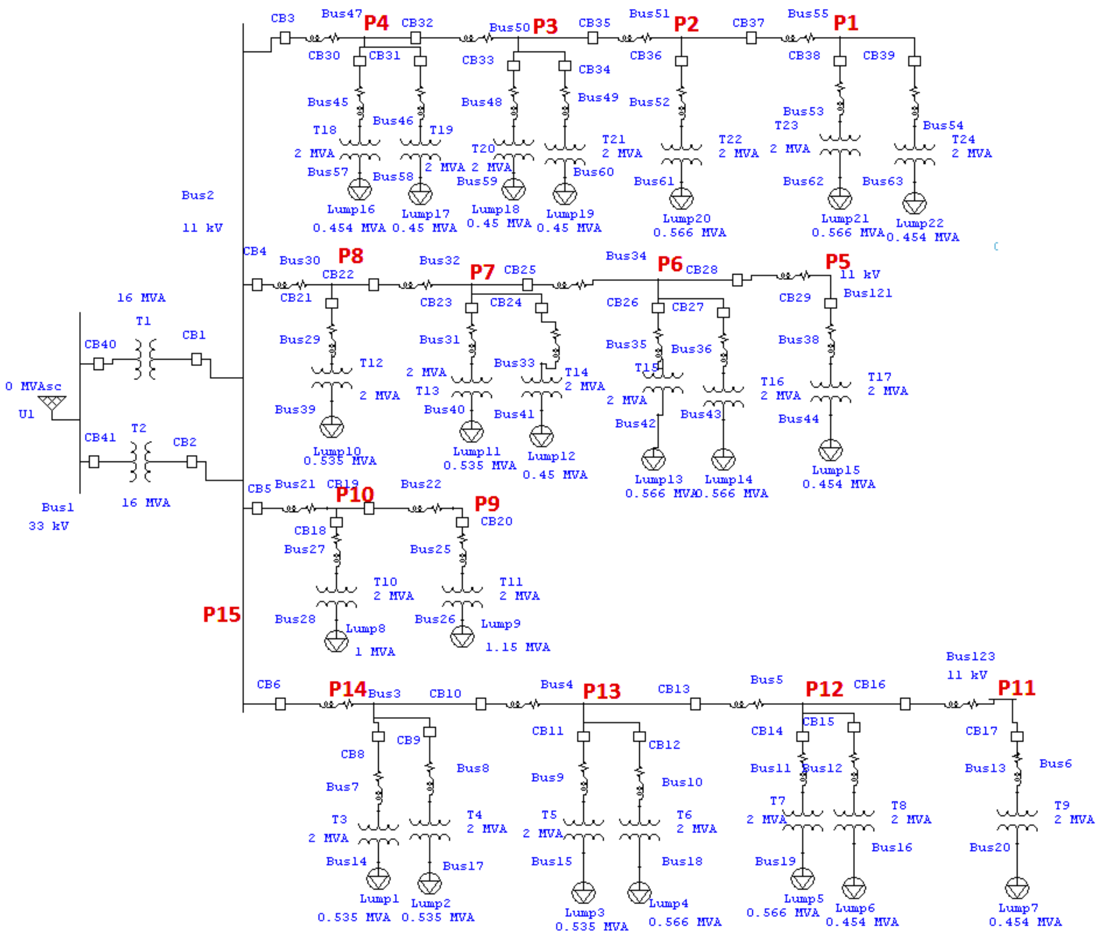

Figure 6. ETAP Modeling of RBTS Bus 2.

Estimating the locational hosting capacity at load points of system equation-1 has been used, assuming the line thermal limit does not exceed. The estimated locational hosting capacity at load points is shown in Table 1. In Table 1a hosting capacity shown is estimated considering 0.98 power factor and average power demand. In Table 1b, the hosting capacity presented is estimated considering 0.98 power factor and maximum power demand. The highest hosting capacity for each feeder load point is indicated in bold in Table1. We see that hosting capacity at different load points depends on the location and load connected. Table 1 also shows the reliability performance index EENS after integrating the DER. We found that the highest hosting capacity and improvement in reliability index EENS are not at the same load point in all feeders. For example, in feeder2, the highest HC is at load point P6, and the maximum improvement in reliability index is at P5.

The improvement in reliability indices is seen at all load points after DER integration. The level of improvement depends on the locations of DER. In Table2, reliability indices estimated without DER as the base case and after integrating DER at all the load points is shown. The best site for the DER connection is the farthest distance from the feeder, and improvement in system reliability indices is highest. The comparative details of system performance improvement are shown in Table2 with respect to distance from their respective feeder. The 15 interconnection points of DER in Bus2 of RBTS are shown in Figure 6.

Table 1. a. Hosting capacity in RBTS BUS 2 considering power factor 0.98 and average power demand.

Feeder No.	Load Point	Load1 (MW)	Load 2 (MW)	Total Load (MW)	Hosting Capacity (MW)	EENS (MW hr. / yr.)
1	P1	0.454	0.566	1.02	**1.999**	**27.062**
	P2	0.566	-	0.566	1.554	27.498
	P3	0.45	0.45	0.9	1.882	28.206
	P4	0.45	0.454	0.904	1.886	29.451
2	P5	0.454	-	0.454	1.445	**27.539**
	P6	0.566	0.566	1.132	**2.109**	27.724
	P7	0.45	0.535	0.985	1.965	28.452

	P8	0.535	-	0.535	1.524	29.598
3	P9	1.15	-	1.15	**2.127**	**29.417**
	P10	1	-	1	1.980	29.908
4	P11	0.454	-	0.454	1.445	**27.465**
	P12	0.454	0.566	1.02	1.999	27.667
	P13	0.566	0.535	1.101	**2.079**	28.325
	P14	0.535	0.535	1.07	2.048	29.475
Bus 2 / P15		8.084	4.207	12.291	26.040	30.531

Table 1. b). Hosting Capacity in RBTS BUS 2 at power factor of 0.98 and maximum power demand.

Feeder No.	Load Point	Load1 (MW)	Load 2 (MW)	Total Load (MW)	Hosting Capacity (MW)	EENS (MW hr. /yr.)
1	P1	0.75	0.9167	1.6667	**2.633**	**27.062**
	P2	0.9167	-	0.9167	1.898	27.498
	P3	0.7219	0.7219	1.4438	2.414	28.206
	P4	0.7219	0.75	1.4719	2.442	29.451
2	P5	0.75	-	0.75	1.735	**27.539**
	P6	0.9167	0.9167	1.8334	**2.796**	27.724
	P7	0.7219	0.8668	1.5887	2.556	28.452
	P8	0.8668	-	0.8668	1.849	29.598
3	P9	1.8721	-	1.8721	**2.834**	**29.417**
	P10	1.6279	-	1.6279	2.595	29.908
4	P11	0.75	-	0.75	1.735	**27.465**
	P12	0.75	0.9167	1.6667	2.633	27.667
	P13	0.9167	0.8668	1.7835	**2.747**	28.325
	P14	0.8668	0.8668	1.7336	2.698	29.475
Bus2 / P15		13.149	6.8224	19.9718	33.564	30.531

Table 2. System reliability indices with and without incorporating DER I RBTS Bus 2.

Feeder No.	**DG location**	**Distance from feeder (km)**	**SAIFI**	**SAIDI**	**EENS**	**ECOST**	**AENS**	**IEAR**
BASE CASE		0	0.4336	3.0448	34.446	127824	0.0181	3.711
FEEDER 1	**P1**	**2.9**	**0.3242**	**2.4123**	**27.062**	**102011**	**0.0142**	**3.769**
	P2	2.3	0.3249	2.4154	27.498	104036	0.0144	3.783
	P3	1.55	0.3257	2.4189	28.206	106607	0.0148	3.780
	P4	0.80	0.3540	2.5428	29.451	109938	0.0154	3.733
FEEDER 2	**P5**	**2.9**	**0.3251**	**2.4166**	**27.539**	**103751**	**0.0144**	**3.767**
	P6	2.15	0.3257	2.4193	27.724	105252	0.0145	3.796
	P7	1.55	0.3266	2.4229	28.452	107903	0.0149	3.792
	P8	0.75	0.3535	2.5409	29.598	110988	0.0155	3.750
FEEDER 3	**P9**	**1.35**	**0.3835**	**2.6602**	**29.417**	**111724**	**0.0154**	**3.798**
	P10	0.75	0.3835	2.6604	29.908	112371	0.0157	3.757
FEEDER 4	**P11**	**2.85**	**0.3349**	**2.4602**	**27.465**	**100013**	**0.0144**	**3.642**
	P12	2.25	0.3356	2.4632	27.667	101666	0.0145	3.675
	P13	1.50	0.3370	2.4693	28.325	105430	0.0148	3.722
	P14	0.75	0.3525	2.5371	29.475	109967	0.0154	3.731
P15		0	0.3836	2.6608	30.531	113135	0.0160	3.706

The variations in interrupting rate, outage duration, EENS, ECOST, and IEAR compared before and after DER integration. From the comparison, we found that there is an improvement in indices after the integration of DER. The fundamental failure data and reliability indices after connecting DER at the P1 load point and without DER are shown in Table 3. Maximum improvements in reliability indices are seen when DER is integrated at load point P1. When DER is integrated at other load points, minor improvement in indices is observed. From the results, we found that the best location of DER is the P1 point. At some load points, the average outage duration value seems to be increased after incorporating DER, but that is only due to the outage time of DER. Annual outage duration is reduced considerably for the same, which shows the positive impact of DER on a distribution system. The Change in indices in percentage is shown in Table 4 with the base case.

Table 3. Reliability Indices after connecting DER at load point P1.

Load Point	Av. Int. Rate (f/yr.)		*Av. Outage Duration (hr.)*		Ann. Outage Duration (hr. /yr.)		EENS (MW hr. /yr.)		ECOST ($/yr.)		IEAR ($/kW hr.)	
	Without DER	With DER	Without DER	With DER	Without DER	With DER	Without DER	With DER	Without DER	With DER	Without DER	With DER
1.	0.3508	0.3008	7.63	7.62	2.6767	2.2928	1.1461	0.9816	2193	1875	1.914	1.911
2.	0.3638	0.3138	7.54	7.51	2.7417	2.350	1.1739	1.0095	2232	1915	1.902	1.897
3.	0.4915	0.4415	6.71	6.60	3.2995	2.9155	1.4127	1.2483	2546	2229	1.803	1.786
4.	0.4785	0.4285	6.76	6.65	3.2345	2.8505	1.4651	1.2912	4274	3719	2.917	2.881
5.	0.6192	0.5692	6.23	6.10	3.8572	3.4732	1.7472	1.5732	4793	4238	2.744	2.694
6.	0.6160	0.5660	6.24	6.11	3.8410	3.4570	1.3955	1.2560	13401	11968	9.603	9.529
7.	0.7262	0.6762	5.95	5.82	4.3202	3.9362	1.5697	1.4302	14821	13389	9.443	9.362
8.	0.3578	0.3077	7.60	7.58	2.7177	2.3338	2.1750	1.8677	4149	3556	1.908	1.804
9.	0.4638	0.4138	6.85	6.75	3.1787	2.7947	2.9255	2.5721	5328	4646	1.821	1.806
10.	0.3448	0.2948	7.69	7.70	2.6527	2.2688	1.1358	0.9714	2180	1863	1.920	1.918
11.	0.4855	0.4355	6.75	6.64	3.2755	2.8915	1.4024	1.2380	2533	2216	1.807	1.790
12.	0.4888	0.4388	6.74	6.63	3.2917	2.9077	1.4813	1.3085	2673	2340	1.805	1.788
13.	0.6035	0.5535	6.27	6.14	3.7845	3.4005	1.7412	1.5403	4730	4175	2.760	2.711
14.	0.6067	0.5567	6.26	6.14	3.8007	3.4167	1.7216	1.5477	4745	4191	2.756	2.708
15.	0.7095	0.6595	5.98	5.86	4.2455	3.8615	1.5425	1.4030	14595	13163	9.462	9.382
16.	0.3638	0.2227	7.54	8.96	2.7417	1.9957	0.9962	0.7251	10146	7683	10.185	10.596
17.	0.3540	0.2130	7.61	9.14	2.6930	1.9470	1.2119	0.8761	2315	1782	1.911	2.034
18.	0.4818	0.2098	6.75	9.21	3.2507	1.9307	1.4628	0.8688	2645	1771	1.808	2.039
19.	0.4948	0.2227	6.70	8.96	3.3157	1.9957	1.4921	0.8981	2687	1813	1.801	2.019
20.	0.6165	0.2168	6.24	9.10	3.8495	1.9718	1.7437	0.8931	4790	3034	2.747	3.398
21.	0.7252	0.2038	5.95	9.36	4.3182	1.9068	1.9560	0.8637	5171	2974	2.644	3.444
22.	0.7285	0.2070	5.95	9.29	4.3345	1.9230	1.5749	0.6987	14866	7463	9.400	10.682

Table 4. Improvement in Reliability Indices after DER integration in %.

Load Point	Indices	Base Case Vs. P1	Base Case Vs. P2	Base Case Vs. P3
LUMP 22	Av. Interrupting Rate	**71.58**	54.86	37.34
	Annual Outage Duration	**55.63**	43.32	30.45
	EENS	**55.62**	43.31	30.42
	ECOST	**49.80**	39.14	28.02
LUMP21	Av. Interrupting Rate	**71.90**	55.12	37.49
	Annual Outage Duration	**55.84**	43.49	30.57
	EENS	**55.85**	43.48	30.57
	ECOST	**42.49**	33.96	25.08
LUMP 20	Av. Interrupting Rate	**64.84**	64.84	44.12
	Annual Outage Duration	**48.78**	48.78	34.29
	EENS	**48.78**	48.78	34.29
	ECOST	**36.66**	36.66	27.08

When connecting multiple DERs in the same feeder in the presence of DER at load point where indices improved maximum, there were no significant improvements in reliability due to the adequacy of load demand. However, incorporating multiple DGs in two different feeders best DER locations, there were more significant enhancements in reliability, as we can see from Table5 and Figure 7.

Table 5. Impact of Multiple DGs on System Indices of Bus 2 of RBTS.

Indices	**Base Case Without DG**	**WITH SINGLE DG**				**WITH MULTIPLE DGs**					
		P1	**P5**	**P9**	**P11**	**P1 & P5**	**P1 & P9**	**P1 & P11**	**P5 & P9**	**P5 & P11**	**P9 & P11**
SAIFI	0.4336	0.3240	0.3251	0.3835	0.3349	0.2657	0.3240	0.2755	0.3250	0.2764	0.3348
SAIDI	3.0448	2.4123	2.4166	2.6602	2.4602	2.1681	2.4116	2.2117	2.4159	2.2160	2.4596
CAIDI	7.022	7.441	7.433	6.937	7.346	8.161	7.443	8.029	7.435	8.017	7.347
ASAI	0.9997	0.9997	0.9997	0.9997	0.9997	0.9998	0.9997	0.9997	0.9997	0.9997	0.9997
ASUI (10^{-3})	0.35	0.28	0.28	0.30	0.28	0.25	0.28	0.25	0.28	0.25	0.28
EENS	34.446	27.062	27.539	29.417	27.465	24.070	25.948	23.996	26.425	24.473	26.351

Indices	**Base Case Without DG**	**WITH SINGLE DG**				**WITH MULTIPLE DGs**					
		P1	**P5**	**P9**	**P11**	**P1 & P5**	**P1 & P9**	**P1 & P11**	**P5 & P9**	**P5 & P11**	**P9 & P11**
ECOST	127824	102011	103751	111724	100013	92627	100599	88889	102340	90629	98602
AENS	0.0181	0.0142	0.0144	0.0154	0.0144	0.0126	0.0136	0.0126	0.0138	0.0128	0.0138
IEAR	3.711	3.769	3.767	3.798	3.642	3.848	3.877	3.704	3.873	3.703	3.742

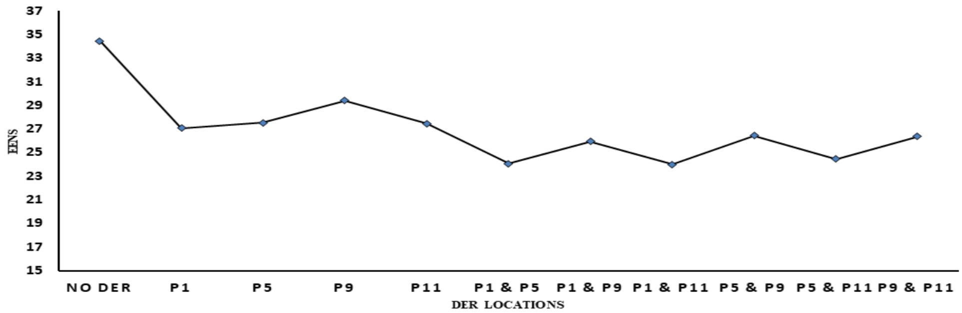

Figure 7. Improvement in EENS after DER integration at load points.

5. Selection of DER location by confidence interval Method

The case study results show that the maximum hosting capacity and better reliability indices location are different in some feeders. The bus's in the feeders have the same location for the highest LHC and improved reliability indices selected for DER integration. In the feeders, where the locations are different for maximum LHC and maximum improvement in reliability indices, we must choose the location considering both factors. For such cases, we are proposing a statistical method for deciding the location for DER integration. We can use Confidence Interval (CI) method to determine the DER location in the feeder where the Highest LHC location is different from the location for the maximum improvement in reliability indices. Confidence Interval tells us that we are 99 percent confident that the actual mean lies within the interval 99 to 101. Because we are 99 percent sure that the actual data means falls within our confidence interval, there is a 1 percent chance that the data mean does not fall within the interval. Confidence Interval gives a range of values so defined that there is a specified probability that the value of a parameter lies within it. We can use CI of 99%, 95%, or any other value depending on how confident we want. We had used a 99% confidence interval to select a location for DER integration considering maximum LHC and reliability indices.

Confidence Interval for

a. Known population

Lower bound $= \bar{x} - z\frac{\sigma}{\sqrt{n}}$ and Upper bound $= \bar{x} + z\frac{\sigma}{\sqrt{n}}$ (8)

b. Unknown population

Lower bound $= \bar{x} - t\frac{s}{\sqrt{n}}$ and Upper bound $= \bar{x} + t\frac{s}{\sqrt{n}}$ (9)

Where, $\bar{x} - average\ value\ of\ x,$ t and z are constant

$\sigma - standard\ deviation,$ $n - population\ size$

For calculation of the confidence interval, the value of z is shown in Table 6, and for the value of t, use t table. The confidence interval for hosting capacity and reliability index is estimated and shown in Table 7. Based on the 99% CI interval, we can decide the location of DER in the feeder in which two performance indices are at two distinct locations. Load point P6 was selected for DER integration using the confidence interval method. P6 load point had the highest HC and EENS in 99% CI. From Table8, we can see that the deterioration in EENS is only 0.67% if load point P6 is selected in place of P5 load point, which has the maximum improvement in EENS. The maximum deviation in the reliability indices in the studied system is 3% only if we select the load point for DER integration based on the CI method.

Table 6. Value of z for different confidence Interval.

Confidence Interval	80%	85%	90%	95%	99%	99.50%	99.90%
Value of Z	1.282	1.44	1.645	1.96	2.576	2.807	3.291

Table 7. Confidence Interval for HC

Feeder No.	Confidence Interval for HC				Confidence interval for EENS			
	Standard Deviation	Mean	99% CI	CI Interval	Standard Deviation	Mean	99% CI	CI Interval
1	0.196	1.848	0.252	1.596 - 2.100	1.044	28.054	1.344	26.710-29.398
2	0.333	1.777	0.429	1.348 -2.206	0.934	28.328	1.203	27.125-29.531
3	0.106	2.075	0.193	1.882 - 2.268	0.347	29.663	0.632	29.031-30.295
4	0.307	1.911	0.353	1.558 – 2.264	0.906	28.233	1.043	27.190-29.276

Table 8. Load point selected for DER integration by the Confidence interval.

Feeder No.	Load Point with Highest LHC	Load Point with the highest Improvement in EENS	Load point for DER Integration using CI	Deviation in the EENS in %
1	P1	P1	P1	0
2	P6	P5	P6	0.67
3	P9	P9	P9	0
4	P13	P11	P13	3.0

6. Conclusion

A reliable locational hosting capacity is necessary to avoid deterioration of the system performance and maximum renewable energy harvesting. The LHC of the distribution system and reliability indices were calculated to prevent excessive penetration. The reliability indices values show significant improvement after integration of DER at all the load points. The location of DER integration decided considering reliability indices after DER integration and LHC at load points. The obtained results demonstrated that the DER located at the farthest distance from the feeder impacts most system reliability indices by reducing the annual outage time. Thus, applying DER at these locations will change the cost consideration of the system. While using multiple DER in the same feeder, there is no change in indices when one is at the farthest point from the feeder. When the DERs connected to multiple feeder's best locations, significant improvement in reliability indices was observed. The primary reliability data was used to find the reliability indices. Present results revealed that the LHC of the distribution system depends on the DER integration location. However, the location of the highest LHC in some feeders may differ from maximum improvement in reliability indices location. The selection of DER integration locations in such feeder can be made by the proposed confidence interval method. The results also demonstrated that the location selected P6 based on CI in feeder 2 has the highest LHC with 0.67% deterioration in EENS. Thus, the deterioration in the indices is insignificant in selecting a location using CI. Therefore, the authors conclude that CI can be used to select DER locations considering many performance indices.

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