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Effects of integration of distributed generation on reliability in distribution system

Rudresha Sogilu Jayappa[1], Marulasiddappa Hallikeri Basappa[2], Kirankumar Gama Ramaiah[1], Gopinath Harsha Rajappa[3]

[1]Department of Electrical and Electronic Engineering, P.E.S. Institute of Technology and Management, Visvesvaraya Technological University, Shivamogga, India
[2]Department of Electrical and Electronic Engineering, Jain Institute of Technology, Visvesvaraya Technological University, Davanagere, India
[3]Department of Electrical and Electronic Engineering, Poojya Doddappa Appa College of Engineering, Visvesvaraya Technological University, Kalaburagi, India

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ABSTRACT

The reliability of power supply to consumers is the main factor that is to be considered while designing, planning and operation of a distribution network. This problem can be solved by incorporating distributed generation (DG) at the consumer side itself. In order to enhance service availability, power quality, reliability, and loss reduction, DG is positioned optimally at the consumer end within the system. The optimal DG location and size is to be calculated in such a way that the total loss in the system should be minimal and cost savings should be maximal. In this study, for the investigation of effects of DG on reliability of distribution system, a practical 11 KV feeder with 41-bus, was employed. The selected practical feeder is modelled using the power world simulator (PWS) software and reliability of the system is verified by calculating various reliability indices such as system average interruption frequency index (SAIFI), system average interruption duration index (SAIDI), customer average interruption duration index (CAIDI), average system utility index (ASUI) and average service availability index (ASAI). After applying proposed loss sensitivity factor (LSF) method, the active and reactive power loss reduction are 41.30 % and 38.64 % respectively, least bus voltage is enhanced to 0.9405 pu from 0.8978 pu and the reliability indices are also improved.

Corresponding Author:

Rudresha Sogilu Jayappa
Department of Electrical Engineering, PESITM, VTU
Shivamogga, Karnataka, India
Email: rudreshsj@pestrust.edu.in

1. INTRODUCTION

Every power utility's primary goal is to offer electricity to customers in a way that is both economical and reliable. The cost of power supply interruptions to customers will decrease as a result of effective planning and maintenance of a reliable energy supply. Reliability plays a critical role in planning and design of a distribution system, which will function cost-effectively with few interruptions to customer loads [1]. According to the reports that have been published in the literature, distribution system failures are responsible for around 80% of customer interruptions. As a result, both from a technical and financial standpoint, the reliability of distribution networks is regarded as one of the most major challenges. For this reason, to be in competition, the service company will see for means to reduce expenses and also supply the suitable level of reliability for its consumers [2]. The main function of electrical utility company operating in a deregulated atmosphere is to rise the market value of facilities it offers to customers. This can be done by building new, more affordable electrical infrastructure and offering reliable electricity at lower operational and maintenance costs [3]. All of these aspects will contribute to lower customer billing, which is likely to increase customer satisfaction. One of the ways by which above objective can be met is integration of distributed generation (DG) [4].

Many researches are done to find the benefits of DG integration into the electrical system [5]. Presently, DG technology is inviting the power engineer as a substitute for the conventional central power supply, to reduce voltage drop, losses and recover the reliability in the system. DG is also known as dispersed generation, is a kind of small generation that is primarily linked at the distribution system's end user. To ensure a more reliable supply, DG will be easily accessible during system failure [6].

Doung *et al.* [7] ideal position and size of solar units in radial distribution systems (RDS) is explained. Using the power stability index to identify key buses, the best DG placements are discovered in [8]. To locate and raise the voltage profile in the system, modified voltage index is employed in [9], and mixed-integer nonlinear programming is used to explain the optimization problem. The researcher [10] a broad analysis of the voltage stability indices is given. The words in [11] the various optimization techniques are explained and in [12] a cuckoo search algorithm is used to resolve the best DG location difficulty. The authors in [13]–[15] a various solution to multi-objective optimal placement DG problem of power distribution networks is addressed.

A number of reliability indices, including the system average interruption duration index (SAIDI), customer average interruption duration index (CAIDI), average service availability index (ASAI), system average interruption frequency index (SAIFI) and average service unavailability index (ASUI) [16] are used to estimate the system's reliability. The studies of power system reliability employs a variety of methodologies [17]. Mathematical models are used in analytical methodologies to measure the reliability of electrical distribution systems. In addition to thermal overloads, the analytical method based on emergency enumeration can detect voltage collapse issues. However, the enumeration approach must make a number of simplifying assumptions because it is unable to describe a broad range of operational situations [18].

For evaluating the system's reliability, Monte Carlo simulation has a number of benefits that become more obvious when DGs are heavily integrated into the system. The various operational problems that DGs pose are avoided using Monte Carlo simulation. However the transmission outages, voltage drop and voltage collapse issues is not possible to model in this technique [19]. The significant assistances of this paper depend on development of loss sensitivity factor (LSF) based method for optimal DG incorporation and reliability analysis based on following important issues:

- A position of DG is considered in distribution system to reduce the overall losses, which intern reduces the cost in the system.
- Voltage at various buses in the distribution system is considered.
- Reliability indices of the system are considered.
- The proposed method's ease of use, accuracy, and suitability for use in practical distribution systems must be considered.

The next part of the paper is organized as follows: i) Section 2 gives the definitions of reliability indices; ii) Section 3 presents the problem statement; iii) Section 4 provides the proposed DG placement and sizing approach; iv) Section 5 gives simulation results and discussion; and v) The conclusions and remarks are given in section 6.

2. RELIABILITY INDICES

The distribution system's main goal is to provide the consumer with continuous power supply. The frequency of interruptions, the length of each interruption, and overall power lost throughout the interruptions are used to evaluate the power system's reliability indices. The commonly used distribution indices comprise SAIDI, SAIFI, CAIDI, ASUI and ASAI and are described below [20]:

a) SAIFI (system average interruption frequency index)

$$\text{SAIFI} = \frac{\text{total number of customer interruptions}}{\text{total number of customers served}} \tag{1}$$

b) SAIDI (system average interruption duration index)

$$\text{SAIDI} = \frac{\text{sum of customer interruption durations}}{\text{total number of customers served}} \tag{2}$$

c) CAIDI (customer average interruption duration index)

$$\text{CAIDI} = \frac{\text{sum of customer interruption durations}}{\text{total number of customer interrruptions}} \quad (3)$$

d) ASUI (average system utility index)

$$\text{ASUI} = \frac{\text{Duration of outages in hours}}{\text{total hours demanded}} \quad (4)$$

e) ASAI (average service availability index)

$$\text{ASAI} = 1\text{-ASUI} \quad (5)$$

3. PROBLEM STATEMENT

This manuscript examines a real-world distribution feeder that runs from the 110/11 KV Alkola substation near Shivamogga in Karnataka. The feeder contains 41 distribution transformers and a maximum load of 1.987 MW and 0.626 MVAR. As the population grows, the demand on the distribution system also grows over time, this result in rise of system loss and fall in voltage in system. The purchaser at the end bus will experience a low voltage issue, where the voltage is below the permitted boundary as a result supply to the customer gets affected, which results in interrupted power supply to the consumer. By placing DG at the user end, the voltage at the buses will be improved, and the system's overall loss will be reduced, which further provides the reliable supply to the consumer [21], [22].

This study investigates the major uncertainties faced by the customer in the real-world distribution feeder, which are low voltage level and more system losses. The voltage in the practical feeder is shown in Figure 1 and its daily load curve is shown in Figure 2. According to standard rule, we used 6% variable voltage throughout analysis, which corresponds to V_{min} = 0.94 pu and V_{max} = 1.06 pu. In subsequent section we'll demonstrate how the best DG size and placement affect the voltage level at the various buses in the power system, which intern affect the reliability of the distribution system.

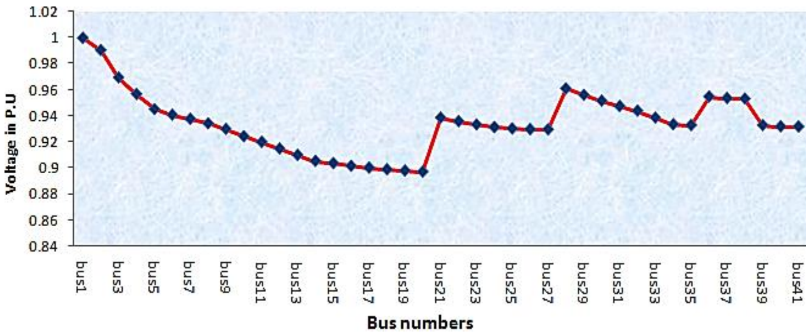

Figure 1. Voltages of 41-bus distribution feeder

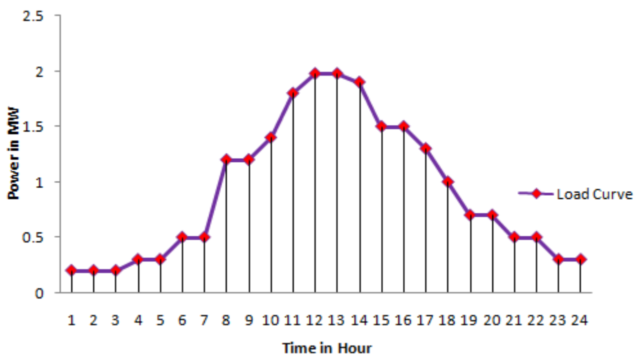

Figure 2. Daily load curve of practical feeder

4. METHOD OF ANALYSIS SUGGESTED

Power world simulator (PWS) software is utilized in our analysis to decide appropriate size and position of DG to lessen losses and recover the voltages in various buses, which develops the reliability of the system. The formula to determine the loss sensitivity factor (LSF) for a particular system after the size of the DG is changed from P_{DG1} to P_{DG2}, and resulting variation in power loss is from P_{L1} to P_{L2} and is given by [23].

$$\frac{dP_L}{dP_i} = \frac{P_{L1}-P_{L2}}{P_{DG1}-P_{DG2}} \tag{6}$$

In this study, the Sensitivity factor is determined for each bus by applying above equation. The bus with the greatest sensitivity is then identified, and other buses with sensitivity factor that are extremely close to the highest value are chosen for study. Then, change the DG size with high values at each of these chosen buses to determine power loss. The best position is on the bus that has the lowest loss for each DG size, and the ideal DG size corresponds to that generation [24], [25]. The Computational procedure for the Proposed Methodology is shown in Figure 3.

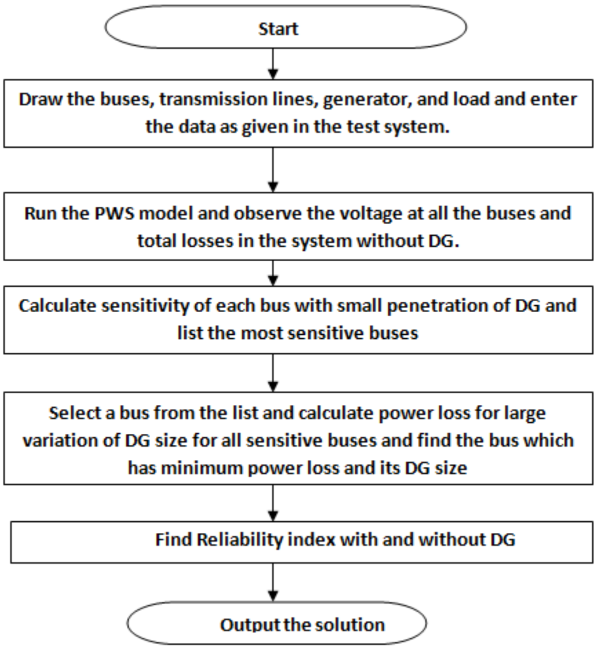

Figure 3. Step by step computation of proposed methodology

5. RESULTS AND DISCUSSION

– Case-1: Analysis of practical system without DG

One of the 11 KV practical distribution feeder from Alkola substation in Shivamooga, Karnataka, is having 41-bus is simulated in PWS software. The reliability analysis of this feeder is studied without and with position of DG. Excluding DG, active and reactive power loss is 0.1334 MW and 0.096 MVAR respectively and lowest system voltage is 0.8978 pu at maximum load.

– Case-2: Analysis of practical system with Incorporation of DG unit (solar PV unit)

The simulation model of practical feeder using PWS is displayed in Figure 4. The projected LSF method is used to discover best place and size of DG. The best location attained in this process is at bus 18 and DG size is 30% of whole generation without DG. The ideal DG position and size found in this technique is bus-18 and 0.633 MW respectively. In this case the solar PV module can be used as a DG unit which can supply power from morning 9 am to 5 pm in load curve, which will reduce the burden on the central grid and will improve the reliability of the system.

The outcomes, obtained with and without DG employment, are presented in Table 1. After DG employment the active power loss is decreased to 0.0783 MW, reactive power loss is condensed to 0.0589 MVAR and lower most system voltage is enhanced to 0.9405 p u from 0.8978 pu. The Figure 5 shows improve in voltage profile with DG placement. The active and reactive power losses for various scenarios are depicted in Figures 6 and 7 respectively. The figure demonstrates that adding DG to the distribution system results in a greater decrease in actual and reactive power losses. Figure 5 compares the voltages for a 41-bus actual distribution system with and without DG placement.

The customer data of practical distribution system without DG for reliability analysis is given in Table 2 and reliability indices with and without DG in the practical system is given in Table 3. As observed in Table 3 the performance of reliability indices is improved with DG integration into the distribution system. The reliability of the system before and after DG is shown in Figures 8 and 9 respectively. As observed in the figures the reliability of the system is improved after location of DG in the practical distribution system and is shown in Figure 9.

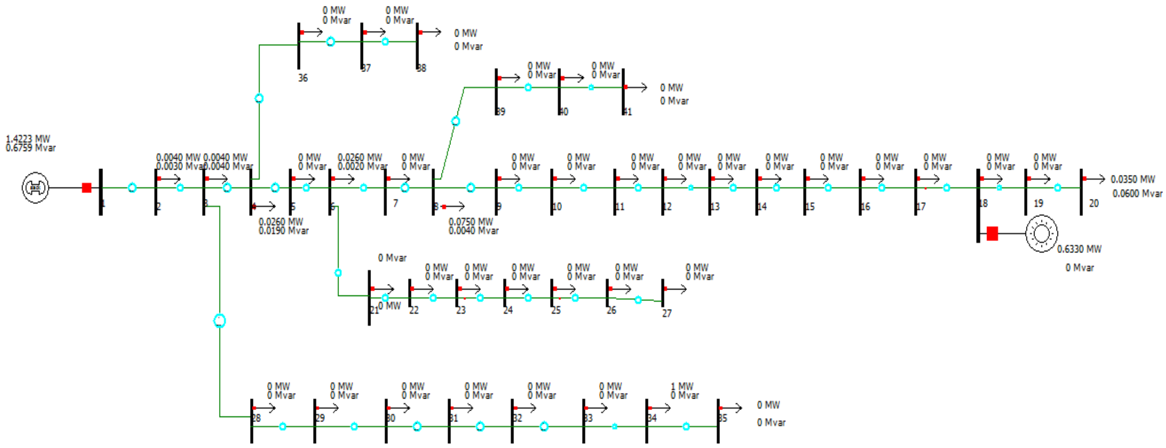

Figure 4. 41-bus practical distribution feeder is modelled in PWS with DG

Table 1. Loss analysis in the system

Cases	DG location at bus	Active power supplied by DG in MW	Active power Loss in MW	Reactive power Loss in MVAr	P Loss Reduction in %	Q Loss Reduction in %
Without DG	-	-	0.1334	0.096	-	-
With DG	18	0.633	0.0783	0.0589	41.30	38.64

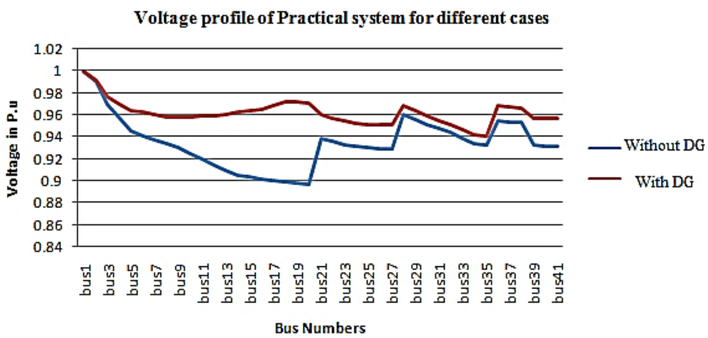

Figure 5. 41-bus practical distribution system voltage profile with and without DG

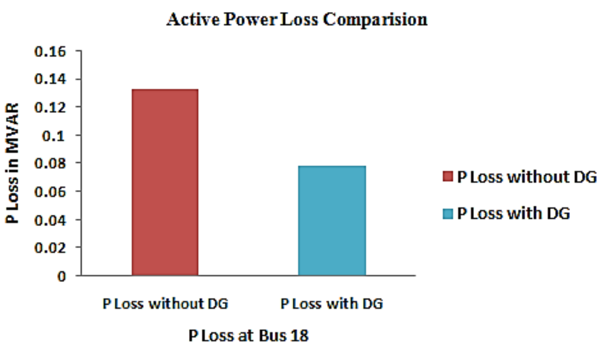

Figure 6. Actual power loss of a 41-bus distribution system with and without DG

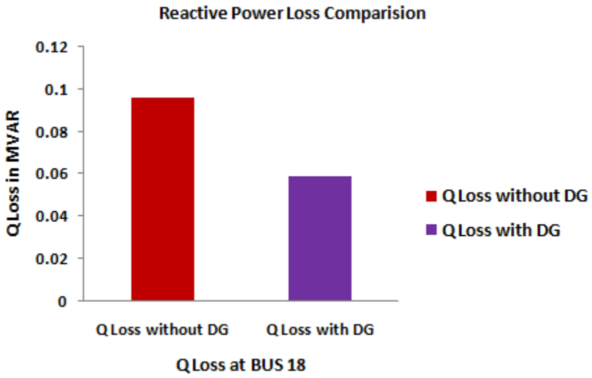

Figure 7. Reactive power loss of a 41-bus distribution system with and without DG

Table 2. Customer data of practical distribution system for analysis

Months	Outage From 9 am to 5 pm		Outage From 5 pm to 9am		Total hours of service required
	Number of times	Total hours	Number of times	Total hours	
January	75	16:35	45	5:25	744
February	60	17:35	33	2:45	672
March	85	23:05	49	7:20	744
April	73	18:10	55	14:45	720
May	70	17:50	45	13:55	744
June	45	15:16	20	2:36	720
July	50	17:05	40	15:04	744
August	36	6:38	17	3:32	744
September	55	29:25	15	4:27	720
October	50	8:28	07	1:49	744
November	44	6:30	15	4:45	720
December	87	20.27	46	6:42	744

Table 3. Reliability Indices with and without DG in the system

Months	SAIFI without DG	SAIFI with DG	SAIDI without DG	SAIDI with DG	CAIDI without DG	CAIDI With DG	ASAI without DG	ASAI With DG	ASUI without DG	ASUI With DG
January	2.9268	1.0975	0.5268	0.1280	0.1799	0.1166	0.9710	0.9929	0.0290	0.0070
February	2.2682	0.8048	0.4829	0.0597	0.2129	0,0741	0.9705	0.9963	0.0295	0.0036
March	3.2682	1.1951	0.7378	0.1756	0.2257	0.1469	0.9594	0.9903	0.0406	0.0096
April	3.1219	1.3415	0.7939	0.3524	0.2543	0.2626	0.9548	0.9799	0.0452	0.0200
May	2.8048	1.0975	0.7573	0.3304	0.2700	0.3010	0.9583	0.9817	0.0417	0.0182
June	1.5853	0.4878	0.4273	0.0575	0.2695	0.1178	0.9757	0.9967	0.0243	0.0032
July	2.1951	0.9756	0.7826	0.3668	0.3565	0.3759	0.9569	0.9797	0.0431	0.0202
August	1.2926	0.4146	0.2365	0.0809	0.1829	0.1951	0.9870	0.9955	0.0130	0.0045
September	1.7073	0.3658	0.8175	0.1041	0.4788	0.2845	0.9535	0.9940	0.0465	0.0059
October	1.3902	0.1707	0.2382	0.0363	0.1714	0.2126	0.9869	0.9979	0.0131	0.0020
November	1.4390	0.3658	0.2621	0.1085	0.1821	0.2966	0.9851	0.9938	0.0149	0.0062
December	3.2439	1.1219	0.6509	0.1565	0.2006	0.1394	0.9642	0.9913	0.0358	0.0086

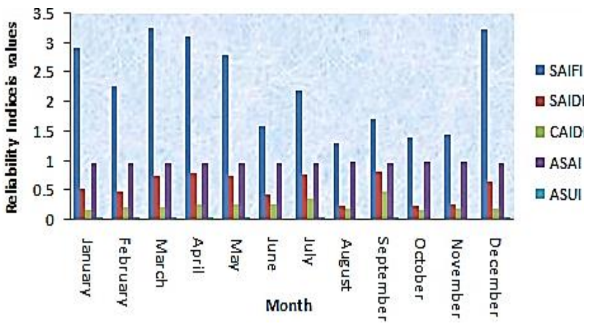

Figure 8. Reliability Indices without DG placement in the system

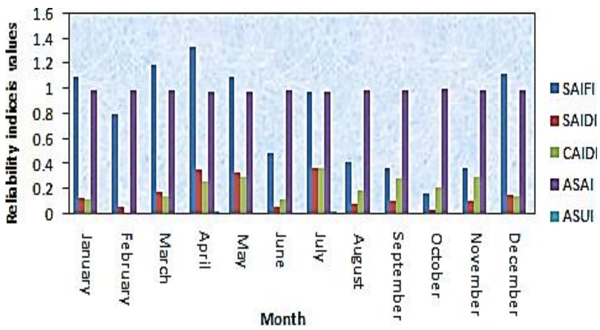

Figure 9. Reliability Indices with DG placement in the system

6. CONCLUSION

In This work the effect of DG on the reliability of a distribution network is examined, for this practical feeder is taken and is modeled in PWS software. The progress in entire system after DG integration units has indicated by reliability indices values. After applying proposed method, the optimum position of DG is obtained at bus 18 with 0.633 MW of DG size. The real and reactive power loss reduction are 41.30 % and 38.64 % respectively, lowermost bus voltage is enhanced to 0.9405 p u and the reliability indices are also improved. The reliability indices became better with DG when compared in the system without DG. The addition of DG units into practical feeder resulted into reliability improvement of the system, therefore it is suggested that practical distribution feeder which comes under Mangalore electricity supply company (MESCOM) should install DG units into their network to assure the electricity requirement of their consumers.

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BIOGRAPHIES OF AUTHORS

Rudresha Sogilu Jayappa is currently working as Associate professor in the department of EEE in PESITM Shimoga. He obtained his B.E., M.Tech. and Ph.D. from Visvesvaraya Technological University, Belgaum, Karnataka. He is having 12 years of teaching experience and he has published more than 10 papers in various international and national conferences and journals. His field of interest includes distribution system reliability analysis, distributed generation, voltage stability analysis, power quality and energy system. He can be contacted at email: rudreshsj@pestrust.edu.in.

Marulasiddappa Hallikeri Basappa is currently a research fellow at Jain University, Kanakpura, Karnataka, India. He received his B.E. and M-Tech degree in Electrical and Electronics Engineering and Power systems in 2005 and 2011 respectively from VTU, Belagavi, Karnataka, India. From March 2015 to August 2020, he worked as Assistant Professor in the department of Electrical and Electronics Engineering at Jain Institute of Technology, Davanagere, Karnataka, India. Area of Interest Power Electronics and Drives. He can be contacted at email: marulasiddappahb@jitd.in.

Kirankumar Gama Ramaiah is currently working as Assistant professor in the department of EEE in PESITM Shimoga. He obtained his B.E., M.Tech. from Visvesvaraya Technological University, Belgaum, and Karnataka. He is having 12 years of teaching experience and he has published more than 10 papers in various international and national conferences and journals. His field of interest includes High voltage engineering and control engineering. He can be contacted at email: kirankumargr@pestrust.edu.in.

Gopinath Harsha Rajappa is currently working as Assistant Professor, EEE Department. Poojy Doddappa Appa College of Engineering, Kalaburagi. He obtained his B.E., M.Tech. from Visvesvaraya Technological University, Belgaum, Karnataka. He is having 11 years of teaching experience. His field of interest includes distribution system reliability analysis, distributed generation and power quality. He can be contacted at email: gopinath.harsha@gmail.com.