# Optimal Placement of DG to Improve the Reliability of Distribution Systems Considering Time Varying Loads using Genetic Algorithm

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Received: August 2012 Revised: September 2012 Accepted: October 2012

**ABSTRACT:**
This paper presents determination of optimum size and location of distributed generators (DGs) for reliability improvement of distribution systems in the presence of time varying loads using Genetic Algorithm (GA). The main innovation of this paper is considering of the annual load duration curve for determination of size and location of DGs for reliability improvement. For this purpose, a load duration curve, including four load levels with different weighting factor is considered. For reliability assessment, the customer-oriented reliability indices such as SAIFI, SAIDI, CAIDI, ASUI and also load- and energy-oriented indices such as ENS are evaluated. In this paper, the effects of system reconfiguration and load shedding are also considered for reliability improvement. The best size and location of DGs in distribution systems are determined based on different reliability indices, separately. The effectiveness of the proposed algorithm is examined on a standard distribution system consisting of 33 nodes, and comparative studies are conducted in the different cases to investigate the impacts of optimal DGs placement and its size determination on reliability improvement. The obtained results show the effectiveness of the proposed method for reliability improvement.

**KEYWORDS:** Distributed Generation, Genetic Algorithm, Reliability, Time Varying Loads.

## 1. INTRODUCTION

The ability to secure the customer electricity supply with an acceptable quality is called reliability to the power system. The power system subdivisions, i.e. generation, transmission, distribution, can be analyzed separately in reliability issue. System reliability improvement means a reduction in either the duration or the number of service interruptions to customers who quantified by IEEE standard indices [1].

Conventionally, utilities have served peak demand by building central generation and transmission and distribution infrastructures. However, in the last decade, technological innovations, especially advances related to the micro turbines and fuel cells have created the possibility of competitive electricity generation with Distributed Generation (DG) units. Distributed generation (DG) means the use of small generating units installed on some specific points of the electric power system which are close to load centers. DG can be used in two methods, the stand-alone way, supplying the consumer's local demand, or utility connected way, supplying energy to the remaining of the electric system. In distribution systems, so DG can also help the rest of the system in many situations in where there are shortages in the transmission system or the central generation is impracticable.

In some cases DG can be highly cost effective in compare wiyh the main network, giving higher reliable power to the customer. Well-planned DG deployment as islanded or grid connected systems can provide significant advantages in power system operation and reliability. There are a variety of ways to improve reliability by means DG like backup generation [2]. DG can serve the loads while there is a fault on the distribution system. For example, when one element whitin a distribution system fails, some load points would be disconnected from the grid and if switches are available DG can supply these loads. So in this case, making intentional island and managing an un-faulted part of the network is the important function of DG [3]. If DGs be used as backup generations will only decrease the duration of the outage, and each fault causes interruption.

Furthermore, load powers will change using tie switches in distribution system and can improve the reliability indices in distribution systems. The reconfiguration process in power systems can have positive influences like improving the reliability of the distribution systems. There are many studies focused on the optimal sitting and sizing of DG in distribution systems. In [4], the authors studied the DG effect of the reliability to the system as a distribution system in Iran. The analysis showed that reliability indices were highly sensitive to location. In [5] the authors discussed about the impact of installing DG on the reliability, loss and voltage profile on the distribution system and show that the place and capacity of DG can improve reliability indices. The authors in [6] illustrate an analytical method evaluating the reliability of distribution system incorporating DG, which considers different modes of DG operation. In [7] a Monte Carlo simulation is used in order to show the influence of installing DG on the distribution system reliability. In [8] a combination of DPSO and GA is implemented to determine the optimal place and capacity of DG units for the purpose of improving reliability and minimizing cost. In [9] using an analytical-based method, optimal allocation and sizing of DGs are solved in order to minimize the line loss. In [10] for improving the system reliability, line loss, and voltage profile, in addition to the line loss, the system reliability is included in the DG planning problem as a constraint, and the genetic algorithm (GA) is used as an optimization method.

In this paper, optimum size and location of distributed generators (DGs) for reliability improvement of distribution systems with time varying loads are determined using genetic algorithm. An annual load duration curve, including four load levels with different weighting factor is considered for determination of size and location of DGs. Furthermore, distribution system reconfiguration and load shedding is implemented for reliability improvement in this paper. Some reliability indices such as SAIDI, SAIFI, CAIDI, ASAI, ASUI and ENS are evaluated in the reliability assessment and size and location of DGs in distribution systems is determined based on different reliability indices, separately. For simulation purpose, a standard distribution system consisting of 33 nodes is considered.

## 2. RELIABILITY INDICES

In order to quantify this impact, many studies have been done. Reliability indices are mostly classified into load-based and customer-based reliability indices. These indices are averages considering the load size and customer numbers plus the duration and rate of failure. In this paper, SAIDI, SAIFI, CAIDI, ASAI and ASUI are used as customer-based reliability indices and ENS is used as load-based reliability indices, which are defined as below equations [11]:

$$\mathrm{SAIDI} = \frac{\sum \text{interruption durations}}{\text{total number of customers}} = \frac{\sum U_i N_i}{\sum N_i} \quad (1)$$

$$\mathrm{SAIFI} = \frac{\text{total number of interruptions}}{\text{total number of customers}} = \frac{\sum \lambda_i N_i}{\sum N_i} \quad (2)$$

$$\mathrm{CAIDI} = \frac{\sum \text{interruption durations}}{\text{total number of interruptions}} = \frac{\sum U_i N_i}{\sum \lambda_i N_i} \quad (3)$$

$$\mathrm{ASAI} = \frac{\sum \text{customer hours of available service}}{\text{customer hours demanded}} = \frac{\sum N_i \times 8760 - \sum U_i N_i}{\sum N_i \times 8760} \quad (4)$$

$$\mathrm{ASUI} = \frac{\sum \text{customer hours of unavailable service}}{\text{customer hours demanded}} = \frac{\sum U_i N_i}{\sum N_i \times 8760} = 1 - \mathrm{ASAI} \quad (5)$$

$$\mathrm{ENS} = \sum \text{Load} \times \text{interruption durations} = \sum L_{a(i)} U_i \quad (6)$$

where $N_i$ is the number of customers at load points i, $\lambda_i$ is the failure rate at load points i, $L_{a(i)}$ is the average load connected to load point i and U is the annual outage time which is defined as below:

$$U = \lambda \times r \quad (7)$$

where r is outage time.

## 3. LOAD MODELING

The input data and its correct analysis specify the accuracy of optimization of objective function. One important data is the definition of load modeling. Although, this issue may have influence of the accuracy to the results, just a few papers have included multi-levels of loading [8]. In this paper, four load levels (light, medium, heavy and peak load) are considered for annual load duration curve for determination of size and location of DGs and presented in Table 1.

**Table 1.** Four load levels considered for annual load duration curve.

| Load level Number | Network Load level | Load level interval timing (h/year) |
|---|---|---|
| 1 | Light load | $T_1$ |
| 2 | Medium load | $T_2$ |
| 3 | Heavy load | $T_3$ |
| 4 | Peak load | $T_4$ |

## 4. DISTRIBUTION SYSTEM RELIABILITY ANALYSIS

The overall algorithm for the reliability assessment is the determination of three areas within the system consisting of safe, interrupted and isolated. For the next step, the reliability indices for all load points in these areas are calculated. For this purpose, at first, during system failure, the distribution system is divided into different classes by protective devices, which are described in section 4.1. Then, the interrupted area is identified and load points that are fed with the main source or distributed generator (s), are recognized after reconfiguration.

### 4.1. Classification of nodes

The distribution systems are divided into different sections by the protection and isolation devices such as circuit breakers, fuses, disconnect/ sectionalizing switches, tie switches, etc. In distribution systems, a section is defined as a group of components whose entry component is a switch or a protection device. As a result, there is only one switch or protection device in each section. When a failure occurs in the system, first it must be isolated by the nearest upstream breaker or fuse. Then, the sections that are affected by this failure must be isolated from the system by opening proper downstream and upstream switches. Based on the location of sectionalizers, normally open switch and DG location(s), load points in each node on distribution system are divided into different classes as follows:

Class A: The healthy load points not affected by a fault with zero duration timing for out of service;

Class B: The load points with duration timing out of service equal to the time of isolating the fault plus the reclosing time of the breaker;

Class C: The load points with duration timing out of service equal to the time of isolating the fault plus the reconnection time of the breaker plus the switching time of a tie switch or normally open switch;

Class D: The load points with duration timing out of service equal to the time of isolating the fault plus the starting time of DG.

Class E: Nodes with duration of service loss equal to the repair time of the failed component [12].

It should be noted when a section is connected to a DG, it is necessary to check if DG can supply the total loads of this section. If the total load connected to the DG is greater than the maximum capacity of DG, some of the load points must be shed. As mentioned above a section is defined as a group of load, which is connected to a protection device. Therefore, in a distribution system with X sections, X is the number of protection devices in the local area for load shedding action, and the total number of sections sets is $2^X$-1. To select the best section for shedding, a Priority Weighting Factor (PWF) has been used based on the Sector Customer Damage Functions (SCDF) and feeder load [13] and is used in this paper. SCDF provides the customer interruption cost models for different customers consisting of large user, industrial, commercial, agriculture, residential, government and institutions and office and buildings categories. PWF for section j in the distribution system for the outage of component i with failure duration $r_i$, is determined using the following equation [13]:

$$PWF_{ij} = \sum_{k=1}^{N} L_k C_k (r_i) \quad (8)$$

where, k represents load point k, N is the number of loads connected to section j , $L_k$ is the load connected to load point k, and $C_k(r_i)$ is the per unit customer cost for duration $r_i$.

The load shedding procedure for determining which section or sections of load points should not be restored consists of the following steps:

1) The Priority Weighting factor (PWF) for each section is calculated and then the sections are sorted in ascending manner.

2) The first section from the sorted list is selected and the total load to be cut for this section is determined.

3) The selected section is shed from the determined area.

Flowchart for identifying classes of nodes is presented in Fig. 1.

### 4.2. Calculation of $SAIDI_{SYS}$, $CAIDI_{SYS}$ and $ENS_{SYS}$

In order to determination of $SAIDI_{SYS}$, $CAIDI_{SYS}$ and $ENS_{SYS}$, at first, these indices are calculated for each load level using (1), (3) and (6), respectively. Then, these indices are determined using the following equations:

$$SAIDI_{SYS} = \sum_{L} W_L SAIDI_L \quad (9)$$

$$CAIDI_{SYS} = \sum_{L} W_L CAIDI_L \quad (10)$$

$$ENS_{SYS} = \sum_{L} W_L ENS_L \quad (11)$$

$W_L$: weight factor for each load level (in this paper, it is considered based on the duration of each load level in the load duration curve), L: number of load levels.

## 5. OPTIMAL DG ALLOCATION AND SIZING METHODOLOGY

Great attention should be rendered to the DG placement and sizing problem. The installation of DG units at non-optimal places has a negative effect on the desired goal. So, the development of an optimization method that can determine the optimal DG unit allocation and sizing improving the system operation characteristics seems necessary for the system planning engineer dealing with the increase of DG penetration that is happening nowadays. This improvement is resulted from the deterministic duration change at the load points.

### 5.1. GA optimization

A Genetic Algorithm (GA) is a programming technique that mimics biological evolution as a problem-solving strategy. Based on Darwinian's principle of evolution and survival of fittest to optimize a population of candidate solutions towards fitness. GA uses an evolution and natural selection that use a data structure like chromosomes and evolve the chromosomes, using selection, crossover, and mutation operators. The process starts with a random population of chromosomes, which represent all possible solutions of a problem that are considered candidate solutions. The size of the population depends on the size and the nature of the problem.

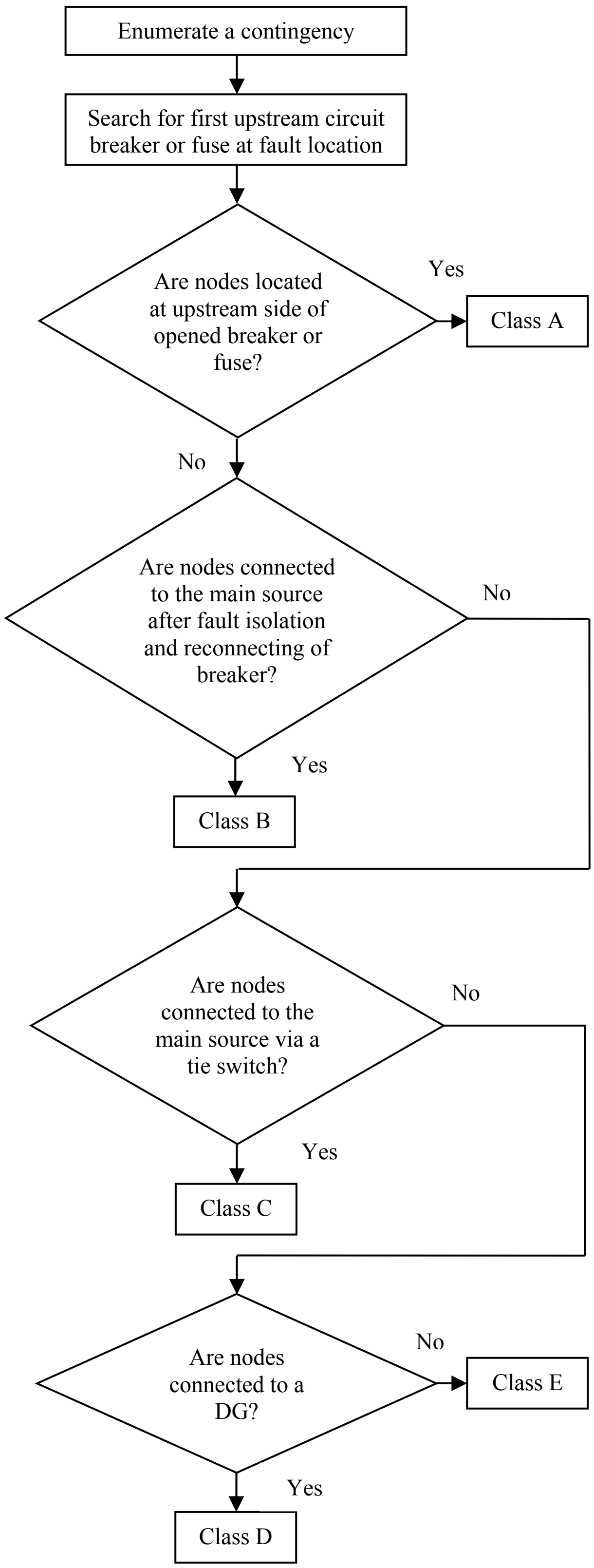

**Fig. 1.** Flowchart for identifying classes of nodes.

The positions of each chromosome are encoded as characters or numbers and could be referred to as genes. Then, according to the desired solution, an evaluation function is used to calculate the goodness of each chromosome known as “Fitness Function”. Two basic operators, crossover and mutation, are used to simulate the natural reproduction and mutation of species during evaluation. The main aim of crossover is to search the parameter space, and it is the most important operator in GA. The crossover operator takes two strings from the old population and exchanges the next segment of their structures to form the offspring. The function of mutation is used to prevent the loss of the information. Mutation can keep the population more diverse, so that it alters a string locally to create a better string. Once the new proportion is completed, the program will continue to generate new population. The iteration can be stopped while no further significant change during the solution occurs or when the specified number of iteration is reached [14].

The selection of chromosomes for survival and combination is biased towards the fittest chromosomes. A GA generally has four components. A population of individuals represents a possible solution. A fitness function which is an evaluation function by which we can tell if an individual is a good solution or not. A selection function decides how to pick good individuals from the current population for creating the next generation. Genetic operators such as crossover and mutation, which explore new regions of search space, keep some of the current information at the same time. In this paper, mutation probability and crossover probability considered as 0.2 and 0.8, respectively. The flowchart of GA is presented in Fig. 2.

### 5.2. Objective Function

The main objective of the proposed optimization is to find the optimal location and size of DGs in distribution networks to improve reliability. An annual load duration curve is used to obtain more accurate solution. At each load level, reliability assessment is also considered for calculation of reliability indices. The objective functions (OF) used in the proposed optimization are as follows:

$$\text{Min } \{SAIDI_{SYS}\} \tag{12}$$

$$\text{Min } \{CAIDI_{SYS}\} \tag{13}$$

$$\text{Min } \{ENS_{SYS}\} \quad (14)$$

These objective functions optimized, separately, subject to the following constraints:

1) Protection works in the new configuration [15]. The system configuration may alter due to switching operations did during the restoration.

2) Switching operations do not cause any over load, under voltage, or unbalance problems that exceed the system limits.

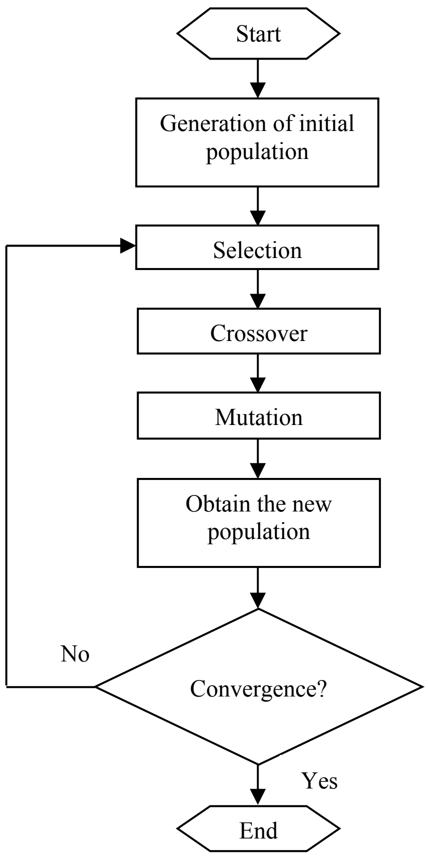


**Fig. 2.** Simple GA flowchart.

## 6. CASE STUDY

33 buses test system is used to examine the effectiveness of DG installation on distribution system reliability. Single line diagram of the 12.66 kV, 33-bus, 4-lateral radial distribution system is shown in Fig. 3. Furthermore, annual load duration curve with four load levels (light, medium, heavy and peak load) are considered for used for determination of size and location of DGs and presented in Fig. 4.

Total load on the system in the heavy load level is (3715+ j 2300) kVA [16]. Weighting factors used in the objective functions is selected proportion of duration of each load level in load duration curve and represented in Table 2.

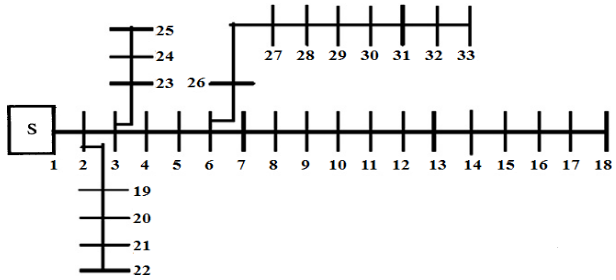


**Fig. 3.** Single line diagram of a 33-bus radial distribution system.

Because of having more duration for heavy load level, this load level is more important than other levels, for example.

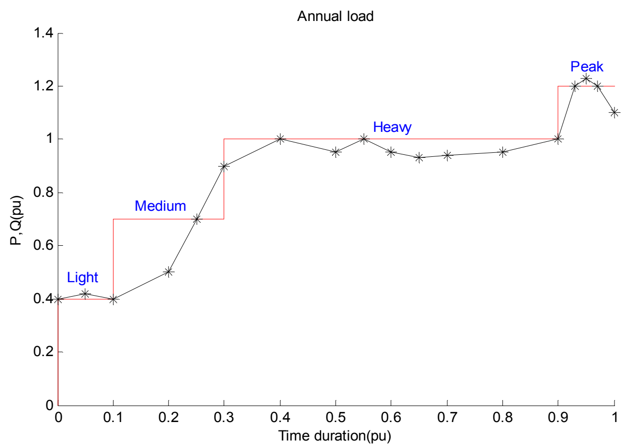


**Fig. 4.** Annual load duration curve for 33 bus distribution system.

**Table 2.** Weight factors for different load levels.

| $W_1$ | $W_2$ | $W_3$ | $W_4$ |
|---|---|---|---|
| 0.1 | 0.2 | 0.6 | 0.1 |

Reliability parameters are taken from the RBTS-BUS2 [17] (length of all feeders is considered to be 0.75 km). Furthermore, normally open data switches is taken from [16]. Restoration time (hour) of classes, B, C, D, and E in the test systems is considered as below [18], [19], [20]:

$r_B = 1$, $r_C = 1.2$, $r_D = 1.6$ and $r_E = 5$.

It should be noted that for optimization problem, two DGs are considered, and maximum active and reactive power generation for each DG are considered 200 kW and 100 kVar, respectively. Furthermore, the objective functions for each case in the test system considered based on $SAIDI_{SYS}$, $CAIDI_{SYS}$ and $ENS_{SYS}$, separately and different cases are considered as follows:

Case ‘1’: test system for the base case without DGs and tie switches;

Case '2': test system without tie switches considering DGs;
Case '3': test system without DGs considering tie switches;
Case '4': test system considering both of DGs and tie switches.

Table 3 shows the results of determination of optimum size and location of two DGs using genetic algorithm based on $SAIDI_{SYS}$, $CAIDI_{SYS}$ and $ENS_{SYS}$ as objective function, separately. Furthermore, the other reliability indices of 33 bus test system considering $SAIDI_{SYS}$, $CAIDI_{SYS}$ and $ENS_{SYS}$ as objective function for different cases are shown in Table 4, Table 5 and Table 6, respectively. It can be seen from these tables that each of DGs installation (case 2) and network reconfiguration (case 3) methods can improve reliability indices, separately.

**Table 3.** Optimum size and location of DGs.

| Objective Function | Location | Size | |
|---|---|---|---|
| | Node | P(Kw) | Q(Kvar) |
| $SAIDI_{sys}$ | 5 | 131.1481 | 17.1187 |
| | 32 | 190.0444 | 64.6352 |
| $CAIDI_{sys}$ | 21 | 169.8259 | 27.6923 |
| | 17 | 190.0444 | 64.6313 |
| $ENS_{sys}$ | 9 | 172 | 97 |
| | 32 | 168 | 39 |

For example, it can be seen from table 4 that using DGs installation with optimum size and location (case 2) SAIDI, CAIDI, ENS, ASAI, and ASUI are improved from 5.3314, 3.9028, 18646, 0.9994, and $6.0861*10^{-4}$ (case 1) to 4.8804, 3.7888, 17731, 0.9994, and $5.5712*10^{-4}$ , respectively. Also, it is observed that these indices are improved to 4.3081, 3.1223, 16630, 0.9995, and 4.9179 (case 3). Moreover, the obtained results shows that using both of DGs installation and network reconfiguration methods causes to more reliability improvement on the test system. For example, table 4 shows that SAIDI, CAIDI, ENS, ASAI, and ASUI are improved to 3.7307, 2.8667, 15442, 0.9996 and $4.2587*10^{-4}$, respectively.

Furthermore, similar to Table 4, the same results are concluded from Table 5 and Table 6 in different cases. It should be noted that since there is one breaker in the system, any outage in the system may result in the breaker action. Therefore, by network reconfiguration, the frequency indices such as SAIFI are not changed for case 3, but because of considering one breaker for each DG, this index is improved for case 2 as shown in Table 4, Table 5 and Table 6.

The summary of reliability indices improvements in different cases based on different objective functions are presented in Table 7. Similar to Table 4, Table 5, and Table 6, the results of Table 7 show that reliability indices are improved by DGs installation or network reconfiguration methods, separately.

Furthermore, it is observed that using DGs installation and network reconfiguration methods, simultaneously, has

**Table 4.** Reliability indices of 33 bus test system considering $SAIDI_{SYS}$ as objective function.

| Different cases | | SAIDI [hr/cus.yr] | SAIFI [int./cus.yr] | CAIDI [hr/cus.int] | ENS [kWhr/yr] | ASAI | ASUI $*10^{-4}$ |
|---|---|---|---|---|---|---|---|
| 1 | Without DG&Tie switch | 5.3314 | 1.3614 | 3.9028 | 18646 | 0.9994 | 6.0861 |
| 2 | Without Tie switch With DG | 4.8804 | 1.2841 | 3.7888 | 17731 | 0.9994 | 5.5712 |
| 3 | Without DG With Tie switch | 4.3081 | 1.3614 | 3.1223 | 16630 | 0.9995 | 4.9179 |
| 4 | With DG&Tie switch | 3.7307 | 1.2841 | 2.8667 | 15442 | 0.9996 | 4.2587 |

**Table 5.** Reliability indices of 33 bus test system considering $CAIDI_{SYS}$ as objective function.

| Different cases | | SAIDI [hr/cus.yr] | SAIFI [int./cus.yr] | CAIDI [hr/cus.int] | ENS [kWhr/yr] | ASAI | ASUI$*10^{-4}$ |
|---|---|---|---|---|---|---|---|
| 1 | Without DG&Tie switch | 5.3314 | 1.3614 | 3.9028 | 18646 | 0.9994 | 6.0861 |
| 2 | Without Tie switch With DG | 5.3037 | 1.36 | 3.6974 | 18647 | 0.9994 | 6.0545 |
| 3 | Without DG With Tie switch | 4.3081 | 1.3614 | 3.1223 | 16630 | 0.9995 | 4.9179 |
| 4 | With DG&Tie switch | 3.8983 | 1.36 | 2.8442 | 15824 | 0.9996 | 4.4502 |

**Table 6.** Reliability indices of 33 bus test system considering $ENS_{SYS}$ as objective function.

| Different cases | | SAIDI [hr/cus.yr] | SAIFI [int./cus.yr] | CAIDI [hr/cus.int] | ENS [kWhr/yr] | ASAI | ASUI*$10^{-4}$ |
|---|---|---|---|---|---|---|---|
| 1 | Without DG&Tie switch | 5.3314 | 1.3614 | 3.9028 | 18646 | 0.9994 | 6.0861 |
| 2 | Without Tie switch With DG | 4.8804 | 1.2841 | 3.7888 | 17731 | 0.9994 | 5.5712 |
| 3 | Without DG With Tie switch | 4.3081 | 1.3614 | 3.1223 | 16630 | 0.9995 | 4.9179 |
| 4 | With DG&Tie switch | 3.7307 | 1.2841 | 2.8667 | 15442 | 0.9996 | 4.2587 |

**Table 7.** The system reliability indices improvements in different cases base on different objective functions.

| Different cases | Improvement (%) | | |
|---|---|---|---|
| | $SAIDI_{SYS}$ | $CAIDI_{SYS}$ | $ENS_{SYS}$ |
| Without Tie switchWith DG | 8.5 | 5.26 | 4.9 |
| Without DG With Tie switch | 19.19 | 20 | 10.8 |
| With DG&Tie switch | 30.024 | 27.12 | 17.18 |

a considerable effect on reliability improvement.

## 7. CONCLUSIONS

In this paper, optimum size and location of DGs for reliability improvement considering time varying loads are determined using genetic algorithm. For this purpose, an annual load duration curve, including four load levels with different weighting factor is considered. For determination of optimum size and location of DGs, customer-oriented reliability indices such as SAIDI and CAIDI and also, load-oriented and energy-oriented indeces such as ENS are used as objective functions in genetic algorithm, separately. Furthermore, the effects of system reconfiguration and load shedding are considered for reliability assessment. For simulation purpose, a 33 nodes distribution system is selected, and different cases are considered. The obtained results show that DGs installation and network reconfiguration methods resulted in reliability improvement, separately. Using both methods, simultaneously, improved reliability indices, significantly.

## 8. APPENDIX

**Table 8.** Line information.

| Sending bus | Receiving bus | R (Ω) | X (Ω) | λ |
|---|---|---|---|---|
| 0 | 1 | 0.0922 | 0.0470 | 0.0650 |
| 1 | 2 | 0.4930 | 0.2511 | 0.0650 |
| 2 | 3 | 0.3660 | 0.1864 | 0.0488 |
| 3 | 4 | 0.3811 | 0.1941 | 0.0390 |
| 4 | 5 | 0.8191 | 0.7070 | 0.0650 |
| 5 | 6 | 0.1872 | 0.6188 | 0.0520 |
| 6 | 7 | 0.7114 | 0.2351 | 0.0650 |
| 7 | 8 | 1.0300 | 0.7400 | 0.0488 |
| 8 | 9 | 1.0440 | 0.7400 | 0.0488 |
| 9 | 10 | 0.1966 | 0.0650 | 0.0488 |
| 10 | 11 | 0.3744 | 0.1238 | 0.0650 |
| 11 | 12 | 1.4680 | 1.1550 | 0.0650 |
| 12 | 13 | 0.5416 | 0.7129 | 0.0488 |
| 13 | 14 | 0.5910 | 0.5260 | 0.0390 |
| 14 | 15 | 0.7463 | 0.5450 | 0.0650 |
| 15 | 16 | 1.2890 | 1.7210 | 0.0520 |
| 16 | 17 | 0.7320 | 0.5740 | 0.0650 |
| 1 | 18 | 0.1640 | 0.1565 | 0.0488 |
| 18 | 19 | 1.5042 | 1.3554 | 0.0488 |
| 19 | 20 | 0.4095 | 0.4784 | 0.0488 |
| 20 | 21 | 0.7089 | 0.9373 | 0.0650 |
| 2 | 22 | 0.4512 | 0.3083 | 0.0650 |
| 22 | 23 | 0.8980 | 0.7091 | 0.0488 |
| 23 | 24 | 0.8960 | 0.7011 | 0.0390 |
| 5 | 25 | 0.2030 | 0.1034 | 0.0650 |
| 25 | 26 | 0.2842 | 0.1447 | 0.0520 |
| 26 | 27 | 1.0590 | 0.9377 | 0.0650 |
| 27 | 28 | 0.8042 | 0.7006 | 0.0488 |
| 28 | 29 | 0.5075 | 0.2585 | 0.0488 |
| 29 | 30 | 0.9744 | 0.9630 | 0.0488 |
| 30 | 31 | 0.3105 | 0.3619 | 0.0650 |
| 31 | 32 | 0.3410 | 0.5302 | 0.0650 |

**Table 9.** Bus information

| Bus number | P(KW) | Q(KVar) | N_Customer | Customer Types |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | - |
| 1 | 120 | 72 | 210 | Residential |
| 2 | 108 | 48 | 210 | Residential |
| 3 | 144 | 96 | 210 | Residential |
| 4 | 72 | 36 | 1 | Government & Institution |
| 5 | 72 | 24 | 1 | Government & Institution |
| 6 | 240 | 120 | 10 | Commercial |
| 7 | 240 | 120 | 10 | Commercial |
| 8 | 72 | 24 | 1 | Industrial |
| 9 | 72 | 24 | 1 | Industrial |
| 10 | 54 | 36 | 210 | Residential |
| 11 | 72 | 42 | 210 | Residential |
| 12 | 72 | 42 | 200 | Residential |
| 13 | 144 | 96 | 1 | Government & Institution |
| 14 | 72 | 12 | 1 | Government & Institution |
| 15 | 72 | 24 | 10 | Commercial |
| 16 | 72 | 24 | 10 | Commercial |
| 17 | 108 | 48 | 200 | Residential |
| 18 | 108 | 48 | 200 | Residential |
| 19 | 108 | 48 | 200 | Residential |
| 20 | 108 | 48 | 1 | Government & Institution |
| 21 | 108 | 48 | 1 | Government & Institution |
| 22 | 108 | 60 | 10 | Commercial |
| 23 | 504 | 240 | 1 | Large user |
| 24 | 504 | 240 | 1 | Large user |
| 25 | 72 | 30 | 1 | Agriculture |
| 26 | 72 | 30 | 1 | Agriculture |
| 27 | 72 | 24 | 1 | Agriculture |
| 28 | 144 | 84 | 1 | Large user |
| 29 | 240 | 720 | 1 | Industrial |
| 30 | 180 | 84 | 1 | Large user |
| 31 | 252 | 120 | 20 | Office & Building |
| 32 | 72 | 48 | 20 | Office & Building |

**Table 10.** Tie switch information

| Sending bus | Receiving bus | R (Ω) | X (Ω) |
|---|---|---|---|
| 7 | 20 | 2 | 2 |
| 8 | 14 | 2 | 2 |
| 11 | 21 | 2 | 2 |
| 17 | 32 | 0.5 | 0.5 |
| 24 | 28 | 0.5 | 0.5 |

**Table 11.** SCDF data.

| r(time) (min) | Large Users ($/kw) | Industrial ($/kw) | Commerical ($/kw) | Agriculture ($/kw) | Residential ($/kw) | Govermment & Institutions ($/kw) | Office & Building ($/kw) |
|---|---|---|---|---|---|---|---|
| 1 | 1.005 | 1.625 | 0.381 | 0.06 | 0.001 | 0.044 | 4.778 |
| 20 | 1.508 | 3.868 | 2.969 | 0.343 | 0.093 | 0.369 | 9.878 |
| 60 | 2.225 | 9.085 | 8.552 | 0.649 | 0.482 | 1.492 | 21.065 |
| 240 | 3.968 | 25.163 | 31.317 | 2.064 | 4.914 | 6.558 | 68.83 |
| 480 | 8.240 | 55.808 | 83.008 | 4.12 | 15.69 | 26.04 | 119.16 |

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