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*Research Paper*

# AN INVESTIGATION OF THE IMPACT OF SIZE AND LOCATION OF DG ON SYSTEM RELIABILITY BY EMPLOYING SEQUENTIAL MONTE CARLO SIMULATION

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In recent years, the application of Distributed Generators (DG) is increasingly growing in the power systems. Moreover, it is predicted that it will play a significant role in future distribution systems. Nevertheless, incorporating DG into the distribution system alters the structure of the distribution system. This change could have either positive or negative impact on the system reliability which could be determined by DG's size and location. This paper proposes sequential Monte Carlo simulation to evaluate the reliability indices. Moreover, the Genetic Algorithm (GA) is utilized to determine the optimal location and size of DG based on reliability indices. The objective function of the aforementioned optimization algorithm is the loss minimization and confining within the voltage constraints. This paper presents electric system reliability analysis. Additionally, the optimal size and location of DG is determined with considering the loss and voltage constraints. Moreover, by employing Monte Carlo simulation, the distribution of reliability indices is calculated in addition to the average and expected values.

Keywords: Distributed Generation (DG), System reliability, Sequential monte carlo simulation, Genetic algorithm (GA)

## INTRODUCTION

In recent years, the application of Distributed Generators (DG) is increasingly growing in the power systems. This increasing attention stems from many benefits of distributed generators such as peak reduction, improved power quality and reliability, and increased efficiency (Davoudi *et al.*, 2014). Moreover, there are sundry reasons such as growing rate of the population and load demands, environmental issues of licensing traditional power plants and transmission lines investments as well as emerging very efficient small capacity generation technologies that

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pave the way for the ever increasing presence of DGs (Popovic *et al.*, 2005).

DG is usually defined as a small electric power source connected to distribution networks or alternatively to the consumers' side of the meter. However, there is not any consensus in this regards and the definition varies in different documents.

DGs potentially could create many benefits to the power systems. However, it should be noted that these positive effects are significantly hinged on the proper allocation and sizing of these units. Provided the proper size and location, DGs can benefits the system in remarkable ways such as compensating the reactive power to achieve voltage control, reducing the transmission loss, preventing the outage by providing spinning reserve, and also bringing access to the renewable energies and its consequent positive environmental impacts (Borges *et al.*, 2006; and Davoudi *et al.*, 2012).

One of the main benefits of DGs is improvement of reliability in distribution system. Therefore, it is in the best interest of both DG owners and the system operators to allocate and calculate the size and location of DG in an optimal way. If so, the system reliability would be improved and the losses in the system would be minimized (Moghadasi *et al.*, 2008, 2014 and 2015).

Moreover, the reliability is the major factor in planning and scheduling of DG application in distribution systems. Therefore, for a system operator, it is very important to study different methods of DG allocation and find their impact on the system reliability. In this paper, it is tried to evaluate the reliability for different DG allocation scenarios. Generally, there are two main approaches to calculate the system reliability, namely, analytical approach and simulation approach. Analytical approach relies on the theory and gives a deterministic results whereas simulation approach benefits from both deterministic and stochastic methods. In this paper, a sequential Monte Carlo simulation technique is employed to evaluate the system reliability indices in the presence of DGs in the distribution system. Monte Carlo prediction methods are considered as a full Temporal difference method, which do not require a model of the environment (Yousefian *et al.*, 2014). It worth mentioning that analytical reliability evaluation could only evaluates expected or average value of reliability indices. However, for detailed study of the reliability, more nuances are necessary. Therefore, in order to obtain the actual shape of the distribution of reliability indices a simulation approach should be utilized (Mohseni *et al.*, 2011). In this paper, Monte Carlo simulation as a stochastic technique is employed. Moreover, the Genetic Algorithm (GA) is utilized to determine the optimal location and size of DG based on reliability indices. The objective function of the aforementioned optimization algorithm is the loss minimization and confining within the voltage constraints.

## IMPACT OF DISTRIBUTED GENERATIONS ON RELIABILITY

Distribution systems are designed on the assumption that electric power flows unidirectional. In another word, it flows from the source (power plants) through the transmission and distribution system to the load. Therefore, if this unidirectional scheme changes because of the output fluctuations or a reverse flow from generators, there is likely to be some influence on the overall system performances in terms of power quality or protection and safety. Moreover, in this case because of DGs, the distribution system becomes an active system with both energy generation and consumption (Popovic *et al.*, 2005; and Thong *et al.*, 2005). Therefore, the installation of DGs in the distribution system could potentially affect the structure of power systems significantly in terms of power, voltage and reliability indices. This change could either be positive or negative. It is positive if the change is correctly coordinated with the rest of the network. Otherwise, it may pose serious issue to the system. There are many applications found for DG, among others, in what follows two main applications of DGs are illustrated (Yousefian *et al.*, 2011).

### Peak Shaving

There are two occasions in the distribution system that the peak time consumption is troublesome. First, when the capacity of the distribution feeders connecting the main generation to the load are limited and lower than feeder's demand in the peak time. Second, when there is a need of flexible reaction to electricity price evolutions in the presence of demand response programs. Demand response programs are newly emerged conceptual programs that offer real time pricing to the retail customers (Arani *et al.*, 2011; and Mohajeryami *et al.*, 2015).

In these occasions, DGs can support part of the demand and lower the feeders' burden or serve as a hedge against the price spikes in demand response programs. These two application are the major drivers for the US demand for distributed generation, i.e. using distributed generation for continuous use or for peaking shaving purposes.

Distributed generations as main or emergency generations improve both types of reliability indices of duration and number of failures. Interruption occurs when both main generation and DG generation fail to meet the demand.

### Generation Back-Up

Another common application of DG is generation back up. In this application, DG will serve the critical after the failure of the main generation. If a fault occurs somewhere in the power systems and the failure of generation ensue, some of load points would be disconnected from the main generation source. These loads can be served by DGs in an isolated manner. This disconnection is also called intentional islanding. Islanding lets the un-faulted part of the network be served by DGs and it plays a key role in active networks (Pilo *et al.*, 2004).

In this application of DGs, reliability indices of failure's duration are merely improved. Moreover, if any fault in main generation causes interruption, DG could come into the play and increases the restoration capacity of system.

### Monte Carlo Simulation and its Application in Reliability Analysis

The random behavior of system components imposes a stochastic characteristic to the system performance as a whole (Moghaddam *et al.*, 2014 and 2015; and Mohajeryami *et al.*, 2015). In a real system experiment, the occurrence is determined by intrinsic behaviors of factors and input variables, while in simulation, events are determined by different models and types of probability distribution associated with different system components. These stochastic functions are used to model the input variables and the component behavior.

A sequential simulation technique is deployed in this paper to comprehensively include the chronological behavior of the system. This method resembles a series of experiments. There are advantages and disadvantages associated with the analytical and Monte Carlo simulation approaches. Monte Carlo simulation generally requires a large amount of computation time (Borges *et al.*, 2006). However, the ability to provide reliability index probability distribution is a significant advantage for sequential Monte Carlo simulation. This method yields the probability distribution for bulk electric system in addition to the expected values of the indices.

The utilization of probability distribution reliability indices is relatively new in composite power systems adequacy analysis and decision making. The utilization of probability distribution indices addresses the frequent need to identify the range of predictive reliability and evaluates the probability of violating specific limits (Wangdee *et al.*, 2005).

## Monte Carlo Simulation Algorithm

The implementation steps for Monte Carlo simulation are explained in this section. The most difficult problem of this procedure is to identify the load points influenced by the failure of *n* specific element. It is also required to calculate the restoration time. However, these values are dependent on the network configuration. For instance, the failure of a specific element may affect only one, or it may lead to multiple load point isolation. The implementation steps are summarized as follows:

1. The initial operating state of each element is specified. The default is that the all elements are considered in operation mode.
2. A random number is generated for each element of the system, which varies between 0 and 1.
3. The probability distribution of $T_{on}$ is considered as an exponential function. For each component, the duration of remaining in the present state ($T_{on}$) is sampled from this probability distribution.
4. To identify the first failure in the system, $T_{on}$ of all components are compared, and the element associated with the least $T_{on}$ is determined as the first system failure.
5. Protective elements alongside the failure point isolate the failed component to save remaining parts of the network. The time between failure and completion of switching is notified as $T_{sw}$. A uniform random number is assigned for protective component, and $T_{sw}$ is generated using an appropriate distribution function.
6. The down time for elements that could not survive after protective actions are shown by $T_{off}$. A uniform random number is assigned to the failed component using the appropriate distribution function.

$$T_{on} = \frac{1}{a}.\ Ln(U) \quad ...(1)$$

$$T_{off} = \frac{1}{\mu} . Ln(U') \quad ...(2)$$

where λ and μ respectively show the failure and repair rates of the element while U and Ú are uniform random numbers.

In Figure 1 operating and repairing cycle calculated with Equations 1 and 2 is illustrated.

7. Calculate up and down times and also the total number of failure points. Then, return to the first step.
8. The parameters necessary for the calculation of reliability indices such as λ, r and U and also SAIFI, CAIDI and ENS could be calculated as follows:

$$\lambda_i = \frac{N_i}{\sum T_{on_i}} \quad ...(3)$$

$$\mu_i = \frac{\sum T_{off_i}}{N_i} \quad ...(4)$$

$$SAIFI = \frac{\sum \lambda_i N_i}{\sum N_i} \quad ...(5)$$

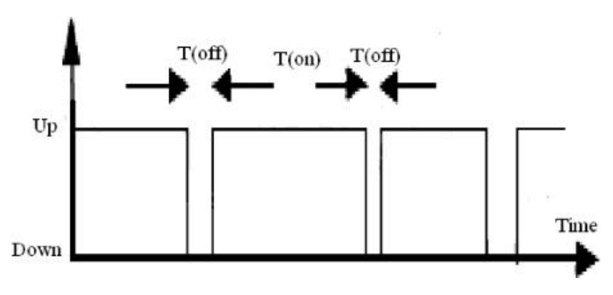
$$CAIDI = \frac{\sum U_i N_i}{\sum \mu_i N_i} \quad ...(6)$$

$$ENS = \sum L_{a(i)} U_i \quad ...(7)$$

Where $\lambda_i$ is the failure rate, $N_i$ is the number of customers at load point i, $U_i$ is the annual outage time, and $L_{a(i)}$ is the average load connected to load point i.

9. In each step, a stopping rule could be utilized in order to extract target simulation results (Billinton *et al.*, 1999; and Wangdee *et al.*, 2005).

Figure 1: Operating and Repairing Time




## Application of Distributed Generations for Reliability Improvement

Optimization methods are strong tools to improve operations in distribution power systems. These methods (from linear programming to robust and stochastic) help planner to reach their predefined goals by searching among different plans and opting the best one. Size and complexity of planning and operating problems will be increased by adding distributed generations in distribution level network. In other words, optimization problem in presence of DG is become more complicated. One of the most common heuristics methods of optimization is Genetic Algorithm which deal with high volume of variables better than common iterative methods. Many works in DG and capacitor placement, Economic Dispatch has been done in the literature by various iterative and heuristic methods like GA, PSO, Clonal Algorithm (Elyas *et al.*, 2011 and 2013; and Nejad *et al.*, 2012).

Adding more distributed generators in feeders lead to this fact that feeder load may be satisfied after fault isolation (Pregelj *et al.*, 2002; and Ehsani, 2010). Moreover, by adding more DG units in distribution power networks, power injection of feeder will be more affected.

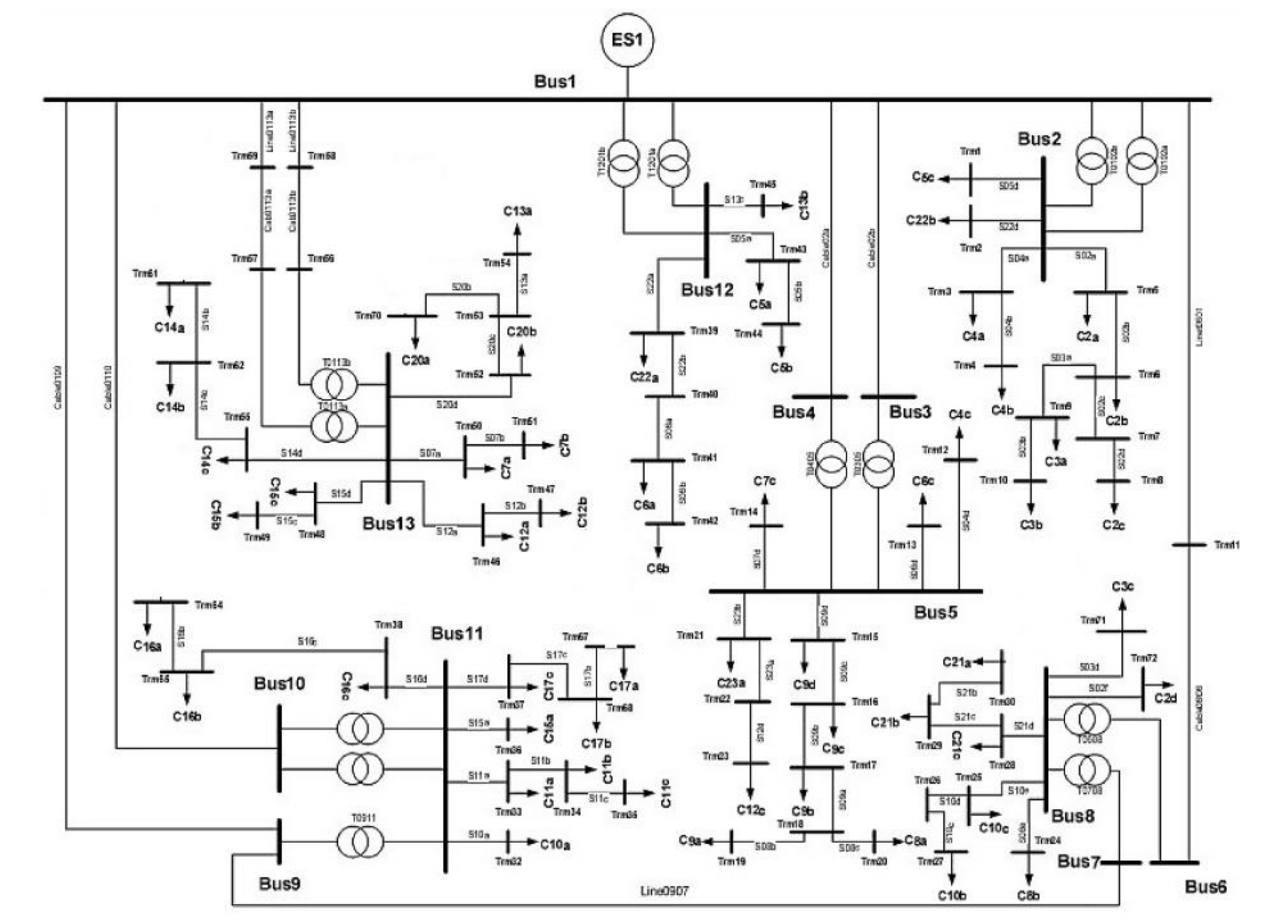
Consequently, power flows and losses will be changed according to changes in generations. In this paper, Matpower is chosen as the simulation tools. All appropriate and necessary constraints and considerations have been taken into the account in Matpower.

DG placement and sizing is one of the most important factors in reliability assessment. DG placement at non-optimal locations will increase losses and costs. Also, non-optimal DG placement results in dramatic reduction of reliability indices. Needless to say, utilizing an optimization methodology in order to find the optimal size of DG and best places to install improves power network reliability and its operation characteristics. Optimal DG sizing and placement is the solution of trade-off between highest benefits and minimum capital and operational costs. In this paper, a methodology is presented to minimize size and optimize location of DGs to find the best solution to enhance reliability level and to minimize power losses and improve voltage profile.

## CASE STUDY

Reliability test case of DIgSILENT package is selected to evaluate the proposed approach (DIgSILENT, 2007). Single line diagram of the selected system is shown in Figure 2. This test case includes 85 buses and 78 distribution

Figure 2: Test System



level lines with 52.8 MW of total demand. Aforementioned test case lets system transfer loads in different lines when contingency happens.

DGs are placed and installed in 11 kV buses in this test case. Primary DGs of the selected reliability test case are not considered in this case study.

Monte Carlo simulation is carried out in distribution system. Reliability indices (failure rate and duration) for all load points are calculated through Equations 3-4. Other indices can be derived though Equations 5-7. The results are shown in Table 1.

Power flow calculation has also been done in Matpower to find primary and final range of feeders' voltages. The results are demonstrated in Table 2.

Table 1: Reliability Indices of Test System Without DGs

| Total Reliability Indices of Test System | | |
|---|---|---|
| **ENS (MWhr)** | **SAIFI (1/yr)** | **CAIDI (hr/yr)** |
| 34.2454 | 3.7063 | 30.6387 |

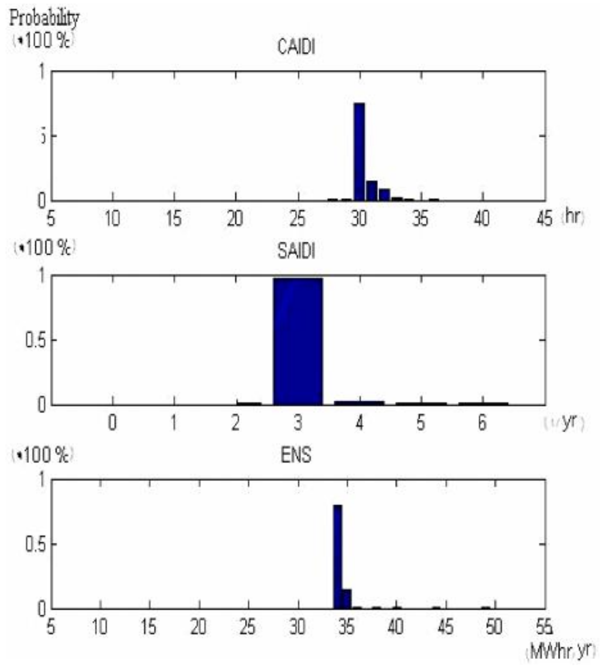
Table 2: Power Flow of Test System Without DGs

| Power Flow | |
|---|---|
| **Voltage Range (Pu)** | **Loss (MW)** |
| 0.9499-1 | 0.0622 |

Distribution profile of reliability indices is evaluated through Monte Carlo simulations which is one of the main benefits of Monte Carlo simulation. Distribution profile of CAIDI, SAIFI and ENS of test system without DG is shown in Figure 3.

By eliminating of some reliable buses (with high reliability indices), simulation's calculation

Figure 3: Distribution of System Reliability Indices Without DGs




time is considerably reduced. Therefore, number of buses for simulation is limited to 20 (those with lower reliability indices).

Candidate locations for DG placement is chosen by comparing the reliability indices of all loads (ENS, etc). Table 3 shows 20 worst buses which is listed based on their ENS index. The maximum DG locations is then decided to be 10. The first column is the substation number and the second column is the number of load point in corresponding substation. In Figure 4, ENSs of all buses are demonstrated. Critical buses and candidates for DG placement are studied based on the buses over the crucial lines.

In order to select the DG size and locations which satisfy the loss and voltage criteria, GA is employed by using Matpower software (Davoudi *et al.*, 2012). The allowable values of voltage magnitudes are between 0.95 and

Table 3: Reliability Indices of Critical Load Points

| Substation Number | Bus Number | $ENS_i$ (MWhr) | a(1/yr) | r(hr) |
|---|---|---|---|---|
| 1 | 1 | 0.057 | 5.1146 | 0.67 |
| 2 | 3 | 0.1132 | 9.275 | 0.525 |
| 3 | 1 | 0.0539 | 5.6037 | 0.6642 |
| 4 | 1 | 0.0614 | 4.6654 | 0.5441 |
| 4 | 8 | 0.0618 | 5.2965 | 0.6871 |
| 4 | 9 | 0.1182 | 3.2811 | 0.5815 |
| 4 | 10 | 0.1182 | 4.0729 | 0.5775 |
| 5 | 5 | 0.0668 | 6.6513 | 0.7998 |
| 5 | 6 | 0.1126 | 10.5846 | 1.6687 |
| 5 | 9 | 0.1138 | 11.4029 | 1.0382 |
| 6 | 1 | 0.2539 | 18.1147 | 5.8196 |
| 6 | 2 | 0.2540 | 21.6214 | 0.5491 |
| 6 | 3 | 0.2540 | 23.1083 | 0.5869 |
| 6 | 4 | 0.2236 | 4.2940 | 1.1523 |
| 6 | 5 | 0.2236 | 4.7400 | 0.7420 |
| 6 | 6 | 0.2192 | 3.1018 | 1.0199 |
| 6 | 7 | 0.2192 | 3.0888 | 0.8125 |
| 6 | 8 | 0.2202 | 2.1641 | 0.5719 |
| 6 | 10 | 0.2786 | 2.3160 | 0.9034 |
| 6 | 11 | 0.2786 | 2.5659 | 1.5728 |

Figure 4: ENS of All Buses

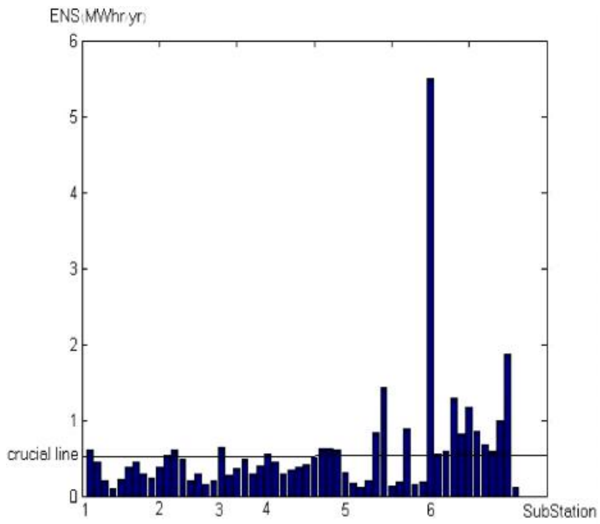



Table 4: Location and Size of DGs Calculated with GA

| DGs Location | | DGs Capacity (MW) |
|---|---|---|
| Substation Number | Bus Number | |
| 2 | 3 | 1.0952 |
| 3 | 1 | 1.9579 |
| 4 | 8 | 1.5130 |
| 4 | 10 | 2.0553 |
| 5 | 6 | 1.3375 |
| 5 | 9 | 0.9589 |
| 6 | 1 | 0.8704 |
| 6 | 4 | 2.39415 |
| 6 | 6 | 1.46732 |
| 6 | 11 | 3.22987 |

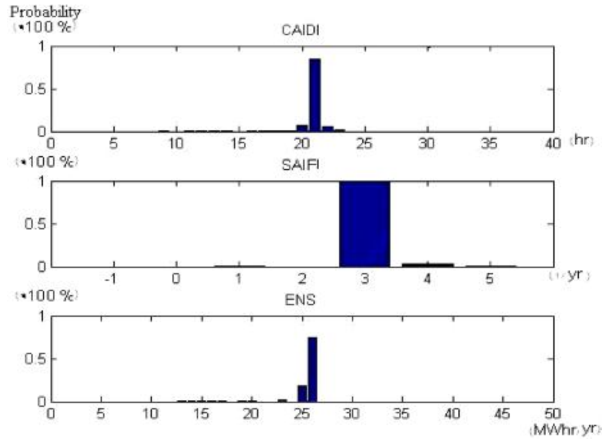
Table 5: Reliability Indices of Test System with DGs

| Total Reliability Indices of Test System | | |
|---|---|---|
| ENS (MWhr) | SAIFI (1/yr) | CAIDI (hr/yr) |
| 26.6664 | 3.6975 | 22.2614 |

Table 6: Power Flow of Test System with DGs

| Power Flow | |
|---|---|
| Voltage Range (Pu) | Loss (MW) |
| 0.9643-1 | 0.0384 |

Figure 5: Distribution of System Reliability Indices with DGs



1.05 per unit. Furthermore, the loss should be limited to 6% of total MW consumption of the distribution system. Table 4 shows the optimization results.

As shown in Table 5 and Table 6 reliability indices as well as loss and voltage levels are improved. The amount of loss is reduced to 61.8% of its initial amount.

Figures 3 and 5 shows the probability distribution of the reliability indices. Moreover, it represents how the parameters are scattered around their mean values probabilistically.

Comparing the SAIFI probability distribution in Figures 3 and 5 reveals that DGs have no influence on occurring the failure because of the same probability distribution shape both with and without DGs. However, comparing the values of CAIDI and ENS with and without DG verifies that these factors have probability distribution functions with lower mean values. This indicates that the reduction in restoring time, due to the backup generation, has improved CAIDI and ENS.

## CONCULSION

While DG can improve the reliability of distribution systems, optimum improvement can be sought through appropriate sizing and siting of DGs in the system. In this paper, a method is presented to optimally locate and size definite number of DG units in the system with special attention to critical load points with higher ENS values. The optimization is constrained by two important operating criteria of distribution systems, namely active losses and bus voltage limits. Evaluation of reliability indices is done by utilizing Monte Carlo simulation. Moreover, Genetic Algorithm is used to find the optimum solution. This paper presents electric system reliability analysis. Additionally, the optimal size and location of DG is determined with considering the loss and voltage constraints. Moreover, by employing Monte Carlo simulation, the distribution of reliability indices is calculated in addition to the average and expected values.

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