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Evaluation of the Reliability of Distribution System with Distributed Generation using ETAP

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Abstract: *Distributed Generation (DG) is an electric source connected directly to the distribution network. DG has been growing rapidly in deregulated power systems due to their potential solutions to meeting localized demands at distribution level and to mitigate limited transmission capacities from centralized power stations. In this paper effort has been made to study the impact of DG on the reliability of the distribution network. IEEE 33 Bus distribution network and Ran feeder from Bauchi distribution network were used for the study. Firstly, DGs were optimally sized and located in the networks using Modified Particle swarm optimization and ETAP software was used to model and evaluate the reliability indices. Two scenarios were considered. Scenario one was the integration of single DG and two was integration of two DGs. The results obtained showed that as the number of DG in the system increases the reliability of the system also increases.*

Keywords: *Distributed Generation, Reliability indices, Modified particle swarm optimization, ETAP.*

1. INTRODUCTION

Distributed Generation (DG) has been growing rapidly in deregulated power systems due to their potential solutions to meeting localized demands at distribution level and to mitigate limited transmission capacities from centralized power stations. Penetration of DG into an existing distribution system has so many impacts on the system. However, incorrect sizing and siting of DG sources in power system would jeopardize reliable system operation. Consequently, there is need to identify the optimal location and size of the DG to be installed in distribution network infrastructure.

In power systems, reliability evaluation can be defined as analyzing the ability of the system to satisfy the load demands. The Reliability computation of the whole system depends on the reliability of each component included in that system. Each component has two states, an operating state and a failed state. By specifying whether the component is operating or failed we can discern the status of the system. Reliability analysis and assessment are essential factors for the continuous operation of the system. The primary objective is to evaluate the impact of DG on the reliability of the system. IEEE 33 Bus distribution network and Ran feeder from Bauchi distribution network were used for the study. The optimal placement and sizing of DG was done using Modified Particle swarm optimization and ETAP software was used for the modeling and reliability evaluation.

Several studies have been conducted on the integration of DG in distribution networks and analysis of reliability of distribution system with DG. The authors in [1] realized the sitting of the wind and solar based DG, but the sizing of DG was not considered. An approach to find the optimum size of DG of three types at optimal power factor is presented in [2], the optimum location for the DG is not solved. A quantum particle swarm algorithm (QPSO) based method for optimal placement and sizing of wind and solar based Distributed Generation (DG) units in distribution system is presented in [3] however the reactive power compensation was not considered.

Johnson (2015) Presents a reliability analysis of the 11/0.415 kV substations at Ede town (Osun State, Nigeria), covering a period from March 2014 to February 2015. The findings serve as an aid to facilitate proper monitoring, maintenance and upgrade of substations. In this research, the distribution system reliability of the substations was analyzed using the different reliability indices. The data collected was used to evaluate the reliability indices of each substation under the study and the result showed that different customers experience different levels of reliability and availability of supply even if they are under the same feeder and/or substation.

Jibril and Ekundayo (2013) analyzed the reliability performance of the 33kV Kaduna Electricity Distribution Feeders, Northern Region, Nigeria. The monthly reliability parameters for the 33kV distribution feeders were calculated using the daily outage data of the feeders for 16 months (January, 2011 to December, 2012). The results of the analysis carried out showed that the system availability is low compared to the IEEE standard of ASAI which is 0.99989.

Sonwane and Kushare (2015) presented an overview of useful methods used in reliability analysis. In reliability study of distribution system development of accurate and consistent models to represent system behavior is always a main concern to researchers. In this paper, an overview is carried out for distribution system reliability for various substation configurations. Various reliability indices and reliability cost mentioned in literature are discussed in the paper.

The inclusion of aging components when using conventional reliability analysis as a means to better the reliability evaluation of distribution network was done by Wang and Wu (2011). The analysis carried out presented the relationship between aging components and their limit age (time). Failure Mode and Effect Analysis (FMEA) was used to calculate the reliability indices. A simple distribution network was generated and used for the research and the focus was on supply lines.

This work presents optimal placement and sizing of DG in a distribution network using MPSO and evaluation of the reliability of distribution network with DG using ETAP to address the issues identified.

2. PROBLEM FORMULATION

In this work the objective of the placement technique for the DG is to minimize the real power loss and to improve the voltage profile at the distribution level. The real power loss reduction in a distribution system is required for efficient power system operation.

The loss in the system can be calculated using (1) in [1], called the 'exact loss formula' given the system operating conditions. The objective of the placement technique is to minimize the total real power loss and improved voltage profile. Mathematically, the objective function can be written as:

$$Minimize\ \ P_L = \sum_{i=1}^{N} |I_i|^2 R_i \tag{1}$$

Subject to power balance constraints.

$$\sum_{i=1}^{N} P_{DGi} = \sum_{i=1}^{N} P_{Di} + P_L \tag{2}$$

$$Voltge\ Constraints: |V_i|^{min} \leq |V_i| \leq |V_i|^{max} \tag{3}$$

$$Currents\ Limits: \left|I_{ij}\right| \leq \left|I_{ij}\right|^{max} \tag{4}$$

where *i* is the number of bus, *N* is the total number of Buses, P_L is the real power loss in the system, P_{DGi} is the real power generation of DG at bus *i*, P_{Di} is the power demand at bus *i* , I_{ij} is the current between buses *i* and *j* and R_i is the resistance. The current I_i is determined from the load flow using Hybrid load flow studies Method called Backward – Forward and Newton Rhapson. For single source network all the power is supplied by the source but with DG that are optimally placed there is going to be reduction in power loss [1]. This reduction in power loss is determined as the difference of the power loss with DG and without DG. Thus, the new power loss in the network with DG is:

$$P_{L-new} = \sum_{i=1}^{N} |I_i^{new}|^2 R_i \tag{5}$$

$$P_{L-new} = \sum_{i=1}^{N} I_i^2 R_i - 2JI_i I_{DG} R_i - JI_i I_{DG}^2 R_i \tag{6}$$

where *j=1* for a feeder with DG or else *j = 0* Hence, the power loss reduction value for bus *i* with DG is obtained by subtracting (5) from (6) as;

$$PLR = P_{L-new} - P_L \tag{7}$$

$$PLR_i = -\sum_{i}^{N} (2JI_i I_{DG} R_i + JI_i I_{DG}^2) R_i \tag{8}$$

The bus that gives the highest value of PLR is selected as the optimal location of DG. The emphasis is to place the DG at a location that will give maximum loss reduction. To obtain the DG current that will give maximum loss reduction, equation (8) is differentiated with respect to I_{DG} and equated to zero, hence the current is given by equation (9) below.

$$I_{DG1} = -\frac{\sum_{i=1}^{n} I_{ai} R_i}{\sum_{i=1}^{n} R_i} \tag{9}$$

The procedure is repeated for all the buses in order to obtain the highest power loss reduction value as the DG units are singly located. Assuming there is no significant changes in the voltage as DG units are connected, the power that can be generated is

$$P_{DGi} = I_{DG}V_i \tag{10}$$

Where V is the voltage magnitude of the bus i and the optimum DG size is obtained from equation (10). The optimal location of the DG is bus i for maximum power loss reduction.

3. PARTICLE SWARM OPTIMIZATION (PSO)

Standard PSO is an attractive stochastic optimization technique, introduced by Dr. Kennedy and Dr. Eberhart in 1995. During each iteration of the algorithm, the velocity and position of each particles are updated by following equation (6) and (7) till the stopping criterion is met.

$$V_{m,n}^{new} = V_{m,n}^{old} + G_1 \times r_1 \times (P_{m,n}^{local\ best} - P_{m,n}^{old}) + G_2 \times r_2 \times (P_{m,n}^{global\ best} - P_{m,n}^{old}) \tag{6}$$

$$P_{m,n}^{new} = P_{m,n}^{old} + V_{m,n}^{new} \tag{7}$$

Where $V_{m,n}^{old}$ = Particle velocity, $P_{m,n}^{old}$ = Particle position, $r_1 = r_2$ independent uniform random number
$G_1 = G_2$ Learning Factors, $P_{m,n}^{local\ best}$ = Best local solution, $P_{m,n}^{global\ best}$ = Best global solution

3.1 Modified PSO (MPSO)

Standard PSO uses both current global best and the local best, represented by $P_{m,n}^{global\ best}$ and $P_{m,n}^{local\ best}$respectively to update the position and velocity. The purpose of local best is to increase the diversity in the quality solution. However, this same diversity can be simulated with some randomness. There is no need to use individual best until and unless the optimization problem of interest is highly non-linear. In a simplified version of PSO, the global best can accelerate the convergence of an optimization algorithm. Hence the velocity vector at k+1 iteration can be generated by the following equation (8).

$$V_{m,n}^{new} = V_{m,n}^{old} + \alpha \times randn\ (k) + \beta \times (P_{m,n}^{global\ best} - P_{m,n}^{old}) \tag{8}$$

Where α *and* β are the acceleration constants and *randn* is random variable with values from 0 to 1.
The update of the position at new iteration is simply by

$$P_{m,n}^{new} = P_{m,n}^{old} + V_{m,n}^{new} \tag{9}$$

Where m = 1, 2…y and n = 1, 2….z
In order to increase the convergence even further, we can write the update of position in single step as

$$P_{m,n}^{new} = (1-\beta)\ P_{m,n}^{old} + \beta P_{m,n}^{global} + \alpha\ randn\ (k) \tag{10}$$

The values of α is from 0.1 to 0.5 and the value of β is from 0.1 to 0.7.

3.2 MPSO Implementation

Optimal DG placement and sizing to reduce the power loss in distribution system using MPSO based method takes the following steps.
Step 1. Read the input data including bus data and branch data, base voltage, base MVA, desired accuracy (1×10^{-3}) of system.
Step 2. Calculate the power loss of each branch and voltage of each node using forward backward load flow.
Step 3. Set the number of iteration, number of particles, α *and* β values.
Step 4. Generate the initial population randomly for velocity v_i and position p_i.
Step 5. Calculate total power loss for each particle using forward backward load flow.
Step 6. Check out the system constraints.
Step 7. Compare the objective function from individual best for each particle.
Step 8. Select the particle associated with lowest individual pbest and set this value as gbest.
Step 9. Update the particle's velocity.
Step 10. Update the particle's position.

Step 11. Check the number of iteration reaches to the final value, if it so then go to next step otherwise go step 6 for k = k+1.
Step 12. Print the optimal solution. This will be the best solution for optimal placement and sizing of DG in radial distribution system.

4. RELIABILITY EVALUATION

The term reliability means the ability of the system to perform its intended function, where the past analysis helps to estimate future performance of the system. Reliability is the probability of a device or system performing its function adequately, for the period of time intend, under the specified operating conditions.[9] System reliability can be computed from the failure probability of the composite power system due to outage of lines, transformers and generators. There may be more than one failure condition for outage of a line, transformer or generator.

Results from a reliability study can be expressed using different reliability indices. There are many possible reliability indices, which often are interdependent [6]. In order to reflect the severity or significance of a system outage, reliability indices are evaluated. Depending on the application, a suitable set of indices has to be chosen, to perform the reliability evaluation. It is fairly common practice in the electric utility industry to use the standard IEEE reliability indices like CAIDI, SAIFI, SAIDI to track and benchmark reliability performance. These reliability indices include measures of outage duration, frequency of outages, system availability and response time. The standard deviation of the reliability indices provides distribution engineers with information on the expected range of the annual values [6]. The evaluation of reliability indices for a composite system is very much computationally demanding.

SAIFI: System average interruption frequency index
The SAIFI index gives information about how often these interruptions occur on the average for each customer.

$$SAIFI=\frac{Total\ number\ of\ all\ interruptions}{Total\ number\ of\ customers\ connected}(f/c/r) \tag{11}$$

SAIDI: System average interruption duration index
The SAIDI index gives information about the average time the customer is interrupted in minutes (or hours) in one year.

$$SAIDI=\frac{Total\ duration\ of\ all\ interruption}{Total\ number\ of\ customers\ connected}(hr/cr) \tag{12}$$

CAIDI: Customer average interruption duration index.
CAIDI captures the average time that the utility responds by measuring the average time to restore service.

$$CAIDI=\frac{Total\ duration\ of\ all\ interruption}{Total\ number\ of\ all\ interruption}(hr/c/Int.) \tag{13}$$

ASAI: Average service availability index.

$$ASAI=\frac{Total\ number\ of\ hours\ availability}{Total\ demand\ hours}\ (p.u) \tag{14}$$

ASUI: Average Service Unavailability Index

$$ASUI=1-ASAI \qquad (p.u) \tag{15}$$

EENS: Expected energy not supplied.
EENS = Capacity outage x Probability of Capacity outage x Time of Capacity outage (MW/Yr)
These are measuring tool that are used in order to evaluate the performance of the system. Utility supply companies are seeking to be within the standard approved range to motivate customers selecting them among others. [4]

5. FINDINGS

5.1 Optimal location and sizes of DG

Table 1: optimal location and sizes of DGs

S/No	Distribution Network	Type of DG	Location(s)	Size(s) MW
1.	IEEE 33 Bus with 1 DG	Solar	Bus 6	2.51
2.	IEEE 33 Bus with 2 DG	Solar	Bus 7 and 16	2.14 and 0.654
3.	Ran feeder with 1 DG	Solar	Bus 41	1.062
4.	Ran feeder with 2 DG	Solar	Bus 30 and 50	0.598 and 0.67

Table 2: IEEE 33 Bus system results comparison

S/N	Method	Location and Size with one DG		Location and Size with two DG		% loss Reduction	
		Location	DG size (MW)	Locations	DG sizes (MW)	One DG	Two DG
1.	Heuristic Search	12	2.49	-		41.8	-
2.	Differential Evolution	22	2.59	20 and 25	1.58 and 0.97	47.3	50.6
3.	Particle Swarm Optimization with Newton Raphson Power flow studies	25	1.98	-	-	38.8	-
4.	Particle Swarm Optimization with Backward Forward sweep Power flow studies	6	2.57	-	-	44.6	-
5.	Modified Particle Swarm Optimization with Hybrid Backward - Forward sweep with Newton Raphson Power flow studies	28	1.87	18 and 33	1.41 and 0.51	48.85	61.51

5.2 Solar Photovoltaic Design

Suniva ART245-60 modules of 240 Wp solar panels was used in the design. ART245-60 module is a well-known robust solar cell's type that is designed to be used in grid tied solar projects and power stations. The characteristics of the ART245-60 are taken under STC "Standard Test Conditions" in laboratory environment. The standard conditions are 1000W/m2 irradiation, 25°C, and 1.5 solar spectrum air mass. Basic features of the used modules are presented in Table 3.

$V(T) = V@25\,C\,(1 + \beta \times \Delta T)$

where β is the temperature de-rating factor shown in Table 3.

Table 3: Basic features of the PV modules

S/No	Parameter	Rating
1.	Maximum power	240W
2.	Voltage @ maximum power point	30.9V
3.	Current @ maximum power point	7.95A
4.	Open circuit voltage	37.4V
5.	Short circuit current	8.44A
6.	Cells per module	60
7.	β (Voltage de-rating factor (Voc % / °C))	-0.332
8.	α (Current de-rating factor (Isc % / °C))	0.035
9.	γ (Power de-rating factor (Pmax % / °C))	-0.465

Table 4: Features of the ABB 1 MW central inverter

S/No	Parameter	Rating
1.	Rated power	1000 Kw
2.	Maximum power	1200 kW
3.	DC voltage range (MPPT)	600-850 V
4.	Maximum DC voltage	1100 V
5.	Maximum DC current	1710 A
6.	DC inputs	8-20 A
7.	Nominal AC voltage	400 V
8.	Nominal AC current	1445 A

5.3 Modelling of the Distribution Networks

IEEE test system has 33 bus and 32 sections with the total load of 3.72 MW and 2.3 MVAR. Base MVA 100, conductor type is All Aluminum Alloy Conductor (AAAC), Base voltage 12.66kV, Resistance of 0.55per km and reactance of 0.35ohm per km and Ran feeder in Bauchi has 69 bus and 68 sections with the total load of 3.985 MW and 11.56 MVAR. Base MVA 100, conductor type is All Aluminum Alloy Conductor (AAAC), Base voltage 11kV, Resistance of 0.55 ohm per km and reactance of 0.35 ohm per km. In ETAP IEEE 33 Bus Model was created in edit mode with the configuration status set to normal. ETAP's electrical system diagram is a one line representation of balanced three phase system. It was constructed graphically by connecting the buses, branches, transformers and protective devices from the one line diagram edit toolbar. Elements were graphically connected to the buses by using info page of the device property editor. The property editor was opened by double clicking on the element. The engineering properties of the element such as ratings, settings, loading, connection etc. were assigned using the editor. The DG (solar PV) were designed and placed at the optimal location as suggested by the MPSO. The ETAP Models of the systems are shown in Figures 1 and 2.

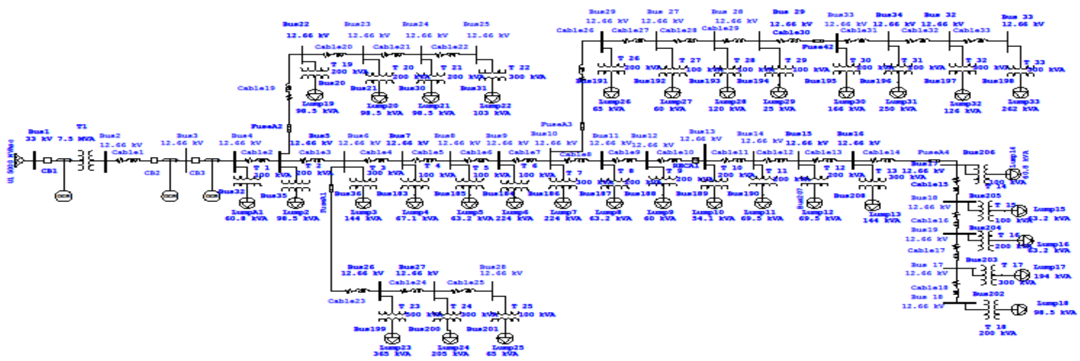

Figure1. ETAP Model of IEEE 33 Bus Test system

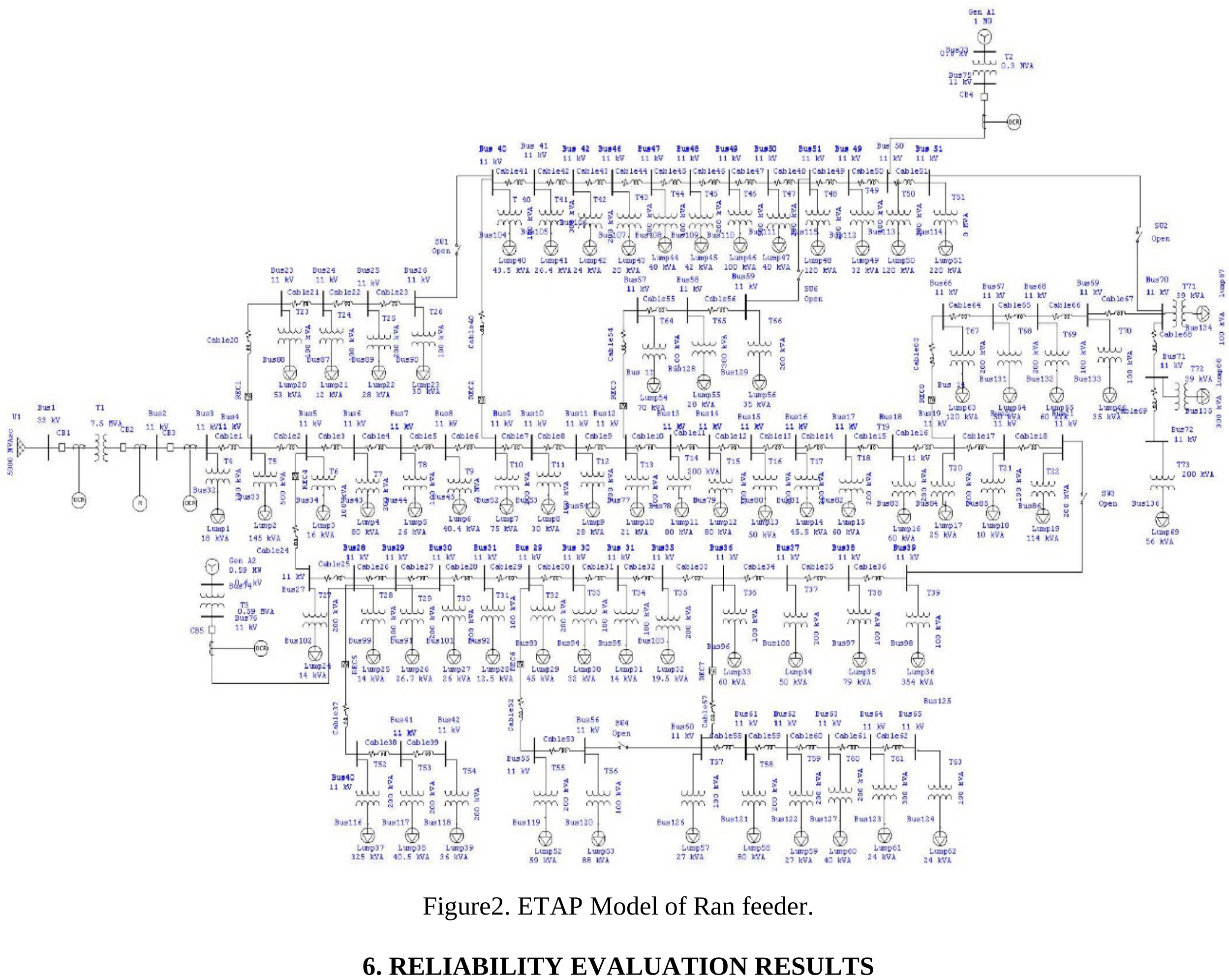

Figure2. ETAP Model of Ran feeder.

6. RELIABILITY EVALUATION RESULTS

In other to investigate the reliability of the system, the following reliability indices such as SAIDI. SAIFI, CAIDI, EENS, ASAI, ASUI and ECOST of the systems were evaluated using ETAP. The reliability data for each component provided in the reliability library of ETAP were used for the analysis. The indices were evaluated considering two scenario cases. Scenario one was IEEE 33 Bus system with 1 DG and scenario two was IEEE 33 Bus system with two DGs. The results are presented in Table 2

Table 5: Reliability indices value for system with and without DG

Configuration	SAIFI (f/c.yr)	SAIDI (hr/c. yr)	CAIDI (hr/c. Int.)	EENS (MW hr/yr)	ECOST ($/yr)	ASAI (p.u)	ASUI (p.u)	AENS (MWhr /c.yr)
IEEE 33 Bus System Base Case	1.897	8.208	4.326	29.336	112,970.40	0.9991	0.00094	0.1424
IEEE 33 Bus System with 1 DG	0.523	3.442	6.581	16.147	73,976.11	0.9996	0.00039	0.0784
IEEE 33 Bus System with 2 DG	0.447	3.029	6.776	11.211	40,872.68	0.9997	0.00035	0.0544

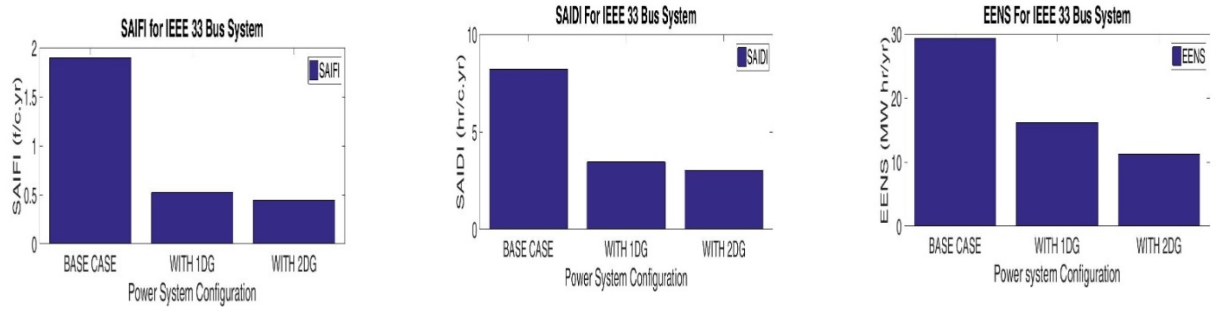

Figure 3: SAIFI, SAIDI and EENS Plot for IEEE 33 Bus System

Table 6: Reliability Indices value for Ran feeder with and without DG

Configuration	SAIFI (f/c.yr)	SAIDI (hr/c.r)	CAIDI (hr/c. Int)	EENS (MW/ hr/yr)	ECOST ($/yr)	ASAI (p.u)	ASUI (p.u)	AENS (MWhr /c.y)
Ran Feeder Base case	1.6216	17.4595	10.767	60.513	425,058.10	0.9980	0.00199	0.8899
Ran Feeder with 1DG	0.7941	12.3512	15.553	42.449	267,138.90	0.9986	0.00141	0.6243
Ran Feeder with 2DG	0.5804	8.6102	14.835	28.328	195,189.20	0.9990	0.00098	0.4166

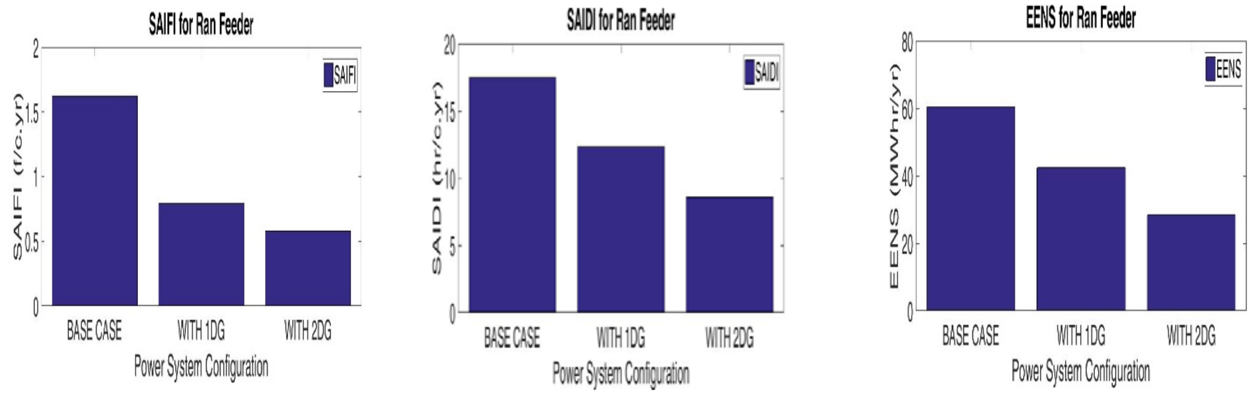

Figure 4: SAIFI, SAIDI and EENS Plot for Ran feeder.

7. CONCLUSIONS

In this paper IEEE 33 Bus test system and 69 Bus Ran feeder has been modelled using ETAP software. Optimal placement and sizing of DG was done using MPSO. The technique was first tested on IEEE 33 Bus test system and finally applied to a typical Nigerian distribution network. The results obtained showed that optimal sizing and placement of DG in distribution system improves the performance of the network which in turn increase the reliability. Furthermore, the more the integration level of DG, the better the reliability of the network.

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