University of Thi-Qar Journal Vol.11 No.2 June 2016
Web Site: https://jutq.utq.edu.iq/index.php/main *Email: journal@jutq.utq.edu.iq*

تحديد الموقع الامثل للمولدات الموزعة في نظم التوزيع
على اساس
دلائل كلفة قطع التجهيز ووثوقية النظام

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الخلاصة

نظم القدرة الكهربائية تشمل ثلاث مناطق وظيفية: نظم التوليد والنقل والتوزيع, وحيث ان تقييم وثوقيه المنظومة بأكملها عملية معقدة جداً تحدد البحث الحالي بتقييم وثوقيه منظومة توزيع شعاعية. ان الاحمال المربوطة للشبكة تتنامى بشكل مستمر ولامركزي وعليه اصبح التوقع للزيادة المستقبلية في الطلب على الطاقة من الامور الواجب مراعاتها لضمان استمرارية التجهيز في حالات الخروج القسري لا حدى الوحدات التوليدية او حدوث زيادة مفاجئة بالطلب على الطاقة اعلى من الطاقة التصميمة. من التقنيات المعتمدة تقنية حقن مولد كهربائي مع قاطع دورة للشبكة عند احد المغذيات على ان يتم فصلة عن الشبكة حال رجوع الحمل الى قيمته الاعتيادية. اضافة مولد كهربائي الى منظومة التوزيع يعزز من وثوقيه التجهير بشرط ان يكون المولد المضاف بالمكان والحجم الامثل وذلك من خلال احتساب دلائل وثوقيه المنظومة والدلائل المتعلقة بكلفة قطع التجهيز. تم اختبار الطريقة المقترحة على منظومة توزيع شعاعية مخصصة للأغراض التعليمية بواقع (6) عموميات و(4) مغذيات شعاعية واشارت النتائج الى ان اختيار الموقع والحجم الامثل يعزز من وثوقية النظام .

Optimal Placement of Distribution Generating in Distribution System Based on Cost worth & System Reliability indices.

https://doi.org/10.32792/utq/utj/vol11/2/3

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ABSTRACT

Electrical power systems include three functional areas: generation, transmission and distribution systems. Evaluate the reliability of the whole system is very complex so the present research is limited on evaluate the reliability of radial distribution system. Since the demand loads have continuously growth and uncertainties it became one of the important things to be observed, so that we can forecast an accurate demand loads in the future .To ensure the continuity of providing demand loads and the possibility of covering the expected increase demand the technology of injected **D**istributed **G**eneration in a radial distribution system through circuit breaker was adoption. DG works to generate energy to cover the increased in demand loads or to compensate the shortfall in generation during a Failure.

To enhances the reliability of the test system optimal location and size of DG should be identifies. Basic reliability indices for load points and the overall system have been developed. A additional reliability (i.e. cost worth& System Reliability) indices are suggested. The cost worth indices serve as a guide to locate position where reliability needs to be supported. The suggested approach has been tested on Roy Billinton Test System 6 bus with four radial feeders. The Results that we got from this approach clearly shows the best location and sizing of DG and so support the reliability of the system.

Keywords: distributed generation**,** system reliability indices**,** radial distribution network.

1. Introduction

The ultimate goal of the power system is to supply an sufficient electrical to its customers taking into account the economic side and the high reliability. During the previous years, distribution systems have received significantly little interest especially in the field of reliability modeling and evaluation than the generating and the transmission systems. The reasons for this are that the generating stations and the transmission systems are require huge capital and they have extensive serious consequences for both community and the environment, while the cost and impact are less for distribution systems. After a recent analysis of statistical studies of consumer failure which indicated approximately 90% of the probability unavailability of supply to a customer caused by electric power distribution systems [1], the distribution reliability is one of the most important in the electric power industry due to its high impact on the cost of electricity and its high correlation with customer satisfaction. [2].

2. Distributed Generators

The increase in demand for electric power at normal condition is expected to reach 1.4 % per annual in early 2020. Power companies are seeking an a way to reduce costs and remains provide energy with acceptable level of reliability [3]

Distributed Generations, DG are considered as a key to solving the problems arising due to the increased demand for energy. DG is defined as a small-modular generation of capacity ranging from few kilowatts up to 10MW, then it can be injected at the loading points or at a distance from it in any distribution system. The technologies for DG sources are based on conventional such as oil, natural gas and coal and non-conventional electricity sources, i.e. Photovoltaic, fuel cells, wind turbines …etc. [4].

DG is often used as backup power source in the case of costumer supply interruption and as a support to the distribution system in a period of peak load. In the backup mode of operation, DG improves the system adequacy index while in the peak load period, DG increases system reliability by lowering feeder loading and reducing energy costs. Some benefits of DG include the following:

1. A Contingency reserve during forced customer outages
2. Decrease drop voltage.
3. Improved reliability [5]

The aim of the paper focuses on the benefiters about DG. That is related to improved reliability.

3. Review of Reliability Concept in Power System

Reliability as a concept can be explained by three terms:

1. Adequacy, as the ability of the system to cover the energy demand at all times under normal and abnormal condition (i.e. forced outage of the elements).
2. Security, as the susceptibility of the system to facing the disturbances such as demand fluctuations.
3. Quality, regarding the level of stability of the voltage and frequency characteristics, etc. [5].

4. Methodology of the Research

In order to analyze the reliability of the system, it is necessary to create an appropriate model for such a system which is done according to the following steps:

1. Identification and description of the system under test.
2. Identify the criteria of the failure.
3. Determine the permitted assumptions set.
4. Construction the model of the system (i.e one line diagram of it).
5. Calculating the primary failure indices i.e. (λ,r,U) of each load in the system and developed additional sets of Reliability Indices which are System Reliability Indices & Cost worth Indices.
6. Analysis and discuss the results.
7. Develop a plan to improve the reliability of the system

4.1 Identification & Description of the Test System (case study)

Abnormal conditions faced by the electrical systems in Iraq prevented the selection of a local distribution system to complete this research especially the process of data collection (that related with reliability studies) , so we had choose a distribution system dedicated for research and educational purposes known as Roy Billinton Test System. RBTS that it is developed by the University of Saskatchewan for education and research purposes [6]. Test system consist of six bus bars, two of them are generator bus bars with installation capacity of (240) MW and the remainder are load buses. in the present research focuses will be placed on the bus2 for the completion of the analysis. Bus2 in test system consist of (4) radial outgoing feeders feeding through two parallel step-down transformers (33/11kv,2*16MVA), serving 22 mix load point (industrial, commercial, agricultural, residential, government & institutions, office& building and large user) RBTS shown in figure1.

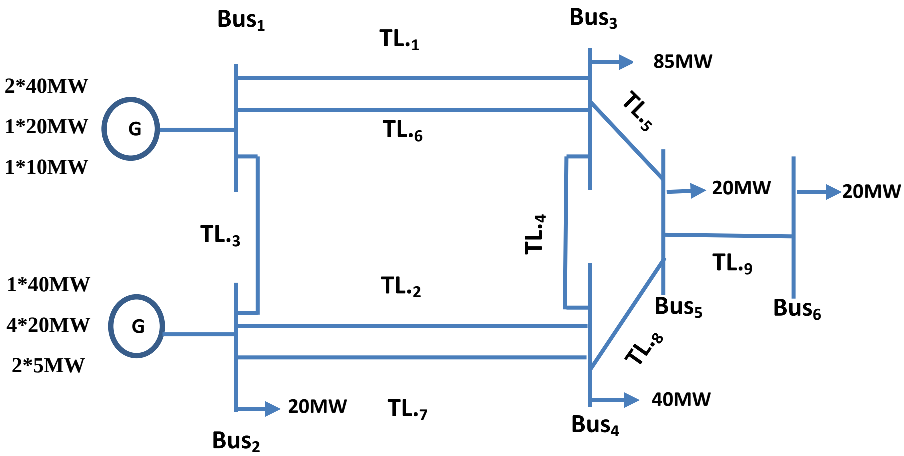


Fig.(1) Roy Billinton Test System for education and research

4.2 Identify the criteria of the failure.

Typically, in reliability assessment of a power distribution system dealing with the Interruptions, three key criteria's (primary indices) should be considered [7]:

1. Rate of failure, λs

$\lambda_s = \sum_{i=1}^{i=n} \lambda_i \ldots\ldots(1)$ where $\lambda_i = rL_T + r_i'$

λ_i is the rate of load point failure, r is the rate of failure per meter of the segment

L_T is the length of all segments in meter, r_i' is the lateral failure duration that connected to LPi

2. **Average annual outage time, Us**

$$U_s = \sum_{i=1}^{i=n} \lambda_i r_i \text{ ....(2)}$$

3. **Average duration of failure, rs**

$$r_s = \frac{U_s}{\lambda_s} = \frac{\sum_{i=1}^{i=n} \lambda_i r_i}{\sum_{i=1}^{i=n} \lambda_i} \text{ ......(3)}$$

The annual outage time for the LP_i can be determined by equation (4)

$$U_i = rL_eR + r(L_T - L_e)R' + r'_i r''_i \text{ ... ... (4)}$$

r = The rate of failure per meter of the segment.

L_T = length of all segments in meter, L_e = Length of segments that result failure

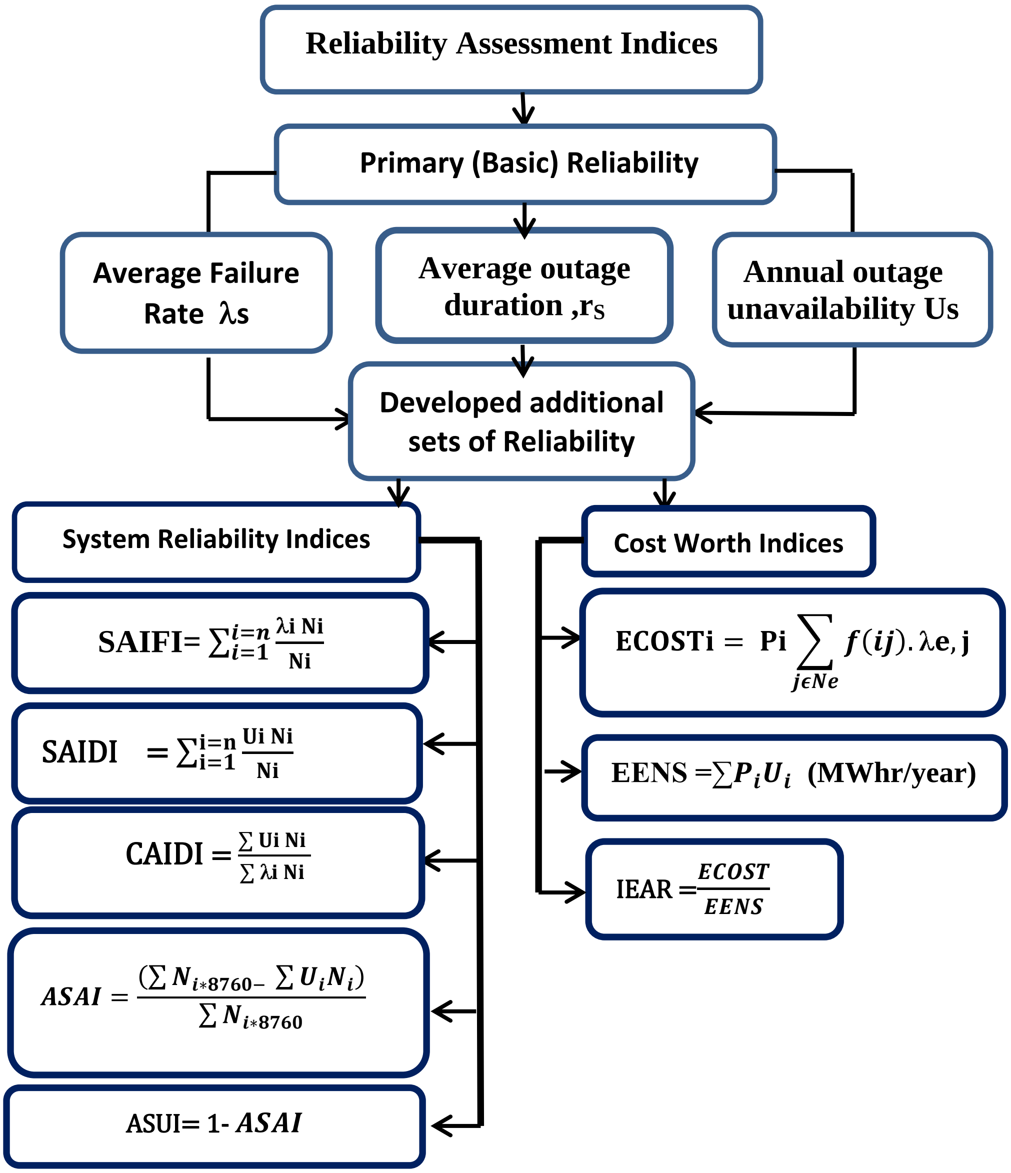
R = The time required for the segment repairing, R' = The time required for segment switching

r_i''= The time required for repairing lateral

Then the average outage time (or average duration of failure) r_i of load point i can be calculated using equation (5)

$$r_i = \frac{U_i}{\lambda_i} \text{ ... ... (5)}$$

Despite the importance of these primary indices, they give information for an individual customer's load point only, since they are not enough to explain the performance and response of the overall system it has been developed two additional sets of indices that can be used to evaluate the overall performance of distribution systems, Which are described in the following chart. [8]:


Reliability Assessment Indices
Primary (Basic) Reliability
Average Failure Rate λs
Average outage duration ,rs
Annual outage unavailability Us
Developed additional sets of Reliability
System Reliability Indices
Cost Worth Indices
SAIFI= $\sum_{i=1}^{i=n} \frac{\lambda i\ Ni}{Ni}$
SAIDI $= \sum_{i=1}^{i=n} \frac{Ui\ Ni}{Ni}$
CAIDI $= \frac{\sum Ui\ Ni}{\sum \lambda i\ Ni}$
$ASAI = \frac{(\sum N_{i*8760} - \sum U_i N_i)}{\sum N_{i*8760}}$
ASUI= 1- $ASAI$
ECOSTi = Pi $\sum_{j\epsilon Ne} f(ij).\lambda e, j$
EENS $=\sum P_i U_i$ (MWhr/year)
IEAR $= \frac{ECOST}{EENS}$

The following is the definition of the two additional sets of the reliability indices:-

1. **S**ystem **A**verage **I**nterruption **F**requency **I**ndex, **SAIFI**, approaching to the optimum value by reducing the number of times interruptions per year for affixed number of customers.
2. **S**ystem **A**verage **I**nterruption **D**uration **I**ndex, **SAIDI** access to the optimum value when reducing number at a time of sustained interruptions or reducing the duration period of these sustained interruptions. i.e. SAIDI is inversely proportional to reliability.
3. **C**ustomer **A**verage **I**nterruption **D**uration **I**ndex, **CAIDI** Is a measure of the average time period for the continuous interruption, therefore best method to reach the optimum value of this index (i.e. minimizes CAIDI) is reduce the period of interruption , On the other hand minimizes CAIDI can be achieved by An increase in the number of short-term outage. According to that, low CAIDI does not indicate an raising in reliability.
4. **A**verage **S**ervice **A**vailability **I**ndex, ASAI is directly proportional to reliability.
5. **E**xpected **I**nterruption **C**ost **I**ndex, $ECOST_i$ is the cost of not supplying energy to any load point. This index depends on the costumer characteristics. Where **f(rij)** is a Composite Costumer Damage Function, CCDF, which it is a linking function between the interruptions of all users sectors versus interruption duration within a specific service area [3].
6. **E**nergy **E**xpected **N**ot **S**upplied **I**ndex, **EENS**
7. **I**nterrupted **E**nergy **A**ssessment **R**ate, IEAR is the most important index that identifies the weak points in the system. Enhance these points is reflected positively on the consumer's' reliability in providing power at a cost acceptable economically, i.e. the IEAR is a convenient index, which provides instantaneously evaluation of energy shortage for the network from the perspective of a customer damage cost. [9].

4.2.1 Study the Outage Cost

The main objective of any electric system is to achieve a state of balance between the reliability of the supplying power to the consumer and taking into account the economic side during that. The impact of power outages for consumer determined on the basis of both the consumer type (sector) and the period of time in which the consumer is out of service, and then the evaluation procedure can be in two steps which are:

a. Outage cost model

b. Outage cost estimation.

In the former step and based on the electricity tariff the consumers are classified in to seven sectors which are: industrial, commercial, agricultural, residential, government & institutions, office& building and large user, while the latter step is concerned with the collection of data relating to completing the study and usually are obtained this data from Professionals working in this field. [10].

4.2.2Concept of Composite Customer Damage Function

To get CCDF apply the following steps:

a. Specify the **C**ustomer **D**amage **F**unction, **CDF** which is defined as a linking function between the cost of the interruption of specified consumers group with the duration period of the interruption case.[1], Table 1 illustrates CDF for the seven sectors of the costumers.

Table1 Customer Damage Function expressed in $/MW

Duration Time (min)	Costumers Type						
	Agric.	Com..	Indus.	Larg. User.	Off.& buil.	G.& I.	Resi.
1	1.5	4.82	6.5	16.68	59.72	0.73	0.001
20	8.575	37.11	15.47	25.134	123.47	6.15	0.16
60	21.64	122.17	32.45	24.72	300.85	16.58	0.91
240	68.8	447.43	89.86	44.08	983.28	72.87	9.27
480	137.34	1185.86	199.32	91.56	1702.85	289.34	29.6

b. Adjustment (weighting) the values of CDF.

According to [9], the weighting of CDF is based on the duration of the interruption, in the case that the period of interruption is less than one hour, the weighting is based on the percentage of the maximum value of annual load composition while the weighting for long periods, depending on the percentage of the energy consumed per year. For a part of a test distribution system designated as the Roy Billinton Test System .[6]

Table 2 load compositions for RBTS

Consumer Sector	Max. annual load consumption %	Energy consumed % Per annual
Agriculture	4	3
commercial	8	7
Industrial	25	20
large user	6	9
office& building	8	7
government& institutions	5.55	4
residential	7.3	5.3

The Composite Customer Damage Function (CCDF) for the study area is obtained as shown in Table 3.

Table3 Composite Customer Damage Function (CCDF) for the study area in $/MW

Study area	Interruption Duration (min)				
	1 min	20 min	1h	4h	8h
Agriculture	1.5*.04	8.6*.04	21.6*.03	68.8*.03	137.3*.03
commercial	4.8*.08	37.1*.08	122.2*.07	447.4*.07	1185.8*.07
industrial	6.5*.25	15.5*.25	45.4*.2	125.8*.2	279*.2
large user	16.7*.06	25.1*.06	24.7*.09	44.1*.09	91.6*.09
office& building	59.7*.08	123.5*.08	300.8*.07	983.3*.07	1702.8*.07
government& institutions	.8*.055	6.71*.055	37.3*.04	163.9*.04	651*.04

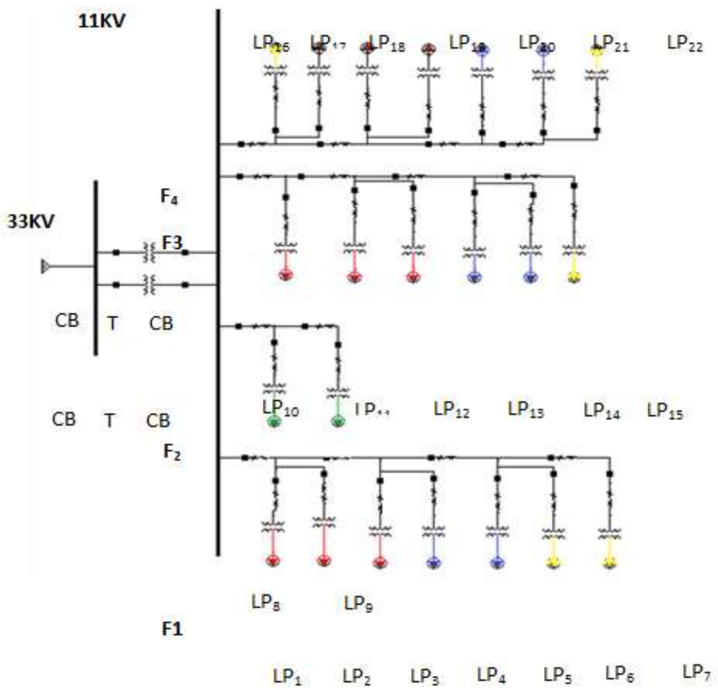
Residential	.014*.073	.128*.073	6.65*.053	67.8*.053	216.4*.053
Total customer cost ($/MW)	7. 90	18.95	43.41	141.49	307.87

4.3 The permitted assumptions set.

- The components on 33kV side are 100% reliable.
- The effect of Periodic maintenance is not taken into account.
- Considering the switching time of all component is equal to (1hr)

4.4 Construction the model of the system (i.e one line diagram of it).

Constructing using Graphical User Interface (GUI), which it is provided by the ETAP package.



Definition of loads characteristics in terms of the customer sector, average load, peak load and the number of customer per load point using substation data as shown in table4.

Table 4 Data for the consumer and the amount of loading of RTBS [6]

$L.P_i$	Distance between SP & $L.P_i$	Customer Sector	Number of Customer / LP_i	Average load / LP_i MW	Peak load / LPi MW
1	1.35	Resi.	210	0.535	0.8668
2	1.55	Resi.	210	0.535	0.8668
3	2.3	Resi.	210	0.535	0.8668
4	2.1	G&I	1	0.566	0.9167
5	3.05	G&I	1	0.566	0.9167
6	3.05	Commer.	10	0.454	0.7500
7	3.65	Commer.	10	0.454	0.7500
8	1.55	Indust.	1	1.000	1.6279
9	2.15	Indust.	1	1.150	1.8721
10	1.35	Resi.	210	0.535	0.8668
11	2.3	Resi.	210	0.535	0.8668
12	2.35	Resi.	200	0.450	0.7291
13	2.9	G&I	1	0.566	0.9167
14	2.95	G&I	1	0.566	0.9167
15	3.5	Commer.	10	0.454	0.7500
16	1.55	Commer.	10	0.454	0.7500
17	1.4	Resi.	200	0.450	0.7291
18	2.15	Resi.	200	0.450	0.7291
19	2.35	Resi.	200	0.450	0.7291
20	3.1	G&I	1	0.566	0.9167
21	3.65	G&I	1	0.566	0.9167
22	3.7	Commer.	10	0.454	0.7500
			1908	12.291MW	20MW

Specify the failure rate, repair time of each component i.e. (Transformers, circuit breakers, bus bars and feeders), these data are in table5.

Table 5 Reliability Parameters of RTBS [6]

Components of Test System	Failure Rate f/yr	Repair Time hr
H.T. Transformers	$15*10^{-3}$	15
L.T. Transformers	$15*10^{-3}$	10
H.T. Circuit Breaker	$2*10^{-3}$	4
L.T. Circuit Breaker	$6*10^{-3}$	4
H.T. Bus-Bar	$1*10^{-3}$	2
L.T. Bus-Bar	$1*10^{-3}$	2
Feeders	$65*10^{-3}$	5

4.5 Calculating the primary failure indices i.e. (λ, r, U) of each load in the system under base case and developed additional sets of Reliability Indices which are System Reliability Indices & Cost Worth Indices.

Referred to the value of the basic indices and the CCDF for the study area, cost worth and system reliability indices can be calculate for each load point or for the whole system. All of the indices can be calculated using the ETAP reliability analysis module.

Table 6 basic & cost/worth reliability indices under base case

Load point	λ_I (f/yr)	r_i (hr)	U_i hr/year	EENSi hr/yr	Ecosti $/yr	$IEAR_i$ $/KWhr
1	0.160	5.189	0.830	0.444	0.656	1.477
2	0.178	5.188	0.923	0.493	0.705	1.430
3	0.240	5.021	1.205	0.645	0.940	1.458
4	0.238	4.904	1.167	0.661	1.396	2.11
5	0.310	4.670	1.448	0.820	1,809	2.208
6	0.316	4.669	1.475	0.670	6.135	9.174
7	0.334	4.668	1.560	0.708	6.445	9.010
8	0.164	4.612	0.756	0.756	4.764	6.289
9	0.222	4.704	1.044	1.200	7.032	5.848
10	0.161	4.999	0.805	0.431	0.765	1.776
11	0.243	4.889	1.188	0.636	0.989	1.555
12	0.246	4.890	1.203	0.541	0.800	1.479
13	0.300	4.779	1.434	0.811	1.784	2.198
14	0.304	4.779	1.453	0,822	1.791	2.179
15	0.351	4.780	1.678	0.762	6.987	9.174
16	0.185	4.600	0.850	0.383	3.465	9.047
17	0.171	5.077	0.868	0.390	0.600	1.538
18	0.240	4.988	1.197	0.539	0.699	1.297
19	0.252	4.787	1.206	0.542	0.763	1.408
20	0.315	4.700	1.481	0.838	1.541	1.839
21	0.358	4.698	1.682	0.952	1.999	3.000
22	0.370	4.689	1.735	0.788	6.234	7.911

Also the rest of reliability indices (SAIFI, SAIDI & CAIDI) provide us with valuable information, its important varies from one to another but they give us an idea about the points of weakness of the test system that need to support.

Table7 system reliability indices under base case

Load point	SAIFI	SAIDI	CAIDI
1	33.600	174.3	5.188
2	37.380	193.83	5.185
3	50.400	253.05	5.021
4	0.238	1.167	4.903
5	0.310	1.448	4.671
6	3.160	14.75	4.668
7	3.340	10.56	3.162
8	0.164	0.756	4.610
9	0.222	1.044	4.703
10	33.810	169.05	5.889
11	51.030	249.48	4.889
12	49.200	240.6	4.890
13	0.300	1.434	4.780
14	0.304	1.453	4.780
15	3.510	16.78	4.781
16	1.850	8.5	4.595
17	34.200	173.6	5.076
18	48.000	239.4	4.988
19	50.400	241.2	4.786
20	0.315	1.481	4.702
21	0.358	1.682	4.698
22	3.700	17.53	4.689
TOTAL	$\frac{405.791}{1908} = 0.213$	$\frac{2012.915}{1908} = 1.055$	**4.953**

4.6 Analysis and discuss the results.

- Referred to the result in table6 the value of IEAR confirmed interdependence with the consumer type. IEAR was higher for commercial loads and followed by industrial and less value for residential, then it is represent an indicator of the energy interruption cost of the load point.
- In general the probability of Cost worth indices can be used to estimate the reliability of distribution system and to give us helpful planning information to develop the existing system. ECOST & EENS represent an indicator of the energy outage cost of the costumers; the higher the value of cost worth indices for each load point is the higher the unreliability at the corresponding feeder. Based on the results of table 8 the focus is on the first feeder , F_1 to support the reliability of the system.

Table8 Cost worth & system reliability indices for each feeder in the test system

indices	$Feeder_1$	$Feeder_2$	$Feeder_3$	$Feeder_4$
Load point	1….7	8…..9	10….15	16….22
EENS	4.441	1.956	4.003	4.432
Ecost	18.086	11.796	13.116	15.301
IEAR	4.073	6.031	3.277	3.452
SAIFI	0.197	0.193	0.219	0.223
SAIDI	0.996	0.9	1.074	1.098
CAIDI	5.056	4.663	4.904	4.920
ASAI	0.999	0.999	0.999	0.999
ASUI	0.0001	0.0001	0.0001	0.0001

4.7 Develop a plan to improve the reliability of the system

The plan adopted in the current research consisted of injected Distribution Generating that work as a source of reserve energy to compensate load losses of consumer due to forced outage of the original generating units, transmission or distribution lines or increasing in the demand load. Let the DG. Unit used is a 650MW diesel engine integrated with an electrical generator used as a mobile emergency unit (i.e. without connected to the distribution system unless at abnormal conditions). The reliability data such as failure rate and repair time are 0.87f/yr , 3.9hr respectively. As indicated in table8, F_1 is most affected by the interruption and losses load in term of cost worth indices, then we will shed light on the following case studies:

4.7.1The impact of injection one DG. in F_1 on other feeders.

In table 9 were compared between the various groups of feeders at the basic status with that injected one DG in F_1.The results of reliability system indices especially with respect to EENS & ECOST indicate that the largest impact of injected DG in F_1 (i.e. location of add DG) while it is a very few affected on the other feeders.

Table 9 The impact of injection one DG. in F_1 on other feeders.

Cost worth indices	$F_1+F_2+F_3+F_4$		$F_2+F_3+F_4$		F_1	
	Test system at basic condition	Test system With Inject DG	Test system at basic condition	Test system. With inject DG	Test system at basic condition	Test system With Inject DG
SAIFI	0.212	0.179	0.208	0.199	0.197	0.127
SAIDI	1.057	0.957	1.037	1.009	1.003	0.699
CAIDI	4.975	5.009	4.985	5.078	5.086	5.504
EENS	14.805	12.989	10.394	9.889	4.437	2.676
ECOST	61.411	56.957	42.997	40.011	18.085	11.001

4.7.2 Determine the optimum location of DG along F_1

In order to determine the optimum location for DG on F1, we study the effect of injection DG at a various distance from the supply point (i.e. 11kv-busbar) by determine the cost worth and reliability system indices.

Table 10 reliability system indices of injection one DG. in F1 at different distance from supply point

Cost worth indices	Base Case	Probable sites to injection DG on main feeder, F_1.				
		A At S.P.	B 0.75km	C 1.5km	D 2.25km	E 2.85km
ECOST	18.086	17.699	16.801	13.375	10.517	8.999
EENS	4.441	4.432	4.399	3.452	2.996	2.598
SAIFI	0.197	0.189	0.178	0.1576	0.1394	0.137
SAIDI	1.003	0.987	0.895	0.764	0.749	0.738
CAIDI	5.091	5.222	5.028	4.848	5.373	5.387

According to the results in table 10 the effect of adding DG be greater the more away from supply point close to the end of the feeder.

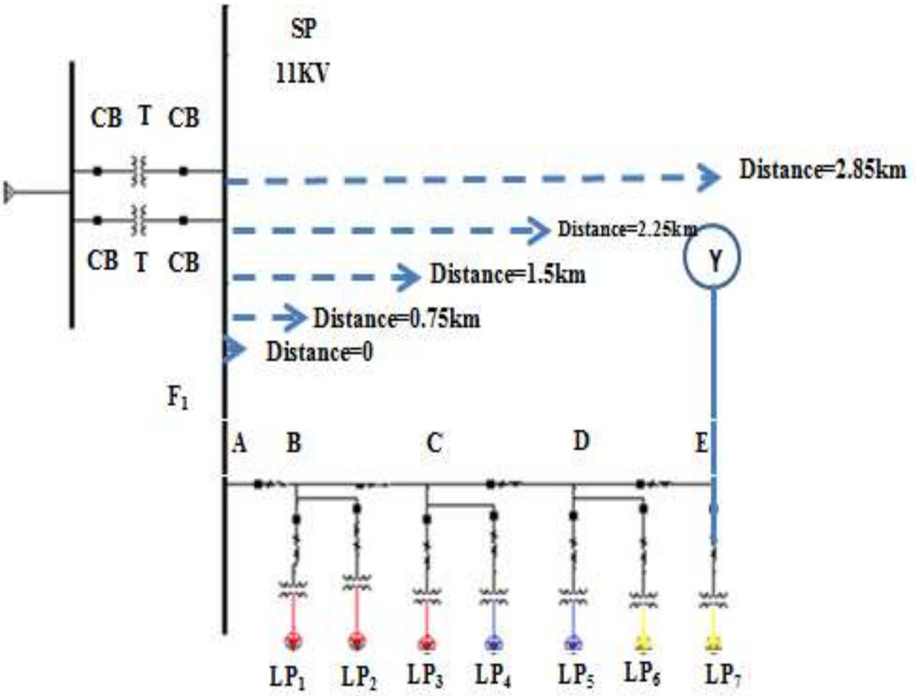


Fig. 3 one line diagram showing F1 of the test system with DG

4.7.3 Determine the number of DG units along F_1

To determine the benefits of injected more than one DG on F_1, more than one DG was injected in all possible location. we study the effect of that by determine the cost worth and reliability system indices. According to the results that shown below, injected more than one DG in the same feeder does not achieve positive change with regard to the system reliability.

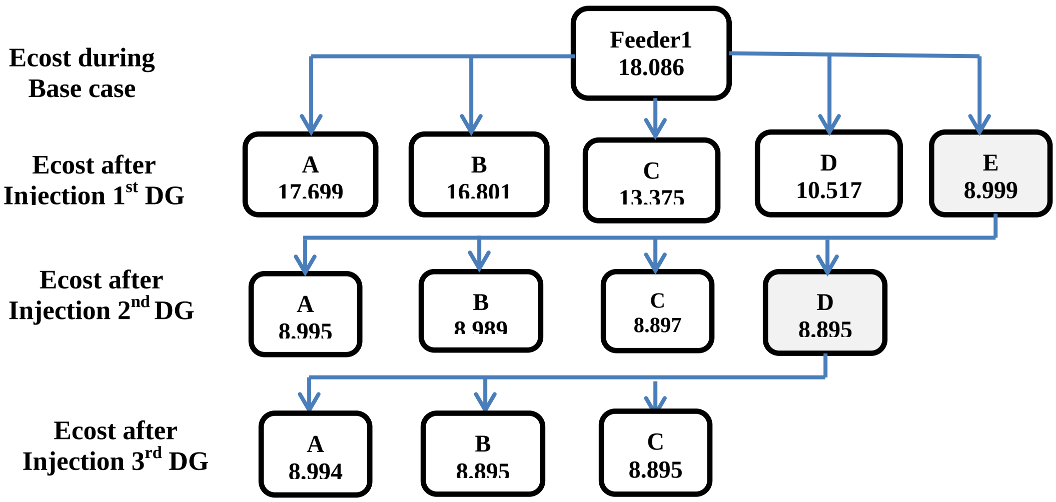


Fig 4 Chart showing the reduction in ECOST versus increasing the number of DG'S

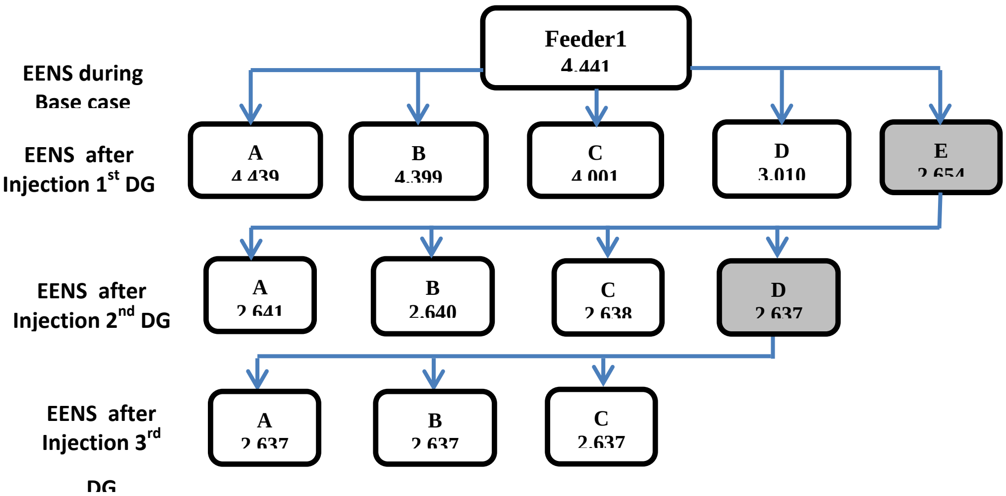


Fig5 Chart showing the reduction in EENS versus increasing the number of DG'S

5. conclusions

1. exclusively for a radial distribution system, high failure rate of the loading points that away from the supply point and vice versa.
2. Loading points classified within the commercial sector have the higher weakness in term of worth; ECOST , EENS and then IEAR is higher than other sectors.
3. Based on the reliability indices of the four feeders, the first one (i.e. F_1) is the less reliable hence it is the optimum location for injection DG to improve the reliable of all system.
4. The injection of DG at F1, has high effects on the same feeder while less than on the others.
5. In term of reliability worth benefits, injection DG close to supply point will rarely improve the cost worth and system reliability indices. Optimum location is at the end of the feeder.
6. Injected more than one DG in the same feeder does not achieve positive change with regard to the system reliability.

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