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RELIABILITY IMPROVEMENT IN DISTRIBUTION SYSTEM BY INJECTED DISTRIBUTED GENERATION BASED ON ZONE BRANCHES METHODOLOGY

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Abstract: The aim of this paper is to reach the best balance point between the maximum reliability and minimum lost cost when injecting Distributed Generation (DG). The new Al-Kadimeya substation in Al-Kadimeya sector in Iraq – Baghdad was chosen for this research, because there is a group of four diesel generator injected in it is mesh. These DGs suffers from stop working and interruptions in the supply of energy, which causes its failure to do its task of supporting the national grid in electrical power. This substation has fifteen different feeders. Five diverse feeders were selected to inject DGs in it. The injection was in several locations on the selected five feeders sequentially. Zone branch methodology applied in analysis these feeders and the required calculations were carried out until the best site with the lowest failure rates was reached to inject these generators, which is feeder 2. The failure rates of the five feeders were reduced by 151 times, about 14%. Outages duration were reduced by five h/y, approximately 3.67%.The lost power costs for all previous test sites of injecting distributed generation were then calculated too. Then the site with the highest lost power (i.e. the one of the highest lost cost) was selected to inject the generators to it which was feeder 2 also, where the expected lost costs due to interruptions were reduced by 510,000 USD /y, about 16.4%. Results show that feeder 2 represents the best location for injection of the DGs instead of the current location on feeder 4.

Keywords: *Distributed Generation, Zone Branch Methodology (ZBM), failure rate, average repair time, Expected Customer Interruption Cost (Ecost).*

تحسين الوثوقية في منظومة التوزيع بحقن مولدات توزيع باعتماد منهجية فروع المنطقة

الخلاصة: الهدف من هذا البحث هو الوصول الى نقطة التوازن بين اعلى وثوقية واقل كلف ضائعة عند حقن مولدات التوزيع. تم اختيار محطة الكاظمية الجديدة الثانوية في قطاع الكاظمية في العراق – بغداد لهذا البحث، وذلك لوجود مجموعة من اربعة مولدات ديزل مربوطة على شبكتها. هذه المولدات تعاني من توقفات في العمل وتقطعات في عملية تجهيز الطاقة، والذي سبب فشلها في اداء مهمتها في اسناد المنظومة الوطنية بالقدرة الكهربائية. تم حقن المولدات في عدة اماكن على خمسة مغذيات منتخبة وبشكل تتابعي. تم تطبيق منهجية فروع المنطقة في تحليل هذه المغذيات واجراء الحسابات المطلوبة لحين الوصول الى افضل موقع لحقن هذه المولدات باقل معدلات فشل والذي كان على مغذي 2. معدلات الفشل للمغذيات الخمسة قلت 151 مرة، اي قرابة 14%. كما ان فترات الخروج عن الخدمة قلت بمعدل خمسة ساعات لكل لسنة، اي تقريبا 3.67%. كذلك تم حساب كلف القدرة الضائعة لكل من مواقع الحقن اعلاه. وموقع اعلى قدرة ضائعة (اي اعلى كلفة ضائعة) رشح لحقن المولدات فيه. والذي كان مغذي 2 ايضا، حيث ان كلف الضياع المتوقعة بسبب التقطعات قلت بمقدار 510.000 دولار امريكي لكل سنة، اي قرابة 16.4%. من خلال النتائج تم ملاحظة ان مغذي 2 يمثل افضل موقع لحقن مولدات التوزيع بدلا من الموقع الحالي في مغذي 4.

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1. Introduction

Electrical power can be divided to three zones according to the function and voltage levels. Firstly the power generation sector which has medium voltage level (MV) , secondly transmission power sector which has high voltage level (HV), finally power distribution sector which has medium voltage level (MV) and low voltage level (LV)[1].

The generation should consent the load demand plus losses in transmission and distribution sectors. The transmission facilities should carriage power for long distances keeping stability in acceptable range. The distribution sector should link power to customer with sufficient voltage drop and sufficient reliability.

n general reliability defined as the probability that a system will work sufficiently for at least a designed time when used under specified conditions. Therefore, “system reliability” or "survival probability "is a system work successfully as state. Unreliability defined as the probability of system failure or not success. A system can be defined as a group of subsystems combined to make specified operational functions [2].

The reliability of the electrical power system can be classified on two basic essentials, adequacy and security reliability.

1- Security reliability, an analysis system, taking into account the faults and disturbances (i.e. transient condition)
2- Adequate reliability, that deals with provide consumer by efficient and stable rating power of component, frequency and voltage limit, considering the forced and planned component outage (i.e. steady state conditions of post contingencies)[3].

2. Zone Branch Methodology (ZBM)

The ZBM can be easily used to assess the impact of protection-coordination arrangement on individual load reliability indicators within large operating networks.

The main element in the representation of an energy system is a connection between any two buses or nodes. A connector may be a segment of electrical equipment that connects two points in a circuit such as a regulator or the length of a line, or transformer. Protected equipment shall normally be at the beginning of a connection, branch or electrical supply sector, to protect subsequent element from the abnormal condition in that link [4].

It is meaningful to note that the operation or non-functioning of the protection systems directly affects the reliability of the power system, it is necessary to classify the electrical power system into protected areas. Essentially, a protection area is part of an energy system that can be isolated or separated manually or automatically from the remaining system in the event of an abnormal case occurring in any of its links [5].

The concept and formation of branches of the protective zone is based on the following assumptions:

1. Separators (circuit breaker, link disconnect, fuse, relay, automatic isolating switches, sectionalizes) isolate all fault elements precisely and instantly, it has right operation coordinate, the closest fault separator works first.
2. The mesh is divided to several zones according to separators, from source to load. The separators number represents the zones number.
3. The mesh is converted to simple lines and blocks, the block represent the separator and all elements before it like (transformers, cables, lines, bus bars, connection and termination points, etc.)
4. The zone code is indicated by S(i,j) where (S: sector, i: zone number , j: branch number)
5. (λ (i,j)) represent the summation of components failure rates whose failure will result the operation of separator device , just in zone i , branch j.
6. Overlap in circuit breakers will not take in consideration. The separators is not ideal, (unreliability will take 50%, i.e. q=0.5) to the separator in action zone and to the separators nearest of this zone.
7. The element between adjacent spaces has an unreliability equal to 0%, (q= 0).
8. Switching time is according to operator setting or separator technical specification, which will not concern.

The principle of the zone branches methodology is:

1. The responsibility of protection system (instrument transformers / transducers, relays and circuit breaker / automatic on-load switches) is to isolate the fault within the zone and prevent it to reach to other zones.
2. The circuit breaker / automatic on load switches / fuses, isolate the fault, and located in the end and the beginning of zone.
3. All circuit breakers in faulty zone are open to insure isolating operation.
4. The isolation must be only for the element or sector in which the defect is.
5. The zones contain transformers, capacitors, conductors, generators, lines and other mesh element.
6. There are only primary protection (each zone to its components). No overlap between zones, so no need to current transformers or relays for overlapping.
7. The back-up protection is disabled.

3. Electrical Networks

3.1 New Al-Kadhimeya Substation

The new Al-Kadhimeya substation 33/11 kV, 2X31.5 MVA, hit in Iraq in Baghdad in the sector of Al-Kadhimeya. It has two 33 kV incoming feeders, first from Shimal Baghdad power station 132/33/11 kV, and second from Huzam Al-kadhmiya 132/33/11 kV, by two underground cables.

The substation network is characterized by a newly qualified network. Feeders in this network are diverse and different in purpose, including special and general feeders, residential, industrial, commercial and governmental feeders.

The structure of some of them consists of two parts, overhead and underground meshes, with different lengths as well as their loads. The load shading program has stable and low hours cut off power.
Distributed generations have been installed on the network, and unfortunately they have not been used well. It faced a series of failures and problems at work. Therefore, it was chosen in this paper for scientific analysis in order to obtain the highest work efficiency.

This substation contains 15 different outgoing feeders with an 11 kV voltage. Five different feeders were chosen for the study.
To support the current project, figures 1and 2 show the electrical grid in Baghdad/ Al-Karkh and Al-kadhmiya respectively.

The industrial power network which was analyzed and calculated in the source book of ZBM, has been re-analyzed and all calculations performed on the basis of the same data contained in The IEEE recommended practice for the design of reliable industrial and commercial power systems, which referred by Gold Book [6], on the network reliability, which is globally approved information prepared for the purposes of the studies. Results have been obtained, that are fully conformity to the results obtained by the source, which confirms that we follow a correct methodology in the solution that qualifies us to apply the branch methodology on the Al-Kadhimeya network.

3.2 Distributed Generation

The IEEE defined distributed generation as generate electrical power by facilities that are smaller than main generating station in the power system [7].
The connection of DG on distribution power systems have become a widespread practice. Connecting DGs have some important benefits. It is used as emergency backup, decrease voltage drop, advancement reliability and advancement utility potential [8].
Al-kadhmiya diesel station (a group of eight diesel generator each of 2 MVA capacity making two sub group of four generators, each one connect to specific feeder. One of these sub groups was selected with all of his actual data. These generators generate 400 volt electric power. This voltage is raised to 11 kV by step up transformer. The power is then transferred to Al-Kadhimeya substation to be distributed to the electrical grid, the selected group was connecting in feeder 4.
The generators are operated on demand by the control and operation center for a specified time period of 12 h/ day. The all group generators treated as one big generator.

3.3 New Al-Kadhimeya Substation Analysis Approach

The network was analyzed according to ZBM. The specifications and the Iraqi work process were approved. It has taken into account the excesses on the electrical power and the resulting acts of unmeant destruction.

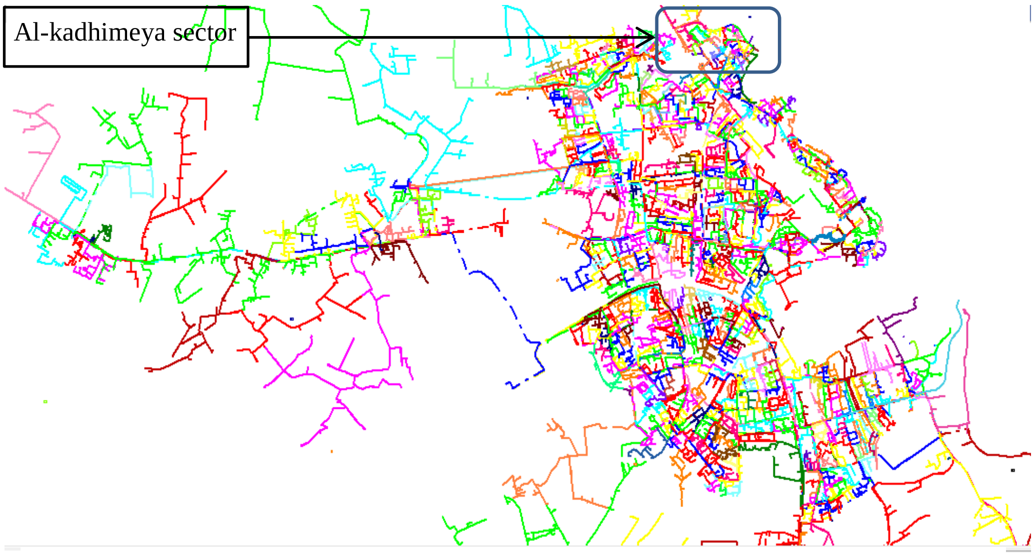

Figure 1. The electrical network of Al- Karkh side in Baghdad

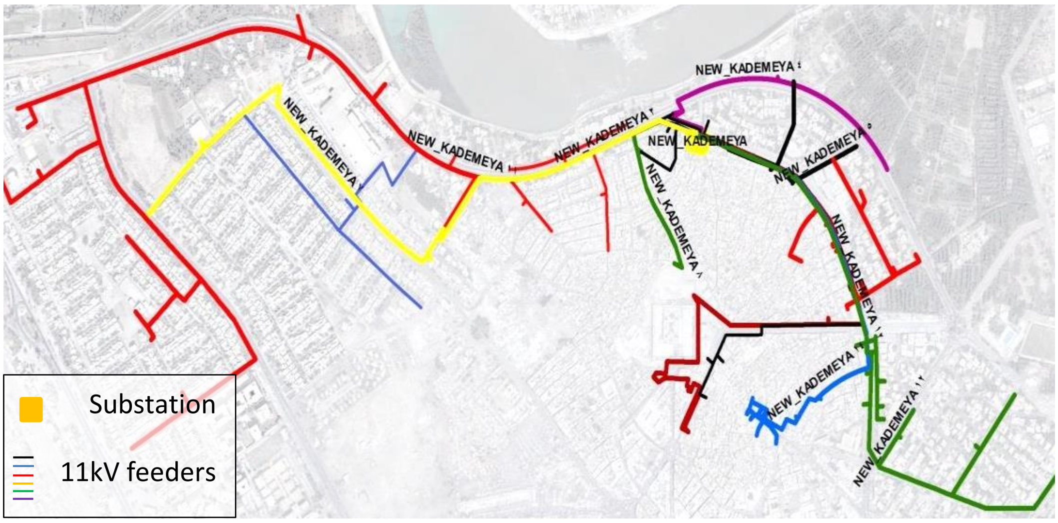

Figure 2. The electrical network of the new Al-Kadhimeya substation

The five selected feeders from the new Al-Kadhimeya substation have the following advantages:

1. The diversity in the quality of consumers.
2. Possibility of inject DGs.
3. They feed important areas of the city.

The five feeder's type is as following:

1. Feeder 2 is an industrial.
2. Feeder 4 and No. 13 are a governmental.
3. Feeder 11 is a residential.
4. Feeder 12 is a commercial.

The legend in figure 3 shows the symbols used for mapping the S.L.D. of new Al-Kadhimeya network, which is approved by the Iraqi ministry of electricity.

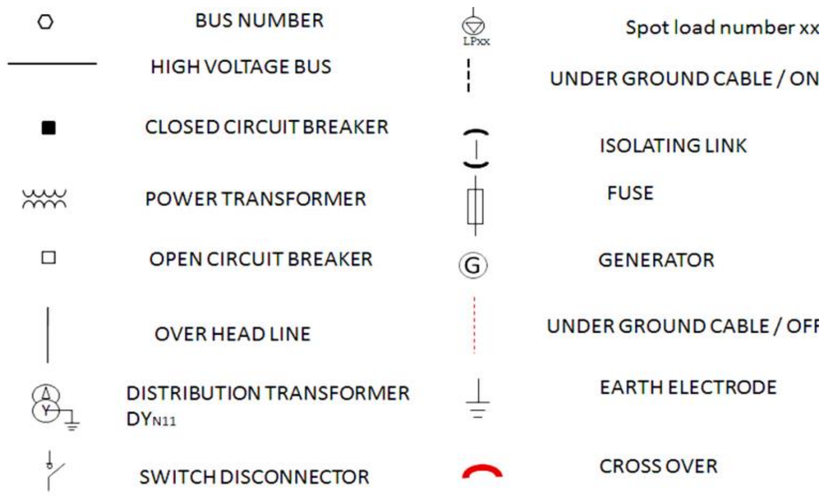

Figure 3. The legend used in network analysis.

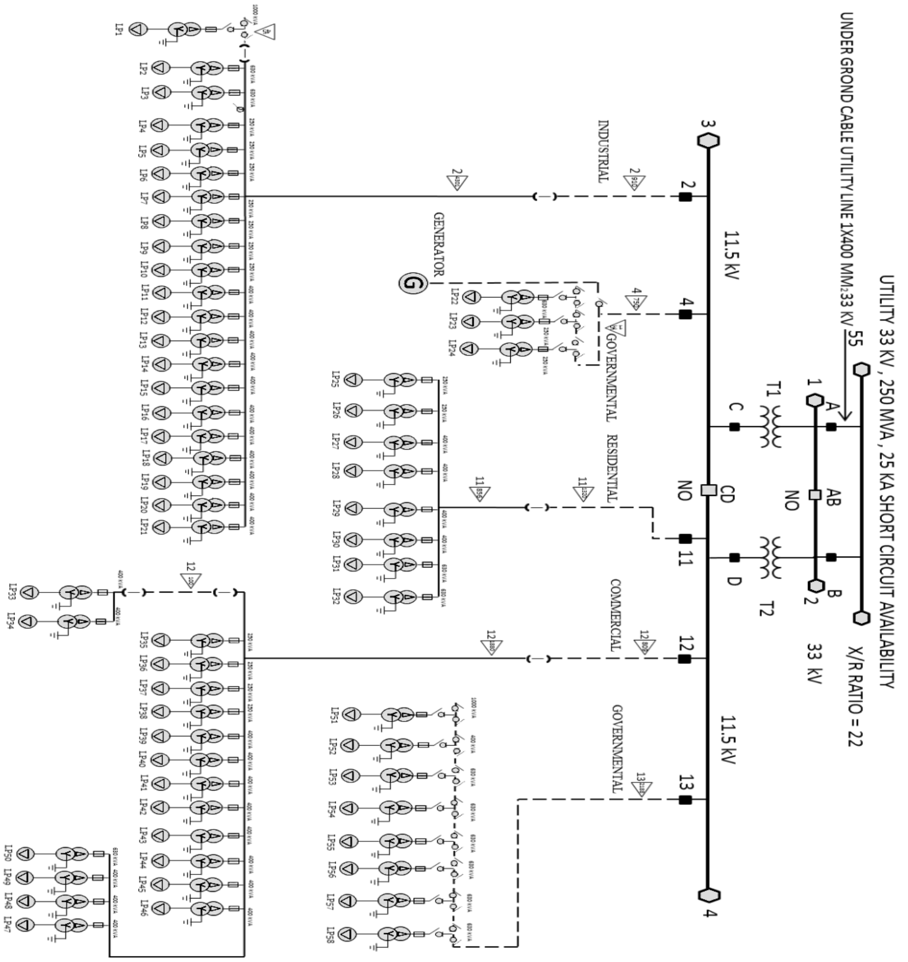

Figure 4. The S.L.D. of new Al-Kadhimeya network.

The analysis and calculation for new Al-Kadhimeya network depending on:

1. The analysis is starting on feeders (2, 4, 11, 12, and 13), without injecting DGs.
2. Distribution generators will be injected to all selected feeders in a sequential manner, and do the necessary computations.

3. When injecting the generators to any feeder, its effect is taken on the rest feeders and all parts of their network.
4. The failure rates and the repair duration will be calculated for each case.
5- The cost of each case will be studied and analyzed.

The figure 4 shows the analysis of the new Al-Kadhimeya network, and the figure 5 shows the system after its conversion into zones and branches

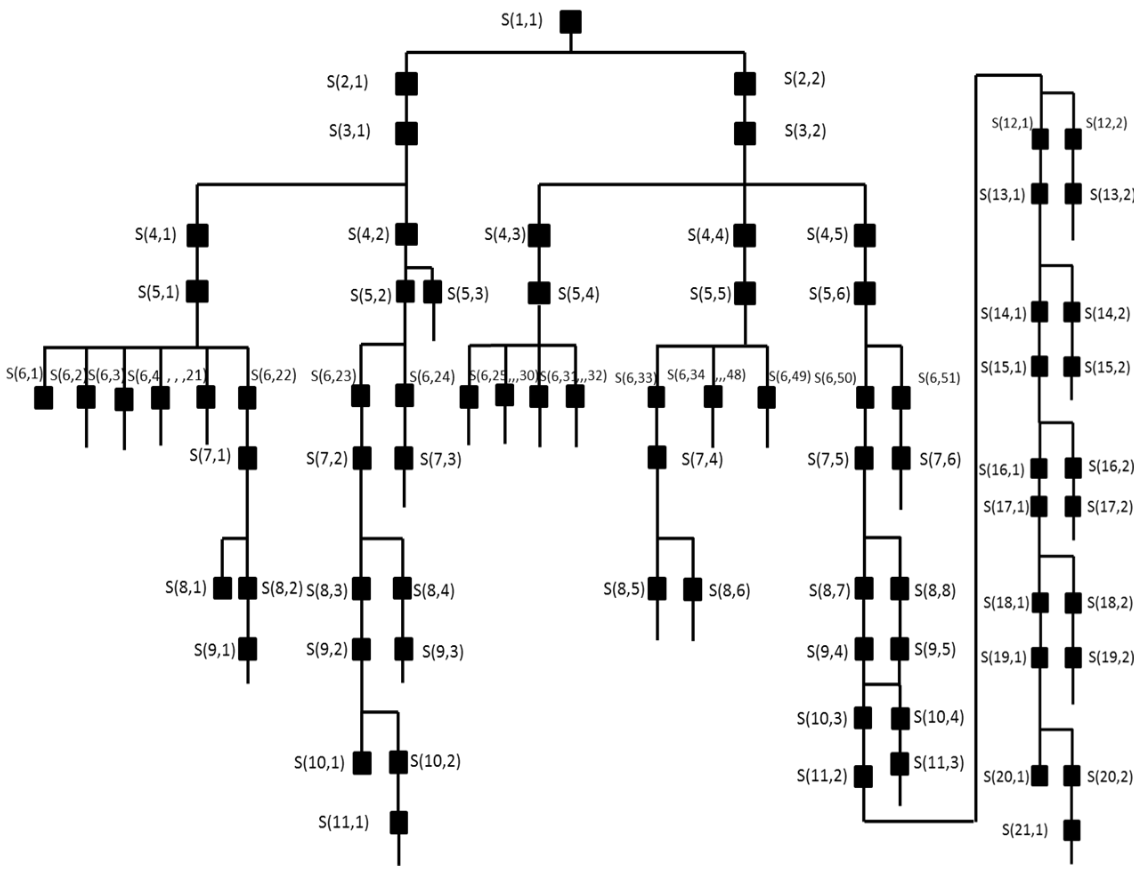

Figure 5. The S.L.D. of zones and branches of selected five feeders from new Al-Kadhimeya network

3.4 New Al-Kadhimeya Substation Calculation Approach

Reference [6], was depended to calculate the failure rate and average repair time for each network components, as listed in table 1, according to equation (1) below. The ZBM approach was used in reliability calculation. The Iraqi network actual data were used.

$$\lambda\ (\text{f/h}) = \frac{T_f}{T_p} \qquad (1)$$

Where T_f is the total number of failed throughT_p, and T_p is the time of the item data was collected (hours), i.e. total operating time (Total period).
The repair downtime (r) was calculated as in equation (2).

$$\mathrm{r} = \frac{R_{dt}}{T_f} \tag{2}$$

Where R_{dt} is the total downtime for unplanned maintenance (Without logistic time), for intended T_p (hours).

$$\mathrm{U\ (h/y)} = \lambda\, r \tag{3}$$

Where U is the annual outage duration.
According to reliability indices listed in table 1, and ZBM approach, the tables of summarized calculation with DG injected in feeders 2, 4, 11, 12, and 13 respectively are listed in tables 2-6.

Table 1. Equipment's Reliability Parameters Calculation.

Description	Item	Failure Rate (f /y)	Average Repair Time (r)(h/f)
254 MVA Available	Utility System 33 kV	1.000114168	1
Power Tr. 31.5 MVA	Transformer 33/11 kV	1.100552789	4
Distribution Tr.	Transformer 11/0.416 kV(1,0.63 MVA)	0.100009133	8
Distribution Tr.	Transformer 11/0.416 kV(400, 250 kVA)	0.200009133	2
Outgoing cables feeder2	3 X 150 mm^2 11 kV	0.300061657	6
Outgoing bare wires feeder2	3 X 95 mm2	13.74298605	2
Outgoing cables feeder4	3 X 150 mm^2 11 kV	2.002743484	6
Outgoing cables feeder 11	3 X 150 mm^2 11 kV	0.400109619	6
Outgoing bare wires feeder 11	3 X 95 mm2	3.602961338	2
Outgoing cables feeder 12	3 X 150 mm^2 11 kV	0.300061657	6
Outgoing bare wires feeder 12	3 X 95 mm2	19.78900534	2
Outgoing cables feeder 13	3 X 150 mm^2 11 kV	1.000685401	6
Circuit Breaker 1250A	33 kV Circuit breaker	0.200002283	0.5
Circuit Breaker(1250,630)A	11 kV Circuit breaker	0.50001427	0.5
C. B.(1.6,1,0.63,0.4,0.25)kA	416 V Circuit breaker	0.400045667	2.5
Link for Over Head 400 A	Isolated link - off load	0.02000016	3.5
Indoor On-Load 630 A	Isolated link - on load	0.070001398	2.5
Spot load	416V Grid and residential consumer	36.36226415	0.41322314
Spot load	416V Grid and industrial consumer	61.16338164	0.383606557
Spot load	416V Grid and commercial consumer	35.00199783	0.014285714
Spot load	416V Grid and governmental consumer	4.000456673	0.25
Generator	400V- 4x2000 kVA Diesel Generator	15.75280457	33
Switchgear bus	33 kV	0.028801137	12.00694444
Switchgear bus	11 kV	0.028804549	48.03125
Cut out fuse	11 kV	0.200004566	1

Table 2. The summarize calculation when DG injected on feeder 2

Feeder no.	Failure rate		difference	Average repair time		difference
	with DG	without		with DG	without	
2	364.6596	436.0563	-71.3967	37.7992	40.6252	-2.8260
4	15.4476	21.8812	-6.4336	9.6286	9.0468	0.5818
11	58.5016	75.6592	-17.1576	15.0421	16.2585	-1.2164
12	436.8542	475.4588	-38.6046	34.0973	35.0567	-0.9594
13	39.5138	56.6714	-17.1576	20.2604	20.2912	-0.0308

Table 3. The calculation summarize when DG on feeder 4

Feeder no.	failure rate		difference	Average repair time		difference
	With DG	Without DG		With DG	Without DG	
2	390.7005	436.0563	-45.3558	39.1533	40.6252	-1.4719
4	13.1527	21.8812	-8.7285	10.1581	9.0468	1.1113
11	58.3843	75.6592	-17.2749	15.0594	16.2585	-1.1991
12	436.5903	475.4588	-38.8685	34.1092	35.0567	-0.9475
13	39.3965	56.6714	-17.2749	20.3026	20.2912	0.0114

Table 4. The calculation summarize when DG is on feeder 11

Feeder no.	*Failure rate*		*difference*	*Average repair time*		*difference*
	with DG	without		with DG	without	
2	390.7383	436.0563	-45.3180	39.1484	40.6252	-1.4768
4	15.4072	21.8812	-6.4740	9.6456	9.0468	0.5988
11	47.4531	75.6592	-28.2061	13.0281	16.2585	-3.2304
12	436.6072	475.4588	-38.8516	34.1066	35.0567	-0.9501
13	39.4040	56.6714	-17.2674	20.2957	20.2912	0.0045

Table 5. The calculation summarize when DG on feeder 12

Feeder no.	failure rate		difference	Average repair time		difference
	with DG	without		with DG	without	
2	391.1814	436.0563	-44.8749	39.1293	40.625	-1.4959
4	15.4705	21.8812	-6.4107	9.6189	9.0468	0.5721
11	58.5592	75.6592	-17.1000	15.0368	16.258	-1.2217
12	413.6702	475.4588	-61.7886	33.2470	35.057	-1.8097
13	39.5714	56.6714	-17.1000	20.2445	20.291	-0.0467

Table 6. The calculation summarize when DG on feeder 13

Feeder no.	*failure rate*		*difference*	*Average repair time*		*difference*
	with DG	without		with DG	without	
2	390.6564	436.0563	-45.3999	39.1531	40.6252	-1.4721
4	15.3955	21.8812	-6.4857	9.6511	9.0468	0.6043
11	58.3600	75.6592	-17.2992	15.0606	16.2585	-1.1979
12	436.5356	475.4588	-38.9232	34.1100	35.0567	-0.9467
13	33.3954	56.6714	-23.2760	20.7777	20.2912	0.4865

The figure 6 shows the failure rate changes in each feeder as the DG was injected in varies positions. The maximum difference between upper and lower points for each feeder was on feeder 2, which was selected to inject DG.

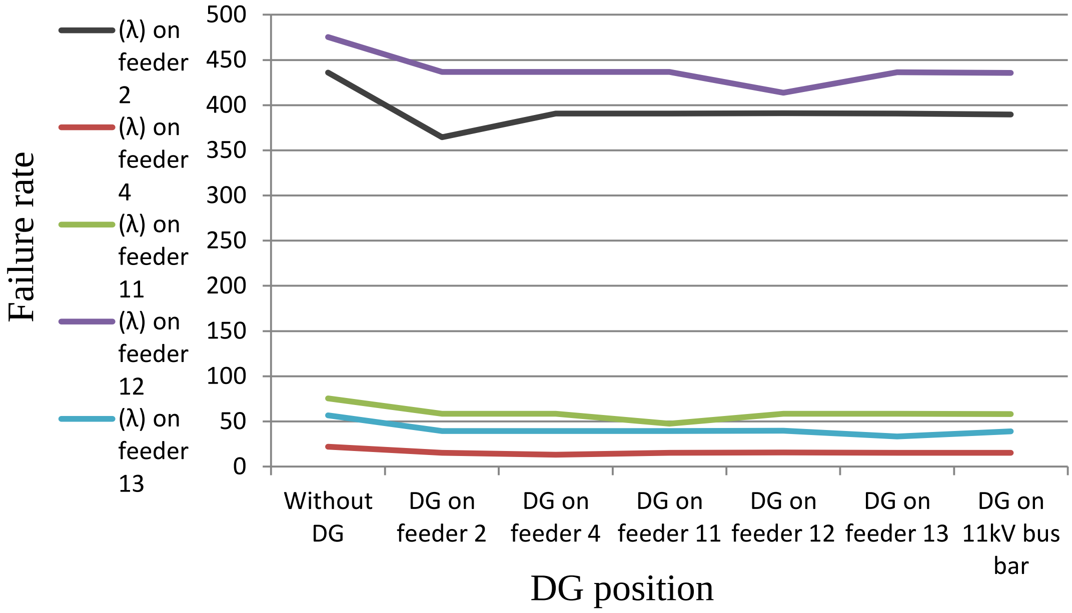

Figure 6. A chart shows the difference in failure rate values with and without injecting DG on the five feeders

4. The Cost Calculation Cases

From the tables 8,9and 10, it is clear that feeder 2 has the highest failure rates due to the interruption. Therefore the study in reliability indices calculation focuses on it. The computation is to choose the best feeder with respect to cost to inject generators [9].

It's important to mention the reliability cost indices [10]:
System average interruption frequency index, SAIFI.
System average interruption duration index, SAIDI.
Customer average interruption duration index, CAIDI.
Expected energy not supplied index, EENS.
Average expected energy not supplied index, AENS.
Average service availability index, ASAI.
Average service unavailability index, ASUI.
System interrupted energy assessment rate index, IEAR.
Expected customer interruption cost, ECOST.
Composite costumer damage Function, CCDF[11].

The details of calculations of reliability cost indices when DG injected in feeder 2 are listed in table 7.
The equations used to calculate above indices are listed below.

$$\text{SAIFI (f/customer.y)} = \frac{\sum \lambda\text{cNc}}{\sum \text{Nc}} \quad (4)$$

Where λc is the failure rate at the consumer, Nc is the number of consumer at load point c (consumers).

$$\lambda\text{c} = \sum_{i}^{j} \lambda\text{ij} \quad (5)$$

Where i is the number of element, and j is the total elements from supply to load point.

$$\text{SAIDI (h/customer.y)} = \frac{\sum \text{UcNc}}{\sum \text{Nc}} \quad (6)$$

Where Uc is the annual outage time at load point c, and Nc is the number of consumer of load point c.

$$\text{CAIDI (h/customer interruption)} = \frac{\sum \text{UcNc}}{\sum \lambda\text{cNc}} \quad (7)$$

$$\text{EENS (MWh/y)} = \sum_{\text{c}} \text{Pc Uc} \quad (8)$$

Where Pc is the average load interrupted at c, and Uc annual outage time at load point c

$$\text{AENS (MWh/customer.y)} = \frac{\sum \text{EENSc}}{\sum \text{Nc}} \quad (9)$$

$$\text{ASAI} = \frac{\sum Nc\,.8760 - \sum Uc\,Nc}{\sum \text{Nc}\,.8760} \quad (10)$$

$$\text{ASUI} = 1 - \text{ASAI} = \frac{\sum Uc\,Nc}{\sum \text{Nc}\,.8760} \quad (11)$$

$$\text{CCDF (\$/kW)} = \frac{\text{Tariff x total down time}}{\text{average power consumed}} \quad (12)$$

$$Pc = 0.8(from\ full\ capacity)\ X\ kVA(for\ Tr.)\ X\ 0.85(p.f.) \quad (13)$$

$$\text{ECOSTc} = Pc \sum \text{CCDF} \,.\, \lambda\text{c} \quad (14)$$

$$\text{IEAR ((\$/kWhr))} = \frac{\text{ECOST}}{\text{EENS}} \quad (15)$$

Table 7.The reliability cost indices calculations

Feeder No.	Load piont No.	λ (i,j) f/yr	Ui= λ r (i,j) hr/yr	Ni total No. of the costumer	λi x Ni failure rate per costumer yr	Ui x Ni hr per costumer yr
2- Kadmeya	1.000	17.508	41.058	1.000	17.508	41.058
Industrial	2 - 3	34.535	63.154	2.000	69.070	126.309
	4 - 10	121.573	218.241	3.000	364.720	654.722
	11- 21	191.044	342.950	5.000	955.218	1714.748
	total	364.660	665.403	0.000	0.000	0.000
4- Kadmeya	22.000	5.346	17.300	1.000	5.346	17.300
Governmental	23.000	5.206	16.450	1.000	5.206	16.450
	24.000	4.896	15.825	1.000	4.896	15.825
	total	0.000	0.000	0.000	0.000	0.000
11- Kadmeya	25-26	14.675	27.297	34.000	498.964	928.084
Residential	27-30	29.351	54.593	88.000	2582.870	4804.200
	31-32	14.475	28.097	83.000	1201.458	2332.017
	total	58.502	109.986	0.000	0.000	0.000
12- Kadmeya	33-34	48.924	92.321	6.000	293.543	553.924
Commercial	35-38	97.008	183.701	8.000	776.061	1469.609
	39-49	266.771	505.178	36.000	9603.752	18186.416
	50.000	24.152	46.325	1.000	24.152	46.325
	total	436.854	827.525	0.000	0.000	0.000
13- Kadmeya	51.000	5.859	14.324	1.000	5.859	14.324
Governmental	52.000	5.724	14.137	1.000	5.724	14.137
	53.000	5.414	13.512	1.000	5.414	13.512
	54.000	5.104	12.887	1.000	5.104	12.887
	55.000	4.794	12.262	1.000	4.794	12.262
	56.000	4.484	11.637	1.000	4.484	11.637
	57.000	4.274	10.612	1.000	4.274	10.612
	58.000	3.864	10.387	1.000	3.864	10.387
	total	39.514	99.755	278.000	16442.277	31006.743

Table 8. Composite Costumer Damage Function (CCDF) Computation

Type of feeder	average power consumed kW	Tariff Dinar/) (kWh	Dinars/h	Dollar($)s/h	Total Downtime (h)	Wasted Dollars for one year	CCDF $/kW	CCDF k$/kW
Industrial	5718.8	60	343128	293.3	23.4	6862.6	1.1999	0.0012
Governmental	768.4	120	92208	78.8	0.0	0.0	0	0
	3522.4	120	422688	361.3	1.0	361.3	0.102564	0.000103
Residential	1500	10	15000	12.8	0.0	0.0	0	0
	784.8	35	27468	23.5	0.0	0.0	0	0
	total		42468	36.3	15.0	544.5	0.2383	0.0002
Commercial	4644.4	60	278664.0	238.2	0.5	119.1	0.0256	2.56E-05

Table 9. The calculation of ECOST and IEAR without DG injected

Feeder No.	No. of L.P.(Tr.)	average power consumed kW	average power consumed MW	λ r h/y	EENS MWh/y	λ (i,j) f/y	ECOST (k$) / y	IEAR $/kWh
2	21	5718.8	5.7188	843.58	4824.257	436.1	2992.4625	0.620295
11	8	2284.8	2.2848	153.75	351.2956	75.66	41.142141	
12	18	4644.4	4.6444	930.40	4321.154	475.5	56.530454	0.013082
13	8	3522.4	3.5224	143.52	505.5433	56.67	20.560792	0.040671
Total	55	16170.4	16.1704		10002.25		3110.6959	0.311

Table 10. The calculation of ECOST and IEAR when DG injected on feeder 2

Feeder No.	No. of L.P. (Tr.)	average power consumed kW	average power consumed MW	λ r h/y	EENS MWh/y	λ (i,j) f/y	ECOST (k$) / y	IEAR $/kWh
2	21	5718.8	5.7188	665.40	3805.307	364.7	2502.4984	0.0002628
11	8	2284.8	2.2848	109.99	251.2968	58.50	31.812141	0.0039794
12	18	4644.4	4.6444	827.53	3843.358	436.9	51.940497	0.0002602
13	8	3522.4	3.5224	99.755	351.3786	39.51	14.335891	0.0028459
Total	55	16170.4	16.1704		8251.341		2600.5869	0.0001212

4.1 Reliability Indices Computation

From observation tables 9 and 10, feeder 2 has a clear advantage when calculating failure rates and the annual outage duration, and tables 11 and 12, shows its preference when calculating reliability indices related to costs, where the surplus amount is about 510,000 dollars per year, or about 16.4%.

Table 11. Reliability indices without injecting DG

SAIFI System Average Interruption Frequency Index	68.313 interruption/y
SAIDI System Average Interruption Duration Index	145.98 h /y
CAIDI Customer Average Interruption Duration Index	2.137 h/ interruption
ASAI Average service Availability Index	0.98333 per unite
ASUI Average Service Unavailability Index	0.01666 per unite
EENS Expected Energy Not Supplied	10002.24982 MWh/y
ECOST Expected Interruption Cost	3110.695909 k$/y
AENS Average Energy Not Supplied	35.979 MWh/costumer y
IEAR Interruption Energy Assessment Rate	0.311 $/kWh

Table 12. Reliability indices when DG is injected in feeder No. 2

SAIFI System Average Interruption Frequency Index	59.144 interruption/y
SAIDI System Average Interruption Duration Index	111.53 h /y
CAIDI Customer Average Interruption Duration Index	1.8858 h/ interruption
ASAI Average service Availability Index	0.987268 per unite
ASUI Average Service Unavailability Index	0.01273 per unite
EENS Expected Energy Not Supplied	8251.341124 MWh/y
ECOST Expected Interruption Cost	2600.586913 k$/y
AENS Average Energy Not Supplied	29.68 MWh/costumer y
IEAR Interruption Energy Assessment Rate	0.315171422 $/kWh

5. Conclusions

1. The zone branch methodology proved that, it can be applied in the reliability analysis of complex electrical power systems smoothly, and in fact one of the Iraqi distribution meshes was analyzed and enhanced.
2. Injected DGs are increasing the reliability of distribution mesh. The current location of generators which is on feeder 4, does not achieve the highest possible work efficiency. The Maximum reliability obtained when injected DGs in highest load demand point, which is at feeder 2. The failure rate reduces about 14.14%. And the surplus amount is approximately 510,000 dollars /y, or about 16.4%.
3. It is feasible to change the current generator site to the location suggested in this study.
4. The decision to choose the final location of generators was based on two important and contradictory factors, reliability and cost, and it was done by achieving a balance between them, by get maximum improvement in failure rates, and maximum gain by minimizing loses energy cost .

Abbreviation

C.B.	circuit breaker
h	hour
kWh	kilo watt hour
L.P.	load point
r	average repair time
S.L.D.	single line diagram
Tr.	Transformer
U	Annual outage duration
y	year
λ	failure rate

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