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A Weighted Sum of Multi-Objective Function based Reliability Analysis with the Integration of Distributed Generation

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***Abstract:** New trends in power system include the placement of the distributed generators (DGs) to overcome the drawbacks of the conventional power system, it can be connected near to the load points. Hence, the placement of DG is an important factor to be considered for the analysis due to its positive as well as negative impacts. An improved analytical approach for enhancing the reliability of the power system has been developed in this paper. By integrating DG of selected penetration level at all nodes of the test system, a set of reliability indices are evaluated based on interruption, improvement indices and blended as the multi-objective functions. Combinations of LVDI and PLRI with reliability improvement index are calculated by selecting the blended indices. Hence, enhanced system reliability is achieved. The analysis is carried out under the MATLAB platform on the standard RTBS bus distribution system.*

***Keywords:** Distributed Generation, Reliability, multi-objective function, power loss reduction index.*

I. INTRODUCTION

The electrical distribution network has been affected by disturbances and failures due to environmental as well as human issues. The invention of DG enhances the reliability of the system by improving the energy supplied [1]. This is advantageous to the services where the interruption in energy is unacceptable, like in health and industrial sectors. The improvement in the reliability can be measured in terms of the reliability indices [2]. There are mainly two methods of evaluation- analytical and simulation. The reliability of the power system is calculated by using mathematical equations using different indices by fallowing a methodology that uses the input data [4]. In the analytical approach, the system is represented by the simplified mathematical models. The equations are derived and the reliability indices are calculated using simple mathematical solutions [3]. The system performance at the customer end was used for the reliability evaluation of the system. The capability to deliver the power uninterrupted is called as the reliability. The flow of power in distribution network as the continuity in the service is an important factor of consideration. This can be defined by, The average failure rate (‘λ’), average outage time (‘r’) and average annual unavailability or average annual outage time (‘U’) are the three basic load point data [6]. This data can be used to analyze the performance of the considered system.

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II. RELIABILITY INDICES EVALUATION PROCEDURE

The reliability indices such as SAIDI, SAIFI, SAIVI, and ASAI in the system are evaluated by considering λ_i, U_i, and r_i of all sections and laterals in the distribution system. In this section after identifying the above-said parameters, the unavailability of load point L is given by $\sum\lambda_i$ is calculated as shown below,

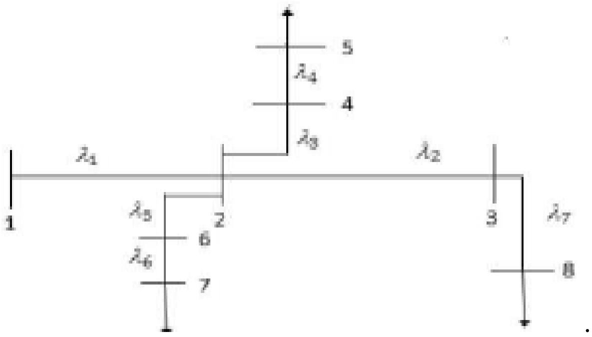

Fig 1. Typical Distribution circuit

$$\lambda_{L2} = \lambda_1$$
$$\lambda_{L3} = \lambda_1 + \lambda_2$$
$$\lambda_{L4} = \lambda_1 + \lambda_3$$
$$\lambda_{L5} = \lambda_1 + \lambda_3 + \lambda_4$$
$$\lambda_{L6} = \lambda_1 + \lambda_5$$
$$\lambda_{L7} = \lambda_1 + \lambda_5 + \lambda_6$$
$$\lambda_{L8} = \lambda_1 + \lambda_2 + \lambda_7$$

Where λ is a failure rate of line and λ_L represents the load point indices.

A. Problem formulation

The integration of DG at optimal location for selected level of penetration in this paper concentrates on the improvement of Reliability indices, Reduction of active power losses and Reduction of voltage deviation.

The calculation of load point reliability indices is as fallows

$$\lambda L = \sum_{i=0}^{n} \lambda i \quad (1)$$

$$rL = \frac{\sum_{i=0}^{n} \lambda i * ri}{\sum_{i=0}^{n} \lambda i} \quad (2)$$

$$UL = \lambda L * rL \quad (3)$$

Where

i = feeder sections connecting the load points to the supply.

λ_l = Average failure rate at load point L

r_L = Average outage time at load point L

U_L = Average annual unavailability or average annual outage timeat load point L

B. System Average Duration Index (SAIDI)

The average time of customers interrupted information can found by SAIDI

$$SAIDI = \frac{\sum_{i=0}^{n} Ui*Ni}{\sum_{i=0}^{n} Ni} \quad (4)$$

C. System Average Interruption Frequency Index (SAIFI)

It is the average number of interruptions per customer per unit time also defined as the ratio of a total number of interruptions to the total number of customers served.

$$SAIFI = \frac{\sum_{i=0}^{n} \lambda i *Ni}{\sum_{i=0}^{n} Ni} \quad (5)$$

D. Average Service Unavailability Index (ASUI)

It is the ratio of service availability of a total number of customer hours during a year to the customer hour demanded.

$$ASAI = \frac{\sum_{i=0}^{n} Ni * 8760 - \sum_{i=0}^{n} Ui * Ni}{\sum_{i=0}^{n} Ni * 8760} \quad (6)$$

Ni = number of customers at load point I, i=1, 2, 3, , , , , n

λi = failure rate at load point I, i=1,2,3,,,,, n

Ui = λ*r, where r is the outage time and 8760 is the number of hours in a calendar year.

III. TO FIND THE OPTIMAL LOCATION OF DG

The best location of DG has been chosen based on the multi-objective function, which gives the least Blended Index, Three different cases to improve the reliability indices are considered as follows

Optimal DG Placement for Reduction of Voltage deviation, Power loss, and Improvement of SAIFII

$$BI = w1 * LVDI + w2 * PLRI + w3 * SAIFII \quad (7)$$

Where,

$$LVDI = Log10 * \frac{V_{DG}}{V_{Base}} \quad (8)$$

$$PLRI = \frac{P_{loss\ Base} - P_{loss\ DG}}{P_{loss\ Base}} \quad (9)$$

$$SAIFII = \frac{SAIFII_{Base} - SAIFII_{DG}}{SAIFII_{Base}} \quad (10)$$

W1, W2, and W3 are the weighting factors for LVDI, PLRI and Reliability indices respectively,

W1+W2+W3 =1

LVDI= Logarithmic Voltage Deviation Index,

Voltage Base = Base Case Voltage in Volts

Voltage Dg= Voltage after Installation of DG in Volts,

PLRI = Real Power Loss Reduction Index

Ploss Base = Base Case Active Power Losses in KW,

Ploss DG = Active Power Losses with DG in KW

SAIVI= System Average Interruption Frequency index, SAIVII= System Average Interruption Frequency improvement index, BI= Blended Index.

IV. TO FIND THE OPTIMAL SIZE OF DG

The penetration level of DG is chosen based on the following equation.

$$PLDG\% = \frac{Size\ of\ DG}{Total\ demand} * 100 \quad (11)$$

Where,

PLDG = penetration level of DG

V. PROCEDUCRE FOR DG INTEGRATION

Step 1: Select and fetch the data of the test system.

Step 2: Calculate the actual size of DG for a selected penetration level using eq 11.

Step 3: Select and Compute the weighted sum of the multi-objective function index (WMOFI) by penetrating DG at each individual bus of the test system and rank indices on all buses.

Step 4: Choose the bus with minimum value of WMOFI as the optimal (best) location of DG.

Step 5: The above steps are repeated for different selected penetration levels of DG with relevant WMOFI.

VI. RESULTS AND DISCUSSIONS

The RBTS 2 consists of 5 load bus bars (BUS2-BUS6). Bus2 and Bus4 are considered for the analysis. Bus 2 is having its generation integrated with it and Bus4 don't have any generation units connected which permits the effects and difference from generation and transmission system on the overall load point indices to be seen

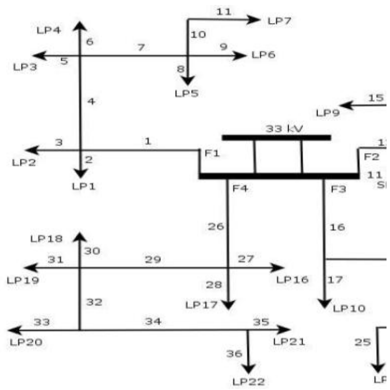

Fig 2: RBTS BUS 2

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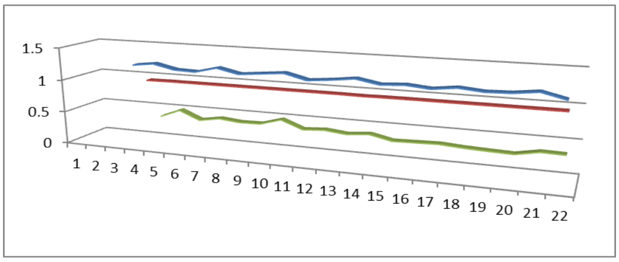

Fig 1:Voltage Profiles at Different Penetration levels of DG of RBTS BUS 2

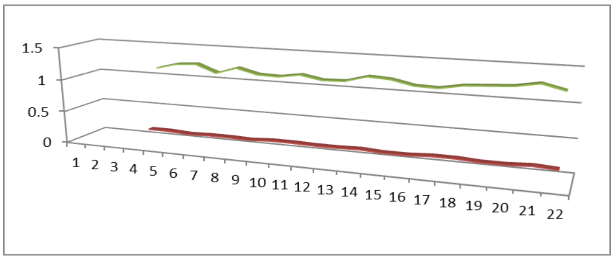

Fig 2: Losses at different Penetration levels of DG of RBTS BUS2

Voltage and power loss profiles, PLRI and Values of different reliability indices at Different Penetration levels of DG for Standard RTBS BUS RDS are shown figures 2,3 and 4 respectively.

Table 1: Values of different Reliability indices at 50%

Load Point	At 50% DG Penetration					
	PLRI	LVDI	SAIFI	SAIDI	ASAI	BIA
1	0.67973	0.00198	0.21	1.13	0.9956	0.2551
2	0.8228	0.0044	0.21	1.21	0.9995	0.30018
3	0.69085	0.00487	0.19	1.23	0.9996	0.28593
4	0.79456	0.00018	0.2	1.11	0.9996	0.29402
5	0.51449	0.01168	0.2	1.21	0.9996	0.22263
6	0.67657	0.00999	0.19	1.13	0.9996	0.27423
7	0.92368	0.00853	0.21	1.12	0.9996	0.32327
8	0.53236	0.01701	0.21	1.17	0.9995	0.21728
9	0.56612	0.01906	0.2	1.11	0.9999	0.21612
10	0.82456	0.01416	0.2	1.12	0.9996	0.30519
11	0.5101	0.0196	0.21	1.21	0.9956	0.20633
12	0.5801	0.02213	0.19	1.19	0.9995	0.24303
13	0.54091	0.01403	0.19	1.12	0.9996	0.23935
14	0.45283	0.02187	0.21	1.11	0.9996	0.17032
15	0.65404	0.02001	0.21	1.17	0.9996	0.24726
16	0.44048	0.01618	0.19	1.19	0.9996	0.20224
17	0.53273	0.00367	0.19	1.21	0.9996	0.23386
18	0.70169	0.00328	0.21	1.27	0.9996	0.2562
19	0.68107	0.00418	0.19	1.19	0.9999	0.28637
20	0.59052	0.00311	0.19	1.19	0.9995	0.24764
21	0.54512	0.00076	0.21	1.25	0.9995	0.21122
22	0.83649	0.00047	0.2	1.31	0.9995	0.32986

Table 2 and 3 show the values of different reliability indices and corresponding power losses, powerloss reduction index and algorithmic voltage deviation index values at all the load points for 50% and 75% of DG penetration respectively. Values of Blended index (BI) at all the load points are shown from which the optimal location of DG will be decided at the minimum value bus.

Table 2: Values of different Relaibility indices at 75%

Load Point	At 75% DG Penetration					
	PLRI	LVDI	SAIFI	SAIDI	ASAI	BIA
1	0.667468	0.002764	0.2	1.01	0.9956	0.268295
2	0.81179	0.002994	0.2	1.01	0.9995	0.313027
3	0.553788	0.005755	0.18	1.11	0.9996	0.262067
4	0.757384	0.000672	0.19	0.99	0.9996	0.300235
5	0.50628	0.012662	0.19	1.12	0.9996	0.237218
6	0.637249	0.011247	0.17	1.01	0.9996	0.297726
7	0.818622	0.009616	0.2	0.98	0.9996	0.309051
8	0.424248	0.025994	0.21	1.01	0.9995	0.185139
9	0.537193	0.020044	0.19	0.99	0.9999	0.225712
10	0.757113	0.015696	0.19	1.03	0.9996	0.30274
11	0.482526	0.02112	0.2	1.01	0.9956	0.215302
12	0.551168	0.024632	0.18	1.11	0.9995	0.252871
13	0.531371	0.015722	0.18	1.03	0.9996	0.254214
14	0.425384	0.020012	0.19	1.01	0.9996	0.197829
15	0.640412	0.021819	0.19	1.01	0.9996	0.277524
16	0.411662	0.018279	0.17	0.97	0.9996	0.229461
17	0.517746	0.001289	0.17	1.12	0.9996	0.263077
18	0.685239	0.004293	0.19	1.03	0.9996	0.285407
19	0.668781	0.000467	0.17	1.02	0.9999	0.315171
20	0.561743	0.004746	0.17	1.01	0.9995	0.274281
22	0.807739	0.00612	0.19	1.01	0.9995	0.338989

Table 3: Summary of results with different penetration levels of DG for CASE-B of RBTS BUS 2

Load Points	Number of customers	Base case	Penetration Level	
			50%	75%
1	210	0.9866	0.9911	0.9911
2	210	0.9831	0.9836	0.9836
3	210	0.9745	0.9855	0.9855
4	1	0.9692	0.9696	0.9696
5	1	0.9498	0.9757	0.9757
6	10	0.9453	0.9673	0.9673
7	10	0.9424	0.9611	0.9611
8	1	0.9361	0.9735	0.9735
9	1	0.9294	0.9711	0.9711
10	210	0.9293	0.9601	0.9601
11	210	0.9271	0.9699	0.9699
12	200	0.9219	0.9701	0.9701
13	1	0.9196	0.9498	0.9498
14	1	0.9182	0.9586	0.9586
15	10	0.9161	0.9593	0.9593
16	10	0.9142	0.9489	0.9489
17	200	0.9423	0.9403	0.9403
18	200	0.9362	0.9433	0.9433
19	200	0.9301	0.9277	0.9277
20	1	0.9191	0.9257	0.9257
21	1	0.9183	0.9199	0.9199
22	10	0.9161	0.9171	0.9171
Total number of customers affected		1277	655	644

Table 4 :Summary of results with different penetration levels of DG.

DG Penetration	Base case	50 %	75%
Location of DG		14	8
Size of DG(in kW)		0.236	0.472
Bus number Affected	5-22	13-22	13,16-22
No of affected customers	1277	644	623
Losses	0.734	0.33	0.31
PLRI	0.6677	0.45283	0.424248
LVDRI	0.00276	0.02187	0.025994
SAIDI	1.29550	1.11	1.01
ASAI	0.9996	0.9996	0.9995
BI	0.2973	0.17032	0.185139

From table 5 it is clear that with the integration of DG at the optimal location with different penetration levels will reduce the number of customers getting affected by the voltage sag and their voltage profile at load points from a specified value of 0.96 p.u.

In the base case without DG integration the number of customers getting affected by voltage sag is 1277 and with 50% and 75% of DG penetration, the customers getting affected by voltage sag will be reduced to 644 and 623 y. From table 5 it is clear that with the integration of DG at the optimal location with different penetration levels will reduce the number of customers getting affected by the voltage sag and their voltage profile at load points from a specified value of 0.96 p.u.

V. CONCLUSION

An improved analytical approach for enhancing the reliability of the power system is developed in this paper. By integrating DG of selected penetration level at all nodes of the test system, a set of reliability indices including indices based on interruption, improvement indices and blended indices including the combination of LVDI and PLRI with reliability improvement index are calculated selecting the blended indices as the multi-objective functions. For each function (BI-A) all the indices are calculated which gives the number of customers affected in the system. The minimum number of customer affected with 75% penetration of DG is 644. The system average voltage buses below 0.96 are considered and calculated to show the total number of customers affected by the voltage sag. Hence, enhanced system reliability is achieved.

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