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Analytical approaches for Optimal Placement and sizing of Distributed generation in Power System

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Abstract- *This work proposes a new algorithm which investigates the performance of Distribution system with multiple DG sources for the reduction in the line loss, by knowing the total number of DG units that the user is interested to connect. Strategic placement of multiple DG sources for a distribution system planner is a complex combinatorial optimization problem.*

The new and fast algorithm is developed for solving the power flow for radial distribution feeders taking into account embedded distribution generation sources. Also, new approximation formulas are proposed to reduce the number of required solution iterations. Power flow techniques (PF) for calculating Network performance index (NPI),Genetic algorithm in search of best locations, with considering NPI as fitness function.

I. INTRODUCTION

The impact of DG in system operating characteristics , such as electric losses, voltage profile, stability and reliability needs to be appropriately evaluated. The problem of DG allocation and sizing is of great importance. The installation of DG units at non-optimal places can result in an increase in system losses, implying in an increase in costs and thereof having an effect of opposite to the desired. For that reason the use of an optimization method capable of indicating the best solution for a given distribution network can be very useful for the system planning engineer when dealing with the increase of DG penetration that is happening nowadays.

II. MATHEMATICAL FORMULATION

System Description

Consider a three-phase, balanced radial distribution feeder with n buses, *I* laterals and sublatera generations. Also, *n*DG distributed and *n*C shunt capacitors as shown in figure 331ls.

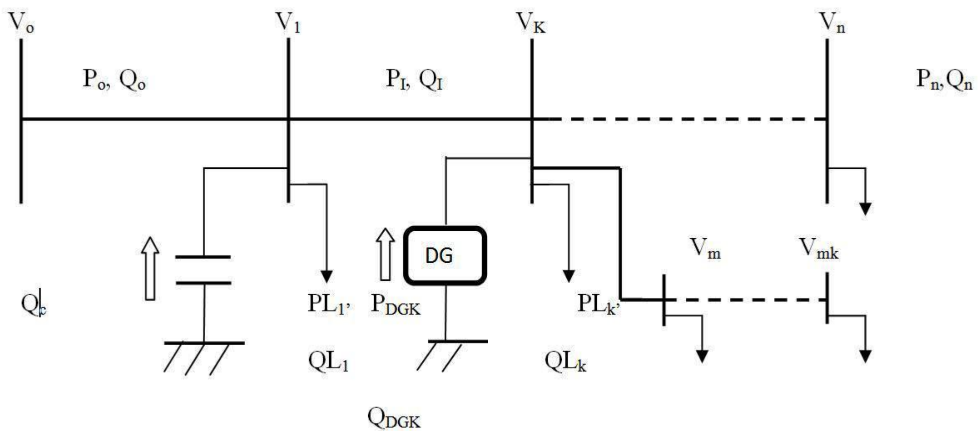


Fig. 1 : Redial Distribution feeder model including DG and Capacitor

The three recursive branch power flow equations are:

$$P_{i+1} = P_i - r_{i+1}(P_i^2+Q_i^2) / V_i^2 - P_{Li+1} + \mu_p AP_{i+1} \quad (2.1\ a)$$

$$Q_{i+1} = Q_i - x_{i+1}(P_i^2+Q_i^2) / V_i^2 - Q_{Li+1} + \mu_p AQ_{i+1} \quad (2.1\ b)$$

V_{2i+1} = V_i^{2-} $2(r_{i+1}P_i+x_{i+1}Q_i) + (r^2_{i+1}+x^2_{i+1})$ x $(P^2_i+Q^2_i) / V_i^2$ (2.1 c)

The following terminal conditions should be satisfied [6]:

i. At the end of the main feeder, laterals and sublaterals as shown in fig.2.1:

$$P_n = Q_n = 0 \quad (2.2)$$

$$P_{km} = Q_{km} = 0 \quad (2.3)$$

ii. The voltage at bus k is the same voltage of its lateral i.e:

$$V_k = V_{k0} \quad (2.4)$$

The real and reactive power losses of each section connecting two buses are:

$$P_{lossi+1} = (P_i^2 + Q_i^2 / V_i^2)r_{i+1} \quad (2.5)$$

$$Q_{lossi+1} = (P_i^2 + Q_i2/V_i^2)x_{i+1} \quad (2.6)$$

III. DG SIZING ISSUES

For single DG case, The DG optimal Size will be done by using Analytical Method based on Exact Loss Formula.

The real power loss in a system is given by

$$P_L - \sum_{i-1}^{N}\sum_{j-1}^{N} [x_{ij}(P_iPj + Q_iQj) + \beta_{ij}(Q_iP_i - PjQj)] \quad (2.7)$$

Where

$X_{ij} = \frac{rg}{ViVi}\cos(\delta i - \delta j)$, $\beta = \frac{nij}{ViVi}(\delta i - \delta j)$

Ri + $jx_{ij}=z_{ij}$ are the ij^{th} element of $[Z_{Bus}]$ matrix.

Analytical method is based on the fact that the power loss against injected power is a parabolic function and at minimum losses the rate of change of losses with respect to injected power becomes zero.

$$\frac{\partial P_L}{\partial P_i} = 2 \sum(x_{ij}\, P_j - \beta_i\, Q\cdot_i) = 0) \quad (2.8)$$

Where P_i is the real power injection at node I, which is the difference between real power generation and the real power demand at that node.

$$P_i - (iP_{DGi} \quad P_{Di}) \quad (2.9)$$

Where P_{dgi} is the real power injection from DG placed node I, and Pli is Load at node i. By combining equations results in to

$$P_{Dgi} - P_{Di}+1/\alpha_{ij}[\beta_{ij}Q_i-\sum_{i=1j\neq i}^{N}](\alpha_{ij}P_j-\beta_{ij}Q_i) \quad (2.10)$$

The above equation gives the optimum size of DG for each bus I, for the loss to be minimum. Any size of DG other than P_{dgi} placed at bus I, will lead to higher loss. In calculating the optimum sizes of DG at various locations, using equation (2.10), it was assumed that the values of variable remain unchanged. This result in small difference between the optimum sizes obtained by this approach and repeated load flow.

IV. PROPOSED ALGORITHM

4.1 Algorithm for Single DG case

The developed algorithm is explained stepwise as follows:
Step 1: First Read the Distribution Network Data and DG size.
Step 2: Give Network Data to Power flow Algorithm to get base case power flow.
Step 3: Save base case power flow for later use.
Step 4: Calculate the Network performance for Different DG.
Step 5: Insert the DG at which the NPI value closer to unity & optimize the DG size.
Step 6: Evaluate NPI with the help of base case power flow and Power flow with single DG inserted case.
Step 7: Print results and stop.

4.2 Algorithm for Multiple DG

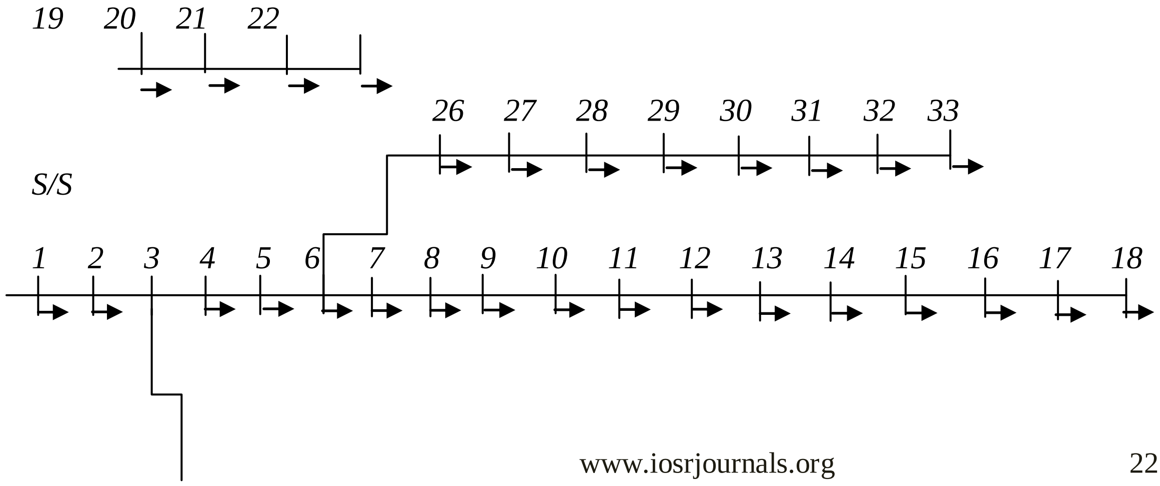
The following Algorithm is developed with the help of New and Fast Power Flow Solution Algorithm and Genetic Algorithm and is used to get the appropriate results. The developed algorithm is explained stepwise as follows:

Step 1: First read the Distribution Network Data.
Step 2: Give Network Data to New and Fast Powerflow Algorithm to get base case powerflow.
Step 3: Save base case powerflow for later use.
Step 4: Read Inserting Distributed Generators capacities. [Market available DG sizes 100KW, 220KW, 300KW, 500KW, 750KW, 1KW, 1.6MW]
Step 5: Read Bus numbers for DG insertions from Genetic Algorithm. If this is first time GA will give Initial population, otherwise GA will give New Population.
Step 6: Again apply powerflow for Distribution system with the inserted DG at the position from GA with the help of New and Fast powerflow Algorithm.
Step 7: Evaluate Multi Objective Index with the help of Base case powerflow and powerflow with DG inserted.
Step 8: Repeat step 6&7 for all combination of GA population.
Step 9: Check for number.
Step 10: Give NPI values as fitness values to the GA.
Step 11: With the help of fitness function values GA will do the operations (Selection, Crossover, Mutation, and Elitism) and generate new population next go to step5.
Step 12: Save the n best results and go to next Step
Step 13: For every best result decrease the capacity of DG with fixed % of their individual capacities and do the same for the maximum number of iterations.
Step 14: Lower limit of DG capacity will be 1% of Total load.
Step 15: Run powerflow with for all combinations of new capacities of DG and calculate NPI.
Step 16: Now compare these results with previously saved results fitness values, and print the results according to the best fitness values.
Step 17: Stop Corresponding Flowchart is as follows:

V. CASE STUDY AND ANALYSIS

5.1 TEST SYSTEM

The radial system with 33 buses and 32 branches with the total load of 3.715 MW and 2.28 MVAR, 11KV is taken as test system. The single line diagram of 33bus distribution system is shown in Figure 6.1. System Data is given in appendix-B.



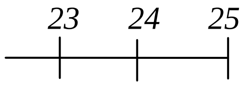


Fig.2. Single line diagram of 33 bus distribution system

5.2 GENETIC ALGORITHM SET UP

Representation

A Binary genetic algorithm (BGA) is employed to generate the combination of bus numbers.

Initialize Population

An initial population of size 30 is selected.

Selection

Tournament Selection is chosen for testing.

Reproduction

Two point Cross Over [0.8], [60% to 95% range] and Binary Mutation of ratio [0.05], [0.5% to 1% range] is used.

Generation-Elitism

Generation Elitism is taken 5, which copies the best chromosomes into next generation.

Fitness Evaluation

The network performance index for the distribution system with DG sources is aimed to be maximum and is selected for fitness evaluation.

Termination

The algorithm stops if the number of generations reaches 300, each simulation is a fairly lengthy process, but given that this process is a strategic one, the durations reasonable.

5.3 RELEVANCE FACTORS OF NPI

The NPI will numerically describe the impact of DG, considering a given location and size, on a distribution network. Close to unity values for the Network Performance Index means higher DG benefits. Table 6.0 shows the value for the relevance factors utilized in here, considering a normal operation stage analysis.

IL_p W_1	IL_Q W_2	IVD_Q W_3	IVR W_4	VSI W5
0.33	0.10	0.15	0.10	0.32

Table.1.NPI Relevance factors

5.4. Results and analysis

A series of simulations were run to evaluate the performance of Distribution System With a defined number of potential DG units. The capacities of DGs are considered in two ways with constant capacity and with tuned capacity. These were for the best set of 1,3 and 5 DG units located within the 32 possible sites and the corresponding Distribution system performance results.

Base case

PLOAD	QLOAD	PLOSSES	QLOSSES	PUTILITY	QUTILIITY	VSI
3.715MW	2.28MVAR	210.3KW	137.3KVAR	3.916MW	2.417MVAR	0.675

Table.2 Base System load flow Data

Bus Number	Voltage (p.u)
1	1.0000
2	0.9972
3	0.9836
4	0.9763
5	0.9691
6	0.9511
7	0.9475
8	0.9339
9	0.9276

10	0.9217
11	0.9208
12	0.9193
13	0.9132
14	0.9109
15	0.9095
16	0.9088
17	0.9067
18	0.9067
19	0.9061
20	0.9967
20	0.9931
21	0.9924
22	0.9918
23	0.9801
24	0.99734
25	0.9701
26	0.9491
27	0.9466
28	0.9351
29	0.9269
30	0.9234
31	0.9192
32	0.9183
33	0.9180

Table 2.1 Base case Voltage Profile

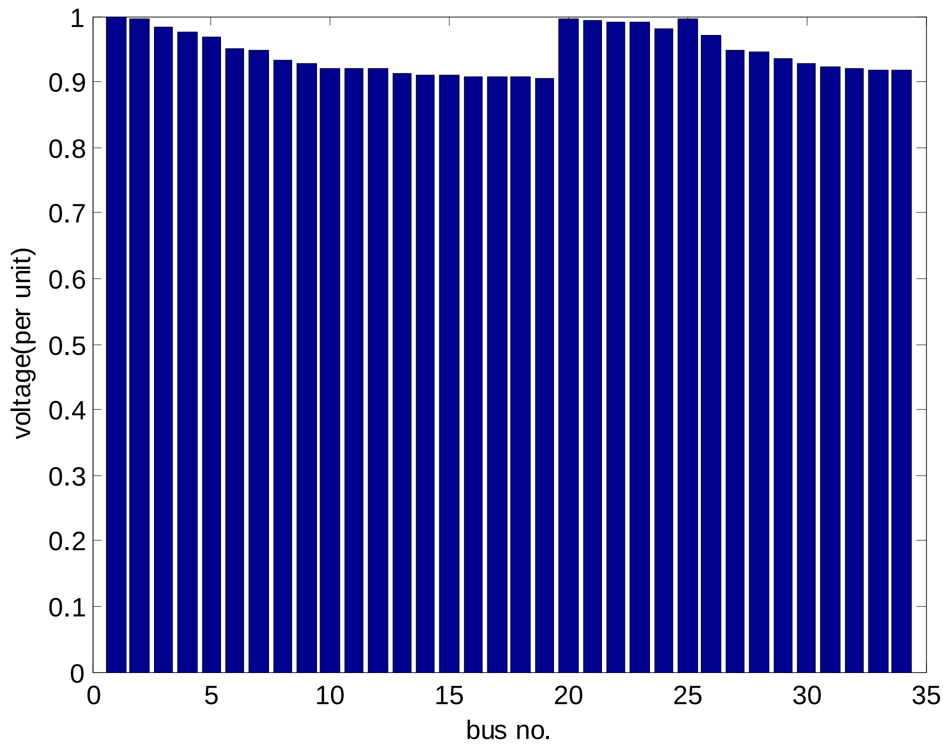


Fig. 3. Base case Voltage Profile Plot

Single DG Case

The Following table represents the IVD, IVR values for best combination

IVD	IVR

0.95499	0.95393

NPI	Bus Number	P_{DG} (KW)	P_{Loss} (KW)	Q_{Loss} (KVAR)	VSI	$P_{UTILITY}$ (KW)	Q_{UTLITY} (KVAR)
0.5489	31	1296.190	105.496	78.833	0.7971	2524.298	2378.832
0.5477	32	1244.690	105.718	79.501	0.7923	2576.028	2379.506
0.5411	33	1183.540	107.125	82.370	0.7865	2638.548	2382.369
0.5328	30	1471.350	108.178	80.041	0.8134	2351.828	2380.041
0.5331	6	1491.520	108.671	80.375	0.7923	13332.152	2380.376

Table 2.2. Single DG Test Result with 5 best combinations

Bus Number	Voltage (p.u)
1	1.0000
2	0.9988
3	0.9936
4	0.9925
5	0.9917
6	0.9877
7	0.9844
8	0.9713
9	0.9652
10	0.9596
11	0.9587
12	0.9573
13	0.9514
14	0.9492
15	0.9478
16	0.9472
17	0.9452
18	0.9446
19	0.9982
20	0.9947
21	0.9940
22	0.9933
23	0.9900
24	0.9834
25	0.9802
26	0.9875
27	0.9874
28	0.9852
29	0.9840
30	0.9848
31	0.9889
32	0.9881
33	0.9878

Table 2.3 Voltage Profile with Single DG at bus 31

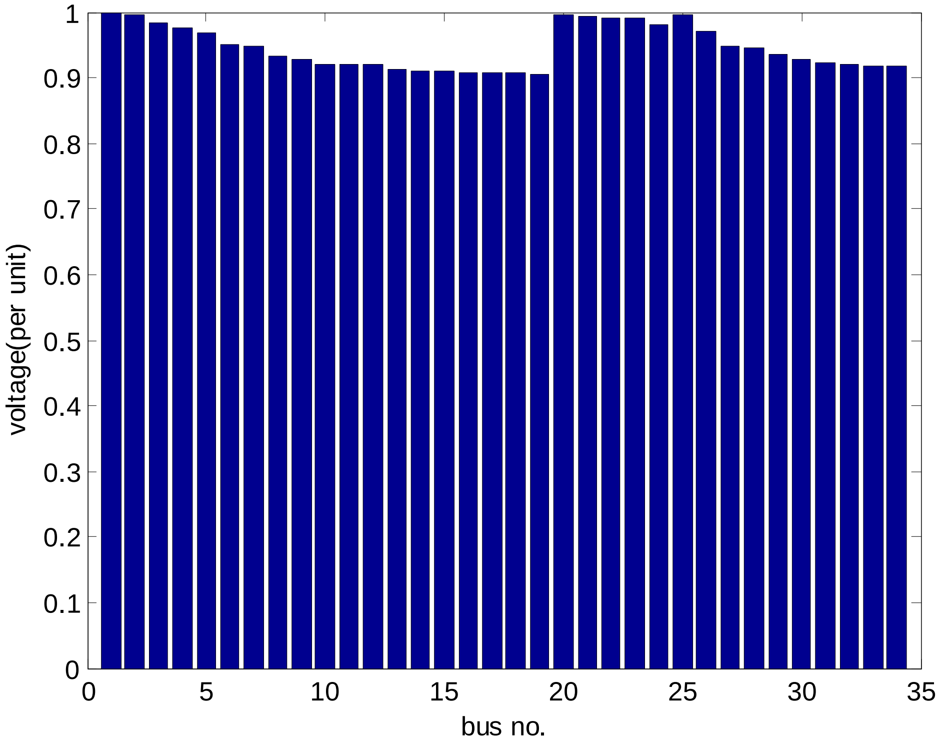


Fig.4. Voltage Profile plot with Single DG at bus 31

3DG Case

The following table represents the IVD, IVR values for best combination.

IVD	IVR
0.9675	0.95657

Without Tuning

DG sizes are 1000 KW, 750 KW, and 500 KW

NPI	Bus Number	DG (KW)	P_{DG} (Total) (KW)	P_{Loss} (KW)	Q_{Loss} (KVAR)	VSI	$P_{UTILITY}$ (KW)	$Q_{UTILITY}$ (KVAR)
0.79106	31 14 25	1000 750 500	2250	69.339	51.6276	0.9176	1534.339	2351.623
0.78828	30 25 16	1000 750 500	2250	70.89669	57.962	0.9104	535.890	2351.962
0.78611	29 15 16	1000 750 500	2250	71.741	52.3996	0.89038	1536.743	2352.400
0.77022	11 31 4	1000 750 500	2250	75.8641	54.9118	0.89486	1540.665	2354.912
0.7644	30 9 25	1000 750 500	2250	77.088	55.8658	0.86670	1542.087	2355.866

Table 2.4. 3DG test Results without Tuning 5 best combinations.

With Tuning

NPI	Bus Number	DG (KW)	PDG (Total) (KW)	PLoss (KW)	QLoss (KVAR)	VSI	PUTILITY (KW)	QUTILITY (KVAR)
0.79612	31 14 25	899.977 678.183 449.838	2027.699	68.4845	48.2754	0.9273	1755.786	2348.276
0.78903	30 25 16	955.671 724.049 480.026	2159.98	69.031	49.207	0.9138	1624.328	2349.021
0.78657	29 15 16	955.744 713.188 477.872	2146.805	70.181	49.479	0.9119	1638.377	2349.48
0.77024	11 31 4	980 731.25 490	201.25	72.1742	51.4284	0.8987	1585.924	2351.428
0.7625	30 9 25	931.994 706.110 465.997	2104.102	74.52	52.297	0.88297	18685.421	2352.298

Table 2.5. 3DG test Results with Tuning 5 best combinations.

Bus Number	Voltage (p.u)
1	1.0000
2	0.9995
3	0.9980
4	0.9974
5	0.9971
6	0.9942
7	0.9918
8	0.9871
9	0.9861
10	0.9874
11	0.9858
12	0.9861
13	0.9874
14	0.9879
15	0.9865
16	0.9859
17	0.9840
18	0.9835
19	0.9989
20	0.9954
21	0.9947
22	0.9940
23	0.9959
24	0.9922
25	0.9918
26	0.9936
27	0.9930
28	0.9889
29	0.9863
30	0.9862
31	0.9884

32	0.9876
33	0.9873

Table2.6 Voltage Profile with 3DGs at bus 31, 14, 25

5 DG Case
The Following table represents the IVD, IVR values for best combination.

IVD	IVR
0.9949	0.9852

NPI	Bus Number	P_{DG} (KW)	P_{DG} (Total) (KW)	P_{Loss} (KW)	Q_{Loss} (KVAR)	VSI	$P_{UTILITY}$ (KW)	Q_{UTLITY} (KVAR)
0.7877	24 18 33 8 9	1000 250 750 300 500	2800	74.9616	51.5129	0.91643	989.9644	2351.515
0.7847	32 25 2 15 12	1000 250 750 300 500	2800	75.2615	53.1826	0.91241	990.262	2335.184
0.7761	3 12 13 32 31	1000 250 750 300 500	2800	78.5738	78.5738	54.9075	0.89104	2354.902
0.7664	30 25 14 27 21	1000 250 750 300 500	2800	86.984	86.984	60.672	0.88.632	2360.675

Table. 2.7. 5DG Test Results without tuning 5 best combinations

NPI	Bus Number	P_{DG} (KW)	P_{DG} (Total) (KW)	P_{Loss} (KW)	Q_{Loss} (KVAR)	VSI	$P_{UTILITY}$ (KW)	Q_{UTLITY} (KVAR)
0.79027	24 18 33 8 9	868.4808 222.6871 671.4525 264.5321 438.6601	2465.813	687794	47.6779	0.92094	1317.967	2374.678
0.78721	32 25 2 15 12	922.604 324.181 695.465 279.598 461.302	2593.151	71.703	50.63	0.91868	1193.553	2350.631
0.7772	3 12 13 32 31	940.3366 237.7294 709.5862 283.8345 477.8723	2650.359	71.9391	50.8451	0.908348	1136.580	2350.845
0.77432	30 25	821.808 206.4949	2287.264	72.488	51.145	0.91399	1500.224	2351.145

	14 27 21	603.998 244.058 410.904						

Table. 2.8. 5DG Test Results with tuning 5 best combinations

Bus Number	Voltage (p.u)
1	1.0000
2	1.0001
3	0.9989
4	0.9996
5	1.0007
6	1.0009
7	0.9985
8	0.9939
9	0.9929
10	0.9924
11	0.9925
12	0.9929
13	0.9941
14	0.9946
15	0.9933
16	0.9927
17	0.9908
18	0.9902
19	1.0001
20	1.0012
21	0.0018
22	1.0012
23	0.9961
24	0.9910
25	0.9891
26	1.0007
27	1.0006
28	0.9966
29	0.9940
30	0.9939
31	0.9900
32	0.9892
33	0.9889

Table2.9 Voltage Profile with 3DGs at bus 24,18,33,8,9

In table 2, the base system load data, losses, voltage, voltage stability index and utility generated real and reactive power are given. The base case voltage profile and corresponding voltage profile plot are in table 2.1 and fig.3 , the single DG case results are given for best five combinations in NPI priority order. This is the case in which the user wants to connect single DG unit to utility in order to reduce loss and to improve voltage profile and voltage stability index of the distribution system. The voltage improvement and voltage profile plot with this case is shown in table 2.4 and fig.4.

In the table 2.4, the 3DG case results are given for best five best combinations in NPI priority order. This is the case in which the user wants to connect 3DG with market available DG capacities to utility in order to reduce loss and to improve voltage profile, voltage stability index and hence the NPI of the distribution system from the previous single DG case. The voltage improvement and voltage profile plot with this case is shown in table 2.6 and table 2.5, represents the 3DG case results for five best combinations with tuning of market available DG sizes, which results reduction in losses, improvement in voltage stability index and hence NPI of Distribution system from case of fixed DG capacities.

Similarly in the 5DG case results are given for best five combinations are given in the tables 2.7 and 2.8 with market available DGs and with tuning of market available DGs. These cases results reduction in losses improvement in voltage profile, voltage stability index of system and hence NPI.

VI CONCLUSION

This work present a method of combining a new and fast power flow and genetic algorithms with an aim to provide a means of finding the combination of sites within a distribution network for connecting a predefined number of DGs. The network performance index is used in finding best combination of sites within network. In doing so it evaluates the distribution system performance with DG capacities and maximizes the Network Performance index. Voltage stability index is used to determine the weak branches in the distribution network. Its use world be to enable Distribution System Planner to search a network for the best sites to strategically connect a small number of DGs among a large number of potential combinations in order to improve Distribution system performance.

This work concentrated on the technical constraints on DG development like voltage limits, thermal limits and especially the loss reduction (DG impacts on losses is an area that is being extensively researched at present).

This work can be easily being adapted to cope with variable energy sources.

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