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Optimal Placement of Distributed Generation (DG) in a Distribution Network

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Abstract: In this paper power flow analysis of 15MVA, 33/11 kV Injection substation and its associated feeders is carried out to determine the status of voltage magnitudes, power losses and load flows at each bus. To improve the voltage magnitudes and reduce power losses Distributed Generators were placed optimally in the Network by developing a Genetic Algorithm (GA) programme in Matrix Laboratory (MATLAB) and effecting the simulation in an Electrical Transient Analyzer Programme (ETAP).

With the insertion of DG optimally, the results was compared with when the DG were not optimally placed. When the load flow for the entire network was simulated, the losses during peak period was 6.59MW, 2.22Mvar and off peak was 3.78MW, 2.01Mvar. The highest percentage voltage drop was 13.55% for peak and 11.1% for off peak.

When DG was placed optimally, the loss for peak was 2.73MW, 1.59Mvar and for off peak 2.02MW, 1.09Mvar. The percentage highest voltage drop for peak period was 7.98% and 6.71% for off peak.

With the insertion of DG optimally, enhancement in voltage at various buses, reduction in system power loss and improvement in load flow values were achieved.

Keywords: Distributed Generation (DG), Genetic Algorithm (GA), Electrical Transient Analyzer Programme (ETAP), load flow.

I. Introduction

DG may play an increasingly important role in the Electric power system infrastructure and market. The siting of distributed generator in distribution feeders is likely to have an impact on the operations and control of power system, a system designed to operate with large, central generating facilities. DG devices can be strategically placed in power systems for grid reinforcement, reducing power losses and on-peak operating costs, improving voltage profiles and load factors, differing or eliminating for system upgrades, and improving system integrity, reliability, and efficiency [1]-[3]. Generalized reduced gradient method or the second order method is previously used to compute the amount of resources in selected buses to make up a given total to achieve the desired optimizing objectives [1],[4]. The benefit expressed as a performance index can be the minimization of active Power losses, VAR losses, or loading in selected lines.

Introduction of generation resources such as DGs on the distribution system can significantly impact the flow of power and voltage conditions at customers and utility equipment. Voltage regulation for maintaining the voltage conditions within a permissible range is normally achieved using LCT (load-tap Changing Transformer) and LDC (Line Drop Compensator) at substation bus [5],[6].

Distributed Generation is an emerging technology in this new era and it provides clean electric power. Distributed Generation should be located at or near an electrical load Centre. Installation of Distributed Generation at optimal places provides the clean electric power to the customer [7]. Distributed Generation is connected directly to the radial distribution network or it connected directly to the customer side in the distribution Network.Different issues have been mentioned to define theDistributed generation more importantly .Some of the issues of DG is Distributed Generation rating, technology, sizing, sitting, mode of operation and Distributed Generation penetration [8]. Distributed Generation is a small generating unit located in the effective point of the electric power system near to the load center. DG Technology comprises of Wind energy, Solar Energy, micro-turbine, fuel cell and gas turbine [9].

Optimal DG allocation by single DG placement at the corresponding bus voltage profile at various buses is evaluated and the total power loss is also calculated using Newton-Raphson method [10]. Distribution Network analysis using power flow study plays an important role in the power system area. Distribution network is mostly characterized by their high R/X ratio and radial topology. Backward/forward sweep method is used as an initial power flow for radial distribution system with the consideration of Distributed Generation [11]. Optimal placement and sizing of DG using NR method for load flow study in analyzing the network in other to know the proper bus location, minimizes both the losses and the costs simultaneously which helps in maximizing the potential benefits [12].

DG sources have attracted serious attention due to their potential solution for some issues, like the deregulation in power system, increasing the power consumption and the shortage of transmission capacities. The optimal placement of DG is necessary for maximizing the DG potential benefits in power system such as maintaining and/or improving reliability and stability. There are several research studies to determine the optimal DG location by their imposed constraints and objectives. However, the systematic principle for this issue is still an unsolved problem. Some of the most popular DG placement methods are, including 2/3 Rule, Analytical Methods,Optimal Power Flow and Evolutionary Optimization (PSO), Fuzzy Systems (FZ), Tabu Search (TS), Computational Methods (Genetic Algorithm, AntColony Search (ACS), Particle Swarm Optimization and many more.

The major objective of DG placement techniques is to minimize the losses of power systems. However, other objectives like improving the voltage profile, reliability, maximizing DG capacity, cost minimization and etc has to be considered.

DG is a kind of electricity production which is onsite or close to the load center and is interconnected to the distribution system. The plenitude of the advantages of DG justifies the planning of electric systems at presence of

DG. Some important reasons for the increasingly widespread use of DG could be summarized as follows:

- DG units are closer to customers. Therefore Transmission and Distribution (T&D) costs are reduced;
- The latest technology has made available plants with high efficiency and extended ranging in capacity (ranging in capacity from l0kW to 15MW);
- It is easier to find sites for small generators;
- Natural gas as fuel in DG stations is easily accessible and prices are more stable;
- Usually DG plants require shorter installation times and the investment risk is not too high;
- DG plants yield fairly good efficiencies especially in cogeneration and in combined cycles (larger plants);
- The liberalization of the electricity market contributes to creating opportunities for new utilities in the power generation sector;

DG offers greater values as it provides a flexible way to choose a wide range of combinations of cost and reliability. [13]

II. The Objective Function or Fitness Value (Of)

This paper is aimed at proposing an algorithm to find the best place, capacity, and number of DG resources according to the technical parameters in the distribution network. Therefore, an objective function is proposed that includes the most important parameters of the network. The considered parameters include the total power loss of the network, voltage profile of the distribution buses and the appropriate number of DG units.

To minimize a function consisting of some parameters, the general function can be written as a summation of those parameters.

$$f = f_1 + f_2 + \dots + f_N = \sum_{i=1}^{N} f_1 \qquad (1)$$

Here, N is the number of factors that affect the OF.

III. Summary of the Objective Function

According to the preceding equations, the final OF to be minimized is acquired as follows:

$$f = f_1 + f_2 + f_3 (2)$$

Substituting f_1 , f_2 and f_3 by their obtained values will result in the following equation:

$$f = a_n \frac{P_{loss}^{With\ DG}}{P_{loss}^{Without\ DG}} + \sum_{n=1}^{N} b_n \left(V_{bus,n}^{With\ DG} - 1\right)^2 + \sum_{n=1}^{N} d_n \frac{CG_n}{S_{base}} \qquad (3)$$

By simplifying Eq. (4) is obtained as follows:

$$f = \sum_{n=1}^{N} \left(a_n \frac{P_{loss}^{With\ DG}}{P_{loss}^{Without\ DG}} + b_n \left(V_{bus,n}^{With\ DG} - 1\right)^2 + d_n \frac{CG_n}{S_{base}} \right) (4)$$

IV. Methodology

The load flow is simulated on this 15MVA, 33/11 kV Injection substation and its associated feeders, the network consists of eighty five (85) buses. Figure. 1. Presents a section of the load flow simulation in ETAP software environment. The results from the load flow are presented in Table 1. Table 2 presents the load flow result of a section of the Network for Peak period.

Table 1. Load Flow Result for 15 MVA Injection Substation

	Peak	Off Peak
Voltage Profile	0.8645 – 0.9560pu	0.889 – 0.9799pu
Active Load Demand	25.210MW	17.273MW
Reactive Load Demand	10.243Mvar	9.93Mvar
Losses (Real)	6.59MW	3.78MW
Losses (Reactive)	2.218Mvar	2.01Mvar

Table 2. Load Flow Result Obtained From Existing Network for Peak Period for Some Substations

Connected Bus			**Sending End**		**Receiving End**		**Line Losses**		**Feeder Losses**	
From		**To**	**Active (kW)**	**Reactive (kVar)**	**Active (kW)**	**Reactive (kVar)**	**Active (kW)**	**Reactive (kVar)**	**Active (kW)**	**Reactive (kVar)**
1.	Otovwodo 4	Bishop Emuobor	3820.03	2754.81	3745.02	2695.40	75.01	59.41	19.10	11.30
2.	Otovwodo 4	Otovwodo 2	3623.63	2698.01	3571.22	2650.30	52.41	47.71	17.00	23.70
3.	Otovwodo 2	Otovwodo 3	3472.63	2533.81	3417.52	2495.30	55.11	38.51	11.80	9.10
4.	Otovwodo 2	AgbarhaJunt.	4000.53	2781.71	3946.72	2741.30	53.81	40.41	12.70	8.40
5.	AgbarhaJunt.	Agbarha Road	3400.33	2108.01	3334.82	2051.00	65.51	57.01	18.00	12.20
6	Agbarha Road	White House	3884.83	2841.01	3831.22	2795.40	53.61	45.61	16.10	11.30
7	White House	Slaughter Road	3403.63	2706.01	3342.12	2652.40	61.51	53.61	11.40	8.10
8	Slaughter Road	Uduere II	3260.03	2207.71	3176.52	2149.10	83.51	58.61	15.10	10.30
9	Uduere II	Uduere I	3191.33	2007.91	3147.32	1967.10	44.01	40.81	16.40	12.30
10	Uduere I	Owevwe	3260.53	2108.01	3179.32	2048.60	81.21	59.41	12.50	10.10
11	Owevwe	Opherin	3300.23	2305.81	3227.42	2242.60	72.81	63.21	13.80	11.30
12	Uduere I	Saniko	3238.63	2863.41	3185.62	2834.80	53.01	28.61	19.00	13.80
13	Saniko	Gana	3638.83	2697.41	3572.12	2634.20	66.71	63.21	15.2	10.10
14	Gana	Omavwowe II	3292.63	2763.61	3239.02	2714.90	53.61	48.71	11.80	7.80
15	Omavwowe II	Omavwowe I	3401.53	2764.51	3357.92	2728.00	43.61	36.51	13.70	10.90
16	Gana	Okpa - Agbarha	3274.33	2640.31	3188.02	2576.80	86.31	63.51	13.10	8.90
17	Okpa - Agbarha	Oteri	3404.63	2742.21	3339.42	2686.60	65.21	55.61	16.50	11.50
18	Oteri	Etefe	2938.83	2653.21	2869.42	2589.80	69.41	63.41	14.70	10.80
19	Etefe	Awirhi	3360.53	2664.11	3282.02	2599.70	78.51	64.41	11.80	8.20
20	AgharhaJunct.	Mr Biggs	3398.73	2707.01	3326.02	2676.10	72.71	30.91	19.30	12.40

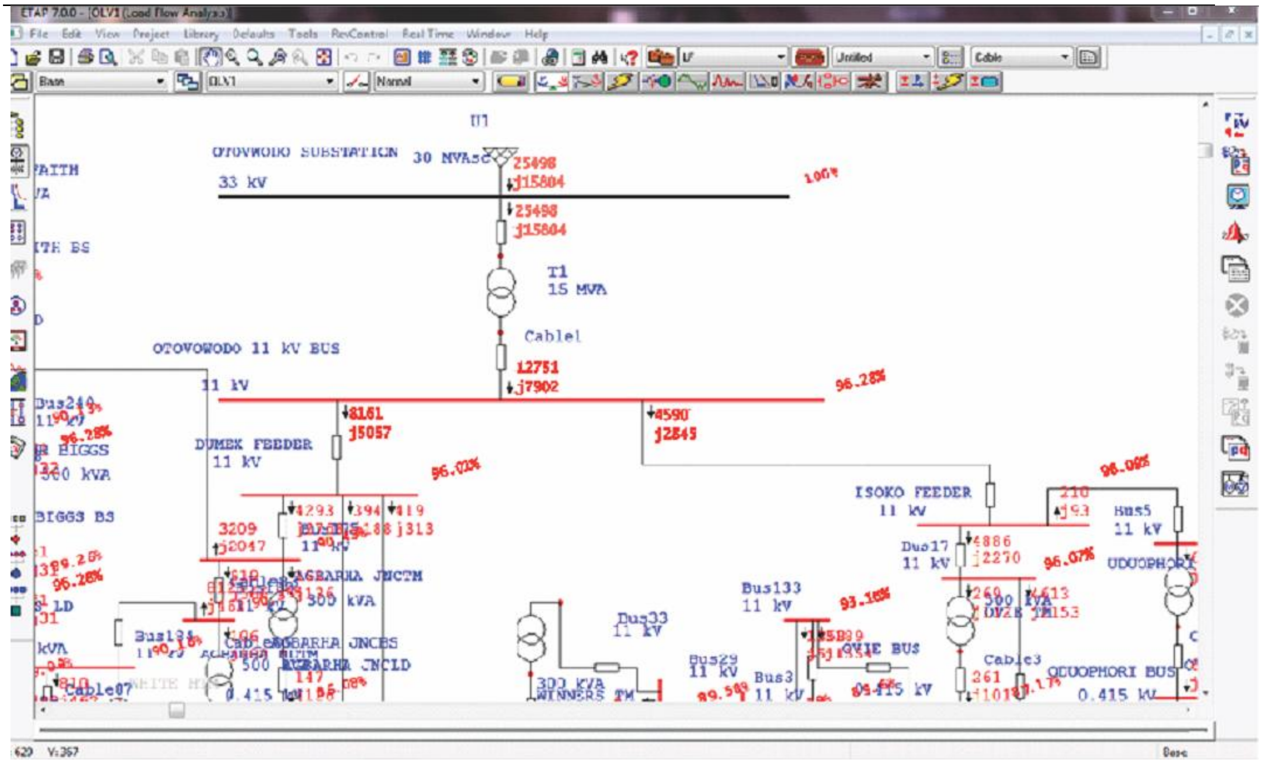

Figure 1. A Section of the Existing Network in ETAP 7.0 Environment.

Using the multi-objective function and various constraints as shown in equation (1), (2), (3) & (4) as a GA code developed in MATLAB Environment. The equations are the Loss, Voltage and DG size, a combination of these equations is known as a multi-objective function. The size of the DGs ranged from 90 – 130kW, this was determined by the radiation intensity of the various substations. Figure 2 presents the Matlab Environment showing some DG locations. The implementation of the DG sizes was simulated in ETAP 7.0 Environment, as presented in Figure 3.

Table 3 presents results of DGs optimally placed and Table 4 presents power flow result obtained from existing Network in the presence of DG.

Table 3 Results of DGs optimally placed in the existing Network.

	Peak	**Off Peak**
Voltage Profile	0.9202 – 0.9776pu	0.9329 - 1.004pu
Active Load Demand	27.169MW	18.403MW
Reactive Load Demand	10.965Mvar	10.12Mvar
Losses (Real)	2.73MW	2.02MW
Losses (Reactive)	1.59Mvar	1.09Mvar

Table 4. Load Flow Result Obtained From Existing Network in The Presence Of Dg Optimally Placed for Peak Period for Some Substations.

Connected Bus			Sending End		Receiving End		Line Losses		Feeder Losses	
From		To	Active (kW)	Reactive (kVar)	Active (kW)	Reactive (kVar)	Active (kW)	Reactive (kVar)	Active (kW)	Reactive (kVar)
1.	Otovwodo 4	Bishop Emuobor	3402.90	2440.20	3382.30	2420.20	20.60	20.00	9.60	7.22
2.	Otovwodo 4	Otovwodo 2	3228.50	2399.40	3208.50	2379.10	20.00	20.30	7.80	5.15
3.	Otovwodo 2	Otovwodo 3	3107.50	254.20	3087.80	233.10	19.70	21.10	9.70	5.90
4.	Otovwodo 2	AgbarhaJunt.	3635.40	2483.10	3614.00	2476.10	21.40	7.00	10.50	6.81
5.	AgbarhaJunt.	Agbarha Road	3000.20	1809.40	2973.10	1788.80	27.10	20.60	6.60	2.63
6	Agbarha Road	White House	3497.70	2542.40	3468.50	2524.20	29.20	18.20	8.90	4.65
7	White House	Slaughter Road	3008.50	2407.40	2989.40	2391.20	19.10	16.20	9.20	6.60
8	Slaughter Road	Udure II	2864.90	1909.10	2843.80	1887.90	21.10	21.20	9.90	7.74
9	Uduere II	Uduere I	2846.20	1709.30	2822.60	1689.90	23.60	19.40	7.90	5.63
10	Uduere I	Owevwe	2869.40	1809.40	2841.60	1808.40	27.80	1.00	8.40	6.95
11	Owevwe	Opherin	2905.10	2007.20	2882.70	1991.40	22.40	15.80	7.40	5.72
12	Uduere I	Saniko	2849.50	2564.80	2832.90	2559.60	16.60	5.20	8.40	3.38
13	Saniko	Gana	3243.70	2398.80	3219.40	2393.00	24.30	5.80	7.50	5.01
14	Gana	Omavwowe II	2897.50	2465.00	2876.30	2459.70	21.20	5.30	8.80	6.29
15	Omavwowe II	Omavwowe I	3009.40	2465.90	2992.20	2451.80	17.20	14.10	5.10	2.55
16	Gana	Okpa - Agbarha	2879.20	2341.70	2865.30	2332.60	13.90	9.10	11.70	7.23
17	Okpa – Agbarha	Oteri	3009.50	2443.60	2986.70	2425.40	22.80	18.20	10.40	6.21
18	Oteri	Etefe	2543.70	2354.60	2516.70	2329.60	27.00	25.00	6.50	3.72
19	Etefe	Awirhi	2965.40	2357.50	2942.30	2338.50	23.10	19.00	11.30	6.74
20	AgharhaJunct.	Mr Biggs	3029.60	2438.40	3009.30	2414.90	20.30	23.50	9.10	5.85

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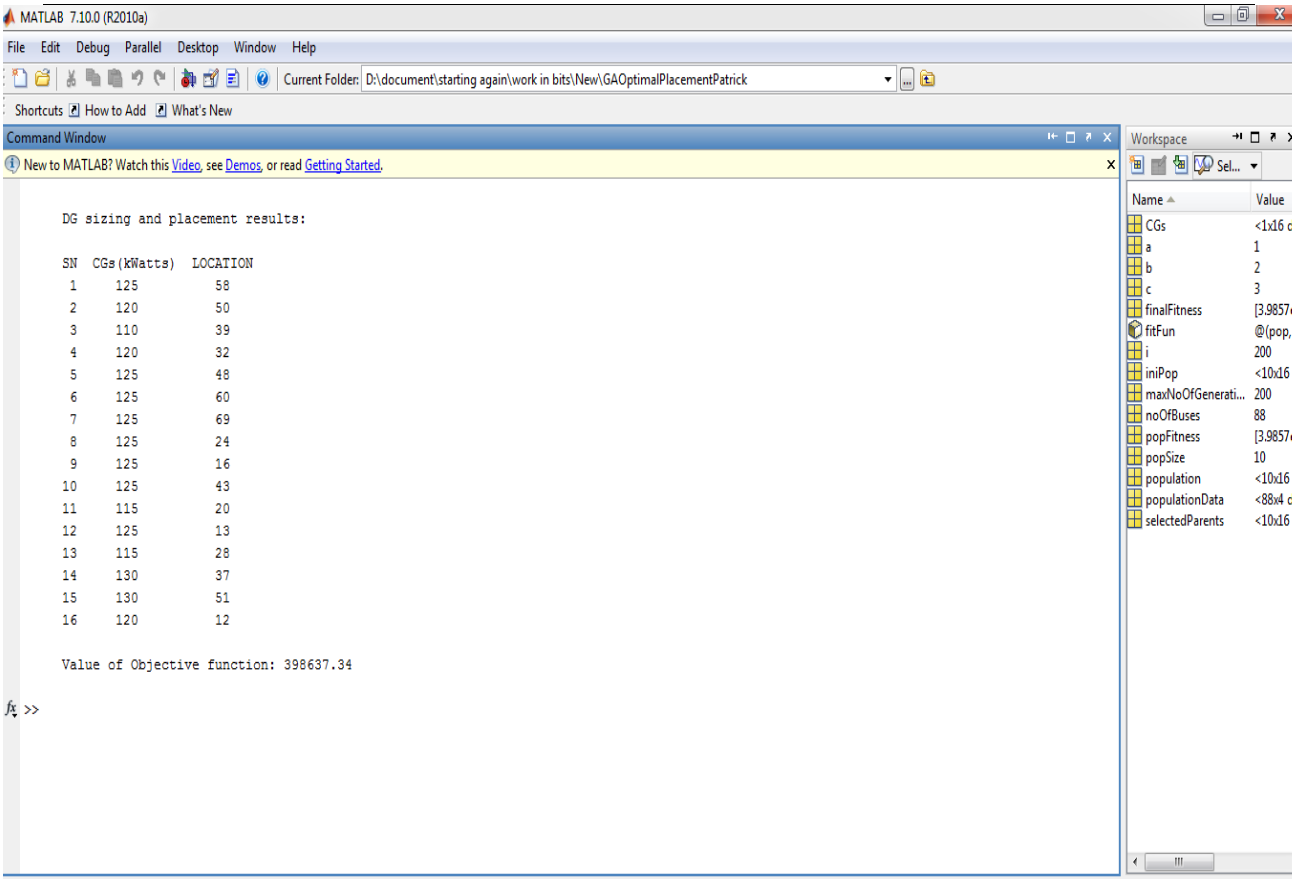

Figure. 2. Matlab Environment Showing DGs Sizes and Optimal Placement for Peak Period

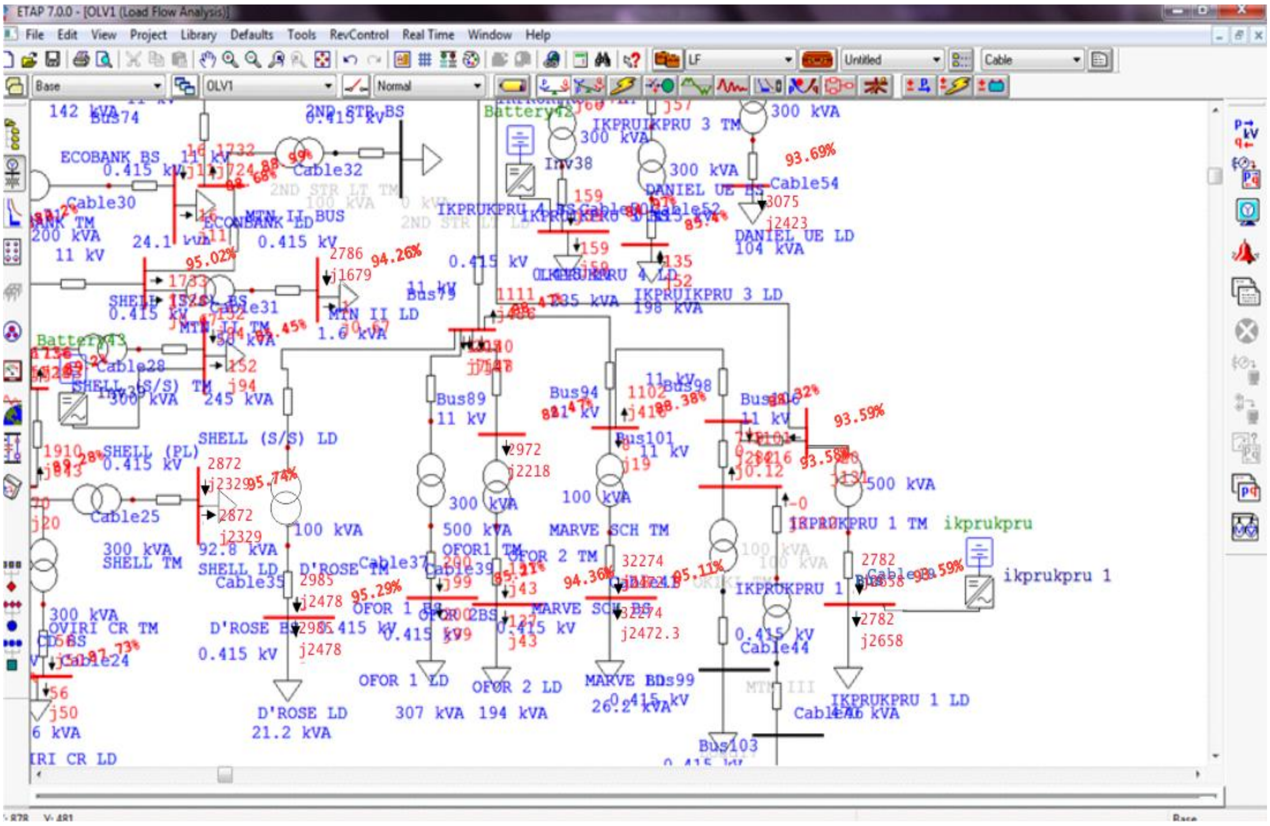

Figure. 3. ETAP Environment showing some of the DG locations in the existing network.

V. Results and Discussions

When the load flow of the entire Network was simulated the following results were obtained:

1. The load during the peak period is 25.210MW and 10.243Mvar, while that for off peak was 17.273MW and 9.93Mvar. This is an indication that the 15MVA Injection Substation Transformer is overloaded.
2. The voltage range was between 0.8645 pu to 0.9560 pu.for Peak period and0.889 to 0.9799 for Off peak period. The acceptable range for per unit voltage is ±6%. I.e. 0.94 to 1.06. With this it's observed that most of the buses were under voltage.
3. The total losses in the Network during peak period are 6.59MW, 2.218Mvar and off peak are 3.78MW, 2.01 Mvar. For peak period the losses are 26.14% (real) and 21.65% (reactive) while that for off peak is 21.88% and 20.24%.

These results are in Table 2. When DGs were optimally placed the following results were obtained:

4. The load during the peak period is 27.169MW and 10.965Mvar, while that for off peak was 18.403MW and 10.12Mvar.
5. The voltage range was between 0.9202 pu to 0.9776pu.for Peak period and0.9329 to 1.004 for Off peak period.
6. The loss for peak was 2.73MW, 1.59Mvar and for off peak 2.02MW, 1.09Mvar. Which indicated that the percentage reductions in power losses are: 10.05 %(real), 14.50 %(reactive) for peak and 10.97% (real), 10.77 %(reactive).
7. When DG was not optimally placed, with emphases on peak period only, the voltage profile was 0.9128 to 0.9699. Losses were increased to 3.42MW, and 2.44Mvar.

VI. Conclusion

This paper analyses power loss reduction, voltage profile improvement, power quality improvement,optimal placement of DGs and its impact in an electrical network, with a case study of a 15MVA, 33/11kV substation. The Newton Rapson (N-R) method was used in ETAP 7.0 software to determine the load flow analysis of the entire network. The load flow revealed the total load demand, the distribution losses and the voltage profile of the Network.

Upon placement of DGs optimally, more power was injected into the Network, voltage profile improved and distribution losses reduce.

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