PROPER SIZE AND LOCATIO OF DISTRIBUTING GENERATION ON RADIAL SYSTEMS FOR REDUCED LOSSES+

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Abstract

Electric utilities have historically satisfied customer demand by generating electricity centrally and distributing it through an extensive transmission and distribution network. As demand increases, the utility generates more electricity. But if the capacity of the generation, transmission, or distribution systems is constrained, the traditional utility response to these constraints is to build new facilities. An alternative approach under consideration by utilities is to satisfy demand locally and incrementally by investing in distributed generation. Distributed generation facilities are strategically sited to deliver electricity where it is needed. This can relieve capacity constraints on the generation, transmission, and distribution systems and represents a prompt solution until it is possible to build new facilities. This paper presents an algorithm based on distribution power flow methodology to determine the near optimal, with respect to system losses, size and location of these units on the power grid. The algorithm is implemented on a tested radial feeder. The results show the importance of the selection for minimizing losses and maximizing capacity savings.

المستخلص

تستخدم الوحدات التوليدية الصغيرة (وحدات الديزل أو الوحدات التوربينية) من قبل المستهلكين عادة كمصادر احتياطية لاسيما عند انقطاع مصدر القدرة الكهربائية في الشبكة الوطنية. وفي الوقت الحاضر فأن شركات توليد الطاقة الكهربائية اتجهت إلى ربط مثل هذه الوحدات مع منظوماتها وعلى مستوى جهد التوزيع لتحقيق فوائد عدة منها:

- توفير مصدر معتمد و قريب من الحمل.
- تغطية الأحمال وقت الذروة.
- تقليل الخسائر الناجمة عن نقل الطاقة لمسافات طويلة في خطوط النقل والتوزيع.
- تحسين معامل القدرة.
- تعزيز مستوى الجهود عند العقد.

وفي العراق هناك نقص شديد في مقدار إنتاج الطاقة وعجز في منظومات النقل عن تلبية حاجة الحمل المتزايد لذا فأن إدخال مثل هذه الوحدات التي يمكن ربطها مع الشبكة الوطنية عبر المغذيات الشعاعية أصبح مفيدا حيث تمتاز بسهولة و سرعة النصب والتشغيل والإدارة ويمكن أن تنصب قرب مصادر الوقود وهذا سوف يساعد في تعزيز قدرة المنظومة الكهربائية في الوقت الراهن. تم إعداد برنامج حاسبي لتحديد السعة اللازمة والموقع المناسب لربط هذه الوحدات في المغذيات الشعاعية من أجل تقليل الخسائر من خلال حساب تدفق الحمل في المنظومة وتبين من تطبيق

+ Received on 13/3/2004 , Accepted on 20/10/2004

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هذا البرنامج على أحد المغذيات أهمية اختيار السعة اللازمة والموقع المناسب من أجل تحقيق أعلى الفوائد من عملية الربط.

Introduction

Distributed Generator: a type of electrical generator producing alternating current that has the capability of parallel operation with the utility distribution system, or is designed to operate separately from the utility system and can feed a load that can also be fed by the utility electrical system.

An IEEE working group recently developed a Draft Standard for Distributed Resources Interconnected with the Electric Power System; it defines the distributed generation (DG) as electric generation facilities connected to an area electric power system (EPS) through a point of common coupling (PCC) [1].

In this work distributed generation refers to small-scale (typically 1 MW – 5 MW) electric power generators that produce electricity at a site close to customers or that are tied to an electric distribution system and limited to synchronous generators driven by engines or combustion gas turbines.

Thus integrating DG into the utility's power grid, reducing system loads and has the multiple active effect of reducing system losses.

In particular, heavily loaded feeders or transmission corridors can be relieved. It may also be an opportunity to improve power quality allowing customers and utility equipment more years of usage [2].

This paper investigates the proper size and location for the distribution generator to interconnect among the distribution feeder to satisfy the following requirements:

(1) Voltage support by leveling the voltage profile from substations to loads.
(2) Reactive power compensation.
(3) Generating capacity relief via reduction in feeder load demand.
(4) Feeder loss reduction.

Interconnection Requirements

In addition to the IEEE working group [1] several utilities put safety requirements for interconnecting distribution generators among radial feeders [3,4,5].
Some of these requirements suitable for the scope of this work are discussed here.

The interconnecting process ensuring that the voltage levels at the Point of Common Coupling (PCC) is maintained within the acceptable limits.

Voltage levels must be at least equal to the voltage levels at all feeder load conditions, prior to the interconnection. Synchronous generators connected to the distribution system must be equipped with excitation controllers capable of controlling voltage.

The generator bus voltage set point shall be stable at, as well as adjustable to, any value between 95% and 105% P.U. to maintain voltage with the limits on its system.

The interconnecting process requires that the generator operates in a power factor control mode. This means operating within a constant power factor set point range.

The voltage/ power factor regulator must be capable of controlling the power factor of the generator between +0.9 and -0.9. In power factor control mode, the voltage regulator must have a voltage override that causes it to reduce excitation if the voltage at the PCC exceeds a specified upper limit.

The normal upper limit is 105% of nominal; however, the voltage regulator shall have the provision to adjust this upper limit between 100% and 110% of nominal. The voltage regulator must also have provision for a time delay between sensing an excursion of the upper voltage and initiating control action.

The power factor control equipment must have the capability to allow for the adjustment of this time delay from between 0 and 180 seconds.

Formulation of the Problem

Distribution load flow methodology [6,7] with the extended algorithm for interconnection of distribution synchronous generator [8] is applied here.

A new algorithm to determine the proper location and size for distribution generator on a radial feeder is proposed.

* Distribution Load Flow

Consider a distribution system which consists of a radial main feeder comprising (n) branches as shown in Figure (1).

Load flow is performed under the assumption that distribution generator is modeled as a negative load referred to a PQ model with a constant power factor. Generation at bus (i) is modeled as a constant power source given by , $S_{Gi} = P_{Gi}+jQ_{Gi}$

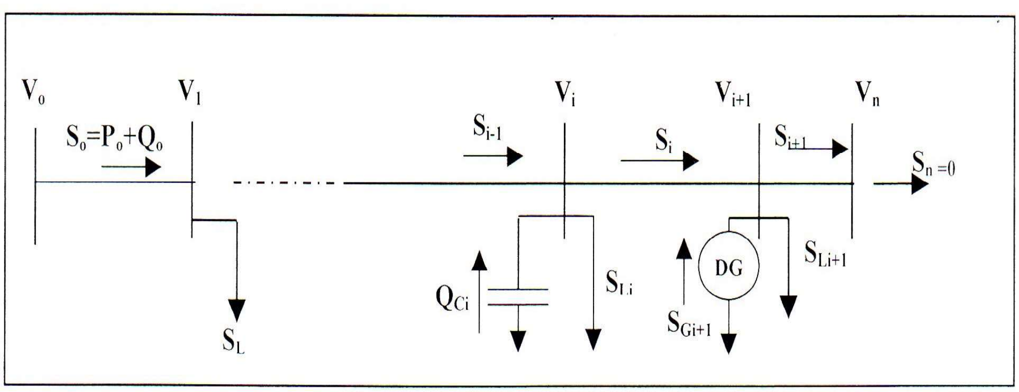


Fig. (1): One-Line Diagram for a Radial Disribution Feeder

If the power supplied from the substation $S_o = P_o+jQ_o$ is primarily specified then the active and reactive power and the voltage at the receiving end of the first branch can be calculated as follows:

$$S_1 = S_o - S_{loss1} - z_1 \frac{P_o^{\,2} + Q_o^{\,2}}{|V_o|^2} - S_{L1} \qquad \text{.................(1)}$$

$$V_1 \angle \theta_o = V_o - z_1 \frac{S_o^{\,*}}{V_o} \qquad \text{.............................(2)}$$

Similarly the active and reactive power flowing at the receiving end of branch i+1, P_{i+1}, and Q_{i+1} and the voltage magnitude at the sending end $|V_{i+1}|$ for the nodes can be expressed by the following equations:

$$P_{i+1} = P_i - R_{i+1} \frac{P_i^2 + Q_i^2}{|V_i|^2} - P_{Li+1} + P_{Gi+1} \qquad \text{.....................................(3)}$$

$$Q_{i+1} = Q_i - X_{i+1} \frac{P_i^2 + Q_i^2}{|V_i|^2} - Q_{Li+1} + Q_{ci+1} + Q_{Gi+1} \qquad \text{.......................... (4)}$$

$$|V_{i+1}|^2 = |V_i|^2 - 2(R_{i+1}.P_i + X_{i+1}.Q_i) + (R^2_{i+1} + X^2_{i+1}) \frac{P_i^2 + Q_i^2}{|V_i|^2} \qquad \text{..............(5)}$$

And at the end of main feeder $P_n = 0$ and $Q_n = 0$. where:

P_i, Q_i : active and reactive powers flowing into the sending end of branch (i+1).
$|V_i|$: bus voltage magnitude at node i.

Equations (3 to 5) are called the branch flow equations. An iterative procedure following the flow chart defined in figure (A1) in the Appendix is developed to obtain the unique solution for the node voltages and hence line active and reactive power flow.

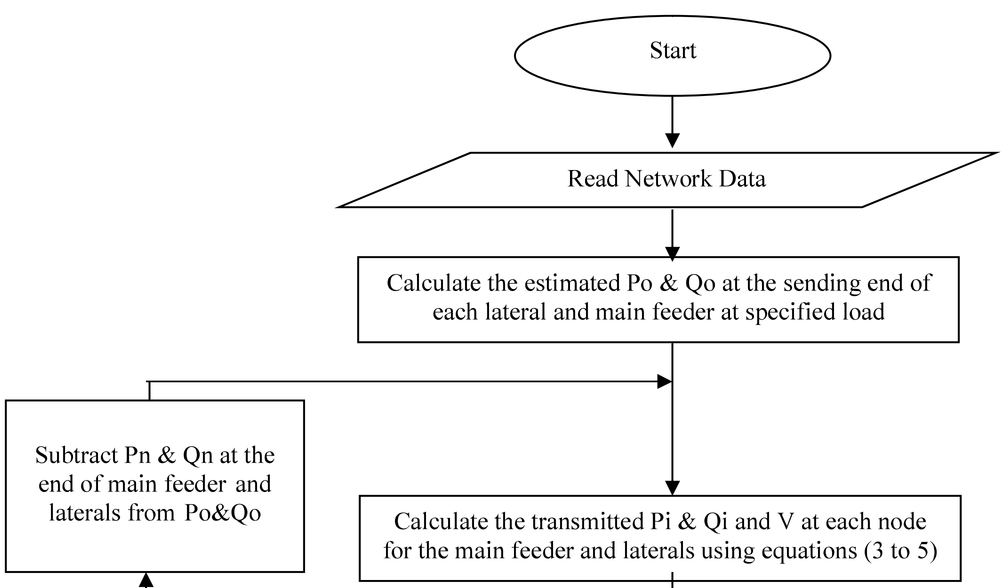


Fig. (A1): Flow Chart for Distribution Load Flow

* Size and Location of Distribution Generation

The term ($R_{i+1}\dfrac{P_i^2+Q_i^2}{|V_i|^2}$) in equation (3) above represents the active power loss and related to the power flow between the feeder nodes. To reduce the loss the criterion is to minimize the flow. This is achieved by equipping the generation as near the loadas possible. The generation location is decided primarily by examining feeder voltage profile through the application of the distribution load flow methodology without distribution generation under a heavy daily load period. The possible location of distribution generator unit is in the nearest node to the substation at which the voltage drops to not less than (0.95) P. U.

Generation size is then limited to the sum of the loads and line losses for the following nodes. Assuming that the proposed location is the node (k) in Figure (2) then active generated power is:

$$P_{Gk} \approx 2 * P_{k-1} \qquad \text{....................(6)}$$

This specification satisfies the mid-point distributor rule and can be proved by the first principles and is defined in Figure (2). The DG location (kth node) is specified depending on its rated power.

Note that if there is no node voltage which violates the generator voltage constraint then the location is chosen at any node that the received injected active power is proper to the half of generator size.

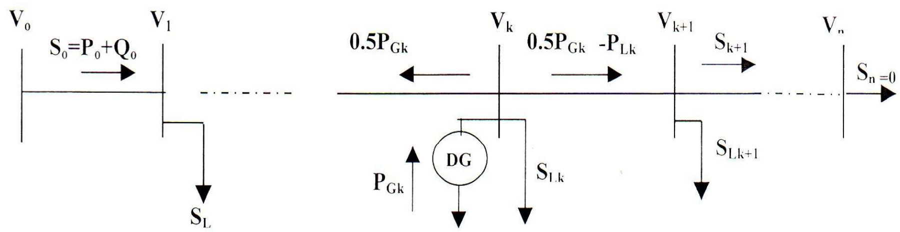


Fig. (2) DG location on a Radial Distribution Feeder

The reactived generated power is constrained to the generator power factor (between +0.9 and -0.9) and because of the inductive manners of the load the generator power factor is assumed to equal 0.9. This assumption aims to cover the possible reactive power for the load locally.

$$Q_{Gk} = P_{Gk} * \tan(\cos^{-1} 0.9) \qquad \text{......................(7)}$$

The algorithm proceeds as follows:

1. Perform distribution power flow calculations without distribution generation.
2. Depending on the results from step 1, select possible location of distribution generator unit at the nearest node to the substation at which the voltage drops to not less than (0.95) P. U. based on feeder voltage profile.
3. Specify active and reactive generation using equations (6 &7).
4. Perform again power flow calculations if the specified generation is added.

Tests and Results

In order to test the proposed algorithm, an example of distribution system is used. The system is a typical 11 kV feeder with twenty-four sections and three laterals.

The one-line diagram of this system is shown in Figure (3), and the corresponding technical and load data are given in the Appendix. Distribution load flow results without distribution generation are presented in Table (1).

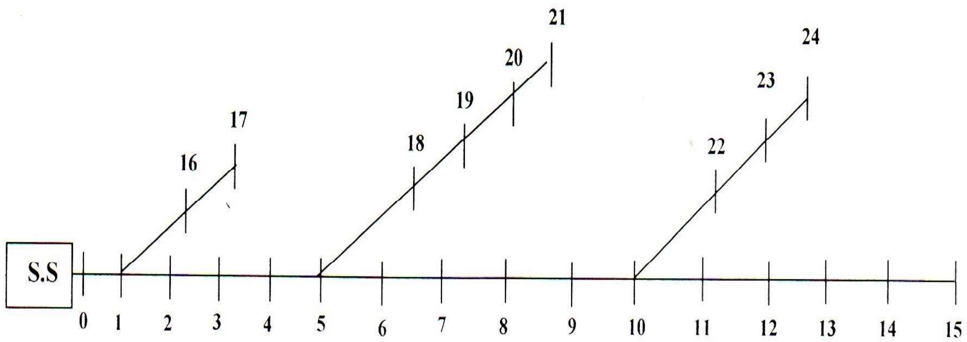


Fig. (3): Test System One-Line Diagram

Table(1): Distribution Load Flow Results Without Distribution Generation

load factor = 1 , Vo=11.0 kV , load p.f = 0.85 lag.							
Feeder section	Rec. Node Voltage (P.U)	Power Flow		Feeder section	Rec. Node Voltage (P.U)	Power Flow	
		MW	MVAr			MW	MVAr
0-1	0.9968	5.0693	3.1591	12-13	0.9670	0.6379	0.3949
1-2	0.9898	4.3746	2.7366	13-14	0.9666	0.4252	0.2632
2-3	0.9880	4.1366	2.5780	14-15	0.9665	0.2125	0.1315
3-4	0.9845	3.9178	2.4398	1-16	0.9966	0.6801	0.4201
4-5	0.9811	3.6934	2.2957	16-17	0.9966	0.3400	0.2100
5-6	0.9732	2.8327	1.7644	5-18	0.9808	0.8503	0.5263
6-7	0.9723	2.4738	1.5343	18-19	0.9807	0.6376	0.3946
7-8	0.9710	2.2594	1.4008	19-20	0.9806	0.4250	0.2631
8-9	0.9708	1.9169	1.1882	20-21	0.9805	0.2125	0.1315
9-10	0.9697	1.7040	1.0563	10-22	0.9695	0.6377	0.3947
10-11	0.9679	1.0649	0.6600	22-23	0.9693	0.4251	0.2631
11-12	0.9675	0.8508	0.5268	23-24	0.9692	0.2125	0.1315

From the load flow results all the node voltages are within the acceptable limits. If a distributing generation of (2.75 MW) as a random capacity is added at any node of the main feeder as shown in Figure (4), then the fewer amounts of the losses are obtained when the generation is added at node (10).

From Table (1) this capacity is nearly double the amount of the power flow which enters this node.

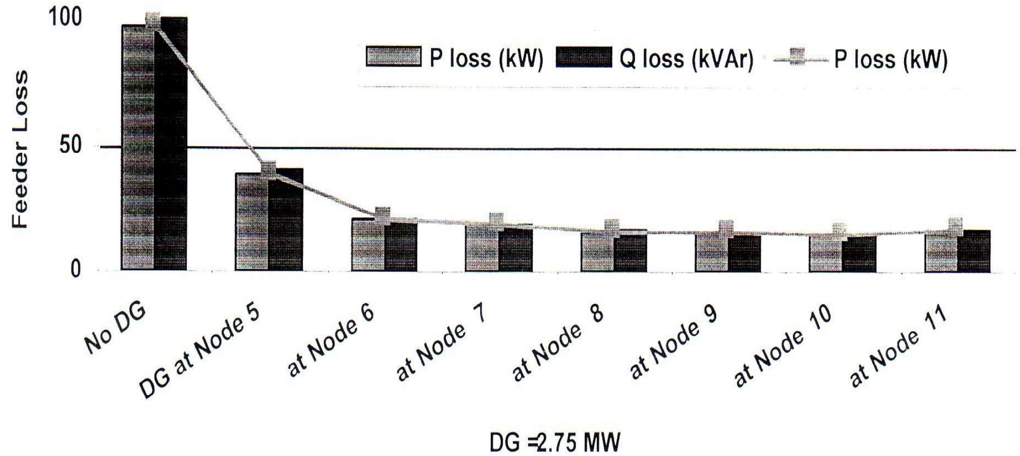


Fig. (4): Test System Active and Reactive Power Loss

When the generation with several capacities is suggested to add at node (11), then less loss happens when the generation nearly equals (3.4 MW).

This capacity equals nearly the double amount of node (10) power flowing to the main feeder and the lateral (1.064+0.6377 =1.7MW). This is defined in figure (5).

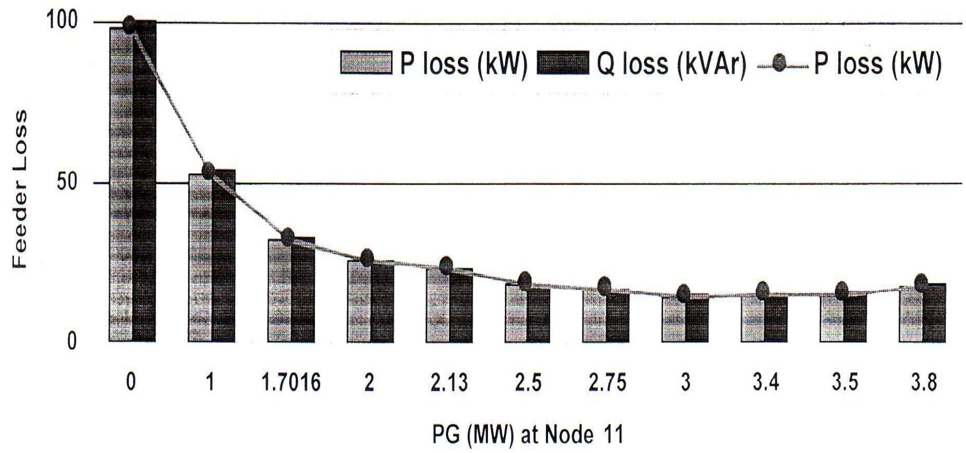
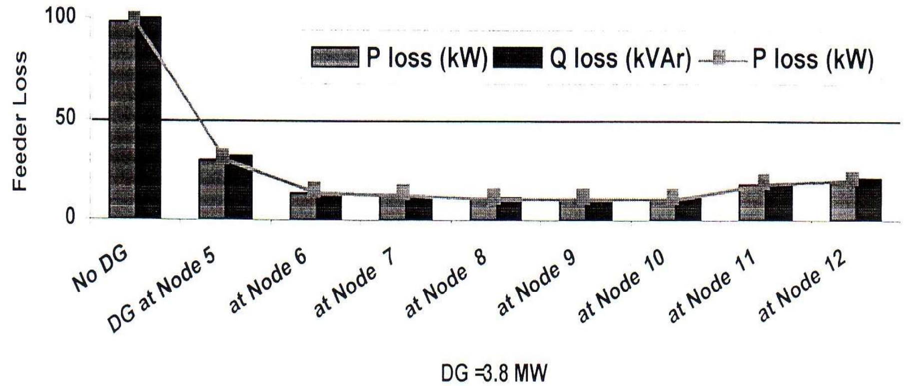


Fig. (5): Test System Active and Reactive Power Loss for Several Generation Capacities

If the generation size is specified to equal doubles of the power flow in a specified node (e.g. the power flow at node (9) = 3.8 MW), and is suggested to be added at several nodes, again the minimum loss occurs only when the generation is added at node (9).

Also several capacities applied at this node yield the same result that minimum loss happens when the generation size equals 3.8 MW. This is shown in the two parts of Figure(6).



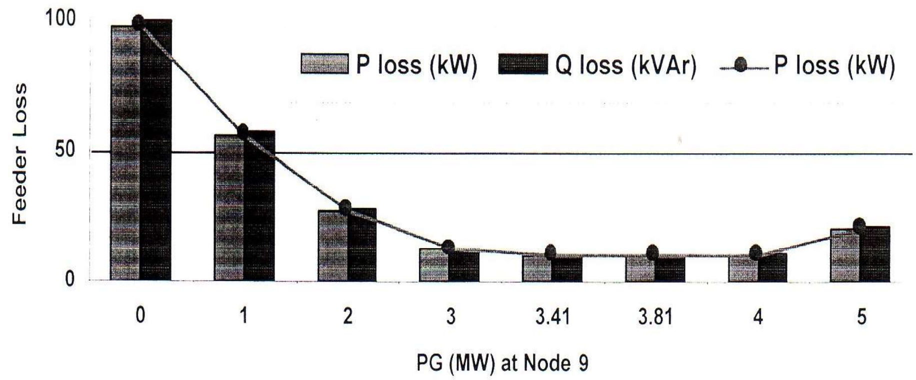


Fig. (6): Test System Minimum Loss Node 9

Figure (7) shows the effect of distributing generation on leveling feeder voltage profile from substation to the loads.

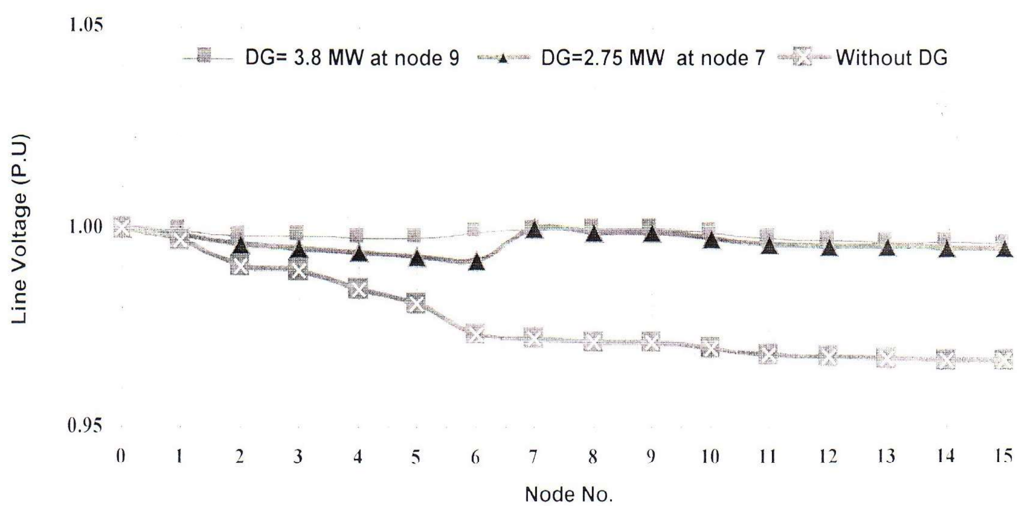


Fig. (7): Test System Votage Profile

Conclusions

This paper presents a simplified rule for the proper size and location of distribution generation units on radial systems depending on the results of distribution load flow. The analysis shows the importance of introducing DG to the distribution network related to the feeder performance and loss reduction and suggests that proper location on a feeder depends greatly on the load distribution along the feeder and the thermal losses arising from different placements varying greatly, and further, that one must consider both generator size and feeder load when determining appropriate location on the feeder.

Table (A1): Test System Technical Data

load factor = 1 , Vo=11.0 kV , load p.f = 0.85 lag.							
Feeder section	R (Ω)	X (Ω)	Load (kVA)	Feeder section	R (Ω)	X (Ω)	Load (kVA)
0-1	0.04960	0.04240	0	12-13	0.05148	0.05460	250
1-2	0.11550	0.12250	250	13-14	0.06600	0.07000	250
2-3	0.03135	0.03325	250	14-15	0.03300	0.03500	250
3-4	0.06600	0.07000	250	1-16	0.01815	0.01925	400
4-5	0.06600	0.07000	0	16-17	0.01815	0.01925	400
5-6	0.19800	0.21000	400	5-18	0.01815	0.01925	250
6-7	0.02640	0.02800	250	18-19	0.01815	0.01925	250
7-8	0.03960	0.04200	400	19-20	0.01815	0.01925	250
8-9	0.00825	0.00875	250	20-21	0.01815	0.01925	250
9-10	0.04785	0.05075	0	10-22	0.01815	0.01925	250
10-11	0.11550	0.12250	250	22-23	0.03120	0.03350	250
11-12	0.03828	0.04060	250	23-24	0.03120	0.03350	250

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