World Academy of Science, Engineering and Technology
International Journal of Energy and Power Engineering
Vol:1, No:11, 2007

GA based Optimal Sizing & Placement of Distributed Generation for Loss Minimization

Deependra Singh, Devender Singh, and K. S. Verma

***Abstract*—**This paper addresses a novel technique for placement of distributed generation (DG) in electric power systems. A GA based approach for sizing and placement of DG keeping in view of system power loss minimization in different loading conditions is explained. Minimal system power loss is obtained under voltage and line loading constraints. Proposed strategy is applied to power distribution systems and its effectiveness is verified through simulation results on 16, 37-bus and 75-bus test systems.

***Keywords*—**Distributed generation (DG), Genetic algorithms (GA), optimal sizing and placement, Power loss.

I. INTRODUCTION

DISTRIBUTED GENERATION (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. Distributed generator benefits are site specific. Distributed generation (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, 9 and 10]. 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, 2]. 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 [3, 4].

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Analytical approaches for optimal placement of DG with unity power factor is to minimize the power loss of the system. A “2/3 rule” is used to place DG on a radial feeder with uniformly distributed load, where it is suggested to install DG of approximately 2/3 capacity of incoming generation at approximately 2/3 of the length of line. In above approaches size of DG is not optimized. Line loading constraint is not considered during optimization [5].

An optimization technique should be employed for the design of engineering systems, allowing for the best allocation of limited financial resources. In electric power systems, most of the electrical energy losses occur in the distribution systems. It is a tool that can be used both for the design of a new distribution system and for the resizing of an existing system [6].

Distributed Generation sometimes provides the most economical solution to load variations. Under voltages or overloads that are created by load growth may only exist on the circuit for a small number of hours per day or/ month or/ year. There may be many locations that do not have overload or voltage problems, where the DG can be located and provide the necessary control [15].

This paper provides the detailed analysis of GA based system power loss minimization approach and system energy loss minimization approach for optimal sizing and placement of DG in electrical power systems. The methods are presented to find optimal size and bus location for placing DG using power loss and energy loss minimization in a networked system based on bus admittance, generation information and load distribution of the system. The proposed methods are tested by simulations on 10-bus test system, 37-bus system[7] and 75-bus distribution system. An effectiveness of proposed methods is tested by determining the optimal size and bus for placing DG under voltage and line loading constraints with uniform loading conditions in system power loss minimization and time-varying loading conditions in system energy loss minimization. In above loading conditions, Peak load, medium load i.e. 70% of peak load & low load i.e. 80% of medium load are considered for implementations.

In practice, there are more constraints on availability of DG sources and we may only have one or a few DGs with limited output available to add. The method to determine the optimal size and bus for placing the DG may also need to take into account other factors, such as economic and geographic considerations. These factors are not discussed in this paper.

II. GENETIC ALGORITHM

A powerful class of optimization methods is the family of GA. The GA become particularly suitable for the problem posed here. In this paper a GA based power loss minimization and energy loss optimization technique is proposed for finding size and site for DG to place in power systems. If network structure is fixed, all branches between nodes are known and evaluation of the objective functions depends only on the size and location of DG units.

The GAs are employed to designate optimization algorithms that perform a kind of approximate global search such that:

(i) They rely on the information obtained by the evaluation of several points in the search space. Each "current point" is called an individual, and the set of "current point" is called the population. The algorithm keeps this set of "current points", instead of keeping a single "current point" as would be the case of in most optimization algorithms.

(ii) The population converges to a problem optimum through sequential applications, at each iteration, of genetic operators [8].

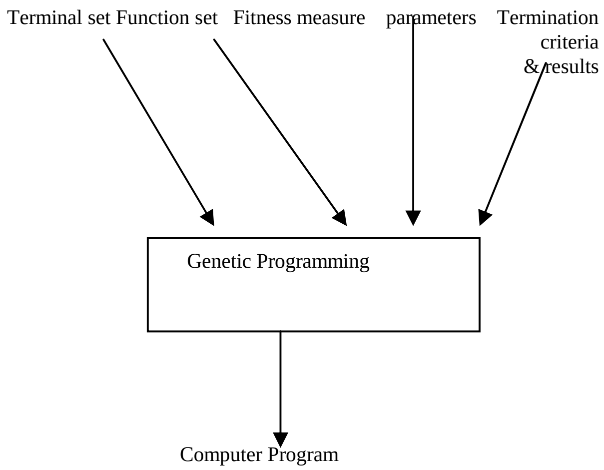

Fig. 1 Preparatory Steps of Genetic Algorithms

Preparatory steps are the basic version of genetic programming. The human user communicates the high level statement of the problem to the genetic programming system by performing certain well-defined preparatory steps. The preparatory steps are the human supplied input to the genetic programming system. The computer program is the output of genetic programming system. Fig. 1 shows five major preparatory steps for the basic version of genetic programming [11].

Genetic algorithm that yields good results in many practical problems is composed of three operators:

- Crossover: The individuals, randomly organized pair-wise, have their space locations combined, in such a way that each former pair of individuals gives rise to a new pair.
- Mutation: Some individuals are randomly modified, in order to reach other points of the search space.
- Selection: The individuals, after mutation and crossover, are evaluated. They are chosen or not chosen for being inserted in the new population through a probalistic rule that gives a greater probability of selection to the "better" individuals.

The advantages in using GA are that they require no knowledge or gradient information about the response surface; they are resistant to becoming trapped in local optima and they can be employed for a wide variety of optimization problems. On other hand GA could have trouble in finding the exact global optimum and they require a large number of fitness functions evaluations. It is very difficult to achieve analytic relationship between sensitivity of simulated power system and the parameters values to be optimized. Since GA don't need this kind of information, it is suitable in our optimization task.

If there is an explicit knowledge about the power system being optimized, that information can be included in the initial population. In this work we initialize the population to the best-fit results.

An evolutionary strategy needs to be adopted in order to generate individuals for the next generation. The individuals are arranged by their fitness and only the best of them are taken unchanged into the next generation. In this way good individuals are not lost during a run. Other children come from crossover and mutation. The aim of the fitness function is to numerically represent the performance of an individual.

In order to end the evolution of the population we choose certain termination criterion. The final result of the GA optimization is the best individual of the last iteration.

III. Problem Formulation

DG sources are normally placed close to load centers and are added mostly at the distribution level. They are relatively small in size (relative to the power capacity of the system in which they are placed) and modular in structure [8, 9, 13]. A common strategy for sizing and placement of DG is either to minimize system power loss or system energy loss of the power systems. The voltage at each bus is in the acceptable range and the line flows are within the limits. These limits are important so that integration of DG into the system does not increase the cost for voltage control or replacement of existing lines. The formulation to determining the optimal size and location of DG in a system is as follows:

Formulation for System power loss minimization

$$Min. \quad Ploss\{DG(i, size)\}$$

$$Ploss = \sum_{line(i,j)=1}^{m} P_{line(i,j)} \tag{1}$$

$$P_{line(i,j)} = P_i - P_j \tag{2}$$

subject to

$$P_i = DG(i, size) - P_{Di}$$
$$= |V_i| \sum |V_k| \left[g_{ik} \cos(\theta_i - \theta_k) + b_{ik} \sin(\theta_i - \theta_k) \right] \tag{3}$$

$$Q_i = -Q_{Di}$$
$$= |V_i| \sum |V_k| [g_{ik} \sin(\theta_i - \theta_k) + b_{ik} \cos(\theta_i - \theta_k)] \quad (4)$$

$$V_{i\max} \geq V_i \geq V_{i\min} \quad (5)$$
$$P_{line(i,j)} \leq P_{line(i,j)\max} \quad (6)$$

In the above formulation i is the location which ranges from bus 2 to n, bus 1 being the slack node or the feeder node and n being the total number of buses in the system. Size is also considered as variable that varies from 0 to 0.63 p.u.. The variables P_i, Q_i, V_i, and θ_i carry the usual meaning as in power flow studies. P_{Di} and Q_{Di} are the real and reactive load at bus i. The important operational constraints are same as previous formulation shown in equations (5) and (6).

IV. Sizing & Placement of DG Using GA

Proper placement of DG in power system is important for obtaining their maximum potential benefits. The goal is to find out proper size and optimal location for a DG in distribution systems and assure that the voltage V_x in every bus are in the acceptable range, 1+0.05 or 1-0.05 p.u. and transmission lines are loaded under specified MVA limits.

Algorithm for System Power Loss minimization

Step 1: randomly generate size-location pairs of distributed generation system in a predefined range of sizes and the buses. Set k=1. Enter the maximum number of iteration m.

Step 2: Run power flow and calculate Power loss of the system for each size-location pair under uniform loading condition, and record the power loss and its corresponding size-location pairs.

Step 3: Check whether the voltage limits and transmission line MVA limits are satisfied for all the buses for each of the size-location pairs.

Step 4: If all the voltages and MVA limits are in acceptable range for a particular size-location pair, accept that pair for next generation population.

Else reject the size-location pair which does not satisfy criteria given in step 3 in the next generation.
Obtain the size-location pair with minimum power loss (min_ploss_size_location (k)).

If k=m, the size and location corresponding to this is the optimum-size location pair. STOP and END the program.

Step 5: Use the available population of size-location pair (parent population) for cross-over and mutation for obtaining new generation of (offspring) population. If population size after step 4 is zero go to step 1.

Step 6: Use the newly generated population size i.e. off springs and parents as new generation. Go to step 2.

V. Simulation Results

Several simulation studies have been carried out to obtain the best size and location of a DG for 16-bus, 37-bus and 75-bus test systems. The data used as shown in appendix-1A in the studies corresponds to a hypothetical 12.66 KV, 37-bus system [7]. A smaller 16-bus system (a subsystem of 37-bus system) as shown in fig. 2 and 75-bus system (an integration of 37-bus system) are also used for illustrative purpose. The 37-bus and 75-bus systems, which can be considered as a sub-transmission/ distribution system, are used to verify the method presented above.

GA based system power loss minimization approach was implemented to place single DG in any distribution systems. This approach is tested with three types of uniform loading conditions: Peak load; medium load i.e. 70% of peak load and low load i.e. 80% of medium load. The simulation results on 16-bus system, 37-bus and 75-bus systems are presented as case-I, case-II and case-III respectively.

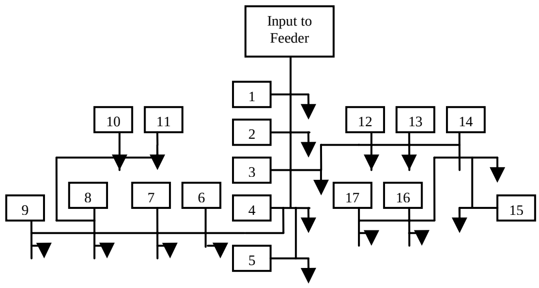

Fig. 2 16-bus test system

Case-I: 16-bus system

A 0 - 0.63 p.u. range DG was selected to be placed in the 16-bus test system shown in Fig. 2. Total system power loss is obtained from the results of power flow studies when DG in said range is placed at all the 16 buses for peak, medium and low system loadings.

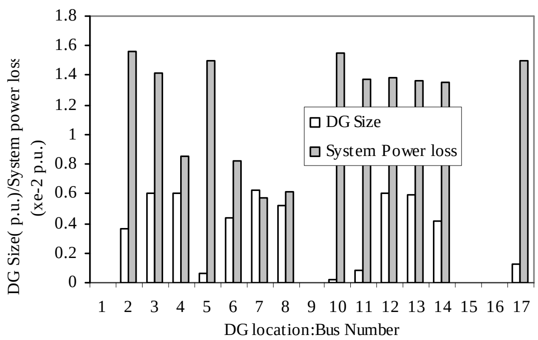

Fig. 3 DG size, Bus location & System power loss of 16-bus test system with peak loading condition

From the above studies the size for the DG for a particular set of buses which satisfies all the voltage and line flow limits are depicted in Figs. 3, 4, and 5 for peak, medium and low system loadings respectively. DG sizes obtained for system power loss corresponding to bus locations is presented in these bar charts.

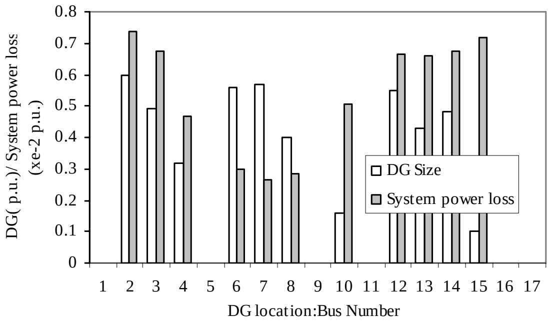

Fig. 4 DG size, Bus location & System power loss of 16-bus test system with medium loading condition

It is observed from Fig. 3 that buses 2-8, 10-14 & 17 are locations at which a DG of 0-0.63 p.u. can be added without violating the system's voltage and line flow limits. It is also observed that bus-7 with DG size of 0.62 p.u. is suitable for minimum power loss. From Fig. 4 it is seen that, in case of medium loading condition, buses 2-4, 6-8, 10 & 12-15 are sensitive. From Fig. 5 it is seen that, in case of low loading condition, sensitive buses are 2-4, 6-9, 11-14 & 16. The minimum system loss is obtained by placing a DG at bus 7 of 0.53 p.u. and 0.40 p.u. respectively for medium and low loading conditions.

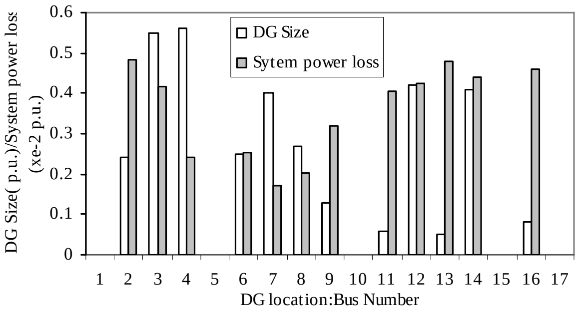

Fig. 5 DG size, Bus location & System power loss of 16-bus test system with low loading condition

TABLE I
OPTIMAL PLACEMENT OF DG FOR 16-BUS TEST SYSTEM

Types of load	DG Bus Location	Optimal DG size (p.u.)	System power loss with DG (x e-3 p.u.)	System power loss without DG (x e-3 p.u.)
16-bus peak load	7	0.62	5.76	15.98
16-bus medium load	7	0.53	2.63	7.83
16-bus low load	7	0.40	1.70	5.00

It is to be noted that though the maximum allowable DG size was 0.63 p.u. but the DG sizes which can be employed without violating voltage or line limits is 0.62 p.u., 0.53 p.u., and 0.40 p.u. for at bus-7 for peak, medium and low system loading conditions respectively.

The size and location obtained using the proposed GA method for minimum system power loss for three loading conditions are given in Table I. It is observed that the solutions which were obtained through detailed analysis were same as that obtained by proposed method.

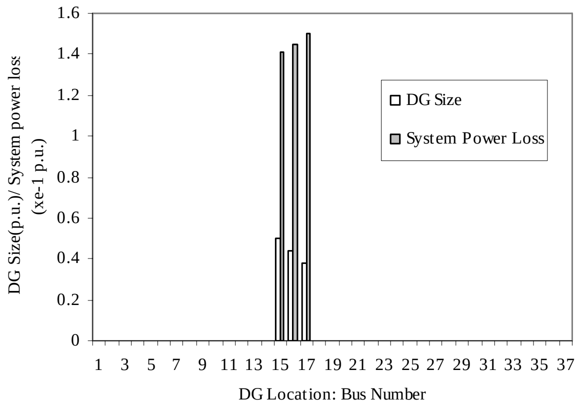

Fig. 6 DG size, Bus location & System power loss of 37-bus system with peak loading condition

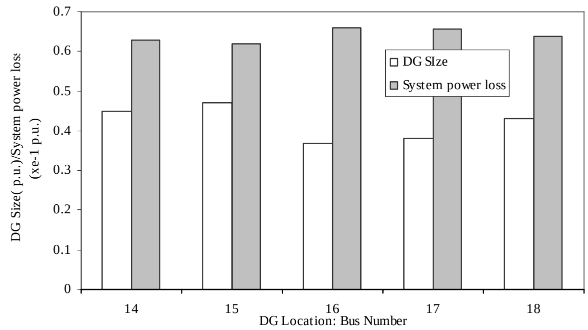

Fig. 7 DG size, Bus location & System power loss of 37-bus system with medium loading condition

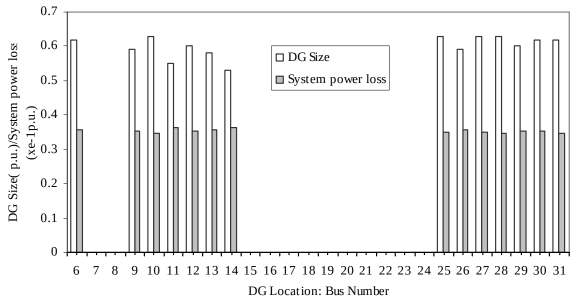

Fig. 8 DG size, Bus location & System power loss of 37-bus system with low loading condition

Case II: 37-bus system

Proposed GA based algorithm was used to solve a larger 37-bus network and the results are tabulated in table-II for the

World Academy of Science, Engineering and Technology
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Vol:1, No:11, 2007

three loading conditions. In this case also a DG in the range 0-0.63 p.u. is added to reinforce the system.

The results provided by the proposed GA method are also verified through detailed simulation studies. Total system power loss is obtained from the results of power flow studies when DG is placed at different buses with peak, medium and low loading conditions. The set of buses satisfying the line flow and voltage constraints for peak loading condition are depicted in fig 6. It is observed that for peak loading condition though the maximum allowable size is 0.63 p.u., the maximum acceptable value is only 0.50 p.u. owing to the line flow and voltage limit constraints.

TABLE II
OPTIMAL PLACEMENT OF DG FOR 37-BUS SYSTEM

Types of load	DG Bus Location	Optimal DG size (p.u.)	System power loss with DG (x e-2 p.u.)	System power loss without DG (x e-2 p.u.)
37-bus peak load	15	0.50	14.12	18.89
37-bus medium load	15	0.47	6.2	8.875
37-bus low load	28	0.63	3.45	5.62

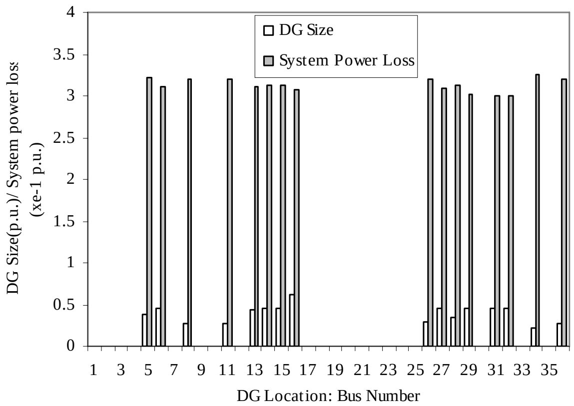

Fig. 9 DG size, Bus location & System power loss of 75-bus system with peak loading condition

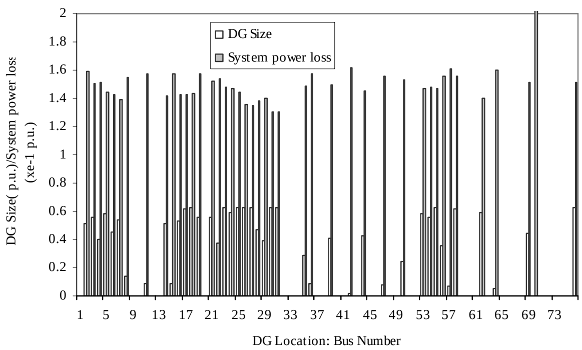

Fig. 10 DG size, Bus location & System power loss of 75-bus system with medium loading condition

It is noted from Fig. 6 that minimum system power loss is achieved when DG is placed at bus 15 with DG of 0.50 p.u.. Bus Number 15, 16, & 17 are the buses to yielding low system power loss with satisfied constraints. While most of buses, not shown in the figure, either fall out of the acceptable voltage or line flow limits.

Similarly, for medium loading condition, minimum system power loss is achieved at bus number 15 with DG of 0.47 p.u. as shown in Fig. 6. Sensitive buses for this loading condition are same as previous. With low load condition, minimum system power loss is achieved at bus number 28 with DG of 0.63 p.u. as shown in Fig. 8. The sensitive buses are 8-14 and 25-31.

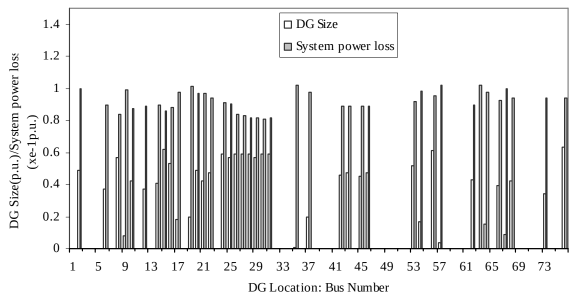

Fig. 11 DG size, Bus location & System power loss of 75-bus system with low loading condition

Case III: 75-bus system

Proposed GA based algorithm was also used to solve a larger 75-bus network and the results are tabulated in table-III for three loading conditions. In this case also a DG in the range 0-0.63 p.u. is added to reinforce the system.

TABLE III
OPTIMAL PLACEMENT OF DG FOR 75-BUS SYSTEM

Types of load	DG Bus Location	Optimal DG size (p.u.)	System power loss with DG (x e-2 p.u.)	System power loss without DG (x e-2 p.u.)
75-bus peak load	32	0.45	29.93	34.19
75-bus medium load	30	0.63	13.06	16.21
75-bus low load	30	0.59	8.09	10.22

The results provided by the proposed GA method are also verified through detailed simulation studies. Total system power loss is obtained from the results of power flow studies when DG is placed at different buses with peak, medium and low loading conditions. The set of buses satisfying the line flow and voltage constraints for peak loading condition are depicted in Fig. 9. It is observed that for peak loading condition though the maximum allowable size is 0.63 p.u., the maximum acceptable value is only 0.62 p.u. owing to the line flow and voltage limit constraints.

It is noted from Fig. 9 that minimum system power loss is achieved when DG of 0.45 p.u. is placed at bus 32. Bus Numbers 5, 6, 8, 11, 13-16, 26-29, 31, 32, 34 & 36 are the buses to yielding low system power loss with satisfied constraints. While most of buses, not shown in the figure, either fall out of the acceptable voltage or line flow limits.

Similarly, for medium loading condition, minimum system power loss is achieved at bus number 30 with DG of 0.63 p.u. as shown in fig. 10. Sensitive buses for same loading condition are 2-8, 11, 14-19, 21-31, 35, 36, 39, 42, 44, 47, 50, 53-58, 62, 64, 69 & 76. With low loading condition, minimum system power loss is achieved at bus number 30 with DG of 0.59 p.u. as shown in Fig. 11. The sensitive buses are 2, 6, 8-10, 12, 14-17, 19-22, 24-31, 35, 37, 42, 43, 45, 46, 53, 54, 56, 57, 62,-64, 66-68, 73 and 76.

VI. Conclusion

This paper discusses simulation approach for the optimal size and placement of a DG for different loading conditions. Minimization of power loss in 10-bus, 37-bus and 75-bus distribution systems is performed under three types of loading: peak, medium and low loads. It is pointed out that losses vary as a function of loading. Often, DGs are placed at substations for convenience. However, placing a DG further out on the system as opposed to locating the DG at the substation can reduce power losses. Often in industry, decisions are based on power flow analysis run for the peak load. Placing a DG where peak load condition is evaluated may not provide the best location for minimum loss. The optimal DG placements for minimum loss are different during light load conditions and close to one another during heavy load periods.

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Appendix

TABLE AI
Load Data for 37 Bus System

		Line Impedance in p.u.				Loads on to-node (p.u)		
F	T	R p.u.	X p.u.	L	S_L	P	Q	L_T
1	2	0.000574	0.000293	1	4.6	0.1	0.06	R
2	3	0.00307	0.001564	6	4.1	0.09	0.04	I
3	4	0.002279	0.001161	11	2.9	0.12	0.08	C
4	5	0.002373	0.001209	12	2.9	0.06	0.03	R
5	6	0.0051	0.004402	13	2.9	0.06	0.02	I
6	7	0.001166	0.003853	22	1.5	0.2	0.1	C
7	8	0.00443	0.001464	23	1.05	0.2	0.1	C
8	9	0.006413	0.004608	25	1.05	0.06	0.02	I
9	10	0.006501	0.004608	27	1.05	0.06	0.02	C
10	11	0.001224	0.000405	28	1.05	0.045	0.03	C
11	12	0.002331	0.000771	29	1.05	0.06	0.035	R
12	13	0.009141	0.007192	31	0.5	0.06	0.035	C
13	14	0.003372	0.004439	32	0.45	0.12	0.08	R
14	15	0.00368	0.003275	33	0.3	0.06	0.01	C
15	16	0.004647	0.003394	34	0.25	0.06	0.02	I
16	17	0.008026	0.010716	35	0.25	0.06	0.02	C
17	18	0.004558	0.003574	36	0.1	0.09	0.04	I
2	19	0.001021	0.000974	2	0.5	0.09	0.04	R
19	20	0.009366	0.00844	3	0.5	0.09	0.04	C
20	21	0.00255	0.002979	4	0.21	0.09	0.04	I
21	22	0.004414	0.005836	5	0.11	0.09	0.04	R
3	23	0.002809	0.00192	7	1.05	0.09	0.05	C
23	24	0.005592	0.004415	8	1.05	0.42	0.2	C
24	25	0.005579	0.004366	9	0.5	0.42	0.2	C
6	26	0.001264	0.000644	14	1.5	0.06	0.025	C
26	27	0.00177	0.000901	15	1.5	0.06	0.025	I
27	28	0.006594	0.005814	16	1.5	0.06	0.02	C
28	29	0.005007	0.004362	17	1.5	0.12	0.07	C
29	30	0.00316	0.00161	18	1.5	0.2	0.6	C
30	31	0.006067	0.005996	19	0.5	0.15	0.07	R
31	32	0.001933	0.002253	20	0.5	0.21	0.1	R
32	33	0.002123	0.003301	21	0.1	0.06	0.04	C
8	34	0.012453	0.012453	24	0.5	0	0	

9	35	0.012453	0.012453	26	0.5	0	0
12	36	0.012453	0.012453	30	0.5	0	0
18	37	0.003113	0.003113	37	0.5	0	0
25	38	0.003113	0.003113	10	0.1	0	0

F=From node, T=To node, L=Line number, S_L =Line MVA limit in p.u., P= Real MW load in p.u. ,Q= Reactive MVAr load in p.u., L_T =Load Type, R=Residential, I=Industrial, C=Commercial

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