International journal of Advance Engineering and Research Development (IJAERD)
Volume 1 Issue 2, March 2014, ISSN: 2348 - 4470 (Online)

Optimum Distributed Generation Allocation in Distribution Network Using Continuation Power Flow Method-Review

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Abstract—Distributed generation (DG) units in distribution Network has become more and more important in recent years. The aim of the optimum DG unit allocation is to provide the best locations. Here an attempt has been made to determine the most sensitive buses to voltage collapse of electric power system. Here a method for allocation of DG units in distribution networks has been presented. The method is based on the analysis of power flow continuation and determination of most sensitive buses to voltage collapse. Here first compute load flow study by using Newton Raphson method on a sample IEEE 30-bus test system and then the proposed method is implemented on this test system. The proposed method shows considerable reduction in real and reactive power losses, improve voltage profile, it also may permit an increase in power transfer capacity, and voltage stability margin, and enhances the loading capability of transmission network.

Keyword—DG Technologies, CPF method, Placement algorithm, Effect of Placement of DG units.

I. INTRODUCTION

An electric power system is a network of electrical tools used to supply, transmit and use electric power. An electric power system largely separated in mainly two parts: the generators that supply the power and the transmission system that carry the power from the generating station to the load area and the distribution system that induced the power to nearby homes and industries [15, 24].

Distributed generation refers to relatively small-scale generators that produce several kilowatts (kW) to tens of megawatts (MW) of power and are generally connected to the grid at the distribution or substation levels. Distributed generation units use a wide range of generation technologies, including gas turbines, diesel engines, solar photovoltaic (PV), wind turbines, fuel cells, biomass, and small hydroelectric generators.

Distributed generation, also called on-site generation, embedded generation, decentralized generation, decentralized energy, generate electricity from many small energy sources [22]. Distributed generation allows collection of energy from many sources and may give lower environmental impacts and improved security of supply. As a consequence, the connection of DG to the network may influence the stability of the power system, i.e., angle, frequency, and voltage stability [5].

The best and fast placement and transfer DG units are one of the main challenges in the design area and various methods were used for locating. Lagrange method, two degrees gradient method, and sensitivity analysis method have been used for placement [4, 14].

This project presents a method for placement of DG units in transmission networks. It is based on the analysis of power-flow continuation and determination of most sensitive buses to the voltage collapse. After that, the DG units with certain capacity will be installed in these buses via an objective function and an iterative algorithm. In this algorithm, continuation power-flow method is used for determination of the voltage collapse point or maximum loading, however; it is needed to analysis tools for studying of voltage stability. This method will be executed on an IEEE 30 -bus test system.

II. DISTRIBUTED GENERATION (DG) TECHNOLOGIES

In the recent years the electrical power benefits have experienced fast restructuring process worldwide. Really, with deregulation, progress in technologies and concern about the environmental impacts, competition is particularly adopted in the generation side, thus allowing increased interconnection of generating units to the utility networks. These generating sources are called distributed generators (DG) and defined as the plant which is directly connected to network and is not centrally planned and transmitted. These are also called fixed or distributed generation units. DG system is nothing but one type of a connection between the transmission system and the electricity users [25]. The rating of the DG systems can lies between few kW to 100 MW. Various new types of distributed generator systems, such as micro turbines and fuel cells in addition to the more traditional solar and wind power are generating important new opportunities for the addition of diverse DG systems to the utility. Interconnection of these generators will offer a number of benefits such as improved reliability, power quality, efficiency, improvement of system constraints along with the environmental benefits [8].

The main advantages of DG units can be listed as follows:

- Reduction of power loss
- Voltage profile improvement
- High reliability
- Power quality improvement
- Voltage stability improvement

III. IMPACT OF DG TECHNOLOGIES ON VOLTAGE STABILITY

A.Synchronous Generator

Conventional synchronous generators are capable of both generating and absorbing reactive power. Therefore, the use of DGs utilizing overexcited synchronous generators will allow on-site generation of reactive power. The local generation of reactive power reduces its import from the feeder, thus reduces the related losses, and improves the voltage profile [13, 14].

P-V curves have been usually used as graphical tools for studying voltage stability in electric power systems. Fig. 3.1 theoretically shows the impact of a synchronous generator on voltage stability of a theoretical node. As can be seen in the figure, the installation of a DG unit ΔP MW moves the operation point from point A to point B on the related P-V curve, which results in an increase of the node voltage by the amount V_{DG}-$V_0$and improvement in voltage security: the stability margin increases from m_0 to m_{DG} . The overall impact of a DG unit on voltage stability is positive. This is due to the improved voltage profiles as well as decreased reactive power losses, as the following equation suggests:

$$Q_{loss} = \frac{(P_{load} - P_{DG})^2 + (Q_{load} - Q_{DG})^2}{V^2} X_{line}$$

Where, P_{load}, Q_{load}, P_{DG}, and Q_{DG} are the active and reactive power of the load and DG, respectively, and X_{line} is the cumulative reactance of the line connecting the load to the feeding substation. Note that for simplicity, the resistance of the line is neglected. Clearly, as the active power injected by distributed generator increases, the reactive power loss decreases. Thus, it has a positive impact on the voltage stability [13, 14].

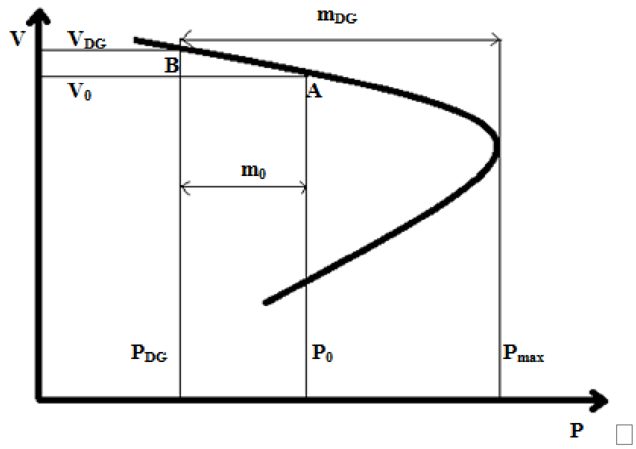

Fig.1. P-V curve extension of voltage stability margin.

B.Asynchronous Generator

An asynchronous generator possesses a number of advantages that make it very suitable for DG. Some of these advantages are: relatively not expensive prices, minor maintenance requirements, also these motors are robust. On the other hand, when directly connected to the network, this type of DG will always consume reactive power, thus contributing to the factors increasing the possibility of meeting voltage stability problems. The reactive power consumption of asynchronous generators is normally compensated by shunt capacitor banks.

However, this is only a partial solution to the voltage stability problem, since a voltage reduction will decrease the amount of reactive power generated by the capacitor banks, while increasing the reactive power consumption of the asynchronous generator. Therefore, there is a risk that instead of supporting the network at an under voltage situation, the asynchronous generator will further decrease the system voltage and in principle it might cause a voltage stability [13, 14].

C.Line-Commutated and Self-Commutated Converter

It is well-known fact that conventional line commutated converters always consume reactive power. The amount of the consumed reactive power can be as high as 30% of the rated power of the converter. To compensate the demand, capacitor banks are normally installed on the ac side of the converter. This makes a line commutated converter qualitatively equivalent to a directly connected induction generator. Therefore, under certain situations, the presence of such a converter can negatively affect voltage stability. Moreover, the capacities of DG are often quite small, which makes the utilization of advanced power electronics devices economically beneficial. Therefore, it can be anticipated with certain degree of confidence that in the near future most of the power electronics converters will be self-commutated.
The utilization of self-commutated converters for interfacing DG units with network allows fast and accurate control of the output voltage magnitude and angle. Therefore, reactive power can be either generated or absorbed, depending on the control mode. Since normally the power factor of such a converter is close to unity, no reactive power is injected in the network. Case studies

presented [18] in report a significant improvement of transient stability by a fuel cell power plant interfaced with power electronic converters [13, 14].

IV. CONTINUATION POWER FLOW (CPF) METHOD

The use of steady state continuation program is now well established and explanation of the continuation power flow (CPF) method [10]. This method can be implementing with any set of power system balance equations as well as the standard power-flow equations.
The CPF method is a numerical method that is used to trace the trajectory of a power system from a stable equilibrium point up to a bifurcation point [11].Such a method employs the following model:

$$g(y, \lambda) = 0 \qquad (2)$$

where, y represents the state variables and λ is a system parameter used to drive the system from one equilibrium point to another.

The continuations methods expect on the selection of a continuation parameter like the degree of system loading and on a two-step predictor-corrector iterative route.
The predictor step, used to point out a direction to move. The tangent vector will be used for this reason. It is derived by

$$\mathrm{Tp} = J^{-1}\begin{bmatrix} P \\ Q \end{bmatrix} \qquad (3)$$

where, J =Power-flow Jacobian matrix and P and Q equal to the net active and reactive powers related to each bus. The Tp are in terms of angle changes Δθ and ΔV .The predictor step size is given by

$$\frac{1}{\|\mathrm{Tp}\|} \qquad (4)$$

where, ‖ ‖stands for tangent vector norm. Thus, the sharper the curve, the smaller the predictor step. It makes the method take larger steps when the system is away from the junction point, and smaller steps as the junction is approached. The actual operating point is obtained by the help of the corrector stage, which is obtained from additional equation. From this equation the reality is predictor and corrector vectors are orthogonal. Using the CPF, it is possible to solve the problem. So that get to the maximum loading point due to voltage collapse. More essential, possible to decide the Jacobian matrix at this operating point. The Jacobian matrix will be most useful tool for purposes of selecting the locations where additions and changes of the system from the point of view of market power should take place. The CPF method implemented in a predictor step is realized by the computation of the tangent vector and a corrector step that can be obtained either by means of a local parameterization or a perpendicular intersection [13].

1. Predictor Step: At a generic equilibrium point, we have the following relation:

$$g(y_P, \lambda_P) = 0 \rightarrow \frac{dg}{d\lambda} = 0 = \Delta_y g \frac{dy}{d\lambda} + \frac{\partial g}{\partial \lambda} \qquad (5)$$

and the tangent vector can be approximated by

$$\mathrm{T}_P = \frac{dy}{d\lambda} \approx \frac{\Delta yp}{\Delta \lambda p} \qquad (6)$$

a step size control k has to be chosen for determining the increment Δy_P and $\Delta\lambda_P$, along with a normalization to avoid large step when $\|\tau p\|$ is large

$$\Delta\lambda_P \cong \frac{k}{\|\tau p\|} \qquad (7)$$

$$\Delta y_P \cong \frac{k\tau p}{\|\tau p\|} \qquad (8)$$

where, k = $\pm$1, and its sign determines the increase or the decrease of λ. Fig. 2 presents a pictorial representation of the predictor step.

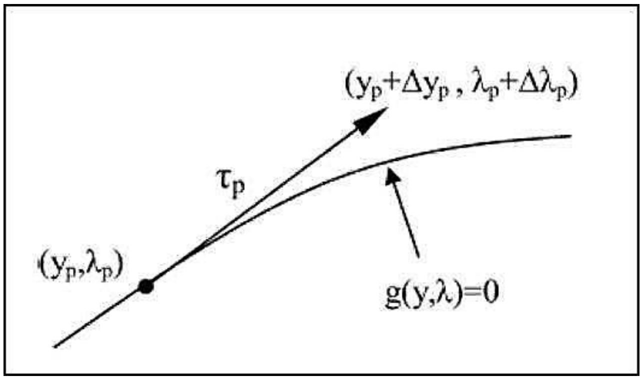

Figure 2: CPF predictor step obtained by means of tangent vector.

2. Corrector Step: In the corrector step, a set of n+ 1 equation is solved

$$g(y, \lambda) = 0 \qquad (9)$$

$$\rho(y, \lambda) = 0 \qquad (10)$$

where, the solution of g must be in the bifurcation manifold and ρ is an additional equation to guarantee a nonsingular set at the bifurcation point. For the choice of ρ, there are two options: the perpendicular intersection and the local parameterization. In the case of perpendicular intersection, whose pictorial representation is illustrated in Fig. 3, the expression of ρ becomes,

$$\rho(y, \lambda) = y_{ci} - (y_{pi} + \Delta y_{pi}) \qquad (11)$$

or

$$\rho(y, \lambda) = \lambda_c - (\lambda_p + \Delta\lambda_p) \qquad (12)$$

Whereas for the local parameterization, either the parameter λ or a variable y_i is forced to be a fixed value

The choice of the variable to be fixed depends on the bifurcation several of g.

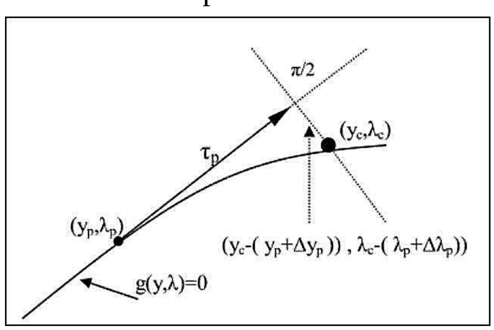

Figure 3: CPF corrector step obtained by means of perpendicular intersection.

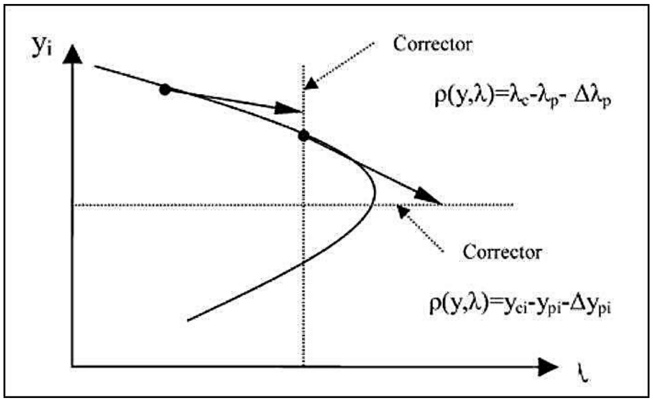

Figure 4: CPF corrector step obtained by means of local parameterization.

V. PLACEMENT ALGORITHM

For placement of DG units, it is necessary to define objective function to solving this problem. According to structure of placement algorithm in Fig.5, the objective function should be selected for reducing of power losses, increasing of maximum loading, or increasing of voltage stability margin in the system. So, for this purpose, the precise active power losses reduction as an objective function has selected.

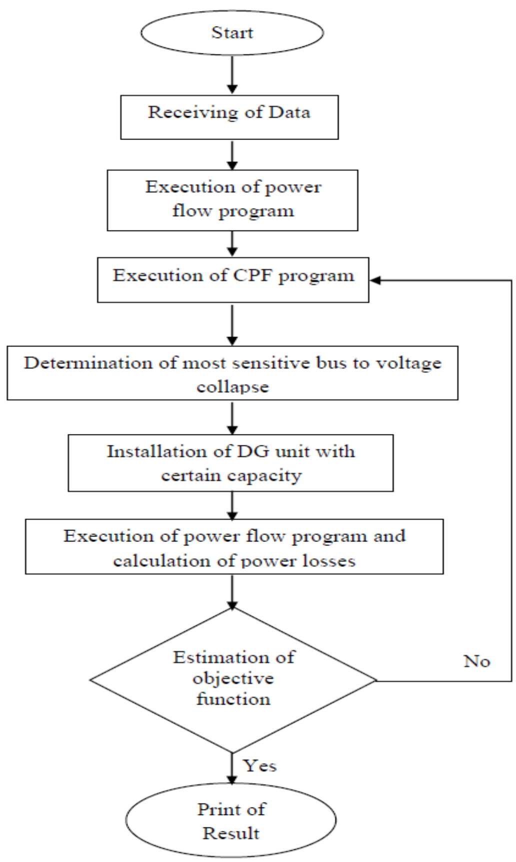

Fig 5: Flowchart of DG Placement method.

VI. EFFECT OF PLACEMENT OF DG UNITS

1. Power Losses: For calculation of accurate active power losses reduction (PLR) by DG units, we have the following relation:

$$\mathrm{PLR} = \frac{P_{loss} - P_{loss}^{DG}}{P_{loss}} \times 100\ \% \quad (13)$$

2. Power Transfer Capacity: The power transfer capacity of transmission network by using of DG units can be defined as follows:

$$\mathrm{PTC} = \frac{P_{slack} - P_{slack}^{DG} + P_{loss} - P_{loss}^{DG}}{P_{slack}} \times 100\ \% \quad (14)$$

Where,

$P_{slack} = P_{loss} + P_{load}$, $P_{loss} = P_G - P_{load}$, $P_{loss}^{DG} = P_G^{DG} - P_{load}$

P_{slack} =Total active Power of the slack bus;

P_{slack}^{DG} =Total active power of the slack bus with DG units;

P_{loss} =Total active power losses of the transmission lines;

P_{loss}^{DG} =Total active power losses with DG units;

P_{load} =Total active power of the loads;

P_G=Total active power of the generation units;

P_G^{DG} =Total active power of the generation units with DG units.

3. Voltage Stability Margin: The voltage stability margin (VSM) has the following relation:

$$\mathrm{VSM} = \frac{\lambda_k^{max} - \lambda_k}{\lambda_k^{max}} \times 100\ \% \quad (15)$$

Where,$\lambda_k$the base loading parameter for low is limit operating voltage and λ_k^{max} is the maximum loading of the system.

VII. CASE STUDY

The size and type of the test system play a very vital role in the analysis of the transient stability. A large system may increase the time and complexity of the analysis whereas a small system may lead to neglecting necessary factors. Therefore, a medium sized representative 30-bus system has been chosen for the study. The one-line diagram of the test system is shown in Fig. 6. Table 1: Characteristics of the IEEE 30-bus test system In this system bus 1 is consider as a slack bus, buses 2, 5, 8, 11 and 13 as a generator bus and buses remaining bus as a load bus. The system consists of a main source, which is connected to bus 2 and three distributed generators connected to buses 30, 29, and 27. The DGs connected to buses 5, 8, 11 and 13 are represented by synchronous condenser

System Characteristics	**Value**
Total number of buses	30
Total number of source	5
Main source	1
Distributed source	3
Number of load buses	21
Total number of transformers	5

Here given test system study by Newton Raphson Method for only load flow study and then we can implement on it proposed method.

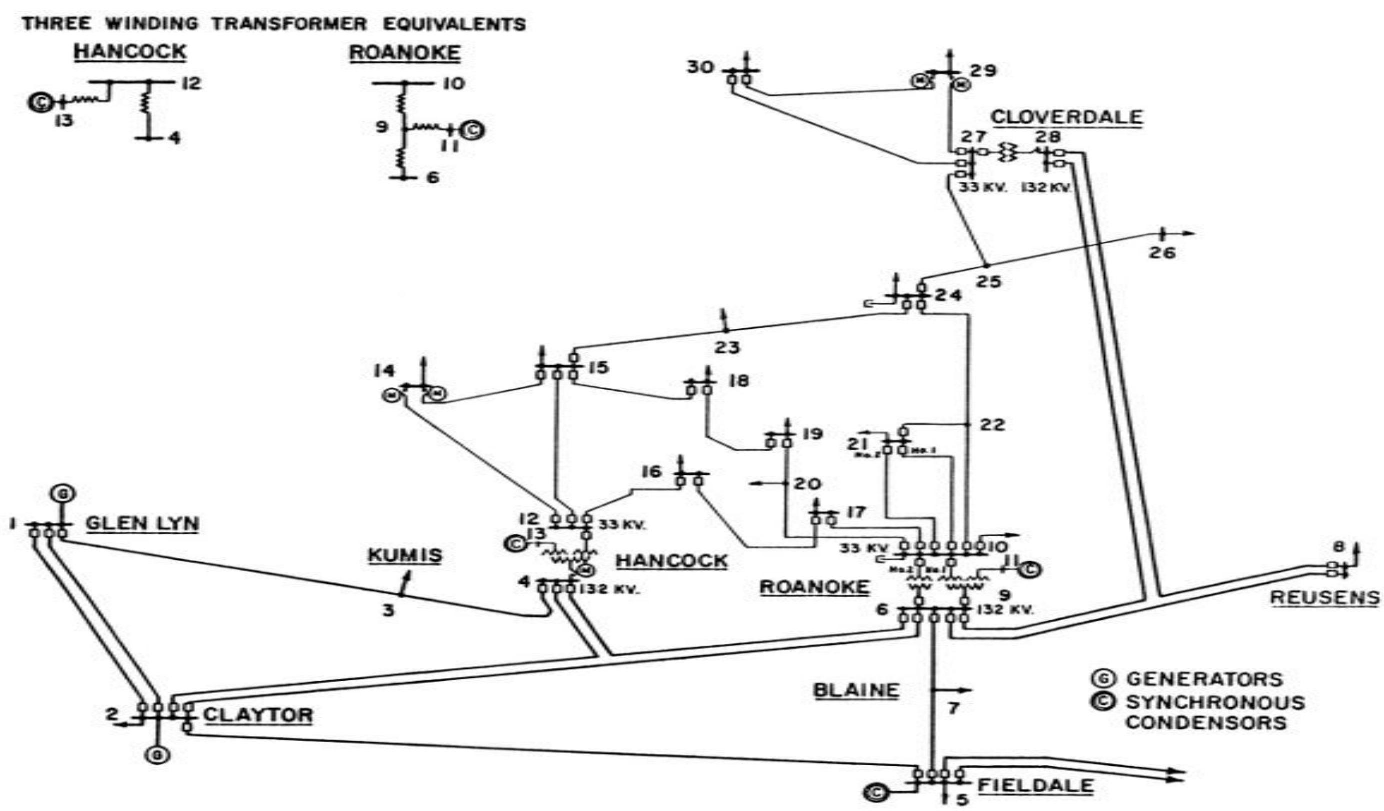

Fig. 6 IEEE 30-bus test system

The Newton-Raphson procedure is as follows:

Step-1: Choose the initial values of the voltage magnitudes |V |(0) of all no load buses and n – 1 anglesδ(0) of the voltages of all the buses except the slack bus.
Step-2: Use the estimated |V |(0) and δ(0) to calculate a total n – 1 number of injected real powers Pcalc (0) and equal number of real power mismatch ΔP (0).
Step-3: Use the estimated |V |(0) and δ(0) to calculate a total np number of injected reactive power Q calc (0) and equal number of reactive power mismatch ΔQ(0).
Step-4: Use the estimated |V|(0) and δ(0) to formulate the Jacobean matrix J(0).
Step-5: Calculate Δδ(0) and Δ|V |(0) ÷|V |(0).
Step-6: Obtain the updates from

$$\delta^{(1)} = \delta^{(0)} + \Delta\delta^{(0)} \qquad (16)$$

$$|V|^{(1)} = |V|^{(0)}\left[1 + \frac{\Delta|V|^{(0)}}{|V|^{(0)}}\right] \qquad (17)$$

Step-7: Check if all the mismatches are below a small number. Terminate the process if yes. Otherwise go back to step-1 to start the next iteration with new value given by equation (16) and (17) [17].

Bus No	Voltage	Angle	Bus No	Voltage	Angle
1	1.0600	0.000	16	1.0304	-15.6251
2	1.0430	-5.3543	17	1.0188	-15.8687
3	1.0196	-7.5308	18	1.0114	-16.6067
4	1.0104	-9.2840	19	1.0066	-16.7658
5	1.0100	-14.1738	20	1.0095	-16.5502
6	1.0096	-11.0581	21	1.0082	-16.2178
7	1.0020	-12.8649	22	1.0120	-15.9811
8	1.0100	-11.8193	23	1.0085	-16.2294
9	1.0392	-14.0644	24	0.9991	-16.3007
10	1.0215	-15.6706	25	1.0032	-16.0720
11	1.0820	-14.0644	26	0.9852	-16.5038
12	1.0496	-15.1245	27	1.0145	-15.6559
13	1.0710	-15.1245	28	1.0078	-11.7163
14	1.0320	-16.0018	29	0.9944	-16.9077
15	1.0251	-16.0084	30	0.9828	-17.8067

Table 2: Effect of N-R method on Voltage and Angle on IEEE 30-Bus system

VIII. CONCLUSION

In this review paper, a method for placement of DG units in distribution network based on CPF approach is present. The method is simple and straightforward, because one has to simply observe the voltages at weak buses at the voltage collapse point, which are obtained at the end of NR solution. The identified buses are selected for deciding location of DG units. Base on survey this method is efficient for improvement of voltage profile, reduction of power losses and also an increase in maximum loading and voltage stability margin.

APPENDIX

IEEE 30-BUS TEST SYSTEM

Generator Data:
Base: SB=100 MVA and VB=20 kV
Slack generator: Voltage 1 p.u.
DG units: PV controlled, Voltage 1p.u,
PDG= 25 MW and DDG= 25 MVar
Bus and transmission Lines Data: TableA1, TableA2.

Bus	Voltage (V)	P_G (MW)	Q_G (MVar)	P_L (MW)	Q_L (MVar)
1	1.06	0	0	0	0
2	1.043	40	50.0	21.7	12.7
3	1.0	0	0	2.4	1.2
4	1.06	0	0	7.6	1.6
5	1.01	0	37.0	94.2	19.0
6	1.0	0	0	0.0	0.0
7	1.0	0	0	22.8	10.9
8	1.01	0	37.3	30.0	30.0
9	1.0	0	0	0.0	0.0
10	1.0	0	0	5.8	2.0
11	1.082	0	16.2	0.0	0.0
12	1.0	0	0	11.2	7.5
13	1.071	0	10.6	0.0	0.0
14	1.0	0	0	6.2	1.6
15	1.0	0	0	8.2	2.5
16	1.0	0	0	3.5	1.8
17	1.0	0	0	9.0	5.8
18	1.0	0	0	3.2	0.9
19	1.0	0	0	9.5	3.4
20	1.0	0	0	2.2	0.7
21	1.0	0	0	17.5	11.2
22	1.0	0	0	0.0	0.0
23	1.0	0	0	3.2	1.6
24	1.0	0	0	8.7	6.7
25	1.0	0	0	0.0	0.0
26	1.0	0	0	3.5	2.3
27	1.0	0	0	0.0	0.0
28	1.0	0	0	0.0	0.0
29	1.0	0	0	2.4	0.9
30	1.0	0	0	10.6	1.9

Table A1: Bus Data of sample IEEE 30-bus test system

From Bus	To Bus	R(pu)	X(pu)	B/2 (pu)	X'mer TAP
1	2	0.0192	0.0575	0.0264	1
1	3	0.0452	1.1652	0.0204	1
2	4	0.0570	0.1737	0.0184	1
3	4	0.0132	0.0379	0.0042	1
2	5	0.0472	0.1983	0.0209	1
2	6	0.0581	0.1763	0.0187	1
4	6	0.0119	0.0414	0.0045	1
5	7	0.0460	0.1160	0.0102	1
5	7	0.0267	0.0820	0.0085	1
5	8	0.0120	0.0420	0.0045	1
5	9	0.0	0.2080	0.0	0.978
5	10	0.0	0.5560	0.0	0.969
9	11	0.0	0.2080	0.0	1
9	10	0.0	0.1100	0.0	1
4	12	0.0	0.2560	0.0	0.932
12	13	0.0	0.1400	0.0	1
12	14	0.1231	0.2559	0.0	1
12	15	0.0662	0.1304	0.0	1
12	16	0.0945	0.1987	0.0	1
14	15	0.2210	0.1997	0.0	1
16	17	0.0824	0.1923	0.0	1
15	18	0.1073	0.2185	0.0	1
18	19	0.0639	0.1292	0.0	1
19	20	0.0340	0.0680	0.0	1
10	20	0.0936	0.2090	0.0	1
10	17	0.0324	0.0845	0.0	1
10	21	0.0348	0.0749	0.0	1
10	22	0.0727	0.1499	0.0	1
21	23	0.0116	0.0236	0.0	1
15	23	0.1000	0.2020	0.0	1
22	24	0.1150	0.790	0.0	1
23	24	0.1320	0.2700	0.0	1
24	25	1.1885	0.3292	0.0	1
25	26	0.2544	0.3800	0.0	1
25	27	0.1093	0.2087	0.0	1
28	27	0.0000	0.3960	0.0	0.968
27	29	0.2198	0.4153	0.0	1
27	30	0.3202	0.6027	0.0	1
29	30	0.2399	0.4533	0.0	1
8	28	0.0636	0.2000	0.0214	1
6	28	0.0169	0.0599	0.065	1

Table A2: Line Data of sample IEEE 30-bus test system

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