Impacts and Compensation of Distributed Generation in Modern Power System

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Abstract — Nowadays power requirement are increasing in an irregular pattern and with the increase in the population is playing a very important role in increased power requirement. Also the excessive industrialization leads to the development of new technologies with increased power demand. To handle the power requirements engineers have developed or is developing a new technology which is distributed generation (DG). Nowadays distributed generation is being used widely to deliver the power to the end users as well as add to the power generation capability of any power plant. This paper shows the impacts that were raised due to the connection of distributed generation into the existing network. To test the effectiveness of proposed method an IEEE 30 bus network is used. The impacts are studied and are shown with the help of graph.

Keywords — Distributed generation, non-renewable energy, renewable energy, solar energy, tidal energy etc.

1. INTRODUCTION

Distributed generation includes the solar panels, photovoltaic cell, micro turbines, wind turbines, combustion gas turbines, biomass gasification, and various other small generation units which are based on renewable energy sources. The distributed generation is a technology with has evolved in the present time and has become one of the major field of interest for the researchers. The distributed generation has the advantage over the conventional methods of power generation that they can be installed at the sites where the power requirement has increased and also it is not possible to set up a new power generation station at every few km distance.

Other advantage which it posses is that this technology is environment friendly which means it does not produce harmful by-products which in a direct or indirect way affects the environment.

Third advantage of DG is that it is not costly and it works on the non conventional sources of energy like wind energy, solar energy, increases the reliability, reduces the losses etc. A distributed generation offers several advantages but to make the full use of the DG potential it is necessary that we should again think on our power generation methods. Today DG has become an essential part of distributed energy resources including storing of energy. Much work has already done in the past about the sizing and location of distributed generation into the network so that the transmission and distribution losses are minimized.

Disadvantages of distributed generation are that it disturbs the power flow in the network which in turn disturbs the voltage profile and reduces the stability of the power system.

Also if the distributed generation is not connected to the optimal location and is of optimal capacity as required by the particular location it will increase the losses thereby degrading the quality of the voltage.

Methods such as optimal power flow method, particle swarm optimization, ant colony optimization, genetic algorithm, monte-carlo simulation methods have been discussed in [6] [13] [14] [5] [4]. In this a new method have been suggested which is very simple to operate and is very effective. In this paper the simulation of the IEEE 30 bus test network is done using Power System Analysis Tool (PSAT) of MATLAB.

The IEEE 30 bus network consists of PV and PQ busses. PV bus is the bus where we give values of active power and magnitude of voltage and DG is connected to the distribution grid via the synchronous generator with excitation control mode for voltage control, on the other hand PQ bus is the bus where we input the values of active power and reactive power. In PQ bus the DG is connected to the distribution grid via synchronous generator with excitation control mode for power factor control as given [16].

In our test network PV buses are bus no. 1, 2, 5, 8, 11, 13 and the remaining are PQ buses. Slack bus is connected to the bus 1 whose voltage magnitude is set to 1 p.u. It consists of three transformers of 100MVA rating. The network is designed for 11kV transmission line.

Section I of this paper gives the details about the distributed generation technology. Advantages and disadvantages of the distributed generation and also gives the detailed description of the method used in this paper.

Section II of this paper deals with the proposed method and with the working.

Section III of this paper shows the results and compare the results obtained after the simulation and analysis of the impacts of DG and their compensation method.

2. Methodology

Here the simulation results were obtained using the PSAT (power system analysis toolbox) which is a tool for the analysis of the power system. PSAT is based on MATLAB and in this method one need not solve long and complex mathematical equations that means this method is easy to understand and use. Steps involved in the operation of PSAT are as follows:

1. Start MATLAB.
2. Run PSAT.m file.
3. Open the library from PSAT window.
4. Select the elements which are required to draw the network.
5. Draw the network and save it.
6. In the PSAT window load the saved network and run the continuous power flow.
7. Click on the static report tab. It will generate the report of the continuous power flow.
8. From the static report one can also get the graphs showing the variation in voltage profile of the network.

Besides continuous power flow, PSAT also performs the optimal power flow, time domain analysis, frequency domain analysis etc

Fig.1 shows the IEEE-30 bus network designed using PSAT.

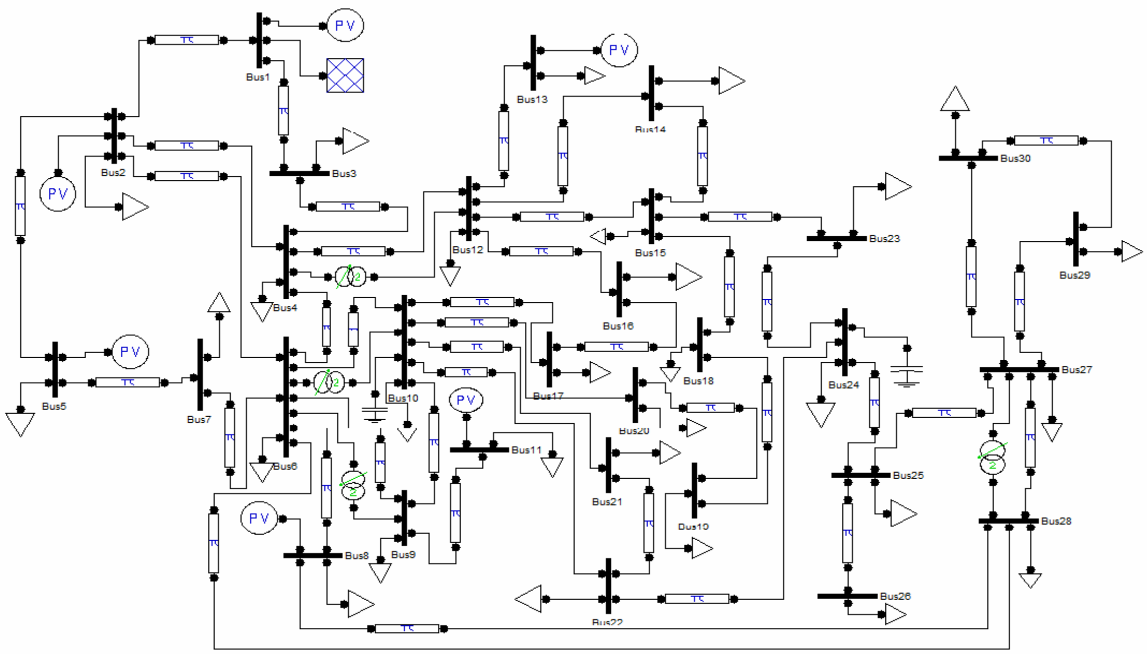

Figure 1: IEEE-30 bus load flow diagram

TABLE I

LOAD FLOW ANALYSIS WITHOUT DG

Bus	Voltage (p.u.)	Q load (p.u.)	P load (p.u.)	Q. gen (p.u.)	P. gen (p.u.)
Bus1	1	0	0	1.1661	12.6445
Bus2	1	0.41728	0.713	7.5514	1.3143
Bus3	0.77822	0.03943	0.07886	0	0
Bus4	0.79257	0.05257	0.24971	0	0
Bus5	1	0.62428	3.0951	3.8059	0
Bus6	0.85474	0	0	0	0
Bus7	0.87731	0.35814	0.74914	0	0
Bus8	1	0.98571	0.98571	5.6517	0
Bus9	0.85428	0	0	0	0
Bus10	0.77546	-0.04854	0.19057	0	0
Bus11	1	0	0	0.70008	0
Bus12	0.82312	0.24643	0.368	0	0
Bus13	1	0	0	1.2629	0
Bus14	0.74862	0.05257	0.20371	0	0
Bus15	0.72304	0.08214	0.26943	0	0
Bus16	0.76643	0.05914	0.115	0	0
Bus17	0.74989	0.19057	0.29571	0	0
Bus18	0.67757	0.02957	0.10514	0	0
Bus19	0.6677	0.11171	0.31214	0	0
Bus20	0.69	0.023	0.07229	0	0
Bus21	0.71068	0.368	0.575	0	0
Bus22	0.71168	0	0	0	0
Bus23	0.66704	0.05257	0.10514	0	0
Bus24	0.63608	0.20274	0.28586	0	0
Bus25	0.65423	0	0	0	0
Bus26	0.54677	0.07557	0.115	0	0
Bus27	0.71943	0	0	0	0
Bus28	0.83797	0	0	0	0
Bus29	0.55653	0.02957	0.07886	0	0
Bus30	0.45864	0.06243	0.34828	0	0

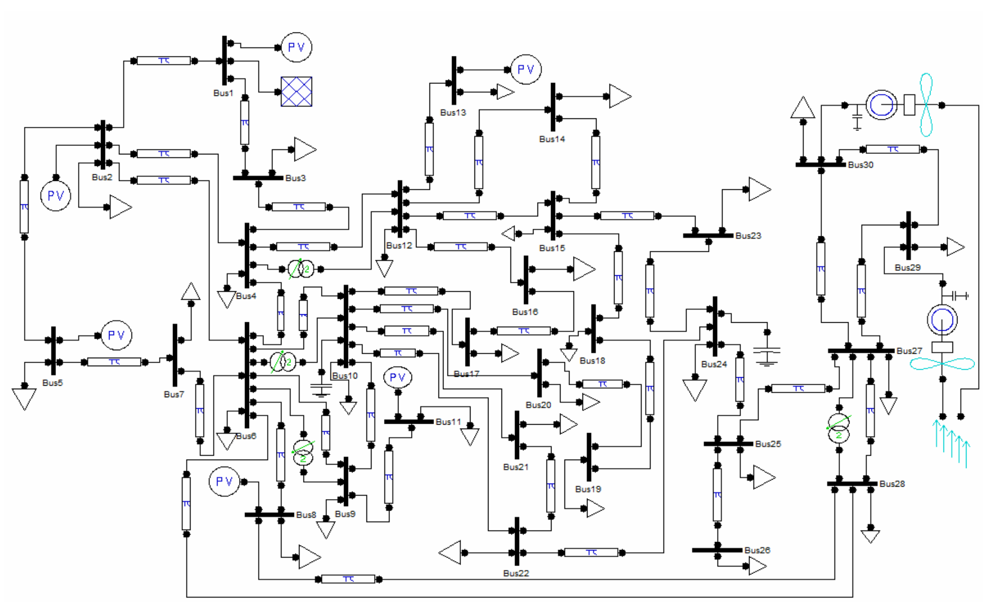

Figure 2: Load flow diagram with DG

TABLE II

LOAD FLOW ANALYSIS WITH DG

Bus	Voltage (p.u.)	Q load (p.u.)	P load (p.u.)	Q. gen (p.u.)	P. gen (p.u.)
Bus1	1	0	0	1.1675	12.6465
Bus2	1	0.41718	0.71282	7.5545	1.314
Bus3	0.77808	0.03942	0.07884	0	0
Bus4	0.79242	0.05256	0.24965	0	0
Bus5	1	0.62412	3.0943	3.8061	0
Bus6	0.85459	0	0	0	0
Bus7	0.87723	0.35805	0.74895	0	0
Bus8	1	0.98546	0.98546	5.6571	0
Bus9	0.85414	0	0	0	0
Bus10	0.77525	-0.0485	0.19052	0	0
Bus11	1	0	0	0.70077	0
Bus12	0.82299	0.24636	0.3679	0	0
Bus13	1	0	0	1.2638	0
Bus14	0.74846	0.05256	0.20366	0	0
Bus15	0.72283	0.08212	0.26936	0	0
Bus16	0.76627	0.05913	0.11497	0	0
Bus17	0.7497	0.19052	0.29564	0	0
Bus18	0.67737	0.02956	0.10512	0	0
Bus19	0.66749	0.11169	0.31206	0	0
Bus20	0.68979	0.02299	0.07227	0	0
Bus21	0.71042	0.3679	0.57485	0	0
Bus22	0.7114	0	0	0	0
Bus23	0.66671	0.05256	0.10512	0	0
Bus24	0.6356	0.20271	0.28578	0	0
Bus25	0.65332	0	0	0	0
Bus26	0.54566	0.07555	0.11497	0	0
Bus27	0.71835	0	0	0	0
Bus28	0.83757	0	0	0	0
Bus29	0.5542	0.02956	0.07884	0	0
Bus30	0.45544	0.06241	0.3482	0	0

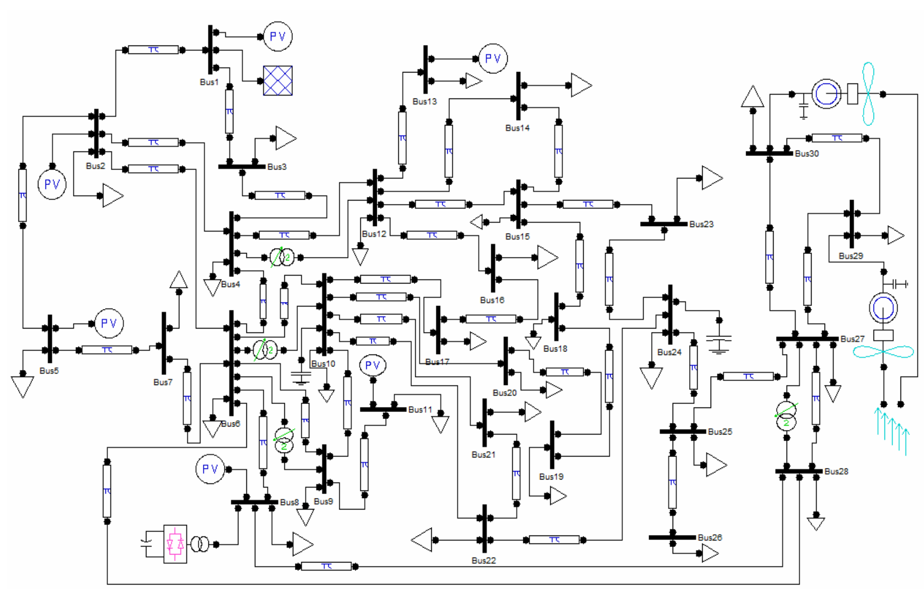

Figure 3: Load flow with DG and STATCOM

TABLE III

LOAD FLOW ANALYSIS WITH DG AND STATCOM

Bus	Voltage (p.u.)	Q load (p.u.)	P load (p.u.)	Q. gen (p.u.)	P. gen (p.u.)
Bus1	1	0	0	-0.00951	0.0028
Bus2	1	0	0	-0.06005	0
Bus3	1.0013	0	0	0	0
Bus4	1.0015	0.	0	0	0
Bus5	1	0	0	-0.04515	0
Bus6	1.0087	0	0	0	0
Bus7	1.0051	0	0	0	0
Bus8	1.0148	-0.81183	0	-0.65575	0
Bus9	1.0226	0	0	0	0
Bus10	1.0368	-0.20424	0	0	0
Bus11	1	0	0	-0.1089	0
Bus12	1.0267	0	0	0	0
Bus13	1	0	0	-0.19118	0
Bus14	1.0281	0	0	0	0
Bus15	1.029	0	0	0	0
Bus16	1.0311	0	0	0	0
Bus17	1.0351	0	0	0	0
Bus18	1.0321	0	0	0	0
Bus19	1.0337	0	0	0	0
Bus20	1.0346	0	0	0	0
Bus21	1.036	0	0	0	0
Bus22	1.0358	0	0	0	0
Bus23	1.0303	0	0	0	0
Bus24	1.0318	-0.04578	0	0	0
Bus25	1.0114	0	0	0	0
Bus26	1.0116	0	0	0	0
Bus27	0.99821	0	0	0	0
Bus28	1.0129	0	0	0	0
Bus29	0.99868	0	0	0	0
Bus30	0.99873	0	0	0	0

Determining the location of distributed Generation and STATCOM

Authors of [3] have given that the desired location of distributed generation is the weakest node in the network. From the weakest node it means the node at which the magnitude of voltage drop is maximum. Table I and Table II shows that the most weakest bus in the network is the bus no. 30, 29 and 26 with bus no. 30 being the most sensitive bus therefore a DG has to be necessarily installed at bus no. 30 whereas it can also be connected to bus no. 26 and 29 it depends on the system planner.

A STATCOM can be connected to the bus where the reactive power loss is maximum. In our test network bus no. 8 has maximum loss therefore we have connected the STATCOM at bus no. 8 to minimize the losses.

3. RESULT

The load flow results obtained after the simulation are listed in Table IV, Table V and Table VI. From the study of Table I, Table II and Table III it can be seen that the active power losses as well as reactive power losses are almost reduced to zero which proves the efficiency of this method and also the system becomes stable if the DG is installed at the location defined in this paper. The losses are summarized below.

TABLE IV

LOAD FLOW ANALYSIS

From Bus	**To Bus**	**Line**	**P Loss [p.u]**	**Q Loss [p.u]**
Bus 2	Bus 1	1	1.5913	4.7648
Bus 1	Bus 3	2	0.67865	2.4796
Bus 6	Bus 9	3	0	0.02444
Bus 10	Bus 6	4	0	0.05224
Bus 11	Bus 9	5	0	0.10122
Bus 10	Bus 9	6	0	0.11889
Bus 4	Bus 12	7	0	0.17896
Bus 13	Bus 12	8	0	0.22263
Bus 14	Bus 12	9	0.01692	0.03455
Bus 12	Bus 15	10	0.05194	0.10171
Bus 12	Bus 16	11	0.01199	0.02457
Bus 14	Bus 15	12	0.00182	0.0011
Bus 2	Bus 4	13	0.24574	0.74805
Bus 17	Bus 16	14	0.00191	0.00643
Bus 15	Bus 18	15	0.0097	0.01927
Bus 18	Bus 19	16	0.00128	0.00213
Bus 20	Bus 19	17	0.00451	0.00856
Bus 10	Bus 20	18	0.0209	0.04612
Bus 10	Bus 17	19	0.00298	0.00719
Bus 10	Bus 21	20	0.02813	0.05999
Bus 10	Bus 22	21	0.01382	0.02795
Bus 21	Bus 22	22	5e-005	-0.0004
Bus 15	Bus 23	23	0.00872	0.01714
Bus 3	Bus 4	24	0.19006	0.54508
Bus 23	Bus 24	25	0.0019	0.00347
Bus 22	Bus 24	26	0.01635	0.02499
Bus 24	Bus 25	27	0.00054	0.00053
Bus 25	Bus 26	28	0.01609	0.02368
Bus 25	Bus 27	29	0.01013	0.01888
Bus 27	Bus 28	30	0	0.07181
Bus 29	Bus 27	31	0.03963	0.07447
Bus 30	Bus 27	32	0.07937	0.14904
Bus 30	Bus 29	33	0.01795	0.03365
Bus 8	Bus 28	34	0.04046	0.12638
Bus 2	Bus 5	35	0.6029	2.5319
Bus 6	Bus 28	36	0.01249	0.04356
Bus 2	Bus 6	37	0.43933	1.3322
Bus 4	Bus 6	38	0.16003	0.55608
Bus 5	Bus 7	39	0.06151	0.15423
Bus 7	Bus 6	40	0.04649	0.14202
Bus 6	Bus 8	41	0.19302	0.6747
Bus 6	Bus 10	42	0.00879	0.17576
Bus 6	Bus 9	43	0.00143	0.02863
Bus 4	Bus 12	44	0.01224	0.24478
Bus 27	Bus 28	45	0.00601	0.12015

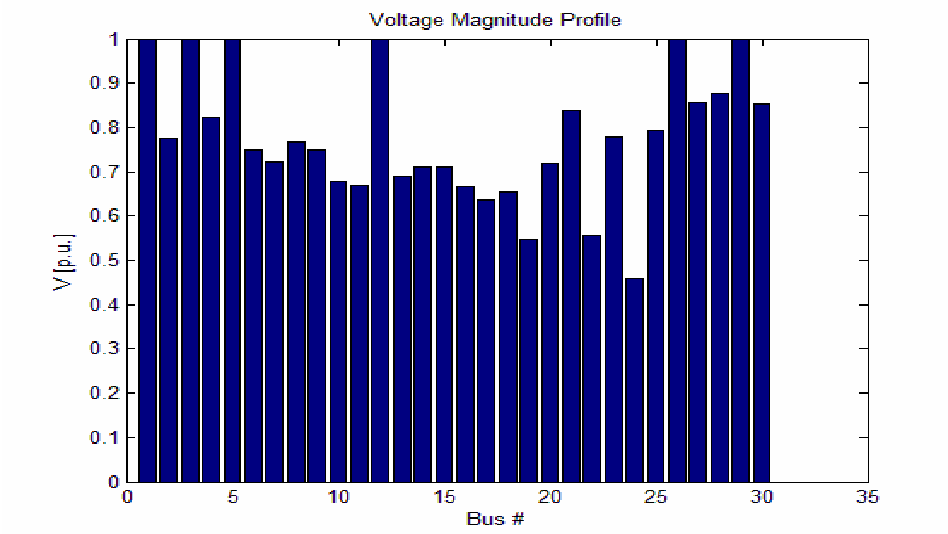

Figure 4: Voltage profile without DG connected

TABLE V

LOAD FLOW ANALYSIS WITH DG

From Bus	To Bus	Line	P Loss [p.u]	Q Loss [p.u]
Bus 2	Bus 1	1	1.592	4.7666
Bus 1	Bus 3	2	0.67886	2.4803
Bus 6	Bus 9	3	0	0.02445
Bus 10	Bus 6	4	0	0.05228
Bus 11	Bus 9	5	0	0.10143
Bus 10	Bus 9	6	0	0.11902
Bus 4	Bus 12	7	0	0.17904
Bus 13	Bus 12	8	0	0.22296
Bus 14	Bus 12	9	0.01693	0.03457
Bus 12	Bus 15	10	0.05199	0.10181
Bus 12	Bus 16	11	0.012	0.02459
Bus 14	Bus 15	12	0.00183	0.00111
Bus 2	Bus 4	13	0.2459	0.74854
Bus 17	Bus 16	14	0.00191	0.00644
Bus 15	Bus 18	15	0.00971	0.01927
Bus 18	Bus 19	16	0.00128	0.00213
Bus 20	Bus 19	17	0.00451	0.00856
Bus 10	Bus 20	18	0.0209	0.04612
Bus 10	Bus 17	19	0.00298	0.00719
Bus 10	Bus 21	20	0.02817	0.06008
Bus 10	Bus 22	21	0.01385	0.028
Bus 21	Bus 22	22	5e-005	-0.0004
Bus 15	Bus 23	23	0.00876	0.0712
Bus 3	Bus 4	24	0.19012	0.54525
Bus 23	Bus 24	25	0.00192	0.0035
Bus 22	Bus 24	26	0.01644	0.02513
Bus 24	Bus 25	27	0.00052	0.00049
Bus 25	Bus 26	28	0.01615	0.02376
Bus 25	Bus 27	29	0.01008	0.01878

Bus 27	Bus 28	30	0	0.07239
Bus 29	Bus 27	31	0.04011	0.07538
Bus 30	Bus 27	32	0.08042	0.151
Bus 30	Bus 29	33	0.01821	0.03451
Bus 8	Bus 28	34	0.04065	0.12698
Bus 2	Bus 5	35	0.60292	2.532
Bus 6	Bus 28	36	0.01253	0.0437
Bus 2	Bus 6	37	0.43957	1.333
Bus 4	Bus 6	38	0.16008	0.55625
Bus 5	Bus 7	39	0.06153	0.15427
Bus 7	Bus 6	40	0.04644	0.14189
Bus 6	Bus 8	41	0.19337	0.67594
Bus 6	Bus 10	42	0.00879	0.17588
Bus 6	Bus 9	43	0.00143	0.02864
Bus 4	Bus 12	44	0.01224	0.24488
Bus 27	Bus 28	45	0.00606	0.12117

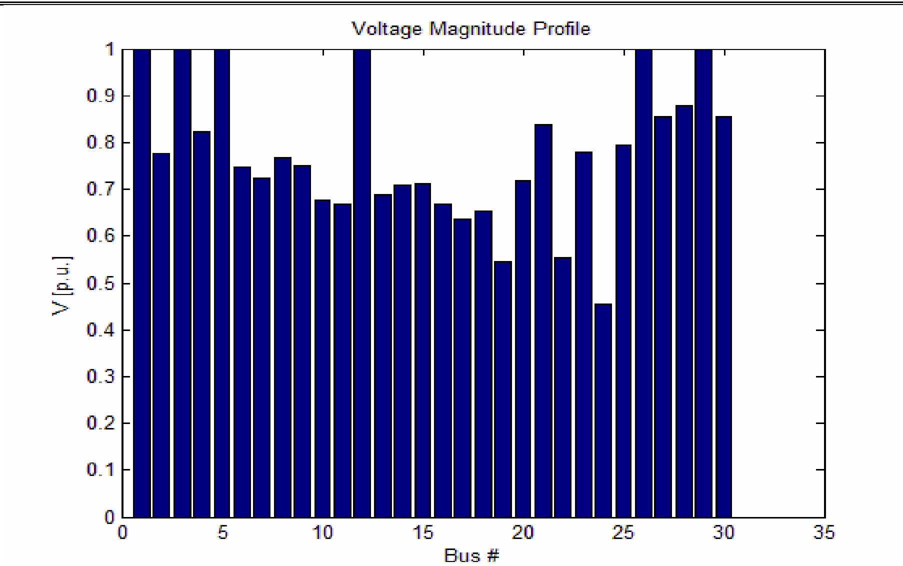

Figure 5: Voltage profile with DG connected

TABLE VI

LOAD FLOW ANALYSIS WITH DG AND STATCOM

From Bus	**To Bus**	**Line**	**P Loss [p.u]**	**Q Loss [p.u]**
Bus 2	Bus 1	1	0	-0.001
Bus 1	Bus 3	2	0	-0.00099
Bus 6	Bus 9	3	0	-0.00011
Bus 10	Bus 6	4	0	0.00038
Bus 11	Bus 9	5	0	0.00142
Bus 10	Bus 9	6	0	0.00079
Bus 4	Bus 12	7	0	0.00145
Bus 13	Bus 12	8	0	0.00406
Bus 14	Bus 12	9	0	-0.00105
Bus 12	Bus 15	10	3e-005	-0.00101
Bus 12	Bus 16	11	5e-005	-0.00096
Bus 14	Bus 15	12	0	-0.00105
Bus 2	Bus 4	13	1e-005	-0.00099
Bus 17	Bus 16	14	2e-005	-0.00098
Bus 15	Bus 18	15	2e-005	-0.00102
Bus 18	Bus 19	16	1e-005	-0.00105

Bus 20	Bus 19	17	0	-0.00106
Bus 10	Bus 20	18	1e-005	-0.00105
Bus 10	Bus 17	19	1e-005	-0.00104
Bus 10	Bus 21	20	0	-0.00107
Bus 10	Bus 22	21	0	-0.00107
Bus 21	Bus 22	22	0	-0.00107
Bus 15	Bus 23	23	1e-005	-0.00104
Bus 3	Bus 4	24	0	-0.001
Bus 23	Bus 24	25	1e-005	-0.00104
Bus 22	Bus 24	26	4e-005	-0.001
Bus 24	Bus 25	27	0.00056	-7e-005
Bus 25	Bus 26	28	0	-0.00102
Bus 25	Bus 27	29	0.00035	-0.00035
Bus 27	Bus 28	30	0	-0.00046
Bus 29	Bus 27	31	0	-0.001
Bus 30	Bus 27	32	0	-0.001
Bus 30	Bus 29	33	0	-0.001
Bus 8	Bus 28	34	1e-005	-0.001
Bus 2	Bus 5	35	0	-0.001
Bus 6	Bus 28	36	8e-005	-0.00075
Bus 2	Bus 6	37	0.00014	-0.00058
Bus 4	Bus 6	38	0.00036	-0.00023
Bus 5	Bus 7	39	9e-005	-0.00078
Bus 7	Bus 6	40	5e-005	-0.00086
Bus 6	Bus 8	41	0.00025	-0.00015
Bus 6	Bus 10	42	0	9e-005
Bus 6	Bus 9	43	2e-005	0.00039
Bus 4	Bus 12	44	0.00057	0.01145
Bus 27	Bus 28	45	8e-005	0.00169

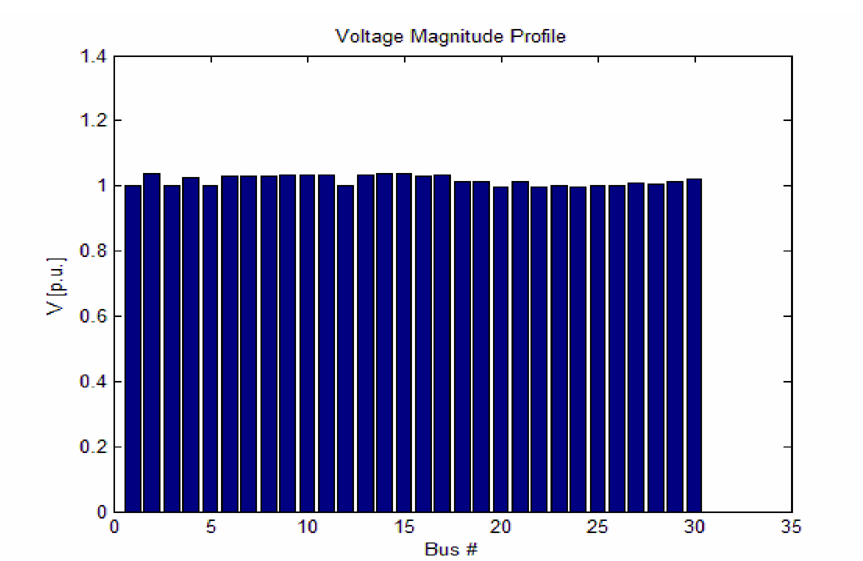

Figure 6: Voltage profile with DG and STATCOM

From fig.4, fig.5, and fig. 6 shows the voltage profile of an IEEE-30 bus network when DG is not connected, with DG connected and when distributed generation is compensated with the STATCOM. A STATCOM is a device which is used to compensate for the reactive power mismatch in the network. We have used STATCOM because of the advantages it posses over other FACT devices that it can inject as well as reduce the reactive power if it goes beyond the limit.

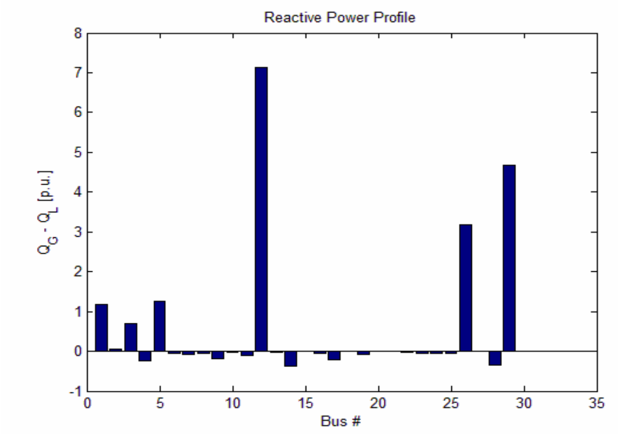

Figure 7: Reactive power profile without DG

The results obtained for load flow without DG is as follows:

Total Generation	
Real power [p.u.]	13.9588
Reactive power [p.u.]	20.138
Total Load	
Real power [p.u.]	9.3117
Reactive power [p.u.]	4.0149
Total Losses	
Real power [p.u.]	4.6471
Reactive power [p.u.]	16.1231

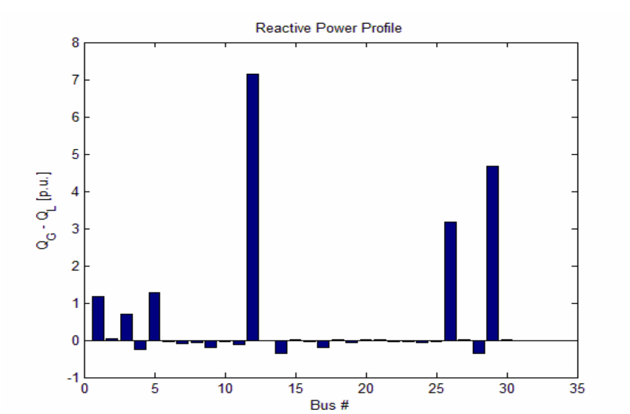

Figure 8: Reactive power profile with DG

From the graphs shown in fig.4, fig.5 and fig.6 it is clear that the introduction of DG into the existing network disturbs the voltage profile as well as reactive power and active power profile which in turn decreases the stability and reliability of the network.

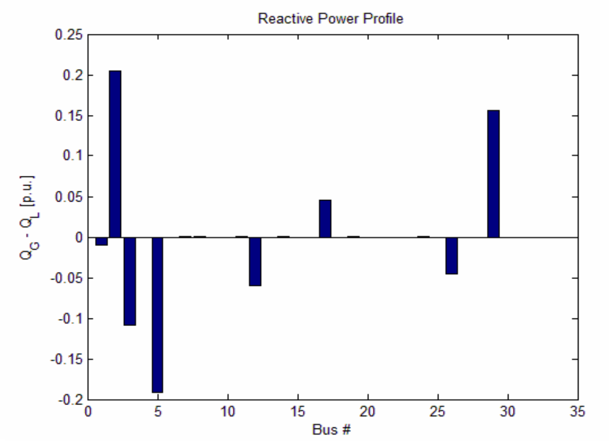

Figure 9: Reactive power profile with DG and STATCOM

The result of load flow with DG connected is as follows:

Total Generation	
Real power [p.u.]	13.9605
Reactive power [p.u.]	20.1497
Total Load	
Real power [p.u.]	9.3093
Reactive power [p.u.]	4.0139
Total Losses	
Real power [p.u.]	4.6512
Reactive power [p.u.]	16.1358

The results of load flow with DG and STATCOM is shown below:

Total Generation	
Real power [p.u.]	0.0028
Reactive power [p.u.]	-1.0705
Total Load	
Real power [p.u.]	0
Reactive power [p.u.]	-1.0619
Total Losses	
Real power [p.u.]	0.0028
Reactive power [p.u.]	-0.00869

Result shows that the reactive power loss and active power loss are reduced to zero with the above network configuration. It is therefore suggested that before connecting the distributed generation it is necessary that the system designer must think of the compensation devices as well as location of the distributed generation so that the losses are minimum. The optimal size of the DG is also very important in reducing the losses. If a DG of any size is connected it will inject or absorbs the reactive power thereby again disturbing the voltage profile of the associated network.

4. CONCLUSION

The study of IEEE-30 bus test network has been done and it has been found that the besides the advantages of connecting distributed generation, the engineers also has to study the impacts that a distributed generation can create and the compensation methods involved to reduce the losses and increase the system stability and reliability is the responsibility of the system planner.

In our network we have used an 11kV, 100MVA transmission line and six generators are connected to the bus no. 1, 2, 5, 8, 11, and 13 which are also the PV bus. The proposed is very efficient in the analysis of a power system as the losses are reduced to approximately 100%. In this paper the test network that we have used is a radial distribution network. A radial distribution network is the one in which the power flow from main generating station to the sub-stations and reaches the costumers. This method can also be applied to other bus networks.

Real power at the load decreases from 9.0393 p.u. to 0 p.u. and reactive power at the load decreases from 4.0139 p.u. to -1.0619 p.u. similarly when DG alone is connected to the network the real power losses are increased from 4.6471 p.u. to 4.6512 p.u. and reactive power losses are increased from 16.1231 p.u. to 16.1358 p.u.

From the above discussion it is clear that if a distributed generation is integrated to the network the losses are increased and to reduce these losses we have to go for flexible AC transmission (FACT) devices.

5. REFERENCES

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