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Article

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Research paper

Impact assessment of DG in distribution systems from minimization of total real power loss viewpoint by using optimal power flow algorithms



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ABSTRACT

This paper presents the enhancement and impacts of the system losses, voltage profile and cost by using distributed generations (DGs) of different size in distribution network. Distributed Generation (DGs) is expected to play a key role in the residential, commercial and industrial sectors of the power system. Distributed Generation (DG) provides an alternative to the traditional electricity sources and can also be used to enhance the current electrical system. DG produces a series of important influence on the distribution network. It mainly introduces four effect areas, namely, distribution network real power loss, voltage, distribution grid planning and relay protection. In this analysis, load flow method is used for optimization of objective function for minimization of total real power loss and reactive power loss of the system. The work is focused on analyzing the impact of DG installation on distribution network operation including system voltage profile analysis, real and reactive power losses and cost of the system. First, various sizes of DG penetration levels and the impact of distributing the DG across the bus where load is maximum are explored. Secondly, the real power losses of the system are analyzed. Thirdly, the voltage profile and cost of the system are analyzed. The proposed methodology has been tested for IEEE-14 bus distribution test system. This work is also helpful for practitioner whose are working in the fields of renewable energy sources.

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1. Introduction

Maturing technologies play a significant role in improvement of power generation. There are mainly three main driving forces which increases the penetration of distributed generation. They are environmental, commercial and regulatory factors. Development of renewable energy resources also forced to adopt distributed generation. DG is used to enhance reliability of distribution system. It provides a clean, reliable, and efficient and environment friendly alternative to the traditional centralized electric power system.

1.1. Literature review

Zhu and Broadwater (2006), is presented that the difference of DG placement between optimum efficiency and optimum reliability varies under different load conditions. Hou and Gao (2011), discussed that when DG access to distribution network the change of

distribution network voltage, distribution grid planning and relay protection, and also proposed some solutions. Singh et al. (2016a) is presented the impact assessment of optimally placed different types of DGs such as DG-1 (T1), DG-2 (T2), DG-3 (T3), and DG-4 (T4) with DMLs by using GA in distribution systems from minimum total mega volt ampere (MVA) intake viewpoint of main substation. Doyle (2002) discussed the impacts of DG on system protection and coordination particularly in cases where DG is added to a distribution feeder with existing line re-closers and fuses. Akorede et al. (2011) proposed an effective method to guide electric utility distribution companies (DISCOs) in determining the optimal size and best locations of DG sources on their power systems. Wang and Singh (2008), discussed an ant colony system algorithm is used to derive the optimal recloses and DG placement scheme for radial distribution networks. Singh et al. (2007b) provided 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. Kashem et al. (2006), discussed the techniques to minimize power losses in a distribution feeder by optimizing DG model in terms of size, location and operating point of DG. Padmalalitha et al. (2009–2010),

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Abbreviations

DGs	Distributed generations
DSs	Distributed systems
VPWoDG	Voltage profile without DG
DGs	Distributed generations
PF	Power factor
LFA	Load flow analysis
VPWDG	Voltage profile with
DSs	Distributed systems

Symbols

n	Bus number
δ	Real power exponent
Θ	Reactive power exponent
P_L	Real power loss of the system (p.u.)
P_r	Real power of system at bus r (p.u.)
Q_r	Reactive power of system at bus r (p.u.)
$DG-T1$	T1 Type distributed generation
$DG-T2$	T2 Type distributed generation
$DG-T3$	T3 Type distributed generation
$DG-T4$	T4 Type distributed generation
γ	Loading parameter
f	Supply frequency (50 Hz)

allocation of marginal losses and the other on the allocation of total losses. [Pregelj et al. \(2004\)](#), investigated the effects of dispersed generation (DG) devices on electric power distribution systems. [Singh et al. \(2016b\)](#), performed sensitivity analysis to determine the appropriate size and operating point of DG for minimization of power losses in distribution systems. [Ajay-D-Vimal Raj et al. \(2008\)](#), proposed and discussed the primary factors that have leads to an increasing interest in DG. DG reduces line losses, increases system voltage profile and hence improves power quality. [Singh et al. \(2014\)](#) have been presented a comprehensive survey on application of various conventional, optimization and artificial intelligence based computational techniques for impact assessment of optimally placed and coordinated control of DGs and FACTS controllers in power systems. [Singh and Sharma \(2017\)](#) presented the impact assessment of optimally placed different types of DGs such as DG-1 (T1), DG-2 (T2), DG-3 (T3), and DG-4 (T4) with DMLs by using GA in distribution systems from minimum total mega volt ampere (MVA) intake viewpoint of main substation. [Payasi et al. \(2015\)](#), presented the multi-objective optimization for high penetration of different type of DGs considering voltage step constraint. In most of the studies in literature, the commonly used constraints are bus voltage limits and line power capacity limit.

1.2. Contribution of paper

The main objective of this research work is to find out optimal sizing & placement of DG for improvement of voltage of power system performances such as real and reactive power losses, voltage profile and cost with and without DG operating at 0.80, 0.81, 0.82, 0.83 and 0.84 power factors by using Newton-Raphson load flow solution in distribution network. The result is carried out on IEEE-14 Bus System.

1.3. Organization of paper

The organization of paper are as follows: Section 2 discusses the mathematical problem formulation. Section 3 discusses the simulation results and discussions. Section 4 introduces the conclusion and future scope of this paper.

2. Mathematical problem formulation

Power flow equality constraints, bus voltage or voltage drop limits and line or transformer overloading are the main common constraints in the optimal DG placement formulation. Here mathematical modeling of load is analyzed. The load models can classified in two types of load models such as static and dynamic load models. In this analysis only static load models are taken.

2.1. Different types of DGs

There are four different types of DGs (such as) are used in power sector. These are DG-T1, DG-T2, DG-T3 and DG-T4. DG-T1 gives only active power and operated at unity power factor load. DG-T2 gives active and reactive both and operated at 0.80 to 0.99 power factor leading. DG-T3 gives reactive Power only and operated at zero power factor loads. DG-T4 gives active power and consumes reactive power. It operates at 0.80 to 0.99 power factor lagging. This paper deals with DG-T2 type for of IEEE-14 bus test system.

presented a new methodology using a new population based meta-heuristic approach namely Artificial Bee Colony algorithm (ABC) for the placement of Distributed Generators (DG) in the radial distribution systems to reduce the real power losses and to improve the voltage profile. [López-Lezama et al. \(2011\)](#), proposed a bi-level programming approach to determine the optimal contract price of dispatchable distributed generation (DG) units in distribution systems. [Shayani and de Oliveira \(2011\)](#), presented and discussed studies proving that conductor capacity and voltage rises are limiting factors that manifest themselves under different conditions. [Keane and O’Malley \(2007\)](#), presented a methodology which maximizes the amount of energy that may be reaped from a given area, while taking account of the available energy resources, connection costs, losses, frequency of constraint breaches, and other technical constraints. [Singh et al. \(2007a\)](#), addressed a novel technique for placement of 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. [Coster et al. \(2011\)](#), addressed several possibilities to handle grid planning issues. Effects on voltage control, grid protection, and fault levels are investigated and described. [Qian et al. \(2011\)](#), proposed a methodology to study the effect of load models on the assessment of energy losses based on time series simulations to take into account both the variations of renewable generation and load demand. [Padhi and Nimje \(2012\)](#), presented the reason for the current interest in distributed generation and the challenges that are faced while increasing its share in the electricity generation mix. The paper also addresses DG impacts on short circuit levels and the islanding operation of DG. [Soroudi et al. \(2011\)](#), proposed a fuzzy evaluation tool for analyzing the effect of investment and operation of DG units on active losses and the ability of distribution network in load supply at presence of uncertainties. [Singh et al. \(0000\)](#), the main problem studied in the paper is to find the optimal types of DG and their corresponding sizes and locations in distribution feeders. The proposed methods try to solve the optimal DG placement from the viewpoint of the value-based planning method. [Mutale et al. \(2000\)](#), presented two new loss allocation schemes are proposed; one based on the

2.2. Mathematical modeling of DG

The total real power loss of system with n buses is calculated by the given formula.

$$P_L = \sum_{r=1}^n \sum_{s=1}^n [\delta_{rs} (PrPs + QrQs) + rs (QrPs - PrQs)] \quad (1)$$

The P_L is a function of all system bus voltage. This is termed as the exact loss formula.

Where

P_L = total real power loss

n = bus number

Pr, Ps = active power injections at bus r and s

Qr, Qs = reactive power injections at bus r and s .

$$\delta_{rs} = \frac{Rrs}{VrVs} \cos(\delta_r - \delta_s) \quad (2)$$

$$\Theta_{rs} = \frac{Rrs}{VrVs} \sin(\delta_r - \delta_s) \quad (3)$$

The active power injection of the bus r is given as:

$$P_r = P_{dgr} - P_{dr} \quad (4)$$

where, r = the bus where DG is installed

P_{dgr} = injection power

P_{dr} = load demand

Generations and loads values of base case are increased with the help of following relation.

$$P_d = P_{dr}^{or} + \gamma_r P_{dr}^{pf} \quad (5)$$

Where, γ = loading parameter

P_{dr}^{pf} = load power increment directions

P_{dr}^{or} = load active power at base case

From Eqs. (1), (4) and (5) the total active power loss equation with DG is as follows:

$$P_{dgr} = (P_{dr}^{or} + \gamma_r P_{dr}^{pf}) + \frac{1}{\delta_{rs}} [\Theta_{nr} Q_r - \sum_{s=1, s \neq r}^n rs (QrPs - PrQs)] \quad (6)$$

Thus Eq. (6) gives the optimal size of DG at bus r . The total power loss depends on the voltage profile of the system.

3. Simulation results and discussions

The simulation results and discussion are presented in the following sections.

3.1. General

The software is written in MATPOWER4.0b4 computing environment and applied on a 2.63 GHz Pentium IV personal computer with 3 GB RAM. The simulation results and discussions are carried out for IEEE 14-Bus test distribution system. The DG is connected at bus-7 where demand of load is maximum. The simulation results and discussions corresponding to DG operating at different power factors i.e. 0.8, 0.81, 0.82, 0.83, 0.84, and 0.85 respectively are presented as follows.

The IEEE-14 bus test system and its data are given in Fig. 3.1 and Table 3.1, respectively.

3.2. IEEE-14 bus test system operating at power factor 0.80 without and with DG

This shows the simulation results for IEEE-14 bus test system operating at power factor 0.80 without and with DG. The power system performance parameters such as *real and reactive power loss* are shown in Table 3.2 and Fig. 3.2.

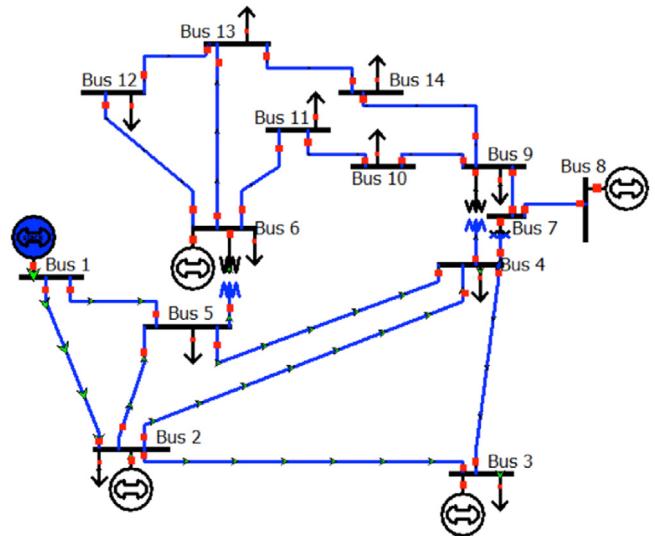


Fig. 3.1. Single line diagram of the IEEE 14-bus test system.

3.3. IEEE-14 bus test system operating at power factor 0.81 without and with DG

This shows the simulation results for IEEE-14 bus test system operating at power factor 0.81 without and with DG. The power system performance parameters such as *real and reactive power loss* are shown in Table 3.3 and Fig. 3.3.

From Fig. 3.3, it is clear that the real and reactive power loss decreases as the size of DG increases from 7.5 MVA to 137.5 MVA and increases from the size 147.5 MVA. Thus 137.5 MVA is the optimal size of DG operating at power factor 0.81.

3.4. IEEE-14 bus test system operating at power factor 0.82 without and with DG

This shows the simulation results for IEEE-14 bus test system operating at power factor 0.82 without and with DG. The power system performance parameters such as *real and reactive power loss* are shown in Table 3.4 and Fig. 3.4.

From Fig. 3.4, it is clear that the real and reactive power loss decreases as the size of DG increases from 7.5 MVA to 137.5 MVA and increases from the size 147.5 MVA. Thus 137.5 MVA is the optimal size of DG operating at power factor 0.82.

3.5. IEEE-14 bus test system operating at power factor 0.83 without and with DG

This shows the simulation results for IEEE-14 bus test system operating at power factor 0.83 without and with DG. The power system performance parameters such as *real and reactive power loss* are shown in Table 3.5 and Fig. 3.5. From Fig. 3.5, it is clear that the real and reactive power loss decreases as the size of DG increases from 7.5 MVA to 137.5 MVA and increases from the size 147.5 MVA. Thus 137.5 MVA is the optimal size of DG operating at power factor 0.83.

3.6. IEEE-14 bus test system operating at power factor 0.84 without and with DG

This shows the simulation results for IEEE-14 bus test system operating at power factor 0.84 without and with DG. The power system performance parameters such as *real and reactive power loss*

Table 3.1

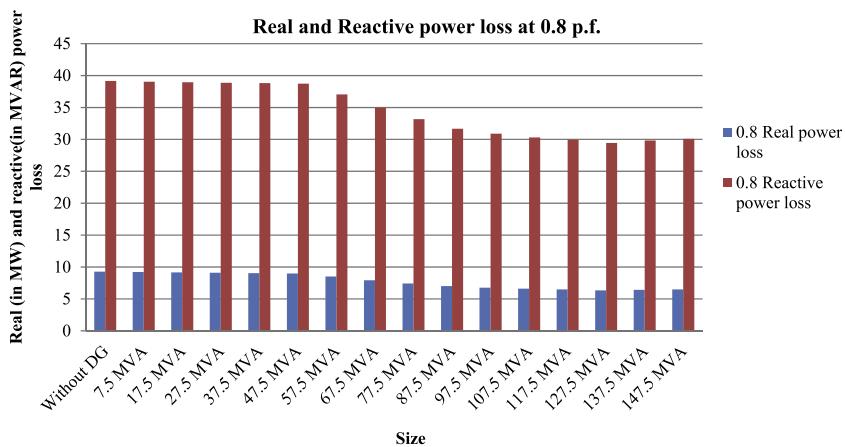
Line parameter and load data for IEEE-14 buses test system.

F_bus	T_bus	Line impedance (p.u.)		Line no.	S_L (p.u.)	Load on the bus (p.u.)	
		R_L	X_L			P_L	Q_L
1	2	0.01938	0.05917	1	2.8	0.11	0.062
1	5	0.05403	0.22304	2	2.5	0.091	0.043
2	3	0.04699	0.19797	3	2.1	0.125	0.078
2	4	0.05811	0.17632	5	0.84	0.061	0.034
4	5	0.05695	0.17388	6	1.5	0.059	0.019
6	4	0.06701	0.17103	11	1.3	0.23	0.10
7	5	0.01335	0.04211	7	1.04	0.20	0.133
8	7	0.02711	0.20912	12	0.48	0.06	0.027
8	9	0.08205	0.55618	13	1.5	0.06	0.02
10	4	0.22092	0.25202	14	0.18	0.047	0.035
3	12	0.09498	0.1989	9	0.64	0.06	0.034
12	13	0.12291	0.25581	4	0.55	0.062	0.035
13	14	0.06615	0.13027	8	0.45	0.131	0.081
10	11	0.03181	0.0845	14	0.12	0.058	0.017
12	13	0.12711	0.27038	10	0.15	0.06	0.021

F_{bus} = From bus, T_{bus} = To bus, P = Real power load, Q = Reactive power load and S_L = Line apparent power limit.**Table 3.2**

Real and Reactive power loss at 0.80 power factor.

P.F.	Power loss	Without DG	7.5 MVA	17.5 MVA	27.5 MVA	37.5 MVA	47.5 MVA	57.5 MVA	67.5 MVA
0.8	Real power loss	9.287	9.232	9.163	9.097	9.036	8.982	8.509	7.932
	Reactive power loss	39.16	39.05	38.94	38.86	38.81	38.73	37.05	34.98
0.8	Power loss	Without DG	77.5 MVA	87.5 MVA	97.5 MVA	107.5 MVA	117.5 MVA	127.5 MVA	137.5 MVA
	Real power loss	9.287	7.433	7.017	6.777	6.602	6.486	6.345	6.433
	Reactive power loss	39.16	33.18	31.66	30.89	30.31	29.94	29.45	29.83

**Fig. 3.2.** Real and Reactive power loss at 0.8 power factor.**Table 3.3**

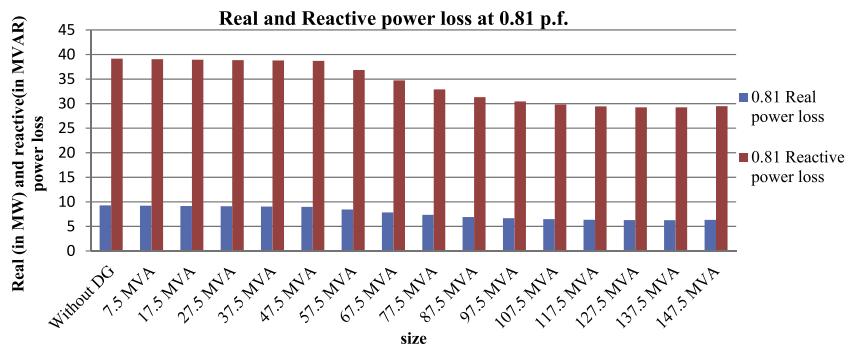
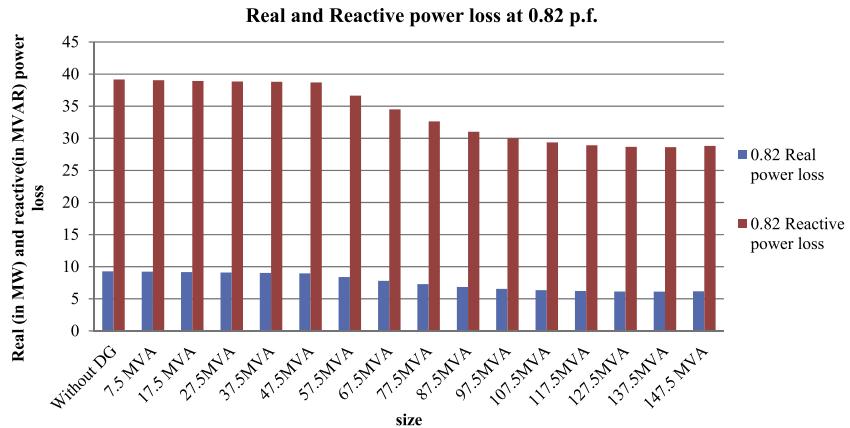
Real and Reactive power loss at 0.81 power factor.

P.F.	Power loss	Without DG	7.5 MVA	17.5 MVA	27.5 MVA	37.5 MVA	47.5 MVA	57.5 MVA	67.5 MVA
0.81	Real power loss	9.287	9.232	9.161	9.095	9.033	8.974	8.45	7.862
	Reactive power loss	39.16	39.05	38.94	38.86	38.8	38.71	36.84	34.73
0.81	Power loss	Without DG	77.5 MVA	87.5 MVA	97.5 MVA	107.5 MVA	117.5 MVA	127.5 MVA	137.5 MVA
	Real power loss	9.287	7.354	6.921	6.66	6.477	6.353	6.289	6.285
	Reactive power loss	39.16	32.9	31.32	30.45	29.84	29.43	29.24	29.25

Table 3.4

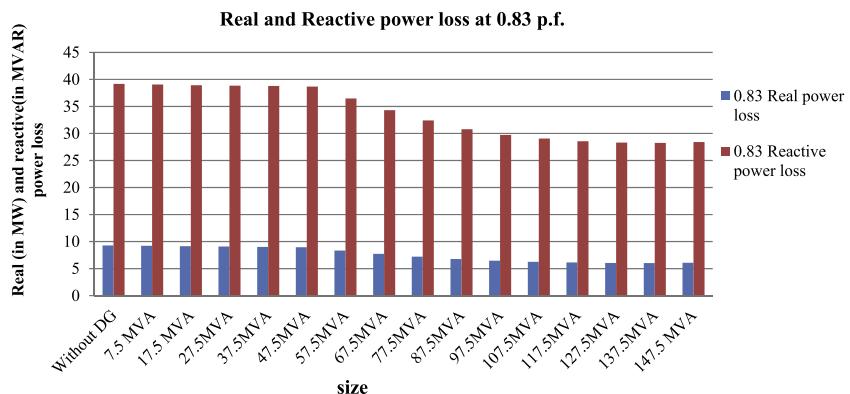
Real and Reactive power loss at 0.82 power factor.

P.F.	Power loss	Without DG	7.5 MVA	17.5 MVA	27.5 MVA	37.5 MVA	47.5 MVA	57.5 MVA	67.5 MVA
0.82	Real power loss	9.287	9.231	9.16	9.093	9.03	8.967	8.395	7.798
	Reactive power loss	39.16	39.05	38.94	38.85	38.8	38.7	36.65	34.51
0.82	Power loss	Without DG	77.5 MVA	87.5 MVA	97.5 MVA	107.5 MVA	117.5 MVA	127.5 MVA	137.5 MVA
	Real power loss	9.287	7.28	6.838	6.548	6.352	6.217	6.141	6.125
	Reactive power loss	39.16	32.64	31.03	30.02	29.36	28.91	28.67	28.63

**Fig. 3.3.** Real and Reactive power loss at 0.81 power factor.**Fig. 3.4.** Real and Reactive power loss at 0.82 power factor.**Table 3.5**

Real and Reactive power loss at 0.83 power factor.

P.F.	Power loss	Without DG	7.5 MVA	17.5 MVA	27.5 MVA	37.5 MVA	47.5 MVA	57.5 MVA	67.5 MVA
0.83	Real power loss	9.287	9.23	9.158	9.091	9.027	8.959	8.344	7.74
	Reactive power loss	39.16	39.05	38.93	38.85	38.8	38.67	36.47	34.3
P.F.	Power loss	Without DG	77.5 MVA	87.5 MVA	97.5 MVA	107.5 MVA	117.5 MVA	127.5 MVA	137.5 MVA
0.83	Real power loss	9.287	7.217	6.77	6.468	6.268	6.127	6.048	6.029
	Reactive power loss	39.16	32.41	30.79	29.73	29.05	28.57	28.31	28.26

**Fig. 3.5.** Real and Reactive power loss at 0.83 power factor.

are shown in [Table 3.6](#) and [Fig. 3.6](#). From [Fig. 3.6](#), it is clear that the real and reactive power loss decreases as the size of DG increases from 7.5 MVA to 137.5 MVA and increases from the size 147.5 MVA. Thus 135.5 MVA is the optimal size of DG operating at power factor 0.84.

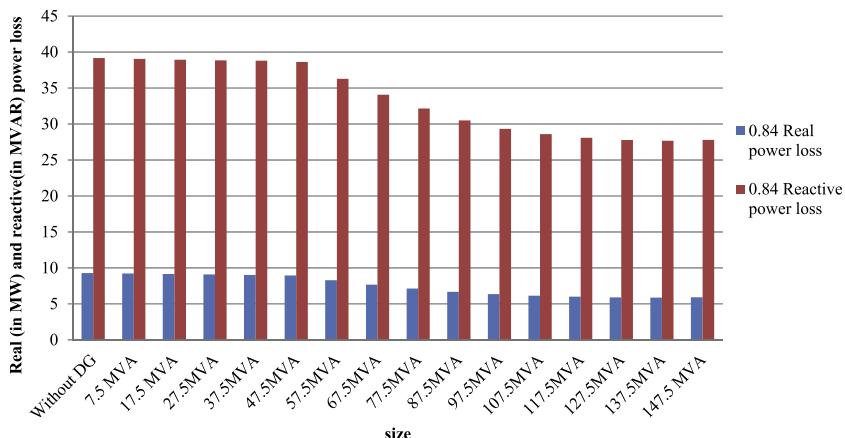
3.7. IEEE-14 bus test system operating at power factor 0.85 without and with DG

This shows the simulation results for IEEE-14 bus test system operating at power factor 0.85 without and with DG. The power

Table 3.6

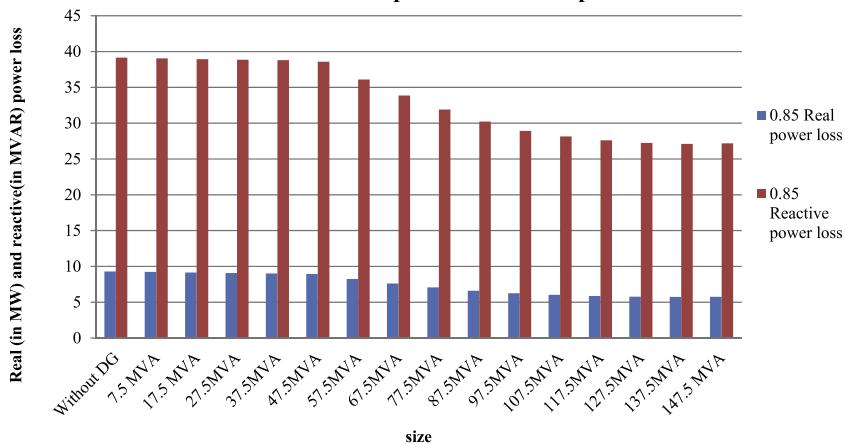
Real and Reactive power loss at 0.84 power factor.

P.F.	Power loss	Without DG	7.5 MVA	17.5 MVA	27.5 MVA	37.5 MVA	47.5 MVA	57.5 MVA	67.5 MVA
0.84	Real power loss	9.287	9.23	9.157	9.088	9.024	8.945	8.291	7.678
	Reactive power loss	39.16	39.05	38.93	38.85	38.8	38.62	36.28	34.08
0.84	Power loss	Without DG	77.5 MVA	87.5 MVA	97.5 MVA	107.5 MVA	117.5 MVA	127.5 MVA	137.5 MVA
	Real power loss	9.287	7.146	6.691	6.361	6.15	5.999	5.908	5.879
	Reactive power loss	39.16	32.16	30.5	29.32	28.6	28.08	27.77	27.67

Real and Reactive power loss at 0.84 p.f.**Fig. 3.6.** Real and Reactive power loss at 0.84 power factor.**Table 3.7**

Real and Reactive power loss at 0.85 power factor.

P.F.	Power loss	Without DG	7.5 MVA	17.5 MVA	27.5 MVA	37.5 MVA	47.5 MVA	57.5 MVA	67.5 MVA
0.85	Real power loss	9.287	9.229	9.155	9.086	9.022	8.935	8.238	7.617
	Reactive power loss	39.16	39.05	38.93	38.85	38.8	38.59	36.1	33.87
0.85	Power loss	Without DG	77.5 MVA	87.5 MVA	97.5 MVA	107.5 MVA	117.5 MVA	127.5 MVA	137.5 MVA
	Real power loss	9.287	7.076	6.613	6.256	6.035	5.874	5.774	5.735
	Reactive power loss	39.16	31.91	30.23	28.92	28.16	27.6	27.25	27.11

Real and Reactive power loss at 0.85 p.f.**Fig. 3.7.** Real and Reactive power loss at 0.85 power factor.

system performance parameters such as *real and reactive power loss* are shown in Table 3.7 and Fig. 3.7. From Fig. 3.7, it is clear that the real and reactive power loss decreases as the size of DG increases from 7.5 MVA to 137.5 MVA and increases from the size 147.5 MVA. Thus 135.5 MVA is the optimal size of DG operating at power factor 0.85.

3.8. IEEE-14 bus test system operating at power factor 0.8, 0.82, 0.83, 0.84 and 0.85 without and with DG

This shows the simulation results for IEEE-14 bus test system operating at power factor 0.80, 0.81, 0.82, 0.83, 0.84, 0.85 without and with DG. The power system performance parameters such as *real loss* are shown in Table 3.8 and Fig. 3.8. From Fig. 3.8, it is clear

Table 3.8

Real power loss at 0.8, 0.82, 0.83, 0.84 and 0.85 power factor with and without DG.

P.F.	Power loss	Without DG	7.5 MVA	17.5 MVA	27.5 MVA	37.5 MVA	47.5 MVA	57.5 MVA	67.5 MVA	
0.8	Real power loss	9.287	9.232	9.163	9.097	9.036	8.982	8.509	7.932	
0.81	Real power loss	9.287	9.232	9.161	9.095	9.033	8.974	8.45	7.862	
0.82	Real power loss	9.287	9.231	9.16	9.093	9.03	8.967	8.395	7.798	
0.83	Real power loss	9.287	9.23	9.158	9.091	9.027	8.959	8.344	7.74	
0.84	Real power loss	9.287	9.23	9.157	9.088	9.024	8.945	8.291	7.678	
0.85	Real power loss	9.287	9.229	9.155	9.086	9.022	8.935	8.238	7.617	
P.F.	Power loss	Without DG	77.5 MVA	87.5 MVA	97.5 MVA	107.5 MVA	117.5 MVA	127.5 MVA	137.5 MVA	147.5 MVA
0.8	Real power loss	9.287	7.433	7.017	6.777	6.602	6.486	6.345	6.433	6.496
0.81	Real power loss	9.287	7.354	6.921	6.66	6.477	6.353	6.289	6.285	6.341
0.82	Real power loss	9.287	7.28	6.838	6.548	6.352	6.217	6.141	6.125	6.17
0.83	Real power loss	9.287	7.217	6.77	6.468	6.268	6.127	6.048	6.029	6.071
0.84	Real power loss	9.287	7.146	6.691	6.361	6.15	5.999	5.908	5.879	5.911
0.85	Real power loss	9.287	7.076	6.613	6.256	6.035	5.874	5.774	5.735	5.758

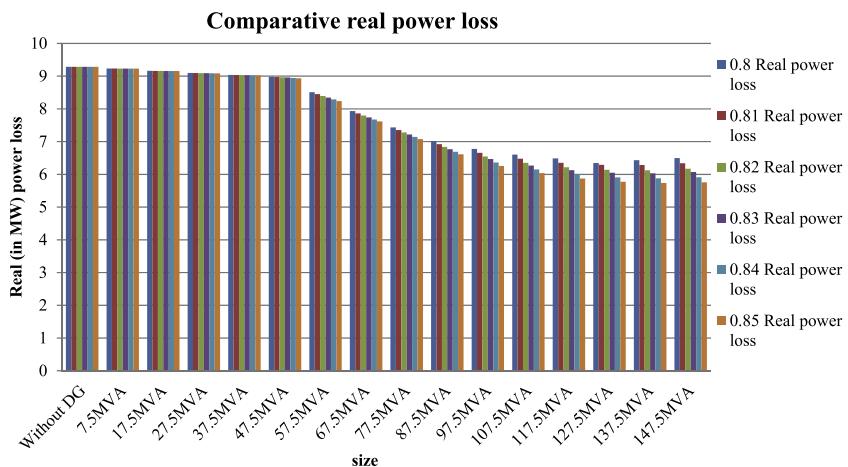


Fig. 3.8. Real power loss at 0.8, 0.82, 0.83, 0.84 and 0.85 power factor with and without DG.

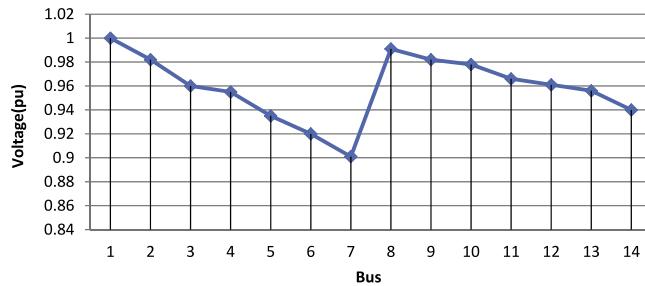


Fig. 3.9. Voltage profile of IEEE-14 bus test system.

that the real loss decreases as the size of DG increases from 7.5 MVA to 137.5 MVA and increases from the size 147.5 MVA. Thus 135.5 MVA is the optimal size of DG operating at power factor 0.80, 0.81, 0.82, 0.83, 0.84, 0.85.

3.9. Voltage profile of IEEE-14 bus test system operating at power factor 0.8 without and with DG

The voltage profile of IEEE-14 bus ill system is given in the Fig. 3.9. Bus number 7 is most sensitive to voltage collapse. The voltage at bus 7 is 0.901 pu. The voltage limit of a healthy system is 0.95 pu to 1.05 pu. When optimal size of DG is placed at bus 7, its voltage increases 13.7% absolute and 15.2% to its base case.

This shows the simulation results for IEEE-14 bus test system operating at power factor 0.8 without and with DG. The power

system performance parameters such as *Voltage profile* are shown in Table 3.9.

From Fig. 3.10, it is clear that voltage profile improves at all buses when injecting a DG of size 127.5 MVA to an IEEE-14 bus system. Improvement in the voltage of bus 7 is highest. From Fig. 3.11, it is shown that voltage at buses 2, 6, 7, 8, 12 and 14 increases beyond its upper voltage limit which is 1.05 V when injecting a DG of size 137.5 MVA to an IEEE-14 bus system. (See Table 3.10.)

3.10. Voltage profile of IEEE-14 bus test system operating at power factor 0.84 without and with DG

This shows the simulation results for IEEE-14 bus test system operating at power factor 0.84 without and with DG (137.5 MVA). The power system performance parameters such as *Voltage profile* are shown in Table 3.11 and Fig. 3.12.

From Fig. 3.13, it is clear that voltage profile improves at all buses when injecting a DG of size 137.5 MVA to an IEEE-14 bus system. Improvement in the voltage of bus 7 is highest.

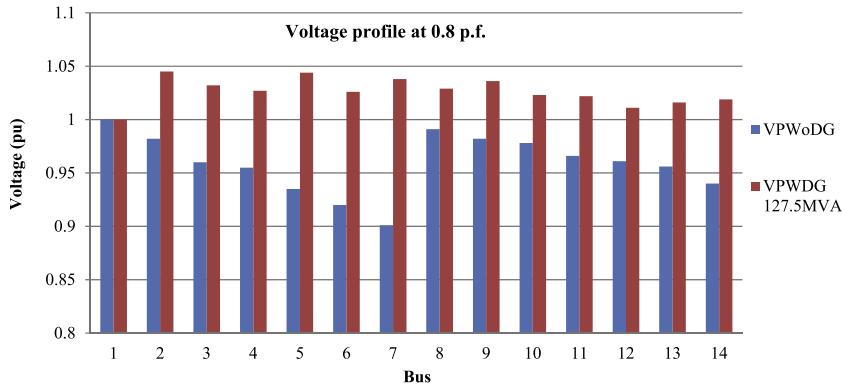
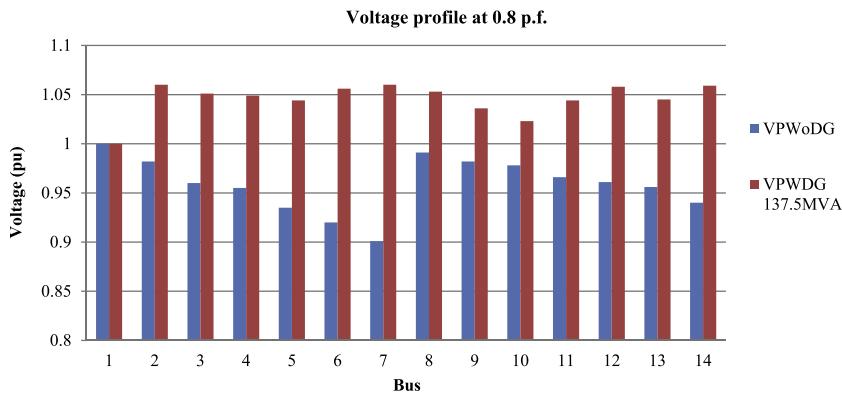
From Fig. 3.13, it is clear that voltage increases beyond its upper limit when injecting a DG of size 137.5 MVA to an IEEE-14 bus system. Thus from the above discussion of results obtained from IEEE-14 bus system, it is clear that voltage profile improves when size of DG increases up to 127.5 MVA and 137.5 MVA and deformation takes place after 137.5 MVA with 0.8 p.f. and 147.5 MVA with 0.84 p.f respectively. According to the voltage profile enhancement 127.5 MVA and 137.5 MVA is the optimal size of DG at power factor 0.8 and 0.84, respectively.

Table 3.9

Voltage profile at power factor 0.8 without and with DG.

Bus No	VP WoDG	VPWDG 7.5 MVA	VPWDG 17.5 MVA	VPWDG 27.5 MVA	VPWDG 37.5 MVA	VPWDG 47.5 MVA	VPWDG 57.5 MVA	VPWDG 67.5 MVA
1	1	1	1	1	1	1	1	1
2	0.982	0.982	0.982	0.982	0.982	0.984	0.987	0.987
3	0.96	0.96	0.96	0.96	0.961	0.966	0.969	0.969
4	0.955	0.955	0.955	0.955	0.955	0.955	0.965	0.965
5	0.935	0.935	0.935	0.935	0.936	0.936	0.956	0.956
6	0.92	0.92	0.92	0.921	0.921	0.925	0.945	0.949
7	0.901	0.901	0.91	0.912	0.912	0.922	0.942	0.947
8	0.991	0.991	0.991	0.991	0.991	0.991	0.995	0.995
9	0.982	0.982	0.982	0.982	0.982	0.982	0.987	0.987
10	0.978	0.978	0.978	0.978	0.978	0.978	0.979	0.979
11	0.966	0.966	0.966	0.966	0.966	0.966	0.968	0.968
12	0.961	0.961	0.961	0.961	0.961	0.961	0.967	0.967
13	0.956	0.956	0.957	0.957	0.967	0.967	0.967	0.969
14	0.94	0.94	0.95	0.95	0.951	0.951	0.951	0.951

Bus No	VP WoDG	VPWDG 77.5 MVA	VPWDG 87.5 MVA	VPWDG 97.5 MVA	VPWDG 107.5 MVA	VPWDG 117.5 MVA	VPWDG 127.5 MVA	VPWDG 137.5 MVA
1	1	1	1	1	1	1	1	1
2	0.982	0.987	0.991	0.992	0.993	1.002	1.045	1.06
3	0.96	0.969	0.988	0.989	0.99	1	1.032	1.051
4	0.955	0.965	0.972	0.975	0.975	0.999	1.027	1.049
5	0.935	0.957	0.967	0.968	0.968	0.989	1.044	1.044
6	0.92	0.95	0.963	0.968	0.975	1.003	1.026	1.056
7	0.901	0.957	0.963	0.97	0.98	1.009	1.038	1.06
8	0.991	0.996	0.997	0.998	0.998	1	1.029	1.053
9	0.982	0.987	0.988	0.988	0.988	0.999	1.036	1.036
10	0.978	0.98	0.985	0.989	0.989	1.001	1.023	1.023
11	0.966	0.968	0.969	0.979	0.979	0.997	1.022	1.044
12	0.961	0.967	0.977	0.978	0.979	0.989	1.011	1.058
13	0.956	0.969	0.97	0.976	0.978	0.978	1.016	1.045
14	0.94	0.958	0.958	0.965	0.975	0.983	1.019	1.059

**Fig. 3.10.** Voltage profile at 0.8 p.f. and 127.5 MVA.**Fig. 3.11.** Voltage profile at 0.8 p.f. and 137.5 MVA.

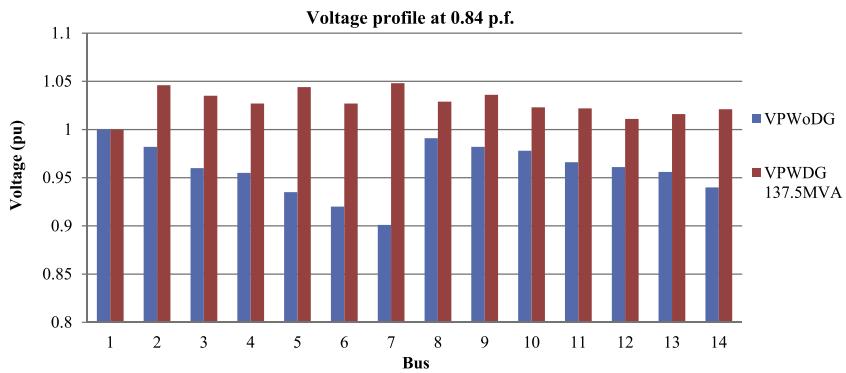


Fig. 3.12. Voltage profile at 0.84 p.f. and 137.5 MVA.

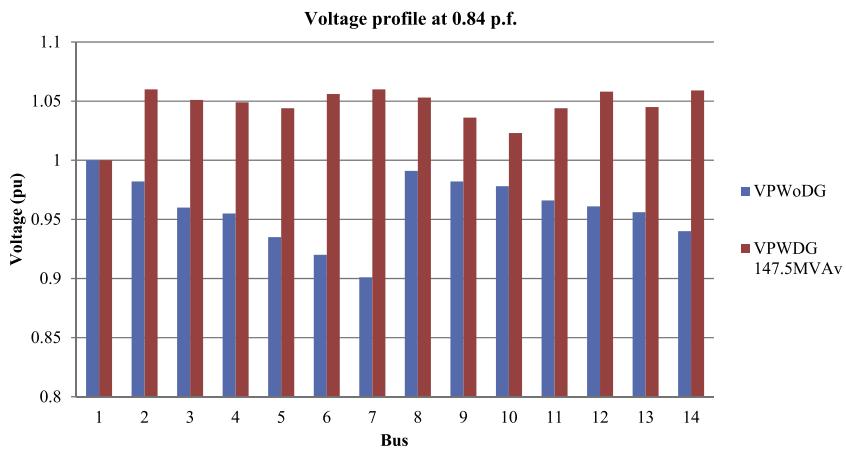


Fig. 3.13. Voltage profile at 0.84 p.f. and 147.5 MVA.

Table 3.10

Voltage profile at 0.8 p.f. and 127.5 MVA.

Bus No	Voltage profile without DG	Voltage profile without 127.5 MVA DG
1	1	1
2	0.982	1.045
3	0.96	1.032
4	0.955	1.027
5	0.935	1.044
6	0.92	1.026
7	0.901	1.038
8	0.991	1.029
9	0.982	1.036
10	0.978	1.023
11	0.966	1.022
12	0.961	1.011
13	0.956	1.016
14	0.94	1.019

Table 3.11

Voltage profile at 0.84 p.f. and 137.5 MVA.

Bus No	Voltage profile without DG	Voltage profile with 137.5 MVA DG
1	1	1
2	0.982	1.046
3	0.96	1.035
4	0.955	1.027
5	0.935	1.044
6	0.92	1.027
7	0.901	1.048
8	0.991	1.029
9	0.982	1.036
10	0.978	1.023
11	0.966	1.022
12	0.961	1.011
13	0.956	1.016
14	0.94	1.021

3.11. Cost of IEEE-14 bus test system operating at power factor 0.8 without and with DG

This shows the simulation results for IEEE-14 bus test system operating at power factor 0.8 without and with DG for different size of DG. The cost for real power and reactive power decreases with increase in size of DG.

The power system performance parameters such as Cost are shown in Table 3.12. It is clear that the cost of real and reactive power loss decreases with increase in size of DG. This will improve economical efficiency and environmental impact. DG units can be placed at optimal locations where they provide the best reduction in feeder losses.

4. Conclusions

The main objective of this paper is to analyze the impact that different configurations and penetration levels of DG may have on the real power loss and reactive power loss, voltage profile and cost of distribution systems. The analytical method of optimal power flow is analyzed on the basis of exact loss formula. The proposed technique is tested on a typical IEEE-14 Bus distribution test system and results are improved in a very significant manner.

The following conclusions made from this research work:

Table 3.12

Cost of Real and Reactive power.

pf	(λ)WoDG		(λ)WDG 7.5MVA		(λ)WDG 17.5MVA		
0.8	P 558.395	Q 2.223	P 557.847	Q 2.232	P 557.143	Q 2.229	
(λ)WDG 27.5MVA			(λ)WDG 37.5MVA			(λ)WDG 47.5MVA	
P 556.438	Q 2.236		P 555.73	Q 2.027	P 554.825	Q 2.027	
(λ)WDG 57.5MVA			(λ)WDG 67.5MVA			(λ)WDG 77.5MVA	
P 546.631	Q 1.709		P 535.784	Q 1.699	P 525.102	Q 1.175	
(λ)WDG 87.5MVA			(λ)WDG 97.5MVA			(λ)WDG 107.5MVA	
P 514.063	Q 0.564		P 503.99	Q 0.239	P 493.89	Q 0.191	
(λ)WDG 117.5MVA		(λ)WDG 127.5MVA		(λ)WDG 137.5MVA		(λ)WDG 147.5MVA	
P 482.99	Q 0.182	P 473.891	Q 0.171	P 475.466	Q 0.162	P 466.373	Q −0.151

- The real power loss and reactive power loss decrease with increase of size of DG and after a certain size the losses increase.
- The real power loss and reactive power loss also decrease with increase of power factor from 0.80 to 0.99.
- The optimal size of DG for IEEE-14 bus system is 137.5 MVA.
- Improvement of VP obtained on connecting DG operating at different power factors i.e. 0.80 and 0.99 in IEEE-14 bus distribution system.
- The cost for real power and reactive power decreases with increase in size of DG.
- The system has control capability for real and reactive power flow.
- Power system performance (such as losses, voltage profile and cost) improves when we add the DGs in bus-7 as we can see in above discussion.
- More extensive data collection would provide the ability to refine and expand the usefulness of this study.

The following future scopes of research work are as follows:

- Practical systems are implemented.
- Hybrid techniques are used for better results.
- Different other load models are used for validity of proposed method.

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