Planning of different types of distributed generation with seasonal mixed load models

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Abstract

   The comparison of different types of distributed generation (DG) may help for appropriate selection of type of DG for distributed generation planning (DGP) in distribution system for various load scenario. The load on each bus of distribution system may be, in practice, the composition of industrial, residential, and commercial types of load which may also vary with seasonal day, and night. Therefore, in this paper the seasonal mixed load models at each bus are assumed and study is carried out with bus voltage and line power capacity limits for different types of DG using incremental power flow and exhaustive search method as deterministic approach. This analysis shows that mixed load model, types of DG, and power factor of DG have significant impact on size and location of DG.

Keywords: Distributed generation, distribution system, distributed generation planning.

1. Introduction

   Distributed generation (DG), unlike traditional generation, aims to generate part of required electrical energy on small scale closer to the   places   of   consumption   and interchanges the electrical power with the network. It represents a change in the paradigm of electrical energy generation. Distributed generation, also termed as embedded generation or dispersed generation or decentralized generation, is defined as small electric power source that can be connected to a distribution network by a distribution company (DISCO) at any node or by customer at the customer side of the meter (Ackermann *et al*, 2001). The emergence of new technological alternatives allows the DG technologies in distribution network to achieve immense technical, economical and environmental benefits (Chiradejaand *et al*, 2004; El-Khattam and Salama, 2004; Pepermans *et al*, 2005). These benefits could be maximized by proper planning i.e. placement of DGs at optimum locations with optimum size and suitable type under certain constraints for benefits.

   The most important factors associated with practical situations are discussed as follows. The load throughout the year is not constant instead it varies with seasonal day and night. The load models to be adopted to represent such kind of loads are described in (IEEE Task Force, 1993; Qian *et al*, 2011). In practice, the load at every bus may be the mix kind of load i.e. composition of industrial, residential, and commercial loads. To represent such kind of load, mix load model may be adopted for proper distributed generation planning (DGP) (Qian *et al*, 2011). The different types of DG have been considered with analytical expression to determine optimal power factor for minimum loss, but without considering load models, in (Hung *et al*, 2010). In (Dent *et al*, 2010) the network capacity analysis has been performed using optimal power flow with voltage step constraints for three power factors of DG (0.95 lagging, unity, and 0.95 leading) but without considering the load models, and different types of DG.   Thus seasonal load models, mixed seasonal load models, types of DG, and power factor of DG are the influencing factors which must be considered to ensure proper DGP.

   In (Qian *et al*, 2011;Gozel *et al*,2005; Singh *et al*, 2007;Singh *et al*, 2009), different kinds of load models have been considered but the mixed load model at every bus has not been considered except in (Qian *et al*). The variable loads, but without load model, has been considered in (Zhu *et al*, 2006; Ochoa *et al*, 2008; Atwa *et al*, 2010).The DGP problem was solved by adopting the type of DG which can supply both active and reactive power, but without load models in (El-Khattam *et al*,2005;

Vovos *et al*, 2005; Vovos *et al*, 2005; Harrison *et al*, 2008; Algarni *et al*, 2009; Kumar *et al*, 2010; Kumar *et al*, 2010) . The literature review (payasi *et al*, 2011) manifest that comparative study of different types of DGs with seasonal mixed load models is required to be performed for better DG planning.

In this paper, 38 bus test system and data from (Singh *et al*, 2007) is adopted and DGP is performed using incremental power flow and exhaustive search method with summer day, summer night, winter day, and winter night load models which include industrial, residential, and commercial load models at every bus in certain proportion. Different types of DG with bus voltage limits and line power capacity limit, and seasonal mixed load models are considered for investigation. The results are tabulated and analyzed for: 1) minimum power intake; and 2) minimum real power loss with different types of DG and seasonal mixed load models.

This paper is structured as follows: Section 2 describes the types of DG. Section 3 describes the load models and test cases considered for study. Section 4 describes the methodology adopted. Section 5 presents the simulation result. The last section 6 presents the conclusion of the study.

2. Types of Distributed Generation

The different types of traditional and nontraditional DGs are classified and described in (El-Khattam and Salama, 2004) from the constructional, technological, size, and power time duration pint of view. The DGs may also be grouped into four major types based on terminal characteristics in terms of real and reactive power delivering capability as described in (Hung *et al*, 2010). In this paper, the four major types are considered for comparative studies which are described as follows:

Type1: This type DG is capable of delivering only active power such as photovoltaic, micro turbines, fuel cells, which are integrated to the main grid with the help of converters/inverters. However, according to current situation and grid codes the photovoltaic can and in sometimes are required to provide reactive power as well.

Type2: DG capable of delivering both active and reactive power. DG units based on synchronous machines (cogeneration, gas turbine, etc.) come under this type

Type3: DG capable of delivering only reactive power. Synchronous compensators such as gas turbines are the example of this type and operate at zero power factors.

Type4: DG capable of delivering active power but consuming reactive power. Mainly induction generators, which are used in wind farms, come under this category. However, doubly fed induction generator (DFIG) systems may consume or produce reactive power i.e. operates similar to synchronous generator.

In this paper, the analysis of T1, T2, T3, and T4 for optimal size and location is done on the basis of terminal characteristic of basic DGs in terms of their power delivering capability.

3. Load models and Test Cases

To quantify the effect of different types of DG, on DGP, for different load scenario i.e. summer day, summer night, winter day, and winter night loads, a 38 bus distribution system is adopted (Singh *et al*, 2007). In this paper, the line impedances, load data and the line power limits are expressed in p.u. at the base voltage of 12.66 kV and base MVA of 10 MVA (Singh *et al*, 2007) as depicted in Table 5 (Appendix A). The network is also shown in Figure 9 (Appendix A). In conventional load flow analysis, the active and reactive power loads are assumed as constant power load whereas, in practice, the loads may be voltage dependent i.e. industrial, residential, and commercial loads which may be represented by models as described in (IEEE Task Force, 1993). The voltage dependent load model is a static load model that represents the power relationship to voltage as an exponential equation, and represented in following form.

$$P_i = P_{0i}\left(\frac{|V_i|}{|V_{0i}|}\right)^{\alpha} \tag{1}$$

$$Q_i = Q_{0i}\left(\frac{|V_i|}{|V_{0i}|}\right)^{\beta} \tag{2}$$

where, P_i, Q_i, P_{0i}, Q_{0i}, V_i, and V_{0i} are in per unit. Above equations (1) and (2) neglect the frequency dependence of distribution system load, due to the fact that it is pan-system phenomenon which can't be controlled locally and remain same for whole of the system. In practice, the load on each bus may be the composition of industrial, residential, and commercial which may vary with seasonal day and night. Therefore, in this paper the seasonal mixed load model at each bus is considered as described in (Qian *et al*, 2011) and represented in following form.

$$P_i = w_{ipi} \cdot P_{0i} \left(\frac{|V_i|}{|V_{0i}|} \right)^{\alpha_i} + w_{rpi} \cdot P_{0i} \left(\frac{|V_i|}{|V_{0i}|} \right)^{\alpha_r} + w_{cpi} \cdot P_{0i} \left(\frac{|V_i|}{|V_{0i}|} \right)^{\alpha_c} \tag{3}$$

$$Q_i = w_{iqi} \cdot Q_{0i} \left(\frac{|V_i|}{|V_{0i}|} \right)^{\beta_i} + w_{rqi} \cdot Q_{0i} \left(\frac{|V_i|}{|V_{0i}|} \right)^{\beta_r} + w_{cqi} \cdot Q_{0i} \left(\frac{|V_i|}{|V_{0i}|} \right)^{\beta_c} \tag{4}$$

where, α_i and β_i are active and reactive exponents for industrial load model
α_r and β_r are active and reactive exponents for residential load model
α_c and β_c are active and reactive exponents for commercial load model
w_{ipi}, w_{rpi}, and w_{cpi} are the relevant factors for active industrial, residential, and commercial Load models at bus i.
w_{iqi}, w_{rqi}, and w_{cqi} are the relevant factors for reactive industrial, residential, and commercial Load models at bus i.
The following condition must be satisfied for all buses except *buses without load* (BWL) (Bus 1 is slack bus and buses 34 to 38 are not having load).

$$w_{ipi} + w_{rpi} + w_{spi} = 1, \ for \ i = 1 \ to \ N_B, but \ i \neq BWL \tag{5}$$

$$w_{iqi} + w_{rqi} + w_{cqi} = 1, \ for \ i = 1 \ to \ N_B, but \ i \neq BWL \tag{6}$$

The values for exponents of voltage for active and reactive component of summer day, summer night, winter day, and winter night load models are given in Table 1 (Qian *et al*, 2011). The relevant factor of each load model at each bus is (hypothetically generated) given in Table 2. In this study it is assumed that $w_{ip} = w_{iq}$, $w_{rp} = w_{rq}$, and $w_{cp} = w_{cq}$.
The study is performed considering the situations of load, may be, in practice as follows: 1) each bus having mix of industrial, residential, and commercial load in certain proportion; 2) Loads vary   with seasonal day and night. Apart from these situations, T1, T2, T3 and T4 are considered for comparative study. A 38 bus system is assumed to be supplying power to mix of industrial, residential, and commercial load without violating bus voltage and line capacity limits. The following test cases are developed for optimal size and location of DG for constant and seasonal mixed load models for two objectives: 1) Real power loss (P_L) minimization; and 2) Apparent power intake (S_{int}) minimization.

- Type 1 DG
- Type 2 DG
- Type 3 DG
- Type 4 DG

The parameters considered for study are as follows:
a) Number of voltage limit violations (NVLV)
b) Number of line limit violations(NLCLV)
c) Apparent power intake *(S_{int}),* real power intake *(P_{int}),* and reactive power intake *(Q_{int})* at bus 1
d) Real and reactive power loss (P_L and Q_L)
e) Apparent system power requirement (S_{sys})
f) Indices (PLI, QLI ,VPI, and LCI)

Table 1. Exponent values for load models

Load duration		Load models					
		Industrial		Residential		Commercial	
		α_i	β_i	α_r	β_r	α_c	β_c
Summer	Day	0.18	6.00	0.72	2.96	1.25	3.50
	Night	0.18	6.00	0.92	4.04	0.99	3.95
Winter	Day	0.18	6.00	1.04	4.19	1.50	3.15
	Night	0.18	6.00	1.30	4.38	1.51	3.40

Table 2. Values of relevant factors of load models for buses with load.

Bus no.	$w_{ip}(=w_{iq})$	$w_{rp}(=w_{rq})$	$w_{cp}(=w_{cq})$
1(GSP)	0.0	0.0	0.0
2	0.2000	0.6000	0.2000
3	0.1500	0.6500	0.2000
4	0.2000	0.5000	0.3000
5	0.1100	0.3400	0.5500
6	0.1000	0.3500	0.5500
7	0.3000	0.5000	0.2000
8	0.3000	0.5000	0.2000
9	0.0800	0.2000	0.7200
10	0.0800	0.2000	0.7200
11	0.1200	0.2000	0.6800
12	0.2500	0.3000	0.4500
13	0.2500	0.3500	0.4000
14	0.2000	0.3000	0.5000
15	0.0500	0.3000	0.6500
16	0.0800	0.2000	0.7200
17	0.0800	0.2000	0.7200
18	0.3000	0.4000	0.3000
19	0.3000	0.4000	0.3000
20	0.3000	0.4000	0.3000
21	0.3000	0.4000	0.3000
22	0.3000	0.4000	0.3000
23	0.3500	0.4500	0.2000
24	0.2000	0.6500	0.1500
25	0.2000	0.6500	0.1500
26	0.1000	0.2500	0.6500
27	0.1000	0.2500	0.6500
28	0.1000	0.3000	0.6000
29	0.2500	0.3500	0.4000
30	0.5000	0.3000	0.2000
31	0.2500	0.3500	0.4000
32	0.3000	0.5000	0.2000
33	0.2500	0.3000	0.4500
34	0.0000	0.0000	0.0000
35	0.0000	0.0000	0.0000
36	0.0000	0.0000	0.0000
37	0.0000	0.0000	0.0000
38	0.0000	0.0000	0.0000

4. Proposed Methodology

4.1 Problem Formulation

The formulation of DGP problem is proposed on the basis of two objective functions 1) real power loss ; 2) Apparent power intake

Minimization of real power loss: The objective function is total real power loss (P_L) in the system. The P_L in the system is represented by

$$P_L = \sum_{i,j \in N_L} \frac{P_{ij}^2 + Q_{ij}^2}{|V_i|^2} r_{ij} \tag{7}$$

The P_L is function of all system bus voltage (V_i), line resistances ($r_{i,j}$), α, and β. The total losses mainly depend on voltage profile.
Minimization of total power intake at substation: The objective function is apparent power intake (S_{int}) at main substation. The P_{int} is the sum of P_D and P_L, and represented by

$$P_{\text{int}} = P_1(V, P_0, Q_0, \alpha, \beta) = P_D + P_L = \sum_{i=1}^{N_B} P_{0i} (|V_i|/|V_{0i}|)^\alpha + P_L \tag{8}$$

Similarly, the Q_{int} is the sum of Q_D and Q_L, and represented by

$$Q_{\text{int}} = Q_1(V, P_0, Q_0, \alpha, \beta) = Q_D + Q_L = \sum_{i=1}^{N_B} Q_{0i} (|V_i|/|V_{0i}|)^\beta + Q_L \tag{9}$$

Apparent power intake at main substation is expressed as

$$S_{int} = [(P_{int})^2 + (Q_{int})^2]^{1/2} \tag{10}$$

And Apparent power requirement for distribution system is expressed as:

$$S_{sys} = [(P_{int} + P_{DG})^2 + (Q_{int} + Q_{DG})^2]^{1/2} \tag{11}$$

where, based on terminal characteristic

$Q_{DG} = 0.0$ for Type 1 DG
$P_{DG} = 0.0$ for Type 3 DG
$Q_{DG} = -$ ve for Type 4 DG

It is observed that for a distribution system

$$\sum_{i=1}^{N_B} P_{0i}(|V_i|/|V_{0i}|)^\alpha \gg P_L \qquad and \tag{12}$$

$$\sum_{i=1}^{N_B} Q_{0i}(|V_i|/|V_{0i}|)^\beta \gg Q_L \tag{13}$$

Thus the P_{int} and Q_{int} in (8) and (9) respectively are largely decided by the load exponents, α, and β, not by P_L and Q_L.

The above objectives are subject to the following set of power flows, voltage limits, line power capacity limit, and DG size limit.

$$P_i = \sum_{j=1}^{N_B} |V_i||V_j|[G_{ij}\cos(\delta_i - \delta_j) + B_{ij}\sin(\delta_i - \delta_j)], \; for \; i = 1 to \, N_B \tag{14}$$

$$Q_i = \sum_{j=1}^{N_B} |V_i||V_j|[G_{ij}\sin(\delta_i - \delta_j) - B_{ij}\cos(\delta_i - \delta_j)], \; for \; i = 1 to \, N_B \tag{15}$$

$$P_{i,j} = |V_i|^2 G_{ij} - |V_i||V_j|[G_{ij}\cos\theta_{ij} - B_{ij}\sin\theta_{ij}], \, for \; i \, j \in N_L \tag{16}$$

$$Q_{i,j} = -|V_i|^2 B_{ij} - |V_i||V_j|[G_{ij}\sin\theta_{ij} + B_{ij}\cos\theta_{ij}], \, for \; i \, j \in N_L \tag{17}$$

$$V_{min} \le |V_i| \le V_{max}, \quad for \; i = 1 to \, N_B \tag{18}$$

$$S_{i,j} \le CS_{i,j}^{max}, \quad for \; i \, j \in N_L \tag{19}$$

$$P_{DG} \le P_{int} \tag{20}$$

In this paper voltage limits and line power capacity limit are as follows:

$V_{min} = 0.95$ p.u.

$V_{max} = 1.03$ p.u.

$CS_{i,j}^{max}$, for $i, j \in N_L$; Power capacity limits are in Table 5(Appendix A)

4.2 Indices to quantify the benefits of DG

The indices to quantify the benefits of DG are defined as follows (Singh *et al*, 2007).
Real Power Loss Index (PLI): The real power loss index is defined as :

$$PLI = \frac{P_{LWDG}}{P_{LWODG}} \times 100 \tag{21}$$

The lower values of this index indicate better benefits in terms of real power loss reduction accrued due to DG location and size.
Reactive Power Loss Index (QLI): The reactive power loss index is defined as:

$$QLI = \frac{Q_{LWDG}}{Q_{LWODG}} \times 100 \tag{22}$$

The lower values of this index indicate better benefits in terms of reactive power loss reduction accrued due to DG location and size.

Voltage Profile Index (VPI): It is related to the maximum voltage drop between each node and root node. The lower values of this index indicate better performance of network. The *VPI* can be defined as:

$$VPI = \max\left(\frac{|V_1| - |V_i|}{|V_1|}\right) \times 100, \quad for \; i = 2 \; to \; N_B \tag{23}$$

Line Capacity Index (LCI): The power flows may diminish in some sections of the network and released more capacity with the power supplied near to the load. This index provides important information about the level of power flows/currents through the network regarding maximum capacity of distribution lines. Lower values of this index indicate more capacity available. This is defined as:

$$LCI = \max\left(\frac{|S_{i,j}|}{|CS_{i,j}|}\right) \times 100, \; for \; i, j = 1 \; to \; N_L \tag{24}$$

4.3   Computational Procedure

In this paper, T1, T2, T3, and T4 are considered for comparative analysis with two objectives: 1) P_L minimization; and 2) S_{int} minimization. The data base, using incremental power flow method, for the 38-bus distribution system (Singh *et al*, 2007) is obtained for the cases: i) without DG; and ii) with DG for various types of DG and load models. Then using exhaustive search method (given in Appendix B), DG size and location along with values of other relevant quantities are determined for both objectives. The size of DGs are considered in practical range decided as equal to or less than power intake at main substation (bus 1) as power is not intended to flow to grid.   The step size of power of DG is taken as 0.005 p.u. and the step size of power factor is taken as 0.01. The range of power factor is taken between 0.99 to 0.8 leading for T2 and 0.99 to 0.8 lagging for T4. The quantities evaluated with incremental values of DG at each node are P_L, Q_L, S_{int}, P_{int}, Q_{int}, S_{sys}, NVLV, NLCLV, PLI, QLI, VPI, LCI, V_i, and S_{ij}. The steps of the algorithm, for making the data base, are as follows:

Step 1 : Read of load data, line data, number of buses, DG power increment ($\Delta|S_{DG}|$), α and β for all load models,
            voltage limits, and DG power factor decrement (ΔPF_{DG}) for typ2 and type 4 DG.
Step 2 : Select one of the load models (mixed and constant power load models) by selecting exponent values, α and β.
Step 3 : Run power flow program without DG and save the required quantities.
Step 4 : Select one of types of DG.
Step 5   : Decrement of power factor by ΔPF_{DG} from 0.99 leading for Type2, from 0.99 lagging for Type 4 DG and skip this step
            for Type 1 and Type 3 DGs.
Step 6 : Select one of the buses.
Step 7 : Increment of DG value by ΔS_{DG}.
Step 8 : Run power flow program and save the required quantities.
Step 9 : Go to step 7 till DG value reached the set value ($P_{DG} \leq P_{int}$).
Step 10: Go to step 6 to select next bus till all the buses   are considered.
Step 11: Go to step 5 for type 2 and type 4 DG till PF_{DG} is 0.8 and skip this step for type 1 and type 3 DG.
Step 12: Go to step 4 to select other type of DG.
Step 13: Go to step 2 till all the mixed load models are selected.
Step 14: The database obtained in terms of DG_bus, P_{DG}, Q_{DG}, P_L, Q_L, S_{int}, P_{int}, Q_{int}, S_{sys}, NVLV, NLCLV, PLI, QLI, VPI, LCI,
            V_i, and S_{ij} are used to obtain value of quantities (with zero value of NVLV, NLCLV) corresponding to minimum P_L,
            and minimum S_{int} as depicted in Table III, and IV using exhaustive search method (given in Appendix B).

5. Simulation Results and Discussion

In this section, the summary of simulation results obtained for various test cases is presented. The quantities P_{DG}, Q_{DG}, PF_{DG}, S_{int}, P_{int}, Q_{int} , S_{sys}, P_L, Q_L, corresponding to minimum P_L and minimum S_{int} are presented in Table 3 and 4 respectively. The indices corresponding to minimum P_L (for economical operation) and minimum S_{int} (to defer system upgrade) configuration are depicted from Figure 1 to 8. The analysis is presented on the basis of results depicted in Table 3 and 4 for various seasonal mixed load models as well as constant power load model and various major types of DG as follows:

Table 3. Real power loss minimization with various load models and DG types

Load models	W/WO DG	DG Type	P_{DG} (p.u.)	Q_{DG} (p.u.)	PF_{DG}	DG bus	P_{int} (p.u.)	Q_{int} (p.u.)	S_{int} (p.u.)	S_{sys} (p.u.)	P_L(Min.) (p.u.)	Q_L (p.u.)
CP	WODG	-	-	-	-	-	3.9039	2.4260	4.5963	4.5963	0.1889	0.1260
	WDG	T 1	2.5700	0.0	1.0	6	1.2423	2.3700	2.6759	4.4890	0.0973	0.0700
		T2	2.4600	1.7171	0.82 ld	6	1.3127	0.6282	1.4552	4.4422	0.0577	0.0453
		T3	0.0	1.2650	0.0	30	3.8492	1.1251	4.0102	4.5309	0.1342	0.0900
		T4	2.2968	-0.3273	0.99 lg	6	1.5332	2.7082	3.1121	4.5097	0.1150	0.0809
SDM	WODG	-	-	-	-	-	3.8358	2.2306	4.4372	4.4372	0.1667	0.1108
	WDG	T 1	1.0250	0.0	1.0	11	2.7912	2.2969	3.6147	4.4541	0.1094	0.0726
		T2	0.7440	0.5580	0.8 ld	30	3.0520	1.7805	3.5334	4.4585	0.0896	0.0604
		T3	0.0	1.1250	0.0	30	3.8232	1.1867	4.0031	4.4678	0.1295	0.0866
		T4	1.1039	-0.1573	0.99 lg	9	2.7144	2.4488	3.6557	4.4531	0.1166	0.0777
SNM	WODG	-	-	-	-	-	3.8381	2.2131	4.4304	4.4304	0.1654	0.1099
	WDG	T 1	0.7350	0.0	1.0	13	3.0826	2.2706	3.8286	4.4419	0.1160	0.0767
		T2	0.5360	0.4020	0.8 ld	31	3.2693	1.9006	3.7816	4.4477	0.1046	0.0696
		T3	0.0	1.1100	0.0	30	3.8257	1.1941	4.0078	4.4660	0.1296	0.0866
		T4	07920	-0.1129	0.99 lg	12	3.0277	2.3794	3.8508	4.4415	0.1211	0.0803
WDM	WODG	-	-	-	-	-	3.8234	2.2224	4.4224	4.4224	0.1644	0.1093
	WDG	T 1	0.6000	0.0	1.0	14	3.2117	2.2639	3.9294	4.4333	0.1207	0.0795
		T2	0.4360	0.3270	0.8 ld	31	3.3652	1.9623	3.8955	4.4374	0.1129	0.0748
		T3	0.0	1.1150	0.0	30	3.8180	1.1947	4.0005	4.4622	0.1286	0.0860
		T4	0.6534	-0.0931	0.99 lg	14	3.1612	2.3582	3.9439	4.4364	0.1243	0.0822
WNM	WODG	-	-	-	-	-	3.8186	2.2178	4.4159	4.4159	0.1636	0.1086
	WDG	T 1	0.4500	0.0	1.0	15	3.3593	2.2485	4.0424	4.4235	0.1273	0.0838
		T2	0.3280	0.2460	0.8 ld	32	3.4747	2.0228	4.0206	4.4281	0.1229	0.0813
		T3	0.0	1.1150	0.0	30	4.0005	1.1935	4.0006	4.4620	0.1287	0.0860
		T4	0.4851	-0.0691	0.99 lg	14	3.3251	2.3172	4.0529	4.4240	0.1296	0.0854

Table 4. Power intake minimization with various load models and DG types

Load models	W/WO DG	DG Type	P_{DG} (p.u.)	Q_{DG} (p.u.)	PF_{DG}	DG bus	P_{int} (p.u.)	Q_{int} (p.u.)	S_{int} (p.u.)	S_{sys} (p.u.)	P_L (p.u.)	Q_L (p.u.)
CP	WODG	-	-	-	-	-	3.9039	2.4260	4.5963	4.5963	0.1889	0.1260
	WDG	T 1	3.6050	0.0	1	6	0.2210	2.3799	2.3902	4.5058	0.1110	0.0799
		T 2	3.4765	2.1545	0.85 ld	3	0.3632	0.2376	0.4341	4.5240	0.1247	0.0922
		T3	0.0	2.3450	0.0	6	3.8635	0.0563	3.8639	4.5489	0.1485	0.1013
		T4	3.3660	-0.4796	0.99 lg	6	0.4795	2.8716	2.9113	4.5287	0.1305	0.0920
SDM	WODG	-	-	-	-	-	3.8358	2.2306	4.4372	4.4372	0.1667	0.1108
	WDG	T 1	3.825	0.0	1.0	2	0.0092	2.2446	2.2446	4.4428	0.1592	0.1070
		T 2	3.8236	2.1670	0.87ld	2	0.0096	0.0814	0.0819	4.4440	0.1567	0.1057
		T3	0.0	2.2250	0.0	2	3.8350	0.0096	3.8349	4.4385	0.1641	0.1095
		T4	3.4304	-0.4888	0.99lg	2	0.4041	2.7310	2.7608	4.4419	0.1605	0.1077
SNM	WODG	-	-	-	-	-	3.8381	2.2131	4.4304	4.4304	0.1654	0.1099
	WDG	T 1	3.8250	0.0	1.0	2	0.0116	2.2294	2.2294	4.4373	0.1581	0.1063
		T 2	3.5862	2.1279	0.86ld	2	0.2491	0.1047	0.2702	4.4378	0.1556	0.1050
		T3	0.0	2.2100	0.0	2	3.8373	0.0077	3.8373	4.4321	0.1630	0.1087
		T4	3.4353	-0.4895	0.99lg	2	0.4016	2.7162	2.7457	4.4362	0.1594	0.1069
WDM	WODG	-	-	-	-	-	3.8234	2.2224	4.4224	4.4224	0.1644	0.1093
	WDG	T 1	3.8100	0.0	1.0	2	0.0136	2.2380	2.2381	4.4304	0.1572	0.1057
		T 2	2.8985	1.7963	0.85ld	2	0.9229	0.4406	1.0227	4.4280	0.1551	0.1045
		T3	0.0	2.2200	0.0	2	3.8231	0.0068	3.8231	4.4244	0.1620	0.1080
		T4	3.4205	-0.4874	0.99lg	2	0.4032	2.7228	2.7525	4.4291	0.1585	0.1063
WNM	WODG	-	-	-	-	-	3.8186	2.2178	4.4159	4.4159	0.1636	0.1086
	WDG	T 1	2.8650	0.0	1.0	2	0.9530	2.2292	2.4244	4.4211	0.1567	0.1052
		T 2	2.1546	1.3917	0.84ld	2	1.6621	0.8368	1.8608	4.4197	0.1554	0.1045
		T3	0.0	2.2150	0.0	2	3.8247	0.0101	3.8248	4.4249	0.1621	0.1081
		T4	3.0888	-0.4401	0.99lg	2	0.7301	2.6698	2.7679	4.4222	0.1577	0.1057

5.1 Analysis

Constant power load model (CP): In minimum P_L configuration, it is observed that the P_L with T2 is 0.0577 p.u. which is less compared to with other types of DGs and without DG. The P_{DG} is 2.4600 p.u., at 0.82 leading power factor, which is less than with T1 and greater than with T4. The S_{int} with T2 is 1.4552 p.u. which is less than with other type of DGs and without DG. The location of T1, T2, and T4 is at bus 6 whereas of T3 is at bus 30.

In minimum S_{int}, configuration (to defer substation upgrade), the S_{int}, with T2 is 0.4341p.u. which is less than with T1, T3, T4, and without DG. The P_{DG} of T2 is 3.4765 p.u. at 0.85 leading power factor which is less than with T1 and little more than T4.

The P_L with T2 is 0.1247 which is less than with T3 and T4 , and greater than with T1. The location of T1, T3, and T4 is bus 6 (away from substation) whereas for T2 is bus 3 (closer to substation to accommodate greater value of DG).

Summer day mix load model (SDM): In minimum P_L configuration,   the P_L and Q_L with T2 is 0.0896 p.u. and 0.0604 p.u. respectively whereas with other type of DGs and without DG are more. The value of P_{DG} with T2 is 0.7440 p.u., at 0.8 leading power factor, which is less than with T1 and T4. The location of T1 is 11, T2 and T3 is 30, and T4 is 9,.

In minimum S_{int} configuration, the location is same (bus 2) for all types of DG. The S_{int} with T2 is much less (0.0819 p.u.) than with other type of DGs. The P_L and Q_L with T2 is 0.1567p.u. and 0.1057 p.u. respectively which are less than without DG and with other type of DGs. The P_{DG} of T2 is 3.8236 p.u.(at PF_{DG} = 0.87 ld) which is more than that of T1 and T4.

Summer night mixed load model (SNM): In minimum P_L configuration, The P_L and Q_L with T2 is 0.1046 p.u. and 0.0696 p.u. respectively whereas with other DGs and without DG are more. The P_{DG} of T2 is 0.536 p.u. , at 0.80 leading power factor, which is less than other type of DGs. The location of T1, T2, T3, and T4 are 13, 31, 30, and 12 respectively.

In minimum S_{int} configuration, the S_{int} with T2 is 0.2702 p.u. which is much less than with other type of DGs. The P_{DG} with T2 is 3.5862 p.u., at 0.86 leading power factor, which is less than with T1 and greater than with T4. The P_L and Q_L with T2 are 0.1556 p.u. and 0.1050 p.u. respectively which are less compared to without DG and with other type of DGs. The location of all type of DGs is same i.e. bus 2, and it is same as for SDM.

Winter day mixed load model (WDM): In minimum P_L configuration, the P_L and Q_L with T2 are 0.1129 p.u. and 0.0748 p.u. respectively which are less than without DG and with other type of DGs. The P_{DG} is 0.436 p.u. , at 0.8 leading power factor, which is less than T1 and T4. The location of T2 and T3   is same as in case of SNM load model i.e. bus 31 and 30 respectively. The location for T1 and T4 is bus 14.

In S_{int} configuration, the S_{int} with T2 is 1.0227 p.u. which is less than with all other type of DGs. The P_L and Q_L with T2 are 0.1551 p.u. and 0.1045 p.u. which are less than without DG and with other type of DGs. The P_{DG} of T2 is 2.8985 p.u. , at 0.85 leading power factor, which is less than with T1 and T4. The location of all type of DGs is at bus 2.

Winter night mixed load model (WNM): In minimum P_L configuration, the P_L and Q_L with T2 is 0.1229 p.u. and 0.0813 p.u. which are less compared to without DG as well as with other type of DGs. P_{DG} of T2 is 0.3280 p.u. (at PF_{DG} = 0.80 leading) which is less than   with other type of DGs. The location is different for different type of DGs.

In minimum S_{int}, configuration, the S_{int} , with T2 is 1.8608 p.u. which is less than with other type of DGs. The P_L and Q_L with T2 are 0.1554 p.u. and 0.1045 respectively which are less than without DG as well as with other type of DGs. The P_{DG} of T2 is 2.1546 p.u. ,at 0.84 ld power factor, which is less than other type of DGs. The location of all type of DGs is same i.e. bus 2 as in case of other mixed load models.

5.2 Discussion

In minimum P_L configuration, it is observed that in order to minimize P_L , the P_L is less for all seasonal load models only with T2 compared to other type of DGs. The optimum locations for T2 are at bus 29 for SDM, bus 31 for SNM and WDM, and 32 for WNM load models. The optimum P_{DG} is also with T2 compared to with T1 and T4 in for all load models. The operating range of power factor for T2 is 0.8 to 0.82ld to meat reactive power demand.

In case of minimum S_{int} configuration, in order to minimize the S_{int} maintaining the line limits, it is suitable to place the DG at that node where maximum line power limit is found, i.e. the line from main substation to the next node i.e. bus 2. Hence in all mixed load models, the optimum location for minimum S_{int} comes out to be bus 2. In this study, optimum location for minimum S_{int} for all mixed load model with each type of DG has come out as bus 2 because bus 1 is not considered as candidate location. It is also observed that with T2 the S_{int} as well as P_L and Q_L is minimum compared to other type of DGs for all the mixed load models. The operating range of power factor with T2 is 0.85ld to 0.87ld to meet the reactive power demand.

In both configurations, it is observed that optimal performance of Type 4 DG is at 0.99lg (closer to unity). This reveals that such DGs are to be operated on unity power factor if possible or otherwise would impose additional power factor constraints on system. However, in certain case it may not be possible to run on unity power factor such as induction generator. Therefore, they may be represented as having reactive power (fixed or variable) such as DFIG.

For minimum P_L and minimum S_{int} configuration the indices PLI, QLI, VPI, and LCI are depicted from Figure 1 to 4, and Figure 5 to 8 respectively. From the figures it is evident that reduction in P_L, and Q_L with T2 are more, for all load models, compared to T1,T3, and T4 in both configuration.

The voltage profile seems to be improved with all type of DGs for all seasonal load models in both configurations compared to without DG case.

The capacity release for constant load model is more with all type of DGs compared to without DG whereas for seasonal mixed load models the capacity release is less compared to without DG. This reveals that assumption of constant load model may not lead to proper DG planning. Among all type of DGs, T3 depicts more line capacity release for all seasonal load models in both configurations.

Besides, the S_{sys} with all type of DGs is comparable for all seasonal load models but less than constant load model which also reveals that assumption of constant power load model may not be suitable for proper DGP.

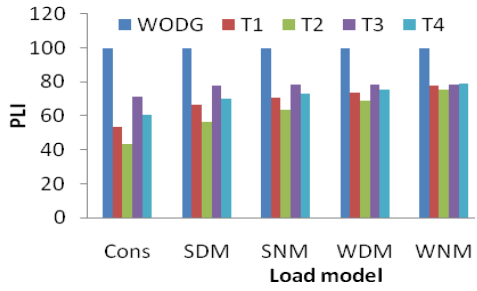*Indices for minimum P_L with various load models*:
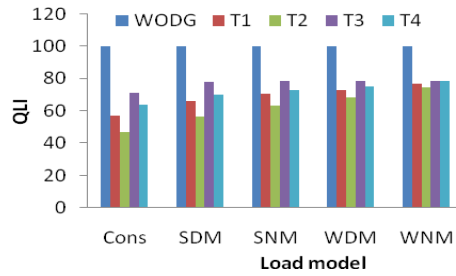

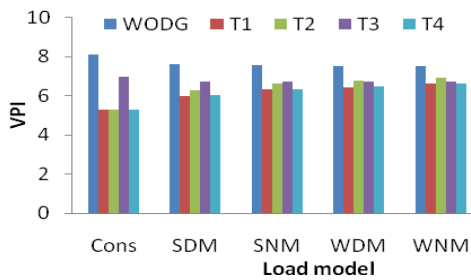Figure 1. PLI   for minimum P_L

Figure 2. QLI for minimum P_L
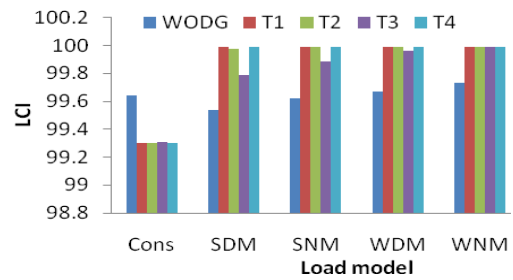

Figure 3. VPI for minimum P_L

Figure 4. LCI for minimum P_L

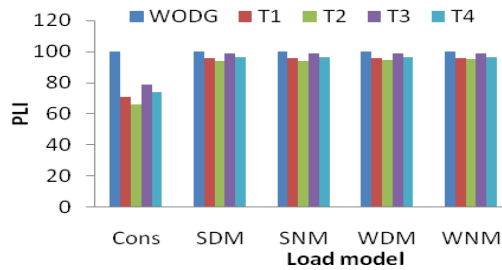*Indices for minimum S_{int} with various load models*:
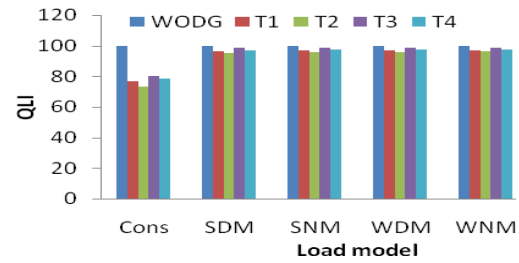

Figure 5. PLI for minimum S_{int}
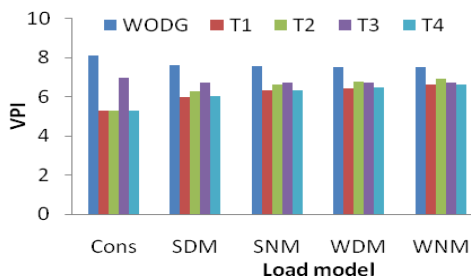

Figure 6. QLI for minimum S_{int}

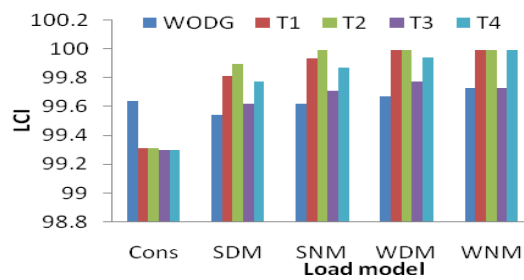Figure 7. VPI for minimum S_{int}

Figure 8. LCI for minimum S_{int}

6. **Conclusion**

In this work mixed load model at every bus, DG types based on terminal characteristic, seasonal mixed load models   as well as constant power load model have been considered. From analysis it is found that Type2 DG has significant impact on DG planning compared to other types of DG. It is also investigated that DG planning based on constant power load model is different than the mixed load models which reveals that the assumption of constant power load model may not lead to proper DG planning. Type2 DG, as compared to others, has significant influence on relevant quantities such as : 1) real and reactive power loss reduction; 2) DG size reduction; 3) Power intake reduction.

Nomenclature

|	
α, β	Voltage exponent of real and reactive load.
CP	Constant power load model.
SDM,SNM,	Summer day and Summer night mix load models
WDM,WNM	Winter day and Winter night mix load models
$CS_{i,j}$, S_{int}	Apparent power capacity of line i-j, Apparent power intake at bus 1.
S_{sys}	apparent system power.
NVLV, NLCLV	Number of voltage, and line capacity limit violation
P_{0i} , Q_{0i}	Real and reactive load at bus i at nominal voltage.
P_D , Q_D	Total system real and reactive power demand.
$P_{DG}, Q_{DG,} S_{DG}$	Real, reactive, and apparent power of DG.
P_i , Q_i	Real and reactive power injection at bus i.
P_{ij} , Q_{ij}	Real and reactive power flow in line i-j.
P_{int} , Q_{int}	Real and reactive power intake at bus 1.
P_L, Q_L	System real and reactive power loss.
r_{ij}	Resistance of i-j
S_{ij} ,	Apparent power flow in line i-j ,.
T1,T2,T3,T4	Type1 DG, Type2 DG, Type3 DG, Type4 DG
θ_{ij}	Voltage angle difference between bus i and j
V_{0i} , V_i	Nominal voltage at ith bus, Voltage at ith bus
WDG, WODG	System with and without DG.
N_B , N_L	Number of buses and number of lines.
$Y_{ij}=G_{ij}+jB_{ij}$	Elements of the bus admittance matrix corresponding to buses i and j.
ld, lg	Leading, lagging power factors

Appendix A
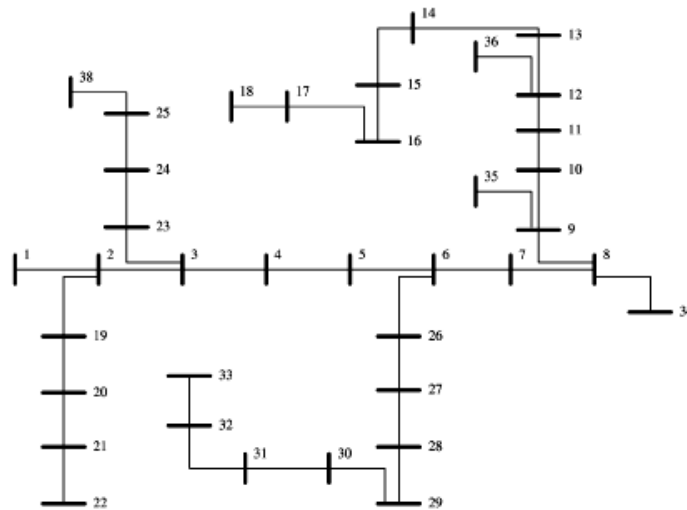
Figure 9. The 38 bus test system (Singh *et al*, 2007).

Table 5. Lines parameter and load data for 38 bus system (Singh *et al*, 2007).

F	T	Line impedance (p. u.)		L	S_L	Load on to bus (p. u.)	
		R	X			P	Q
1	2	0.000574	0.000293	1	4.60	0.10	0.06
2	3	0.003070	0.001564	6	4.10	0.09	0.04
3	4	0.002279	0.001161	11	2.90	0.12	0.08
4	5	0.002373	0.001209	12	2.90	0.06	0.03
5	6	0.005100	0.004402	13	2.90	0.06	0.02
6	7	0.001166	0.003853	22	1.50	0.20	0.10
7	8	0.004430	0.001464	23	1.05	0.20	0.10
8	9	0.006413	0.004608	25	1.05	0.06	0.02
9	10	0.006501	0.004608	27	1.05	0.06	0.02
10	11	0.001224	0.000405	28	1.05	0.045	0.03
11	12	0.002331	0.000771	29	1.05	0.06	0.035
12	13	0. 009141	0.007192	31	0.50	0.06	0.035
13	14	0.003372	0.004439	32	0.45	0.12	0.08
14	15	0.003680	0.003275	33	0.30	0.06	0.01
15	16	0.004647	0.003394	34	0.25	0.06	0.02
16	17	0.008026	0.010716	35	0.25	0.06	0.02
17	18	0.004538	0.003574	36	0.10	0.09	0.04
2	19	0.001021	0.000974	2	0.50	0.09	0.04
19	20	0.009366	0.008440	3	0.50	0.09	0.04
20	21	0.002550	0.002979	4	0.21	0.09	0.04
21	22	0.004414	0.005836	5	0.11	0.09	0.04
3	23	0.002809	0.001920	7	1.05	0.09	0.05
23	24	0.005592	0.004415	8	1.05	0.42	0.20
24	25	0.005579	0.004366	9	0.50	0.42	0.20
6	26	0.001264	0.000644	14	1.50	0.06	0.025
26	27	0.001770	0.000901	15	1.50	0.06	0.025
27	28	0.006594	0.005814	16	1.50	0.06	0.02
28	29	0.005007	0.004362	17	1.50	0.12	0.07
29	30	0.003160	0.001610	18	1.50	0.20	0.60
30	31	0.006067	0.005996	19	0.50	0.15	0.07
31	32	0.001933	0.002253	20	0.50	0.21	0.10
32	33	0.002123	0.003301	21	0.10	0.06	0.04
8	34	0.012453	0.012453	24	0.50	0.00	0.00
9	35	0.012453	0.012453	26	0.50	0.00	0.00
12	36	0.012453	0.012453	30	0.50	0.00	0.00
18	37	0..003113	0.003113	37	0.50	0.00	0.00
25	38	0.003113	0.002513	10	0.10	0.00	0.00

F = From bus, T = To bus, L = line number, S_L = Line apparent power limit in p.u.,
P = Real power load in p. u., Q= Reactive power load in p. u.

Appendix B

1. Exhaustive Search Algorithms

1.1 Steps for minimum P_L

step1 : Load the data_base files
step2 : Assign k=1, min_loss = $P_{LWODG,}$ and k_{max} = no. of set of data.
step3 : Read $P_L(k)$, $NVLV(k)$, $NLCLV(k)$, $P_{DG}(k)$, $P_{int}(k)$.
step4 : if $P_L(k) >$ min_loss go to step8.
step5 : if (NVLV(k) $\neq$0) || (NLCLV(k)$\neq$0)|| ($P_{DG}>P_{int,}$) go to step 8.
step6 : min_loss = $P_L(k)$
step7 : k_{minpl}=k   (k_{minpl} is the value of k corresponding to minimum P_L).
step8 : if $k = k_{max}$, go to step 10.
step9 : k=k+1, go to step3.
step10: Print DG_bus(k_{minpl}), $P_{DG}(k_{minpl})$, $Q_{DG}(k_{minpl})$, $PF_{DG}(k_{minpl})$, $P_L(k_{minpl})$, $Q_L(k_{minpl})$, $S_{int}(k_{minpl})$, $P_{int}(k_{minpl})$,$Q_{int}(k_{minpl})$,$S_{sys}(k_{minpl})$,
        $NVLV(k_{minpl})$, $NLCLV(k_{minpl})$, $PLI(k_{minpl})$, $QLI(k_{minpl})$, $VPI(k_{minpl})$, $LCI(k_{minpl})$.
step11: go to step 1 till all the files are considered.

1.2 Steps for minimum S_{int}

Step1 : Load the data_base files
Step2 : Assign k=1, min_ S_{int} = $S_{intWODG,}$ and k_{max} = no. of set of data.
Step3 : Read S_{int} , $P_L(k)$, P_{LWODG} , $P_{int}(k)$, $P_{DG}(k)$, $NVLV(k)$, $NLCLV(k)$.
Step4 : if S_{int} (k) > min_ S_{int} , go to step9.
Step5 : if ($P_L(k)>P_{LWODG}$) && ($P_{DG}(k)> P_{int}(k)$), go to step9.
Step6 : if (NVLV(k) $\neq$0) || (NLCLV(k)$\neq$0), go to step 9.
Step7 : min_ S_{int} = $S_{int}(k)$
Step8 : k_{minsi} =k   (k_{minsi} is assigned the value of k corresponding to minimum S_{int}).
Step9 : if $k = k_{max}$, go to step 11.
Step10: k=k+1, go to step3.
Step11: Print DG_bus(k_{minsi}), $P_{DG}(k_{minsi})$, $Q_{DG}(k_{minsi})$, $PF_{DG}(k_{minsi})$, $P_L(k_{minsi})$, $Q_L(k_{minsi})$, $S_{int}(k_{minsi})$, $P_{int}(k_{minsi})$,$Q_{int}(k_{minsi})$,$S_{sys}(k_{minsi})$,
        $NVLV(k_{minsi})$, $NLCLV(k_{minsi})$, $PLI(k_{minsi})$, $QLI(k_{minsi})$, $VPI(k_{minsi})$, $LCI(k_{minsi})$.
step12: go to step 1 till all the files are considered.

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