Optimal Sizing and Siting of Distributed Generators by Exhaustive Search

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ABSTRACT

Dispersed generation generally refers to power generation on the customer side of a power network. This article demonstrates the improvement in network parameters which could be achieved by using single and multiple Distributed Generation units in three selected standard networks. A reliable multi variable method is used for finding optimal installation point and size of distributed generation units. Their sites and sizes are recognized by implementation of a proposed method with exhaustive search. Optimization has been applied on network total active and reactive losses together with voltage variation. IEEE 6, 14 and 30 buses standard networks have been selected as study cases. The total active and reactive power losses are minimized while voltage profile is improved by installing Distributed Generation units on recognized optimal points with achieved optimal size.

Keywords: Distributed Generation (DG), Dispersed Generation, Exhaustive Search, Optimal Allocation, Optimal Sizing, Network Loss, Voltage Profile.

Nomenclature

PC : Possible Conditions
$GenNo$: The number of generators for optimization
$BusNo$: The number of distribution buses in network
S_i : Complex injected power in bus i
P_i : Active injected power in bus i

S_i : Reactive injected power in bus i
V_i : Voltage magnitude at bus i
δi : Voltage phase angle at bus i
Y_{ij} : Magnitude of $(i - j)_{th}$ element of admittance matrix
γ_{ij} : Phase angle of $(i - j)_{th}$ element of admittance matrix
S_{L} : Total power loss
P_L : Active power loss
Q_L : Reactive power loss
S_{Gi} : Total generated power at i_{th} bus
S_{Di} : Total demanded power at i_{th} bus
V_{dev} : Voltage deviation of network buses.
IP_L : Index of active power losses
IQ_L : Index of reactive power losses
IV_{dev} : Index voltage deviation
W_p, w_Q : Active and reactive power losses weight factor
w_V : Voltage deviation weight factor

INTRODUCTION

Electricity production field utilities are searching for new technologies of energy production to improve quality and reliability of produced power for newly constructed areas. Power generation utilities are being replaced rapidly by recent technologies around the world, because of their smaller size, lower cost and being friendlier to environment [1-3]. Distributed generation (DG) is a part of such technological improvements.

System efficiency, reliability and environmental advantages are most desired aspects of network planning. Recent improvements in power production techniques open new horizons in front of those favorite features of network management. The main idea behind using DG units is implementation of smaller modular units near to load instead of expanding centralized power plants as well as transmission lines. DG includes variety of power production technologies which could be classified in to two main categories: "Green energies" such as solar, wind, small hydroelectric plants and biomass energy production methods, while the second category of power producers emit greenhouse gasses such as gas or diesel engines, micro-turbines and fuels cells are two examples of this area of electricity generation [4-7].

During last decades wind energy became the dominating energy source among available sources of renewable energy [8].

Respecting to the most familiar definition, Distributed Generation is a power source ranging between 1 kW and 50 MW, which could be a traditional or revolutionary source of power and is connected to distribution network or installed close to consumption centers [9].

DG usage brings number of advantages such as technical, economical and environmental. Technical benefits might be in the form of line loss reduction, voltage profile improvement, enhancing power quality, shaving demand peaks, increasing system reliability and rising grid security [10-17]. Economical advantages could be mentioned as reduction of electricity price, decreasing fuel costs by replacing it with renewable resources, deferring network revamping costs such as transmission line costs and power plan extension costs [18-20]. Reduction of green house gases emission and sound pollution issues are the examples of environmental advantages of using renewable distributed generation [21, 22]. DGs also could be used as stand-alone sources for remote areas.

Most technical and economical advantages could be exploited in the case of optimal allocation and sizing of DG. Lots of researches have been done in this area. Optimal locations of DGs are recognized according to loss minimization in [11, 12]. In some researches DG size optimization on load buses have been done using optimal power flow algorithms [13, 14]. While there was some studies which focused on radial distribution networks for optimal site finding [15], others propose analytical methods for optimal allocation of DGs respecting to network losses [16, 17]. Also many researches have been done by using evolutionary algorithms as approach for optimal DG location finding [23-30]. A Tabu search algorithm has been used as optimization method for DGs allocation in [23], while ant colony was taken up in [24]. Some researchers employed genetic algorithm for finding optimal placement [25] and some other used particle swarm method for optimal point search [26]. Researchers in [27, 28] make use of a combination of evolutionary methods: genetic algorithm along with simulated annealing and fuzzy genetic algorithm respectively. A comparison among different EA for optimization has been accomplished in [29]. On the other side in [30] researchers did multi-objective simple search on different standard networks to find optimal location of a single DG regarding to line losses and cost minimization.

Positive contribution of DGs in power networks up to certain level has been proven by many studies and reported in literatures [5, 21, 31]. Furthermore, it is not concealable that there are lots of difficulties on the way of DGs installation in power grids such as; Technical [32, 33], lack of proper regulation [34], ownership [35], costs, charges [36] and other non-technical matters [37]. All of these barriers, which have been addressed in many works, are challenges to the applicability of DGs in the power system. However, number of solutions was also suggested or investigated [38, 39] and even legislations and standards had been developed and published [40]. This paper is focused on mathematical aspects of position and dimension optimization of DGs; addressing the practical aspects in terms of legislation and standard can be an interesting area for further research.

This work uses an enhanced exhaustive search method with pre-limited search domain to determine optimal position and size of DGs by making use of the Newton-Raphson method for load flow study. Optimal installation buses of DGs are recognized. A new method for size optimization is proposed by dividing DGs to small modules and reserving the opportunity of installing more than one module on each bus, unlike most other researches which have been done by checking the installation of dedicated different size of DGs [41-43]. Optimal sizes of DGs are hand out by summing up total power of all installed DGs on a single bus. Studies will be carried out on 3 different IEEE standard networks 6, 14 and 30 buses which are modified and adopted for this research. Original 6 buses networks data is gathered from [44], and [45] is used to get 14 and 30 buses test case data.

METHODOLOGY

This research used a Newton-Raphson exhaustive search method load-flow method which solved power network equations. Search method domain has been limited by application of discrete mathematic rules. The Newton-Raphson method is used to solve polar equations of power network after modification of network data according to DG installation buses. Respecting to assumptions DGs had the ability of producing reactive power up to 20% of their active power generation. By this assumption network buses type were changed to P-V bus whenever a DG was connected to.

Although in studies such as [31] it is mentioned that maximum allowed level of DG penetration is 20%, but recent studies highlighted that higher penetration levels are also achievable [46] in which the level 24.18% is recognized, for main bus on a radial network. In [47] the exported power by DG to grid has been reported to increase by penetration level from 15% to 25 %. Thus, this study set the total supplying power by DGs at 25% of total consumers' demand, which is the value within practical applications.

The first stage for single DG optimal allocation, with specified calculated values of generation, moved from bus to bus. Calculated load flow values were used for finding appropriate weight factor. Then the single unit DG was split to smaller units while the total number of DGs assumed to be equal to the number of distribution buses in network. By this assumption and awareness of total power required to be supplied, production amount of each connected DG was computed. Multi DG modules could be installed on same bus and size of DG could be achieved by summation of all DGs' power which was connected to that bus. A flowchart for proposed method has been demonstrated in Fig. 1.

Siting and Sizing of DGs

As mentioned before in this study it was assumed that DGs had total production equal to 25% of requested loads. In base case for selected standard networks there were 6, 14 and 30 buses which should be checked for DG installation but, according to distributed generation definition DG should be installed on costumer side of network or in other word on distribution buses of network. By this simplification bus number for DG installation check, reduced to 4, 8 and 21 buses respectively for 6, 14 and 30 buses networks. Siting and sizing procedure were divided to two main sections. For the first step, a single DG with above mentioned characteristics allocated on networks and objective function variation were examined by weight factors changes. On second stage, optimal position of multi generators was inspected by application of calculated weight factors in objective function.

A new approach is proposed for finding optimal size of DGs, in this method DGs divided to smaller modules and multiple generators get the opportunity of being installed on same bus. Size of each module was calculated according to total number of DGs supposed

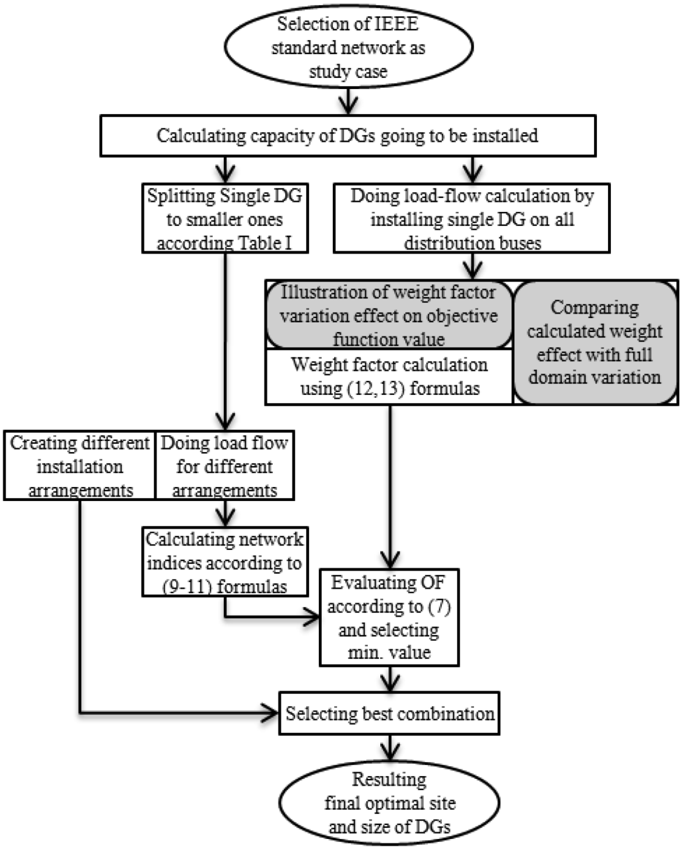


Fig. 1. Flowchart for proposed siting and sizing method

to be installed in network. The number of DG units was equal to the distribution buses number for network and all consequent possible conditions were checked for generator installation. Table 1 shows the total DG supplying power and the number of DG modules with their injecting power for all three selected networks. Finally the size of DG was calculated by summing up the size of all connected DGs to a considered bus. In this method however, unlike the other established methods, search was not done on different sizes of DGs [43], but same results were achieved. Also search domain size remains constant for both methods while proposed method gives the ease for computer code programming. This will be explained in detail in next sections.

Exhaustive Search

Exhaustive search also known as brute force, direct search or generate and test, is an exhaustive test of target function with all possible input values. For discrete problems such as what we have here, this method could be used. However, it is not an efficient solution method, but its results are always reliable because of all possibility checking [48]. This method can ensure that most accurate solutions will be found if there are any. Exhaustive search method could be considered as simplest meta-heuristic method.

The main reason for proposing exhaustive search as an approach for optimal generation positioning is its simplicity and accuracy [49]. Using this approach could enable researchers to be completely sure about their findings. This confidence comes from the fact that in exhaustive search method all candidates are tested and best fitting one or a unique solution definitely will be found.

As candidates' number increase the possible solution number increases rapidly. Therefore exhaustive search is only applicable for small candidates' number. For selected study cases in this paper, the numbers of selectable buses were 5, 8 and 21 and the DG modules count were the same amount respectively for 6, 14 and 30 buses standard networks and those values are demonstrated in 6th column of Table . According to exhaustive search method total number of possible condition could be calculated as follow [50]:

$$PC = BusNo^{GenNo} \tag{1}$$

Where:

PC : Possible Conditions
$GenNo$: The number of generators for optimization
$BusNo$: The number of distribution buses in network

While in current proposed method all conditions don't need to be tested, because of so many repeated arrangements produced with equal DGs sizes. Total examinable condition could be reduced to speed up search algorithm by some mathematical analysis on possible solutions.

Because of the constant size of DG modules, the selected buses order is not important and all combinations with same set of selected buses could be treated as same condition. In other word because the size of DG units are the same it will not matter which one of DGs is

Table 1. Load and DGs power characteristics

	Total Demand		Total DGs Power		Number of DGs	DG Modules Power	
Network	P_D (MW)	Q_D (MVar)	$P_{DGT} = 0.25 \times P_D$ (MW)	$Q_{DGT} = 0.2 \times P_{DGT}$ (MVar)	$DG_{No} = Dist.Bus$	$P_{DG} = \frac{P_{DGT}}{DG_{No}}$	$Q_{DG} = \frac{Q_{DGT}}{DG_{No}}$
6 Buses	21.25	5.75	5.3125	1.0625	4	1.328125	0.265625
14 Buses	259.0	73.5	64.75	12.95	8	8.09375	1.61875
30 Buses	283.4	126.2	70.85	14.17	21	7.8722	1.5744

going to be installed on an assumed bus. Then all possible installation conditions which are produced by generators installation orders on a set of buses could be reduced to one combination. So the total number of possible conditions could be calculated as follow[51]:

$$PC = C_{GenNo}^{GenNo + BusNo - 1} = \frac{\left(GenNo + BusNo - 1\right)!}{\left(BusNo - 1\right)! \times GenNo!} \tag{2}$$

Definition for *PC*, *GenNo* and *BusNo* are the same as (1).

In this method DGs have the chance of being as large as 25% of requested load while they could be as small as one DG module with listed characteristics in last two columns of Table 2. However DGs could be of different size but their total production amount should not exceed 25% of requested load. Possible combination of 4 DGs installation on 4 buses with numbers for instance 3, 4, 5 and 6 are illustrated in Table 2. It is obvious that there are 35 possible conditions for DGs installation.

If the method which was used in [41-43] is employed here for DGs optimal size recognition, different size of DGs should be assumed for size optimization. For instance in the specified example, possible conditions of installation are listed in Table 2, there are 4 DGs of same size. That means if a single DG production capacity assumed to be C then there could be a combination of DGs with sizes C, 2C, 3C and 4C. The possible conditions and combinations for this method are summarized in Table 3 which shows that total possible conditions number is the same amount as proposed method. Mathematically it could be proved that in this method possible combinations number is still achievable from (2).

Study Case Definition and Adoption

As mentioned before three test networks 6, 14 and 30 buses systems have been selected as study cases [11, 45]. Some load and line specification changes have been done on 6 buses network to make DGs effect clearer. Also the sixth bus has been disconnected from slack bus for same reason. Final schematic of this network is shown in Fig. 2 and its data are illustrated in Table 4 and Table 5.

Table 2. Possible combinations of 4 DGs installation on 4 buses

	Bus Numbers for DGs Installation																																		
DG No.1	3	4	5	6	4	5	6	5	6	6	4	5	6	5	6	6	5	6	6	6	4	5	6	5	6	6	5	6	6	6	5	6	6	6	6
DG No.2	3	3	3	3	4	4	4	5	5	6	4	4	4	5	5	6	5	5	6	6	4	4	4	5	5	6	5	5	6	6	5	5	6	6	6
DG No.3	3	3	3	3	3	3	3	3	3	3	4	4	4	4	4	4	5	5	5	6	4	4	4	4	4	4	5	5	5	6	5	5	5	6	6
DG No.4	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	4	4	5	5	5	5	6

Table 3. Possible conditions in the case of using DGs with different sizes

Possible combinations of different DG capacities				Numbers of possible conditions
Capacity	Count	Capacity	Count	
C	4			1
C	2	2C	1	12
C	1	3C	1	12
2C	2			6
4C	1			4
Total number of possible conditions				35

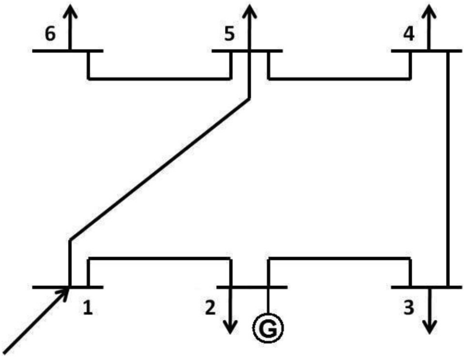


Fig. 2. Modified 6 buses network

Table 4. Bus Data for 6 buses network

Bus number	Bus type	Voltage (p.u.)	Injection (MW)	Request (MW)
1	Slack	1.0∠ 0	---	---
2	PV	1.0∠ 0	8.0+j0	6.0+j1.1
3	PQ	---		7.75+j1.9
4	PQ	---		2.0+j1.0
5	PQ	---		1.0+j2.8
6	PQ	---		4.5+j5.0

Table 5. Line data for 6 buses network

From	To	R (p.u.)	X (p.u.)	B/2 (p.u.)
1	2	0.3038	0.5090	0.0012
1	5	0.1203	0.2482	0.0008
2	3	0.1738	0.3090	0.0016
3	4	0.3738	0.7590	0.0008
4	5	0.2738	0.3090	0.0016
5	6	0.1738	30.90	0.0016

Selected networks were adopted on DGs installation to corporate with them. Here is the list of changes which have been done on selected networks:

1. Installation bus type was changed to PV, to face DG as an ordinary generation unit.
2. All DGs' generation were summed up and added to the network data on connection buses.
3. Generators, condensers and capacitors which were connected to transmission network are left connected
4. Condensers and capacitors that were on distribution network were removed from network to make DG installation reasonable.

DG Installation and Load Flow

Dispersed generation allocation and related network changes for load flow application are described in this section. Load flow equations are accessible in power network analysis references such as [52]. All possible combinations observed in section 0.0 and demonstrated in Table, were examined to find optimized power exports. Every combination of DGs installation buses were applied on modified networks described in section 0. For this application selected buses types were changed to PV buses with regard to DGs ability of reactive power production.

Power delivery always causes line losses and these losses depend on line current and resistances. In current research network characteristics were assumed to remain untouched and only DGs installation buses, which only affect line current, were changed. The following power flow equations were used for injected power calculations.

$$S_i = P_i + jQ_i$$

$$Pi = V_i \sum_{j=1}^{BusNo} Y_{ij} V_j \cos\left(\delta_i - \delta_j - \gamma_{ij}\right) \tag{3}$$

$$Qi = V_i \sum_{j=1}^{BusNo} Y_{ij} V_j \sin\left(\delta_i - \delta_j - \gamma_{ij}\right)$$

Where:

S_i is complex injected power in bus i.

P_i and Q_i are real and imaginary parts of injected power.

V_i is the voltage magnitude at the i_{th} bus with phase of δ_i.

Y_{ij} is the magnitude of $(i-j)_{th}$ element of admittance matrix and phase of γ_{ij}.

System total losses could be expressed as:

$$S_L = \sum_{i=1}^{BusNo} S_{G_i} - \sum_{i=1}^{BusNo} S_{D_i} \tag{4}$$

Where:
S_L is total power loss, S_{Gi} is total generated power at i_{th} bus and S_{pi} is total demanded power at i_{th} bus.

Active and reactive power losses were expressed as real and imaginary parts of system total losses.

$$S_L = P_L + iQ_L \tag{5}$$

Where P_L and Q_L are active and reactive power loss.

The other required value in objective function is voltage deviation for inspecting DGs influence on network voltage profile. Regarding to research assumptions only slack bus voltage has been set to specific value and for this reason first bus voltage is not taken in account for voltage deviation calculation. This value could be calculated by total summation of absolute difference of all mentioned buses voltage from 1. This value is divided by total bus numbers minus one, dropping slack bus which was excluded in calculations. This can make values almost independent from network size:

$$\mathrm{V_{dev}} = \frac{\sum_{\mathrm{i=2}}^{\mathrm{BusNo}} \left| \mathrm{V_i} - 1 \right|}{\mathrm{BusNo} - 1} \tag{6}$$

Where:
V_{dev} is voltage deviation of network buses.

Objective Function (OF)

The reason of power flow and voltage deviation calculation is aimed at evaluation of objective function which is governed by following equations:

$$OF = w_p \ x \ IP_L + w_Q \ x \ IQ_L + w_v \ x \ IV_{dev} \tag{7}$$

$$w_p + w_Q + w_v = 1 \tag{8}$$

Where:

IP_L, IQ_L and IV_{dev} are indices of active and reactive power losses and voltage deviation regarding to original network.

w_p, w_Q and w_v are weight factors with values between 0 and 1 related to every defined indexes.

IP_L, IQ_L and IV_{dev} are defined by following equations:

$$IP_L = \frac{P_{L_{nth}}}{P_{L_0}} \tag{9}$$

$$IQ_L = \frac{Q_{L_{nth}}}{Q_{L_0}} \tag{10}$$

$$IV_{dev} = \frac{V_{dev_{nth}}}{V_{dev_0}} \tag{11}$$

Where:

$P_{L_{nth}}$, $Q_{L_{nth}}$ and $V_{dev_{nth}}$ are power losses and voltage deviation for *nth* DGs installation combination.

P_{L_0}, Q_{L_0} and V_{dev_0} are original network power losses and voltage deviation when no DG was installed.

Study has been accomplished by evaluating load flow equations for all possible installation conditions of a single DG with the prior described parameters in section 0.0. Active and reactive power production on all distribution buses were recognized in this step of study. Those values were used to form related indexes for each of them. All results of this stage have been preserved for illustration of weight factors variation effect on objective function. Weight factor values were varied from 0 to 1 and the step of variation was 0.01 respecting (8). All resulted combinations of weight factors were applied on previously saved losses and voltage deviation Indexes.

Weight Factors Calculation

By finalizing last stage and regarding the effect of weight factors variation on objective function, a method has been proposed for weight factor calculations to give them an equal opportunity for affecting objective function result.

Calculation method has been proposed for proper weight factor achievement. In this method weight factors calculated with respect to

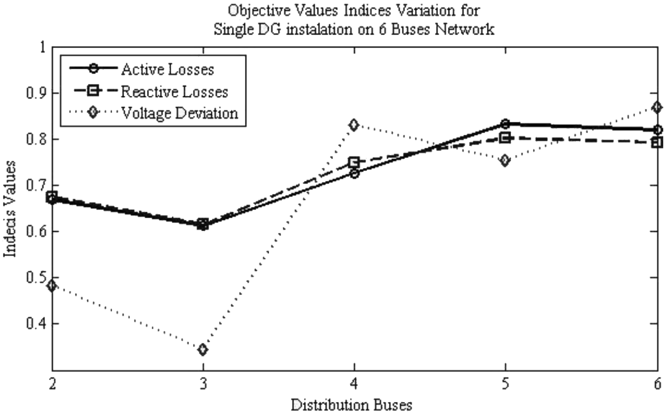


Fig. 3. Indices variation for single DG installation on different buses in 6-bus network

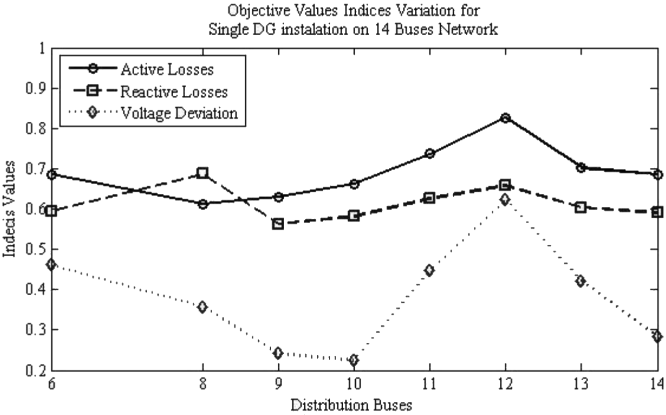


Fig. 4. Indices variation for single DG installation on different buses in 14-bus network

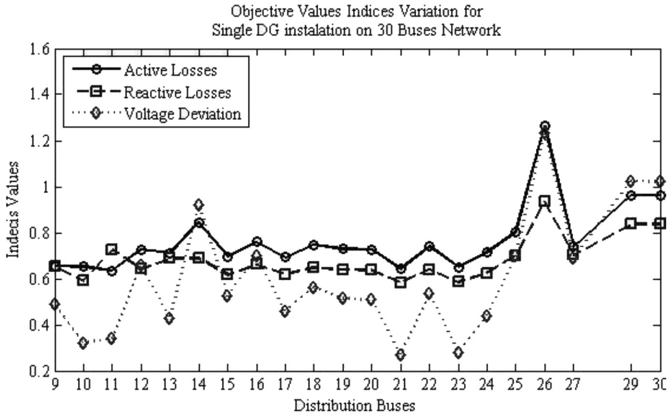


Fig. 5. Indices variation for single DG installation on different buses in 30-bus network

indices achieved the objective values described in last section. Calculated factors had reverse proportion with their related indices mean values. By this way, the smallest value of objective values would have the largest weight factor which gives the objective value equal chance of effecting objective function against bigger objective values. These values could be calculated using following formulas.

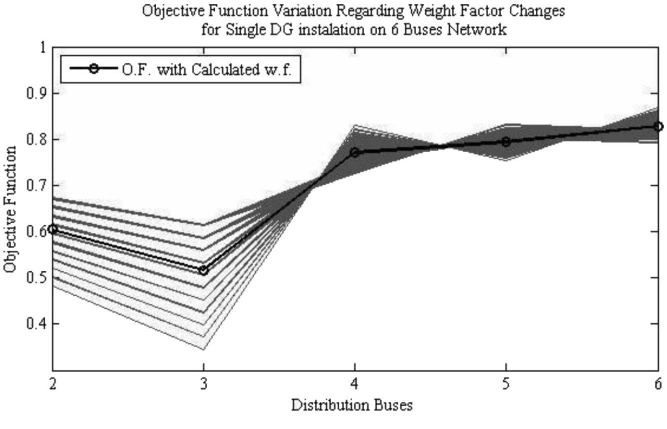


Fig. 6. O.F. Variation with W.f. changes in 6 buses network

$$W_p = \frac{1}{\sum_{Dist\ Bus} 1P_{L_i}}$$

$$W_q = \frac{1}{\sum_{Dist\ Bus} 1Q_{L_i}} \tag{12}$$

$$W_v = \frac{1}{\sum_{Dist\ Bus} 1V_{dev_i}}$$

$$W = w_p + w_q + w_v$$

$$W = \frac{w_v}{w},\ w_q = \frac{w_q}{w},\ w_v = \frac{w_v}{w} \tag{13}$$

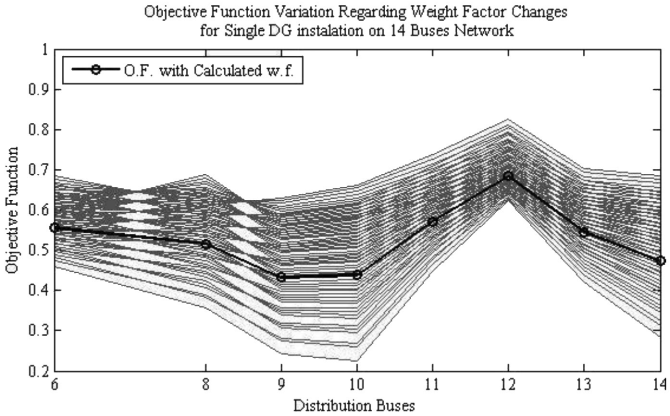


Fig. 7. O.F. Variation with W.f. changes in 14 buses network

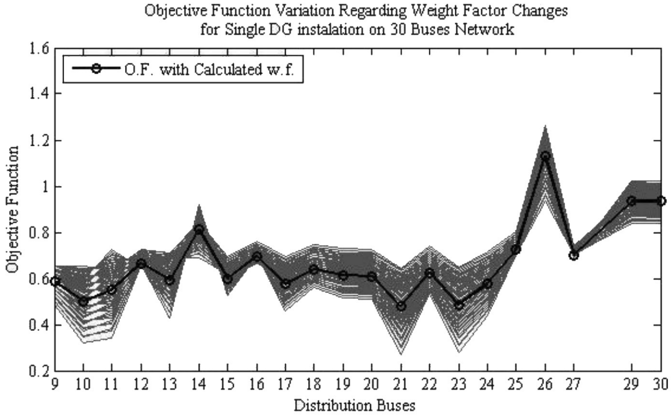


Fig. 8. O.F. Variation with W.f. changes in 30 buses network

Resulted weight factors from (12) were summed up and each of them divided to total sum, to fulfill the condition in (8) and hand out final value for weight factors. Finally, after calculation of weight factors, single generation source has been splashed to smaller units as expressed before and optimal sites for those DGs recognized by minimizing OF using calculated weight factors. Then DGs sizes can be determined by summation of all DGs production characteristics which were connected to a specific bus.

RESULT AND DISCUSSION

Bus Variation Effect of Single DG Installation

Fig. 3 through Fig. 5 illustrate the effects of installing a single DG with demonstrated values in Table on different distribution buses in three selected networks. Effects are observed in three different categories of indexes of active power losses, reactive power losses and voltage deviation, according to (9) and (11). Optimal installation points of DG according to each index minimization are summarized in Table 6.

Table 6. Optimal buses for each objective value in different networks

	Optimal Bus		
Network	$Min.\ IP_L$	$Min.\ IQ_L$	$Min.\ IV_{dev}$
6 buses	3	3	3
14 buses	8	9	10
30 buses	11	21	21

Optimal bus result with respect to minimum active loss are shown in second column of this table, these values could validate result obtained in [30]. However cost effect for optimized allocation is also taken in to account in that research but it seems that siting was not much affected by this value as shown in Fig. 3~Fig. 5 with same optimal sites achieved for all three networks when only active power was considered.

Table 7. Weight factor effect on O.F. and calculated Weights

		Active losses privilege			Reactive losses privilege			Voltage deviation privilege			Calculated Weights		
Network		w_P	w_Q	w_V	w_P	w_Q	w_V	w_P	w_Q	w_V	w_P	w_Q	w_V
6 buses	min	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.32	0.32	0.36
	max	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0			
Opt. Bus		3			3			3			3		
14 buses	min	.87	0.0	0.0	.33	.47	.13	0.0	.12	0.6	0.25	0.29	0.46
	max	1.0	.12	.13	.87	1.0	0.6	.33	.47	1.0			
Opt. Bus		8			9			10			9		
30 buses	min	0.9	0.0	0.0	0.0	.05	0.1	0.0	.05	0.1	0.30	0.33	0.38
	max	1.0	.05	0.1	0.9	1.0	1.0	0.9	1.0	1.0			
Opt. Bus		11			21			21			21		

Table 8. Site and Number of DGs for optimal installation

Network	Selected Buses	Number of DGs	DGs Final Characteristic			
			P	Q	$Qmin$	$Qmax$
6 Buses	3	4	3.4000	0.6800	-0.6800	0.8500
	5	1	0.8500	0.1700	-0.1700	0.2125
14 Buses	10	4	25.900	5.1800	-5.1800	6.4750
	14	4	25.900	5.1800	-5.1800	6.4750
30 Buses	17	6	16.194	3.2388	-3.2388	4.0488
	18	3	8.0970	1.6194	-1.6194	2.0244
	20	4	10.796	2.1592	-2.1592	2.6990
	24	3	8.0970	1.6194	-1.6194	2.0244
	26	2	5.3980	1.0796	-1.0796	1.3496
	27	1	2.6990	0.5398	-0.5398	0.6748
	30	2	5.3980	1.0796	-1.0796	1.3496

Table 9. Comparison on different DG number installation effect on network parameters

Network	Number of DGs	Objective Values			Objective Indices			Obj. Fun.
		P_L	Q_L	V_{dev}	IP_L	IQ_L	IV_L	
6 Buses	No DG	0.7762	1.3434	0.0416	1	1	1	1
	Single DG	0.47502	0.82636	0.0143	0.6120	0.6151	0.3449	0.5168
	Multi DG	0.50788	0.89508	0.0092	0.6543	0.6663	0.2212	0.5022
14 Buses	No DG	14.7153	59.518	0.0395	1	1	1	1
	Single DG	9.26818	33.5024	0.0095	0.6298	0.5629	0.2416	0.4318
	Multi DG	8.95212	32.4288	0.0055	0.6084	0.5449	0.1407	0.3748
30 Buses	No DG	18.8146	71.7814	0.0400	1	1	1	1
	Single DG	12.0958	41.8529	0.0108	0.6429	0.5831	0.2704	0.4853
	Multi DG	11.2845	40.0101	0.0062	0.5998	0.5574	0.1550	0.4212

Weight Factors Effects on OF

Calculated objective values by DG installation bus variation were saved to be manipulated for OF evaluation with different weight factors. In this way, the effect of weight factor variation on objective function was observed. Each weight factor value was changed from 0 to 1 with step of 0.01 respecting to (8). OF values are depicted in Fig. 6~Fig. 8.

Considering Fig. 6, in 6-bus system weight factor changes did not make any difference in optimal installation bus selection, so any value could be selected for each W.f. if and only if they fulfill condition in (8). Almost similar situation was experienced as the impact of different weight factors in 30 buses network.

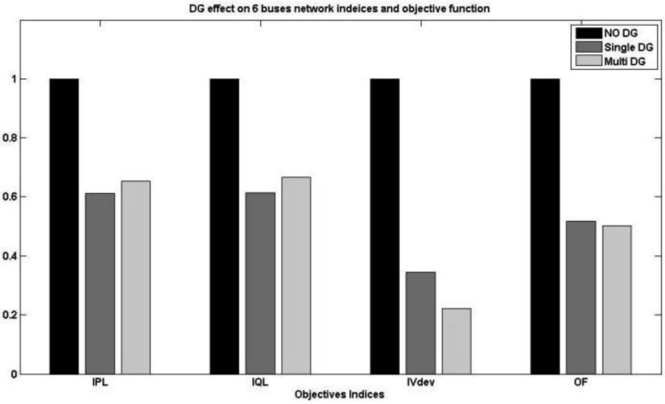


Fig. 9. DG effect on Objective Indices & O.F. in 6 buses network

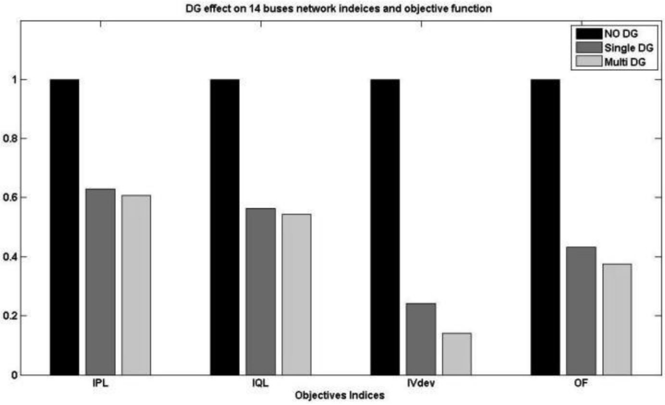


Fig. 10. DG effect on Objective Indices & O.F. in 14 buses network

It is obvious from Fig. 8 that for most of weight factor values best site for DG connection was bus number 21 except for a narrow band of them which moved the optimal site to bus number 11. Referring to Fig. 7, unlike 6 buses and 30 buses networks, 14 buses network site optimization process was much more affected by weight factors changes. Installation site could be any of buses numbered 8, 9 or 10 regarding to weight factor values.

Data depicted in Fig. 6~Fig. 8 are summarized and categorized in Table . In this table values of weight factors are listed separately. They also are categorized according to their values for each network. Minimum and maximum values for each of those factors are listed. Selecting weight factors in these vicinities could contribute the opportunity of domination in optimum site selection to their direct index. In other word by selecting weight factors inside the proposed limits, their related index may get more shares in objective function composition and consequently site selection procedure.

Multiple DG Installation and Sizing

By using calculated weight factors in objective function, size and site of DGs according to prior proposed method in section 0.0 were optimized and the achieved generator arrangements are demonstrated in first three column of Table . In the final stage of optimization proper site of DGs were found by exhaustive search. The achieved connection points for DGs handed out the capacity of generation units. Final sizes of DGs were recognized by summation of all connected power modules

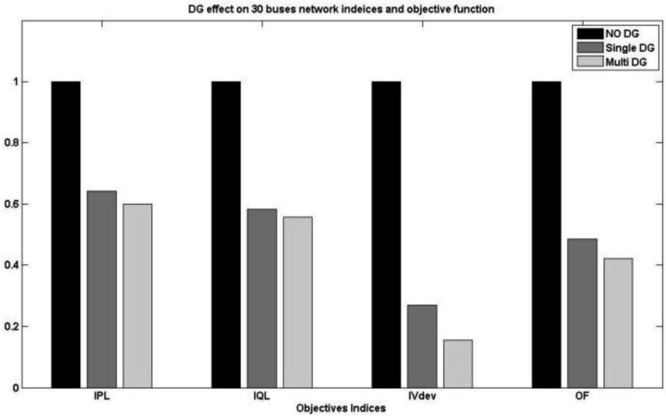


Fig. 11. DG effect on Objective Indices & O.F. in 30 buses network

to a single bus. These values are summarized in Table 8.

Objective function for each network was calculated by using objective values and respective calculated weight factors which were shown in Table 7. These values were gathered from three main states of calculations. First phase was for pure adopted network without any DG unit, the next state was for a single generator which was installed on an optimal bus with objective function minimization. And the last state was multi DG installation organized to produce different arrangements. All these values are shown in first five column of Table 9. Additionally indices values which were introduced for better and more precise comparison along with objective function final values are illustrated in this table.

The tabled objective indices values and objective function values in Table 9 were represented in Fig. 9~Fig. 11 to make more sense and give better conclusion. Regarding to these figures, in all cases adding DG to original network improved all focused network parameters. While adding multiple DGs to same network improved most of the objectives in all networks except active and reactive losses in 6 buses network. However in that network, voltage deviation and objective function value remained reduced.

According to Fig. 9 one DG installation improved network objective parameters noticeably. While using multi DG instead of single DG not only did not make those values better but also showed an increase in losses as compared to values achieved from one DG installation procedure. This happened because of objective function composition and the optimization goal which was minimizing this value.

Fig 10 shows the same result as in Fig. 9, while adding single DG to 14 buses network and all objective values reduced sharply. During multi DG installation, unlike 6 buses network, all objectives are improved in this case in comparison to single DG implementation.

As in other networks, Fig. 11 shows that adding a single DG to 30 buses network made all three objective values better together with objective function. In multi DG usage this network showed the best improvement among the other networks in all areas.

It can be stated that defined indices for objective values give an ease to compare them in a multi objective environment and related weight factors also improved the resolution of these indices in objective function calculation with respect to their magnitude.

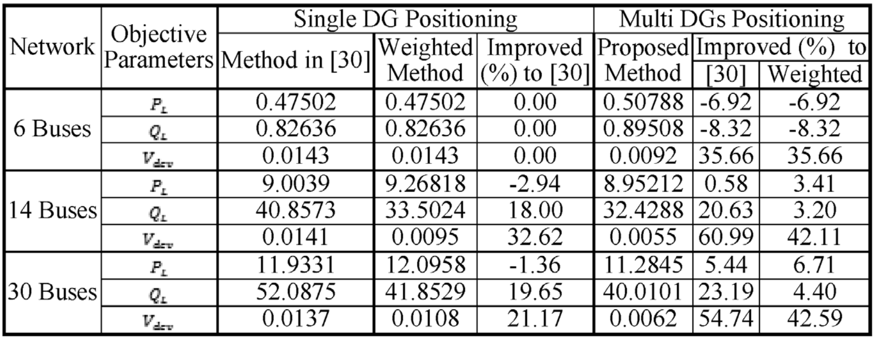
In [30] a combination of minimum active power losses and DG cost are used for finding optimal capacity and location of a single DG. However, it seems that only cost factor affects the size of DG, and the location is much more depended on loss minimization. The study has been accomplished over the same IEEE transmission networks as those of this paper. For comparison objective, values have been calculated by three methods:

i. Method in [30] which employed for positioning a single DG with calculated capacity from Table 10.

ii. The calculated weight factors that obtain the optimal location of the same DG. This method, however, does not change the results for 6 bus network, but it does show huge improvements in reactive power loss and voltage deviation with a little increase in active power loss as compare to method in [30]. This Comparison is given in Table 10.

Finally, the results of proposed method are compared with two previously explained methods. Even though the suggested method is not so better for small systems as the other methods since it is only able to reduce voltage variation, but it shows very good performance for larger networks. Results in the last two columns of Table 10 illustrate the superiority of the proposed method over the other two methods.

Table 10. Comparison of proposed method with method in [30] and single DG optimal positioning with weighted method



Network	Objective Parameters	Single DG Positioning			Multi DGs Positioning		
		Method in [30]	Weighted Method	Improved (%) to [30]	Proposed Method	Improved (%) to	
						[30]	Weighted
6 Buses	P_L	0.47502	0.47502	0.00	0.50788	-6.92	-6.92
	Q_L	0.82636	0.82636	0.00	0.89508	-8.32	-8.32
	V_{dev}	0.0143	0.0143	0.00	0.0092	35.66	35.66
14 Buses	P_L	9.0039	9.26818	-2.94	8.95212	0.58	3.41
	Q_L	40.8573	33.5024	18.00	32.4288	20.63	3.20
	V_{dev}	0.0141	0.0095	32.62	0.0055	60.99	42.11
30 Buses	P_L	11.9331	12.0958	-1.36	11.2845	5.44	6.71
	Q_L	52.0875	41.8529	19.65	40.0101	23.19	4.40
	V_{dev}	0.0137	0.0108	21.17	0.0062	54.74	42.59

CONCLUSION

The underlying exhaustive search method cannot be concluded as the most suitable method of finding optimal arrangement for DG installation. But it always has the ability to hand out correct results. This paper tried to introduce a method for optimizing the site and size of DGs from a multi objective aspect. Also a new method was introduced for DG sizing by dividing DGs to smaller modules and finding optimal installation point for every single DG. Three objectives in network are focused: line losses active and reactive parts together with buses voltage deviation. It could be concluded that adding DG to a network definitely improves network parameters as expected, while using multiple DGs may improve a portion of objective values with respect to the definition of objective values, weight factors and objective function.

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