Sizing and Siting of Types I–IV DG Units using Chaos-assisted Gravitational Search Algorithm

Muhammad Irfan*‡, Sara Ashraf*, Abdul Rehman Imtiaz**

* Department of Electrical Engineering, Khwaja Fareed University of Engineering and Information Technology (KFUEIT), Rahim Yar Khan 64200, Pakistan

** Faisalabad Electric Supply Company (FESCO), West Canal Road, Abdullah Pur, Faisalabad 38000, Pakistan

(muhammad.irfan@kfueit.edu.pk, sara.ashraf@kfueit.edu.pk abdulrehmanimtiaz53@gmail.com)

‡ Corresponding Author; Muhammad Irfan, Khwaja Fareed University of Engineering and Information Technology, Rahim Yar Khan 64200, Pakistan, Tel: +92 68 588 3621, Fax: +92 68 588 2406, muhammad.irfan@kfueit.edu.pk

Received: 17.05.2018 Accepted:09.07.2018

Abstract- Distributed generation (DG) units are generally categorized in four types depending on their deployment for generation and consumption of active and reactive power. Integration of DG units into an electrical distribution system results in several planning and operational challenges. This work proposes a methodology based on a chaos-assisted gravitational search algorithm for optimal sizing and simultaneous placement of DG units of multiple types. The objective of optimization is to minimize the power loss and voltage deviation while abiding by the constraints of the power system. The proposed methodology is tested on three standard test systems (12-, 33-, 69-bus test system) and a practical feeder of Lahore Electric Supply Company (LESCO), Pakistan. The results confirm that optimal sizing and placement of multi-DG units results in better system performance as compared to placement of any one type of DG. Further, the proposed algorithm for optimal sizing and location of DG units outperforms when compared with an analytical and a heuristic search algorithm.

Keywords Distributed Generation (DG); Chaos-assisted Gravitational Search Algorithm; Photo-Voltaic Distributed Generation (PV DG); Types of DG; Objective Function

1. Introduction

The modern electrical power system is foreknown to have increased penetration of distributed generation (DG) due to economic and environmental concerns. For example, according to California Energy Commission's vision statement, more than 25% of total peak demand will be met through DG and cogeneration by 2020 [1] as more power producers, service providers, and consumers are interested in distributed generation. Despite its paybacks and welfare, the integration and operation of DG to the present infrastructure of the power grid is challenging, and a great deal of research is in progress to address the issues related to protection and control of DG-integrated power networks [2]–[5]. An important aspect of the use of DG for power quality improvement is related to calculate the optimal size and location of DG units in a power network [6], [7]. DGs can be categorized based on their size or their use for active/reactive power generation/absorption as shown in Fig. 1. There are four major types of DGs based on whether they inject/absorb the active/reactive power. Practically, most of the power grids consider more than one type of DG which is explored in this study in detail.

In last two decades, there is plenty of work that addresses optimal sizing and placement of DGs for power loss reduction and voltage profile improvement. In [8], the authors considered radially interconnected power systems for the reduction of distribution losses through an analytical approach. However, the proposed method cannot be directly employed without the knowledge of the complexity and size of a system. On the contrary, [9] proposed an algorithm based on two analytical approaches but the authors did not analyze any radial system. A ground-breaking study which has optimally placed and sized different type of DGs using the analytical method [10]. This study, however, did not consider the simultaneous placement of DGs.

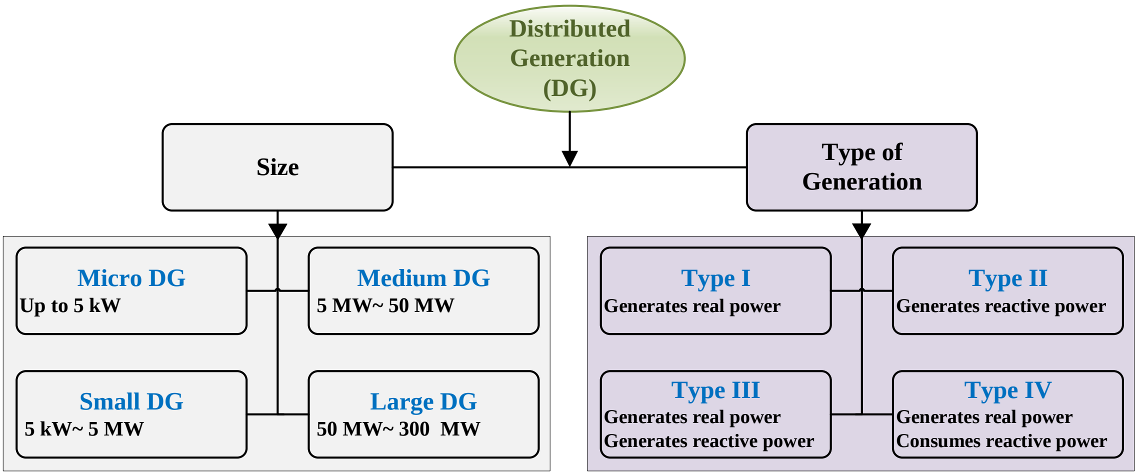

Figure 1. Classification of distributed generation

To find the best location of DG during non-uniform load, [11] presents an algorithm utilizing type-3 DG by hit and trial rule. If the assumed size does not violate the voltage constraint it retains; otherwise, another predicted size follows through. The research studies of [12], [13] have followed similar approach for optimal location of distinctive types of DGs. The above mentioned technique requires large computational power and time. The author of [14] have suggested the optimal power flow method for the sizing and placement of DGs with the constraints viz. social welfare and profit maximization, however, they have neither taken into account a radial feeder nor the collective placement of DGs. In [15], using Differential Evolution technique, the authors have placed DGs in a sequence ranging from 1-7 but, they consider only type-I DG. The work in [16] compares Particle Swarm Optimization (PSO) technique with Genetic Algorithm (GA) while including loss reduction and total harmonic distortion constraints. The work, too, does not consider multi-DG types. Optimal placement of DGs (type-I and II) on radial feeder in [17] implies that PSO outperforms GA for decreasing losses in the system. Though, this paper does not take into account simultaneous DG placement. A method by merging PSO and GA has been presented to find the most feasible location for the placement of DG [18]. The outcome of this study depicts a handsome improvement in reduction of losses, but this work did not consider different DG types or simultaneous DG placement.

The sizing and suitable placement of multi-DG units is known to be a non-linear problem and heuristic optimization techniques perform well for such problems. In this paper, a chaos-assisted Gravitational Search Algorithm (GSA) is proposed for simultaneous placement and sizing of multi-DG units for loss reduction and voltage profile improvement. This novel approach takes into account all four types of DG along with their simultaneous placement. We compare the performance of proposed approach with other existing techniques. The highlights and contribution of this work are summarized below:

1. The existing GSA is improved to incorporate chaotic effects in the search process to avoid trapping in local optima and premature convergence.
2. The validity of proposed methodology is tested on three standard IEEE test systems and a practical feeder in Lahore, Pakistan. The simulation scenarios include sizing and placement of individual as well as multi-DGs in the test systems.
3. A comprehensive comparison of the proposed methodology with an analytical approach [19] and a popular heuristic method, PSO, is provided. The reasons why the proposed methodology outperforms than other methods are also pointed out.

This paper is organized as follows: the proposed algorithm is explained in section 2, the problem formulation is explained in section 3, results are discussed in section 4, and conclusion is provided in section 5.

2. The Proposed Algorithm

In the recent years, GSA received growing attention in the field of engineering optimization and earned successful results in problems related to pattern classification, image segmentation, identification, and clustering [20]. GSA is among the famous optimization algorithms, and it emulates Newton's universal law of gravitation and motion. In GSA population, each agent has a position, inertial mass, active gravitational mass, and passive gravitational mass [21]. Similar to universal objects, each agent (object – in terms of universal gravitation) experiences a gravitational force of attraction by other agents (objects) and the force is calculated according to Newton's universal law of gravitation. Further, Newton's law of motion is used to calculate the velocity of each agent. The gravitational force among agents causes a global motion of agents towards the heavier agents. In GSA, the mass of each agent indicates the superiority of the corresponding solution. Thus, the position of the heaviest agent is the best solution of the optimization problem while its inertial and gravitational masses are controlled using a fitness function. Despite its merits of simple procedure and good performance, GSA has two major weaknesses. The first weak point of this algorithm is its incapability to maintain global optimal position. It may lose global optimal position as the search proceeds. The other weak point is the requirement of balance between exploration and exploitation. The exploration is the ability to expand search space, where the exploitation is the ability to find an optima around a good solution. A premature convergence is observed for high exploration while the convergence rate is affected by the exploitation [22]. These problems limit the applicability of this algorithm to optimization problems; however, there are various methods to overcome this limitation of GSA [20], [23]–[25].

To recover these flaws in GSA, this paper proposes an improved GSA which is assisted with chaos-based search algorithm. The dynamics of chaotic system help GSA to improve the search performance and avoid premature convergence by escaping from local optima. In the following, mathematical formulation of the GSA and the proposed improvement is provided.

Rashedi and coworkers proposed GSA, an algorithm having heuristic nature based on the law of gravity [21]. In this algorithm, each agent specified by four parameters: position, inertial mass, active gravitational mass, and passive gravitational mass, is assumed to be an object whose performance can be measured from the masses of objects. Additionally, each mass suggest a solution. Moreover, all objects attract each other by the gravity force and ultimately converge to the heaviest object. The heaviest object represents the optimal solution for the problem due to their higher fitness values.

Consider a system having N agents (masses), the position of the ith agent is represented by Eq. (1):

$$x_i = \left(x_i^1, \dots\dots, x_i^d, \dots\dots\dots, x_i^n\right) \text{ for } i = 1,2,\dots,N \quad (1)$$

where n represents dimensions of the problem and x_i^d denotes the position of the ith agent in dth dimension. Equation (2) shows the force acting on agent i by agent j at a time t:

$$F_{ij}^d(t) = G(t)\frac{M_{pi}(t)\times M_{aj}(t)}{R_{ij}(t)+\in}\left(x_j^d(t) - x_i^d(t)\right) \quad (2)$$

where $M_{pi}(t)$ and $M_{aj}(t)$ are passive and active gravitational masses of agents i and j, respectively. $G(t)$ represents the gravitational constant at time t, $R_{ij}(t)$ is a measure of Euclidean distance between i and j, and $\in$ is a very small constant (i.e., in the order of 2^{-52}) [26]. $R_{ij}(t)$ can be calculated using following equation:

$$R_{ij}(t) = \left\|X_i(t), X_j(t)\right\|_2 \quad (3)$$

The stochastic behavior of total force on agent i from all other agents in direction d can be realized by Eq. (4) as follows:

$$F_i^d(t) = \sum_{j=1, j\neq i}^{N} rand_j F_{ij}^d(t) \quad (4)$$

where $rand_j$ represents a random number in the interval [0, 1].

By the law of motion, the acceleration of an agent i, having inertial mass M_{ii}, at time t, in direction d is expressed as:

$$a_i^d(t) = \frac{F_i^d(t)}{M_{ii}(t)} \quad (5)$$

Furthermore, the next velocity of the agent is determined by the summation of acceleration and a fraction of its current velocity. Hence, position and velocity of an agent can be calculated using Eq. (6)-(7).

$$x_i^d(t+1) = x_i^d(t) + v_i^d(t+1) \quad (6)$$

$$v_i^d(t+1) = rand_i \times v_i^d(t) + a_i^d(t) \quad (7)$$

A heavier agent having slow motion and more attractive force represents the better solution. Gravitational and inertial masses are updated using Eq. (8)-(9) which is based on fitness evaluation. :

$$m_i(t) = \frac{fit_i(t) - worst(t)}{best(t) - worst(t)} \quad (8)$$

$$M_i(t) = \frac{m_i(t)}{\sum_{j=1}^{N} m_j(t)} \quad (9)$$

where $fit_i(t)$ gives the fitness value of agent i at time t, and $best(t)$ and $worst(t)$ shows the best and worst fitness values, respectively. For a minimization problem, $best(t)$ and $worst(t)$ are given by Eq. (10)-(11) below [18]:

$$best(t) = \min_{y\in\{1,\dots,N\}} fit_y(t) \quad (10)$$

$$worst(t) = \max_{y\in\{1,\dots,N\}} fit_y(t) \quad (11)$$

Now, we come to the improvement proposed in this work. $G(t)$ in Eq. (2) is the gravitational constant and its values is a function of the initial value G_0 and t as given by Eq. (12) where T represents the total time (or a maximum number of iteration for a computer program) and α is decay rate defined by the user. For this work, $G_0 = 100, \alpha = 20$.

$$G(t) = F(G_0, t) = G_0 \times e^{(-\frac{\alpha t}{T})} \quad (12)$$

In the proposed chaos-assisted GSA, the chaotic dynamics is added to improve the searching behavior and avoid the premature convergence. Chaos being an innovative optimization technique has simplicity of execution and ability to escape from being trapped in local optima [26], [27]. In this work, the well-known logistic equation is employed as typical chaotic system for constructing the chaos-assisted GSA [36] described as follows:

$$\varphi(t) = \rho \times \varphi(t-1) \times \left(1 - \varphi(t-1)\right), 0 \leq \varphi(0) \leq 1 \quad (13)$$

where φ(t) is the chaotic value, ρ is a control parameter and has a real value in the range of 0 and 4, and t is the iteration number. The updated equation for calculation of gravitational constant is updated to Eq. (14) which includes dynamics of the chaotic system represented by Eq. (13).

$$G(t) = \varphi(t) \times G_0 \times e^{(-\frac{\alpha t}{T})} \quad (14)$$

By comparing Eq. (12) and Eq. (14), it can be deduced that gravitational constant decreases exponentially with time for both equations but, Eq. (14) shows chaotic or oscillatory behavior which is absent in the case of the former equation.

3. Problem Formulation and Proposed Methodology

3.1 Problem Formulation

The objective of this work is to optimally size and place the DGs to improve voltage profile and minimize losses across the network. For this purpose, the objective function is defined in Eq. (15) which aims at the power losses reduction and voltage deviation minimization.

$$min\, f(P_{Loss}, V_{Dev}) = W_1 \times P_{Loss} + W_2 \times V_{Dev} \quad (15)$$

where P_{Loss} and V_{Dev} represent distribution system's power loss and voltage deviation. The weighting factors W_1 and W_2 in the objective function assign a relative importance to power loss reduction and voltage deviation minimization, respectively. The larger value of weighting factor indicates the higher significance given to the respective aspect of the objective function. The values of these weighting factor are defined by system operator according to network condition and economic constraints. In this work, W_1=W_2=1."

Considering a distribution system with N buses, voltage deviation at ith bus can be calculated using Eq. (16) as follows, where V_i and $V_{ref,i}$ are the values of actual and reference voltage at bus i, respectively. Equation (17) calculates the total voltage deviation.

$$V_{Dev,i} = \frac{V_{ref,i} - V_i}{V_i} \tag{16}$$

$$V_{Dev} = \sum_{i=1}^{N} V_{Dev,i} \tag{17}$$

The total power loss across the entire distribution network is calculated using Eq. (18) as given below [28]:

$$P_{Loss} = \sum_{i=1}^{N}\sum_{j=1}^{N}\left[\alpha_{ij}\left(P_iP_j + Q_iQ_j\right) + \beta_{ij}\left(Q_iP_j - P_iQ_j\right)\right] \tag{18}$$

where,

$$\alpha_{ij} = r_{ij}/V_iV_j cos(\delta_i - \delta_j) \tag{19}$$

$$\beta_{ij} = r_{ij}/V_iV_j sin(\delta_i - \delta_j) \tag{20}$$

and

$$Z_{ij} = r_{ij} + jx_{ij} \tag{21}$$

where r_{ij} is the line resistance, x_i is the line reactance, and Z_{ij} is the line impedance between bus i and j. V_i and V_j are the voltage magnitudes; δ_i and δ_j are voltage angles at bus i and j, respectively. Moreover, P_i and P_j are respective active power injections at bus i and j; Q_i and Q_j are the reactive power injections at respective buses. The objective function is subject to the constraints mentioned by following Eq. (22)-(26).

Power flow must be balanced

$\sum_{i=1}^{n}$ [illegible] + [illegible] = $\sum_{[illegible]=1}^{N}$ [illegible] + [illegible] (22)

where n and N are the total number of DGs and buses, respectively. Slack bus (reference bus) works as a compensator in the system for the difference produced by losses among generated power and scheduled loads [29].

The current through the conductor must not be greater than the specified current

$$I_i \leq I_i^{rated} \tag{23}$$

where I_i^{rated} is the rated current of the conductor.

Voltage constraint of each bus

At each bus, voltage should be within ±5% of rated voltage. The voltage profile of the power system should be maintained in permissible limits. Moreover, when voltage tends to decrease, current will increase which will increase the losses in the system. Similarly, increase in voltage will result in damaging the insulation of devices.

$$V_{min} \leq V_i \leq V_{max}, i = 1,2, \dots, N \tag{24}$$

The capacity of DG should be in explicit constraints.

$0 \leq$ [illegible] ([illegible]) $\leq$ [illegible] (25)

$\sum_{[illegible]=1}^{n}$ [illegible] $<$ $\sum_{[illegible]=1}^{N}$ [illegible] + [illegible] (26)

where n is the number of DGs in the system. The sum of demand and loss must be greater than the output generated from DG so that excessive power flow towards substation can be avoided being damaging for the system.

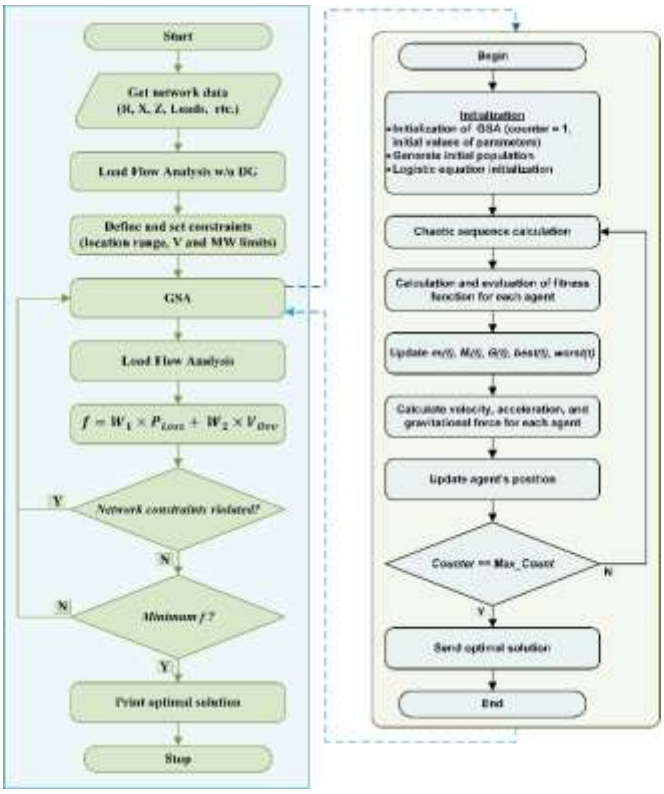

Figure 2. Flowchart for the proposed algorithm and execution procedure

3.2 The Proposed Methodology

Figure 2 explains the steps involved in the implementation of chaos-assisted GSA and its utilization for best placement and sizing of types I-IV DGs. First of all, information about the required network parameters is provided to the algorithm, and a load flow analysis determines the losses in the distribution system. A well acknowledged technique, forward backward sweep is utilized for distribution feeder analysis. Unlike Newton-Raphson method, this technique does not require Jacobian matrix. The simulation have been performed in MATLAB / Simulink environment. The chaos-assisted GSA is exploited to get the suitable sites and sizes for different DGs. The total iterations and agents taken is 80 and 50, respectively.

4. Simulation Results

The proposed approach is validated on 12-bus, 33-bus, and 69-bus standard test systems [30]. Further, the proposed approach is also tested on a radial distribution feeder in Pakistan operated by Lahore Electric Supply Company (LESCO) [31]. The proposed technique is also compared with a technique based on PSO [17] and an analytical technique proposed in [19], and the results are provided at the end of this section.

4.1 12-Bus Test System

When the proposed algorithm for sizing and placement of DG units is applied on an IEEE 12-bus radial distribution test system, a significant improvement in voltage profile and power loss reduction is observed as detailed in Table 1 and Fig. 3.

Following points are observed when individual DG is placed in the system:

1. For all cases, the voltage profile is improved and power losses are reduced as compared to the case when there is no DG available in the system.
2. The best results, in terms of voltage profile improvement and power loss reduction, are obtained with the integration of synchronous DG. This is primarily because of dispatchable nature and built-in dynamics of synchronous DG. The performance of other DGs in descending order is: PVs, induction generator and capacitors.
3. The voltage profile does not exist in 5% for the individually placed capacitor. This problem can be solved by placing PVs along with the capacitor.

The summary of points observed during simultaneous DG placement is as follows:

1. When DG units are placed in combination, the results are better than their induvial placement due to their combined effects.
2. For power loss reduction, the combination of capacitors with PVs or induction generator yields as good results as obtained by placement of synchronous generator.
3. Similarly, voltage profile is improved significantly when a combination of capacitors with induction generator or PVs is utilized. The results are comparable to that of the synchronous generator as shown in Fig. 3.

It is notable that the general effects of DG placement remain similar independent of system size. The overall picture for 33-bus, 69-bus, and LESCO feeder is more or less similar to the results discussed for the 12-bus test system.

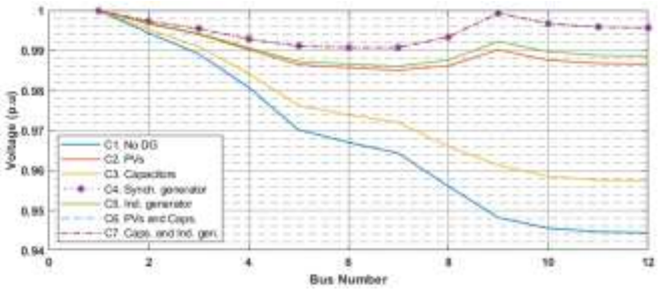

Figure 3. Voltage profile of 12-bus test system

4.2 33-Bus Test System

The results of applying the proposed methodology for sizing and simultaneous placement of DGs on a 33-bus radial distribution test system are summarized in Table 2 and Fig. 4. For all cases, there is a significant improvement in voltage profile and reduction in power losses as compared to the case when there is no DG in the system. However, simultaneous placement of capacitors with induction generator or PV units results in improved voltage profile in some areas as compared to individual placement of synchronous generator. Nevertheless, the synchronous generator alone yields better voltage profile as compared to any other individual DG or their combination. There is a slight increase in voltage for synchronous generator case, but this is well within the allowable limit of ±5%.

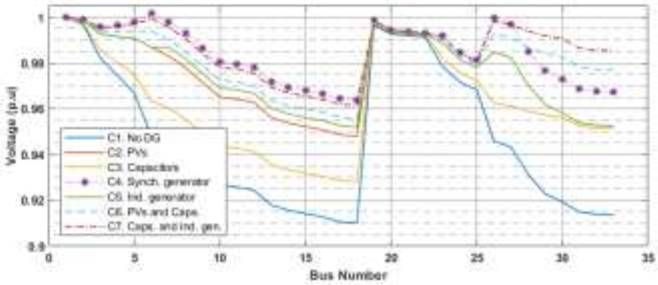

Figure 4. Voltage profile of 33-bus test system

4.3 69-Bus Test System

Table 3 and Fig. 5 represent the results of the application of proposed methodology on a 69-bus radial distribution test system. Simultaneous placement of capacitors with PV units or individual placement of synchronous generator results in improved voltage profile as compared to other cases. There is significant loss reduction for simultaneous placement of capacitors with PV units or induction generator and individual placement of synchronous generator.

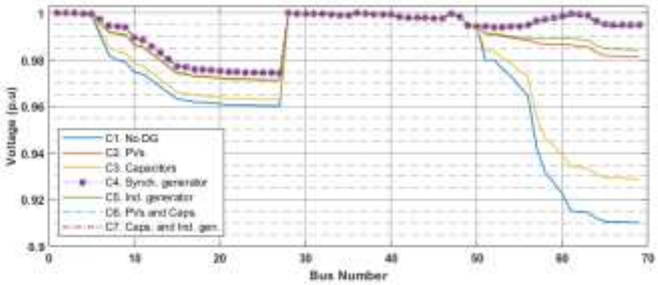

Figure 5. Voltage profile of 69-bus test system

Table 1. Capacity, position, and power loss of DGs for 12 bus system

Case	Description	Size	Location	MW Loss	V_{max}	V_{min}	% Loss Reduction
C.1	No DG	-	-	0.02070	1.0	0.943	-
C.2	PVs	0.239 MW	9	0.01050	1.0	0.985	49.28
C.3	Capacitors	0.217 MVAr	9	0.01240	1.0	0.957	40.1
C.4	Synch. generator	0.314 MVA	9	0.00315	1.002	0.991	84.78
C.5	Ind. generator	0.253 MVA	9	0.01063	1.0	0.986	48.65
C.6	PVs and Cap.	0.232 MW, 0.213 MVAr	9 and 9	0.00316	1.0	0.991	84.73
C.7	Cap. and Ind. generator	0.284 MVAr, 0.243 MVA	9 and 9	0.00316	1.0	0.991	84.73

Table 2. Capacity, position, and power loss of DGs for 33 bus system

Case	Description	Size	Location	MW Loss	V_{max}	V_{min}	% Loss Reduction
C.1	No DG	-	-	0.21100	1.0	0.904	-
C.2	PVs	1.970 MW	6	0.11304	1.0	0.950	46.43
C.3	Capacitors	1.435 MVAr	30	0.14184	1.0	0.928	32.78
C.4	Synch. generator	2.330 MVA	6	0.06730	1.002	0.964	68.1
C.5	Ind. generator	1.800 MVA	7	0.11386	1.0	0.952	46.04
C.6	PVs and Capacitors	1.903 MW and 1.356 MVAr	6 and 30	0.05631	1.0	0.956	73.31
C.7	Capacitors and Ind. generator	1.900 MVAr and 2.000 MVA	6 and 30	0.05651	1.0	0.961	73.22

Table 3. Capacity, position, and power loss of DGs for 69 bus system

Case	Description	Size	Location	MW Loss	V_{max}	V_{min}	% Loss Reduction
C.1	No DG	-	-	0.22500	1.0	0.9092	-
C.2	PVs	2.604 MW	61	0.08387	1.0	0.9712	62.72
C.3	Capacitors	1.311 MVAr	61	0.15987	1.0	0.9289	28.95
C.4	Synch. generator	3.075 MVA	61	0.02097	1.0	0.9743	90.68
C.5	Ind. generator	2.500 MVA	61	0.08590	1.0	0.9715	61.82
C.6	PVs and Capacitors	2.417 MW and 1.244 MVAr	61 and 61	0.02097	1.0	0.9743	90.68
C.7	Capacitors and Ind. generator	1.300 MVAr and 2.600 MVA	61 and 61	0.02097	1.0	0.9742	90.68

Table 4. Capacity, position, and power loss of DGs for a LESCO system

Case	Description	Size	Location	MW Loss	V_{max}	V_{min}	% Loss Reduction
C.1	No DG	-	-	0.38280	1.0	0.9173	-
C.2	PVs	5.538 MW	17	0.08070	1.0	0.969	78.92
C.3	Capacitors	2.914 MVAr	20	0.29260	1.0	0.9559	23.56
C.4	Synch. generator	6.100 MVA	17	0.01870	1.001	0.9941	95.11
C.5	Ind. generator	5.673 MVA	17	0.08120	1.0	0.9675	78.79

C.6	PVs and Capacitors	5.467 MW and 2.599 MVAr	17 and 17	0.01850	1.0	0.9933	95.17
C.7	Capacitors and Ind. generator	2.769 MVAr, 2.600 MVA	17 and 18	0.01870	1.0	0.9938	95.11

Table 5. Proposed method compared with PSO for 33-bus system

Type of DG	Technique							
	Particle swarm optimization				*Particle swarm optimization*			
	V_{min}	V_{max}	MW Loss	% Loss Reduction	V_{min}	V_{max}	MW Loss	% Loss Reduction
PVs	0.9502	1	0.115	45.36	0.9503	1	0.11304	46.43
Capacitors	0.92	1	0.151	28.26	0.9280	1	0.14184	32.78
Synch. gen.	0.957	1.0002	0.0679	67.74	0.9639	1.002	0.0673	68.10
PVs and Capacitors	0.957	1.0002	0.058	72.44	0.9557	1	0.05631	73.31

Table 6. Proposed method compared with PSO for 69-bus system

Type of DG	Technique							
	Particle swarm optimization				*Proposed method*			
	V_{min}	V_{max}	MW Loss	% Loss Reduction	V_{min}	V_{max}	MW Loss	% Loss Reduction
PVs	0.968	1.00	0.083	62.93	0.9712	1.00	0.08387	62.72
Capacitors	0.930	1.00	0.152	32.11	0.9289	1.00	0.15987	28.95
Synch. gen.	0.972	1.00	0.023	89.73	0.9743	1.00	0.02097	90.68
PVs and Capacitors	0.972	1.00	0.023	89.73	0.9743	1.00	0.02097	90.68

Table 7. Proposed method compared with an analytical technique [19]

System for test	Technique							
	Analytical				*Proposed method*			
	Location	DG Size (MW)	MW Loss	Loss Reduction (%)	Location	DG Size (MW)	MW Loss	Loss Reduction (%)
12-Bus	9	0.227	0.0113	45.41	9	0.239	0.0105	49.28
69-Bus	61	1.808	0.0920	59.11	61	2.604	0.08387	62.72

4.4 LESCO's Radial Distribution Feeder

This test feeder, known as Sheikh Zaid feeder and operated by LESCO, emanates from 132/11 kV grid station located in Larkana city in Pakistan. Its single line diagram is shown in Fig. 6. This 11 kV feeder has 39 buses with total real and reactive power demand of 6.268 MW and 3.035 MVAr, respectively. The power loss for this feeder is 0.3828 MW. This feeder constitutes of four different conductors. Table 4 shows the information about power loss and optimal positions and capacities of DGs either placed one at a time or simultaneously. The voltage appeared on each bus in each DG placement case is depicted in Fig. 7. The synchronous generator alone yields better voltage profile as compared to any other individual DG or their combination. However, simultaneous placement of capacitors with induction generator or PV units yields comparable results to the placement of synchronous generator.

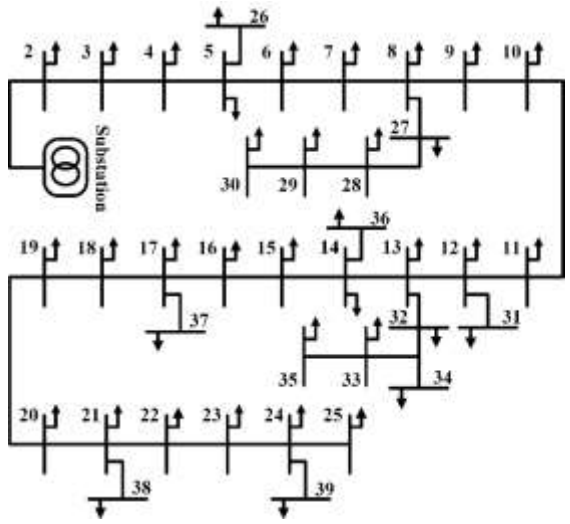

Figure 6. Single line diagram of a LESCO's radial distribution feeder

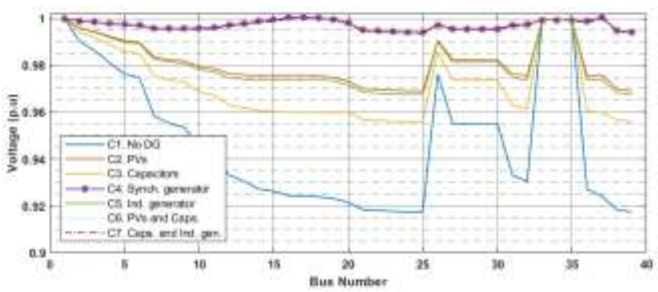

Figure 7. Voltage profile of LESCO feeder

4.5 Comparison of the Proposed Methodology with other Techniques

This work uses chaos-assisted GSA for calculation of optimal position and capacity of DGs aiming to reduce power loss and voltage deviation. The proposed approach is compared with PSO [17] and an analytical technique presented in [19]. The comparison considers results of 12-bus, 33-bus and 69-bus systems for three types of DGs whether placed individually or simultaneously summarized in Tables 5-7.

Tables 6 and 7 demonstrate the comparison of PSO and the proposed technique for 33 and 69 bus systems, respectively. Tabulated results show chaos-assisted GSA to provide improved results over PSO techniques. Additionally, simultaneous placement of DGs is found advantageous to individual DG placement for both optimization techniques. Despite its wide applicability and increased use in modern optimization problems, PSO could not outperform the proposed GSA. The reasons may include:

1. PSO only considers two best positions whereas, GSA considers the influence of all other agents on a single agent to determine its direction [21].
2. Updating in GSA is much more efficient as compared to PSO as GSA considers the quality of solutions by comparison of their fitness values, unlike PSO. In addition, GSA ponders on the distance between objects for updating contrary to PSO [32].
3. The proposed GSA benefits from chaotic dynamics of the logistic equation which help it to avoid local maxima and premature convergence [26], [33].

Table 7 provides the comparison of analytical technique [19] with the proposed GSA technique for 12-and 69-bus systems, indicating the better performance of the proposed technique.

5. Conclusion

In this work, a methodology for simultaneous multi-DG sizing and placement is presented with a goal of improvement in power system efficiency and voltage profile. The proposed approach is applied to optimally assign sizes and locations for different types of DGs on three standard test systems and a LESCO's 39-bus practical feeder.

It is observed that there is a substantial reduction in power loss and voltage deviation across the power system due to proper sizing and placement of DGs. Further, a combination of various types of DGs results in better performance of a power system. The obtained results are compared with other techniques, and it is shown that proposed technique yields better results while observing all the constraints. A consideration of socio-political and (or) socio-economic constraints in problem formulation could be an interesting topic for future research.

Acknowledgements

We would like to thank Muhammad Saeed Uz Zaman (SKKU, South Korea) for simulating discussions.

References

[1] M. Rawson and J. Sugar, "Distributed Generation and Cogeneration Policy Roadmap for California," CEC-500-2007-021, Mar. 2007.

[2] S. Das and A. K. Akella, "Power Flow Control of PV-Wind-Battery Hybrid Renewable Energy Systems for Stand-Alone Application," *International Journal of Renewable Energy Research (IJRER)*, vol. 8, no. 1, pp. 36–43, Mar. 2018.

[3] M. Saeed Uz Zaman, S. B. A. Bukhari, K. M. Hazazi, Z. M. Haider, R. Haider, and C.-H. Kim, "Frequency Response Analysis of a Single-Area Power System with a Modified LFC Model Considering Demand Response and Virtual Inertia," *Energies*, vol. 11, no. 4, p. 787, Mar. 2018.

[4] S. B. A. Bukhari, M. Saeed Uz Zaman, R. Haider, Y.-S. Oh, and C.-H. Kim, "A protection scheme for microgrid with multiple distributed generations using superimposed reactive energy," *International Journal of Electrical Power & Energy Systems*, vol. 92, pp. 156–166, Nov. 2017.

[5] Y. Allahvirdizadeh, M. Mohamadian, and M.-R. HaghiFam, "A Comparative Study of Energy Control Strategies for a Standalone PV/WT/FC Hybrid

Renewable System," *International Journal of Renewable Energy Research (IJRER)*, vol. 7, no. 3, pp. 1463–1475, Sep. 2017.

[6] S. Essallah, A. Bouallegue, and A. K. Khedher, "Optimal sizing and placement of DG units in radial distribution system," *International Journal of Renewable Energy Research (IJRER)*, vol. 8, no. 1, pp. 166–177, Mar. 2018.

[7] K. K. Mehmood, S. U. Khan, S. J. Lee, Z. M. Haider, M. K. Rafique, and C. H. Kim, "Optimal sizing and allocation of battery energy storage systems with wind and solar power DGs in a distribution network for voltage regulation considering the lifespan of batteries," *IET Renewable Power Generation*, vol. 11, no. 10, pp. 1305–1315, Sep. 2017.

[8] C. Wang and M. H. Nehrir, "Analytical approaches for optimal placement of distributed generation sources in power systems," *IEEE Transactions on Power Systems*, vol. 19, no. 4, pp. 2068–2076, Nov. 2004.

[9] S. Ghosh, S. P. Ghoshal, and S. Ghosh, "Two analytical approaches for optimal placement of distributed generation unit in power systems," in *2009 International Conference on Power Systems*, 2009, pp. 1–6.

[10] D. Q. Hung, N. Mithulananthan, and R. C. Bansal, "Analytical Expressions for DG Allocation in Primary Distribution Networks," *IEEE Transactions on Energy Conversion*, vol. 25, no. 3, pp. 814–820, Sep. 2010.

[11] H. Khan and M. A. Choudhry, "Implementation of Distributed Generation (IDG) algorithm for performance enhancement of distribution feeder under extreme load growth", *International Journal of Electrical Power & Energy Systems,* vol. 32, pp. 985–997, March 2010 [Accessed: 19-Apr-2018].

[12] M. M. Aman, G. B. Jasmon, H. Mokhlis, and A. H. A. Bakar, "Optimal placement and sizing of a DG based on a new power stability index and line losses," *International Journal of Electrical Power & Energy Systems*, vol. 43, no. 1, pp. 1296–1304, Dec. 2012.

[13] D. Q. Hung, N. Mithulananthan, and R. C. Bansal, "Analytical strategies for renewable distributed generation integration considering energy loss minimization," *Applied Energy*, vol. 105, pp. 75–85, May 2013.

[14] D. Gautam and N. Mithulananthan, "Optimal DG placement in deregulated electricity market," *Electric Power Systems Research*, vol. 77, no. 12, pp. 1627–1636, Oct. 2007.

[15] I. Hussain and A. K. Roy, "Optimal size and location of distributed generations using Differential Evolution (DE)," in *2012 2nd National Conference on Computational Intelligence and Signal Processing (CISP)*, 2012, pp. 57–61.

[16] M. Sedighi, A. Igderi, and A. Parastar, "Sitting and sizing of Distributed Generation in distribution network to improve of several parameters by PSO algorithm," in *2010 Conference Proceedings IPEC*, 2010, pp. 1083–1087.

[17] K. Bhumkittipich, "Optimal Placement and Sizing of Distributed Generation for Power Loss Reduction Using Particle Swarm Optimization," *Energy Procedia*, vol. 34 pp. 303-313, July 2013.

[18] M. H. Moradi and M. Abedini, "A combination of genetic algorithm and particle swarm optimization for optimal DG location and sizing in distribution systems," *International Journal of Electrical Power & Energy Systems*, vol. 34, no. 1, pp. 66–74, Jan. 2012.

[19] T. Gözel and M. H. Hocaoglu, "An analytical method for the sizing and siting of distributed generators in radial systems," *Electric Power Systems Research*, vol. 79, no. 6, pp. 912–918, Jun. 2009.

[20] B. Yin, Z. Guo, Z. Liang, and X. Yue, "Improved gravitational search algorithm with crossover," *Computers & Electrical Engineering*, vol. 66, pp. 505–516, Feb. 2018.

[21] E. Rashedi, H. Nezamabadi-pour, and S. Saryazdi, "GSA: A Gravitational Search Algorithm," *Information Sciences*, vol. 179, no. 13, pp. 2232–2248, Jun. 2009.

[22] M. Khajehzadeh, M. R. Taha, A. El-Shafie, and M. Eslami, "A modified gravitational search algorithm for slope stability analysis," *Engineering Applications of Artificial Intelligence*, vol. 25, no. 8, pp. 1589–1597, Dec. 2012.

[23] N. Singh, S. Singh, and S. B. Singh, "A New Hybrid MGBPSO-GSA Variant for Improving Function Optimization Solution in Search Space," *Evol Bioinform Online*, vol. 13, p. 1176934317699855, Jan. 2017.

[24] G. Chen, L. Liu, Z. Zhang, and S. Huang, "Optimal reactive power dispatch by improved GSA-based algorithm with the novel strategies to handle constraints," *Applied Soft Computing*, vol. 50, pp. 58–70, Jan. 2017.

[25] A. A. Ibrahim, A. Mohamed, and H. Shareef, "Optimal power quality monitor placement in power systems using an adaptive quantum-inspired binary gravitational search algorithm," *International Journal of Electrical Power & Energy Systems*, vol. 57, pp. 404–413, May 2014.

[26] A. Fazliana Abdul Kadir, A. Mohamed, H. Shareef, A. Asrul Ibrahim, T. Khatib, and W. Elmenreich, "An improved gravitational search algorithm for optimal placement and sizing of renewable distributed generation units in a distribution system for power quality enhancement," *Journal of Renewable and Sustainable Energy*, vol. 6, no. 3, p. 033112, May 2014.

[27] M. Eslami, H. Shareef, A. Mohamed, and M. Khajehzadeh, "An efficient particle swarm optimization technique with chaotic sequence for optimal tuning and placement of PSS in power systems," *International Journal of Electrical Power & Energy Systems*, vol. 43, no. 1, pp. 1467–1478, Dec. 2012.

[28] O. I. Elgerd and H. H. Happ, "Electric Energy Systems Theory: An Introduction," *IEEE Transactions on Systems, Man, and Cybernetics*, vol. SMC-2, no. 2, pp. 296–297, Apr. 1972.

[29] H. Saadat, *Power system analysis*. McGraw-Hill, 1999.

[30] "Power Systems Test Case Archive - UWEE." [Online]. Available: https://www2.ee.washington.edu/research/pstca/. [Accessed: 19-Apr-2018].

[31] "National Transmission And Despatch Company Limited (NTDC) Pakistan." [Online]. Available: http://www.ntdc.com.pk/. [Accessed: 19-Apr-2018].

[32] N. M. Sabri, M. Puteh, and M. R. Mahmood, "An overview of Gravitational Search Algorithm utilization in

optimization problems," in *2013 IEEE 3rd International Conference on System Engineering and Technology*, 2013, pp. 61–66.

[33] T. Okamoto and H. Hirata, "Constrained optimization using the chaotic Lagrange quasi-Newton method - A basic study of its search trajectory and its search capability," in *The SICE Annual Conference 2013*, 2013, pp. 564–570.