



# ARTIFICIAL INTELLIGENCE FOR OPTIMAL SIZING AND LOCATION OF DG IN POWER SYSTEMS

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## ABSTRACT

Distributed generation (DG) is regarded as one of the energy resources concentrated in many and diverse areas and depends on numerous resources, which are distributed and relatively small energy resources, and the generated capacity ranges from the kilowatt to megawatts, where reliable local capacity is supplied, enhancing the efficiency of the energy sources use, and reducing radiation to the lowest possible value. The AI based systems have been employed to simulate smart grids to solve many pressing problems like obtaining the best location and size of distributed generation systems. An example of these algorithms: Genetic Algorithms (GA), Monte Carlo method, Artificial Immune System (AIS), Particle Swarm Optimization (PSO), Evolutionary Algorithm (EA) and Ant Colony Optimization (ACO). The majority of these approaches use population-based optimization, where the search direction and exploration in objective function search space are crucial to efficiently identify a solution. In this article, we will study the Particle Swarm Optimization (PSO) and its simulation in MATLAB. The particle-based optimization algorithms used have improved the quality condition indicators from the maximum voltage deviation and average voltage deviation. The used method provides the best and optimal way to reduce energy losses by choosing the optimal size and location of generator distribution systems and achieving the lowest cost.



**KEYWORDS**

Distributed generation, Particle Swarm Optimization, Artificial Intelligence; Power Factory.

## 1. INTRODUCTION

The study of the optimization of power flows in radial distribution networks is considered important to deliver an electrical energy supply with user quality conditions (Bayat et al., 2016). Radial distribution systems have a centralized generation located far from the demand, for which an implementation of Distributed Generation (DG) contributes to improve the technical, economic and environmental conditions in the supply of electrical energy (Chiradeja and Ramakumar, 2005). Distributed generation is defined as “The process of generating electrical energy by relying on renewable energy stations (solar energy, wind energy, etc.) distributed at various network points and near users. Distributed stations have a relatively small installed capacity compared to conventional stations” (Jain et al., 2017). The generation is distributed frequently uses non-conventional renewable energy sources, such as solar energy, wind power, biomass, among others also considered non-extinguishable and non-polluting, because they do not contribute large gas emissions into the atmosphere, and they contribute to minimizing the ecosystem impact around their facilities (Montoya et al., 2017). The electrical variables improved with the implementation of an optimal flow of power (OFP) from the adequate selection, location and sizing of distributed generation are: the voltage profile improvement, losses reduction due to Joule effect, current flows reduction, higher reliability etc.

The joint improvement of these variables contributes to raising the service quality and efficiency in the distribution networks, as well allowing greater facilities for sectioning the network in the interruptions event in the electrical service (Prakash et al., 2016). The DG is currently in a great technological development and the penetration of new renewable generation technologies is greater every day (Saha et al., 2015). However, investment, operation and maintenance costs still remain relatively high, for this reason it is of vital importance to analyze the injection of power from renewable energies through optimization techniques that involve cost analysis (Aguila et al., 2017). The optimal location of the DG reduces the power consumption of a single generation node, allowing the loads to be supplied from other generations closer to them, minimizing the currents that flow through the distribution lines, achieving a reduction in both the losses of active power and reactive power (Aguila et al., 2015). The injection of active and reactive power generation can be achieved through different types of distributed generation that take advantage of different energy sources (Tellez et al., 2015). However, with traditional photovoltaic solar generation and taking full advantage of the capacity curve of these static generators, it is possible to deliver mostly active power, which can affect the power factor seen by the external network (Ali et al., 2017). Solar energy is transformed into electrical energy through photovoltaic systems composed mainly of

photovoltaic panels; this type of system has benefits such as reducing environmental impact (Amanifar, 2011). The use of an energy source considered almost inexhaustible improves the quality of social life, increases the technical conditions of energy supply, but with a disadvantage that, being under development, has high implementation costs (Amanifar et al., 2012). For this reason, in this research a model is proposed that allows compensating the electrical variables of a distribution system through the optimal location and sizing of solar generation considering the cost restrictions of this technology (Angelim, 2016).

In this paper, a power flow optimization model is proposed using the particle swarm optimization (PSO) algorithm, applied in IEEE 15-node and IEEE 33-node radial distribution systems, optimally locating and sizing distributed generation (Babu and Singh, 2016).

Considering cost minimization as an objective function of the problem (Badran, 2018). The article is organized as follows: Section 2 identifies the data of radial distribution systems to be implemented and presents the formulation of the problem with its objective function and limitations used. In section 3, a methodology of optimal location of the DG by means of the PSO algorithm is proposed. Finally, the Conclusion and extensions may be read in the last Section 4.

## **2. MATERIALS AND METHODS**

### **2.1. Location and sizing of distributed generation**

Many authors have produced papers with proposals for mathematical models to resolve power flows under undesirable conditions. Some authors seek to improve specific variables. In other instances, improvements are proposed with more than one aim, such as voltage profile improvement, cost minimization, loss minimization, environmental impact minimization, or joint analysis of the above variables (Bazrafshan and Gatsis, 2015).

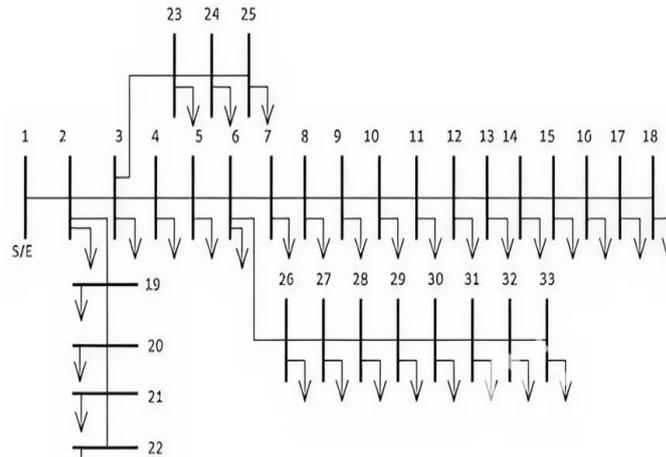
These objective functions have been subject to different scenarios and different restrictions on voltage levels, power flow balance, power factor, power injection limits, type and DG number, etc. (Castillo et al., 2016). The methods implemented for the DG location are extensive and varied, there are traditional, analytical and numerical methods, heuristics and heuristic goals, some of them are Non-Linear Programming (NLP) (Souza et al., 2017), Mixed Integer Non-Linear Programming (MINLP) (Devi et al., 2014), Cuckoo Search Algorithm (CSA) (Dinakara et al., 2017), Particle Swarm Optimization (PSO) (Dixit et al., 2016) (Doagou et al., 2017), (Farasat et al., 2015), Ant Colony Optimization (ACO), Genetic Algorithm (GA) (Imran et al., 2014), Jumping Algorithm Modified Frog Algorithm (MSFL) (Jamil et al., 2016), Artificial Bee Colony (ABC) (Kansal, 2016), Bat Algorithm (BA) (Kaur et al., 2014).

Flower Pollination Algorithm (FPA), Ant Lion Optimization (ALO) (Kumar et al., 2015),



**2.2.2. Radial distribution system of 33 nodes**

The radial distribution system of 33 nodes, Fig.2, used in this investigation as a case study has a base power of 10 MVA and a system voltage of 12.66 kV (Mohamed and Kowsalya, 2014). The power flow was calculated using Matlab, corroborating the results through simulations in the Dig SILENT Power Factory software. The input data for this system are found in Table 2.



**Fig. 2. IEEE 33 Node Radial Distribution Systems**

**Table2. Resistance, impedance and power data of the 33-node radial system**

N° Rama	Barra inicial	Barra final	R (Ω)	X (Ω)	N° Nodo	S (kVA)	Q (kVAr)
1	1	2	0.0922	0.047	1	100	60
2	2	3	0.493	0.2511	2	100	60
3	2	4	0.366	0.1864	3	90	45
4	3	5	0.381	0.1941	4	120	90
5	4	5	0.819	0.707	5	100	100
6	5	6	1.872	1.2351	6	200	100
7	6	7	1.044	0.74	7	150	70
8	7	8	0.1966	0.1784	8	90	45
9	8	9	0.3742	0.1253	9	100	60
10	9	10	1.460	0.4786	10	100	60
11	10	11	0.5961	0.526	11	80	35
12	11	12	0.6015	0.559	12	200	100
13	12	13	0.956	0.600	13	150	50
14	13	14	0.561	0.563	14	20	10
15	14	15	0.232	0.160	15	150	80
16	15	16	0.213	0.135	16	300	100
17	16	17	0.368	0.260	17	200	80
18	17	18	0.920	0.432	18	250	120
19	18	19	0.102	0.100	19	80	30
20	19	20	0.057	0.052	20	90	50
21	20	21	0.7059	0.973	21	40	60
22	21	22	0.1568	0.1605	22	70	30
23	22	23	0.1688	0.1437	23	80	40
24	23	24	0.0899	0.0621	24	90	50
25	24	25	0.0326	0.0235	25	30	10
26	25	26	0.2826	0.1451	26	60	40
27	26	27	0.2147	0.0991	27	150	100
28	27	28	0.966	0.986	28	120	80
29	28	29	0.762	0.614	29	90	60

N° Rama	Barra inicial	Barra final	R ( $\Omega$ )	X ( $\Omega$ )	N° Nodo	S (kVA)	Q (kVAr)
30	29	30	0.341	0.5302	30	60	40
31	30	31	0.730	0.361	31	30	20
32	31	32	0.500	0.250	32	60	40
33	32	33	0.238	0.125	33	60	40

### 2.2.3. Voltages in Matlab and Dig SILENT Power Factory

The voltage values achieved by the Matlab implementation, are displayed in [Table 3](#). These values are compared with the Power Factory results to verify the effectiveness of the used method. In this table, the power flow calculated in Matlab was corroborated with simulations in Dig SILENT Power Factory applying the complete Newton Raphson method, for the 15 and 33 nodes system.

**Table 3. Comparison of voltages obtained in MATLAB and system power factory of 15 and 33 nodes**

IEEE 15 NODE SYSTEM			IEEE 33 NODE SYSTEM		
N° Nodo	V pun MATLAB	V pun DigSilent	Node	V pun MATLAB	V pun DigSilent
1	1,000	1,000	1	1,000	1,000
2	0,971	0,971	2	0,987	0,987
3	0,957	0,957	3	0,975	0,975
4	0,951	0,951	4	0,965	0,965
5	0,948	0,948	5	0,957	0,957
6	0,956	0,956	6	0,945	0,945
7	0,939	0,939	7	0,943	0,943
8	0,956	0,956	8	0,956	0,956
9	0,968	0,968	9	0,920	0,920
10	0,967	0,967	10	0,910	0,910
11	0,950	0,950	11	0,917	0,917
12	0,946	0,946	12	0,918	0,918
13	0,945	0,945	13	0,917	0,917
14	0,949	0,949	14	0,918	0,918
15	0,948	0,948	15	0,934	0,934
-	-	-	16	0,9064	0,9065
-	-	-	17	0,9043	0,9044
-	-	-	18	0,9037	0,9038
-	-	-	19	0,9965	0,9965
-	-	-	20	0,9929	0,9929
-	-	-	21	0,9922	0,9922
-	-	-	22	0,9916	0,9916
-	-	-	23	0,956	0,956
-	-	-	24	0,9726	0,9726
-	-	-	25	0,9693	0,9693
-	-	-	26	0,9475	0,9475
-	-	-	27	0,9450	0,9450
-	-	-	28	0,9335	0,9335
-	-	-	29	0,9253	0,9254
-	-	-	30	0,9217	0,9218
-	-	-	31	0,9176	0,9176
-	-	-	32	0,9167	0,9167
-	-	-	33	0,9164	0,9164

### 2.3. Problem Formulation

The main objective of the proposed method is to minimize the costs of the required distributed generation, guaranteeing compliance with the restrictions: the voltage profiles improvement and the power losses minimization. The following equation defines this analysis:

$$\text{Min } F_0 = \sum_{i=1}^n (\text{ainst} * \text{PDGi} + \text{bO\&G} * \text{PDGi}) + \text{Cperd} * \text{Pperd} \quad (1)$$

Where: Two DG are included-related cost factors, ainst represent installation costs, bO&G operation and maintenance costs, plus a Cperd representing the loss costs of the system, which multiply the powers Pperd, total power losses of the system in (kw) (Prakash and Lakshminarayana, 2016).

$$P_{perd} = \sum_{j \neq i}^n I_{ij}^2 * R_{ij} \quad (2)$$

The total losses of the system must be calculated in order to account the objective function which is given by the square of the currents of line multiplied by its resistance [  $(I_{ij}^2) * R_{ij}$  ] (Prakash and Sujatha, 2016), (Prasad et al., 2017).

$$\sum_{i=1}^n \text{PGDi} + P_{se} = P_c + P_{perd} \quad (3)$$

Eq.3 shows the power balance that the system must comply with where all the active generation power ( $P_{GDi} + P_{se}$ ) must be equal to the sum of the active powers in the loads ( $P_c$ ) plus the power of total active losses ( $P_{perd}$ ) (Khairuddin et al., 2016) (Prasanna et al., 2014).

$$\text{PGD}_{min} \leq \sum_i^n \text{PGDi} \leq \text{PGD}_{max} \quad (4)$$

Eq.4 establishes the search limits of the algorithm for the candidate capacities to install DG, where they are considered from 30% of the total system load up to the maximum power defined as the sum of the active power in the most active losses in the system (Prakash et al., 2016).

$$V_{min} \leq V_i \leq V_{max} \quad (5)$$

The voltage limits for each node are defined in (5) and are restricted to  $\pm 10\%$  of the voltage nominal value, that is, a minimum value of 0.9 p.u and a maximum value of 1.1 p.u (Rama and Jayabarathi, 2016).

$$\text{DPV} = \sum_{i=1}^n \frac{|V_{nom} - V_i|}{n} \quad (6)$$

As an indicator of the results of the voltage profile, the average voltage deviation is defined in (6), which generally shows the improvement achieved in the system. Eq.6 and 7 define the improvement of the voltage profile within the optimization problem.

$$\text{MDV} = \max |V_{nom} - V_i| \quad i=1 \dots n \quad (7)$$

In (7) the maximum voltage deviation Is computed as an indicator that shows the worst voltage condition in the system.

#### 2.3.1. Power flow by Newton Raphson

For the solution of the system power flow from the complete Newton Raphson method, initial

data of the analyzed systems are defined (Tarôco et al., 2016), (Georgilakis et al., 2013), with which the power losses are calculated. In each node, both active and reactive power factor and voltage deviations are also calculated.

**Algorithm 1: Power Flow by Newton-Raphson**

Step 1: Input of line resistance and impedance data, generation and load, bus types.

Step 2: Evaluate the Ybar matrix

Step 3: Calculate  $\Delta P$  and  $\Delta Q$  and get the  $P_{cal}$  and  $Q_{cal}$ .

$$\Delta P = p^{neta} - p^{calc}$$

$$\Delta Q = p^{neta} - p^{calc}$$

$$P_i^{calc} = G_{ii} * V_i^2 + \sum_i^n V_i * V_j [G_{ij} * \cos(\theta_{ij}) + B_{ij} * \sin(\theta_{ij})]$$

$$Q_i^{calc} = -B_{ij} * V_i^2 + \sum_i^n V_i * V_j [G_{ij} * \sin(\theta_{ij}) - B_{ij} * \cos(\theta_{ij})]$$

Step 4: Establish the Jacobian Matrix

$$J = \begin{bmatrix} J_{11} & J_{12} \\ J_{21} & J_{22} \end{bmatrix}$$

$$J_{11} = \begin{bmatrix} \frac{\partial P_1}{\partial \delta_1} & \frac{\partial P_1}{\partial \delta_2} & \dots & \frac{\partial P_1}{\partial \delta_n} \\ \vdots & \ddots & & \vdots \\ \frac{\partial P_n}{\partial \delta_1} & \frac{\partial P_n}{\partial \delta_2} & \dots & \frac{\partial P_n}{\partial \delta_n} \end{bmatrix}$$

$$J_{12} = \begin{bmatrix} \frac{\partial P_1}{\partial V_{pq1}} |V_{pq1}| & \dots & \frac{\partial P_1}{\partial V_{pqn}} |V_{pqn}| \\ \vdots & & \vdots \\ \frac{\partial P_n}{\partial V_{pq1}} |V_{pq1}| & \dots & \frac{\partial P_n}{\partial V_{pqn}} |V_{pqn}| \end{bmatrix}$$

$$J_{21} = \begin{bmatrix} \frac{\partial Q_{pq1}}{\partial \delta_1} & \frac{\partial Q_{pq1}}{\partial \delta_2} & \dots & \frac{\partial Q_{pq1}}{\partial \delta_n} \\ \vdots & \vdots & & \vdots \\ \frac{\partial Q_{pqn}}{\partial \delta_1} & \frac{\partial Q_{pqn}}{\partial \delta_2} & \dots & \frac{\partial Q_{pqn}}{\partial \delta_n} \end{bmatrix}$$

$$J_{22} = \begin{bmatrix} \frac{\partial Q_{pq1}}{\partial V_{pq1}} |V_{pq1}| & \dots & \frac{\partial Q_{pq1}}{\partial V_{pqn}} |V_{pqn}| \\ \vdots & & \vdots \\ \frac{\partial Q_{pqn}}{\partial V_{pq1}} |V_{pq1}| & \dots & \frac{\partial Q_{pqn}}{\partial V_{pqn}} |V_{pqn}| \end{bmatrix}$$

Step 7: Calculate the off-diagonal elements

$$\frac{\partial P_i}{\partial \theta_j} = V_i (G_{ij} \sin \theta_{ij} - B_{ij} \cos \theta_{ij}) V_j$$

$$\frac{\partial Q_i}{\partial \theta_j} = -V_i (G_{ij} \cos \theta_{ij} + B_{ij} \sin \theta_{ij}) V_j$$

$$\frac{\partial Q_i}{\partial |V_j|} |V_j| = \frac{\partial P_i}{\partial \theta_j}$$

$$\frac{\partial P_i}{\partial |V_j|} |V_j| = - \frac{\partial Q_i}{\partial \theta_j}$$

Step 8: Calculate the elements of the diagonal

$$\frac{\partial P_i}{\partial \theta_i} = - Q_i - B_{ii} * V_i^2$$

$$\frac{\partial Q_i}{\partial \theta_i} = P_i - G_{ii} * V_i^2$$

$$\frac{\partial Q_i}{\partial |V_j|} |V_j| = Q_i - B_{ii} * V_i^2$$

$$\frac{\partial P_i}{\partial |V_j|} |V_j| = P_i + G_{ii} * V_i^2$$

Step 9: Obtain the vector of corrections

$$\begin{bmatrix} \frac{\partial \Delta P}{\partial \delta} & V * \frac{\partial \Delta P}{\partial V} \\ \frac{\partial \Delta Q}{\partial \delta} & V * \frac{\partial \Delta Q}{\partial V} \end{bmatrix}^{(K)} * \begin{bmatrix} \Delta \delta \\ \Delta V \\ V \end{bmatrix}^{(K+1)} = - \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix}^{(K)}$$

Step 10: Calculation of the new

$$\begin{bmatrix} \delta \\ V \end{bmatrix}^{(k+1)} = \begin{bmatrix} \delta \\ V \end{bmatrix}^{(k)} + \begin{bmatrix} \Delta \delta \\ \Delta V \end{bmatrix}^{(K)}$$

Step 11: Compare the errors if it meets show the results but repeat step 5.

$$|\Delta P_i^k| \leq \varepsilon = 0.001 \text{ y } |\Delta Q_i^k| \leq \varepsilon = 0.001 \text{ .}$$

Step 12: End

### 2.3.2. Particle swarm optimization Particle swarm

Optimization is a behavioral social method that Is implemented to select node location and DG capacity for this, a random population is generated with a random initial position and velocity, seeking to reach the desired optimum while complying with the restrictions that limit the search space of the particles. The group of initial particles Is evaluated using the objective function, allowing the identification of the best particle in the group, which will act as the leader. This process is repeated in each iteration. For the exploration and change of position of the particles, Eq.8 known as the flight function and defined as follow:

$$v_i^{k+1} = \omega * v_i^k + c_1 r_1 * (pbest_i - x_i^k) + c_2 r_2 * (gbest_i - x_i^k) \tag{8}$$

The updating of the position of each particle is simulated by Eq.9 (Uniyal and Kumar,2016).

$$V_i^{k+1} = x_i^k + v_i^{k+1} \tag{9}$$

When exploring the search space, the inertia of the particles is given by Equation 10, with the

result that at the beginning the search space is wide, but as the iterations increase, the space becomes smaller limiting, approaching the optimum, until reaching the maximum iteration (stopping condition) (Saha et al., 2015).

$$\omega = \omega_{max} - \frac{\omega_{max} - \omega_{min}}{iter_{max}} * iter \quad (10)$$

### Algorithm 2: Particle Swarm Optimization

Step 1: Line data entry, charging and system generation.

Step 2: Calculate initial flow by applying Newton-Raphson.

Step 3: Obtain the total power losses using Eq.2.

Step 4: Initialize the PSO data (population size and maximum number of iterations).

Step 5: Create the population with its random position and velocity for the size and location of the DGs.

$$Position \ x_i = (x_{i1}, x_{i2}, x_{in})$$

$$Speed \ v_i = (v_{i1}, v_{i2}, v_{in})$$

Step 6: Evaluate each particle in the objective function of Eq.1.

Step 7: Initialize each particle as the best individual particle (Pbest).

Step 8: Assign the best group particle (Gbest) to the best of the Pbest group.

Step 9: Limit within the minimum and maximum values of GD injection power by means of (4).

Step 10: Update the speed of each particle and its position with (8) and (9).

Step 11: Evaluate the updated particle in the objective function equation (1) and run the power flow by NR.

Step 12: Limit within the voltage values (5) and minimization of losses.

Step 13: Update the Pbest and Gbest.

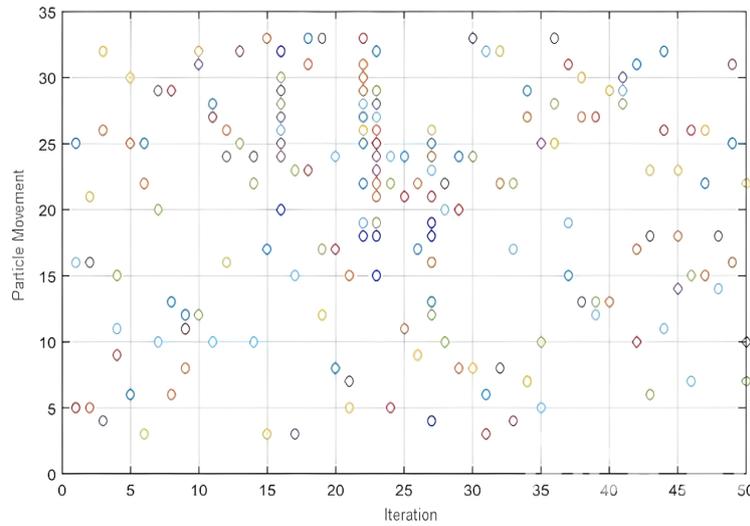
Si  $iter < iter_{max}$  Go back to step 4, visualize the optimal solution.

Step 14: End.

### 3. RESULTS AND DISCUSSION

The nodes and ability to locate from GD must be determined in order to locate and size the optimal distributed generation systems which is based on the optimization algorithm of Particles through Energy Flow which was solved by Newton Raphson. Both output variables need a finite number of n population and a maximum number of iterations to reach the solution Optimization. Fig.3 shows the different behavior of a group of particles as it passes through the proposed iterations and traverses the search space until reaching the best solution in each system scenario of a different number of DG to be implemented. The appropriate value of these

variables had to be chosen so as not to incur in a very extensive search nor to have an optimum from the beginning of the simulation. These values are shown in the Tables 4 and 5 for both the 15-node and 33-node systems.



**Fig. 3. Particle movement in each PSO iteration**

**A/ 15 Node system**

The results obtained in the 15-node system are shown in Table 4, where the location is 2 DG to avoid cost overruns for implementing a greater number of DG in a relatively small system. Losses were reduced by 36, Table 4. 249%, a minimum voltage value of 0 was achieved and 95 included within the proposed limits. These results contribute to raising voltage levels and minimizing active and reactive power losses with respect to the base case, also avoiding generation over sizing that would affect the quality and reliability conditions of the system.

**Table 4. Optimization results in the 15-node radial distribution system**

<b>Algorithm results (15 nodes)</b>		
<b>Case</b>	<b>base case</b>	<b>2 DG</b>
<b>nodes with DG</b>	-	4 ; 8
<b>DG capacity (Kw)</b>	-	265 ; 350
<b>Costs (USD)</b>	-	1172615.864
<b>Losses (kW)</b>	61.8027	39.3998
<b>Loss Reduction (%)</b>	-	36.249
<b>Execution time (s)</b>	-	5.15811
<b>N° Population</b>	-	50
<b>Maximum Iteration</b>	-	30
<b>MIN Voltage p.u</b>	0.94454	0.9557
<b>Max Deviation p.u</b>	0.0555	0.0443
<b>Average deviation of V p.u</b>	0.0419	0.0309
<b>Minimum PF</b>	0.7	0.4511

The improved voltage profile is shown in Fig. 4, where an improvement can be seen in all the nodes of the system, obtaining a notable reduction in the maximum and average voltage deviations. Results are shown in Table 4.

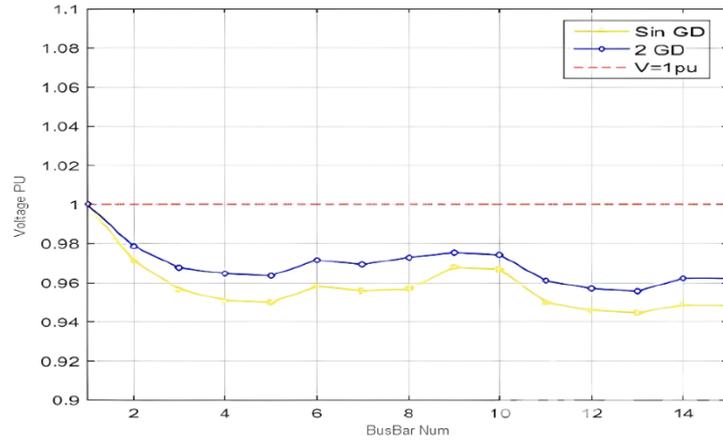


Fig. 4. Voltage profile in comparison with base case and DG

**B/ 33- node system**

The results obtained are satisfactory in the system of 33 nodes. Table 5 shows the results obtained in the reduction of losses, and they compared with the results of having 1, 2, and 3 generations installed. It can be seen that with the increase in generation points in the system, it is possible to reduce the total system losses to reduce a greater extent, fulfilling the main objective of achieving this at the lowest possible cost. Fig.5 shows the three optimal locations obtained.

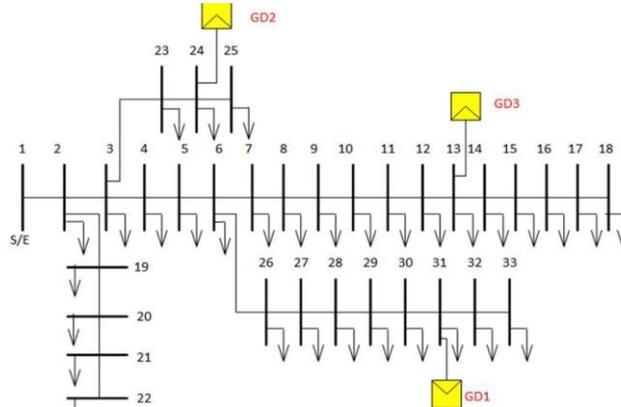
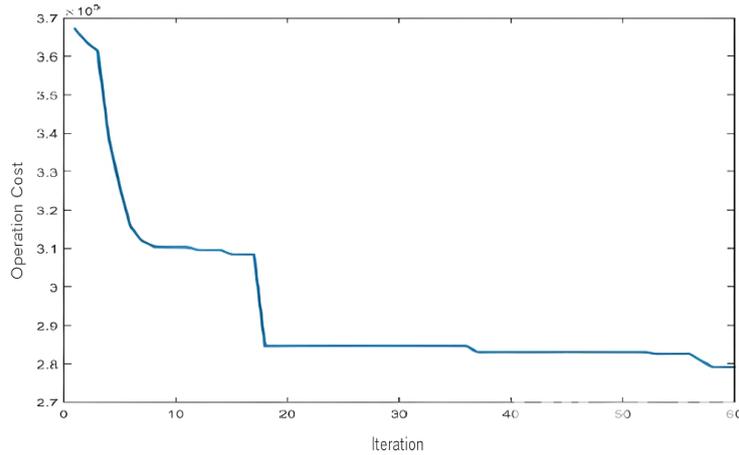


Fig.5. Location of three distributed generations in the IEEE 33-node spoke distribution system

Table 5. Optimization results in the 33-node radial distribution system  
Algorithm results (33 nodes)

Case	base case	1 DG	2 DG	3 DG
Nodes with DG	-	10	30 ; 12	31 ; 24 ; 13
DG capacity (Kw)	1215	1025 ; 930	805 ; 955 ; 800	
Costs (USD)	-	179607.50	229180.19	2792691.21
Losses (kW)	211.1965	125.2122	87.6950	75.1953
Loss Reduction (%)	-	40.7129	58.4771	64.3956
Execution time (s)	-	8.80712	17.0274	43.5604
N' Population	-	30	30	50
Maximum Iteration	-	20	30	60
MIN Voltage p.u	0.9037	0.9350	0.9620	0.9647
Max Deviation p.u	0.0963	0.0650	0.0380	0.0370
Average deviation of V p.u	0.0547	0.0317	0.0222	0.0220
FP system	0.85	0.74	0.62	0.46



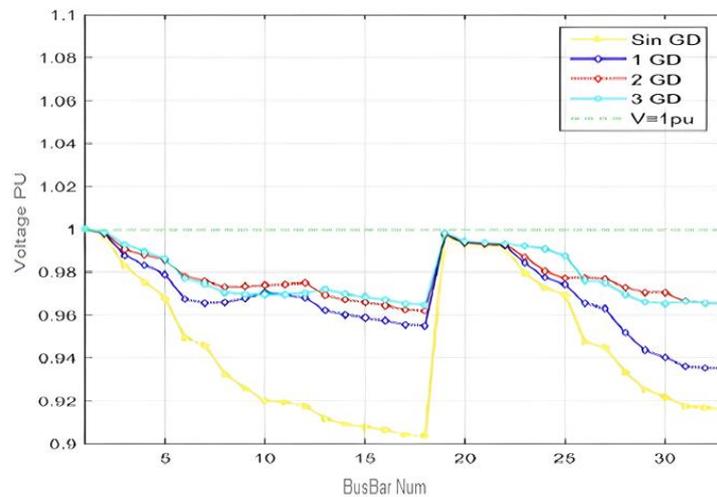
**Fig. 6. Cost variation depending on the SO iterations**

**C/ Costs**

The value obtained from costs is defined as optimal and that it complies with the restrictions of voltage, losses and injection of active power. Fig.6 shows the algorithm evolution over time and how the objective function varies in each iteration until it reaches the minimum value found. Analyzing the costs, in the case of 3 GD it can be seen that upon reaching the maximum iteration. The objective function takes a value of USD 279,269.21 The other cost values in the case of 1 and 2 DG are shown in Table5.

**D/ Node voltages**

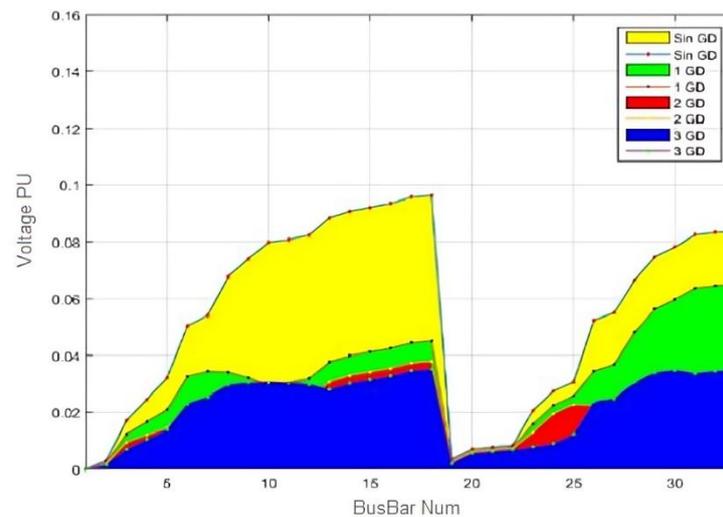
The voltage profile is improved in the 33-node system and this result is shown in Fig.7 with 62 different scenarios of amounts of generation points to install. In this Fig.7, a voltage Rise can be seen in all the system nodes, both cases of a single DG connection and for multiple DG locations. All the compared values of voltages are shown in Table 6. As the most important result, the 3DG scenario stands out, where a minimum voltage value of 0.9647 was achieved, which is significantly high compared to the initial value of 0.9037 of the base case.



**Fig.7. Voltage profiles compared to the base case and with GD**

**Table 6. Voltage comparison obtained in Matlab and the power factory of the 15 and 33 node system**

Node	Voltage Pu			
	without DG	1 GD	2 GD	3 GD
1	0.9070	1	1	1
2	0.9829	0.9790	0.9786	0.9866
3	0.9674	0.9833	0.9825	0.9881
4	0.9513	0.9697	0.9661	0.9784
5	0.9405	0.9653	0.9731	0.9776
6	0.9449	0.9663	0.9713	0.9768
7	0.9323	0.9640	0.9719	0.9753
8	0.9281	0.9643	0.9734	0.9733
9	0.9217	0.9704	0.9693	0.9741
10	0.9211	0.9708	0.9685	0.9706
11	0.9047	0.9671	0.9663	0.9710
12	0.9026	0.9612	0.9661	0.9673
13	0.9025	0.9621	0.9667	0.9671
14	0.8945	0.9573	0.9611	0.9641
15	0.8952	0.9556	0.9596	0.9645
16	0.9023	0.9568	0.9605	0.9623
17	0.9061	0.9530	0.9560	0.9655
18	0.9063	0.9538	0.9554	0.9673
19	0.9034	0.9533	0.9563	0.9667
20	0.9055	0.9645	0.9664	0.9663
21	0.8984	0.9651	0.9646	0.9653
22	0.9172	0.9668	0.9649	0.9658
23	0.9170	0.9670	0.9665	0.9668
24	0.9062	0.9671	0.9676	0.9661
25	0.9191	0.9672	0.9670	0.9663
26	0.9053	0.9676	0.9692	0.9668
27	0.9110	0.9674	0.9685	0.9677
28	0.9032	0.9684	0.9703	0.9682
29	0.9034	0.9683	0.9686	0.9678
30	0.9018	0.9675	0.9701	0.9657
31	0.9092	0.9681	0.9681	0.9655
32	0.9039	0.9670	0.9682	0.9656
33	0.9164	0.9350	0.9663	0.9652



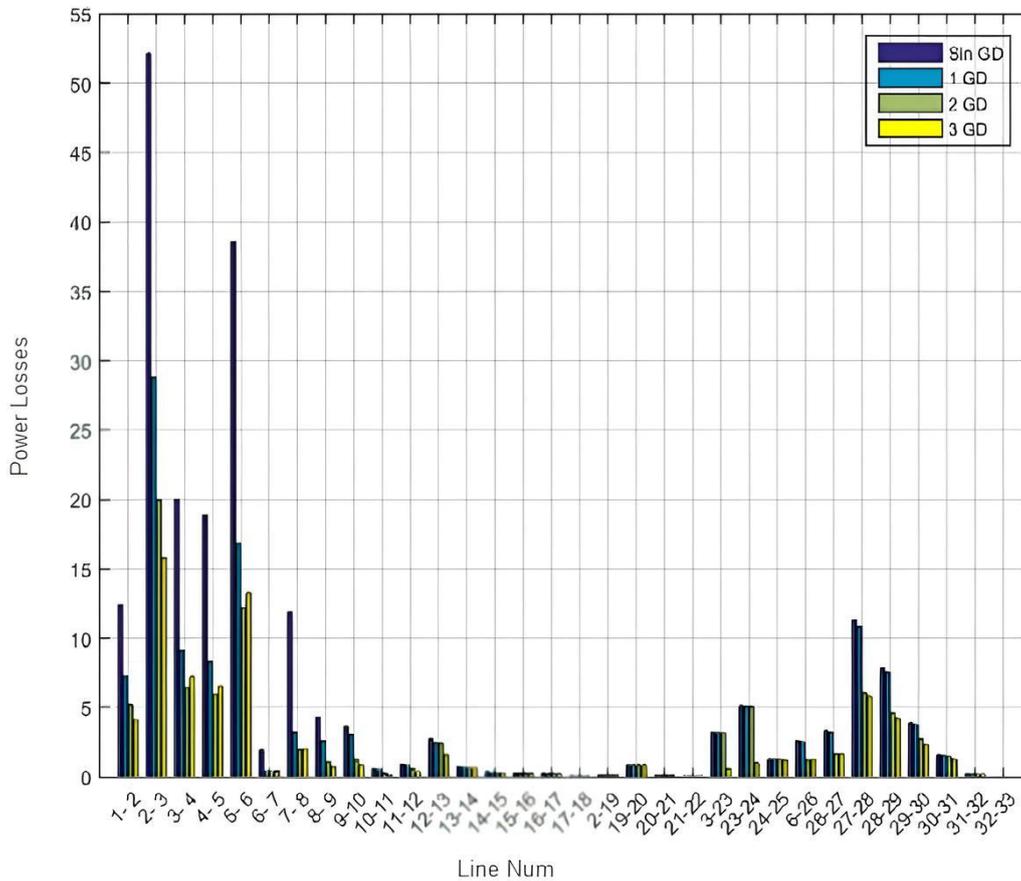
**Fig. 8. Voltage deviations at any node, comparison of the basecase and DG cases**

**E/ Voltage deviations**

The voltage gaps, Fig.8, are indicators of the voltage profile improvement achieved. The best result can be evidenced with the location of 3 GD, resulting in an average deviation of 0.0220 and a maximum deviation value reduced to 0.0353. These values compared to the other cases can be found in Table 6.

**F/ Active power losses**

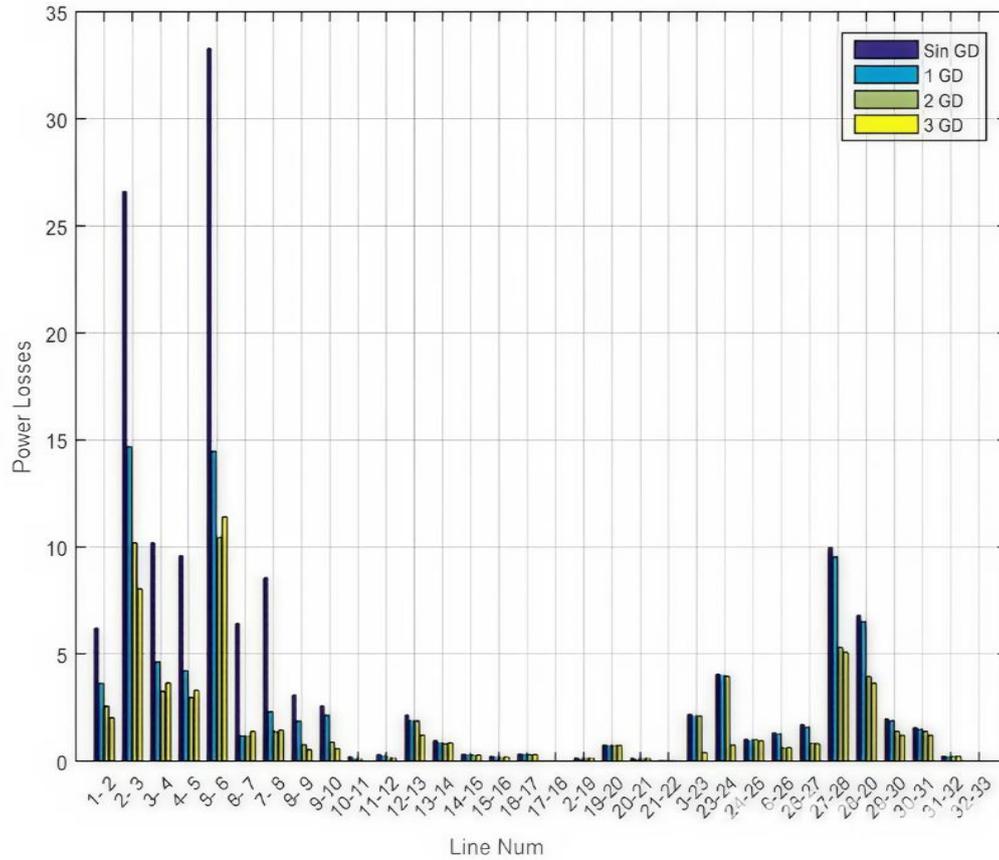
The power losses, Fig.9, show that by including active power injection DG, the flows in the lines are released compared to the centralized generation case. Therefore, in each line there is a current flow decline. The system total losses decrease, in the case of 3 DG, to a value of 75.1953kW, which represent 64.3956% reduction in active power losses. The remaining findings for the other cases can be found in Table 5.



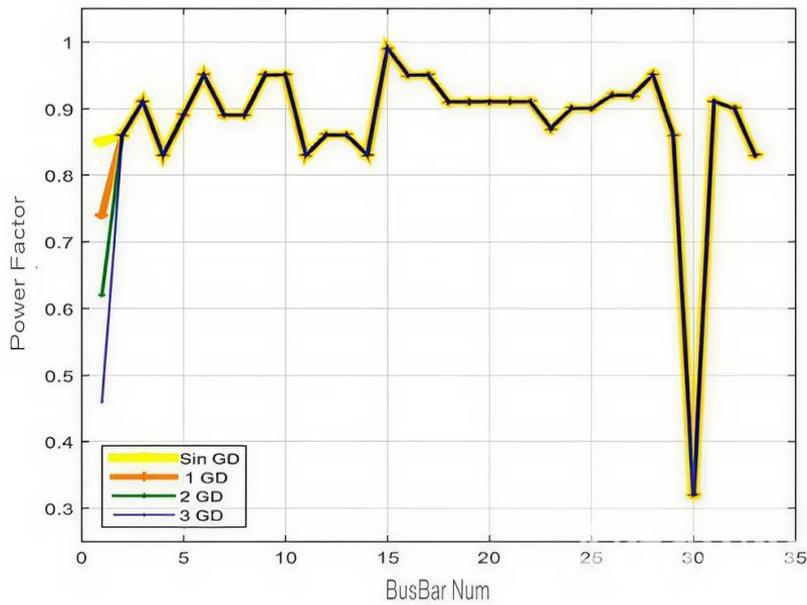
**Fig. 9. Losses of active power in each line, comparison base case with DG**

**G/ Losses of reactive power**

Fig. 10 displays the reactive power loss values in each line, which shows that only by choosing a single DG connection with a single injection of active power the losses can be reduced. The current flows and circulation distances provide a decrease in reactive power losses.



**Fig. 10. Reactive power losses in each line, and base case comparison with DG**



**Fig. 11. Power factor in each node and base comparison with DG**

**H/ Power factor**

The power factor in each node is shown in Fig.11, where a clear decrease can be seen in the grid connection node, due to having only active generation implementation, which increases

the angle of the power triangle for having an almost constant reactive power for which the power factor decreases. The results are shown in the [Table 5](#).

#### **4. CONCLUSION**

In this work, the optimal location, selection and dimensioning of photovoltaic distributed generation in radial distribution systems with restriction of single and multiple generation connection was implemented. With the proposed methodology, it was possible to minimize system losses and improve the voltage profile, complying with the minimum cost criteria as the main objective proposed.

The power flow calculated in Matlab was corroborated with simulations in Dig SILENT Power Factory applying the complete Newton Raphson method, obtaining the results of active and reactive powers, node voltages and total system losses.

The model for the optimization of power flows in distribution networks based on the optimal location and dimensioning of the DG allowed obtaining novel and important results of improvements in the analysis variables. Study scenarios were defined through restrictions on the number of generations to be connected and very important results were achieved in improving voltage profiles and reducing losses. The proposed methodology is generic and can be applied to any electrical power.

As further research, we are in the process of developing a platform (dashboard) allowing the monitoring and the selection in real time of the most appropriate maintenance strategy for the she studied distribution system . The developed dashboard permit real-time data display and allows the supervisor to control the the studied network through a graphical interface.

#### **FINANCIAL AND ETHICAL DISCLOSURES**

This study was not funded by any company or organisation

#### **DATA AVAILABILITY**

The data used to support the findings of this study are included within the article.

#### **CONFLICTS OF INTEREST**

The authors declare that there are no conflicts of interest regarding the publication of this paper

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