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Using PSO Algorithm to Find Optimal Number and Location by Connecting Distribution Generators to Improve the Iraqi 400 kV Super Grid

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Abstract

Nowadays, it is crucial to assess power system contingencies resulting from line outages or generator failures, as they might cause breaches of system constraints. This is a vital part of ensuring the security of modern power supplies. Another hindrance to providing electricity to consumers is the increased system losses and voltage fluctuations resulting from increased demand and diminished power generation capacity. The DG connection is a crucial subject regarding these harmful consequences. This study is focused on clarifying the effect of distribution generators (DG) on mitigating congestion in electrical power transmission lines, minimizing power losses, and enhancing the voltage profile of the Iraqi national grid system. An optimization method is used to identify the optimal size and position based on fitness indicators such as voltage, power losses, and line congestion. The PSO algorithm is executed as proposed. The outcomes illustrate the effectiveness of the proposed technique for estimating the optimal size and placement of distributed generators (DG). At the same time, it reduces congestion and improves the voltage level of the bus. The proposed technique was implemented using the MATLAB/R2018a programming language.

Keywords: Distributed generation (DG), Particle swarm optimization, Iraqi super grid 400 kV.

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1. Introduction

The continual rise in power consumption, combined with the constraints on expanding transmission networks owing to economic and environmental constraints, has resulted in a power grid operating near equilibrium's critical limits. Because these high conditions will lead voltages to fail, device reliability has become an essential consideration as an elevated concern for overloaded lines. Increasingly, electrical networks are utilizing Distributed Generators (DG) to satisfy the growing demand. Distributed generation refers to the localized electricity production on a small scale, close to the intended consumption region. It typically produces from less than a kilowatt to several hundred megawatts.

In contrast, central power systems are larger and more centralized. It does not belong to the central power system, which pertains to the production of electricity on a massive scale at concentrated facilities. These installations are often situated at a considerable distance from demand and connected to a high-voltage distribution network, with capacities ranging from (MW) to (GW) [1]. In order to reduce losses, costs, voltage challenges, and congestion in power transmission lines, the proposed approach is to apply it to interconnect generators located on the distribution grid side to meet the power requirements on the load side [2]. The intricacy of the grid's operations and regulations has also increased due to the significant expansion of electric power networks. Power networks sometimes encounter unplanned interruptions, including substantial variations in demand, short circuit faults, transmission line failures, system outages, and generator problems [3-5]. The flexibility of the electrical network depends on its capacity to manage unplanned disruptions or contingencies while ensuring uninterrupted customer service [6]. Every circumstance inside the contingency set will lead to an excessive load on the transmission line and breach the bus voltage restrictions during operations. It is essential to identify these unexpected events to swiftly carry out a thorough evaluation. The method of analysis used for emergency detection is called the contingency solution. Considering the possibility of a line or a generator failure due to using the highest potential AC load flow program [7]. The Genetic Algorithm (GA) improves the voltage profile approach and minimizes loss. To maintain a high-efficiency level in the most demanding conditions, optimizing the rating of the DG unit by analyzing the active values of power flow performance indicators [8] is necessary. Improvement of voltage levels, enhancement of energy performance, and reduction of losses are specific consequences of DG units in distribution networks. In order to achieve optimal sizing and optimization, the DG machine will now gather a massive amount of research publications [9]. The approach adopted utilizes determining a factor value based on the ratio of changes in line load flow between two buses. This factor identifies and controls congested lines regarding located distribution generators [10]. Particle Swarm Optimization (PSO) estimates an ideal location and the ideal capacity to use distributed generation (DG) to relieve congestion on the power lines [11]. The implementation entails employing like Ant Colony Algorithms and Genetic Algorithms to ascertain the optimal allocation and scalability of Distributed Generation (DG) systems. This study investigates the active power losses linked to the power provided by generators as various generation levels are included from distributed generation (DG) [12].

2. Contingency assessment

Monitoring security against many risks is paramount in the electric grid setting. A significant risk was the violation of its transmission line limitations. An index was created to determine if the analysis of each line's series surpasses or meets the limitation for lines (MVA) to identify and avoid this problem by the operator's system. Contingency assessment involves evaluating the outcomes of exceeding line limits. This study employed the (N-1) approach, where N indicates an outage or failure in the power line or generator. The Real Power Flow Performance Indicator (PI_{RPF}) is a well-known indicator, and its formula is represented by equation (1) [8].

$$(PI_{RPF})^i = \sum_{\substack{all \\ branches}} \left(\frac{w_l}{2n}\right)\left(\frac{P^{(i)}_{flow\ l}}{P^{(max)}_l}\right)^{(2n)} + \sum_{j=1}^{N_{bus}} \left(\frac{w_j}{2n}\right)\left(\frac{\Delta V^{(i)}_j}{\Delta V^{(limit)}_j}\right)^{(2n)} \quad (1)$$

$$\Delta V^{(i)}_j = V^{(i)}_j - V^{(limit)}_j \quad (2)$$

$$V^{(limit)}_j = V^{(max)}_j, \forall V^{(i)}_j \geq 1.0 \quad (3)$$

$$V^{(limit)}_j = V^{(min)}_j, \forall V^{(i)}_j < 1.0 \quad (4)$$

$$V^{(i)}_j = V^{(max)}_j, \forall V^{(i)}_j > V_{max} \quad (5)$$

$$V^{(i)}_j = V^{(min)}_j, \forall V^{(i)}_j < V_{min} \quad (6)$$

$$\Delta V^{(limit)}_j = \frac{V^{(max)}_j - V^{(min)}_j}{2} \quad (7)$$

While, i = 1 to N_{line}, $(PI_{RPF})^i$ refers to the outage's performance indicator for active power, w_l and w_j refers to line weighting factors l and bus j, correspondingly selected by the administrator based on the systems' operational state, $P^{(i)}_{flow\ l}$ refers to the line flow of the l th line for i th outage, a $P_l^{(max)}$ refers to the highest possible rating of the l th line, N_{bus} Refers to the total number of buses, and the term ($2n$) refers to the order of the active power performance index, which is considered 2.

3. Computing line losses

Any line connecting buses i and j will have power losses equal to the total power flows, as shown in equation (8) [13].

$$S_{Lij} = S_{ij} + S_{ji} \quad (8)$$

The total system losses can be determined by applying Eq. (9) to the sum of all line losses.

$$Losses = \sum_{K=1}^{N_{line}} S_L(K) \quad (9)$$

Where S_L is a loss of one branch, N_{line} refers to the total lines, K refers to a specified line.

4. Optimization and the objective function

Particle swarm optimization (PSO) is utilized to identify the most suitable location and capacity for Distributed Generation (DG). Optimization methods refer to performance indices to determine the most suitable location and capacity of Distributed Generation (DG), thereby reducing active power loss, optimizing the performance index, and mitigating voltage deviation. The equation (10) represents the objective function.

$$Minf = W_1 \sum_{i=1}^{N_{bus}} (V_{ref} - V_i)^2 + W_2 \sum_{j=1}^{N_{line}} P_{Lj} + W_3 \sum_{\substack{all\ congested \\ branches}} PI_{RPF} \quad (10)$$

Where V_{ref} refers to the reference voltage, V_i refers to the voltage of i th bus, P_{Lj} refers to the active power losses at j th line, N_{bus} refers to the total busses' number, N_{line} refers to the number of total lines and W_1, W_2, and W_3. Targets are weighted according to deviations in voltage, losses in active power, and performance index of active power.

5. The components of PSO

The fundamental components of PSO can be explain as follows [13]:

5.1. Particle s^k_{id}

The individual's control factors are currently located at i = 1, 2, 3, …. n, d = 1, 2, 3, …… m, n respectively, describe the number of control factors and the number of nominee particles for each control variable. Thus, the control variables can be represented as a vector [S_1, S_2, S_3, … S_n], Subsequently, the particles of n^{th} for the independent variables S_n are (s_{n1}, s_{n2}, s_{n3}, …, s_{nD}). Every particulate is linked to a specific detector inside the search's conclusion region.

5.2. Particle velocity v^k_{id}

The instantaneous velocities of the particles contributing to the swarm population during iteration k are called particle velocities.

5.3. Optimal individual position ($pbest_{id}$ *)*

The individual best position, also known as the local or personal best location, is the optimal location that offers the highest appropriateness value for every single particle.

5.4. The global best site ($gbest^k_i$ *)*

Global best refers to the most optimal position reached among all individual positions. In contrast, $gbest^k_i$ refers to the overall best position between individual locations, the individual best position (i.e., global position) for i th control variable at iteration k.

5.5. Updating

1. Velocity v^{k+1}_{id}

The particle velocity can be updated using the following equation (11):

$$v_{id}^{k+1} = w\, v_{id}^{k} + c_1 \times rand_1 \times \left(pbestidk - s_{id}^{k}\right) + c_2 \times rand_2 \times \left(gbestik - s_{id}^{k}\right) \quad (11)$$

In which v_{id}^{k} is the current particle's velocity during the repetition k. v_{id}^{k+1} is the particles' update velocities at repetition $k + 1$. s_{id}^{k} is the particles' location at repetition k. w is the inertia weight. c_1 and c_2 are arbitrarily chosen numbers. $rand_1$ and $rand_2$ are uniformly distributed randomly amidst [0,1]. k is the number of iterations.

The algorithm will set the particle's velocity to the limit that was violated if it strays from the allowed velocity range.

2. Position

The recent place can be efficient by employing the expression that follows:

$$s_{id}^{k+1} = v_{id}^{k} + v_{id}^{k+1} \quad (12)$$

The algorithm will move the particle to a new location if it detects that it crossed one of the position boundaries.

5.6. Weight of inertia

The weight value should be chosen to balance local and global searches. Accelerating the convergence strategy requires choosing many weight factors in the initial iteration stages, subsequent iterations gradually decrease the weight factor, as shown in equation (13).

$$w = w_{max} - k\,\frac{(w_{max} - w_{min})}{K_{max}} \quad (13)$$

Where $w_{max} = 0.9$, $w_{min} = 0.4$, k represents the current iteration number, K_{max}. It denotes the highest possible number of iterations [14].

6. Results and discussion

The suggested methodology is used on the 400 kV Iraqi super grid [15]. The parameters for the Particle Swarm Optimization (PSO) method are as follows: the population size is set to 50, the number of iterations is set to 50, the maximum inertia weight (w_{max}) is set to 0.9, the minimum inertia weight (w_{min}) is set to 0.4, and both acceleration coefficients (c_2 and c_1) are set to 2. When the (N-1) technique is performed, the network experiences three contingencies. Based on the data reported, according to Table 1, lines 30 (15-20) and 31 (15-20) (AMN4-KUTP) are considered demanding lines. Lines 30 and 31 refer to the interconnection of busses 15 (AMN4) and 20 (KUTP).

Table 1. Contingency results from the application of the objective function.

Branch No.	From bus to bus	*PI* of power	*PI* of voltage	Total of PI_{RPF}	The Congested lines
30	15-20	1.2344	1.8025	3.0369	(31) (15-20) (AMN4-KUTP)
31	15-20	1.2344	1.8025	3.0369	(30) (15-20) (AMN4-KUTP)
20	11-16	1.1403	1.3025	2.4428	(25) (12-15) (BGE4-AMN4)

The research approach utilizing the proposed Particle Swarm Optimization (PSO) enables the alleviation of congestion lines, reduction of losses, enhancement of the voltage profile, and minimization of load flow. This is achieved by strategically connecting a certain number of Distributed Generation (DG) units in the grid to achieve these objectives. The primary size of the generator will decrease. between 0 and 1000 MW collectively. Each group corresponds to one-dimensional generators and contains several instances of them. Table 2 and Figs. 1 and 2 display the reduction of congestion on three lines to avoid congestion and decrease losses when employed by the Particle Swarm Optimization (PSO) method. Starting from the base scenario, the losses are decreased from (46.22 + j413.06) MVA to (17.63 + j153.73), (14.54 + j125.7), (14.21 + j122.6), and (17.18 + j149.34) MVA, respectively. As a percentage, the losses have decreased to 61.84%, 68.54%, 60.26%, and 62.82%, respectively. Linking one of DG, two of DGs, three of DGs, and four of DGs improves the voltage profile by reducing the voltage deviation from 0.01361 to 0.01335, 0.01322, 0.01316, and 0.01331, respectively.

Table 2. Comparison of network performance with and without DG using PSO.

Cases	PSO - The suggested approach for 400 kV Iraq grid					
	P Loss (MW)	Q Loss (Mvar)	The congested lines	DG site bus	DG size (MW)	Voltage Deviation (VD)
Excluding DG	42.42	413.06	3	—	—	0.01361
With 1 DG	17.63	153.73	0	10	1000	0.01335
With 2 DG	14.54	125.7	0	10	1000	0.01322
				18	455.6	
With 3 DG	14.21	122.6	0	18	644.3	0.01316
				10	1000	
				29	195.1	
With 4 DG	17.18	149.34	0	27	5.9	0.01331
				35	0	
				29	397.4	
				10	1000	

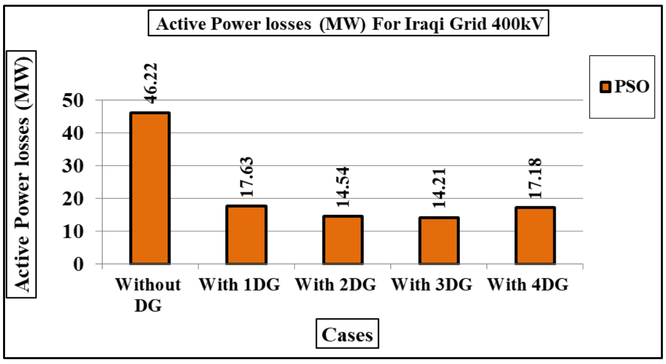

Fig. 1 Demonstrates the outcomes of minimizing active losses in the 400 kV Iraqi grid by utilizing PSO.

Figures 3 and 4 illustrate the decrease in power flow resulting from integrating distributed generators (DGs) into the network. Specifically, the power flow decreased from 10890.63 MVA in the base case to 6910.79 MVA after 4 DGs were connected. Furthermore, the percentage reduction has been augmented from 27.86% to 36.54%.

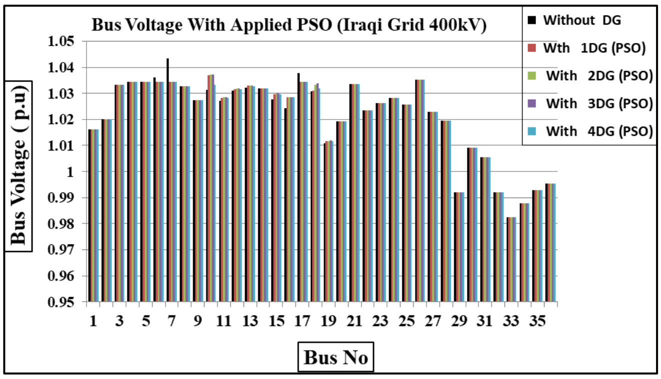

Fig. 2 Analysis of the bus voltage with and without DG using PSO.

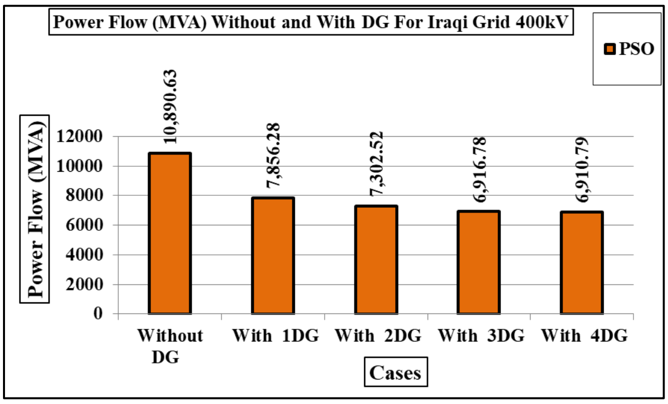

Fig. 3 Power flow (MVA) without and with DG For Iraqi grid 400 kV.

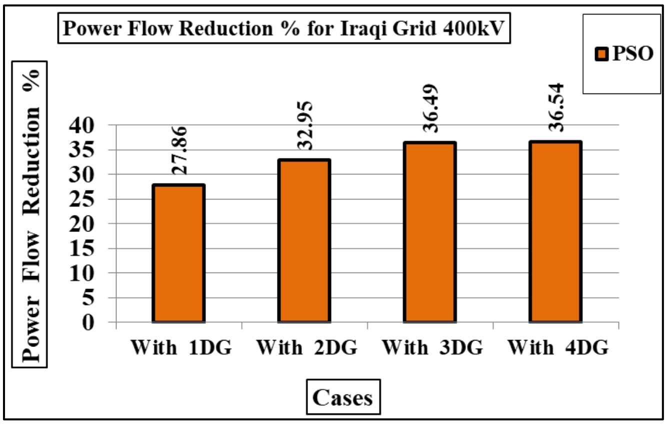

Fig. 4 Percentage reduction in power flow for the 400 kV Iraqi grid with distributed generators DGs.

Loading 5% and 10%, in order to investigate the possibility of increasing the load on the grid. Greater loads were applied by 5% from the typical scenario of (8803.9 + j 3135.8) MVA to (9244.1 + j3292.59) MVA. Furthermore, the loads increase by 10%, resulting in a total of (9684.29 + j3449.38) MVA. This resulted in heightened congestion on lines 4 and 11, financial losses, and a decrease in voltage, as exposed in Table 3 and Figs. 5 and 6. Upon linking the Distributed Generation (DG) units in sequential order to inject active power, observed a significant enhancement in the bus voltage levels from bus 10 to 19 consecutive. The losses decreased from (63.37 + j569.04) MVA to (16.44 + j143.18) MVA with a reduction of 5%, and from (84.95 + j764.84) MVA to (15.85 + j136.88) MVA with a reduction of 10%. The number of congested lines has been lowered from 4 and 11 lines to 5% and 10% without any lines, respectively.

Table 3. The effects of network loads with and without distributed generation.

Cases		Loading (MW)	Loading (Mvar)	Total Losses (MW)	Total Losses (Mvar)
Base case	without any loading	8803.9	3135.8	46.19	413.08
Load increase of **5%** with PSO	Without DG	9244.1	3292.59	63.37	569.04
	With 1DG	8244.1	3292.59	25.32	223.28
	With 2DG	7510.4	3292.59	19.69	172.12
	With 3DG	6872.8	3291.94	15.61	135.1
	With 4DG	7348.17	3292.77	16.44	143.18
Load increase of **10%** with PSO	Without DG	9684.56	3449.18	84.95	764.84
	With 1DG	8684.29	3449.38	37.05	329.84
	With 2DG	7684.3	3449.38	23.32	204.65
	With 3DG	7375.9	3449.38	17.23	149.3
	With 4DG	7383.8	3449.38	15.85	136.88

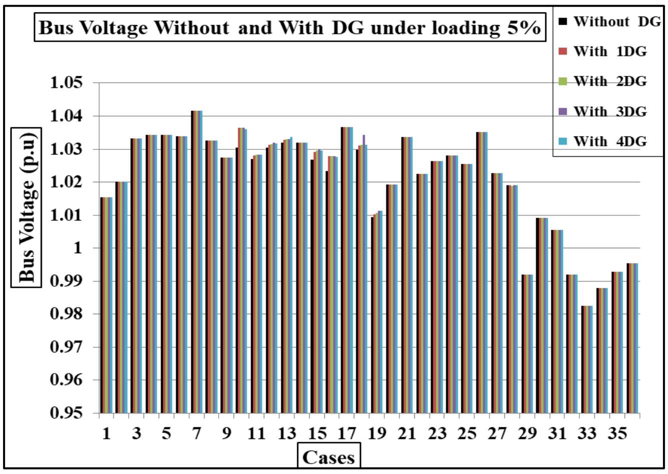

Fig. 5 Analysis of the bus voltage with and without DG while loading 5%.

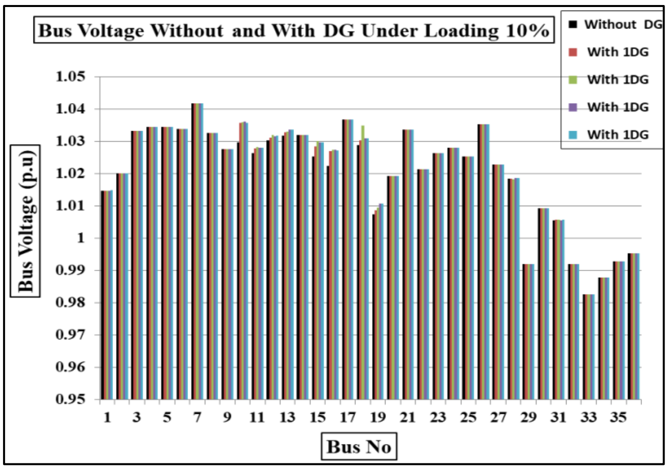

Fig. 6 Analysis of the bus voltage with and without DG while loading 10%.

7. Conclusions

The research paper applies the Particle Swarm Optimization (PSO) technique to analyze the impact of an emergency generator outage and a single line outage on the 400 kV Iraqi power network. PSO demonstrated its efficiency by successfully integrating 1DGs, 2DGs, 3DGs, and 4DGs into the Iraqi Grid. This integration resulted in the elimination of congested lines, lowering them from three lines to none.

In addition, losses decreased significantly from (46.22 + j413.06) MVA, which is refer to the standard case to (17.63 + j153.73) MVA, (14.54 + j125.7) MVA, (14.21 + j122.6) MVA, and (17.18+j149.34) MVA, where the percentage decrease was 61.85%, 68.54%, 69.26%, 62.83%. Also, the load flow rates decreased to 27.86% to 32.95%, 36.49%, and 36.54% by integrating 1DGs, 2DGs, 3DGs, and 4DGs into the Iraqi Grid.

Subsequently, the voltage profile was enhanced as the voltage deviation indicates (VD) presented in Table 2 and Fig. 2. Based on this analysis, The conclusion is that it is possible to upgrade and improve network performance after adding distribution generators. This was evident in various aspects, such as the reduction of fuel costs, the decrease in air pollution emissions, and the potential to increase its ability to handle load by adding more loads.

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