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Optimal integration of Renewable based Distributed Generators via Hybrid GA-PSO approach

Rupika Gandotra*(C.A.) and Kirti Pal*

Abstract: The rising demand for electricity has led to the installation of renewable-based distributed generators in a power system network to meet the increasing load. The eco-friendly nature of these DGs is another compelling reason to incorporate them in a power system network but their installation process requires careful consideration such as determining the optimal quantity and location because these factors have a significant impact on various constraints and parameters of the power system network. The main objective of this paper is to determine the optimal siting and sizing of Type-1 and Type-2 DGs in a power system network such that network has minimum real and reactive power losses in the transmission lines, also fuel cost of convectional generators is reduced and voltage profile is improved. For this purpose, hybrid GA-PSO approach is developed and implemented on case 33 bus system and results were compared under different loading conditions such as 100%, 150%, 200% to show which type of DG is most effective. Further, the evaluated results have been compared with other algorithms including OCDE, WOA, SFSA, TGA and EJSA in order to ensure the validity of the suggested approach. The numerical results validate the performance of this proposed technique for DG unit placement.

Keywords: Renewable-based Distributed Generator, clean energy, transmission line power losses, voltage profile improvement, fuel cost, MATPOWER

Nomenclature

ACA	Ant Colony Algorithm
ACO	Ant Colony Optimization
ALO	Ant Lion Optimization
ANFIS	Adaptive Neuro-Fuzzy Inference System
BB-BC	Big Bang-Big Crunch algorithm
BFOA	Bacterial Foraging Optimization algorithm
BSOA	Back Search Optimization Algorithm
CSA	Cuckoo Search Algorithm
DC	Direct Current
DG	Distribution Generation
DS	Distribution System
DP	Dynamic Programming
FA	Firefly Algorithm
GA	Genetic Algorithm
GOA	Grasshopper Optimization Algorithm
GSA	Gravitational Search Algorithm
HHO	Harris Hawk Optimizer
MINLP	Mixed Integer Non-Linear Programming
OCDE	Opposition based Chaotic Differential Evolution
PSO	Particle Swarm Optimization
SIMBO	Swine Influenza Model-Based Optimization
SKHA	Stud Krill Herd Algorithm
SFSA	Stochastic Fractal Search Algorithm
TGA	Tree Growth Algorithm
TLBO	Teaching Learning Based Optimization
UPQC	Unified power quality conditioner
WISPO	Weight Improved Particle Swarm Optimization
WOA	Whale Optimization Algorithm

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* The authors are with the Department of Electrical Engineering, Gautam Buddha University, Greater Noida, India.
E-mails: rupikagandotra01@gmail.com, Kirti.pal@gbu.ac.in.
Corresponding Author: R. Gandotra

1 Introduction

1.1 Background and Motivation

THERE are numerous benefits of installing DG units which includes to economical, technical and environmental ones. Clean energy is produced by photovoltaic systems and wind turbines DGs which are often known as renewable based distributed generation. The reduction of fuel savings, distribution and transmission costs and electricity prices are examples of the economic and environmental benefits. Voltage profile improvement and power loss reduction are the technical benefits that can be inferred. In this paper, two types of DG units have been introduced. Type-1 DG is producing real power only like solar photovoltaic and fuel cells. These systems inject active power into the grid at unity power factor, meaning that the power they produce is fully utilized by the load without any phase difference between voltage and current. Type-2 DG provides both real and reactive power generation. DG systems such as internal combustion engines, gas turbines, steam turbines and micro-turbines, supply both active and reactive power to the electrical grid. These systems typically operate with a lagging power factor indicating that the current lags behind the voltage in terms of phase angle. Customer's and utility's awareness of power quality may rise as a result of the growing demand for dependable, high-quality electricity and the rise in loads. DG units are therefore regarded as a convenient option for these problems [1, 2]. The best placement of the DG units within power system network is critical aspect of their effective deployment as it can significantly impact system performance and operation. By strategically locating DG units, utilities and system operators can mitigate grid constraints, reduce transmission losses, improve voltage stability and support renewable energy integration. However, determining the optimal locations for different types of DG technologies presents a complex optimization problem, influenced by factors such as load profiles, grid topology, generation capacity, economic considerations and environmental constraints. DGs, which include non-fossil fuel sources such as solar photovoltaics, wind turbines and micro-turbines as well as conventional generators have the potential to offer localized power generation and voltage support within DS. Optimal placement of DGs plays a crucial role in maximizing their benefits while minimizing system losses and improving overall network performance. The inclusion of DG sources within utility DS presents a dual scenario of opportunities and challenges for power utility companies [3]. DG sources offer numerous benefits including losses reduction, enhancement of voltage profiles, improved reliability, high load demand management, savings of cost and the promotion of sustainable energy infrastructure. Although, integrating DG sources into DS introduces complexities due to the inherent variability of the power they generate. The DS originally designed for one-way power flow to consumers, transition into active systems with bidirectional power flow upon DG integration [4]. Enabling the sustainable operation of the DS and grid stability requires effective management and control of this integration [5]. Optimizing the placement and sizing of DG sources is vital before their integration with the utility grid. Strategically locating and appropriately sizing DG sources can help mitigate power losses, enhance voltage profiles, minimize interruptions and improve the reliability of grid and consumer side satisfaction [6-8]. On the other hand, incorrect DG source installation and sizing may result in higher power losses and problems with the voltage variation which will negatively affect DS reliability and customer service. Power systems prioritize reliability, which consider the capability of a system or equipment to fulfil its projected role for a precise duration under stable conditions [9]. Failures within DS significantly contribute to power outages, making DS reliability a top priority for utility companies and operators [10,11]. Reliability analysis plays a critical role in assessing DS effectiveness and suggesting necessary improvements. Hence, to minimize interruptions and ensure a consistent supply of power to end-users, it is crucial to conduct research on power losses occur in distribution lines and reliability assessment in DS network with DG units. Thus, looking into the importance of DG integration for power system sustainability and losses is imperative for effective DS operation, planning and design.

1.2 Analytical techniques for DG placement

One of the crucial tasks that have a big impact on the stability, dependability and efficiency of a DS is placing DG in the best possible locations. The literature review mentions a number of approaches that have been employed to tackle this optimization problem while taking various goals and constraints into account. In [12] a novel VSI was introduced to locate optimal DG locations with the ideal DG size for the minimization of losses. The increased load impact is also studied with DGs placement. Similarly, in [13] an approach based on continuous power flow was employed to optimize DG placement, focusing on replacing buses with lower voltage safety levels. This strategy attempted to lower network losses and improve voltage stability. In [14] various voltage maintaining and stabilizing techniques were utilized to optimize DG placement by the aim of minimizing voltage stability limits and network losses. Additionally, [15] proposed a method to simultaneously increase voltage stability and reduce losses by selecting vulnerable buses through bifurcation analysis for DG installation and optimizing DG sizes using dynamic programming. [16] as a reference point for DG installation, the power stability index was used with optimal DG sizes selected to minimize network losses. The proposed algorithm improved voltage profiles and reduced losses compared to existing methods. Furthermore, [17] presented a method of analytical and loss sensitivity factor for ideal DG placement, while [18] proposed a new index, the DG placement index which combines voltage stability, loss sensitivity, and reliability factors to select optimal DG locations and sizes. Finally, in [14] a hierarchal placement algorithm based on voltage stability analysis was presented, along with a modified reactive compensation method for prioritizing DG locations during reactive power shortages. These studies contribute to the advancement of DG placement optimization, offering diverse approaches to address the multiple challenges of enhancing power system performance and reliability.

1.3 Metaheuristic techniques for DG placement

Different population search algorithms have been proposed to address optimization objectives in recent years, leading to a widespread adoption of DG in power system network. In order to decrease voltage deviation and power loss, algorithms for instance GA-PSO [19], BSOA [20] and ACA [21] have been employed. Conversely, to optimize power loss diminution and enhance voltage profile with network stability PSO [22], CSA [23], FA [24], WOA [25,26] and SKHA [27] have been utilized. Additionally, algorithms like ALO [28], TLBO [29], HHO [30], and SIMBO [31] have been taken into consideration to optimize stability, voltage profile and power loss diminution. The BB-BC move towards [32] has been utilized to optimize reserve capacity, voltage profile index and power loss diminution. To cover economic benefits, algorithms such as BFOA [33], ACO [34], DP [35], MINLP [36], WIPSO [37] combined with GSA [38] and hybrid optimization algorithms combining PSO with GOA [39] have been proposed. This approaches OCDE technique for techno-economic analysis [40, 41] aim to minimize operating costs, DG investment, and operation costs considering factors such as reduced power purchase, improved reliability, and DG installation, operation, and maintenance costs. In standalone DG based grid, PSO is cascaded with ANFIS approach for maximum power point tracking and load voltage regulation [50]. In [51] an effective control strategy is proposed to interface PV system with multilevel inverter. Energy is effectively produced from the regions of high solar and wind potential using rotary system [52]. When power system stabilizers and FACTS controllers such as STATCOM and SSSC is integrated with solar and wind-based grid, then network performance is improved by keeping the voltage and frequency within limits [53]. When wind energy, solar energy and battery system is integrated in grid, the flow of power is effectively managed in a smart grid using intelligent controller approach [54]. These renewable based energy sources have intermittent nature due that power generation is not constant which causes fluctuations. When power flow of hybrid wind energy and fuel cell is controlled using doubly fed induction generator and DC link topology then system power is enhanced [55]. Frequency fluctuation problems due to wind turbine's power generation, were alleviated with the use of non-linear controller [56]. When FACTS controller UPQC is integrated with distributed energy sources, improves fault ride capabilities [57]. Distributed sources biomass and solar energy is integrated in power system network and with the help of electric vehicles the intermittent nature of solar energy is controlled [58].

Overall, literature showcases diverse range of the optimization approach tailored to specific objectives in ideal installation of DG into DS. This paper aims to review and analyze existing methodologies, tools and case studies related to the optimal installation of dissimilar types of DG in DS, providing insights into the challenges, opportunities and best practices for integrating DG effectively into modern power systems. By accomplishing a thorough study of existing literature and experimental data, this article intends to support the creation of well-informed frameworks and guidelines for the planning and implementation of DG infrastructure in power systems across the globe.

Table 1 shows the comparison between previous work done and the proposed work. Many researchers focused on reducing system power losses without accounting for the fuel costs associated with conventional generators (fuel-based generators). Even though certain researchers [46-49] included these costs in their work, but their focus was solely on enhancing the voltage profile and not enough on lowering system losses and expenses. Also, the literature survey also shows that researchers have installed DGs only under 100% (normal) loading condition.

1.4 Main contribution of this research

- Case 33 bus system is installed with two different DGs: Type-1, Type-2 and then the system performance is evaluated under three loading conditions.
- Minimization of fuel cost of conventional generators, real and reactive power losses reduction with voltage enhancement are the objective functions considered in this study.
- Optimization problem of multi-DGs placement and their sizing is done by proposing a hybrid GA-PSO technique.
- Validation of proposed hybrid GA-PSO approach is done by comparing with another existing techniques.
- Results summary shows the comparison between two types of DGs on the basis of parameters such as fuel cost of conventional generators, real power losses, reactive power losses and voltage magnitude under different loading conditions and best DG is concluded.

Table 1. Comparison of proposed research article for case 33 bus system with existing work

References No.	Technique	DG units	Voltage deviation minimization	Power loss minimization	Fuel Cost of conventional generators	Loading Scenarios
19, 21, 24,25, 28, 30, 33, 34, 35,38	GA-PSO, ACA, FA, WOA, TLBO, SIMBO, ACO, DP, MINLP, GOA	1	Yes	Yes	No	100%
22	PSO	3	Yes	Yes	No	100%
23	CSA	3	Yes	Yes	No	100%
26	WOA	3	Yes	Yes	No	100%
27	SKHA	3	Yes	Yes	No	100%
28	ALO	2	Yes	Yes	No	100%
30	HHO	3	Yes	Yes	No	100%
33	BFOA	3	Yes	Yes	No	100%
37	WIPSO	3	Yes	Yes	No	100%
Proposed article	GA-PSO	4	Yes	Yes	Yes	100%, 150%, 200%

1.5 Organization of the paper

This paper is presented in six sections; the introduction and brief literature survey is covered in section one. Section two presents the brief theory of GA, PSO algorithm and proposed Hybrid GA-PSO technique. Section three discusses about the results and effect of integration of two types of DG units for the improvement of voltage profile and reduction in power losses using proposed approach and their comparative results are shown at different loading conditions. The section four discussions present the assessment of proposed effort with previous study. Conclusions of presented work and future work is elaborated in section five and section six respectively.

2 Methodology

2.1 Genetic Algorithm (GA)

GA is the evolutionary algorithm based on the Darwin's reproduction and survival of the fittest theory. The GA creates a population's genetic composition by using fundamental reproduction operators which includes crossover and mutation. Crossover process refers to the way chromosome strands cross over during chromosome exchange and rearrangement, resulting in offspring that carry a combination of information from each parent. Mutation is the process that creates population diversity. GA is based on following steps as Firstly a population of potential solutions is initialized then crossover and mutation operators are used to generate new solutions. From the pool of solutions, fitness is evaluated and the best solution is selected and then pass into the next generation. After that, the process is repeated till maximum iterations. The algorithm then finds the best value of individual who is the ideal solution to the given optimization problem after a number of iterations or generations. Hence, when it comes to transferring helpful features from one generation to the next, GA is quite helpful.

2.2 Particle Swarm optimization (PSO)

PSO is classified in the category of swarm intelligence algorithms from the distinct classes of metaheuristic algorithms. In 1995, Eberhart and Kennedy proposed PSO algorithm, a population-based stochastic optimization technique that draws motivation from the social behavior of creatures like swarms of insects, flocks of birds, school of fish. The benefit of PSO is that it uses particles that relate feature information to one another to conduct a comprehensive search of the search space. PSO employs a collection of possible solutions, known as particles, in each iteration; this group of particles is referred to as a swarm. In a multi-dimensional search space, a vector represents a particle within the swarm. The velocity vector is responsible for controlling the position of next particle. PSO starts its search at random with initialization of swarm particles and velocity to explore. Each particle's position is updated using equation given below:-

$$S_i^{k+1} = S_i^k + V_i^{k+1} \quad (1)$$

where, S_i^k is the position of i^{th} particle at k^{th} iteration and V_i^{k+1} is the velocity of k^{th} particle at k+1 iteration which is updated using following equation :-

$$V_i^{k+1} = \omega * V_i^k + c_1 * d_1 * \left(P_{best} - S_i^k\right) + c_2 * d_2 * \left(G_{best} - S_i^k\right) \quad (2)$$

where, k is the iteration number, i is the individual number, V_i^{k+1} is the velocity of i^{th} individual at $k+1$ iteration, ω is the initial weight, c_1 and c_2 are acceleration constants, d_1 and d_2 lies in between [0, 1], P_{best} is the individual's best local position, G_{best} is the best global position of i^{th} individual, V_i^k is the velocity of i^{th} individual at k iteration.

This equation is divided into three terms; $\left[\omega * V_i^k\right]$ is physical term due to which individual remain in its actual path, $\left[c_1 \times d_1 \times \left(P_{best} - S_i^k\right)\right]$ is cognitive term, due to which individual represents the particle's experience with its prior optimal position and $c_2 \times d_2 \times \left(G_{best} - S_i^k\right)$ is social component that moves in the direction of individual i after receiving information about the optimal locations of all other particles around it. Therefore, every particle tries to flew off in a new direction based on its current position, its own knowledge, and the collective experience of other particles. When the evaluation of objective function is completed, the PSO algorithm terminates. The limitation of PSO algorithm is that, it experiences the premature convergence due to which algorithm converges to local value instead of reaching from a global minimum.

2.3 Hybridization of GA-PSO technique

This optimal search strategy consists of two parts, one is to allocate DG position and another is to find the DG size. Therefore, the first part requires an integer-based optimization so that optimal bus numbers were found to place multiple DGs. For this purpose, GA algorithm is selected, due to its appealing nature. The PSO algorithm optimizes the DG size using the solution obtained from the GA optimization. Different parameter values are provided in Table 2. Due to fast convergence characteristics of PSO algorithm, it provides efficient results for complex problems. Hence, in this hybrid methodology, global data obtained from GA is passed into the PSO algorithm's local search data, such that algorithm has balanced exploration and exploitation capabilities.

To solve the n-dimensional problem, this hybrid methodology, as shown in Fig. 1, has the following steps

- During initialization process, there is generation of individuals at random and then the fittest individual is evaluated with the assessment of objective function.
- According to fitness, the individuals are arranged in order and then GA algorithm uses recombination operators to create new individuals using the best solution vectors.
- The best individual is then updated with the help of the crossover operator using the crossover probability, in which two parents are combined.
- An individual or a particular element of a solution vector is transformed into a new state based on the mutation rate by the mutation operator of GA algorithm.
- These individuals produced by GA are attributed in the initialization process of PSO approach.
- After that update the position and velocity of each individual according to equations 1 and 2. Algorithms stops when maximum iterations are reached.

Pseudo Code of GA-PSO algorithm

Run optimal power flow using MATPOWER and find base case power losses (P_{loss}), bus voltage profile (V_m) and fuel cost of generators (F_c) of case 33 bus system

Set GA & PSO parameters such as population size (P), inertia weight, acceleration constants

Set $k = 0$

for $i = 1: i \leq P$

Generate initial chromosomes in initial population at random and evaluate fitness of all individuals
Apply crossover and mutation to all selected individuals

Update velocity and position of individuals using PSO

$$V_i^{k+1} = \omega * V_i^k + c_1 * d_1 * \left(P_{best} - S_i^k\right) + c_2 * d_2 * \left(G_{best} - S_i^k\right)$$

$$S_i^{k+1} = S_i^k + V_i^{k+1}$$

Evaluate fitness function of all individuals
Update p_{best}, g_{best}

Set $k = k + 1$

Until termination condition is met

Get the best solution

Table 2. Parameter setting for GA and PSO approach

Methods	Parameters	Values
GA	Mutation Rate	0.2
	Crossover Rate	0.8
	Selection fraction	1
	Population size	200
PSO	Inertia Weight	0.5
	Acceleration Constant	2
	Swarm size	200

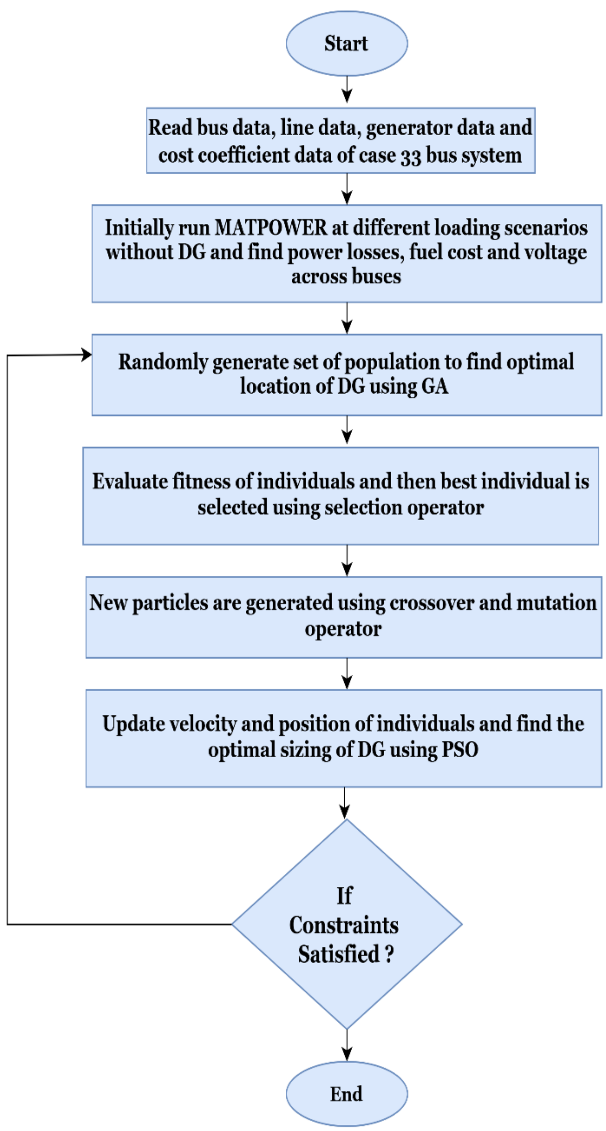

Fig 1. Flowchart for hybrid GA-PSO technique

3 Objective Function

The objective of optimal size and placement of DG are capable of minimizing objective functions given below:

$$f = min \ \ \{f_1 + f_2 + f_3\} \quad (3)$$

where f_1, f_2, f_3 symbolizes the objective function for eq. 4, 5 and 6 respectively.

For this purpose, an improved hybrid GA-PSO technique is used with MATPOWER tool to modify the optimal power flow.

3.1 Real power losses minimization

A clear illustration of objective function, that involves significant minimization of the real power losses in transmission lines, is provided as:

$$f_1(P_{Loss}) = \sum_{\substack{m=1 \\ n\neq 1}}^{N} C_{PQ}(V_m^2 + V_n^2 - 2V_mV_n cos(\delta_m - \delta_n)) \quad (4)$$

where, N is number of the transmission lines, C_{PQ} is conductance between bus m and n.

3.2 Reactive power losses minimization

The objective function to achieve the reactive power losses is provided as below:

$$f_2(Q_{Loss}) = \sum_{\substack{m=1 \\ n\neq 1}}^{N} S_{PQ}(V_m^2 + V_n^2 - 2V_mV_n sin(\delta_m - \delta_n)) \quad (5)$$

where, S_{PQ} is susceptance between the bus m and n.

3.3 Fuel cost minimization of Conventional Generator

The objective function for generator fuel cost is given as

$$f_3(Cost) = a_iP_{CG,i}^2 + b_iP_{CG,i} + c_i \ \$/h \quad (6)$$

where $P_{CG,i}$ is the real power generated by conventional generator and a_i, b_i, c_i represents the cost coefficients of i_{th} generator

3.4 Equality and Inequality Constraints

3.4.1 Voltage limits

The voltage limit is given by

$$V_m^{min} \leq V_m \leq V_m^{max} \quad (7)$$

where V_m^{min} is the minimum voltage ($V_m^{min} = 0.95$), V_m^{max} is the maximum voltage ($V_m^{max} = 1.05$).

3.4.2 Power Balance

Load, DG and generator balance equation:

$$\sum_{i=1}^{4} P_{DG} + P_{CG} = \sum_{i=1}^{33} P_{load} + P_{loss} \quad (8)$$

where P_{DG} is real power generated by Distributed Generators, P_{CG} is real power generated by convectional generator, P_{Load} is the load demand of case 33 bus network, P_{loss} is the real power losses in transmission lines.

3.4.3 DG size limit

Real and reactive power generation constraint of DG is given by equation (9) and (10). Each installed shunt capacitor's size is limited to the following dimensions

$$P_{DG,min} \leq P_{DG} \leq P_{DG,max} \quad (9)$$

$$Q_{DG,min} \leq Q_{DG} \leq Q_{DG,max} \quad (10)$$

where P_{DG} , Q_{DG} are the real and reactive powers generated from Distribute Generators installed in network

3.4.4 Thermal limit

Thermal limit should not exceed up to

$$S_i \leq S_i^{max} \text{ where } i = 1,2 \ldots \ldots . n \quad (11)$$

where S_i is the apparent power at i^{th} bus.

4 Numerical Results

The optimal power flow results obtained with the MATPOWER tool for the Case 33 bus system at normal loading reveals a total load of 3720 KW and 2300 KVar. The active power losses in the transmission lines amount to 211 KW, while the reactive power losses are 143 KVar. Therefore, the power generation under normal loading becomes 3931 KW. The conventional generator at bus 1 is generating 3920 KW and 2440 KVar of power, resulting in a fuel cost of $78.4 per hour. At this configuration, the minimum voltage magnitude (V_m^{min}) is observed 0.913 pu. at bus no. 18, while the maximum voltage magnitude (V_m^{max}) remains 1.00 pu at bus no. 1. The minimum voltage angle (V_θ^{min}) is obtained -0.50 degrees at bus 18, with the maximum voltage angle (V_θ^{max}) is measured 0.5 degrees at bus no. 30. Additionally, the maximum real power loss is observed at bus 2 (branch line 2-3), amounting to 50 KW. The main goal of this research work is to reduce power losses by examining different types of DGs to stabilize the voltage profile, decrease conventional generation costs and minimizing the consumption costs. To meet the load demand requirements, further loading is increased with the installation of multiple DGs. To obtain the benefits of adding DGs into the power system network, there are various types of DGs are available in the power industry but for this research work, only two types of DGs have been studied.

4.1 Loading up to 100%

After the placement of Type-1 DGs at Bus no. 16 (610 KW), 17 (70 KW), 18 (100 KW), and 33 (970 KW), the total losses are reduced to 64.64 KW and 65.34 KVar. The

conventional generator is optimized to generate 2070 KW and 2370 KVar of power, resulting in a fuel cost of $41.1 per hour. The V_m^{min} of 0.966 pu is obtained at bus no. 30, while the V_m^{max} at bus 1 remains 1.00 pu as shown in Fig. 2. The registers for -0.07 degrees at bus no. 22, while the V_θ^{max} angle recorded for 2.72 degrees at bus no. 33. Notably, real power loss at bus 2 (branch line 2-3) is reduced to 22 KW, as depicted in Fig. 3.

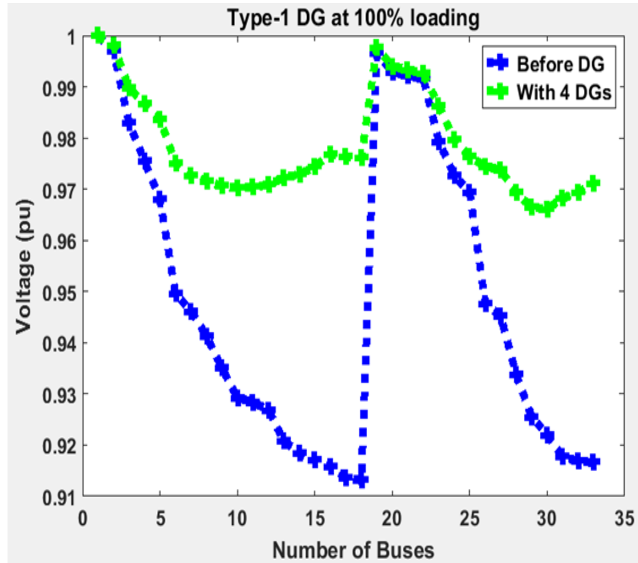

Fig 2. Voltage profile improvement with Type-1 DGs in 33 system under hybrid GA-PSO

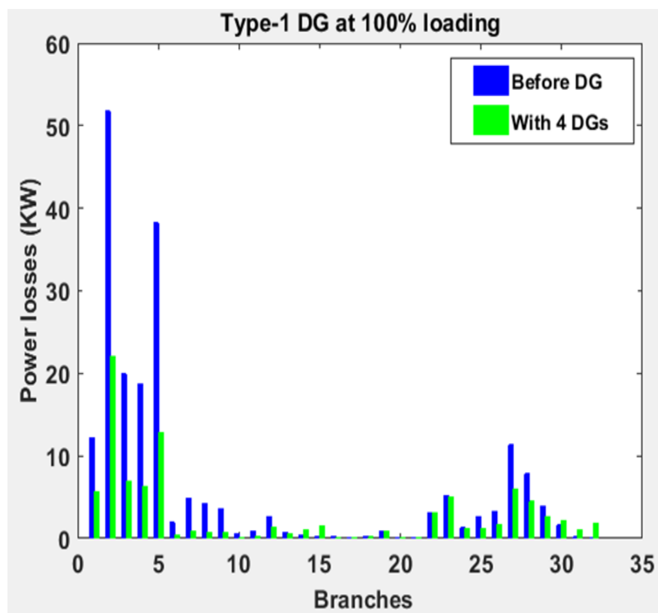

Fig 3. Power losses improvement with Type-1 DGs in 33 system under hybrid GA-PSO

After the placement of Type-2 DGs at Bus 16 (610 KW, 300 KVar), 17 (70 KW, 50 KVar), 18 (90 KW, 50 KVar), and 33 (970 KW, 860 KVar), the total losses were reduced to 10.92 KW and 15 KVar. The conventional generator is optimized to generate 2010 KW and 1080 KVar of power, resulting in a fuel cost of $40.2 per hour. The V_m^{min} comes to 0.978 pu, while the

Table 3. Comparative results for case 33 bus system at 100% loading with Type-1 and Type-2 multi DGs

Parameters	Before DG	With Type-1 DG	With Type-2 DG
DG (location & size)	-	16 (610KW) 17 (70KW) 18 (100 KW) 33 (970 KW)	16(610KW/300Kvar) 17(70KW/50Kvar) 18(90KW/50Kvar) 33(970KW/860Kvar)
Minimum Voltage (pu)	0.913	0.9669	0.978
Real power losses (KW)	211	64.64	10.92
Reactive power losses (KVar)	143.128	65.34	15
Conventional Generator (KW/KVar)	3920/2440	2070/2370	2010/1080
Fuel Cost ($/h)	78.4	41.4	40.2

V_m^{max} at bus 1 rises to 1.005 pu as shown in Fig. 4. The V_θ^{min} registers for -0.15 degrees at bus no. 25 and V_θ^{max} recorded for 0.26 degrees at bus no 33. Notably, real power loss at bus 2 (branch line 2-3) is reduced to 10 KW, as depicted in Fig. 5. Table 3 compares the base case with Type-1 and Type-2 DG at 100% loading condition across various parameters including DG configuration, voltage regulation, power losses, and operational costs.

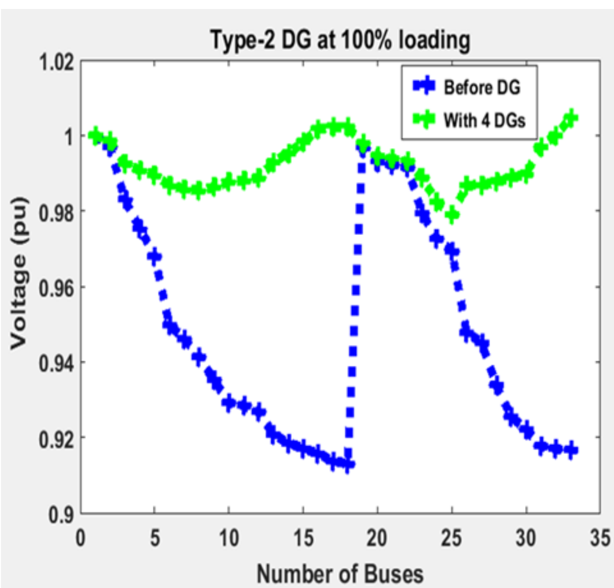

Fig 4. Voltage profile improvement with Type-2 DGs in 33 system under hybrid GA-PSO

In the Type 2 DG scenario, the DG units installed at locations 16, 17, 18 and 33 have similar real power capacities as the Type-1 scenario, but with different reactive power capabilities. This Type-2 DG units also help in reducing real and reactive power losses, albeit to a lesser extent compared to Type-1 DG units. Moreover, the Type-2 DG units are associated with lower operational costs per hour, indicating potential economic benefits.

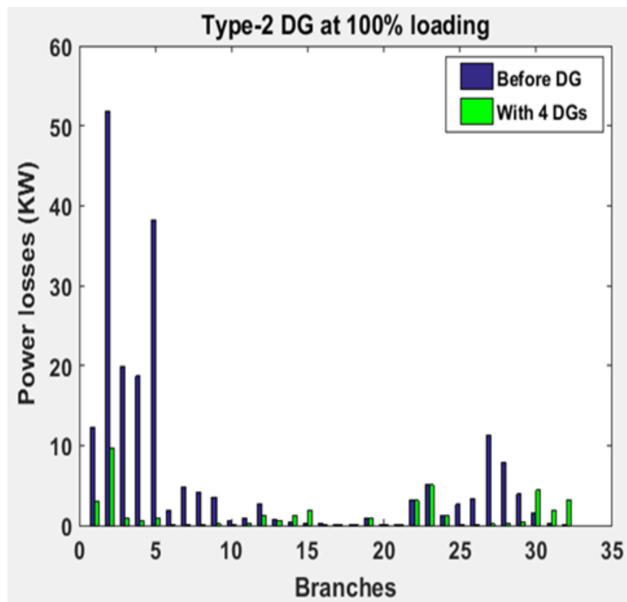

Fig 5. Power losses improvement with Type-2 DGs in 33 system under hybrid GA-PSO

4.2 Loading up to 150%

With loading reaching up to 150%, the total load demand rises to 5580 KW and 3450 KVar, resulting in power losses of 378 KW. The V_m^{min} is recorded as 0.881 pu at bus no.18, while the maximum real power loss occurs at bus 2 (line 2-3), amounting to 100 KW. Following the placement of Type-1 DGs at Bus 16 (930 KW), 17 (120 KW), 18 (120 KW) and 33 (1460 KW), the total losses were reduced to 215 KW and 150 KVar. Subsequently, the V_m^{min} increases to 0.949 pu at bus 30, while the V_m^{max} at bus 1 remains at 1.00 pu as shown in Fig. 6. The V_θ^{min} registers for -0.11 degrees at bus no. 22, while the V_θ^{max} recorded for 4.19 degrees at bus no. 33. Notably, real power loss at bus 2 (line 2-3) is reduced to 50 KW, as depicted in Fig. 7. The conventional generator is optimized to generate 3150 KW and 3500 KVar of power, with a corresponding fuel cost of $63 per hour.

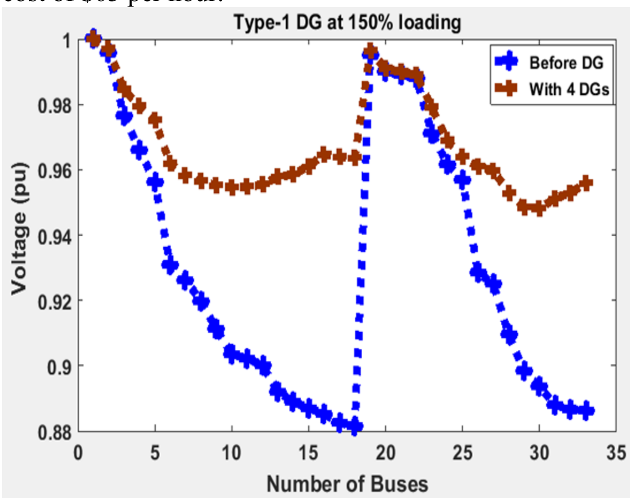

Fig 6. Voltage profile improvement with Type-1 DGs in 33 system under hybrid GA-PSO

After the placement of Type-2 DGs at Bus 16 (930 KW, 470 KVar), 17 (100 KW, 50 KVar), 18 (130 KW, 70 KVar) and 33 (1480 KW, 1310 KVar), the total losses were reduced to 95 KW and 80 KVar. The conventional generator is optimized to generate 3030 KW and 1620 KVar of power, resulting in a fuel cost of $60.6 per hour. Subsequent to these adjustments, the V_m^{min} increases to 0.968 pu at bus no. 25, while the V_m^{max} at bus no. 33 reaches 1.008 pu as shown in Fig. 8. The V_θ^{min} registers of -0.22 degrees at bus no. 25, with the V_θ^{max} recorded for 0.40 degrees at bus no. 33. Notably, real power loss at bus 2 (line 2-3) is reduced to 21 KW, as depicted in Fig.9

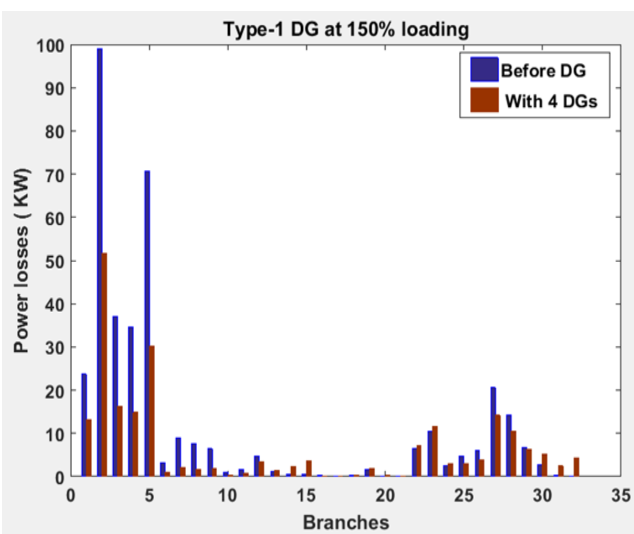

Fig 7. Power losses improvement with Type-1 DGs in 33 system under hybrid GA-PSO

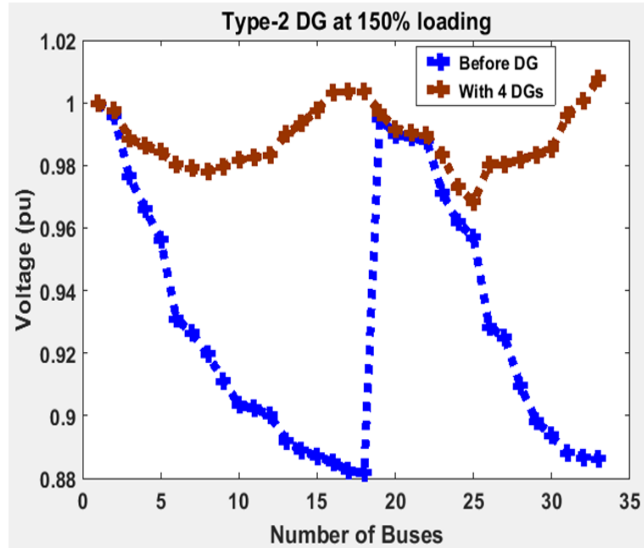

Fig 8. Voltage profile improvement with Type-2 DGs in 33 system under hybrid GA-PSO

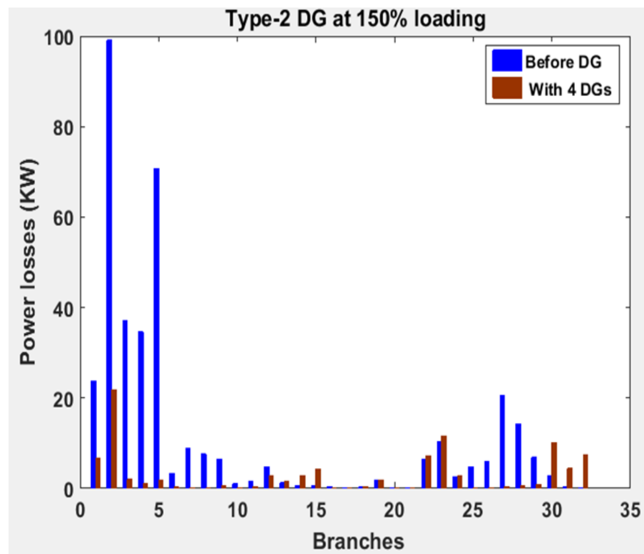

Fig 9. Power losses improvement with Type-2 DGs in 33 system under hybrid GA-PSO

Table 4 presents a comparison between the three scenarios at 150% loading involving: without DG, with Type-1 DG and with Type-2 DG systems. In first case, there are no additional DG units installed beyond the existing infrastructure. In the Type-2 DG scenario, DG units are installed at the same locations as in Type-1 but with variations in size and reactive power support capabilities. While the real power losses are reduced compared to both without DG and Type-1 DG scenario, the reduction in reactive power losses is relatively lower. However, the operational costs associated with Type-2

DG units are lower than both without DG and Type-1 scenario, indicating potential economic benefits despite.

Table 4. Comparative results for case 33 bus system at 150% loading with Type-1 and Type-2 multi DGs

Parameters	Before DG	With Type-1 DG	With Type-2 DG
DG (location & size)	-	16 (930KW) 17 (120KW) 18 (120KW) 33 (1460KW)	16 (930KW/470Kvar) 17(100KW/50Kvar) 18 (130KW/70Kvar) 33 (1480KW/1310Kvar)
Minimum Voltage (pu)	0.881	0.949	0.968
Real power losses (KW)	378	215	95
Reactive power losses (KVar)	200	150	80
Conventional Generator (KW/KVar)	5948/3550	3150/3500	3030/1620
Fuel Cost ($/h)	118.96	63	60.6

4.3 Loading up to 200%

With loading reaching up to 200%, the total load demand escalates to 7430 KW and 4600 KVar. Consequently, power losses at this level of loading amount to 623 KW. The V_m^{min} is recorded for 0.848 pu at bus no. 18, while the maximum real power loss is observed 154 KW at bus 2 (line 2-3). Upon the placement of Type-1 DGs at Bus 16 (1270 KW), 17 (160 KW), 18 (160 KW) and 33 (1940 KW), the total losses were reduced to 408 KW. The conventional generator is optimized to generate 4310 KW and 4890 KVar of power, with a corresponding fuel cost of $86.2 per hour. The V_m^{min} of 0.928 pu is obtained at bus no. 30 while the V_m^{max} remains at 1.00 pu at bus no. 1 as shown in Fig. 10. The V_θ^{min} registers for -0.15 degrees at bus no. 22, whereas the V_θ^{max} is recorded for 5.82 degrees at bus 33. Real power loss at bus 2 (line 2-3) is notably reduced to below 100 KW, as illustrated in Fig. 11.

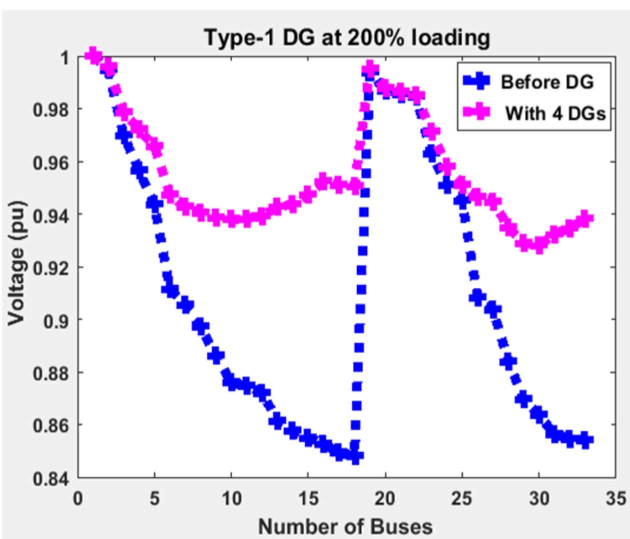

Fig 10. Voltage profile improvement with Type-1 DGs in 33 system under hybrid GA-PSO

After the placement of Type-2 DGs at Bus 16 (1270 KW,660 KVar), 17(130 KW, 60 KVar), 18 (170 KW, 70 KVar), and 33 (1940 KW, 1770 KVar), the total losses amount to 172 KW. The conventional generator is optimized to generate 4060 KW and 2170 KVar of power, resulting in a fuel cost of $81.2 per hour. The V_m^{min} increases to value of 0.957 pu at bus no. 25, while the V_m^{max} at bus 33 remains of value 1.00 pu as shown in Fig. 12. The V_θ^{min} registers for -0.30 degrees at bus no. 22, with the V_θ^{max} recorded for 0.50 degrees at bus no. 33. Notably, real power loss at bus no. 2 (line 2-3) is reduced to 40 KW, as depicted in Fig. 13.

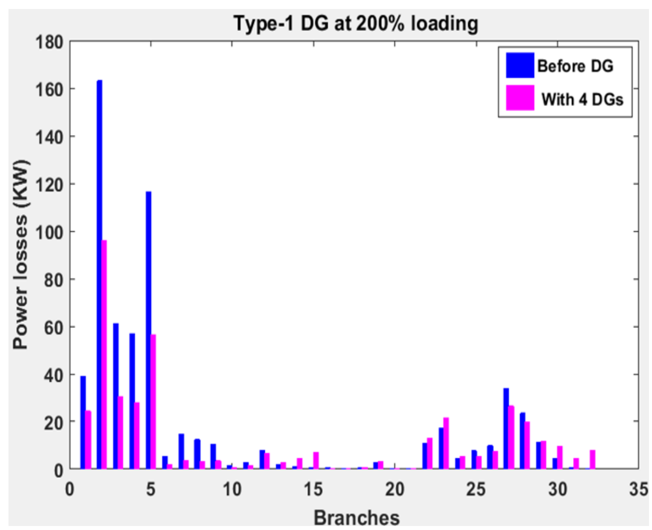

Fig 11. Power losses improvement with Type-1 DGs in 33 system under hybrid GA-PSO

Table 5 presents a comparative analysis of a 33-bus system operating at 200% loading with multi-DGs of Type-1 and Type-2, alongside without DG case. Each scenario is evaluated based on various parameters including DG configuration, voltage regulation, power losses and operational costs. In the Type-2 DG scenario, DG units are installed at the same locations as in Type-1 but with variations in size and reactive power support capabilities. While the real power losses are reduced compared to both without DG and Type-1 DG scenario, the reduction in reactive power losses is slightly lower.

Table 5. Comparative results for case 33 bus system at 200% loading with Type-1 and Type-2 multi DGs

Parameters	Before DG	With Type-1 DG	With Type-2 DG
DG (location & size)	-	16 (1270KW) 17 (160KW) 18 (160KW) 33 (1940KW)	16 (1270KW/660Kvar) 17 (130KW/60Kvar) 18 (170KW/70Kvar) 33 (1940KW/1770Kvar)
Minimum Voltage (pu)	0.848	0.928	0.957
Real power losses (KW)	623	408	172
Reactive power losses (KVar)	300	290	140
Conventional Generator (KW/KVar)	8053/4900	4310/4890	4060/2170
Fuel Cost ($/h)	161.06	86.2	81.2

However, the operational costs associated with Type-2 DG units are lower than both without DG and Type-1 DG scenario, indicating potential economic benefits despite slightly lesser technical performance in terms of power loss reduction and voltage regulation.

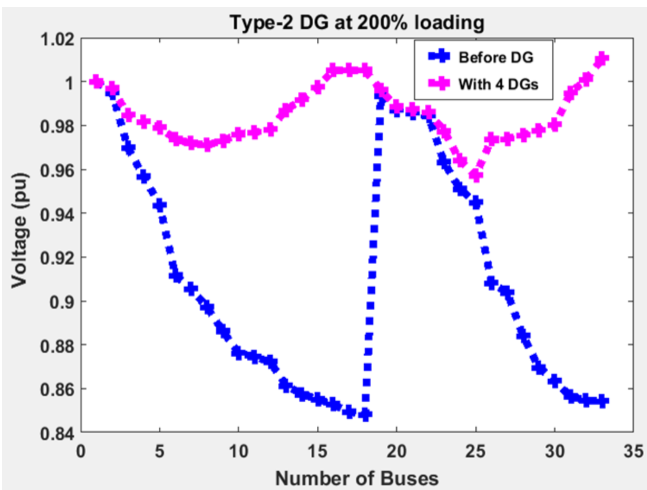

Fig 12. Voltage profile improvement with Type-2 DGs in 33 system under hybrid GA-PSO

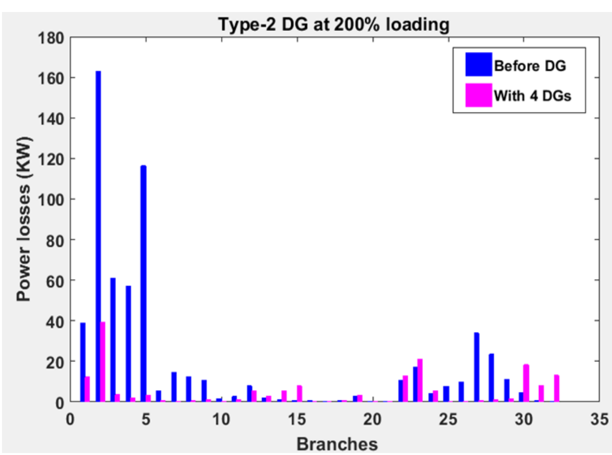

Fig 13. Power losses improvement with Type-2 DGs in 33 system under hybrid GA-PSO

5 Discussions

In this paper, two types of DGs were installed in the DS using proposed hybrid GA-PSO techniques with three objectives- minimizing power losses, voltage variations and fuel cost of conventional generators. When these DG units were optimally placed closure to the load points, it has observed that total energy losses were reduced due to low transmission length and pressure on power grid is reduced. For a power system network, it is important that there should be less variation in voltage profile so that system becomes more stable. Also, fuel cost reduction has great impact on system's total generation cost. Fossil fuel energy usage increases Green House Gases (GHG) production but with the renewable based DGs deployment sustainable energy is produced. This research introduces an innovative GA-PSO method for the optimal integration of renewable-based DGs. By incorporating GA into PSO this approach enhances population density, significantly boosting search capabilities and avoiding local optima. It facilitates a global search in the early stages of the algorithm and a local search in the later stages, achieving a balance between exploration and exploitation. As demonstrated in Tables 6, 7, and 8, a sensitivity analysis was conducted on a population size ranging from 5 to 200 particles, with each acceleration coefficient set at 2, an inertia weight of 0.5, and a maximum of 200 iterations. The results suggest that increasing diversity enhances the algorithm's efficiency and effectiveness, and a higher number of iterations allows particles ample time to explore the search space, preventing premature convergence. Additionally, a smaller inertia weight value enhances only local search capabilities, while a larger inertia weight value enhances only global search capabilities. The cognitive component influences a particle's tendency to follow its own best historical position, while the social component influences its tendency to follow the population's global best position. From Table 6, 7, and 8, it is observed that the similar statistical results are achieved for the population ranging

Table 6. Table 6. Sensitivity analysis of varying N with max^k= 200, c_1, c_2= 2, w = 0.5 at 100% loading

No. of Population (N)	Type-1 DGs		Type-2 DGs	
	Best value	Worst value	Best value	Worst value
5	64.6	67.8	10.92	12.86
25	64.6	66.5	10.92	11.92
50	64.6	65.7	10.92	10.92
100	64.6	64.6	10.92	10.92
150	64.6	64.6	10.92	10.92
200	64.6	64.6	10.92	10.92

Table 7. Sensitivity analysis of varying N with max^k = 200, c_1, c_2= 2, w = 0.5 at 150% loading

No. of Population (N)	Type-1 DGs		Type-2 DGs	
	Best value	Worst value	Best value	Worst value
5	215	220	95	98
25	215	218	95	97
50	215	217	95	96
100	215	215	95	95
150	215	215	95	95
200	215	215	95	95

Table 8. Sensitivity analysis of varying N with max^k = 200, c_1, c_2 = 2, w = 0.5 at 200% loading

No. of Population (N)	Type-1 DGs		Type-2 DGs	
	Best value	Worst value	Best value	Worst value
5	408	410	172	174
25	408	409	172	174
50	408	409	172	173
100	408	408	172	172
150	408	408	172	172
200	408	408	172	172

from 100 to 200 with these parameter values. Therefore, with an expanded search area and more iterations, it is crucial to properly adjust the algorithm's control parameters to achieve better optimization performance, ensuring the attainment of a global optimal value and preventing the algorithm from becoming trapped in local minima. Table 9 provides the computational speed of hybrid algorithm for obtaining these objective functions. The results for the optimal location of Type-1 DGs were compared with previous findings as shown in Table 10. The comparison is made with only three papers, as those papers themselves have compared their results with many others. Another reason is that only 3 out of the total 45 reviewed papers have installed 4 DGs simultaneously, and none have minimized reactive loss and fuel cost. In references [40, 41], the authors calculated the annual savings after DG installation; however, they did not optimize the cost of the conventional generator. The results for the optimal location of Type-2 DGs are compared with previous findings, as shown in Table 11. The comparison is made with only four papers, as those papers themselves have compared their results with many others. Another reason is that only 1 out of the total 45 reviewed papers have installed 4 DGs of Type-2 simultaneously, and none have minimized reactive loss and fuel cost. The percentage of DG penetration and reduction of real losses, reactive losses and fuel cost with optimal location of Type-1 and Type-2 DGs at different loading is shown by fig. 14 and 15. With Type-1, DG penetration, real losses, reactive losses and fuel cost were reduced to 47.10%, 69.36%, 54.28% and 47.19% at 100% loading, 47.21%, 43.12%, 25% and 47.04% at 150% loading and 47.5%, 34.51%, 3.33% and 46.47% at 200% loading respectively under GA-PSO. With Type-2, DG penetration, real losses, reactive losses and fuel cost were reduced to 49.11%, 94.82%, 89.51% and 48.7% at 100% loading, 49.64%, 74.87%, 60% and 49.05% at 150% loading and 49.71%, 72.39%, 53.33%, 48.96% at 200% loading respectively under GA-PSO.

Table 9. CPU performance analysis of hybrid GA-PSO approach

Different cases	Type-1 DGs	Type-2 DGs
100% loading	136.44s	153.3s
150% loading	171.51s	187.5s
200% loading	196.38s	215.5s

Table 10. Comparison of proposed approach for Type-1 DGs in case 33 Bus system with existing methods

Reference No.(Year)	Method	DG units	DG size (Kw)	Location (Bus no)	Minimum Voltage (pu)	Real power loss (Kw)	Reactive power loss (Kvar)	Fuel Cost ($/h)
40(2019)	OCDE	4	926.69 646.78 967.34 679.38	6 14 24 31	0.9702	67.735	-	-
41(2020)	OCDE	4	790.99 693.81 681.07 717.31	6 14 25 31	0.9704	68.293	-	-
26(2023)	WOA	4	646.76 967.2 926.3 686.35	14 24 6 31	0.9703	67.63	-	-
Proposed article	GA-PSO	4	610 70 100 970	16 17 18 33	0.9669	64.64	65.35	41.4

Table 11. Comparison of proposed approach for Type-2 DGs in case 33 Bus system with existing methods

Reference No.(Year)	Method	DG units	DG size (Kw/Kvar)	Location (Bus no)	Minimum Voltage (pu)	Real power loss (Kw)	Reactive power loss (Kvar)	Fuel Cost ($/h)
43(2018)	SFSA	3	830.6/273.0 1125.6/370.0 1239.6/407.4	13 24 30	0.9880	28.533	-	-
41(2020)	OCDE	4	640.37/210.48 532.06/174.88 69.54/252.94 1135.89/373.35	8 15 25 30	0.9882	24.587	-	-
44(2020)	TGA	3	635.01/345.32 718.38/94.54 1285.67/1086.60	15 24 30	0.990	17.50	-	-
45(2023)	EJSA	3	793.97/373.48 1070.03/517.29 1029.73/1011.43	13 24 30	0.990	11.74	-	-
Proposed article	GA-PSO	4	610/300 70/50 90/50 970/860	16 17 18 33	0.978	10.92	15.00	40.2

Additionally, it's noteworthy that while the DG penetration level remain consistent across the cases for both Type-1 and Type-2 DGs, there are variations in the reduction percentages of real and reactive losses. Case 1 demonstrates a higher reduction percentage in both types of losses, indicating its effectiveness in mitigating power dissipation. However, the comparative analysis between Type-1 and Type-2 DG reveals an advantage for Type-2 DG due to its capability to provide both active and reactive power. This dual functionality enhances its effectiveness in reducing losses and optimizing the distribution network's performance, underscoring its potential for broader applications in real-world scenarios.

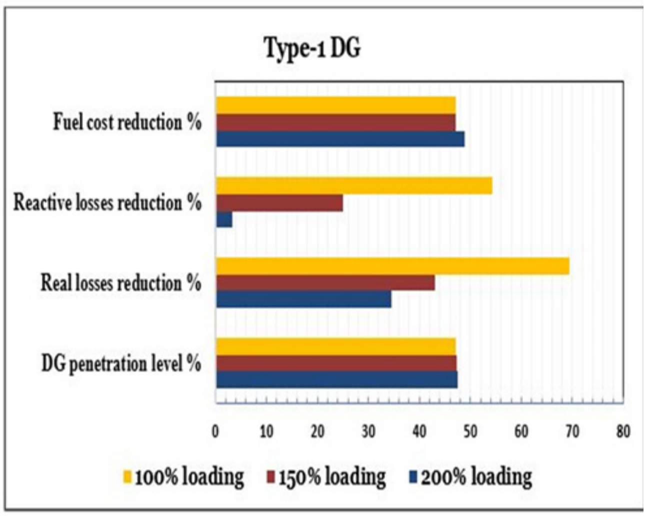

Fig 14. Performance evaluation of 33 bus system at different loading conditions with Type-1 DG

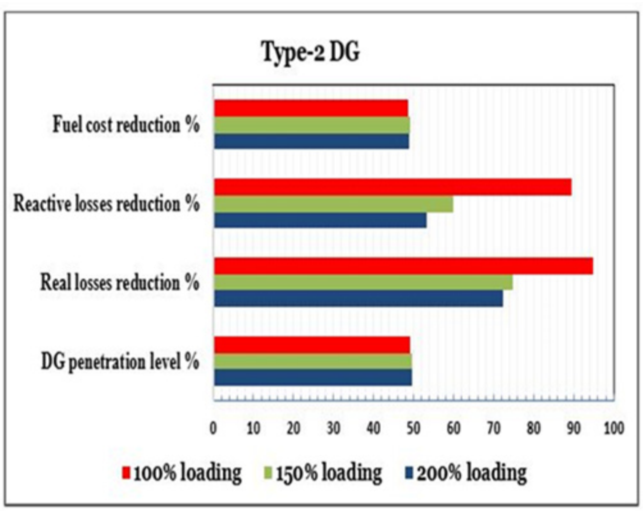

Fig 15. Performance evaluation of 33 bus system at different loading conditions with Type-2 DG

6 Conclusion

A search strategy designed for the ideal placement and size for Type-1 and Type-2 DGs is used in the suggested approach. Specifically, this approach results in a smaller search space and a more tightly distributed set of search results. The search is carried out by the integer-based optimization algorithm known as the GA method since the location is represented by a discrete variable (the bus number). After that, the PSO algorithm uses the solution derived from the GA method to optimize the DG's sizing. This hybrid approach is implemented on case 33 bus system to minimize real and reactive power losses, to enhance voltage profiles and to reduce generation fuel cost of convectional generators. To ensure the validity of the suggested approach, the outcomes of the suggested algorithm for Type-1 and Type-2 DGs have been compared with those of the other techniques as discussed in Table 4 and 5. The outcomes demonstrate the high accuracy and performance solution of the suggested method. It was evident from table 4 and 5 that the suggested approach could effectively reduce fuel cost of conventional generators, improve voltage stability and minimize the system power losses. Also, it is noted that Type-2 DG appears to yield the most favorable outcomes.

7 Future Work

- Benefits of distributed energy sources can be maximized with the integration of power electronic equipment's such as FACTS, power system stabilizers and Electric vehicles into the system.
- Availability of other types of Distributed Generators in power industry and their impact on power system network should be investigated.
- More future work is required with integrating multiple FACTS into the system with renewable based distributed sources in order to enhance system's performance.
- Time varying loads such as integration of Electric vehicle charging station (EVCS) with Distributed Generation and its loading impact should be further studied.
- Other stressed conditions such as faults occurring in a power system network should be further studied as system lacks sufficient reactive power support during this condition.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

R. Gandotra: Conceptualization, Methodology, Software, Formal analysis, Writing - Original draft.
K. Pal: Supervision

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Informed Consent Statement
Not applicable

Declaration of generative AI and AI-assisted technologies
The authors declare that no generative AI or AI-assisted technologies were used in the writing process of this manuscript.

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Biographies

R. Gandotra has received the Master's degree in the Electrical Engineering in 2018 from Chandigarh University India. Currently, she is doing Ph.D. from the Department of Electrical Engineering (EE), Gautam Buddha University, India. She has published many papers in various reputed journals. Her research areas are Renewable energy system integration, Smart Grid, Electric vehicle, FACTS controllers and optimization techniques, soft computing techniques in power system.

K. Pal is an Associate Professor in Electrical Department, School of Engineering, Greater Noida, India. She has total 15 year of teaching experience. Dr. Kirti holds a PhD degree in Electrical Engineering, 2013 from RGTU, Bhopal; M.E. degree from MITS Gwalior, 2006; BE degree from L.N.C.T. Bhopal, 2004. She has published many research and conference paper in various reputed journals and conferences. Her research areas are Restructuring of power System, Power System Analysis and optimization, Soft Computing Techniques, Renewable Energy systems and Electric Vehicle.