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Original Article

Optimal Allocation of Multiple Distributed Generators Based on Hybrid Technique for Reduction of Power Loss

S. Sreedevi[1], G. Angeline Ezhilarasi[2]

[1,2]*School of Electrical Engineering, VIT University, Chennai, Tamilnadu, India.*

[1]*Corresponding Author : sridevi56.m@gmail.com*

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Abstract *- Recently, distributed generation unit selection for the electric distribution area has been essential. The decrement in power loss, environmental pollution, enhanced nodal magnitude enhancement, and reliability is possible by applying an optimal selection of DG units. This research combines the spider monkey optimisation algorithm (SMOA) with the flower pollination algorithm (FPA) to determine the distributed generators' favourable place and value. The behaviour of SMOA is also enriched with the action of FPA. Optimally selected distributed generation units aim to diminish the active power loss and raise the nodal magnitude in the distribution network. This planned technique is enforced through IEEE 33 and IEEE 69 standard systems for multiple distributed generators with numerous load levels. This is also processed to different types of loads. The result is executed through MATLAB/Simulink, and the numerical values are correlated with existing optimisation procedures to confirm their validation.*

Keywords *- Distributed generators, Spider monkey optimization algorithm, Flower pollination algorithm, Loss reduction of active power, Bus magnitude improvement.*

1. Introduction

One of the needs in developing countries is that the generation of station power should full fill the unpredictable load without interruption. Moreover, the power generation plants are far off the distribution point, and power transmission is challenging in the power network. The favourable allotment of distributed generators near the load point of distribution systems is a considerable solution for the above problem. This optimisation also improves the system's efficiency by decreasing active power loss. This optimal selection is made by analytical, heuristic and hybrid methods nowadays. The review of this paper explains the importance of sizing and placing with various techniques for dg units to be optimally selected in power systems [1]. This paper consists of biological inspiration, variants and hybridisation of the flower pollination algorithm [2].

The approach of this paper uses an analytical method to determine the optimal size and particle optimisation technique to determine the suitable placement for variant type dg units [3]. This author reviews various optimisation methods to know the impact assessment of an optimal selection of numerous dg units and for different load models [4, 5]. In this paper, the index vector method finds the apt placement for dg, and the flower pollination algorithm determines the suited value for dg. This approach is implemented on 15, 34 and 69 bus standard systems [6]. This paper explains the modelling of a flower pollination algorithm based on the pollination of flowers and proves that this algorithm is used for efficient optimisation [7]. The author uses a fuzzy approach to search the dg locations and one rank cuckoo to optimise the sizes of dg units. This ideology implementation is done through IEEE 15, 33 and 69-bus systems to prove their efficiency [8]. The salp swarm algorithm is utilised for optimal dg unit selection to 33 and 69 bus systems [9].

LSF (loss sensitivity factor) to select the proper setting for dg segments. The hybridisation of particle swarm optimisation and GWO (grey wolf optimiser) determines the appropriate size for dg units. This is performed on 33 bus systems to improve the overall system's performance [10]. The author of this paper executes PSO (particle swarm optimisation) in selecting the proper location together with the analytical method in selecting the optimal size of generator units simultaneously. This plan proceeded on the 33-node distribution part to pull down the power loss, including developing the bus magnitude with type-III distributed generators [11].

The hybridisation of the FPA with PSO to suppress the power loss, including voltage value improvement. The process was implemented on 69 bus distribution systems and proved the effectiveness of the combination [12, 13]. In this optimisation paper, the hybridisation of fuzzy logic with a genetic algorithm selects the size, position, with type for distributed generators optimally to develop performance in the system [14]. The researcher of this paper combines genetic algorithm with particle swarm optimisation. This combination is used for optimal reactive power flow and maintaining the bus magnitude for 102 nodes distribution network [15].

Hybrid technology consisting of an Imperialist competitive algorithm with GA (genetic algorithm) for optimal selection of capacitors and dg units to minimise power loss and improve voltage stability. The execution is done through IEEE 33 and 69 bus distribution systems to show the strengths [16]. This idea's author introduces a combo with an optimisation-based particle swarm and a genetic algorithm to choose distributed generators to be placed at 33, 69 nodes standard configuration. This combination reduces the loss of power and proves their potential [17].

The author enhances the performance of the harmony search algorithm with the aid of the particle artificial bee colony algorithm in fixing the considerable rating for dg units, then uses loss sensitivity to select the significant nodes for the distribution region. This is worked on 33 and 119-node systems, and power loss reduction is achieved [18, 19].

This work is an effort to hybridising swarm optimisation with the gravitational search for optimal distributed generator selection. This work enhances loss decrement and bus magnitude in 69 nodes' standard distribution domain [20]. This paper aims to drop the loss along with an increment in the nodal magnitude for the desired level by combining the particle swarm optimisation algorithm with quasi newton algorithm. This achievement is performed on IEEE 33 with 69 node radial configurations [21]. This concept applies to the collaboration of ACO (ant colony optimisation) together with ABC (artificial bee colony) for proper sitting, including rating of generator units over33 as well as 69 nodes standard network in attaining the reduction of loss and energy cost [22].

In this work, the stud krill herd (SKH) algorithm is performed for selecting multiple dg units optimally to diminish the loss of power [23]. The author develops the hybridisation consisting of a firefly algorithm and gravitational search algorithm for locating the proper rating of generator units at the proper place while diminishing power loss and increasing voltage at all nodes to reach the desired value. This is simulated on IEEE 33 node system successfully [24]. The author forms SMO (spider monkey optimisation) depending on swarm intelligence for numerical problems [25]. This review represents the result of various procedures in addition to various loads in diminishing the loss in active power with maximising the bus magnitude [26, 27]. Backwards/ Forward load flow is recommended for radial distribution system by the author of this paper [28]. Optimizer finds the favourable point with the rating of generators to be placed in 33, 69 and 85 bus regions [29]. Cosine sine theory collided with the chaos map to determine the optimal dg units in standard 33 and 69 power systems [30]. Simulated annealing has worked for the proper location plus value to the generators for loss limitation in the power [31]. The solution for optimal power flow is enriched by merging spider monkey optimisation and levy's flight search for 30 buses of the IEEE system [32].

The proposed work consists of a hybrid technique of spider monkey optimisation algorithm (SMOA) with flower pollination algorithm (FPA) for allotment of apt sites with rating of generation units in the distribution side. Here SMOA uses FPA to improve the searching skill with considerable power loss reduction while satisfying the limit of voltage value, line capacity and dg penetration. The split up of the work is expressed as the number of divisions. The second division consolidates the work strategy regarding the optimal position and rating of dg units. The third division consists of the problem arrangement of the proposed work. The fourth division explains the hybrid methodology. The numerical outputs and conclusion are covered in the fifth and sixth divisions.

1.1. Recently Done Research Works

The author of this paper works for joining differential evaluation along with the sine cosine concept in improving exploration plus exploitation capabilities in fitting generators on the customer side [34]. This research proposes a combination of the algorithms named (binary particle swarm optimisation) BPSO with (shuffled frog leap) SFL algorithms in lowering the loss of power by the perfect placement of generators near the load point.

This process is applied through 33 69 nodes radial structure, proving their validity [35]. The researcher of this paper diminishes the loss in power, develops the bus magnitude and reduces cost by their tied execution of GSO (Grasshopper Optimization) and CS (Cuckoo Search technique). It also ideally located generators in IEEE 33, including 69 structures [36]. This paper introduces the hybridisation technique to improve the overall system performance by reducing loss at IEEE 33 together with 69 nodes of the radial network for variant types of loads. This is done by selecting the optimal dg size through a simple analytical method while selecting optimal sitting through the salp swarm algorithm [37].

The authors combine the genetic algorithm and particle swam optimisation algorithm for the apt allocation of distributed generator units in the power system and reduce active included reactive power loss. This combination is worked on 33 and 69 bus systems to show their validity [38].

This paper develops hybrid optimisation of genetic and salp algorithm in selecting capacitors together dgs' optimally in improving optimal solution. This hybridisation is carried out on 34 and 112 bus distribution systems and proves their performance [39].

The author does the optimal placing by loss sensitivity factor and rating of distributed generators by spider monkey optimisation algorithm. Power loss is diminished, and the voltage value at all nodes is upgraded through implementing this work on 33, including 69 node structure [40]. This process represents their hybridisation of PPO (phasor particle optimisation) with GS (gravitational search) algorithm to make proper distributed generator selection. To also attain a good voltage profile and power loss reduction, this occurred on the IEEE 69 node system and proved their hybridisation ability [41]. This hybrid is a collaboration of analytical and tree growth algorithms. This reaches the destination of preferable size and power rating for generator units on the 33 and 69 distribution side [42].

The combination of sensitivity based on loss factor, SA (simulated annealing) and particle swarm to penetrate the appropriate dgs for best sitting in this paper. This combo is commenced on 33 bus radial systems to lower power flow loss and raise the bus magnitude [43]. The investigation of combining the tunicate swarm algorithm with the sine-cosine concept is done in IEEE 69 node point to achieve the desirable setting and amount of multiple dg and to reach their goal of getting the loss depression of power and the magnitude of bus increment [44].

This paper executes the lightning search algorithm and simplex method optimisation in determining the excellent rating for generators to be settled in the distribution zone, including STATCOM. It also uses loss sensitivity for the selection of optimal placement. This is worked out under 33, 69 nodal systems, then loss in active power is reduced, and voltage magnitude is increased successfully [45].

The hybridisation of an enhanced grey wolf with particle swarm for the perfect selection in generators and capacitors ratings for the customer side. It uses a voltage stability index for optimal sitting of dg units and capacitors. This performance is presented on 33 nodes together with 69 nodes' radial structure [46].

1.2. Groundwork of the Research

- The essential factor to be considered in the distribution network is not only selecting the proper rating of distributor generation units but also placing them in the proper node of the network. Otherwise, it will lead to more power loss than the conventional system.
- The optimal selection of the distribution generation units is a possible solution to rectifying the power loss problem while benefiting the voltage magnitude.
- This optimal selection helps manage transient states' impact during irregular and overloaded conditions.
- By surveying the research of the work regarding the optimal selection of distributed generation units, the observations are written as follows. The genetic algorithm (GA) has limitations in achieving the exploration. The algorithm of Stud krill herd (SKH) consists of many numbers in parameters even though it has been well done in the selection of dg units. The absence of inertia weight in the salp swarm algorithm (SSA) makes selecting the optimal distribution generation units challenging, and the sine cosine algorithm (SCA) is more complex.
- To improve the exploitation together with exploration, there is a need for hybrid technology to select the optimal value and position of distribution generation units along with the concentration of loss reduction created in power and magnitude of node voltage enhancement.

1.3. Major Contributions to this Task

- A review is done regarding the hybrid meta-heuristic procedure to rectify the issue of the optimal selection of generators for the radial configuration.
- The research proposes the Spider Monkey Optimization hybrid technique with the Flower Pollination Method, which is also a remedy for a considerable selection of generators in the distribution area.
- Aiming to diminish the loss in active power flow and boost the bus magnitude is folded as problem formulation.
- The hybrid technique is implemented for 33 and 69 standard systems, including various levels and types of loads.
- The new technique of the proposed ideology is compared with a recent hybrid technique applying for optimal selection of DG units to show the effectiveness of that.

2. Problem Sequence

The main feature of the distribution zone, high-raise R/X, leads to the loss in power flow, affecting their overall system's performance. The penetration of distributed generation units can solve this problem. However, the optimal rating of injected power plus the placement of dg segments can only lead to a reasonable reduction in loss of power. Otherwise, power loss may be higher than in the living system without dg units. This optimal selection can diminish the bus magnitude deviation and increase the system's stability.

2.1. Mathematical Expression for Basic Load Flow

The radial distribution system consisting of series impedance, balanced power and constant load is taken to solve the power flow problem. The value of power at all line divisions with magnitude at all buses of the distribution system after penetrating dg segments is also worked out by Backward/Forward sweep [28].

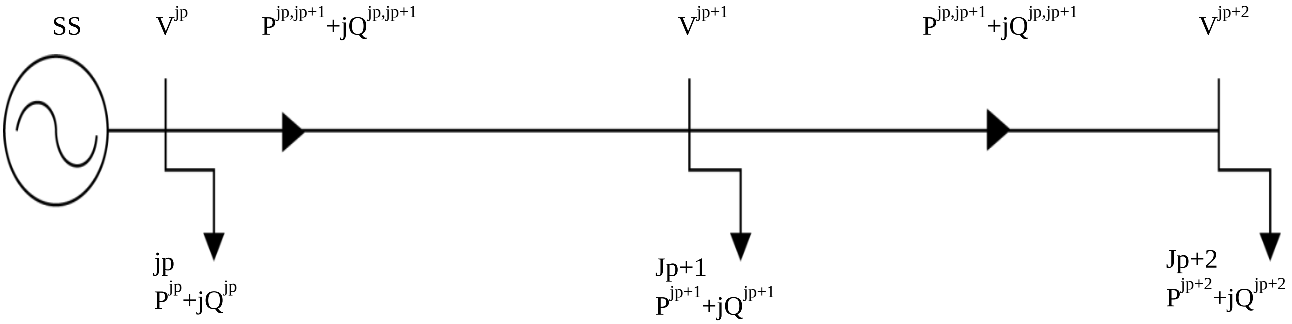

Fig. 1 Radial distribution system

2.1.1. Backward/Forward Sweep

- Fix the number as the maximum for iterations.
- The finding formula for nodal current is written as follows (1). It applies to the end node only.

$$I_{iter}^{jp} = \left[\frac{S^{jp}}{V_{iter-1}^{jp}}\right], \tag{1}$$

$V^{jp} = 1$, for the initial iteration
$I^{jp} =$ Current value of bus jp,
$S^{jp} =$ Power value of bus jp $= P_l^{jp} + iQ_l^{jp}$
$V^{jp} =$ Voltage value of bus jp,
P_l^{jp} = load representing active power of bus jp
Q_l^{jp} = load representing reactive power of bus jp

2.1.2. Backward Move

The current for the line division from bus jp to jp+1 is computed by equation (2).

$$I_{iter}^{jp\ to\ jp+1} = I_{iter}^{jp+1}(current\ at\ bus\ jp+1) + \sum branchcurrent\ existing\ from\ jp+1 \tag{2}$$

Current in each node equals current in each branch for the last node only. Based on this branch current, all line division currents are determined.

2.1.3. Forward Move

The nodal voltages are found in equation (3).

$$V^{jp+1} = V^{jp} - (I^{j\,p\ to\ jp+1} * Z^{j\,p\ to\ jp+1}) \tag{3}$$

Where, $I^{jp\ to\ jp+1}$ - the branch current is determined from the backward flow.

2.1.4. Convergence

If the difference between the specified and determined voltage is lower than the limit of tolerance value, the updated nodal voltage and branch current are fixed. Power Flow from the Fixed Voltage and Branch Current as in equation (4).

$$S^{jp\ to\ jp+1} = V^{jp} * (I^{jp\ to\ jp+1})^{*}\ S^{jp\ to\ jp+1} = P^{jp\ to\ jp+1} + iQ^{jp\ to\ jp+1} \tag{4}$$

$P^{jp\ to\ jp+1}$ = active power flowing in the division jp to jp+1
$Q^{jp\ to\ jp+1}$= reactive power flowing in the division jp to jp+1
Power loss is represented as equation (5).

$$P^{Loss\ jp\ to\ jp+1} = \left(\frac{P^{jp\ to\ jp+1^2} + Q^{jp\ to\ jp+1^2}}{\left|V^{jp+1^2}\right|}\right) * R^{jp\ to\ jp+1} \tag{5}$$

Sum of losses from all line divisions can be written as follows.

$$P_{Total\ active\ Loss} = \sum_1^L P^{Loss\ jp\ to\ jp+1}, \tag{6}$$

L= maximum line divisions

$P_{Total\ active\ loss}$- Full loss of active power

2.2. Determinations Due to DG Units' Penetration

2.2.1. Power Loss Deviation

Power loss deviation (ΔPL) is a fraction of gross loss in power after penetrating dg segments to before penetrating dg segments as in equation (7).

$$\Delta PL = \frac{P_{dg\ Total\ active\ loss}}{P_{Total\ active\ Loss}} \tag{7}$$

2.2.2. Voltage Deviation

To find the maximum voltage deviation (ΔV_D) even after penetrating dg units as in equation (8)

$$\Delta VD = max\left(\frac{\boldsymbol{V^1 - V^{jp}}}{\boldsymbol{V^1}}\right),$$

nodes are numbered as jp = 1, 2, 3….Nb (8)

Vjp represents each node's voltage value, and V^1 represents the reference voltage.

Nb = maximum bus counts

2.3. Objective Function

The main aim of the newly done ideology is to decrease overall active power losses in all line sections. It is achieved by adequately adapting generation units in the distribution section through the spider monkey optimisation and flower pollination algorithm hybrid methodology.

$$ObjectiveFunction = Min\ (P_{Total\ active\ Loss}) \tag{9}$$

There is a need to follow the below constraints to achieve the aim.

2.4. Constraints

2.4.1. Voltage Bounds

Equation (10) determines the bus magnitude.

$$V_{minimum}^{jp} \leq V^{jp} \leq V_{maximum}^{jp} \tag{10}$$

$\mathrm{V}_{\mathrm{minimum}}^{\mathrm{jp}}$ - Low bus magnitude = 0

$\mathrm{V}_{\mathrm{maximum}}^{\mathrm{jp}}$ - High bus magnitude =1

2.4.2. Active Power Drawn from Distributed Generators Units Bounds

Equation (11) determines dg's drawn active power rating in each bus.

$$P_{dg\ min}^{jp} \leq P_{dg}^{jp} \leq P_{dg\ max}^{jp} \tag{11}$$

$P_{dg\ min}^{jp}$ - Minimum drawn active power rating of dg placed in bus jp = 0

$P_{dg\ max}^{jp}$ - Maximum drawn active power rating of dg placed in bus jp = $\frac{\sum_{\mathrm{jp}=1}^{\mathrm{Nb}} \mathrm{P_{TAL}}}{\text{No dg units}}$

$\mathrm{P_{TAL}}$ - Full load representing all active power of all loads.

2.4.3. Current Flow Bounds

Each line section's allowable current rating is like in equation (12).

$$I^{Ld} \leq I_{high}^{Ld} \tag{12}$$

I^{Ld} - Current in-line division.

$\mathrm{I}_{\mathrm{high}}^{\mathrm{Ld}}$ - Maximum current value in line division.

2.4.4. Power Balancing

According to the balancing of power in the power network, the addition of generating active power of general station withdrawing active power value from penetrated all generator units in distribution area should be same as the addition of total loss in active power with all load real power as in equation (13).

$$P_{dg\ Drawn\ Total\ Power} + P_{GS} = P_{TAL}\ P_{dg\ Total\ active\ loss} \tag{13}$$

$\mathrm{P_{dg\ DrawnTotal\ Power}}$ - Fully drawn active power from all dg units

$\mathrm{P_{GS}}$ - Full active power generated from the general station

$\mathrm{P_{dg\ Total\ active\ Loss}}$ - Full loss of active power, including dg $\mathrm{P_{TAL}}$ - Total active load

3. Ideal Position by Loss-Based Sensitivity Approach

LSF is determined by doing the differentiation of loss in power at any branch respecting active power. It also involves loss decrement occurring at active power and bus magnitude improvement.

Power loss for the branch jp to jp+1 is shown here.

$$P^{Loss\ jp\ to\ jp+1} = \left(\frac{P^{jp\ to\ jp+1^2} + Q^{jp\ to\ jp+1^2}}{\left|V^{jp+1^2}\right|}\right) * R^{jp\ to\ jp+1} \tag{14}$$

$$LSF = \frac{\partial P^{Loss\ jp\ to\ jp+1}}{\partial P^{eff\ jp+1}} = \frac{2P^{eff\ jp+1} * R^{jp\ to\ jp+1}}{\left|V^{jp+1^2}\right|} \tag{15}$$

The priority node selection for optimal sitting follows the descending arrangement of the magnitude of LSF. This selection is possibly optimal based on the structure of the radial system and the given load only. The above defect is overcome, and the proposed hybrid SMOA-FPA method determines a better optimal point.

This hybrid method uses the top thirty percentage priority nodes from the LSF list to lower the searching duration in choosing the optimal point. The optimal power rating is fixed by the hybrid approach as follows. Figure 2 describes the flowchart of the proposed hybrid SMOA-FPA method.

4. Hybridisation of SMOA-FPA Optimisation

4.1. Methodology

Step 1 : Initialisation of parameters

The algorithm's parameters, such as the limit for a global leader, perturbation rating, the limit for a local leader, population, maximum groups, and scaling factor, including maximum iterations, are fixed.

Step 2 : Initialisation of variables

The number of spider monkeys in the population is taken as search agents. The variables to be optimised for each spider monkey are randomly initialised using the following equation.

$$Sm_{sg} = Sm_{ming} + R\ (0,1) * (Sm_{maxg} - Sm_{ming}) \tag{16}$$

S - Number of spider monkeys
Sm_{ming} - Minimum dg rating
Sm_{maxg} - Maximum dg rating
$R(0, 1)$ - Randomly generated numbers between 0 & 1

The backward / Forward load procedure found the fitness value for randomly generated ratings for each monkey. All members are grouped here.

Local Leaders for all groups and Global Leaders for the population are also selected based on fitness value.

Step 3 : Local Leader Phase

In this phase, all members are updated based on Local Leader and randomly selected spider monkeys from each group.

R (0, 1) > P_rR, then only

$$Sm_{newsg} = Smsg + U(0,1)*(LL_{zg} - Sm_{sg}) + U(-1,1)*(Sm_{rg} - Sm_{sg}) \quad (17)$$

P_rR - Perturbation Rate
LL_{zg} - Local leader of z group
Sm_{rg} – Selected spider monkey from each group randomly

Step 4 : Global Leader Phase

$$Prob_g = \left(\frac{0.9 * fitness_g}{max\ fitness}\right) + 0.1 \quad (18)$$

$Prob_g$ = Probability of each spider monkey
$fitness_g$ = Fitness of each spider monkey

After the Local Leader phase is completed, members are updated based on Global Leader.

R (0, 1) < $Prob_g$ then only

$$Sm_{newsg} = Smsg + U(0,1)*(GL_g - Sm_{sg}) + U(-1,1)*(Sm_{rg} - Sm_{sg}) \quad (19)$$

GL_g – Random Global leader rating

Step 5 : Phase for Global Leader Learning added with Local Leader Learning

One in Local Leader Learning adds the limit count whenever there is no updating in Local Leader. The local leader of each group counts this.

The global limit count is increased to one in Global Leader Learning whenever there is no updating in Global Leader. This is checked for iterations.

Step 6 : Updating with FPA

If the Local Leader is not updated to the Local Leader Limit, FPA generates a new solution by global pollination and the best Fitness is selected among the population

$$Sm_{newsg} = Sm_{sg} + \gamma * L\,(Sm_{sg} - B^*) \quad (20)$$

B^* - the current best solution
γ - Scaling factor
L - Levy distribution as
$L \sim \frac{\lambda\Gamma(\lambda)\sin(\pi\lambda/2)}{\pi}\frac{1}{Z^{1+\lambda}}$, $Z \gg Z^0 > 0$

Step 7 : Decision phase in Global Leader

The groups are increased if Global Leader is not revised to the Global Leader Limit. All members of all groups are combined as a single group even if the groups are increased, and Global Leader is not revised.

Step 8 : The best value in Fitness among the population is chosen as the best solution

Step 9 : Increment of iteration is one until the maximum iteration and the process is terminated**.**

Table 1. Parameters used in Hybrid SMOA-FPA

Needed Parameters	Used Values
Population size	60
Group numbers	6
Limit to Local Leader	90
Limit to Global Leader	45
Rating of Perturbation	0.1
Scaling factor	0.01
λ index	1.5
Iteration numbers	100

4.2. Stepwise Planning of Hybrid SMOA-FPA

Step 1 : Select the algorithm's parameters.
Step 2 : For randomly initialised placement from LSF, the optimal rating of DG is fixed as follows.
Step 3 : The population of searching agents (Spider Monkeys) with random variables are initialised randomly.
Step 4 : Each spider monkey's fitness value (power loss) is determined through the Backward/Forward sweep primary method for load flow. Members are also grouped to know the Local Leaders and Global Leaders.
Step 5 : Members' values are revised based on Local Leader by considering the perturbation rate.

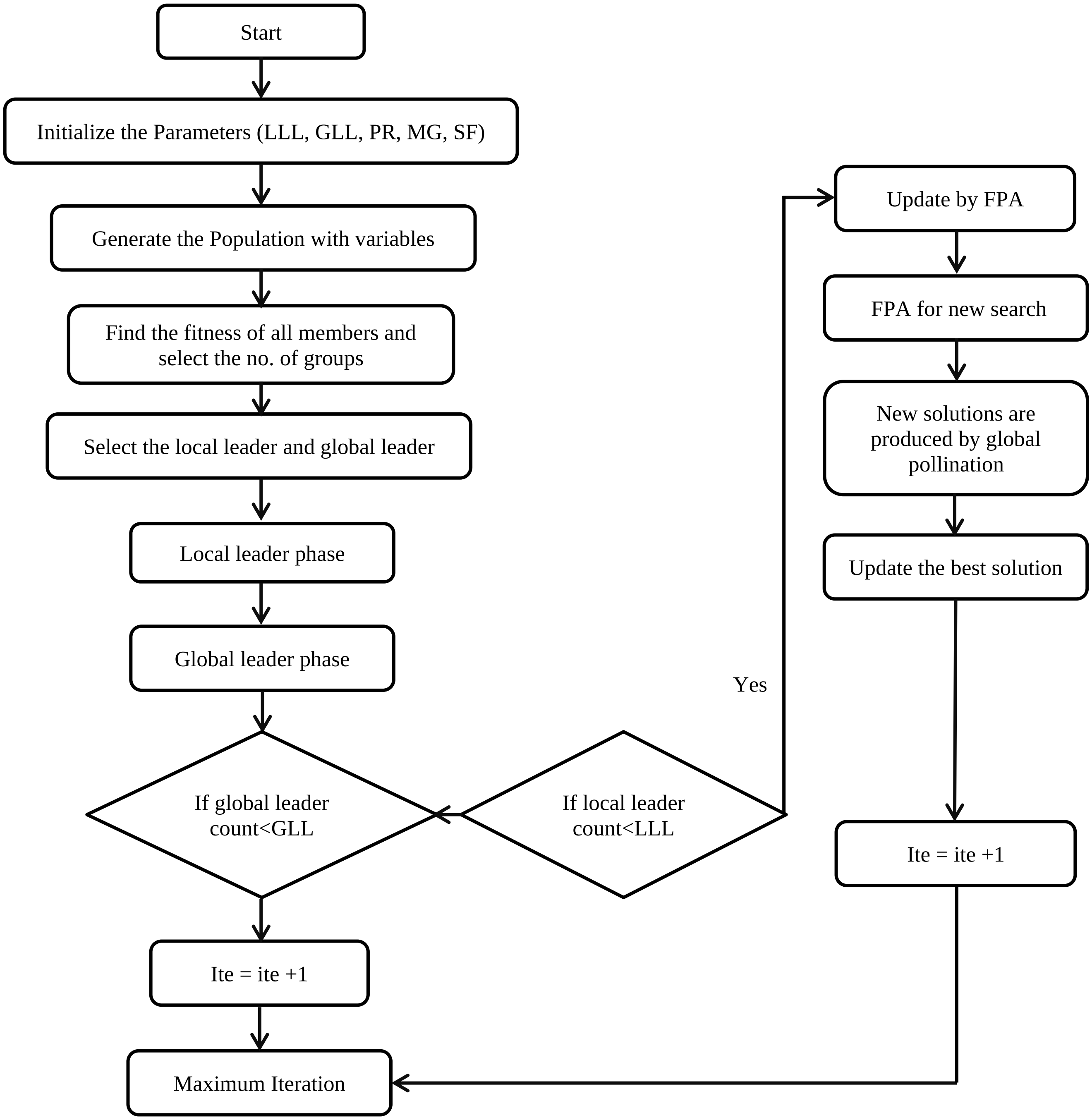

Fig. 2 Hybrid SMO –FPA technique for optimal selection of DG units

Step 6 : After completion of LLP, all members are updated based on Global Leader by considering Probability.

Step 7 : If the Local Leader of any group does not do the updating, the limit count is increased by one for each group. This is allowed to Local Leader Limit.

Step 8 : If the updating is not done in Global Leader, limit count is increased by one. This is allowed to Global Leader Limit.

Step 9 : If the Local Leader is not updated up to limit fixed in Local Leader, the updating is done by global pollination of FPA.

Step 10 : If the updating is not done in Global Leader up to limit fixed in Global Leader, group number is increased. All group members are combined as a single if Global Leader is not updated even after increasing the group number.

Step 11 : The best Fitness in the population gives the optimal rating for dg.

Step 12 : The process is progressed to maximum iterations.

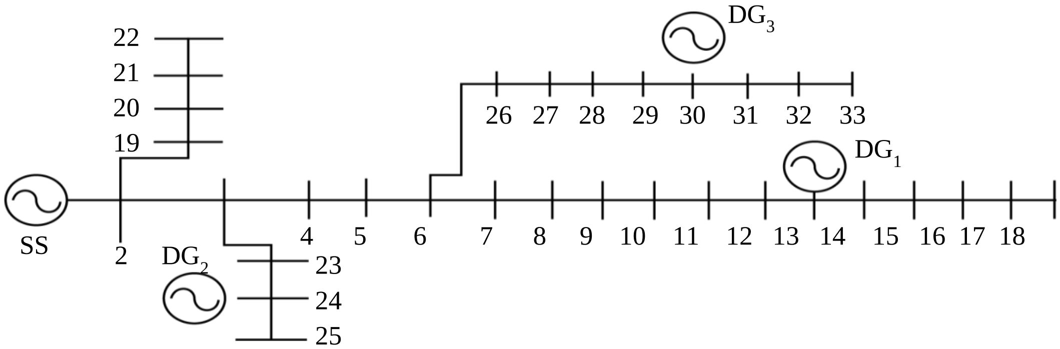

Fig. 3 Single line diagram of 33 bus radial distribution system

Table 2. Numerical results of hybrid SMOA-FPA for various levels of loads through the execution on 33 bus system

Parameters	**Constant Power Load**					
	Heavy Load Level (1.6)		**Level of Nominal Load (1)**		**Level of Light Load (0.5)**	
	Basic	**DG (included)**	**Basic**	**DG (included)**	**Basic**	**DG (included)**
Optimal Place		13 24 30		13 24 30		13 24 30
DG Optimal Value (MW)		1.335 1.268 1.647		0.851 0.810 1.044		0.351 0.570 0.495
Total DG Optimal Value (MW)		4.250		2.705		1.416
Loss of Active Power (kW)	603.36	193.81	210.98	70.55	48.78	17.45
Power Loss Reduction (%)		67.88		66.56		64.23
Minimum Bus Magnitude (p.u)	(18) 0.8360	(33) 0.9458	(18) 0.9038	(33) 0.9680	(18) 0.9540	(33) 0.9832
Voltage Deviation	0.1640	0.0542	0.0962	0.032	0.046	0.017

5. Simulation and Numerical Outputs

This hybrid approach focuses on achieving minimal power loss with the betterment of the voltage profile by properly selecting generator units of the distribution network. Hybrid SMOA-FPA precedes the selection of ideal placement with the help of LSF. The optimal value for DG is fixed at selected ideal locations by hybrid methodology. The IEEE having 33 nodes together with 69 nodes are utilised to make evident the proposed work. The data for test systems are referred from [33]. Simulations are done for the following tests to present the focal point of gratification of the proposed hybrid SMOA-FPA algorithm.

Test -1 : Insertion of three DGs to various levels in loads.
Test -2 : Insertion of three DGs for various load models.

5.1. IEEE 33- Nodes System

This is the radial distribution configuration having a base level voltage of 12.66kV. It also has 3720kW as the overall active load and 2300KVAR as the overall reactive load. This system's basic active power loss is 210.98kW for the nominal load.

The single line in Figure 3 represents this system. Three optimal DG units capable of feeding active powers alone are considered for the simulation. This hybrid approach simulates the optimal positions as 13, 24 and 30. The following optimal values are simulated for the different test cases for the above optimal positions. In test - 1, the optimal value of three distribution generators for different levels of loads on 33 nodes standard system are executed by hybrid

SMOA-FPA algorithm, and the numerical outputs are displayed in Table 2. The desirable values for three distribution generators, 0.851MW, 0.810MW and 1.044MW, are simulated for the nominal load (100%). The loss in active power is reduced to 70.55kW with the minimum bus magnitude of 0.9680 per unit. For higher load levels (160%), three DG units' optimal ratings are simulated as 1.335MW, 1.268MW and 1.647MW. The loss in active power is reduced to 193.81kW with the minimum bus magnitude of 0.9458 per unit. For lower load levels (50%), three optimal distribution generator ratings are 0.351MW, 0.570MW and 0.495MW. The loss in active power is reduced to 17.45kW with the minimum bus magnitude of 0.9832 per unit.

In test - 2, the optimal value of three distribution generators for different load models on 33 nodes standard system is executed by a hybrid SMOA-FPA algorithm. The numerical outputs are displayed in Table 3. The desirable values for three distributed generation segments for constant power load simulated by the hybrid approach are as 0.851MW, 0.810MW, and 1.044MW and the loss in active power is diminished as 70.55kW with the minimum bus magnitude is as 0.9680per unit.

In constant current load, the simulated optimal DG units are 0.741MW, 0.890MW, and 1.028MW; the active power loss is decreased to 62.1kW, and the minimum bus magnitude is 0.9730 per unit. The optimal ratings of generator units for constant impedance load are 0.784MW, 0.747MW, and 0.958MW. The decrement in active power loss is 53.91kW, and the minimum bus magnitude is 0.9755 per unit.

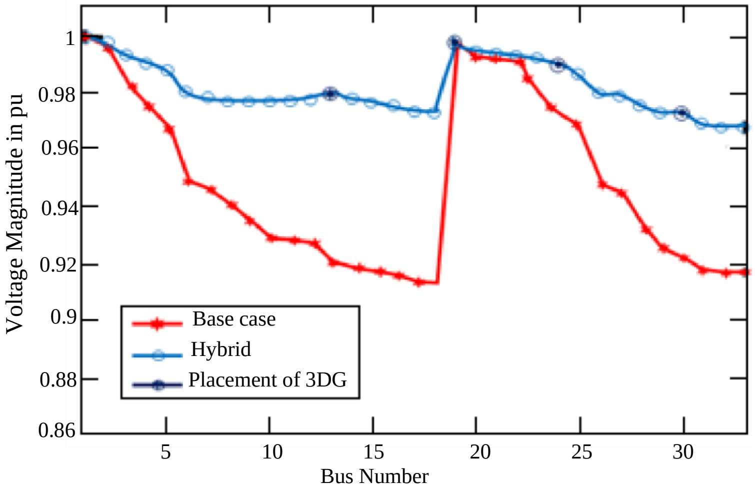

Fig. 4 Voltage level nominal power load

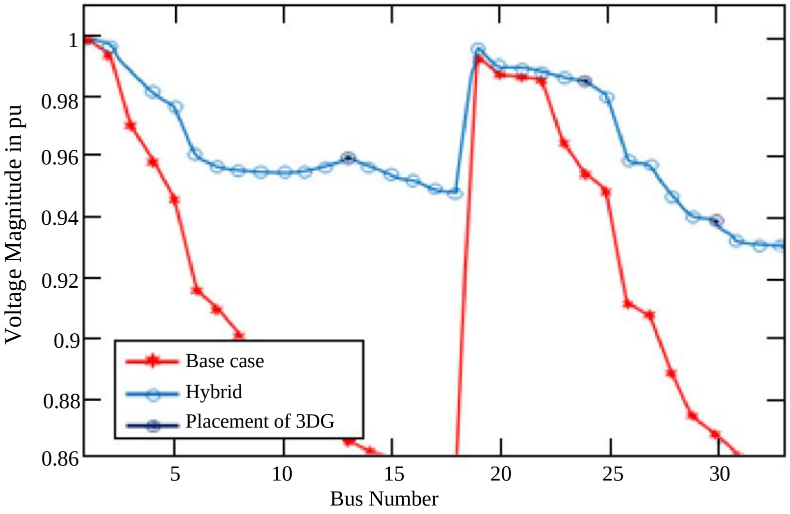

Fig. 5 Voltage level for high power load

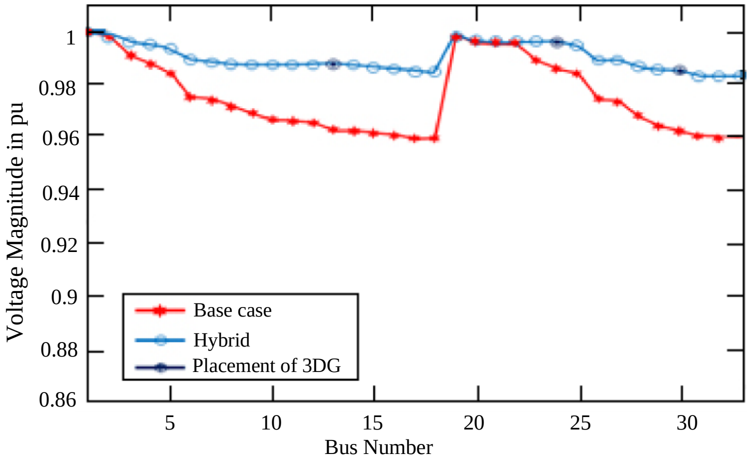

Fig. 6 Voltage level for low power load

Table 3. Execution results in SMOA-FPA through IEEE 33 network with distinct load types

Parameters	**Different Type Loads**					
	Power-Constant-Load		**Current-Constant-Load**		**Impedance-Constant-Load**	
	Basic	**DG (included)**	**Basic**	**DG (included)**	**Basic**	**DG (included)**
Optimal Place		13 24 30		13 24 30		13 24 30
DG Optimal Value (MW)		0.851 0.810 1.044		0.741 0.890 1.028		0.784 0.747 0.958
Total DG Optimal Value (MW)		2.705		2.659		2.489
Loss of Active Power(kW)	210.98	70.55	184.36	62.1	159.78	53.91
Power Loss Reduction (%)		66.56		66.33		66.26
Minimum Bus Magnitude (p.u)	(18) 0.9038	(33) 0.9680	(18) 0.9113	(33) 0.9730	(18) 0.9173	(33) 0.9755
Voltage Deviation	0.0962	0.032	0.0887	0.0264	0.0827	0.0245

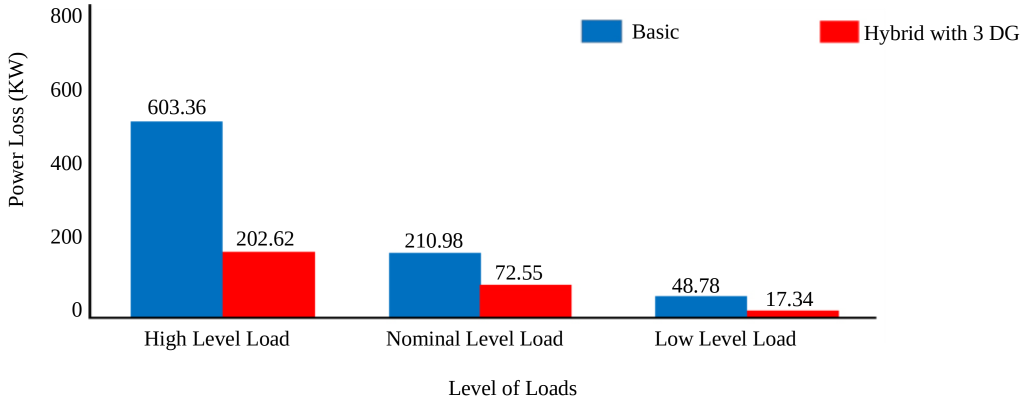

Fig. 7 Power loss for different levels of loads

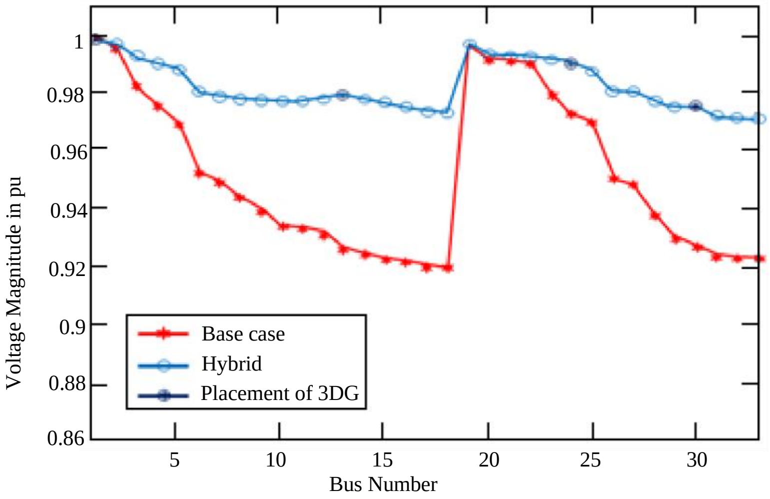

Fig. 8 Voltage level for constant current load

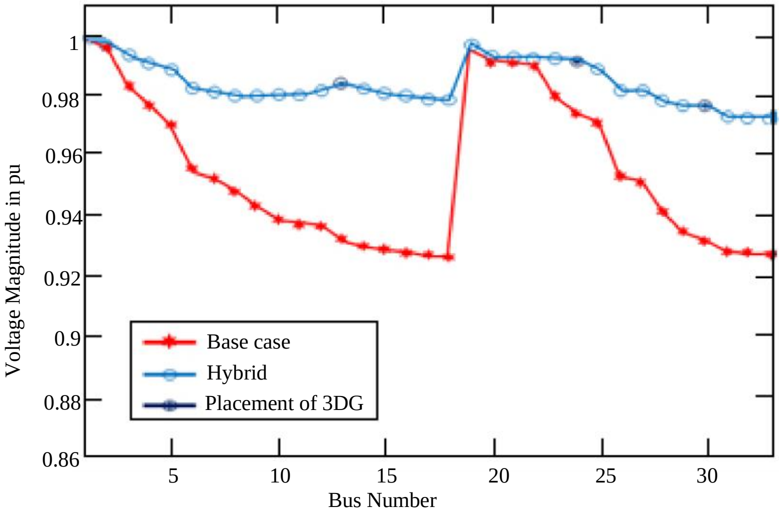

Fig. 9 Voltage level for constant impedance

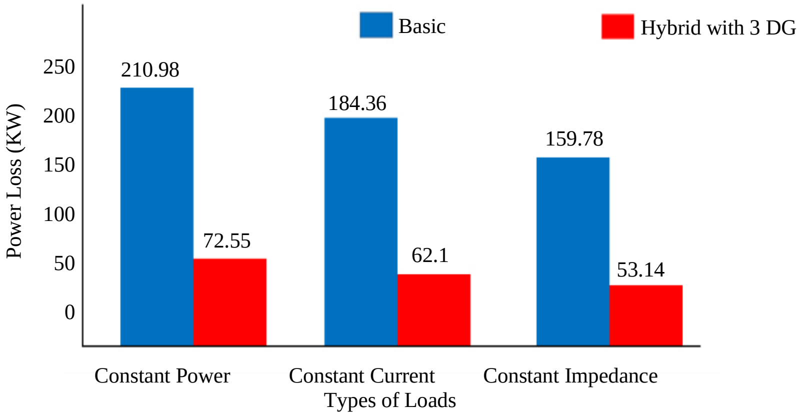

Fig. 10 Power loss for different load models

Table 4. The comparison of the LSF approach and SMOA-FPA approach through the IEEE 33 network for nominal load

Parameters	Optimal Place	DG Optimal Value (MW)	Total DG Rating (MVA)	Power Loss (kW)	Power Loss Reduction (%)	Minimum Voltage	Voltage Deviation
LSF Approach	6 3 28	1.050 0.933 0.784	2.767	95.20	54.88	(18) 0.9443	0.0557
Hybrid Approach	13 24 30	0.851 0.810 1.044	2.705	70.55	66.56	(33) 0.9680	0.032

Table 5. The comparison of hybrid SMOA-FPA with other hybrid methods for 33 node system

Hybrid Methods	Year	Power Factor	Optimal Place	DG Optimal Value (MW)	Total DG Rating (MVA)	Power Loss (kW)	Power Loss Reduction (%)	Minimum Voltage	Voltage Deviation
GA-PSO (15)	2012	Unity	32 16 11	1.2000 0.8630 0.9250	2.9880	103.40	50.99	0.9808	0.0192
HAS-PABC (16)	2016	Unity	30 24 14	1.068 1.073 0.755	2.896	72.81	65.49	0.9684	0.0316
A-SSA (33)	2021	Unity	13 24 30	0.79 1.07 1.012	2.872	72.89	65.45	0.9670	0.033
O-SCMDEA (30)	2022	Unity	30 13 24	1.0483 0.8052 1.0936	2.9471	72.78	65.51	0.9849	0.0151
Proposed SMO-FPA		Unity	13 24 30	0.851 0.810 1.044	2.705	70.55	66.56	0.9680	0.032

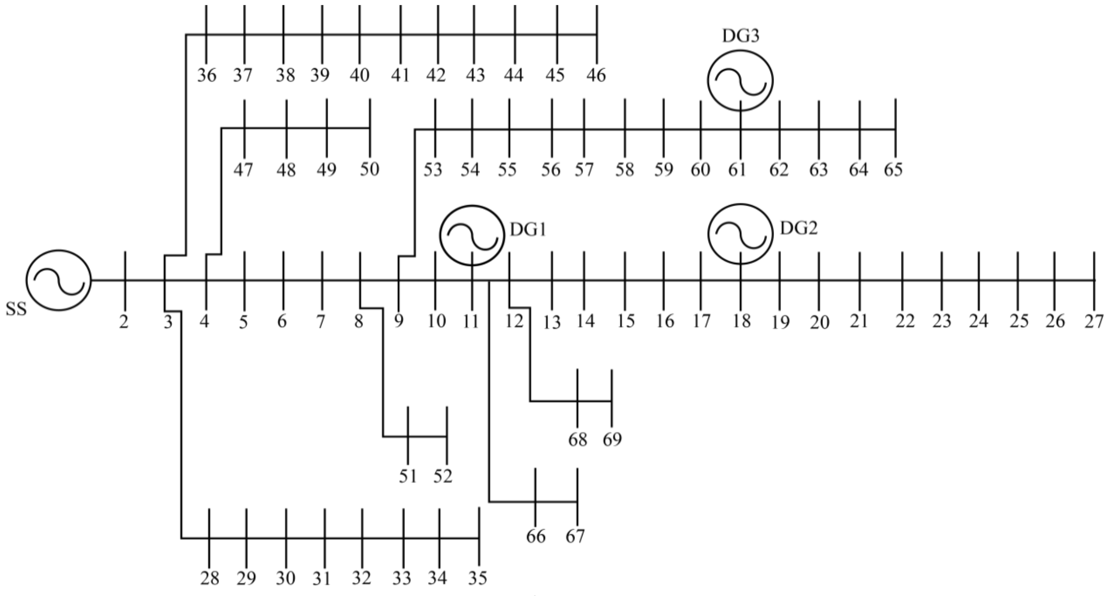

Fig. 11 Single line diagram of 69 bus radial distribution system

Figures 4, 5 and 6 represent the voltage value improvement at all nodes, and the minimum voltage is increased from 0.8360, 0.9038 and 0.9540 per unit to 0.9458, 0.9680 and 0.9832 per unit for higher, nominal and lower load respectively. Figure 7 represents the reduced power loss as 193.81, 70.33 and 17.45kW from basic loss for higher, nominal and lower level loads, respectively. These above representations show the objective achievement.

Table 4 compares the simulated power loss value, 95.20kW and minimum voltage value, 0.9443 per unit of LSF approach, with the simulated power loss value, 72.55kW and minimum voltage value, 0.9680 per unit of hybrid approach. They all have also been done for nominal constant power loads. Figure 8 and 9 represent the voltage value improvement at all nodes, and the minimum voltage is increased from 0.9113 and 0.9173 per unit to 0.9730 and 0.9755 per unit for constant current and constant impedance load model, respectively. Figure 10 represents the reduced power loss as 70.55, 62.1 and 53.91kW from basic loss for constant power, constant current and constant impedance load models, respectively. These above representations also show the effectiveness of the proposed hybridisation for different load models.

In the proposed work, the hybrid SMOA-FPA algorithm is examined with other hybrid methods like GA-PSO, HAS-PABC, Analytical-SSA and O-SCMDEA to prove the validity of the hybridisation. The numerical results consist of power loss and minimum voltage of all methods for the optimal penetrating position of three optimal distribution generators. These results are for nominal constant power load and are figure in Table 5. These analyses conclude that the newly stated method has good attainment.

5.2. IEEE 69- Nodes System

This radial distribution configuration has a base level voltage of 12.66 kV. It has an overall active load of 3720 kW and an overall reactive load of 2300 KVAR. This system's basic active power loss is 224.99 for the nominal load. The single line in Figure 11 represents this system. Three optimal type-1 DG units capable of feeding active powers alone are considered for the simulation. This hybrid approach simulates the optimal positions as 11, 18 and 61. The following optimal values are simulated for the different test cases for the above optimal positions.

In test - 1, the optimal value of three distribution generators for different levels of loads on 69 nodes standard system is executed by a hybrid SMOA-FPA algorithm and the numerical outputs are displayed in Table 6. The desirable values for three distribution generators, 0.500MW, 0.374MW and 1.673MW, are simulated for the nominal load (100%).

The loss in active power is reduced to 65.52 kW with the minimum bus magnitude of 0.9996 per unit. For higher load levels (160%), three DG units' optimal ratings are simulated as 0.492MW, 0.561MW and 2.210MW. The loss in active power is reduced to 200.46 kW with the minimum bus magnitude of 0.9432 per unit. For lower load levels (50%), three optimal distribution generator ratings are 0.225MW, 0.172MW and 0.886MW. The loss in active power is reduced to 17.1 kW with the minimum bus magnitude of 0.9904 per unit.

Table 6. Numerical results of hybrid SMOA-FPA for various levels of loads through the execution on 69 bus system

Parameters	Constant Power Load					
	Heavy Load Level (1.6)		Level of Nominal Load (1)		Level of Light Load (0.5)	
	Basic	DG (included)	Basic	DG (included)	Basic	DG (included)
Optimal Place		11 18 61		11 18 61		11 18 61
DG Optimal Value (MW)		0.492 0.561 2.210		0.500 0.374 1.673		0.225 0.172 0.886
Total DG Optimal Value (MW)		3.263		2.547		1.283
Loss of Active Power (kW)	652.42	200.46	224.99	65.52	51.59	17.1
Power Loss Reduction (%)		69.27		70.88		66.85
Minimum Bus Magnitude (p.u)	(65) 0.8445	(65) 0.9432	(65) 0.9091	(65) 0.9996	(65) 0.9567	(65) 0.9904
Voltage Deviation	0.1555	0.0568	0.0909	0.0004	0.0433	0.0096

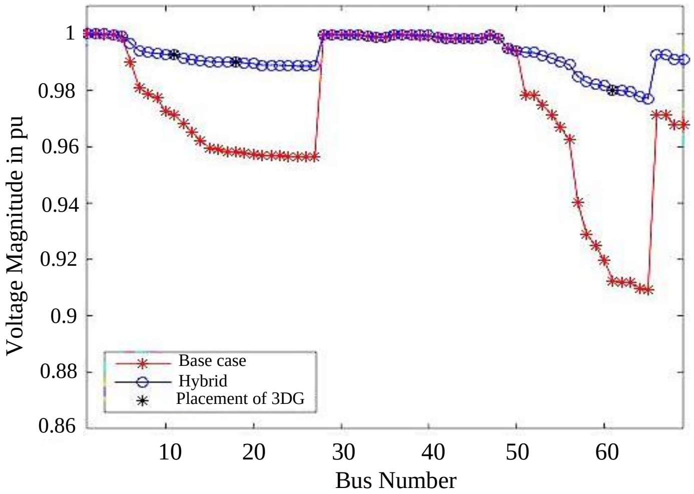

Fig. 12 Voltage level for nominal power load

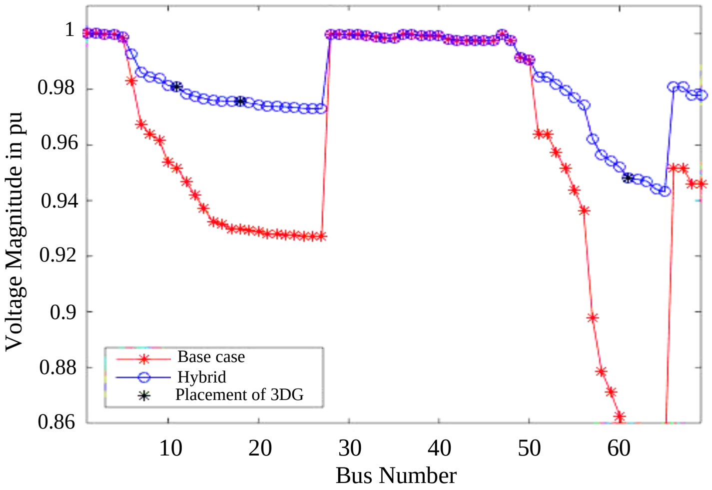

Fig. 13 Voltage level for high power load

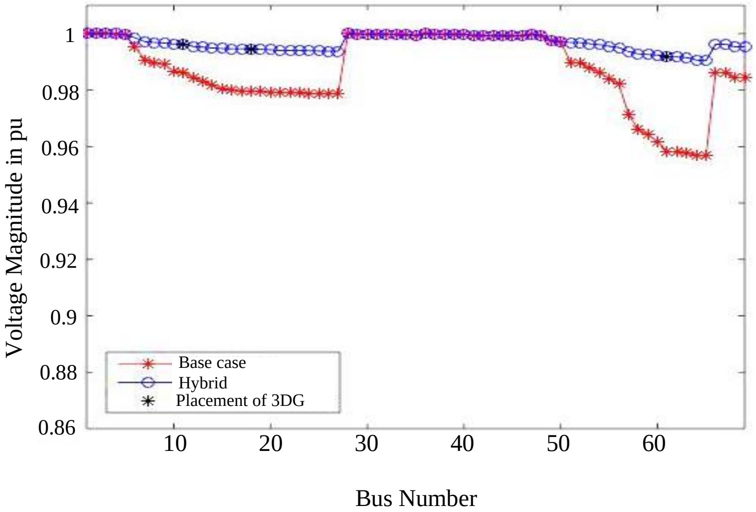

Fig. 14 Voltage level for low power load

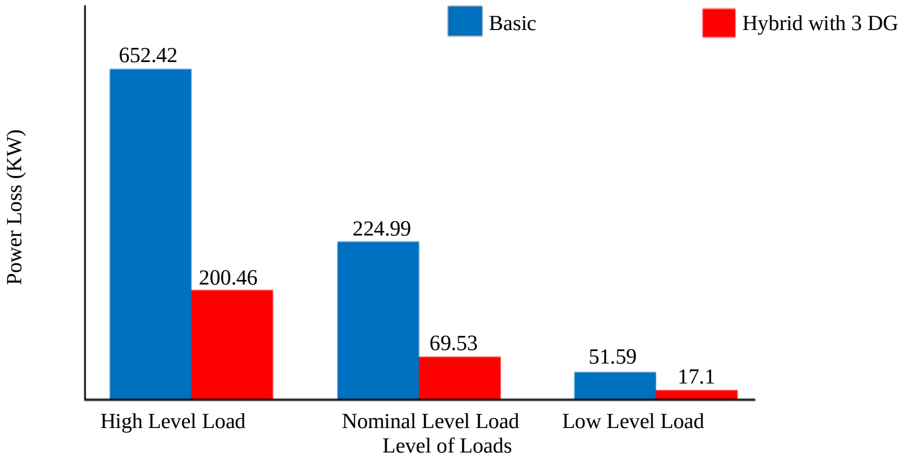

Fig. 15 Power loss for different levels of loads

Table 7. The execution result of SMOA-FPA through the IEEE 69 network with distinct load types

Parameters	**Different Constant Loads**					
	Constant-Power-Load		**Constant-Current-Load**		**Constant-Impedance-Load**	
	Basic	**DG (included)**	**Basic**	**DG (included)**	**Basic**	**DG (included)**
Optimal Place		11 18 61		11 18 61		11 18 61
DG Optimal Value (MW)		0.500 0.374 1.673		0.485 0.355 1.528		0.490 0.356 1.432
Total DG Optimal Value (MW)		2.547		2.368		2.278
Loss of Active Power(kW)	224.99	65.52	191.5	59.32	167.2	50.69
Power Loss Reduction (%)		70.88		69.02		69.68
Minimum Bus Magnitude (p.u)	(65) 0.9091	(65) 0.9996	(65) 0.9167	(65) 0.9791	(65) 0.9226	(65) 0.9842
Voltage Deviation	0.0909	0.0004	0.0833	.0209	0.0774	0.0158

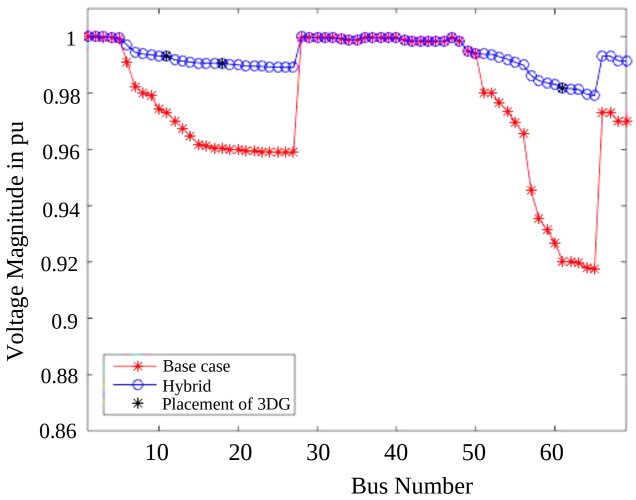

Fig. 16 Voltage level constant current load

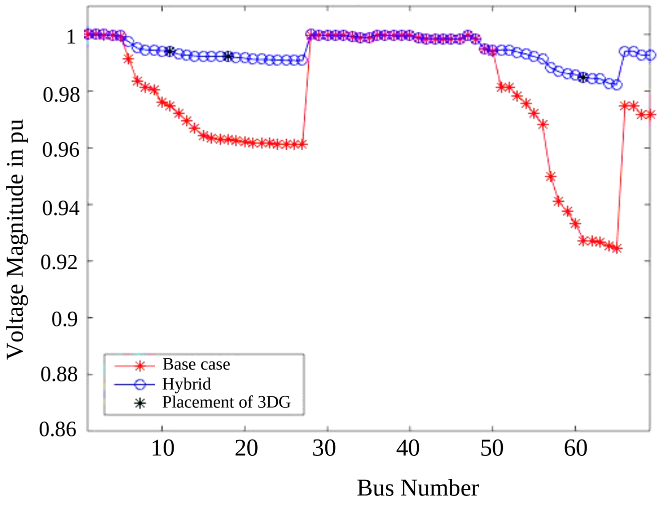

Fig. 17 Voltage level for constant impedance

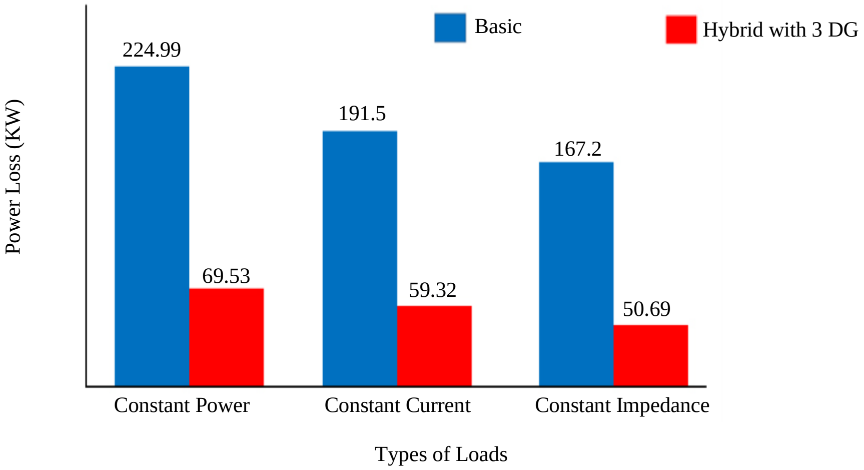

Fig. 18 Power loss for different types of loads

Table 8. The execution result of the LSF approach and SMOA-FPA approach through the IEEE 69 network for nominal load

Parameters	Optimal Place	DG Optimal Value (MW)	Total DG Rating (MVA)	Power Loss (kW)	Power Loss Reduction (%)	Minimum Voltage	Voltage Deviation
LSF Approach	65 27 61	0.609 1.174 0.834	2.617	109.19	51.47	(61) 0.9735	0.0265
Hybrid Approach	11 18 61	0.500 0.374 1.673	2.547	69.53	69.10	(65) 0.9772	0.0228

Table 9. The comparison result of hybrid SMOA-FPA with other hybrid methods for 69 node system

Hybrid Methods	Year	Power Factor	Optimal Place	DG Optimal Value (MW)	Total DG Rating (MVA)	Power Loss (kW)	Power Loss Reduction (%)	Minimum Voltage	Voltage Deviation
GA-PSO (15)	2012	Unity	63 61 21	0.8849 1.1926 0.9105	2.988	84.60	62.4	(65) 0.9925	0.0075
A-PSO (3)	2016	Unity	11 17 61	0.51 0.38 1.67	2.56	69.54	69.09	(65) 0.9771	0.0229
A-TGA (38)	2020	Unity	11 17 61	0.509 0.382 1.732	2.615	69.41	69.15	(65) 0.9790	0.021
Proposed SMO-FPA	2023	Unity	11 18 61	0.500 0.374 1.673	2.547	69.53	69.1	(65) 0.9772	0.0228

In test - 2, the optimal value of three distribution generators for different types of load models on 69 nodes standard system is executed by a hybrid SMOA-FPA algorithm and the numerical outputs are displayed in Table 7. The desirable value for three distributed generation segments for constant power load simulated by the hybrid approach is 0.500MW, 0.374MW, and 1.673 MW. The loss in active power is diminished to 65.52 kW, and the minimum bus magnitude is 0.9996 per unit. In constant current load, the simulated optimal DG units are 0.485 MW, 0.355MW, 1.528 MW, and the loss of active power is decreased to 59.32 kW, and the minimum bus magnitude is 0.9791 per unit. The optimal ratings of generator units for constant impedance load are 0.490 MW, 0.356 MW, and 1.432 MW. The decrement in active power loss is 50.69 kW, and the minimum bus magnitude is 0.9842 per unit.Table 8 compares the simulated power loss value, 109.19kW and minimum voltage value, 0.9735 per unit of LSF approach, with the simulated power loss value, 69.53kW and minimum voltage value, 0.9772 per unit of a hybrid approach. They all have also been done for nominal constant power loads.

Figure 16 and 17 represent the voltage value improvement at all nodes, and the minimum voltage is increased from 0.9167 and 0.9226 per unit to 0.9791 and 0.9842 per unit for constant current and constant impedance load model, respectively. Figure 18 represents the reduced power loss as 65.52, 59.32 and 50.69kW from basic loss for constant power, constant current and constant impedance load models, respectively. These above representations also show the effectiveness of the proposed hybridisation for different load models. The proposed work, the hybrid SMOA-FPA algorithm, is examined with other hybrid methods such as GA-PSO, Analytical–PSO, and Analytical-Tree grow algorithm to prove the validity of their hybridisation. The numerical results consist of the power loss of all methods for the optimal penetrating position of three optimal distribution generators. These results are for nominal constant power load and are figure in Table 9. These analyses conclude that the newly stated method has good attainment.

6. Conclusion

The ideology of this paper submits hybrid SMO-FPA to prefer the proper placement and size for multiple generation units in the distribution zone to suppress the loss of power together with raising the bus magnitude. To justify the expertisation of this technique, this is enforced for various loads, namely constant impedance, power and current type, and changeable load levels. The performance of this work is approved by testing on 33 and 69 bus topology. The simulated figure confirms that the suggested hybridisation lowers active power loss and boosts the voltages at all nodes for incorporating three DGs, even for varying types and loads.

Nomenclature

jp = bus count
Nb = maximum bus counts
Ld = line division
L = maximum line divisions
I^{Ld} = current in-line division
$I^{\mathrm{Ld}}_{\mathrm{high}}$ = high current value in line division
I^{jp} = current value of bus jp
V^{jp} = voltage value of bus jp
S^{jp} = power value of bus jp
$I^{\mathrm{jp\ to\ jp+1}}$ = current flowing in the division jp to jp+1 without dg
$I^{\mathrm{jp+1}}$ = current value of bus jp+1
$V^{\mathrm{jp+1}}$ = voltage value of bus jp+1
$P_{\mathrm{l}}^{\mathrm{jp}}$ = load represents the active power of bus jp
$Q_{\mathrm{l}}^{\mathrm{jp}}$ = load represents reactive power of bus jp
$Z^{\mathrm{jp\ to\ jp+1}}$ = impedance of the division jp to jp+1
$R^{\mathrm{jp\ to\ jp+1}}$ = resistance of the division jp to jp+1
$P^{\mathrm{jp\ to\ jp+1}}$ = active power flowing in the division jp to jp+1 without dg
$Q^{\mathrm{jp\ to\ jp+1}}$ = reactive power flowing in the division jp to jp+1 without dg
$S^{\mathrm{jp\ to\ jp+1}}$ = power flowing in the division jp to jp+1
$P_{\mathrm{dG}}^{\mathrm{jp}}$ = the drawn active power from dg placed at bus jp
$P^{\mathrm{Loss\ jp\ to\ jp+1}}$ = power loss occurred in the division jp to jp+1 without dg
$P_{\mathrm{dg\ DrawnTotal\ Power}}$ = fully drawn active power from all dg units
$P_{\mathrm{Total\ active\ loss}}$ = full loss of active power excluded dg
$P_{\mathrm{dg\ Total\ active\ Loss}}$ = full loss of active power included dg.
$V_{\mathrm{minimum}}^{\mathrm{jp}}$ = the minimum level of voltage at any bus jp
$V_{\mathrm{maximum}}^{\mathrm{jp}}$ = maximum level of voltage at any bus jp
$P_{\mathrm{dg\ min}}^{\mathrm{jp}}$ = the minimum drawn active power from dg placed at bus jp
$P_{\mathrm{dg\ max}}^{\mathrm{jp}}$ = the maximum drawn active power from dg placed at bus jp
P_{TAL} = full load represents all active power of all loads
P_{GS} = full active power generated from general station

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