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Novel JAYA-IWO approach for Optimal Distributed Generation Placement to Minimize Power Losses

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Abstract: This paper proposes a novel technique to optimally place multiple distributed generators in radial type of distribution network for mitigating real power losses and enhancing voltage characteristics. Two conventional methods namely, JAYA algorithm and Invasive Weed optimization (IWO) algorithm are examined on IEEE 33-bus and 69-bus RDS. Then, a hybrid approach involving both JAYA and IWO algorithms is proposed. Efficacy of all the optimization techniques is used on various load models. Each test system is tested with integration of type-1 and type-3 Dispersed Generators. Apart from loss minimization and voltage profile improvement, VDI, PLI, TOC and CPDG are also calculated. Final results are juxtaposed with other optimization methods and better performance of suggested technique is recorded.

Keywords: JAYA algorithm, Invasive Weed Optimization, JAYA-IWO algorithm, Voltage Deviation Index, Total Operational Cost, CPDG, Box Plot, radial distribution network, distributed generation.

1. Introduction:

Distribution networks are generally radial, considering operational simplicity. In such networks, power is fed from one end and on the other end, consumers receive the electricity, which means that power flow in such network is uni-directional. Radial distribution network is having the property of low X/R ratio and unbalanced burden, which is a prominent root-cause of drop in voltage, unstable supply and higher system losses. To suffice all up to a certain extent, integration of dispersed generation or distributed generation into distribution network is quite popular. According to Thomas Ackermann [1], distributed generation is a power source to be installed near the proximity of load. These sources could be varying from 1 kW to 50 kW. Generally distributed generating sources are synchronous generators, induction generators, reciprocating engines but now-a days, renewable sources like, PV modules and wind turbine are also employed.

Distributed Generation (DG) are of crucial importance in shaping the future of smart grids, offering a range of techno-economic, and environmental benefits to the existing power system. The increasing penetration of DG plants in electric distribution systems reflects the recognition of their potential impact. For ensuring the efficient and reliable operation of power system, consequences of integration of DG are to be evaluated. Some technical concerns are to be considered before implementing DG into distribution system such as, voltage characteristics, loss of active power, better power quality and dependability, power system protection and management and power system stability.

Integrating DG can assist in keeping the voltage levels within permissible limits, which improve overall system stability. Similarly, less power losses improves the effective power transfer and reduced T&D losses. Penetration of DG helps in providing local support amid voltage dips and surges and hence keeps the connected equipment in healthy state. This also provides a resilient, robust and dependable grid network. By installing DG into the power distribution network peak load demands can be fulfilled. But it is also essential to calculate the risks on priority basis associated with integration of dispersed generators with the network. Apart from techno-economic benefits, there are also environmental issues with the DG integration. Insertion of DG requires lesser installation time with reduced costs and increased stability and reliability [2].

To maximize the benefits of integrating DG, correct capacity and best location is to be chosen, otherwise there could be disastrous consequences, like, higher power loss, voltage fluctuations and higher installation costs [3].

It matters most that any loss in the system reduces the efficiency and stability of power network. Therefore, decrease in losses is an essential factor to consider before installation of DG.

Many researchers have formulated this problem as various objective functions and solved using different techniques. In [4], analytical technique is used for optimal allocation of dispersed generators in IEEE 30, 33 and 69-bus system using loss sensitivity factor with Elgerd's formula [5]. Tah et al [6], proposes a novel analytical method to optimally place the DG over 33 & 69-bus network using 'P' and 'PQV' buses. Similarly, Mithulananthan et.al. [7] also used loss sensitivity factor (LSF) to mitigate the losses in primary distribution network. [8] - [11] utilizes genetic algorithm based approach to optimize the similar problem. These literatures provide solution to various kinds of distribution models for active power loss reduction as well cost reduction. [12] - [15] uses Particle swarm optimization approach to optimize this problem along-with improvement in voltage profile. While, [16], [15], [2], [17]-[19] proposes use of PSO and its improved technique combined with other methodologies to achieve better and faster results for the similar objective. In [16], PSO with fuzzy control is applied over IEEE – 18 bus system to achieve charge/discharge mode of storage unit with effective pricing. Continuation power flow is utilized with PSO in [15] to identify the consequences of DG connection on delicate buses that are vulnerable to power outages. Combined GA/PSO technique is shown in [2] with detailed analysis of performance for IEEE33 & 69-bus system in order to mitigate power losses with improved voltage regulation. Abidi and Afshar [17] describes the application of combined IPSO-Monte Carlo method for identification of the optimal DG allocation with capacity by various objectives like cost reduction of losses, better system reliability and voltage stability. The outcomes are contrasted with artificial bee colony method to verify the efficacy. In [18], problem of multi-stage planning of distribution network expansion with DG penetration is solved for minimized capital cost, minimum operational cost and maximum reliability indices, using PSO in conjunction with Shuffled Frog Leaping optimization technique. [19] proposes I-GWOPSO methodology to mitigate real power losses, enhancement in voltage profile and optimal reduction of costing with optimal capacity of DG in IEEE 33- and 69-bus system. There are some latest optimization techniques, utilized for achievement of the similar problem. In [20], modified teaching learning algorithm is discussed for solving continuous nonlinear optimization problem of lower dimension. [21] describes use of bacterial foraging optimization (BFO) algorithm for mitigation of power losses with improved voltage stability and profile in 33 & 69-bus radial network. [22], [23] elaborates application of simulated annealing optimization technique for enhancement of voltage characteristics and power loss mitigation. [24] describes application of new ant lion optimization methodology for combining multi objective optimization problem with single objective problem to achieve loss reduction, reliability enhancement, reduction in operational cost and voltage deviation on 33 and 69-bus distribution system. Almost, similar multi objective optimization problem, for reduction in loss, betterment in voltage profile, and decrement in cost, is solved by incorporating multiple type-1 and type-2 DGs in RDN using Whale Optimization Algorithm in [3]. [25] analyses impact assessment of various types of DGs working at variable power factors along with SVC for different load models. This paper presents multi objective optimization approach like, voltage improvement, loss minimization, reduction in MVA line capacity and environmental (GHG) concerns. The efficacy of the proposed method is examined on IEEE 37-buses system. [26] uses I-DBEA (improved decomposition based evolutionary algorithm) over small, medium and large (33, 69 and 119-bus) radial distribution network for loss reduction and voltage deviation. It proves that I-DBEA method is a fast and efficient direct load flow approach to achieve the goals. For identifying the optimal placement of distributed generators with its appropriate size, this method has been used for the very first time. There is a remarkable paradigm shift in calculating the parameters through NRLF or any other conventional method, as a new approach has been introduced for load flow computations and the name is given BIBC-BCBV matrix load flow [27] and using this kind of load flow, the Genetic Algorithm is implemented over 33-bus and 69-bus radial network to minimize losses by optimally placing dispersed generators [28]. Implementation of Jaya algorithm, developed by [29], is used by [30] to optimally place DG and shunt capacitors. This paper uses two constraints free BWOs I.e. Jaya and Rao-1 for maximizing their searching power of finding suitable placement location.

SMA (Slime Mold Algorithm) mixed with weighted sum technique and fuzzy clustering is used in [31] to reduce operational cost of DGs employed in industrial, commercial and residential load in, to reduce average daily active power losses and growth in daily voltage levels. Test system considered, are 33-bus and 69-bus RD system. Proposed technique is examined using 24 hour testing time This article provides solution in three stages. Solution to power loss problem is dealt first, then voltage profile is improved in next stage. Finally, both the problems are combined and solved to attain optimal solution of placing and sizing of DGs. Effectiveness of the method is compared with SCA and GHO algorithms. [32] uses hybrid GA-PSO technique for optimal placing the PEVCS into IEEE 33- and 69-bus distribution system, as dispersed generators. Here PV arrays with 0.95 p.f. are taken into consideration for DG. MOP of mitigating power loss and voltage deviation index is formulated as objective function. Leader based Jellyfish Search Optimization algorithm is trailed and tested on various benchmark functions and then implied on IEEE 33-bus, 69-bus and 94-bus Portuguese system to optimally allocate DG for reducing active power losses and voltage deviation, in [33]. Three types of DGs are considered i.e. type – 1, type – 2 and type – 3 and type-3 produced notable achievement in objective function. A novel holomorphic embedding LF method is used in [34] to find voltage stability index at different nodes of radial distribution network. Using this approach, need of calculating maximum load margin is eliminated. Test system includes IEEE 33 and 69-bus system cost function reduction is remarkable. Optimally allocation of PV energy storage through internal linear programming into DC distribution system is discussed in [35]. Objective function includes ageing of energy storage unit and reduction in the operational income.

Various notable research contributions in the field of DG sizing and siting by using optimization methodologies in well versed in [36]. DG along with energy storage system allocation is also extensively reviewed in this literature.

This paper explores about three different optimization methods for achieving the goal of finding best suitable location of distributed generators in radial type of power distribution network for the depreciation in ‘P’ losses as well as up-gradation of voltage profile. The methodologies tested in this literature are, Jaya and Invasive-Weed Optimization and a novel Hybrid Jaya-IWO method. The radial networks considered for testing are 33 and 69-bus network. Various load models are considered for checking the efficacy and efficiency of these methods.

2. Problem Formulation:

Optimal DG placement problem for placement of numbers of DGs of various type to minimize the objective function is provided by

$$Min\ P_{loss} = \sum_{i=1}^{N} I_i^2 R_i \text{ such that } i \in N$$

Where I_i represent i^{th} branch current, R_i shows the resistance of that particular branch and N is number of total branches in the system.

Following constraints must be satisfied to minimize the objective function:

i. The size and placement are based on full load only.
ii. Voltages at every bus must not violate the permissible range of ±5% i.e. 0.95 to 1.05 p.u.

$$V_{min}(0.95) \leq V \leq V_{max}(1.05)$$

iii. Generators must operate within allowable limits i.e.

$$P_i^{min} \leq P_g \leq P_i^{max}$$

iv. Current in every branch must remain below I_i^{rated}

$$I_i \leq I_i^{rated} \ \forall_i \in \{branches\ of\ network\}$$

3. Problem Solution Methodology:

In order to reduce radial distribution network power losses, individual feeder branch loss is to be determined along with maximum voltage fluctuation achieved with load flow analysis. For this, base case load flow is to be run. In this approach, forward/Backward Sweep LF technique is utilized. This technique includes two steps: (i) backward-sweep and (ii) forward-sweep.

Backward-sweep: Load current of every node, in a system on N number of nodes, is calculated using this method as:

$$I_l(m) = \frac{P_l(m) - jQ_l(m)}{V^*(m)} \quad [m = 1,2,3 \ldots \ldots \ldots . N]$$

Where $P_l(m)$ &$Q_l(m)$ are the real and imaginary power demands at node m. Then the current in every individual branch is computed as,

$$I_{mn} = I_l(n) + \sum\nolimits_m I_l(m)$$

Forward-sweep: Voltage at each node is determined after backward sweep technique, in a distribution network,

$$V(n) = V(m) - I_{mn}Z_{mn}$$

Here m and n are the sending and receiving end nodes respectively. Z_{mn} is the impedance of that branch and I_{mn} is the branch current.

This load flow technique is based on relationship matrix development like BIBC and BCBV matrices [27].

At any node of radial network, the complex load S_i is,

$$S_i = P_i + Q_i \qquad i = 1,2,3, \ldots \ldots \ldots N_{BUS}$$

Equivalent current injection at k^{th} iteration at i^{th} node can be written as,

$$I_i^k = I_i^r(V_i^k) + jI_i^i(V_i^k) = \left\{\frac{P_i + jQ_i}{V_i}\right\}^* \qquad i = 1,2,3, \dots \dots \dots N_{BUS}$$

Here, r and i means real and imaginary components of the equivalent current injection.

Bus current injection and branch current relationship is provided by a multiplier matrix called as BIBC (Bus Injection to Branch Current), which is an upper triangular matrix contain only 0s and +1s.

[B]= [BIBC][I]

Similarly, branch current and bus voltage relation is given by,

[ΔV]=[BCBV][B]

Here [ΔV] represents difference in node voltages, which is a function of branch currents I, line variables(BIBC and BCBV) and substation voltage (V).

After this, DLF matrix is calculated using [DLF] = [BIBC][BCBV].

Then the equation is changed to [ΔV]=[DLF][I].

Update Voltages after every iteration k=k+1, like,

$$[V^{k+1}] = [V^0] + [\Delta V^{k+1}]$$

This process is repeated until tolerance level is achieved, which is

$$((|V^{k+1}| - |V^k|) > tolerance)$$

From final node voltages, branch currents and power losses are calculated.

Now, a DG is to be optimally connected at any i^{th} node for minimization of losses, for which a radial network is considered having N number of branches and single power source. Due to this DG connection, active power components and reactive power components of the system will be changed.

The apparent power at node *i* will be then,

$$S = S_{D@i} = \sum_{i=1}^{N_{BUS}} P_{D@i} + Q_{D@i}$$

Current at node I, before placing DG,

$$I_D = I_{D@i}^{without\ DG}$$

After placing DG, active and reactive power components would be modified by,

$$P_{D@i}^{with\ DG} = P_{D@i}^{without\ DG} - P_{G@i}^{DG}$$

And $$Q_{D@i}^{with\ DG} = Q_{D@i}^{without\ DG} \mp Q_{G@i}^{DG}$$

Calculating DG power at node i, is

$$S_{DG@i} = \sum_{i=1}^{N_{BUS}} P_{G@i}^{DG} \pm Q_{G@i}^{DG}$$

Total new apparent power at node i, in matrix form, is

$$[S] = [S_{D@i}] - [S_{DG@i}]$$

After placing DG into network, perform the load flow as usual like base case, like calculating BIBC and BCBV matrix and then computing DLF. Then, for every iteration update the value of voltage. Check for tolerance and when tolerance level achieved, calculate branch current and power losses.

- Load Models:

Load models [21] are categorized according to the load factor **ρ,** bus voltage and both the imaginary and real component of the power. Change in load at any node 'k' is given by $P_k = \rho P_{k,actual} V_k^{\beta}$ and $Q_k = \rho Q_{k,actual} V_k^{\beta}$. The load factor ρ, is the multiplier that accounts for variations in load power at any node.
The parameters for different load models are:

Type of load	**ρ**	**β**
Cons. Power (CP) load	1	0
Cons. Current (CC) load	1	1
Cons. Impedance (CI) load	1	2

- Power Loss Reduction:

Mitigation in power loss is obtained after combining DG with the distribution system, which can be given by,

$$Reduction\ in\ Loss = \frac{P_{loss}^{without\ DG} - P_{loss}^{with\ DG}}{P_{loss}^{without\ DG}}$$

It is the difference between Power loss before and after integrating DG divided by the power loss without DG.

- Power loss index:

It is the power loss after integrating DG divided by the power loss without DG. This ratio may be minimized to elevate the net power loss decline by incorporating DG into the network.

$$Power\ Loss\ Index(PLI) = \frac{P_{loss}^{with\ DG}}{P_{loss}^{without\ DG}}$$

- Voltage Deviation:

This parameter must remain closer to zero for a stable system and improved performance, therefore while choosing DG size, this voltage deviation plays a crucial role. It can be written as,

$$\Delta V_D = \max\left(\frac{V_1 - V_k}{V_1}\right) \qquad \forall\ k = 1,2,3, \dots \dots \dots . N_{BUS}$$

- Total Operating Cost:

Operational cost of distribution network includes two key factors, one that is about real power supplied from the power station and another for the real power fed by installed DG. First factor can be reduced to minimum by controlling real power losses of the system, while second factor can be addressed by drawing lesser power out of DG. It can be written as,

$$Total\ Operating\ Cost\ (TOC) = \left(c_1 P_{loss}^{with\ DG}\right) + (c_2 P_{DG})$$

Where c_1 and c_2 are the cost coefficients in \$/kW. These are considered as 4 \$/kW and 5 \$/kW respectively for calculating TOC.

- Performance Economic Index:

This index defines the operating cost of dispersed generator subjected to its size [19]. It should be minimum. It is called cost of the power from DG (CPDG). Its unit is \$/MWh. Its expression is written as,

$$CPDG\left(\$/_{MWh}\right) = \alpha_1 (S_{DG}.pf)^2 + \alpha_2 (S_{DG}.pf) + \alpha_3$$

Where, α_1=0, α_2=20 and α_3=0.25.

4. Overview of Optimization Techniques applied:

Here two conventional approaches are utilized namely, JAYA algorithm and Invasive Weed algorithm and a novel hybrid approach is proposed for DG placement problem.

- Jaya algorithm:

The algorithm's name Jaya, derived from Sanskrit meaning victory, embodies its core objective of attaining success by reaching the optimal solution. The algorithm proposed by Rao [29] in 2016, has only single phase of computation and is rather easy to implement. It is a cutting edge optimization method to efficiently handle both constrained and unconstrained problem. Apart from the conventional algorithms, Jaya operates seamlessly without the need for any specific parameters, streamlining the optimization process.

Within the Jaya algorithm, candidate solutions undergo iterative updates based on their proximity to the best and worst options within the population. This methodology pushes the solutions towards the best outcome while clearing the worst, and approaches effectively for optimal results. The straightforward yet powerful nature of this algorithm positions it as a promising tool for diverse optimization problems.

According to Rao, for any objective function *f(x)* that needs to be minimized or maximized, there would be *m* kind of design variables (j=1,2,3….m) and *n* number of candidate solutions (i.e. population size, k=1,2,3….n) at any repetition *i*. Among the candidate solutions, the best suitable candidate, denoted as *best*, acquires the optimal value of f(x), here called as $f(x)_{best}$, while the worst candidate, denoted as *worst*, obtains the least favorable value of f(x), represented as $f(x)_{worst}$. If $X_{j,k,I}$ represents the value of the j^{th} attribute for the k^{th} candidate during the i^{th} repetition, then it keeps on updating using the following equation, till the convergence achieved.

$$X'_{j,k,i} = X_{j,k,i} + r_{1,j,i}\left(X_{j,best,i} - \left|X_{j,k,i}\right|\right) - r_{2,j,i}\left(X_{j,worst,i} - \left|X_{j,k,i}\right|\right),$$

Where, $X_{j,best,i}$ signifies the value of the attribute for the best suitable candidate, $X_{j,worst,i}$ represents the value of attribute *j* for the worst candidate, and $r_{1,j,i}$ and $r_{2,j,i}$ are random integers for attribute *j* during repetition *i* within the range [0,1]. The term $r_{1,j,i}\left(X_{j,best,i} - \left|X_{j,k,i}\right|\right)$ implies that the solution tends to approach the best solution, while $-r_{2,j,i}\left(X_{j,worst,i} - \left|X_{j,k,i}\right|\right)$ signifies the tendency to steer clear of the worst solution. The updated value $X'_{j,k,i}$is only acceptable, if it produces a better function value. All acceptable function values at the last iteration are kept and considered as input for the next iteration.

Procedure to optimize through Jaya algorithm includes the following steps:

1. *Initialization:* Initialize the population of candidate solutions randomly within the specified variable range.

2. *Evaluation:* Calculate the objective function for every candidate solution, and find a best and a worst solution.
3. *Update:* Update the candidate solution based on the best and worst solutions in the population.
4. *Termination:* Check for the convergence criterion (like, total number of iteration completed).
5. *Continue:* If the convergence criterion is not met, repeat the optimization process from step 2 until convergence reached.

- Invasive-Weed Optimization algorithm:

Mehrabian and Lucas [37] presented the invasive-weed optimization method in 2006. This numerical stochastic optimization technique is inspired by the natural procedure of invasive weed colonization, which is grounded in weed biology and ecology. In natural ecosystem, weeds spread through dispersal, exploiting available resources to grow into mature plants that independently generate new weeds. These weeds are analyzed and ranked according to their fitness values, determining the reproduction of new weeds according to their individual fitness levels. Subsequently, these new weeds are randomly scattered across the search space, facilitating their development into mature plants. Plant competition determines the maximum number of emerged plants in the colony, and lower-ranked plants are phased out to maintain this threshold.

Surviving plants maintain the capability to develop new weeds dependent on their position in the colony. This procedure continues until the maximum number of iterations is reached or the convergence criterion is met.

Invasive-weed optimization methodology:

1. Algorithm begins with the random initialization of a specific number of weeds within the search space.
2. Fitness values are then computed for each weed, determining their reproductive potential based on their fitness ranking.
3. Reproduction takes place as weeds generate seeds proportional to their fitness levels, with higher fitness resulting in the production of more seeds.
4. Spatial dispersions is executed by dispersing the produced seeds randomly across the search space employing a normal distribution with varying standard deviation.
5. Competitive exclusion is enforced, where plants engage in a survival competition, leading to the extinction of plants that fail to produce offspring.
6. The iterative process continue by treating the grown plants in the colony as genitor plants, cycling through step 2 to step 4 until the maximum number of iteration is reached.

In this process, generated seeds are such scattered in d-dimensional search space that they grow near parent plant. It means that the standard deviation of the perturbation or mutation is gradually reduced to fine-tune the solution. Assuming the standard deviation σ is reduced in a linear manner over N steps, the standard deviation at step n can be calculated as:

$$\sigma_n = \sigma_{initial} - \left(\frac{\sigma_{initial} - \sigma_{final}}{N}\right) n$$

Where, σ_n is standard deviation at step n, $\sigma_{initial}$ is initial SD, $\sigma_{final}$is the final SD, N is the total number of generations n is the current generation, with 0≤n≤N.

If the reduction is exponential, the expression could be re-written as

$$\sigma_n = \left(\frac{\sigma_{final}}{\sigma_{initial}}\right)^{\frac{n}{N}}$$

In this case, the standard deviation decreases exponentially from $\sigma_{initial}$to σ_{final}over N steps.

In IWO algorithm, the standard deviation σ is reduced neither in linear fashion nor in exponential manner, but in non-linear pattern, which can be derived as,

$$\sigma_{data} = \left(\frac{iter_{max} - iter}{iter_{max}}\right)^n (\sigma_{initial} - \sigma_{final}) + \sigma_{final}$$

Where, $\sigma_{data}$is standard deviation at current iteration, $iter_{max}$is max. number of iterations, $iter$ is current iteration and n is an exponent that controls the rate of reduction. In this expression, $\left(\frac{iter_{max}-iter}{iter_{max}}\right)$ represents the proportion of the remaining iterations. At the start ($iter$ =0), this fraction is 1, and at the end ($iter$ =$iter_{max}$), this fraction is 0. By placing an exponent of n, controlled decrease of standard deviation is obtained. $(\sigma_{initial} - \sigma_{final})$ represents the total range of standard deviation reduction. Adding σ_{final} ensures that the standard deviation decreases to σ_{final} at the last iteration.

- Hybrid Jaya-IWO algorithm:

The above two simple but powerful algorithms are combined to form the proposed hybrid Jaya-IWO algorithm. In this technique, the key features of both algorithms are utilized to discover the optimal location and capacity of distributed generators in radial networks. In this hybrid approach, location is obtained using JAYA algorithm and size of DG is obtained by executing Invasive Weed Optimization algorithm. For each optimal location obtained from JAYA, there is a check for variable size of DG placed on that location via IWO, to fulfill the objective function.

Steps for placing DG through hybrid JAYA-IWO algorithm:

1. Initialization of the parameters like, minimum and maximum size of DGs, constrained voltage limits, initial population, maximum number of iterations.
2. Run the base case load flow to get real and reactive power losses in the network.
3. Calculate fitness of the population based on Jaya algorithm.
4. Find the best and worst value for each population candidate and approach for the best solution for the size of DG to be connected.
5. Result obtained in step 4 is treated as initial number of seed for IWO algorithm.
6. Calculate σ_{data} after obtaining p_{best} and g_{best} value for minimum location.
7. Update the new seed update value and check for predecessor value.
8. Continue till the optimum solution for placement position and capacity of DG is not obtained, for minimization of losses.

5. Simulation and Results:

Above mentioned optimization techniques are evaluated on IEEE 33- and IEEE 69-bus RDNs for different load models. A MATLAB code is developed and trialed on an Intel® Core™ i7-7700 CPU @ 3.60GHz Desktop with 8 GB installed RAM.

Parameters for JAYA algorithm considered are w_{max} = 10 and w_{min} = -10 only, while for IWO algorithm s_{max}=10, s_{min}=0, $\sigma_{initial}$ = 1, σ_{final}= 0.0001, n= 3. Cost coefficients c_1 and c_2 are taken as 4$/kW and 5 $/kW respectively. Efficacy of the methods over test systems are simulated for various loading conditions, CP(half), CP(full), CP(overload), CC and CI. Type-1 DGs are operating at u.p.f. while type-3 DGs are operating at 0.866 p.f. Maximum DG penetration is taken as 50%. Voltage limits are established from 0.95 p.u. (min) to 1.05 p.u. (max). Population size is changed from 10 to 100 with maximum iteration criteria of 100 iterations. 30 consecutive trials are performed to obtain the best performance.

IEEE 33-bus system: IEEE 33-bus RDS is having 32 branches connected with real power load of 3.72 MW and reactive load of 2.3 MVAr. The power flow diagram for this network is shown in fig. 1. The bus data and line data are referred from Baran and Wu [38]. Without connecting DG, the power losses for base case load flow for various load flow models constant power (half load), constant power (full load), constant power (overload), constant current load and constant impedance load are 47.07 kW, 202.67 kW, 575.36 kW, 174.77 kW and 151.10 kW respectively.

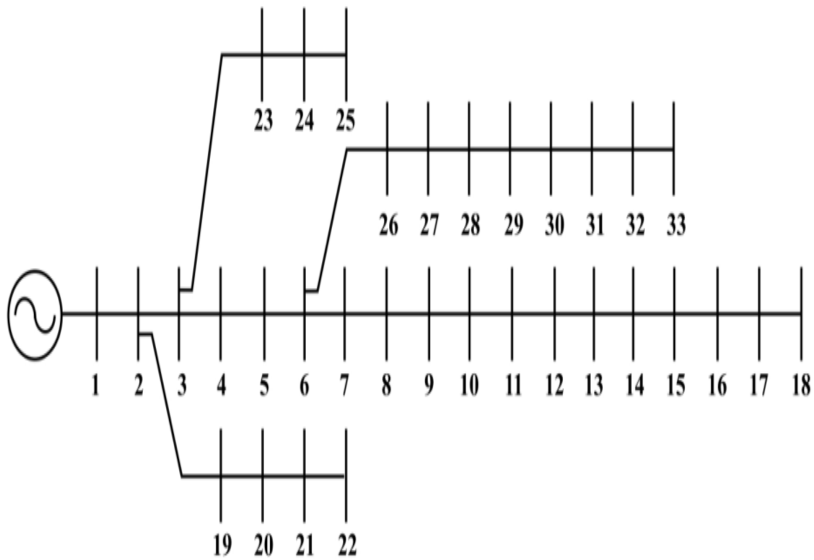

Fig. 1 Schematic Diagram of IEEE 33-bus Radial Distribution Network

For reduction in power losses, integration of distributed generation is proposed. They are primarily of 4 types [39]:

1. Type–1: provides only real power 'P' at u.p.f., like, PV array, Gas plants etc.
2. Type-2: Supplies only imaginary power ('Q') at z.p.f. like Synchronous capacitor, LC banks etc.
3. Type-3: Gives real ('P') and imaginary power ('Q') at p.f. 0.8 to 0.99 (leading) such as, tidal, wind and geo-thermal plants etc.
4. Type-4: Provides imaginary power ('Q') as well as and absorbs real power ('P') at 0.8 to 0.99 (lagging) p.f. like DFIG based wind farms.

In this study, three DGs of type-1 and type-3 are considered for implementation. Performance evaluation of JAYA algorithm is given in table 1, where for different loads, real power loss, Percentage loss reduction, power loss index, minimum voltage at bus of network, voltage deviation index and total operational cost is given after implementing type-1 DG. Similarly, parameters after optimal locating DG using Invasive Weed optimization algorithm is given in table 2. Proposed JAYA-IWO algorithm shows better results than the earlier two approaches and are shown in table 3. The results of these three optimization technique is then compared with results published in [2], [23], [40] and [21]. It can be clearly observed that with the penetration of type-1 DG operating at u.p.f., losses are reduced upto 63.65% with proposed method, while earlier conventional techniques are also showing 62.38% and 62.87% saving in losses. Percentage reduction in loss for CP(half), CP(full), CP(overload), CC and CI load models came as 61.23%, 62.38%, 67.11%, 61.23 and 61.90% respectively using JAYA algorithm. Voltage deviation index is also improved and tends towards zero after placement of DG. Similarly, by using IWO algorithm, power losses have considerably reduced and percentage of loss reduction is improved for all the load models. Hybrid approach application reduces power losses significantly as compared to previous methods. Also, VDI after using proposed approach shows better results. Proposed methodology is showing significant reduction in losses with 92.87%, while type-3 DG operating at 0.866 p.f. is connected. Also, enhancement in voltage profile can be observed.

Table 1. Results of **IEEE-33 bus system** for various load models using **JAYA** algorithm

Evaluation Criterions	Constant Power (CP) load						Constant Current (CC) load		Constant Impedance (CI) load	
	CP (half)		CP (full)		CP (Overload)					
	No DG	Using DG	No DG	Using DG	No DG	Using DG	No DG	Using DG	No DG	Using DG
DG Size (in MW) (at Bus)	-	0.436(10) 0.343(25) 0.423(30)	-	0.839(25) 1.157(29) 0.637(11)	-	1.135(12) 0.627(23) 1.007(24)	-	1.062(8) 0.545(25) 0.823(30)	-	0.544(13) 1.090(24) 0.839(28)
Power loss (in kW)	47.0708	18.2466	202.67	76.2349	575.3616	189.2111	174.7678	67.7426	151.1048	57.5655
%RL	-	61.2358	-	62.386	-	67.1144	-	61.2385	-	61.9036
PLI	-	0.3876	-	0.3761	-	0.3289	-	0.3876	-	0.3810
V_{min} (p.u.) (at bus)	0.958257 (18)	0.980067 (18)	0.913056 (18)	0.956916 (18)	0.852736 (18)	0.95 (18)	0.919838 (18)	0.956303 (18)	0.92602 (18)	0.962006 (33)
VDI	0.041743	0.019933	0.086944	0.043084	0.147264	0.05	0.080162	0.043697	0.07398	0.037994
TOC ($)	-	6082.98	-	13469.94	-	14601.84	-	12420.97	-	12595.26

Table 2. Results of **IEEE-33 bus system** for various load models using **IWO** algorithm

Evaluation Criterions	Constant Power (CP) load						Constant Current (CC) load		Constant Impedance (CI) load	
	CP (half)		CP (full)		CP (Overload)					
	No DG	Using DG	No DG	Using DG	No DG	Using DG	No DG	Using DG	No DG	Using DG
DG Size (in MW) (at Bus)	-	0.411(13) 0.421(33) 0.605(24)	-	1.052(24) 0.838(33) 0.816(14)	-	0.977(13) 1.135(26) 1.061(25)	-	1.053(29) 0.672(15) 1.036(24)	-	0.964(24) 0.646(14) 0.827(29)
Power loss (in kW)	47.0708	18.1293	202.67	75.2563	575.3616	179.0249	174.7678	62.8459	151.1048	54.7389
%RL	-	61.485	-	62.869	-	68.8848	-	64.0404	-	63.7742
PLI	-	0.3851	-	0.3713	-	0.3111	-	0.3596	-	0.3622
V_{min} (p.u.) (at bus)	0.958257 (18)	0.972302 (18)	0.913056 (18)	0.966136 (30)	0.852736 (18)	0.95 (18)	0.919838 (18)	0.968479 (33)	0.92602 (18)	0.966938 (33)
VDI	0.041743	0.027698	0.086944	0.033864	0.147264	0.05	0.080162	0.031521	0.07398	0.033062
TOC ($)	-	7257.51	-	13831.02	-	16581.09	-	14056.38	-	12403.95

Table 3. Results of **IEEE-33 bus system** for various load models using **JAYA-IWO** algorithm

Evaluation Criterions	**Constant Power (CP) load**						**Constant Current (CC) load**		**Constant Impedance (CI) load**	
	CP (half)		**CP (full)**		**CP (Overload)**					
	No DG	**Using DG**	**No DG**	**Using DG**	**No DG**	**Using DG**	**No DG**	**Using DG**	**No DG**	**Using DG**
DG Size (in MW) (at Bus)	-	0.412(33) 0.587(24) 0.427(13)	-	1.001(12) 0.890(31) 0.912(25)	-	1.100(6) 0899(25) 0.984(13)	-	0.745(33) 0.902(12) 1.098(24)	-	0.704(33) 0.865(12) 0.994(24)
Power loss (in kW)	47.0708	16.62	202.67	73.6728	575.3616	165.5855	174.7678	58.8455	151.1048	50.5952
%RL	-	64.6915	-	63.6502	-	71.2206		66.3293	-	66.5165
PLI	-	0.3530	-	0.3635	-	0.2878		0.3367	-	0.3348
V_{min} (p.u.) (at bus)	0.958257 (18)	0.983961 (30)	0.913056 (18)	0.968287 (18)	0.852736 (18)	0.95 (18)	0.919838 (18)	0.96957 (18)	0.92602 (18)	0.972948 (18)
VDI	0.041743	0.016039	0.086944	0.031713	0.147264	0.05	0.080162	0.03043	0.07398	0.027052
TOC ($)	-	7196.48	-	14309.69	-	15577.34	-	13960.38	-	13017.38

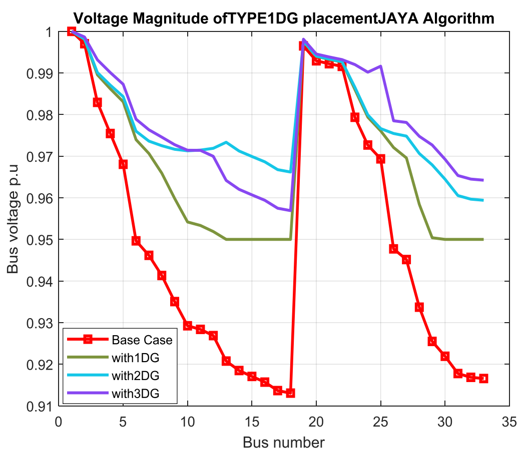

Fig.2 Voltage curve at upf with JAYA

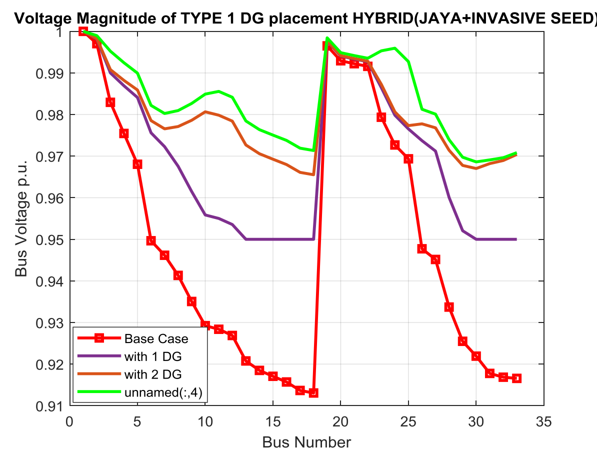

Fig.4 Voltage curve at upf with HYBRID algorithm

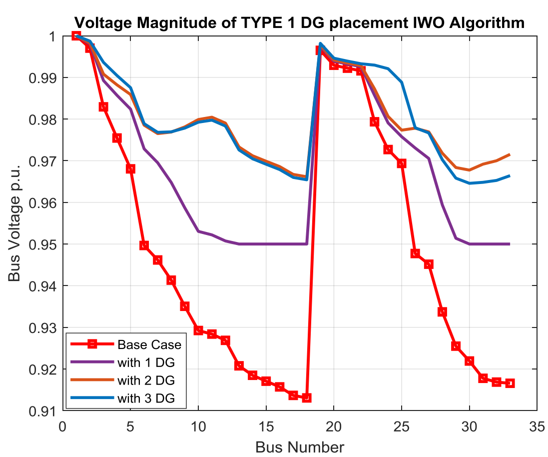

Fig.3 Voltage curve at upf with IWO algorithm

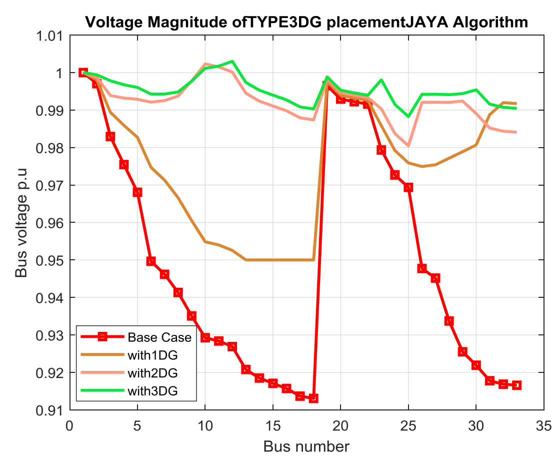

Fig.5 Voltage curve with type 3 DG(JAYA algorithm)

Comparative Analysis for IEEE 33- bus:

Method	PL_{DG} (kW)	%RL	V_{min} (bus)	DG position	DG size (MW)	S_{DG} (MVA)	pf	TOC ($)	CPDG ($)
GA *[Moradi et.al.]*	106.30	49.61	0.9809 (25)	11 29 30	1.5000 0.4228 1.0714	2.9942	upf	15396.2	60.134
PSO *[Moradi et.al.]*	105.35	50.06	0.9806 (30)	13 32 8	0.9816 0.8297 1.1768	2.9881	upf	15361.9	60.012
GA/PSO *[Moradi et.al.]*	103.40	50.09	0.9808 (25)	32 16 11	1.2000 0.8630 0.9250	2.9880	upf	15353.6	60.01
SA *[Injeti et.al.]*	82.03	61.12	0.9676 (14)	6 18 30	1.1124 0.4874 0.8679	2.4677	upf	12666.6	49.604
BFOA *[Imran et.al.]*	89.90	57.38	0.9705 (29)	14 18 32	0.6521 0.1984 1.0672	1.9176	upf	9948.1	38.602
IWO *[R. Prabha et. Al.]*	85.86	57.47	0.9716 (29)	14 18 32	0.6247 0.1049 1.0560	1.7856	upf	9271.44	35.962
JAYA	76.2349	62.386	0.956916 (18)	25 29 11	0.839 1.157 0.637	2.633	upf	13469.94	52.91
IWO	75.2563	62.869	0.966136 (30)	24 33 14	1.052 0.838 0.816	2.706	upf	13831.02	54.37
JAYA-IWO	73.6728	63.6502	0.968287 (18)	12 31 25	1.001 0.890 0.912	2.803	upf	14309.69	56.31
SA *[Injeti et.al.]*	26.72	87.33	0.9826 (25)	6 18 30	1.1976 0.4778 0.9205	2.9975	0.866	13086.3	52.17
BFOA *[Imran et.al.]*	37.85	82.06	0.9802 (29)	14 18 32	0.6798 0.1302 1.1085	2.2153	0.866	9743.9	38.62
IWO *[R. Prabha et. Al.]*	37.05	81.64	0.9838 (25)	14 18 32	0.5176 0.1147 1.0842	1.9821	0.866	8730.7	34.58
JAYA	21.5749	89.3551	0.988247 (25)	12 30 23	0.959 1.049 0.955	3.421	0.866	14899.23	59.50
IWO	18.1042	91.0674	0.982622 (18)	11 24 30	0.739 0.850 1.369	3.415	0.866	14859.37	59.39
JAYA-IWO	14.4503	92.8703	0.991727 (8)	14 24 31	0.800 0.971 1.034	3.239	0.866	14082.67	56.35

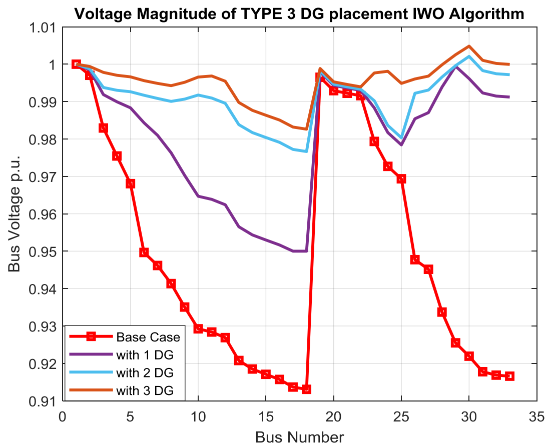

Fig.6 Voltage curve with type 3 DG (IWO algorithm)

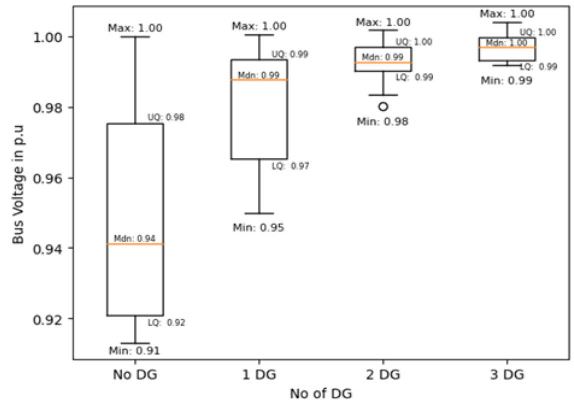

Fig. 8 Box Plot for Bus voltage of 33-bus with Type1 DG using JAYA-IWO

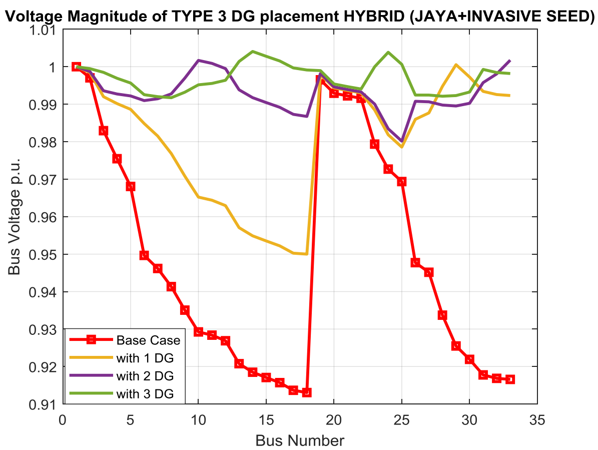

Fig.7 Voltage curve with type 3 DG (HYBRID algorithm)

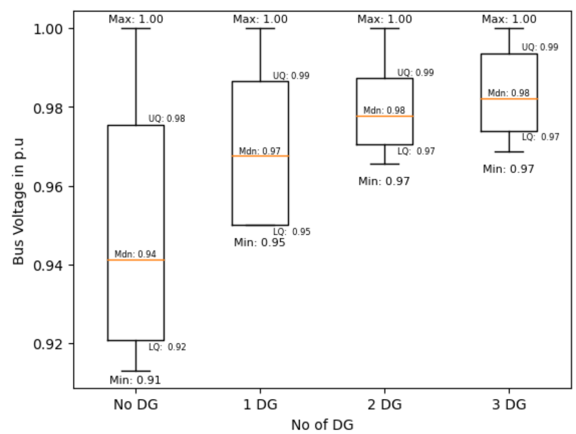

Fig.9 Box Plot for Bus voltage of 33-bus with Type3 DG using JAYA-IWO

IEEE 69-bus system: This system is having 68 branches connected with 3.79 MW real and 2.69 MVAr reactive load. Line diagram is as per the fig. 10. The bus data and line data are referred from Baran and Wu [41]. The power losses obtained from executing base case load flow for various load flow models constant power (half load), constant power (full load), constant power (overload), constant current load and constant impedance load are 51.59 kW, 224.96 kW, 652.41 kW, 188.60 kW and 158.75 kW respectively.

Two types of DGs *i.e.* type-1 and type-3 DGs in three numbers are considered for implementation. Results of implementing JAYA algorithm is given in table 4 where, active power loss, Percentage reduction in loss, power loss index, minimum voltage at a bus of network, VDI and total operational cost, for different loads is given after implementing type-1 DG. Similarly, results acquired after solving optimal DG placement problem using Invasive Weed optimization algorithm is given in table 5. Proposed JAYA-IWO algorithm shows more effective results than the earlier two approaches and is shown in table 6. The results of these three optimization technique is then compared with results published in [2], [23], [40] and [21]. It can be clearly observed that with the penetration of type-1 DG operating at u.p.f., losses are reduced up to 68.47% with proposed method, while earlier conventional techniques are also showing 67.51% and 68.38% saving in losses. Proposed methodology is showing significant reduction in losses with 96.95%, while type-3 DG at 0.866 p.f. is connected. Voltage profile is improved and can be observed with various figures. Box plot is showing the distribution of voltage range. VDI is also reached near to zero value after appropriate placement of DG.

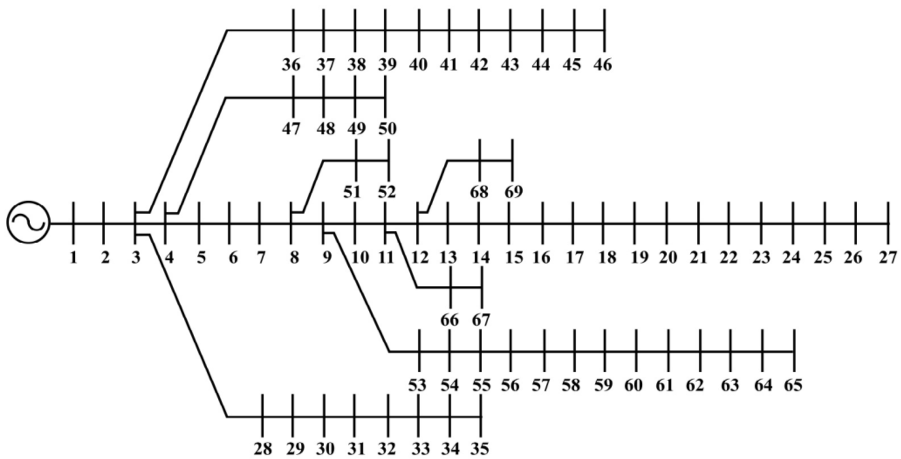

Fig. 10 Schematic Diagram of IEEE 69-bus Radial Distribution Network

Table 4. Results of **IEEE-69 bus system** for various load models using **JAYA** algorithm

Evaluation Criterions	**Constant Power (CP) load**						**Constant Current (CC) load**		**Constant Impedance (CI) load**	
	CP (half)		**CP (full)**		**CP (Overload)**					
	No DG	**Using DG**	**No DG**	**Using DG**	**No DG**	**Using DG**	**No DG**	**Using DG**	**No DG**	**Using DG**
DG Size (in MW) (at Bus)	-	0.319(69) 0.600(61) 0.251(64)	-	0.222(69) 1.0506(61) 0.516(22)	-	1.828(56) 0.554(69) 0.567(22)	-	0.680(62) 0.463(19) 0.743(61)	-	0.492(22) 0.837(61) 0.641(62)
Power loss (in kW)	51.5971	18.2285	224.9606	73.0741	652.41	170.2724	188.6015	65.668	158.7467	53.1178
%RL	-	64.6714	-	67.5169	-	73.901	-	65.1816	-	66.5393
PLI	-	0.3533	-	0.3248	-	0.2610	-	0.3446	-	0.3346
V_{min} (p.u.) (at bus)	0.956638 (65)	0.989248 (27)	0.909007 (65)	0.969664 (65)	0.843982 (65)	0.95 (65)	0.917227 (65)	0.980564 (27)	0.924602 (65)	0.981595 (65)
VDI	0.043362	0.010752	0.090993	0.030336	0.156018	0.05	0.082773	0.019436	0.075398	0.018405
TOC ($)	-	5922.91	-	9235.29	-	15426.08	-	9692.67	-	10062.47

Table 5. Results of **IEEE-69 bus system** for various load models using **IWO** algorithm

Evaluation Criterions	Constant Power (CP) load						Constant Current (CC) load		Constant Impedance (CI) load	
	CP (half)		CP (full)		CP (Overload)					
	No DG	Using DG	No DG	Using DG	No DG	Using DG	No DG	Using DG	No DG	Using DG
DG Size (in MW) (at Bus)	-	0.884(62) 0.255(69) 0.156(19)	-	1.074(61) 0.157(69) 0.429(16)	-	1.026(54) 0.968(69) 1.153(56)	-	0.954(62) 0.602(69) 0.621(61)	-	1.505(61) 0.291(69) 0.370(24)
Power loss (in kW)	51.5971	17.6696	224.9606	71.1103	652.41	181.6988	188.6015	64.223	158.7467	51.7682
%RL	-	65.7547	-	68.3899	-	72.1496	-	65.9478	-	67.3894
PLI	-	0.3424	-	0.3161	-	0.2785	-	0.3405	-	0.3261
V_{min} (p.u.) (at bus)	0.956638 (65)	0.990674 (65)	0.909007 (65)	0.974567 (65)	0.843982 (65)	0.95 (65)	0.917227 (65)	0.979023 (27)	0.924602 (65)	0.980635 (65)
VDI	0.043362	0.009326	0.090993	0.025433	0.156018	0.05	0.082773	0.020977	0.075398	0.019365
TOC ($)	-	6545.67	-	8584.44	-	16461.79	-	11141.89	-	11037.07

Table 6. Results of **IEEE-69 bus system** for various load models using **JAYA-IWO** algorithm

Evaluation Criterions	Constant Power (CP) load						Constant Current (CC) load		Constant Impedance (CI) load	
	CP (half)		CP (full)		CP (Overload)					
	No DG	Using DG	No DG	Using DG	No DG	Using DG	No DG	Using DG	No DG	Using DG
DG Size (in MW) (at Bus)	-	0.451(69) 0.673(61) 0.364(64)	-	0.475(23) 0.348(69) 1.718(61)	-	1.684(56) 0.715(69) 0.576(22)	-	1.164(61) 0.692(69) 0.419(64)	-	0.492(22) 0.837(61) 0.641(62)
Power loss (in kW)	51.5971	17.4663	224.9606	70.92917	652.41	169.0971	188.6015	60.493	158.7467	51.413
%RL	-	66.1487	-	68.4704	-	74.0812	-	67.9255	-	67.6132
PLI	-	0.3385	-	0.3153	-	0.2591	-	0.3207	-	0.3238
V_{min} (p.u.) (at bus)	0.956638 (65)	0.989248 (27)	0.909007 (65)	0.979718 (65)	0.843982 (65)	0.956484 (27)	0.917227 (65)	0.980564 (27)	0.924602 (65)	0.98595 (65)
VDI	0.043362	0.010752	0.090993	0.020282	0.156018	0.043516	0.082773	0.019436	0.075398	0.01405
TOC ($)	-	7509.86	-	12988.71	-	15551.38	-	11616.97	-	10055.65

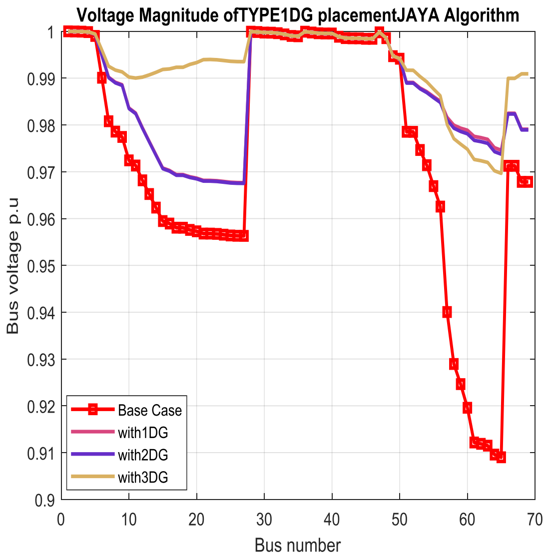

Fig.11 Voltage curve at upf with JAYA

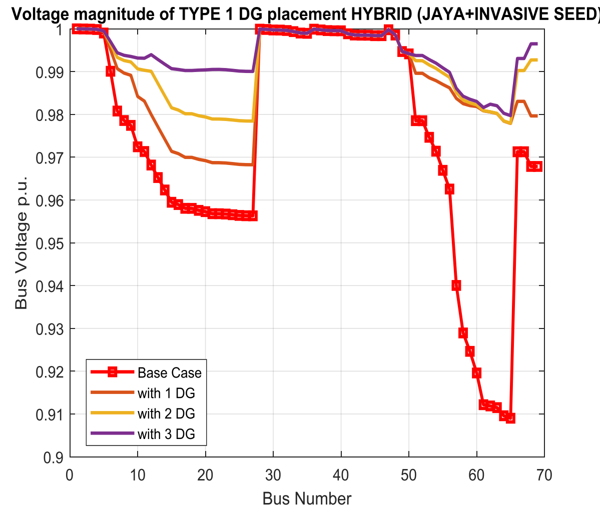

Fig.13 Voltage curve at upf with HYBRID algorithm

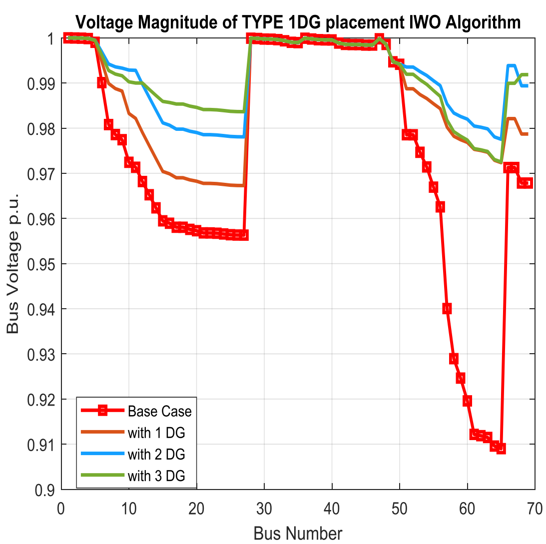

Fig.12 Voltage curve at upf with IWO algorithm

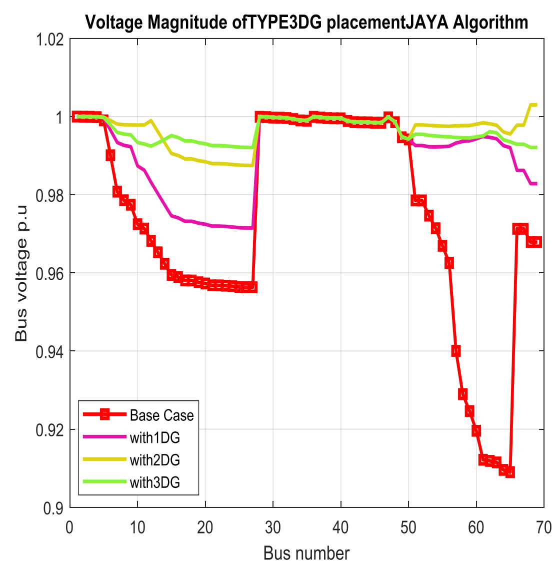

Fig.14 Voltage curve with type 3 DG (JAYA algorithm)

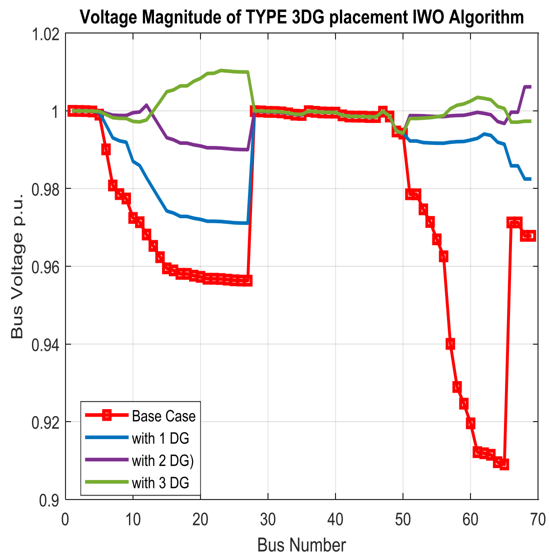

Fig.15 Voltage curve with type 3 DG (IWO algorithm)

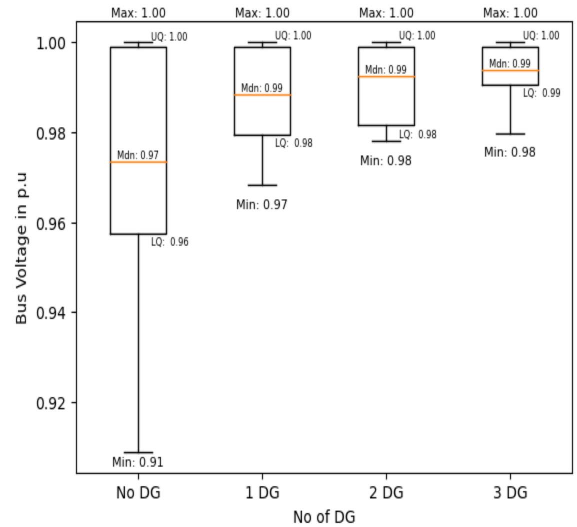

Fig. 17 Box Plot for Bus voltage of 69-bus with Type1 DG using JAYA-IWO

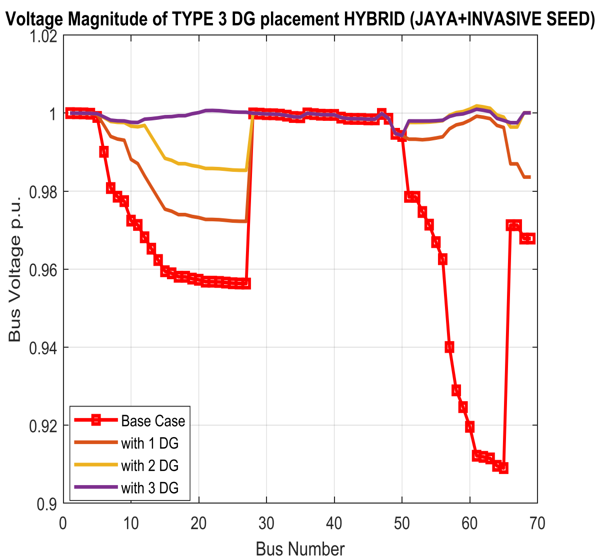

Fig.16 Voltage curve with type 3 DG (HYBRID algorithm)

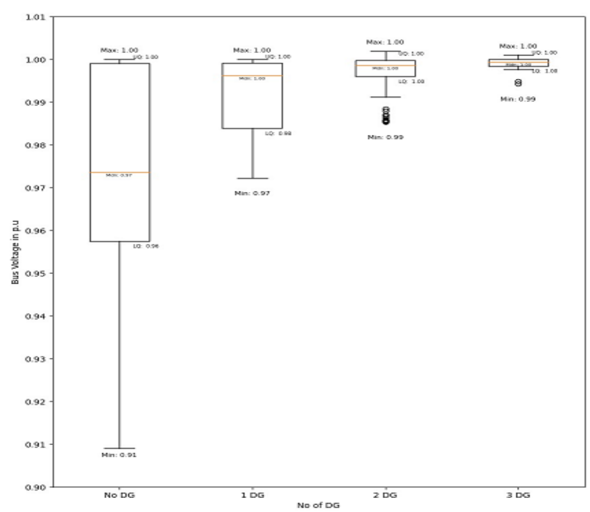

Fig. 18 Box Plot for Bus voltage of 69-bus with Type1 DG using JAYA-IWO

Comparative Analysis for IEEE 69- bus:

Method	**PL_{DG} (kW)**	**%RL**	**V_{min} (bus)**	**DG position**	**DG size (MW)**	**S_{DG} (MVA)**	**pf**	**TOC ($)**	**CPDG ($)**
GA *[Moradi et.al.]*	89.0	60.44	0.9936 (57)	21 62 64	0.9297 1.0752 0.9925	2.9974	upf	15343.30	60.19
PSO *[Moradi et.al.]*	83.2	63.02	0.9901 (65)	61 63 17	1.1998 0.7956 0.9925	2.9879	upf	15272.3	60.00
GA/PSO *[Moradi et.al.]*	81.1	63.95	0.9925 (65)	63 61 21	0.8849 1.1926 0.9105	2.9880	upf	15264.4	60.01
SA *[Injeti et.al.]*	77.1	65.73	0.9811 (61)	18 60 65	0.4204 1.3311 0.4298	2.1813	upf	11214.9	43.87
BFOA *[Imran et.al.]*	75.23	66.56	0.9808 (61)	27 65 61	0.2954 0.4476 1.3451	2.0881	upf	10741.4	42.01
IWO *[R. Prabha et. Al.]*	74.59	66.78	0.9802 (18)	27 65 61	0.2381 0.4334 1.3266	1.9981	upf	10288.86	40.21
JAYA	73.0741	67.5169	0.969664 (65)	69 61 22	0.222 1.0506 0.516	1.7886	upf	9235.29	36.02
IWO	71.1103	68.3899	0.974567 (65)	61 69 16	1.074 0.157 0.429	1.66	upf	8584.44	33.45
JAYA-IWO	70.92917	68.4704	0.979718 (65)	23 69 61	0.475 0.348 1.718	2.541	upf	12988.71	51.07
SA *[Injeti et.al.]*	16.26	92.77	0.9885 (61)	18 60 65	0.5498 1.1954 0.3122	2.3757	0.866	10352.0	41.39
BFOA *[Imran et.al.]*	12.90	94.26	0.9896 (64)	27 65 61	0.3781 0.3285 1.3361	2.3587	0.866	10265.1	41.10
IWO *[R. Prabha et. Al.]*	13.64	93.92	0.9946 (68)	27 65 61	0.3709 0.3156 1.0905	2.0520	0.866	8939.56	35.79
JAYA	11.7523	94.77	0.986976 (27)	15 2 62	0.474 0.607 1.016	2.421	0.866	10529.94	42.18
IWO	11.139	95.04	0.994251 (50)	23 29 61	0.389 0.049 1.086	1.759	0.866	7661.026	30.71
JAYA-IWO	6.852	96.95	0.994249 (50)	69 22 61	0.202 0.221 1.044	1.694	0.866	7362.42	29.59

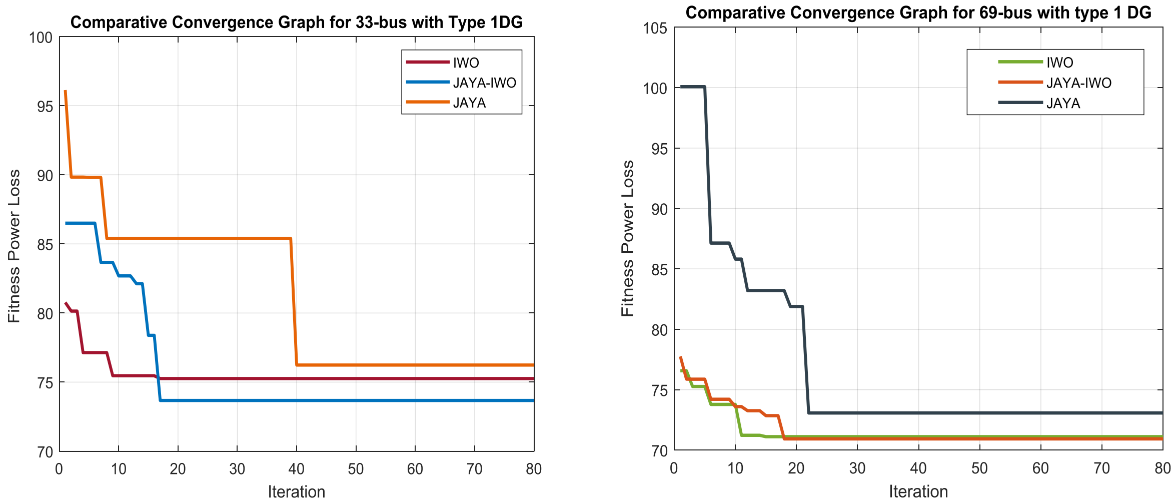

Fig. 19 Comparative Convergence Characteristics of IEEE 33-bus and 69-bus with Type 1 DG

6.Conclusion:

In this paper, JAYA-IWO algorithm is proposed as a hybrid approach of its predecessor JAYA and Invasive Weed Optimization. All the optimization techniques are trialed on IEEE 33- and 69-bus radial electrical power distribution networks. Effect of integration of multiple DGs of type-1 (at u.p.f.) and type-3 (at 0.866 p.f.) are seen. Comparison is viewed with application of these methods over various load models like CP(half), CP(full), CP(overload), CC and CI. Though the main objective was only to mitigate real power losses in the distribution network and improvement of bus voltages, but various indices are also calculated for these models, like, VDI, PLI, TOC and CPDG. Voltage profile is shown in conventional graphs as well as box plots are drawn to show the upper and lower limit of the voltage along with median value while no DG was connected and when multiple DGs are integrated. Also convergence characteristics of power loss objective function is shown in a comparative manner for all the methodologies used, and effectiveness of proposed algorithm can be observed. Simulated results are also cross-examined with other published works and proposed method is found effectively better.

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