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A Novel Approach of DG Allocation using Grey Wolf Optimization and Particle Swarm Optimization

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Abstract – **Distributed generations (DGs) connected to distribution networks are becoming more and more popular. They can be used as a means to reduce the environmental impacts of energy production. However, despite the many advantages the DG brings to the network, poor planning and malfunctioning can lead to negative effects on distribution networks. An increase in power losses, a problem of voltage stability and poor functioning of the control equipment are three of the main impacts that a poor integration of a DG can bring to the network. To compensate for these negative effects, this paper presents an approach to find the optimal location and sizing of the integration of new DGs into the network while reducing power losses and improving the voltage profile. In addition, a coordinated voltage control is presented to find the optimal setting of the active and reactive powers of the DG. This paper proposes a framework for DG allocation unit using Grey Wolf Optimization and Particle Swarm Optimization to minimize the active power loss. IEEE-33 bus test system is used for Type-I, Type-II and Type-IV DG allocation.**

Keywords – **Distributed Generation, Electric Power Systems, Grey Wolf Optimization, Particle Swarm Optimization, Distribution System.**

I. INTRODUCTION

The Distributed Generation (DG), understood as the generation of electrical energy by means of installations much smaller than the conventional power stations and located in the vicinity of the loads, has existed for many years in all the industrialized countries. Thus, in some applications that are far from the electric networks, diesel generators of a great variety of powers have been used. Another example is the cogeneration plants existing in a large number of industrial facilities, where the process uses large amounts of thermal energy.

There is not yet a commonly accepted definition for the Distributed Generation, and even the denomination itself differs according to the documentary source. Sometimes the term Dispersed Generation is used.

A well-known definition is that of the IEEE (Institute of Electrical and Electronic Engineers): "Distributed Generation is the production of electricity with facilities that are sufficiently small in relation to large generation plants, so that they can be connected almost anywhere of an electrical system, it's a subset of distributed resources."

In this definition no reference is made to the power margin of the generators, but in general it is accepted that it goes from about 3 to 5 kW the smallest ones, up to 10-20 MW the larger ones.

The tariff of electricity is roughly calculated as around 50% for fuel, 20% for generation, 25% for distribution and 5% for transmission [1]. A distribution network has high R/X ratio as compared to transmission networks, this causes drop in voltage magnitude and high power losses along radial distribution networks. We are also aware of that a distribution network has appreciably high losses as compared to transmission networks [2]. In a distribution network roughly 13% of the total generated power is wasted as real power losses [3]. The overall performance/efficiency and the financial issues of distribution utilities are directly affected by these non-negligible losses. To improve the overall performance/efficiency of distribution utilities, it is necessary to reduce the losses at distribution networks. Distribution network power losses can be reduced by using traditional methods like shunt capacitors installation at low voltage buses and installation of automatic voltage regulator, these methods reduce the power loss by properly compensating the reactive power [4]. There are other modern techniques to reduce power losses like placement of distributed generation, network reconfiguration, etc. Allocation of distributed generation on distribution network/transmission

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network will reduce the power losses, peak load demand losses and improve the distribution networks voltage profile, stability and reliability, by supplying either part of active power demand or reactive power demand, hence reducing the line current and line flows in transmission networks and distribution networks [1, 5, and 6].

The installation of distributed generations in distribution networks/transmission network is a numerous challenge considering safety and technical problems [7-8]. Hence, to analyze the technical impacts of DG in power networks is critical. Therefore, DG should be installed in such a manner that it does not degrade the power quality and reliability of distribution network system. Poor allocation of DG with regard to its location and size (capacity) may diminish or increase power losses, causes voltage variations, lead to increase in fault level currents, interfere in voltage-control processes, increase system capital and operating costs, etc. [8]. Installation of DG units is not an easy task, and hence the allocation of DG units should be carefully tackled [8, 9].

Allocation of DG units is fundamentally a complex integrative optimization problem which requires simultaneous optimization of multiple objectives [9], for example reduction of power losses, bus voltage deviation, short circuit capacity, line loading, and greenhouse gas emission and improvement of network reliability etc. The objective is to find the optimal locations and sizes of DG units in a distribution network. Voltage limit of the buses, thermal limit of lines, and maximum DG sizes etc. are considered to be as constraints to perform optimization [9].

Investigating this optimization algorithm is the major motivation of this paper.

The main objective of this paper is to implement a DG allocation unit using Grey Wolf Optimization and Particle Swarm Optimization to minimize the active power loss.

II. Proposed Method

A. Problem Formulation

In this subsection mathematical model of cost (objective) function is developed by considering certain constraints for Radial Distribution network in presence of DG.

Optimal allocation of DG unit minimizes the power loss in the distribution network system [10]. Here PSO and GWO algorithms have been used for optimal allocation of DG unit to minimize the system real power loss considering the exact loss formula [11] as objective function. The optimization is carried out by consideration of certain constraints like voltage limit, current limit, and power flow.

B. Objective Function

Considering N bus distribution system, the real power loss minimization problem may be formulated as given below:

$$\text{Minimize } P_L = \sum_{i=1}^{N}\sum_{j=1}^{N}\left[\alpha_{ij}\left(P_iP_j + Q_iQ_j\right) + \beta_{ij}\left(Q_iP_j - P_iQ_j\right)\right] \quad (1)$$

Where, $\alpha_{ij} = \frac{r_{ij}}{V_iV_j}\cos(\delta_i - \delta_j)$,

$\beta_{ij} = \frac{r_{ij}}{V_iV_j}\sin(\delta_i - \delta_j)$ and $Z_{ij} = r_{ij} + jX_{ij}$

Where, Z_{ij} is the impendence of the line between bus i and bus j.

r_{ij} is the resistance of the line between bus i and bus j

X_{ij} is the reactance of the line between bus i and bus j

V_i is the voltage magnitude at bus i

V_j is the voltage magnitude at bus j

δ_i is the voltage angle at bus i

δ_j is the voltage angle at bus j

P_i and Q_i the active and reactive power injections at bus i

P_j and Q_j is the active and reactive power injections at bus j.

C. Constraint

The objective function in (1) Subjected to following constraints.

1. System power flow equations must be satisfied:

$$P_{Gi} - P_{Di} = \sum_{j=1}^{N} V_iV_j\left[G_{ij}\cos(\delta_i - \delta_j) + B_{ij}\sin(\delta_i - \delta_j)\right] \quad \forall i = 1,2,3, \dots \dots \dots N \quad (2)$$

$$Q_{Gi} - Q_{Di} = \sum_{j=1}^{N} V_iV_j\left[G_{ij}\sin(\delta_i - \delta_j) - B_{ij}\cos(\delta_i - \delta_j)\right] \quad \forall i = 1,2,3, \dots \dots \dots N \quad (3)$$

Where, G_{ij} is the conductance of the line between bus i and bus j.

B_{ij} is the susceptance of the line between bus i and bus j.

P_{Gi} and Q_{Gi} are power generations of generators at bus i.

P_{Di} and Q_{Di} are the loads at bus i.

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2. Voltage constraint at each bus (±5% of rated voltage) must be satisfied.

$$V_{min} \leq V_i \leq V_{max} \quad (4)$$

Where $i = 1, 2, 3, \dots \dots \dots N$

3. Line current constraint must be satisfied.

$$I_i \leq I_i^{Rated} \quad (5)$$

$$\forall i \in \{\text{Branches of the network}\}$$

Where I_i^{Rated} is current permissible for branch i within safe limit of temperature.

In this work Backward/Forward Sweep Method of distribution load flow [12] is used.

D. Backward/Forward Sweep Load Flow Algorithm for Radial Distribution System (BFSLFA)

It is an iterative algorithm for calculating currents of branches (lines) and voltage at the nodes. At each iteration, two scans: back and front are executed. The backward scan consists of calculating the currents in the branches (the lines of the network) by the use of the first law of Kirchhoff. Forward scanning consists of calculating the voltages at the nodes of the network by calculating voltage drops along the branches.

(i) Backward Sweep and
(ii) Forward Sweep.

Backward Sweep: A reverse sweep is performed from the network end nodes to the source node to calculate the branch currents by summing the currents at the different nodes of the network [12].

Forward Sweep: The forward sweep is primarily a voltage drop calculation with possible current or power flow updates. The purpose of the forward sweep is to calculate the voltages at each node starting from the source node.

The forward and backward substitutions are performed in each iteration of the load flow. The magnitudes of the voltages at each bus in iteration are compared with their values in the previous iteration. If the error is within the tolerance limit, the procedure is stopped. Otherwise, the steps of backward sweep, forward sweep and check for convergence are repeated. As soon as the procedure is stopped, the voltages at each node and the power flows in all the line segments are used to find the power losses in each line segment.

Backward/Forward Sweep Load Flow Algorithm [12]	
Initialize all bus voltage	
1	Backward Sweep
2	Forward Sweep
Repeat step 1 and 2 until convergence is achieved	

E. Proposed Method

Various soft computing approaches are used for optimal placement of DG in radial distribution networks. This is the field of research, within the artificial intelligence, which studies the behaviour of swarms in nature. Inspired by this, their algorithms are made up of simple individuals who cooperate through self-organization mechanisms, that is, without any central control mechanism.

1) Particle Swarm Optimization

In PSO technique, first of all we randomly initialize the particles position according to problem constraints, which can be mathematically represented as n –dimensional vector.

$$X_m = (X_{m_1}, X_{m_2}, X_{m_3}, \dots \dots \dots X_{mn}) \quad (6)$$

After that we generate random velocities for each particle, it is also represented as n – dimensional vector.

$$V_m = (v_{m_1}, v_{m_2}, v_{m_3}, \dots \dots \dots v_{mn}) \quad (7)$$

In each iteration, the P vector of the particle with best fitness in the local neighbourhood, designated g, and the P vector of the current particle are combined to adjust the velocity along each dimension and a new position of the particle is determined using that velocity.

Mathematically velocity and position of each particle can be updated according to the following equation [13]:

$$V_i^{k+1} = w^* V_i^k + c_1 rand_1(\dots)^* \left(pbest_i - X_i^k\right) + c_2 rand_2(\dots)^* \left(gbest_i - X_i^k\right) \quad (8)$$

Inertia — Personal Influence — Social Influence

And,

$$X_i^{k+1} = X_i^k + V_i^{k+1} \quad (9)$$

Where,

V_i^k: velocity of particle i at iteration k,
w: weighting function,
c_1 : weight of local information,
c_2 : weight of global information

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$rand$: uniformly distributed random number between 0 and 1,
X_i^k : current position of particle i at iteration k,
$pbest_i$: pbest of particle i,
$gbest$: $gbest$ of the group.
The first part of equation represents the inertia of the previous velocity, the second part is the cognition part and it tells us about the personal experience of the particle, the third part represents the cooperation among particles and is therefore named as the social component.

2) Grey Wolf Optimization

The best solution in mathematical representation of social hierarchy of wolves while designing GWO is considered to be alpha 'α'. The 2nd and the 3rd best solutions are 'β' and 'δ' respectively. The hunting decisions are taken by α, β and δ wolves whereas 'ω' (omega) wolves obey above 3 wolves.

The encircling behaviour of the wolves around its prey can be represented mathematically as follows:

$$\vec{D} = |\vec{C}.\vec{X}_P t - \vec{X}(t)| \quad (10)$$

$$\vec{X}(t+1) = \vec{X}_P t - \vec{A}.\vec{D} \quad (11)$$

Where, X is the position vector of the wolf. A and C are coefficient vectors, t is the current iteration

Grey Wolf Optimizer (GWO) Algorithm

1. Grey wolves wander in search of its prey depending on the alpha, beta and delta positions. They go away (divergence) from each other in search of a prey and gather again (convergence) while attacking the prey [14]. This divergence can be mathematically given by A and convergence is represented by C.
$$\vec{A} = 2.\vec{a}.\vec{r}_1 - \vec{a} \quad (12)$$
$$\vec{C} = 2.\vec{r}_2 \quad (13)$$
Where, $\vec{r}_1$ and $\vec{r}_2$ are random vectors:
2. The initialization of GWO population is given by at counter iteration t=0:
$$X_i = (1,2,3 \dots \dots \dots \dots n) \quad (14)$$
3. Further A, C and a are also initialized.
4. Now the fitness function for each searching agent is evaluated and is represented as:
X_α denotes best searching agent
X_β denotes 2nd best searching agent
X_δ denotes 3rd best searching agent
5. If the total no. of iterations is given as $t = n$, then
For $(t = 1; t \leq n)$
Using above equations update the position of searching agents
End for
6. Update A and C coefficients
7. Evaluate fitness function for each searching agent
8. Update $X_\alpha, X_\beta, X_\delta$
9. Set $t = t + 1$ (iteration counter increasing)
10. Return best solution X_α

GWO Working

1. The GWO resolves the optimization problem by generating the best solutions available during iterations.
2. The encircling behaviour gives an idea about the neighbouring circle around the solution which could be further extended into sphere (as shown in Figure 1).
3. A and C coefficient vectors help solutions to have random radii hyper spheres.
4. The hunting behaviour permits the solution to define the exact location of the prey.
5. Values of a and A are responsible for exploitation and exploration.
6. If the value of A decrease, then total number of iterations are equally divided and assigned for exploitation and exploration respectively.

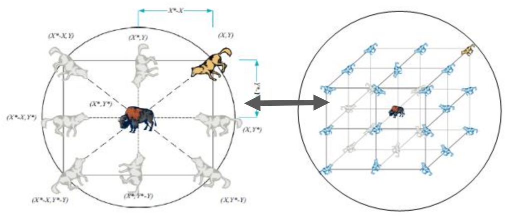

Figure 1: Extension of encircling shape into sphere

III. Simulation And Results

The performance of proposed algorithms has been studied by means of MATLAB simulation.

A. Results using PSO Algorithm

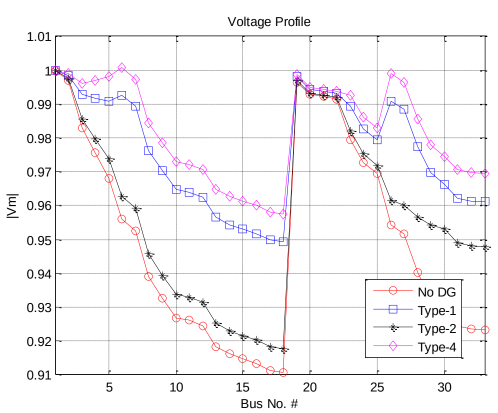

Figure 2: Comparison of voltage profile of 33 bus radial distribution system

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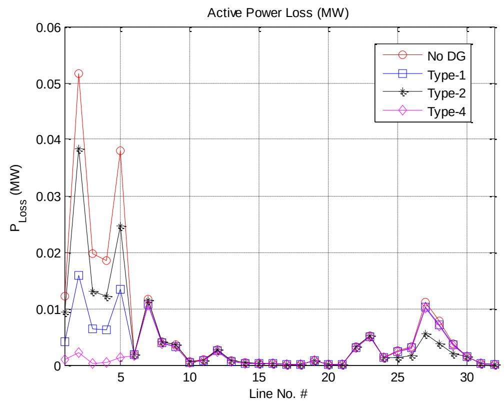

Figure 3: Comparison of active power loss across each line of 33 bus radial distribution system

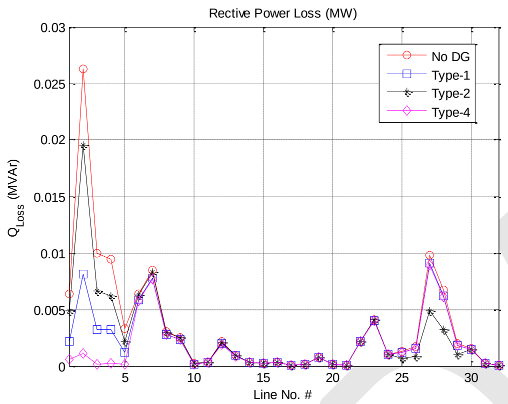

Figure 4: Comparison of reactive power loss across each line of 33 bus radial distribution system

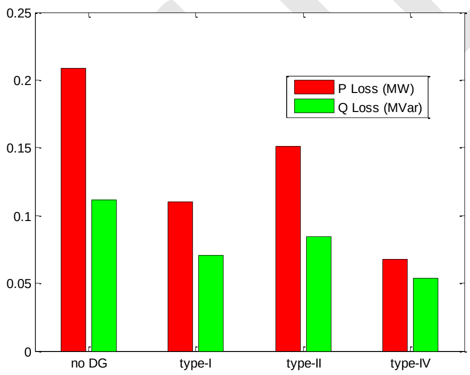

Figure 5: Comparative analysis for active and reactive power loss with DG (Type-I, Type-II and Type-IV) and without DG placement

B. *Results using GWO Algorithm*

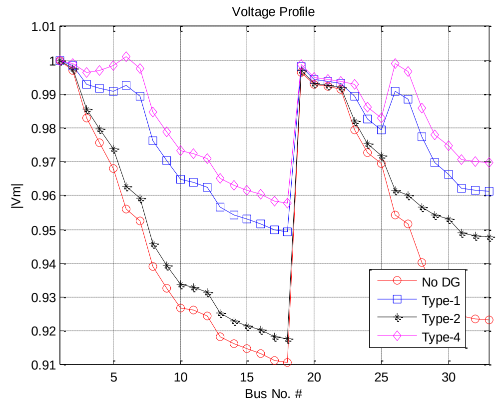

Figure 6: Comparison of voltage profile of 33 bus radial distribution system

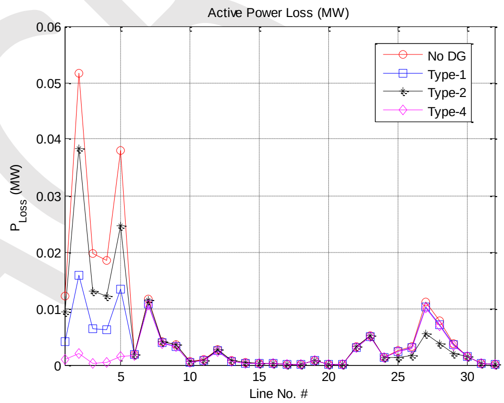

Figure 7: Comparison of active power loss across each line of 33 bus radial distribution system

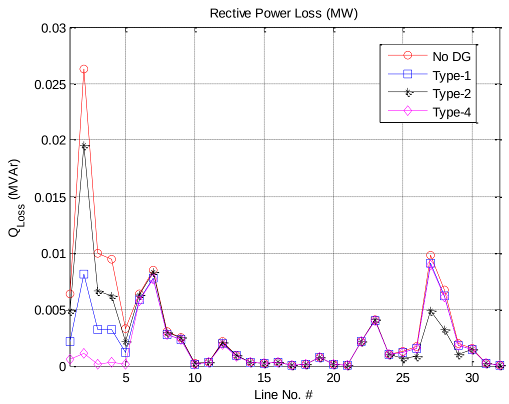

Figure 8: Comparison of reactive power loss across each line of 33 bus radial distribution system

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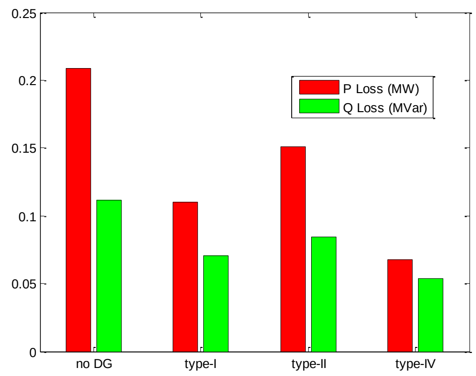

Figure 9: Comparative analysis for active and reactive power loss with DG (Type-I, Type-II and Type-IV) and without DG placement

IV. CONCLUSION

In this paper, DG allocation is accomplished using two optimization algorithms, i.e. GWO and PSO. The outcome of proposed approach clearly shows that the minimization of active power loss is done for the radial distribution network. One more advantage of this approach is that it increases the voltage at weak buses which defines the optimal size and location of distribution generation unit.

It can be seen that the symmetrical results are provided by both of the methods but for the sake of comparison the GWO algorithm outperforms the PSO on the basis of faster convergence.

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