

Optimal location and sizing of DG and D-STATCOM in distribution networks

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ABSTRACT

The main aim of this paper is to determine optimal locations and sizing of Distributed Generations (DGs) and Distribution STATic COMPensator (D-STATCOM) in the distribution network for reducing the system losses and to improve the voltage profile. In this paper, the loss sensitivity factor approach is used to determine optimal location for DG and voltage stability index is used to determine optimal location for D-STATCOM. The objective of proposed optimization problem is to minimize the total real power losses in the system while satisfying several equality and inequality constraints. Artificial fish swarm optimization algorithm (AFSOA) is used to determine the optimal size of DG and D-STATCOM. The simulations are performed on standard 33 bus and 69 bus radial distribution systems and the obtained results show the feasibility and effectiveness of proposed approach.

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NOMENCLATURE

P_D, Q_D Active and reactive power load demands.

I_L Current flow in line.

V_i, V_j Voltages at buses at i and j before D-STATCOM installation.

N_b Total number of branches.

P_{DS} Power supplied from distribution system.

$P_{D-STATCOM}$ Power generated from D-STATCOM.

P_{DG} Power generated from DG.

P_{Di} Power demand at ith bus.

V_i^{min}, V_i^{max} Minimum and maximum voltages at ith bus.

1. INTRODUCTION

In recent years, the demand for electricity is growing rapidly, and the power losses increases as the load demand increases. To meet this increased demand the integration of Distributed Generation (DG) is gaining importance. DG improves voltage profile, energy security, reliability, power quality, and reduces the power losses. Several factors such as reduction of fossil fuel, greenhouse effect and deregulated power markets forces to utilize the use of DG units in distribution networks. Deregulation of power systems introduces voltage fluctuation, sag and instability issues, which results in increased power losses in the system. Several studies were mentioned that 13% of power generated has been wasted as a real power loss in

distribution systems, hence it is an important issue and it is necessary to place the compensating devices such as DGs and Distribution STATic COMpensator (D-STATCOM) in the network [1-2]. D-STATCOM is a rapid and fast compensating device which is a shunt connected voltage source converter used to improve voltage stability, power factor and voltage profile [3].

Optimal location of D-STATCOM and DG separately in a radial distribution network for enhancing the voltage stability by minimizing the power losses is proposed in [4]. In reference [5], optimal location and size of DG and D-STATCOM are determined by stability index and variation technique by increasing the size in steps, respectively. Reference [6] proposes a multi-objective based simultaneous reconfiguration and optimal allocation of DGs for loss reduction, voltage profile improvement, and feeder load balancing. Analytical approach based technique is used in [7] for determining the optimized size and location for DG and D-STATCOM to mitigate power losses and to improve voltage profile in RDS. Optimal allocation of D-STATCOM and DG in RDSs using exhaustive search method to reduce power loss and to improve voltage profile is proposed in [8]. An up to date survey of literature on optimal allocation of D-STATCOM in distribution networks presented in [9]. Now-a-days, evolutionary based algorithms such as Modified Shuffled Frog Leaping Algorithm (MSFLA) [10], Ant Colony Optimization (ACO) [11], Genetic Algorithm (GA) [12], Particle Swarm Optimization (PSO) [13], Hybrid Particle Swarm Optimization (HPSO) [14], Grey wolf optimizer [15] are used to minimize the objective function to achieve the optimal place and size of DGs and D-STATCOMs radial distribution systems (RDSs).

From the above literature survey, it is found that there is a requirement for determining the optimal locations and sizes of DGs and D-STATCOMs in RDSs at optimal bus locations with optimal kW and kVAr to ensure maximum benefits of the system [16-18]. Simultaneous placement of these devices will help the distribution system operator to plan the expansion of distribution network. Flexible AC Transmission system devices (FACTS) devices can increase the reliability and efficiency of transmission and distribution systems. They offer greater flexibility and control in operation. Therefore it is important to find optimal location and rating of the devices required to minimize feeder losses. In this paper, the D-STATCOM is modeled in distribution network, and it is used to inject the reactive power into the distribution system. After installing the D-STATCOM into the network, voltages in the network will improve and power losses will be reduced. Here, Artificial fish swarm optimization algorithm (AFSOA) has been utilized to determine optimal sizes of DGs and D-STATCOMs. Simulations are performed on standard 33 and 69 bus RDSs and the obtained results show significant reduction in total power losses of the system. The proposed approach can be applied to any large scale and practical RDSs.

The remainder of this paper is organized as follows: Section 2 presents the proposed problem formulation including the power flow analysis, optimal locations of DGs, D-STATCOM and objective function. The step-by-step implementation of proposed optimization problem using Artificial fish swarm optimization Algorithm (AFSOA) has been described in Section 3. Simulation results are presented in Section 4. Finally, Section 5 concludes the major findings of this work.

2. PROPOSED METHOD

2.1. Power Flow Analysis

The general load flow techniques such as Gauss-Seidal, Newton-Raphson and Fast Decoupled load flow techniques cannot be applied to the distribution networks because of low reactance to resistance ratios (X/R). Distribution power flow methods are implemented to calculate line flows and voltage magnitudes using forward and reserve sweeps along a radial line [19]. In this paper, backward/forward sweep based distribution load flow is used, because of its accuracy and robust convergence characteristics. The single line diagram of simple RDS is depicted in Figure 1 [20].

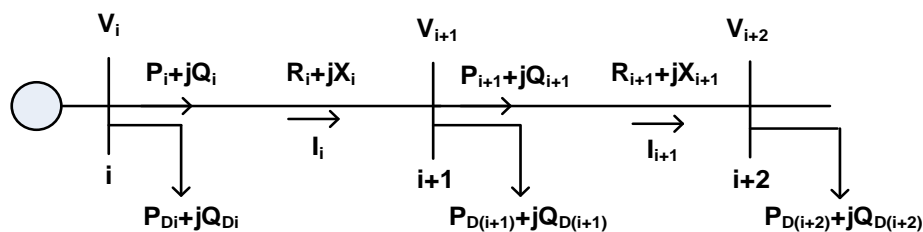


Figure 1. Single line diagram of simple RDS

In the first section of Figure 1, i is the sending end and $i+1$ is the receiving end. The active and reactive power flows in the first section are expressed as [21],

$$P_{i+1} = P_i - P_{D(i+1)} - \left(\frac{P_i^2 + Q_i^2}{V_i^2}\right) R_i \tag{1}$$

$$Q_{i+1} = Q_i - Q_{D(i+1)} - \left(\frac{P_i^2 + Q_i^2}{V_i^2}\right) X_i \tag{2}$$

Voltage at $(i+1)$ th bus is calculated using [22],

$$V_{i+1}^2 = V_i^2 - 2(P_i R_i + Q_i X_i) + (R_i^2 + X_i^2) \left(\frac{P_i^2 + Q_i^2}{|V_i|^2}\right) \tag{3}$$

The active and reactive power loss in first section is calculated using [23],

$$P_{loss,i} = \left(\frac{P_i^2 + Q_i^2}{V_i^2}\right) R_i \tag{4}$$

$$Q_{loss,i} = \left(\frac{P_i^2 + Q_i^2}{V_i^2}\right) X_i \tag{5}$$

The total active power losses of distribution networks can be calculated by adding losses in all sections, and it is given by [24],

$$P_{TL} = \sum_{i=1}^{N_b} P_{loss,i} \tag{6}$$

Distribution Static Synchronous Compensator (D-STATCOM) is a shunt device which can inject and absorb active or reactive power at a bus, and hence improving voltage profile. For detailed modeling of D-STATCOM, the reader may refer reference [25].

2.2. Optimal Location

In this paper, the loss sensitivity factor (LSF) approach is used to determine the optimal location for DG, and voltage stability index (VSI) is used to determine optimal location for D-STATCOM [26].

2.2.1 Loss Sensitivity Factor (LSF) Approach

The LSF reduces the search space of optimization process for faster calculations. The bus with highest value of LSF with respect to active power has the higher probability to place the DG. LSF can be obtained by partially differentiating (4), and it can be expressed as [27],

$$\frac{\partial P_{loss,i}}{\partial P_i} = \frac{2P_i R_i}{|V_i|^2} \tag{7}$$

The calculated LSF values at all buses are calculated and they are arranged in descending order. The top most LSF value has more chance to be selected as candidate bus for placing the DG.

2.2.2 Voltage Stability Index (VSI)

In this paper, VSI is used to determine the bus that has more chance of voltage collapse. The bus with low VSI value has more chance to be selected as candidate bus for installing the D-STATCOM. The VSI at each bus is calculated using [28],

$$VSI_{i+1} = |V_i|^4 - 4[P_{i+1} X_i - Q_{i+1} R_i]^2 - 4|V_i|^2 [P_{i+1} R_i + Q_{i+1} X_i] \tag{8}$$

2.3. Objective Function

The objective of optimal placement and sizing of DG and D-STATCOM in RDS is to minimize the total real power losses in the system while satisfying several equality and inequality constraints [29]. Mathematically, the objective function (J) is expressed as [30],

$$\text{minimize } J = \text{minimize } (P_{TL}) \tag{9}$$

The above objective function is solved subjected to the following equality and inequality constraints.

2.3.1 Equality Constraints

These constraints include the power balance constraints, i.e., total power generation is equal to the total power demand and losses, and they are expressed as [31],

$$\sum_{i=1}^{N_b} P_{Di} + P_{TL} = P_{DG} + P_{D-STATCOM} + P_{DS} \quad (10)$$

2.3.2 Inequality Constraints

a) Voltage Constraints

The voltage at each bus must be maintained within the specified range and it can be expressed as,

$$V_i^{min} \leq |V_i| \leq V_i^{max} \quad (11)$$

b) Constraint on Reactive Power Compensation

The amount of reactive power injected at *i*th candidate bus must be restricted by,

$$Q_{D-STATCOM,i}^{min} \leq Q_{D-STATCOM,i} \leq Q_{D-STATCOM,i}^{max} \quad (12)$$

c) Constraint on Active Power Compensation

The amount of active power injected at *i*th candidate bus must be restricted by,

$$P_{DG,i}^{min} \leq P_{DG,i} \leq P_{DG,i}^{max} \quad (13)$$

3. RESEARCH METHOD

In this paper, Artificial Fish Swarm Optimization Algorithm (AFSOA) is used to solve proposed optimization problem. The AFSOA is a meta-heuristic algorithm, which is a comparatively topical accumulation to the pasture of natural computing, that has rudiments enthused by the societal behaviors of natural swarms, and associates with evolutionary computation. AFSOA has several characteristics that are similar to genetic algorithm (GA) such as sovereignty from incline in sequence of purpose occupation, the capability to resolve multifaceted nonlinear high dimensional exertion [32]. The fundamental idea of the AFSOA is to reproduce the fish behaviors such as praying, swarming, and following with local search of fish individual for attaining the global optimum. Fish habitually reside within the place having a lot of food. Therefore, the behavior of fish is imitated based on this attribute to come across the global optimum, which is the indispensable inspiration of the AFSOA [33]. The flowchart of AFSOA is depicted in Figure 2, and the detailed description has been presented in [34-35].

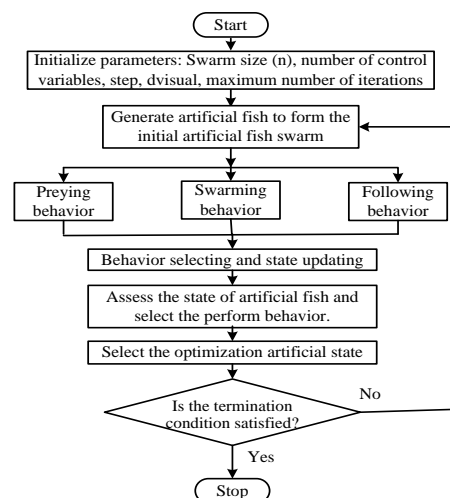


Figure 2. Flow Chart of Artificial fish swarm optimization Algorithm (AFSOA)

3.1. Step-By-Step Algorithm

The step-by-step algorithm of proposed optimization approach is presented next:

- Step 1:** Read the input data of system (i.e., bus data and line data).
- Step 2:** Run the base case backward/forward sweep distribution load flow and determine the active and reactive power losses, voltages and voltage stability index (VSI).
- Step 3:** Determine LSF and VSI to identify the candidate bus location for placing the DG and D-STATCOM.
- Step 4:** Set the lower and upper bounds for all the constraints.
- Step 5:** Randomly initialize the population of size n. Set the parameters of AFSSA and maximum number of iterations.
- Step 6:** Initialize the control variables (i.e., size/amount of kW and kVAr) for DG and D-STATCOM that will be injected within the constraints.
- Step 7:** Run load flow for each artificial fish and evaluate the fitness function using the objective function presented in (9).
- Step 8:** Select the artificial fish with minimum power loss from the population.
- Step 9:** Check for the stopping criteria (i.e., maximum number of iterations is reached or not). If Yes, go to Step 11, otherwise go to Step 10.
- Step 10:** Update the population. Run the load flow with an updated population and then go to Step 9.
- Step 11:** Display the optimal solution.

4. RESULTS AND DISCUSSION

To show the suitability and effectiveness of the proposed optimization approach, two RDSs (i.e., 33 bus and 69 bus) are considered in this paper. Here, the AFSSO algorithm is used to solve the proposed optimization problem. The parameters considered in this paper are: Population size is 60, step is 1 and the maximum number of iterations are 200. All the programs are coded in MATLAB. For each test system under study, two test cases are performed, and they are:

- a) Case 1: System without DG and D-STATCOM (Base case)
- b) Case 2: System with DG and D-STATCOM

4.1. Simulation Results on 33 Bus RDS

The line and bus data of this test system is taken from [36]. This test system has base voltage of 12.66kV and base apparent power of 100MVA. The active and reactive power loads of this RDS are 3.72MW and 2.3MVar, respectively. As mentioned earlier, in this paper, two different case studies are simulated and they are presented next:

4.1.1 Case 1

In this case, DG or D-STATCOM are not installed in the system (this case is termed as base case). Here, the obtained load flow results show that the active and reactive power losses are 210.98kW and 143.13kVar, respectively. The minimum voltage obtained in this case is 0.9038p.u. at 18th bus and the minimum VSI is 0.6610p.u.. The results obtained in Case 1 of 33 bus RDS are presented in Table 1. The voltage profile of this system in base case operation is depicted in Figure 3.

Table 1. Simulation Results for 33 Bus RDS

	Case 1	Case 2
Optimal location and size of DGs	---	1215.6kW at bus 24, 1103.2kW at bus 30
Optimal location and size of D-STATCOM	---	1148.2kVAr at bus 30
V_{min} (p.u.)	0.9037	0.9798
VSI_{min} (p.u.)	0.6610	0.9113
Optimum power loss (P_{loss})	210.98kW	23.17kW
Loss reduction (%)	---	89.02

4.1.2 Case 2

In this case, both DG and D-STATCOM are placed at optimal locations to reduce the power losses and to improve the voltage profile of the system, and the obtained results are presented in Table 1. However, it is assumed that a maximum of only 2 DGs and one D-STATCOM can be installed in this system. Here, the obtained optimal locations of DGs are 24th bus and 30th bus and their optimal sizes are 1215.6kW and 1103.2kW, respectively. The optimal location of D-STATCOM is 30th bus and the optimal size is 1148.2kVAr. The optimal power loss obtained in this case is 23.17kW, which is 89.02% less than the base

case power loss. The minimum voltage of this system has been improved from 0.9037p.u. to 0.9738p.u. and the minimum VSI has been improved from 0.6610p.u. to 0.8813p.u..

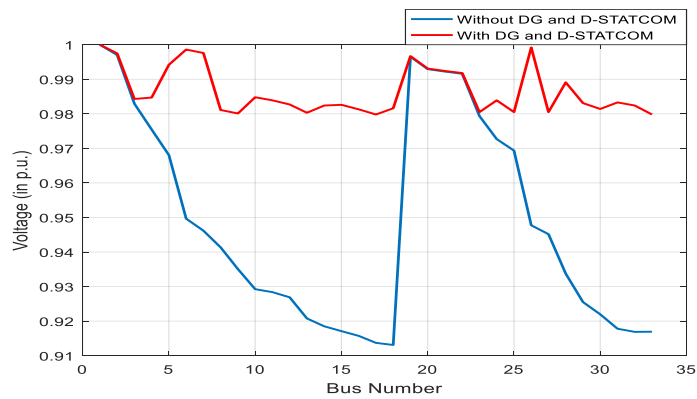


Figure 3. Voltage profile of 33 bus RDS with and without DG and D-STATCOM

4.2. Simulation Results on 69 Bus RDS

The line and bus data of this test system is taken from [36]. This test system has base voltage of 12.66kV and base apparent power of 100MVA. The active and reactive power loads of this RDS are 3.80MW and 2.69MVar, respectively. As mentioned earlier, in this paper, two different case studies are simulated and they are presented next:

4.2.1 Case 1

As mentioned earlier, in this case, DG or D-STATCOM are not installed in the system (this case is termed as base case). Here, the obtained load flow results show that the active and reactive power losses are 225kW and 102.13kVar, respectively. The minimum voltage obtained in this case is 0.9090p.u. and the minimum VSI is 0.6822p.u.. The results obtained in Case 1 of 69 bus RDS are presented in Table 2. The voltage profile of this system in base case operation is depicted in Figure 4.

Table 2. Simulation Results for 69 Bus RDS

	Case 1	Case 2
Optimal location and size of DG	---	512.0kW at bus 11, 371.4kW at bus 19, 1569.3kW at bus 61
Optimal location and size of D-STATCOM	---	1282.6kVar at bus 61
V_{min} (p.u.)	0.9090	0.9874
VSI_{min} (p.u.)	0.6822	0.9315
Optimum power loss (P_{loss})	225kW	18.27kW
Loss reduction (%)	---	91.88

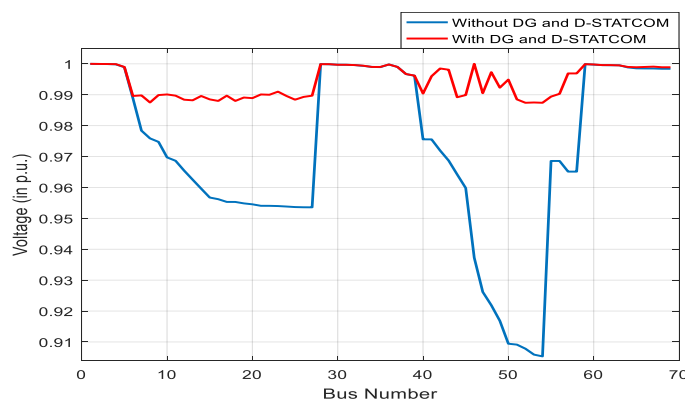


Figure 4. Voltage profile of 69 bus RDS with and without DG and D-STATCOM

4.2.2 Case 2

In this case, both DG and D-STATCOM are placed at optimal locations to reduce the power losses and to improve the voltage profile of the system, and the obtained results are presented in Table 2. However, it is assumed that a maximum of only 3 DGs and one D-STATCOM can be installed in this system. Here, the obtained optimal locations of DGs are 11th bus, 19th bus and 61th bus and their optimal sizes are 512.0kW, 371.4kW and 1569.3kW, respectively. The optimal location of D-STATCOM is 61th bus and the optimal size is 1282.6kVAr. The optimal power loss obtained in this case is 18.27kW, which is 91.88% less than the base case power loss. The minimum voltage of this system has been improved from 0.9090p.u. to 0.9874p.u. and the minimum VSI has been improved from 0.6822p.u. to 0.9315p.u.

5. CONCLUSION

This paper presents a novel methodology to determine optimal locations and sizing of Distributed Generations (DGs) and Distribution STATic COMPensator (D-STATCOM) in the radial distribution systems. Loss sensitivity factor approach is used to find optimal location for DGs and voltage stability index (VSI) is used to find optimal location for D-STATCOM. The objective of proposed optimization problem is to minimize the total real power losses in the system while satisfying several equality and inequality constraints. Artificial fish swarm optimization algorithm (AFSOA) is used to determine the optimal size of DGs and D-STATCOM. The simulation results on 33 bus and 69 bus radial distribution systems show that there has been a significant reduction in power losses and improvement of voltage profile of the system.

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