Network reconfiguration and optimal allocation of distributed generations for Mayangone distribution system

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Abstract. This paper focuses on reconfiguration of radial distribution system incorporated with optimal allocation of Distributed Generation units (DGs). The network reconfiguration is to optimize the structure of radial feeders by changing the status of normally closed sectionalizing and normally open tie switches. The optimal allocation of DGs in distribution system has to determine the DGs location and their correspondent sizing for enhancing the system effectively. There are many investigations with both two researches either separately or incorporated simultaneously. But network reconfiguration by using Particle Swarm Optimization (PSO) incorporated with optimal allocation of DGs based on Voltage Stability Index (VSI) and analytical approach of Forward Backward Sweep (FBS) method in radial power flow is the novelty of this research. The main objective is to achieve the minimum losses and improvement of voltage profile while all distribution constraints are satisfied. In proposed algorithm, optimal allocation is determined by finding the best sizing and location of DGs based on VSI and FBS load flow, and then PSO reconfiguration finds out the optimal location of tie and sectionalizing switches simultaneously. The study of test system is carried out on Mayangone Distribution System (MDS) and the obtained results are inefficient for this research.

Keywords: Network Reconfiguration, Particle Swarm Optimization, Optimal Allocation, Distributed Generation units (DGs), Minimum Losses, Mayangone Distribution System (MDS)

1. Introduction
The electricity demand becomes increasing day by day due to the rapid progress of industrialization and living standard. Thus, it can cause many challenges to be reliable and secure for operating and maintaining of power distribution system. When the load is very high, the load current drawn from the supply of the distribution system increases, and voltage drop and line losses occur consequently. The system performance is lower as the poor voltage profile and higher distribution losses. For these conditions, the operation of power system needed to design and update with efficient techniques [1]. In recent years, the researches for loss reduction and voltage profile improvement have developed in such trends of reactive power compensation, network reconfiguration, and DGs allocation in distribution system. In reactive power compensation, the installation of capacitor banks are mostly used to reduce the voltage drop as well as loss minimization. But the cost is very high for installation
and also necessary to adjust capacitance values according to load variations. Reconfiguration is very efficient technique which changes the network topology by opening and closing of sectionalizing and tie switches. It allows the transfer of loads from over loaded distribution feeders to relevant distribution feeders. Such transfers prevent the worst conditions of voltage drop near the end of feeders, and higher distribution losses as much as possible. DG connected in distribution system is one of the solutions for increasing demand. With the integration of DGs, the performance of distribution system would be higher due to reduce losses and improve the bus voltage for all buses as well as increase reliability and security of power supply [2]. The many researchers have already analysed and pointed out these facts in their research papers by using various conventional and intelligent methods.

In spite of various researches for network reconfiguration and DGs penetration in distribution system, reconfiguration using PSO method and incorporated with optimal allocation of DGs based on VSI and FBS load flow computation have not been investigated as the proposed algorithm. In this research, the first issue is to find out the optimal sizing and location of DGs in Mayangone Distribution System. The test system is very wide as consisting of 139 buses and nine feeders. Thus, FBS using Branch Injection and Branch Current (BIBC), and Branch Current and Branch Voltage (BCBV) matrix for radial load flow analysis is very flexible to rapidly calculate losses for specifying the best location and sizing with respect to the number of DGs depending on VSI. The second issue is simultaneous operation of reconfiguration using PSO algorithm with optimal allocation of DGs finds out the optimal location of sectionalizing and tie switches at the same time. The effectiveness of these algorithms gives the best performance in the result of loss minimization and voltage profile improvement of test system.

2. Problem Formulation

The network reconfiguration is to find a radial structure that includes the losses minimization of objective function with all distribution system constraints. They are described as follow:

\[
\text{Min} P_{\text{Losses}} = \sum_{i=1}^{N} |I_i|^2, R_k, i \in N
\]

Where, \( I_i \) = branch current for \( i \), \( R_k \) = branch resistance for \( i \), \( N \) = the total number of branches, \( k \) = the variable represented the switching state of the branches (1=close, 0=open).

- Radial network constraint: Distribution network must be radial structure.
- Node voltage constraint: Voltage magnitude \( V_i \) at each node must lie within their maximum and minimum limitations.
  \[
  V_{\text{min}} \leq V_{\text{bus}} \leq V_{\text{max}}
  \]
  The maximum and minimum voltage assigns as 1.05 pu and 0.95 pu.
- Generator operation constraints: All DG units must be operated within maximum and minimum of their generating limits.
  \[
  P_i^{\text{min}} \leq P_i \leq P_i^{\text{max}}
  \]
- Feeder capability limits:
  \[
  |I_k| \leq I_{\text{max}} \quad k \in \{1,2,3,...,l\}
  \]
  where, \( I_k \) = maximum capability current in branch \( k \).

3. Proposed Algorithm

There are two main considerations in proposed algorithm which includes for optimal DGs allocation and network reconfiguration. Optimal DGs allocation is based on voltage stability index and analytical approach of forward backward sweep method incorporated as an algorithm. Particle swarm optimization algorithm is applied for optimal network reconfiguration. For integrated performance of the test system, both optimum DGs and network reconfiguration algorithms are emphasized in simultaneously [4].
3.1 Formulation of optimal DGs allocation
Forward backward sweep method: the load flow computation is an iterative method in which, at each two computational stages are performed. The first set for calculation of the power flow through the branches starting from the last branch and proceeding in the backward direction towards the root node. The other set of equations are for calculating the voltage magnitude and angle of each node starting from the root node and proceeding in the forward direction towards the last node [3].

Voltage Stability Index: When increasing the load demand or changing in operation condition, the system a state of voltage is instability. It is defined an index called steady state voltage stability index (VSI) shown in eq (2), evaluated using sensitivity analysis. This index will find the most optimum weakest link in the system which could lead to the voltage stability when the load is increase.

\[
VSI = |V_s|^2 - 4[P_{ij} x_{ij} - Q_{ij} r_{ij}]^2 - 4[P_{ij} x_{ij} - Q_{ij} r_{ij}]x |V_s|^2
\]  

(2)

Where, VSI is Voltage stability index, \(V_z\) is the sending bus, \(P_r\) is active load at receiving end, \(Q_c\) is the reactive load at receiving end, \(r_{ij}\) is resistance of the line \(i-j\), \(x_{ij}\) is reactance of the line.

The optimal sizing of DG: the proposed approach is to minimize the total system power losses by optimal sizing and sitting of distributed generation in radial distribution system, the mathematically formulated as follows

\[
P_i = P_{DGi} - P_{Di}
\]

\[
Q_i = Q_{DGi} - Q_{Di}
\]

(3)

Where, \(P_i\) is real power flow at bus \(i\) in kW, \(Q_i\) is reactive power flow at bus \(i\) in kVAR.

3.2 Formulation of Particle Swarm Optimization
Particle Swarm Optimization (PSO) algorithm is a multi-agent parallel search technique which maintains a swarm of particles and each particle represents a potential solution in the swarm. All particles fly through a multidimensional search space where each particle is adjusting its position according to its own experience and that of neighbours [6]. It is supposed that \(x^i\) denotes the position vector of particle \(i\) in the multidimensional search space (i.e. \(R^n\)), then the position of each particle is updated in the search space by

\[
x_{i+1}^k = x_i^k + v_{i+1}^k \text{ with } x_i^k = U \{x_{\text{min}}, x_{\text{max}}\}
\]  

(4)

Where, \(v_i^k\) is the velocity vector of particle that drives the optimization process and reflects both the own experience knowledge and the social experience knowledge from all particles. PSO method is for gbest and the velocity of particle \(i\) is calculated by

\[
v_{i+1}^k = v_i^k + c_1 r_1^k [P_{\text{best}}^i - x_i^k] + c_2 r_2^k [G_{\text{best}} - x_i^k]
\]  

(5)

The gbest particle swarm optimization (PSO), the velocity equation of the particle with the inertia weight changes from equation is

\[
v_{i+1}^k = \omega v_i^k + c_1 r_1^k [P_{\text{best}}^i - x_i^k] + c_2 r_2^k [G_{\text{best}} - x_i^k]
\]  

(6)

To control the balance between global and local exploration to obtain quick convergence and to reach an optimum, the inertia weight whose value decreases linearly with the iteration number is set according to the following equation:

\[
\omega_{i+1}^k = \omega_{\text{max}} - (\frac{\omega_{\text{max}} - \omega_{\text{min}}}{k_{\text{max}}})k \quad \omega_{\text{max}} > \omega_{\text{min}}
\]  

(7)

Where, \(\omega_{\text{max}}\) and \(\omega_{\text{min}}\) are the initial and final values of the inertia weight respectively, \(k\) is the current iteration number, and \(k_{\text{max}}\) is the maximum iteration number.
3.3 Algorithm for Network Reconfiguration incorporated with optimal DGs allocation

Minimum loss and improvement of voltage for all buses of test system obtained by applied with algorithm procedures are described as following steps.

Step 1: Read system data and run load flow with FBS method for finding the voltage and VSI with initial case.
Step 2: Find the DGs location and sizing on every node except for reference bus.
Step 3: Calculate the Ploss considered from step 2, at every bus.
Step 4: The optimal allocation of DGs is chosen depending on occurrence of min Ploss
Step 5: Check the bus voltage and VSI within the acceptable range (voltage regulation ± 10% and VSI >= 0.75) with the power balance.
Step 6: If the Step 5 is not accepted, and then return to step 4.
Step 7: Add the obtained DGs, and initial tie switches as input data for network reconfiguration.
Step 8: Set initial parameters of PSO, generation of swarm, velocity, Pbest matrix, Random Gbest, max and min weight, and max iteration.
Step 9: Run Newton Raphson Load Flow again.
Step 10: Calculate the fitness function for Pbest and Gbest.
Step 11: Check the all constraints of radial distribution network.
Step 12: Update the velocity of particles with equation 9 and position of particles with equation 10.
Step 13: Check whether the iteration number is maximum or not. If it reaches the max iteration, the algorithm will be stop, otherwise, repeatedly go to step 8 until the end conditions are satisfied.

4. Case Studies

The case study system is carried out at distribution system under Mayangone substation. This distribution system is located in Mayangone Township under Yangon City Electricity Supply Cooperation (YESC). Currently, Mayangone substation is supplying electricity with nine feeders, at 6.6 kV level. The reconfiguration study is executed for voltage improvement of the buses connected to these feeders. Mayangone distribution system for reconfiguration consists of 139-buses and 8 tie lines; the total loads are 9.687 MW and 6.003 Mvar [2]. The normally tie switches are 28-129, 57-129, 104-129, 34-57, 69-104, 74-104, 118-139, 129-139 initial assigned in Mayangone radial distribution system. The DGs is considered at near point of load demand according to the result of optimal DGs allocation algorithm, incorporated with PSO reconfiguration of Mayangone distribution system (MDS). There are four cases in this research. They are:
- Case 1: The initial condition of MDS
- Case 2: Reconfiguration of MDS
- Case 3: Optimal allocation of DGs in MDS
- Case 4: Reconfiguration incorporated with optimal DGs allocation of MDS

5. Results and Discussion

In this paper, the two main results are considered as voltage profile and power losses. For concerning voltage profile, the minimum voltage of initial condition is 0.91373pu which is not acceptable for voltage constraint ± 5%, and voltage profile is very poor especially for the near buses at the end of feeders. Based on case 2, the minimum voltage improves to 0.9628pu and voltage profile is also significantly better than initial conditions while satisfying with the voltage constraint ± 5%. According to result in case 3, the minimum voltage is only 0.93912 pu, which is not satisfied for voltage constraint but it is better than compared to initial condition for all buses. The improvement voltage profile comparisons for both case 2 and case 3 are shown in figure 1 and 2.
Figure 1. Before and after reconfiguration of the voltage profile for MDS

In case 4, the result of minimum bus voltage value is 0.9628 pu, exactly same obtained the value of case 2. But the voltage profile is the best among the four cases. The result comparison of case 1 and case 4 is illustrated in figure 3, and PSO reconfiguration incorporated with optimal DGs allocation of schematic diagram is shown in figure 4. The performance comparisons of the voltage profiles for all cases are clearly observed in figure 5. In addition, the minimum power losses are also achieved better than to compare with initial condition. The power losses for case 1 is 193.6038 kW, the result of case 2 is 123.5312 kW, and case 3 and 4 is 116.021 kW and 82.4511 kW respectively. The case 3 result is slightly better than case 2, and case 4 is the best performance in four cases which are demonstrated in figure 6.
Figure 3. Initial condition and after reconfiguration incorporated with DGs of the voltage profile for MDS

Figure 4. PSO Reconfiguration incorporated with Optimal DGs Allocation of MDS
Table 1. Result summary for all cases.

| Case 1  | Case 2  | Case 3  | Case 4  |
|---------|---------|---------|---------|
| (Initial)| (Reconfiguration)| (DG)    | (Recon + DG) |
| Opened Switch | -   | 20, 50, 128, 142, 143, 144, 145, 146 | -  | 16, 50, 65, 115, 128, 136, 142, 144 |
| DG size and location | -   | -     | 0.43MW @ 27, 0.31MW @ 57, 1.50MW @ 88 | 0.43MW @ 27, 0.31MW @ 57, 1.50MW @ 88 |
| Loss Reduction | -   | 36.1938% | 40.0838% | 57.4124% |
| Min Voltage | 0.91373pu  @ 57 | 0.9628pu  @ 50 | 0.93912 pu @ 57 | 0.9628 pu @ 57 |

**Figure 5.** Performance comparison of the voltage profiles for all cases

**Figure 6.** Performance comparison of power losses for all cases
Furthermore, the result summary and their performance comparison are described in table 1. For the case 2, the result of optimal reconfiguration is obtained the eight opened switches such as 20, 50, 128, 142, 143, 144, 145, and 146. The optimal sizing and location of DGs in case 3 are 0.43MW at bus 27, 0.31MW at bus 57, and 1.50MW at bus 88 respectively achieved from the simulation result. In case 4, the DGs allocation are same with case 3, and opened switches are changed to 16, 50, 65, 115, 128, 136,142, 144 corresponding of simulation with the proposed algorithm. According to these result, the proposed method is the best performance with the proper solution for the Mayangone Distribution Network. At last, the loss reduction and minimum bus voltage are described for all cases in detail.

6. Conclusion
In this paper, the PSO Reconfiguration incorporated with optimal DGs allocation in Mayangone Distribution System is successfully achieved for the loss minimization and improvement of voltage profile. According to the result comparison of power losses, the minimum losses is 82.4511 kW obtained from proposed method in case 4. From the result of voltage profile of PSO Reconfiguration incorporated with optimal DGs allocation in MDS, most of bus voltage per unit values are higher, some of buses are nearly equal and a few of buses is slightly lower than other cases. The overall voltage profile improvement is the best among them, and also the value of minimum bus voltage reaches the acceptable limit. Therefore, the obtained results were satisfactory for all system constraints of radial distribution with optimal DGs allocation. This research could be helpful to integrate of Mayangone Distribution System effectively.

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