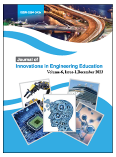

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Optimal network reconfiguration and distributed generation integration for power loss minimization and voltage profile enhancement in radial distribution system

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Abstract

Network Reconfiguration with Distributed Generation (DG) integration can significantly minimize the power loss and enhance the voltage profile. This paper presents power loss minimization and voltage profile enhancement measures in radial distribution systems through optimal network reconfiguration and DG integration. Initially, the approach was tested in a standard IEEE 33-Bus system in MATLAB using the Backward/Forward Propagation Power Flow method. Voltage Stability Index (VSI) was used to determine the candidate bus to locate for DG integration. Artificial Bee Colony (ABC) algorithm was used to find the optimal solution. Six different scenarios for network reconfiguration and DG integration were analysed by using the real distribution network of the Nepal Electricity Authority (NEA), Kirtipur Distribution Center. The simulated results were compared with the base case scenario and were validated with similar results from the previous studies. Among them, Scenario VI (simultaneous network reconfiguration and DG integration) gave a most favorable result in terms of power loss minimization and voltage profile enhancement. Test results in this study show that the active power loss has reduced by 72.19% and 57.69 for IEEE 33-Bus system and NEA 63-Bus system respectively. It also showed that ABC algorithm has outperformed other popular metaheuristic algorithms.

1. Introduction

The electrical distribution system consists of interconnected radial networks. As compared to the transmission system, the distribution system mostly operates at poor voltage, and also the power loss of the whole system is highly associated with distribution system power loss. The power loss minimization in the distribution system can increase revenue.

An electric power system is a network of electrical components associated with the generation, transmission, and distribution of electric power. Among them, the distribution system consists of interconnected radial circuits deployed to supply electrical power to end users. The power flow from generating station is initially stepped up to have minimum power loss in the transmission system which is then stepped down to the utilization voltage.

A Radial Distribution System (RDS) normally consists of the main feeder and lateral distributors which acts as the link between the high voltage transmission line and the low voltage end users. The distribution system usually operates radially, passive in nature, and power flow is unidirectional.

Due to the continuous growth of load and lack of capital investment in the transmission system, utilities are facing acute power system problems. As the electric power systems are expanded, the losses in the distribution network increase resulting poor voltage profile to end users. Studies indicate that almost 10-13 percent of the total power generated is lost as I^2 R losses at the distribution level [1]. High current characteristics and reactive power flow in RDS lead to high power losses and low power factor which increase the cost of energy and reduce the quality of voltage at the consumer site. To overcome the problems in RDS, different optimiza-

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tion techniques including network reconfiguration, DG integration, Flexible Alternating Current Transmission System (FACTS) devices, capacitor placement, and sizing can be incorporated.

The loss minimization techniques using network reconfiguration and DG integration are efficient and give the best solution to implement in the distribution network [2]. Network reconfiguration is the change in topology or structure of the network by opening branch or sectionalizing switch (normally closed) and closing a tie-switch (normally opened). Authors in [3] were the first to apply the theory of utilizing existing ties and sectionalizing switches to reconfigure the distribution system for minimizing line losses using branch and bound-type optimization techniques. The radial structure of the network must be maintained during reconfiguration. In general, network reconfiguration is done to fulfill the objective of reducing power loss or improving voltage profile, or both.

In recent years, passive distribution systems are being transformed into active distribution systems by the widespread deployment of renewable DGs as they provide green energy economically and efficiently at the doorsteps of the end users. DG units are small generating plants connected directly to the distribution network or on the consumer site of the meter. Integration of DGs in the distribution system would lead to the reduction of line losses, improvement of voltage profile, increase reliability and flexibility, relieving the overloading of distribution lines, increase the efficiency of the system, and avoids the need for transmission and distribution capacity upgradation. DG has improvement effects on loss reduction and can increase the system balancing index[4].

Network reconfiguration was handled using power loss indices as the objective function by the authors in [3] using a binary group search optimization (BGSO) method. In the paper [5], the authors applied simultaneous network reconfiguration, and placement and sizing of DGs to minimize power loss using Harmonic Search Algorithm (HSA). Authors in [6] proposed a novel integration technique for simultaneous network reconfiguration and DG integration in a distribution network with an objective of power loss minimization and voltage stability enhancement using the Fireworks Algorithm (FWA). The positive impact of a combination of network reconfiguration, DG coordination, and capacitor coordination on power loss minimization and voltage profile enhancement has been studied in [7]. The optimal placement and sizing of the DGs in an IEEE 33-bus radial distribution system before and after reconfiguration using a multi-objective PSO algorithm has been implemented in [8]. Authors in [9] applied a newly developed Ant Colony optimization for power loss minimization.

Most of the researchers worked either on network reconfiguration or DG integration. But, only a few researchers have focused simultaneously to integrate both the network reconfiguration and DG integration. To get the benefit of power loss minimization and voltage profile enhancement, it is interesting to investigate network reconfiguration with simultaneous integration of DGs and capacitors which are dependent on each other [10].

The novelty of this research is to present an approach to analyzing simultaneous network reconfiguration and placement and sizing of DGs using ABC algorithm. A computer program was developed that prompts the user to enter the number of DGs needed to be incorporated into the distribution network. VSI was used to shortlist n candidate buses for installation of DGs - the value of n varying from the number of DGs to the number of nodes or buses as given by the user. MATLAB programming environment and MATPOWER toolbox were used to exploit faster computation of load flows.

2. Problem formulation

2.1. Objective function

To minimize active power loss and voltage profile enhancement, the objective function (F) of the problem is to formulate the ratio of power loss to the base case and voltage deviation to node or bus voltage which is given below as in [6]:

$$F = \min\left(\frac{P_{\mathrm{TL}}^{\mathrm{NR}} + P_{\mathrm{TL}}^{\mathrm{DG}}}{P_{\mathrm{TL}}} + \max\left(\frac{V_1 - V_m}{V_1}\right)\right) \quad (1)$$

where,
$\mathrm{P}_{\mathrm{TL}}^{\mathrm{NR}}$ = total power loss
of the system after network reconfiguration.
$P_{\mathrm{TL}}^{\mathrm{DG}}$ = total power loss of the system with DG integration,
P_{TL} = total power loss of the system (base case),
V_1 = voltage magnitude at node 1,
V_m = voltage magnitude at node m, where $m = 1, 2, \ldots, n$ (nodes).

Constraints:

Power Conservation Limits:

$$P_{\mathrm{subs}} = \sum_{m=2}^{n} P_{Lm} + \sum_{m=1}^{\mathrm{nbr}} P_{L(m,m+1)} - \sum_{m=1}^{\mathrm{ncd}} P_{\mathrm{DG},m} \quad (2)$$

where,
$\mathrm{P}_{\mathrm{subs}}$ = power delivered by substation,
P_{Lm} = active or real power load at node m,
$P_{L(m,m+1)}$ = active power loss
in the line connecting nodes m and $m+1$,

$P_{DG,m}$ = active power delivered by DG at node m,
n = total number of nodes,
nbr = total number of branches,
ncd = number of candidate nodes for DG integration.

Voltage Deviation Limits:

$$|V_1 - V_m| \leq \Delta V_{\max} \tag{3}$$

where,
$\Delta V_{\max}$ = maximum voltage deviation

Branch Current Limits:

$$J_m \leq J_{m,\max} \tag{4}$$

where,
J_m = current flowing in the line section between nodes m and $m+1$,
$J_{m,\max}$ = maximum current flowing capacity limit of line section between nodes m and $m+1$.

Distributed Generation Capacity Limits:

$$P_{DG}^{\min} \leq P_{DG,m} \leq P_{DG}^{\max} \tag{5}$$

where, $P_{DG}^{\min}$ and $P_{DG}^{\max}$ are the minimum and maximum real power generation limits of DG.

$$P_{DG}^{\min} = 10\% \sum_{m=2}^{n} P_{Lm} \tag{6}$$

and

$$P_{DG}^{\max} = 60\% \sum_{m=2}^{n} P_{Lm}$$

where P_{Lm} is the real power load at node m.

2.2. Radial network structure

Radial topology has to be checked for all the trial solutions using the ABC algorithm followed by load flow analysis. Each section of RDS is connected radially so that it has one parent node and possibly multiple children nodes as presented in [11]. The optimally ordered nodes generate paths that ensure the radial network structure and prevent the formation of mesh loops. So, the load flow is performed after generating the proper parent node-child node path at each phase of network reconfiguration. Table 1 shows the generation of the parent node-child node path for a sample distribution feeder as shown in Figure 1.

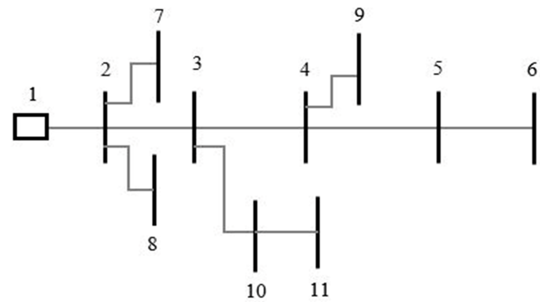

Figure 1: Sample distribution feeder

Table 1: Parent node-child node path generation for Figure 1

Parent Node	Child Node
1	2
2	3
2	7
2	8
3	4
3	10
4	5
4	9
5	6
10	11

2.3. Power loss calculations

Basically in RDS, the load flow is performed by major two techniques which are backward forward sweep and ladder theory approach. Due to efficient computation along with the feature of a fast convergence rate, the backward/forward sweep load flow technique is generally preferred [12]. Power flow in the distribution system is calculated by the following set of recursive equations derived from the sample radial distribution system as shown in Figure 2.
In Figure 2, V_m and V_{m+1} are the voltages at nodes m

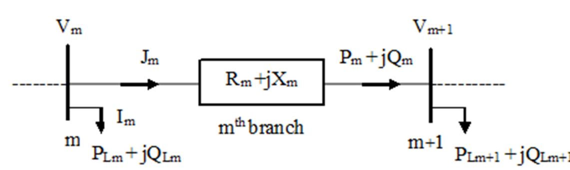

Figure 2: Sample radial distribution system

and $m+1$, respectively.
The equivalent current I_m injected at node m is given by

$$I_m = \left(\frac{P_{Lm} + jQ_{Lm}}{V_m} \right)^* \tag{7}$$

The branch current J¸ in the line section connecting nodes m and m+1 is calculated using Kirchhoff's current law through backward propagation power flow analysis. Once the branch current is calculated, the voltage at the bus m+1 is obtained by using Kirchhoff's voltage law through forward propagation power flow analysis which is given by

$$V_{m+1} = V_m - J_m \cdot (R_m + jX_m) \tag{8}$$

The power loss calculation in the line section connecting nodes m and m+1 is calculated as

$$P_{L(m,m+1)} = R_m \cdot \frac{P_m^2 + Q_m^2}{|V_m|^2} \tag{9}$$

The total power loss of the radial distribution system is the sum of all line sections losses which is given by

$$P_{\mathrm{TL}} = \sum_{m=1}^{\mathrm{nbr}} P_{L(m,m+1)} \tag{10}$$

2.4. Shortlisting nodes for integrating DG

The rapid voltage drop due to heavy load in the distribution system causes voltage stability problems. Even for a small increase in load, the voltage at some buses falls rapidly. In some cases, if it is unable to control the fall in voltage then it may ultimately lead to voltage collapse. The computation of the Voltage Stability Index (VSI) was chosen as a method to shortlist candidate nodes for the integration of DGs [13]. In this research, for integrating n number of DGs, p number of nodes (p>n) with minimum VSI values were selected as candidate nodes.

The following equation can be used to compute VSI as represented in the reference paper [6].

$$\begin{aligned} \mathrm{VSI}_{m+1} = |V_m|^4 - 4(P_{(m+1,\mathrm{eff})}X_m - Q_{(m+1,\mathrm{eff})}R_m)^2 \\ - 4(P_{(m+1,\mathrm{eff})}R_m - Q_{(m+1,\mathrm{eff})}X_k) \\ \cdot |V_k|^2 \end{aligned} \tag{11}$$

For stable operation of RDS,

$$\mathrm{VSI}_{m+1} \geq 0 \tag{12}$$

where $R_m + jX_m$ is the impedance of a branch connecting between nodes m and $m+1$. Also, a load of $P_{L(m+1)} + jQ_{L(m+1)}$ has been connected at node $m+1$.

2.5. Overview of Artificial Bee Colony (ABC) algorithm optimization

ABC algorithm is inspired by the foraging behavior of honey bee swarms to seek a quality food source and was first proposed by Karaboga [14]. The honey bee swarm has many qualities like bees can communicate information, can memorize the environment, can store and share information and take decisions based on that. The algorithm depicts the intelligent behavior of bee swarms. ABC uses the efficient food-finding analogy of bees to find the best solution to an optimization problem. It is a population-based metaheuristic optimization in which there is a population of food positions and the artificial bees modify these food positions over time.

The basic steps in finding the optimum solution in ABC algorithm are

Step 1: Generating random sites as an initial food source

Step 2: Dispatching Employed bees to the sites generated in step 1,

Step 3: Calculating probabilities for each food source for probabilistic selection

Step 4: Using information brought by Employed bees to select sites for food sources by Onlooker bees

Step 5: Abandoning food sources using parameter 'Limit' and producing Scout bees

Initially, ABC produces N solution sets also called food sources for a randomly generated population within the boundaries. The ith food source within the range of jth dimension is given by the following equations as presented in [14].

$$X_i^j = X_{\min}^j + \mathrm{rand}(0,1)(X_{\max}^j - X_{\min}^j) \tag{13}$$

$$X = \begin{bmatrix} X_1^1 & X_1^2 & \dots & X_1^D \\ X_2^1 & X_2^2 & \dots & X_2^D \\ \vdots & \vdots & \vdots & \vdots \\ X_N^1 & X_N^2 & \dots & X_N^D \end{bmatrix} \tag{14}$$

Where X is the initial solution vector generated for radial distribution system optimization, X_i^j corresponds to elements of X for the ith row and jth column, D is the number of variables or parameters to be optimized, $X_{\max}^j$ and $X_{\min}^j$ are the maximum and minimum values for the j-th variable, and rand(0, 1) is the random number within the boundary of 0 and 1. The objective function value f_i is evaluated for each food source or solution set and stored in a variable with i number of rows. Then, the fitness value fitness$_i$ is calculated for each food source as follows:

$$\mathrm{fitness}_i = \begin{cases} \frac{1}{1+f_i} & \text{if } f_i \geq 0 \\ \frac{1}{1+|f_i|} & \text{if } f_i < 0 \end{cases} \tag{15}$$

Secondly, Employed bees (whose number is equal to the number of food sources N) are sent to the food source sites to find a better food source in the neighborhood, using

$$X_i^{j^*} = X_i^j + \varphi_{ij}(X_i^j - X_k^j) \tag{16}$$

Where $X_i^{j^*}$ is the new food source in the neighborhood of X_i^j, j is a random dimension in the range [1, D], and $k \in [1, 2, 3, \ldots, N]$ is chosen randomly other than food source i. Additionally, φ_{ij} is a randomly generated number in the range [-1, 1]. If the new food source $X_i^{j^*}$ has better fitness than X_i^j, the employee bee forgets the old one and remembers the new one.
The third step is to calculate probability values (P_i) for each food source based on a probabilistic selection to send the Onlooker bees in search of better food sources. The probabilistic selection might be one of Roulette Wheel, Stochastic Universal Sampling, Ranking Based, or other similar schemes. The basic ABC algorithm employs Roulette Wheel selection which is evaluated as follows:

$$P_i = \frac{\text{fitness}_i}{\sum_{i=1}^{N} \text{fitness}_i} \tag{17}$$

In the fourth step, the Onlooker bees select food source sites using the information provided by the Employer bees. The value P_i is calculated for each food source and is compared with a randomly generated real number in the range [0, 1]. If $P_i >$ random number, then a new food source is generated by the algorithm for the Employed bees given by the equation (15). If the new solution has better fitness than the old one, the algorithm forgets the old one and remembers the new one. If the old food source is fitter than the new one, then the counter of trials is incremented by one; otherwise, it is reset to 0.
The last step is to abandon the solution based on the count of trials for each food source and employ Scout bees in search of an entirely new food source far away from the existing one. If the count of trials for each food source is larger than a pre-assigned value limit, then the new food source replaces the old one, as per equation (13). The number of Scout bees is assumed one in one cycle in the basic ABC algorithm, however, that number can be increased as per the problem taken into consideration.
The parameters used to initialize ABC algorithm for simulation of networks are number of DGs =3, VSI count limit = 15, population size = 20, number of iterations = 100, and parameter limit =3.
All the above procedures are repeated until a predetermined number of iterations in an attempt to find the best food source or the solution based on the fitness of food sources.

3. Methodology

The proposed methodology for network reconfiguration and optimal sizing, and placement of DGs to minimize active power loss and voltage profile enhancement considering different scenarios have been performed using ABC algorithm under given constraints.
To validate the effective performance of ABC algorithm for any network of a radial distribution system, it was initially applied to a standard IEEE 33-Bus Test System. For modeling a power distribution system, the MATPOWER toolbox in MATLAB was used to conduct load flow analysis.
Firstly, the `nb` number of branch or line data was arranged in the `nb` number of rows. Further, the `ns` number of tie-switch or tie-line data was arranged in the next `ns` number of rows. Line data consist of line resistance and line reactance. Similarly, the `nnode` number of node data was arranged and was used to perform power flow analysis in the MATLAB program. Node data consists of node number, active and reactive power load. The total number of node data is one unit higher than that of branch data, which is represented as `nnode = nb+1`.
The randomly generated solution vector for simultaneous network reconfiguration and DG integration can be represented as below: where $S^1, S^2, \ldots, S^5$

$$X = \begin{bmatrix} \overbrace{S_1^1\, S_1^2 .. S_1^5}^{Tie-Switch}\; \overbrace{D_1^1\, D_1^2\, D_1^3}^{DG\ Size}\; \overbrace{D_1^4\, D_1^5\, D_1^6}^{DG\ Location} \\ S_2^1\, S_2^2 .. S_2^5\; D_2^1\, D_2^2\, D_2^3\; D_2^4\, D_2^5\, D_2^6 \\ . \\ . \\ S_N^1\, S_N^2 .. S_N^5\; D_N^1\, D_N^2\, D_N^3\; D_N^4\, D_N^5\, D_N^6 \end{bmatrix} \tag{18}$$

(S^1, S^2, S^3, S^4, and S^5) are open tie-switches, and D^1, D^2, and D^3 are sizes of DG units at candidate nodes located at D^4, D^5, and D^6 respectively.

3.1. Scenario studies

Studies for six different scenarios were carried out to analyze the effective procedure to conduct network reconfiguration and DGs integration using ABC algorithm.

a. **Scenario I (Base Case)**
   There is no need for optimization in the base case scenario.

b. **Scenario II (Only Network Reconfiguration)**
   In this scenario, the number of tie-switches equals the number of variables. The set of open branch switches with the minimum

value of the objective function would be the optimal solution.

c. **Scenario III (Only DG Integration)**
The number of variables is two times the number of DGs. If n is the number of DGs integrated at candidate nodes then the number of variables corresponding to DG size, and location for the optimal solution would be 2n.

d. **Scenario IV (Network Reconfiguration followed by DG integration)**
Initially, network reconfiguration has to be done. For ns number of open switches or branches, the number of variables would be ns. Then, on adding n number of DGs in the system, 2n is the number of variables corresponding to DG size, and location for the optimal solution.

e. **Scenario V (DG Integration followed by Network Reconfiguration)**
In this scenario, initially, the problem relating to DG integration has to be carried out and subsequently network reconfiguration has to be done. The number of variables for n number of DGs would be 2n corresponding to DG size and location. Then, the value for optimal DGs would be used to perform network reconfiguration. Here, the number of variables is ns corresponding to the number of tie-switches.

f. **Scenario VI (Simultaneous Network Reconfiguration and DG Integration)**
Here, if the number of variables for network reconfiguration and DGs integration is ns and n respectively, then (ns+2n) would be the total number of variables for the system while considering the ns number of tie-switches, n number of DG size, and n number of DG location. The optimal solution would be that for which the combination of (ns+2n) variables give the minimum value of the objective function.

The ratio of percentage loss reduction to DG size is highest when the number of DG locations is three [5]. With the placement of three DG units in a real distribution feeder, the best optimization was found [15]. So, the maximum number of DGs integration in this research paper is limited to three for all the systems under consideration.

4. Results and discussion

To demonstrate the proposed methodology for solving simultaneous network reconfiguration and DG integration using ABC algorithm, all scenarios have been programmed in MATLAB software for generating parent node-child node path, performing power flow analysis, computing voltages, and power losses of the system. The simulations are carried out on a PC with a 1.8 GHz processor, 4 GB RAM, and Windows 10, a 64-bit operating system

4.1. Results for IEEE 33-Bus system

To check the effectiveness of the proposed methodology, initially, it is applied to a 12.66 kV test system consisting of 33 buses, 32 sectionalizing switches which are normally closed and five sets of extra branches also called tie switches (33, 34, 35, 36, and 37) which are normally opened. For this system, the substation voltage is considered to be 1 per unit (p.u).

A single-line diagram of the 33-bus system considering each tie switch forming the loops (L_1 to L_5) is shown in Figure 3. Power flow is used to compute VSI for all

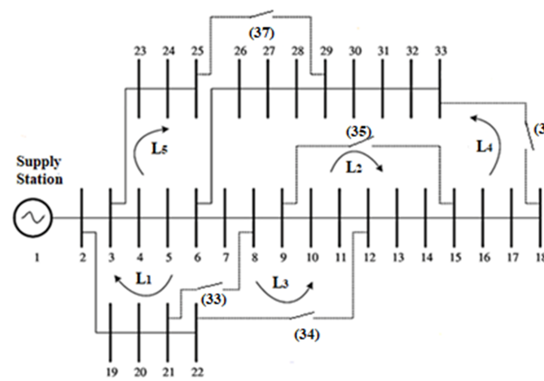

Figure 3: Sample radial distribution system

nodes to locate DGs at the candidate node for scenarios III, IV, V, and VI. The computed VSI at all nodes is sorted and ranked. Only the top three sensitive locations are selected to integrate DGs into the system. To examine the performance of the proposed method, the simulation results of different scenarios are compared using ABC algorithm against that of FWA when DGs inject active power only which is tabulated as shown in Table 2.

It is observed from Table 2 that the power loss (PTL (kW)) for the scenario I using ABC is 202.677 which is reduced to 139.978, 82.724, 61.077, 63.929, and 56.367 for scenarios II, III, IV, V, and VI respectively. The percentage loss reduction for scenarios II to VI is 30.93, 59.18, 69.86, 68.46, and 72.19 respectively. It is also observed that there is an improvement in the magnitude

Table 2: Results Comparison under each scenario

Scenario	Description	FWA [6]	Proposed method-ABC
Scenario I	Open branches	33-34-35-36-37	33-34-35-36-37
	PTL (kW)	202.67	202.677
	Vmin. (p.u)	0.9131 (18)	0.913 (18)
Scenario II	Open branches	07-14-09-32-28	9-7-14-28-32
	PTL (kW)	139.98	139.978
	Vmin. (p.u)	0.9413 (32)	0.941 (31)
Scenario III	Open branches	33-34-35-36-37	33-34-35-36-37
	DG Location	14-18-32	25-26-31
	DG Size (MW)	(0.5897)-(0.1895)-(1.0146)	(0.816)-(1.606)-(0.683)
	PTL (kW)	88.68	82.724
	Vmin. (p.u)	0.9680 (30)	0.950 (33)
	% Loss reduction	56.24	59.18
Scenario IV	Open branches	07-14-09-32-28	9-7-14-28-32
	DG Location	32-33-18	29-24-9
	DG Size (MW)	(0.5996)-(0.3141)-(0.1591)	(1.003)-(0.927)-(0.63)
	PTL (kW)	83.91	61.077
	Vmin. (p.u)	0.9612 (30)	0.970 (22)
	% Loss reduction	58.59	69.86
Scenario V	Open branches	07-34-09-32-28	33-30-28-11-14
	DG Location	14-18-32	25-26-31
	DG Size (MW)	(0.5897)-(0.1895)-(1.0146)	(0.844)-(1.789)-(0.624)
	PTL (kW)	68.28	63.929
	Vmin. (p.u)	0.9712 (29)	0.970 (20)
	% Loss reduction	66.31	68.46
Scenario VI	Open branches	07-14-11-32-28	14-27-31-10-33
	DG Location	32-29-18	25-18-27
	DG Size (MW)	(0.5367)-(0.6158)-(0.5315)	(1.355)-(0.620)-(0.653)
	PTL (kW)	67.11	56.367
	Vmin. (p.u)	0.9713 (14)	0.971 (32)
	% Loss reduction	66.89	72.19

of per unit minimum bus voltage (Vmin. (p.u)) of the system for the scenario I from 0.913 to 0.941, 0.950, 0.970, 0.970, and 0.971 for scenarios II, III, IV, V and VI respectively.

Considering all six scenarios, the power loss reduction and voltage profile enhancement using scenario VI (simultaneous reconfiguration and DG integration) are the highest, which shows that the proposed technique for this scenario is superior. Also, from the above Table 2, it shows that the simulation results obtained using the ABC algorithm are better than that obtained from the FWA algorithm.

4.2. Results for NEA 63-Bus RDS

To check the effectiveness of the proposed technique, the methodology has been applied to an 11 kV real distribution network. For this, one of the radial distribution feeders of NEA, Kirtipur Distribution Center has been chosen for analysis. The feeder under consideration (Kirtipur Feeder) originated from the Teku Substation bus situated in Teku, Kathmandu. The line and load data are taken from the respective distribution center from which the line diagram has been plotted in QGIS. The entered attributes in QGIS have been exported into MS Excel. A Single Line Diagram (SLD) has been created by assigning bus numbers and branch numbers. The substation is considered a reference bus and is represented by the number 1. The feeder consists of 63 nodes with 62 branches. Five tie-lines have been assumed between nodes 9-30, 18-39, 51-60, 28-33, and 6-14 for reconfiguration purposes. The overall SLD of the system is shown in Figure 4.

The power loss of the Kirtipur feeder for Scenario I (Base Case) was found to be 391.564 kW. Using ABC algorithm, there has been a gradual improvement in power loss reduction by 17.87%, 48.09%, 57.53%, 56.78%, and 57.69% for scenarios II, III, IV, V, and VI respectively while compared with scenario I. All the scenarios are

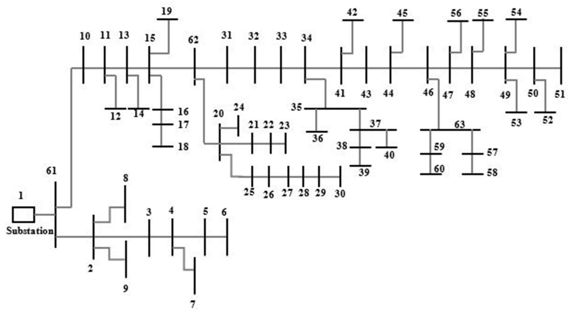

Figure 4: NEA 63-Bus RDS

considered for DGs injecting active power only.
There has been a significant improvement in the minimum bus voltage too. The superior result has been obtained for scenario VI in which power loss reduction is 57.69% and minimum bus voltage obtained is 0.985 at bus number 60 which is the highest among other scenarios. The detailed results for NEA 63-Bus RDS are presented in Table 3.

5. Conclusion

In this research, simultaneous network reconfiguration and Distributed Generation (DG) integration have been used for the minimization of power loss and enhancement of voltage profile of the radial distribution system using Artificial Bee Colony (ABC) algorithm in MATLAB environment. The method applied in this study maintains the radiality of the network. The backward/forward propagation technique has been used to compute load flow analysis, and Voltage Stability Index (VSI) technique was used to locate the candidate bus for DG integration. Six different combinations of reconfiguration and DG integration have been simulated and tested on the IEEE 33-bus test system for DGs generating active power only.
A better result has been obtained for scenario VI (simultaneous reconfiguration and DG integration) for which power loss reduction for IEEE 33-bus test system is 72.19% the minimum bus voltage obtained for the same scenario is 0.985 respectively which is the highest among other scenarios.
To check the effectiveness of the proposed technique using ABC algorithm, the simulated results are also compared with the results produced by Fireworks Algorithm (FWA) in the reference paper [6]. The computational results show that ABC algorithm has outperformed FWA. Later, after proving the effectiveness of the ABC algorithm in the IEEE 33-bus test system, the developed computer program was applied to one of the real distribution feeders of Nepal Electricity Authority (NEA). Similar to a 33-bus test system, a better result has been obtained for scenario VI in which power loss reduction for NEA 63-Bus system is 57.69%, and the minimum bus voltage obtained for the same scenario is 0.985 which is also the highest among other scenarios. All the above results show that scenario VI has superior performance when compared with other scenarios considered.
Hence, it is concluded that the applied technique using ABC performs better than FWA. Finally, the methodology used in the study can be replicated in any large-scale radial distribution network.

6. Recommendations

Further studies on the power loss minimization and voltage profile enhancement of RDS can be performed through other techniques like optimal capacitor placement and utilization of FACTS devices for the studied distribution network. A detail reliability assessment and financial analysis can be done for the system in the future studies.

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Table 3: Simulation results of the NEA 63-Bus RDS

Scenario	Description	Using ABC for NEA 63-Bus RDS
Scenario I	Open branches	64-65-66-67-68
	PTL (kW)	391.564
	Vmin. (p.u)	0.918 (52)
Scenario II	Open branches	34-27-13-49-24
	PTL (kW)	321.608
	Vmin. (p.u)	0.93 (58)
	Loss reduction	17.87%
Scenario III	Open branches	64-65-66-67-68
	DG Location	43-48-36
	DG Size (MW)	(0.917)-(1.450)-(0.749)
	PTL (kW)	203.257
	Vmin. (p.u)	0.96 (60)
	Loss reduction	48.09%
Scenario IV	Open branches	34-27-13-49-24
	DG Location	6-16-46
	DG Size (MW)	(1.400)-(1.848)-(2.330)
	PTL (kW)	166.281
	Vmin. (p.u)	0.974 (43)
	Loss reduction	57.53%
Scenario V	Open branches	50-63-13-34-24
	DG Location	43-48-36
	DG Size (MW)	(0.754)-(1.561)-(0.770)
	PTL (kW)	169.245
	Vmin. (p.u)	0.981(60)
	Loss reduction	56.78%
Scenario VI	Open branches	34-27-13-50-24
	DG Location	32-47-37
	DG Size (MW)	(1.036)-(1.937)-(0.793)
	PTL (kW)	165.68
	Vmin. (p.u)	0.985 (60)
	Loss reduction	57.69%

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