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Reconfiguration of Unbalanced Distribution Network for Improved Voltage Profile and Power Loss Mitigation

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ABSTRACT

The need for improved quality of services, and an increase in energy demand among others necessitated the urgent need for efficient utilization of the available energy via reducing technical losses in the network. This paper proposed a power loss mitigation scheme by developing an optimal reconfiguration for an unbalanced Distribution Network (DN) to reduce technical losses and improve system reliability. The various components that constitute the unbalanced networks were considered and the impedance of the line was modelled using modified Carson's equation. At the same time, a power flow based on the forward-backward sweep process was adopted to ascertain the base case losses. A composite load model was adopted. The optimal status of the switches in order to minimize the real power loss is found by Smell Agent Optimization (SAO) algorithm. The effectiveness of the proposed methodology is demonstrated on an unbalanced (123 Bus) radial distribution system. The active power loss in the base case of the IEEE 123 bus unbalanced network is 19.98 kW whereas after reconfiguration the loss reduced to 12.25 kW representing a 38.67% reduction in power loss.

1. INTRODUCTION

A power system is an interconnected system that is composed of generating units/systems which convert other forms of energy into electricity, substations that distribute the generated power to the loads (consumers), and the transmission lines /systems that tie the generating stations and distribution substations together. According to voltage levels an electric power system can be viewed as consisting of a generating system, a transmission system and a distribution system (Ahmadi *et al* 2015). The transmission system is distinctly different, in both its operation and characteristics, from the distribution system. Whereas the later draws from a single source and transmit to individual loads, the transmission system not only handles the largest blocks of power but also the system. The main difference between the transmission and distribution system shows up in the network structure. The former tends to be looped and the latter generally, a radial structure (Pathan *et al*. 2020). The modern power distribution network is constantly being faced with an ever-growing load demand (Yang *et al*, 2012). Distribution networks experience distinct change from a low to high load level every day (Rani *et al.*, 2015). In certain industrial areas, it has been observed that under certain critical loading conditions, the distribution network experience voltage collapse (Pathan *et al*. 2020). The Distribution systems usually have system loses and poor voltage regulation because of the high current and low voltage levels in distribution systems (Nguyen *et al.*, 2016). The distribution losses can be divided into real and reactive power losses. Compared to the effect of reactive power losses in the system, the real power losses (I^2R) affect the efficiency of the power transfer while the reactive loss I^2X leads to poor voltage profile (Yuvaraj *et al.*, 2017). It is reported that as much as 13% of total power generated is wasted in the form of losses at the distribution level (Naik *et al*., 2013). There are various techniques put in place to curtail these problems in the network. Among these techniques is the distribution network reconfiguration (DNR), distributed generation (DG), and optimal capacitor placement (Ali *et al*, 2017). The DNR is the most commonly used due to its cost effectiveness. The DNR is the process of readjusting or rearranging the network structure with the objectives to improve the power system conditions in the best possible way by opening and closing the available sectionalizing and tie line switches (Saonerkar *et al.*, 2016). Reconfiguration is applied for: service restoration under fault, load balancing to relieve overload on feeders ,improve voltage profile, planning outages for maintenance and power loss minimization (Kalambe & Agnihotri, 2014). Configuration of a power distribution system (PDS) is a complex activity which is important for electric power systems planning. Poor configuration leads to increased power losses, poor voltage profile (VP), and low power factor (PF) (Savier & Das, 2007). The modification of the switches depends on the type of objective function adopted therefore, the need to employ an efficient algorithm to implement an optimal NR having various perspectives such as objective function and constraints. Minimization of real power losses (RPLs) and improve voltage profile (VP) in order to improve distribution systems performance are the main objectives of DNR.

To solve DNR, numerous metaheuristics optimization algorithms have been explored and presented in the literature in the last two decades. (Esmaeilian *et al.*, 2013) worked with Gravitational Search Algorithm (GSA) for optimal reconfiguration of a real distribution network to reduce energy loss and improve reliability. **(**Fathy *et al*., 2017**)** Presented a Binary Particle Swarm Optimization Gravity Search Algorithm (BPSOGSA) for optimal reconfiguration of distribution network to determine the positions of the sectionalizing and tie switches. A Cuckoo search algorithm for distribution network reconfiguration to minimize the active power loss and maximizing the voltage magnitude deviation was presented by (Jahani *et al.* 2019). (Tyagi, *et al.*, 2017)**,** developed an improved harmony search (IHS) for balanced and unbalanced distribution systems reconfiguration, while minimizing the real power purchase cost. Successfully implementation of the Runner Root Algorithm (RRA) to solve the distribution network reconfiguration problems with multi objectives was discussed in (Nguyen *et al.*, (2017**).** (Kaur & Ghosh, 2016)**,** proposed a technique to optimize unbalanced distribution networks (UDNs) for keeping up the voltage profile with respect to the consequence of solving the multi-objective reconfiguration using the Firefly algorithm in a fuzzy domain with a load flow method. (Vasudevan & Sinha, 2017**)** put forward a distribution network reconfiguration method using Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) to identify the optimum positions of the tie and sectionalizing switches. A hybrid intelligent method (comprising of Radial Basis Function Network (RBFN) of Artificial Neural Network (ANN) and Regression Tree of Data Mining) for estimating distribution network reconfigurations with the aim of reducing active losses were present in (Mori & Yokoyama, 2016)**.** (Dahalan *et al*., 2014) developed an algorithm for reconfiguration using fast and Non- elite Dominated Sorting Genetic Algorithm (NSGAII) to determine the optimal locations of the tie and sectionalizing switches within the network and the Backward Forward Sweep (BFS) algorithm was used to ascertain the base power loss. (Amini *et al*., 2018) proposed a non-iterative harmonic load flow (HLF) method based distribution network reconfiguration using backward/forward sweep technique. (Vasudevan and Sinha 2018)**,** used genetic algorithm(GA) and particle swarm optimization (PSO) to identify the optimum positions of the tie and sectionalizing switches to obtain a very efficient reconfigured distribution network. (Kunya *et al.*, 2010), a reconfiguration of distribution systems using a modified Tabu Search (MTS) algorithm.

2. THEORETICAL ANALYSIS

2.1 Distribution Network

Distribution network is one of the main parts of power system as it is connected directly to the load centre. It is defined as a final stage in the delivery of electrical power. The primary purpose of an electricity distribution system is to meet the customer's demands for energy after receiving the bulk electrical energy from transmission or sub-transmission substation (Kansal *et al.*, 2016).

2.2 Radial Distribution Network

Generally, distribution networks are structured in mesh shape but operated in radial configuration by opening their tie-lines. In this type of topology, separate feeders radiate from the injection sub-station and feed the consumers. Radial distribution network is characterized by uncertainties and imperfection of network parameters such as: extremely large number of nodes and branches and unbalanced load.

2.3 Distribution system reconfiguration

Distribution Network reconfiguration (DNR) of the radial distribution networks are employed for the purpose of loss minimization, voltage profile improvement, load balancing, and reliability enhancement. The distribution network reconfiguration is the most widely used method of improving reliability in distribution network by electrical distribution company because it allows the use of resources that already exist in the system. The DNR can be achieved by changing the status of the switches that connect/disconnect the branches of the system, in other to obtain a radial structure (Cruz, 2016).

The DNR problems can be formulated as a mono-objective (i.e., minimization of losses) or multi-objective optimization (i.e., minimization of losses, operating cost minimization, and maximization of the profit). The solution techniques applied to solve DR problems can be categorically classified into two: mathematical techniques and heuristic and metaheuristic techniques (Meneses et al., 2015).

2.4 The Smell Agent Optimization Algorithm

Dafaf The Smell Agent Optimization Algorithm is developed using three distinctive behaviors: the sniffing mode which is based on kinetic theory of gas. The trailing mode which is based on olfaction capacity of the agent and its ability to sniff the location of best and worst molecules of smell and a random behavior which is the strategy agent employs to escape from being trapped in a local minimum (Salawudeen *et al.*, 2018).

The initial position of the smell agent molecules was randomly initialized (generated) using the equations given below:

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

The fitness of the molecule was determined, and the molecule with best fitness is selected as the agent whose olfaction capacity is determined using the equation (2);

$$olf = \frac{f(x_{Agent})}{\sum_{i=1}^{N} f(x_i)/N} \quad (2)$$

The velocity of the molecule is updated and the sniffing mode is performed using the equations (3) and (4)

$$V_i^{(t+1)} = V_j^{(t)} + r_0 \times \sqrt{\frac{3kT}{m}} \quad (3)$$

$$X_i^{(t+1)} = X_j^{(t)} + \left(V_j^{(t)} + r_0 \times \sqrt{\frac{3kT}{m}}\right) \quad (4)$$

Then, the trailing mode of the agent is performed using equation (5)

$$X_i^{(t+1)} = X_i^{(t)} + r_1 \times olf \times \left(X_{agent}^{(t)} - X_{(i)}^{(t)}\right) - r_2 \times olf \times \left(X_{worst}^{(t)} - X_{(i)}^{(t)}\right) \quad (5)$$

The fitness of the trailing mode is evaluated and the position of the agent is updated until the best position is obtained. In a situation where the trailing mode failed to obtain the best solution, the agent goes into random mode hoping to obtain the better solution. If a better solution is obtained, the agent start trailing from this position again. If not, the agent goes back to the sniffing (default) mode and starts the SAO process all over again.

3. METHODOLOGY

3.1 Power Flow Method

Direct methods, Newton-Rapson (NR) methods, and Backward-Forward sweep methods are three methods proposed for solving distribution power flow analysis. The Backward-Forward Sweep method is an iterative means to solving the load flow equations of radial distribution systems which has two steps.

3.1.1 Backward sweep

The aim of backward sweep is to update branch currents in each section, by considering the previous iteration voltages at each node. During backward transmission, voltage values are held constant with updated branch currents transmitted backward along the feeder using backward path. The Backward sweep starts from the extreme end branch and proceeds towards the slack bus.

The branch currents preceding the end buses can be obtained using equation (6)-(7):

$$I_{ij}^{abc} = I_{j}^{abc} \quad (6)$$

$$I_{ik}^{abc} = I_{k}^{abc} \quad (7)$$

These are the currents in branches i-j or i-k, preceding end buses j or k respectively. For intermediate buses, the following equation (8-9) are used,

$$I_{hi}^{abc} = I_{ij}^{abc} + I_{ik}^{abc} + I_{i}^{abc} \quad (8)$$

$$I_{hi}^{abc} = \sum_{r}^{abc} I_{ir}^{abc} + I_{i}^{abc} \quad (9)$$

Where r are all those buses connected to *'i'* downstream, I_{hi}^{abc} is Branch current vector between bus h and i. I_{ij}^{abc} represent Branch current vector between bus i and j. I_{ik}^{abc} is the Branch current vector between bus *i* and *k*.

This analysis would assume a balanced network system, with (n-1) load buses which are treated as load buses and bus 1 as slack/swing bus. The general bus '*i*' current injection k^{th} iteration is given by the equation (10) (Alhaddad & El-Hawary, 2014b):

$$I_{i}^{k} = \left(\frac{S_{i}^{sch}}{V_{i}^{k}}\right) \quad (10)$$

Where S_{i}^{sch} is the scheduled complex power at bus i, V_{i}^{k} is the bus '*i*' voltage at the k[th] iteration. Now, the backward current sweep will apply Kirchhoff's current law (KCL) by starting from the last bus 'n' to the source bus 1 to obtain the branch currents.

3.1.2 Forward sweep

The aim of the forward sweep is to calculate the voltages at each node starting from the source node. The source node is set at unity and other node voltages are calculated as given in equation (11).

$$Vb_{i} = Vb_{i-1} - Ib_{i} \times z_{i} - Ib_{i} \times z_{mutuali} \quad (11)$$

Where Vb_{i} is the voltage of i[th] bus, Vb_{i-1} denotes voltage of (i-1)[th] bus and $z_{mutuali}$ is the mutual impedance. Mutual impedance will be present for both three phase and two phase, but it is absent for single phase.

For three phase unbalanced load, equation (12) was used to calculate the nodal voltage.

$$\begin{bmatrix} \dot{V}_{-abc}^{k} \\ \dot{V}_{-abc}^{m} \\ \dot{V}_{-abc}^{n} \end{bmatrix} = \begin{bmatrix} [A_1A_2A_3] & [0] & [0] \\ [0] & [A_1A_2] & [0] \\ [0] & [0] & [A_1] \end{bmatrix} \begin{bmatrix} \dot{V}_{-abc}^{Sw} \\ \dot{V}_{-abc}^{Sw} \\ \dot{V}_{-abc}^{Sw} \end{bmatrix} - \begin{bmatrix} [A_3A_2\dot{B}_1] & [A_3\dot{B}_2] & [\dot{B}_1] \\ [A_2\dot{B}_1] & [\dot{B}_2] & [0] \\ [B_1] & [0] & [0] \end{bmatrix} \begin{bmatrix} \dot{J}_{-abc}^{e-1} \\ \dot{J}_{-abc}^{e-2} \\ \dot{J}_{-abc}^{e-3} \end{bmatrix} - \begin{bmatrix} [0] & [A_3] & [0] \\ [0] & [I] & [0] \\ [0] & [0] & [0] \end{bmatrix} \begin{bmatrix} 0 \\ \dot{V}_{0} \\ 0 \end{bmatrix} \quad (12)$$

3.2 Problem Formulation

The objective functions for the network reconfiguration considered in this paper are the active power loss reduction and voltage profile improvement.

$$\textit{Optimal Cost} = \min\left(\sum_{i=1}^{Nbr} f_i\right) \quad (13)$$

$$fi = (w_1 f_{\text{loss}} + w_2 f_{\text{SAIFI}}) \times K_j \quad (14)$$

The total power loss of the *K*-th radial configuration is determined by the summation of losses in all line sections according to the following.

$$f_{loss} = P_{loss}^{(ASM)} = \sum_{j=1}^{Nbr} R_j \times \left(\frac{P_j^2 + Q_j^2}{V_j^2}\right) K_j \quad (15)$$

Where: K_j is the switch state of j-th branch, with 0 indicating switch open and 1 indicating switch closed. Nbr is the number of the buses, Rj is the resistance of the j-th branch, Pj is the active power flowing through the terminal of j-th branch, Qj is the reactive power flowing through the terminal of j-th branch, Vj is the terminal node voltage of the j-th branch.

Subjected to constraints

The nodal voltage, branch power, and radial network are considered as the constraints as shown in equation (16-19).

a. Node voltage constraint

$$V_{min}(j) \leq V(j) \leq V_{max}(j) \quad (16)$$

b. Branch Power constraint

$$P_j \leq P_{jmax} \quad (17)$$

$$Q_j \leq Q_{jmax} \quad (18)$$

c. Radial Network constraint

$$\sum_{i=1}^{nl}\sum_{j=1}^{nbus} aij = 1 \text{ or } -1 \quad (19)$$

Where: $nbus$ is the total number of buses, nl is the number of branches, aij is the elements of the incidence matrix A which has dimension of $nl \times nbus$.

3.3 Reconfiguration using SAO

H The algorithmic steps to discover the optimal feeder reconfiguration in radial distribution system are discussed in this section. Let 'm' be the population size and 'N' be the number of decision variables in an optimization problem. For optimal feeder reconfiguration the number of open switch in a radial system is 'n1', Thus, the total number of variables in a particle is N = n1.

Step 1: Read RDS‟s load and line data.

Step 2: Select reasonable esteems for SAO coefficients and set iteration index as t = 1.

Step 3: Arbitrarily arrange workable solution for all 'm' particles in vector form xi = [xi1, xi2,... xin1, xin1+1,], i = 1 to m; where xi1 to xin1 denotes the open switch position of feeder lines on the interim [2, nbus].

Step 4: For particle i, open the tie switch positions (xi1 to xin1) in the power distribution system,

Step 5: For particle i, execute backward/forward sweep power flow algorithm on radial distribution to estimate line flows, node voltage and active power loss using Eq. (13). Specify the estimated active power loss as fitness value to i th particle. Again go to step 4 for all remaining particles.

Step 6: Find the local optimum position pi for i th particle and the global optimum position pg among all particles on the basis of the minimal cost function.

Step 7: Modify SAO global and local parameters using Eq. (1) and Eq. (2).

Step 8: Carry out particle's velocity and position update using Eq. (3) and Eq. (4) respectively.

Step 9: Verify the modified particle's position meets the system constraints Eq. (17) to Eq. (20); if any particles violate the limits, arbitrarily allocate the random solution to the violated position as in step 3; otherwise move to step 10.

Step 10: Whether the halting conditions are met? i.e., is t == tmax?; if yes, ideal feeder reconfiguration in a system, and the load flow solutions are achieved; if no, increase the iteration count, and go to Step 4.

The flow chart for implementing the smell agent optimization is given in Figure 1.

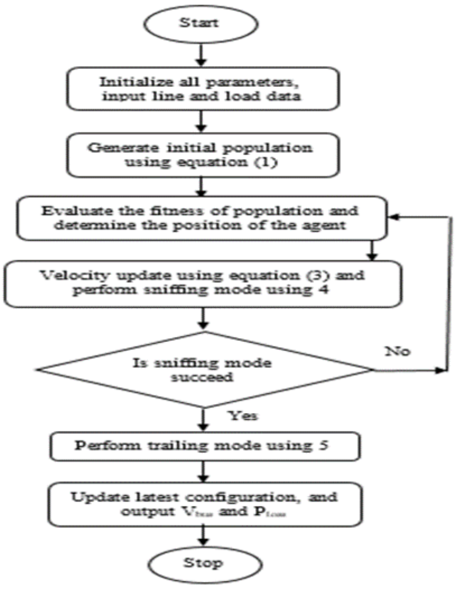


Figure 1: Flow Chart of Proposed SAO Method

4 RESULT AND DISCUSSION

The SAO optimization methodology is implemented in this study and analysed with the standard radial networks comprises of unbalanced IEEE 123 bus system. The BFS load flow analysis was carried out on the IEEE 123 bus distribution network first on the base case (with tie switches: 24 31 43 58 76) and then with SAO applied reconfiguration. Figure 2 show the optimally reconfigured IEEE 123-bus radial distribution system.

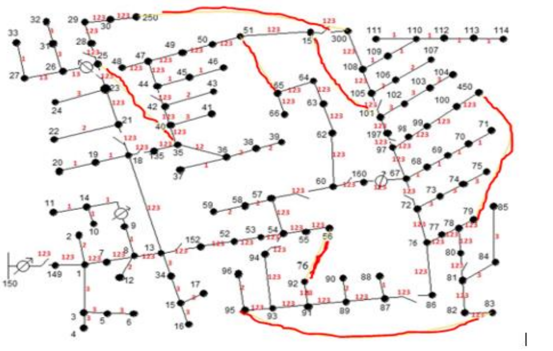


Figure 2: Optimally reconfigured IEEE 123-bus radial distribution system.

The voltage magnitude and active power loss are shown in Figures 3 and 4 respectively.

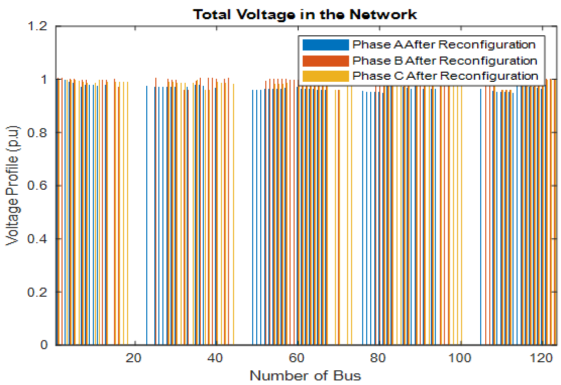
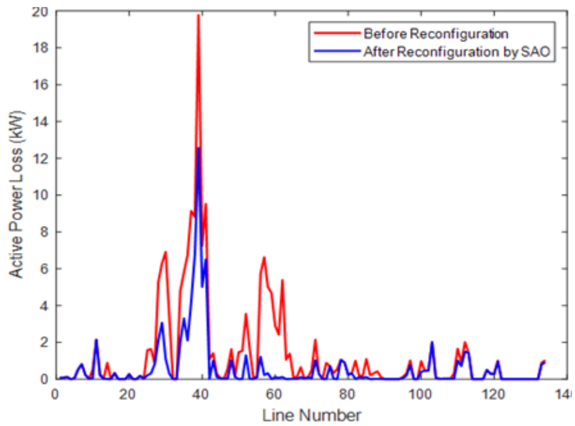


Figure 3: Total Voltage in the IEEE 123 bus Unbalanced Network for Base Case and Reconfiguration

The improvement in voltage profile and a reduction in active power loss is achieved as summarized in Table 1. It can be deduced from the line number that minimum bus voltage of 0.9252pu at phase A, 0.9442pu at phase B, and 0.9262pu at phase occurred at buses 111 to 115 which was much lower than the rest of the buses, but after reconfiguration the voltage was improved to 0.9584pu at phase A, 0.9582pu at phase B, and 0.9873 at phase C respectively, representing 3.59%, 1.48%, and 6.70% increased at phase A, B, C, respectively as shown in Figure 3. It can be deduced from Figure 4. 4 that the highest total active power loss of 19.98kW was experienced at bus 39 which is much higher than the rest of the buses, but after reconfiguration the power loss was reduced to 12.25kW representing 38.67% reduction.



Items (Scenario 2)	Before Reconfiguration	After Reconfiguration
Tie Switches	24 31 43 58 76	28 42 61 72 118
Active Power Loss	19.98 kW	12.25 kW
Active Power Loss Reduction	--------------	38.67%
Reactive Power Loss	256.7 kVar	144.90 kVar
Reactive Power Loss Reduction	----------------	43.67%
Minimum Voltage	Phase A 0.9252pu	0.9584pu
	Phase B 0.9442pu	0.9582pu
	Phase C 0.9262pu	0.9873pu

5 CONCLUSION

This study presented a SAO algorithm for optimal network reconfiguration in for power loss minimization and voltage profile improvement in IEEE 123-bus radial distribution systems. The optimization algorithm consists of a multi-objective function and a number of constraints. Basic analyses carried out include load flow analysis, sensitivity factor analysis, and SAO. Backward and forward load flow analysis was used to compute all the required parameters in the test system. The outcomes obtained from the simulation studies manifest that the presented scheme has been superior in node voltage profile improvement and active power loss minimization. The minimum bus voltage at phase A, B, and C of 0.8992pu, 0.8841pu, and 0.9241pu respectively (in the base case plot) which were improved to 0.998pu, 0.995pu, and 0.984pu after the application of reconfiguration. The tie switches after SAO driven reconfiguration is (28 42 61 72 118). The base case active loss is 19.98 kW but with SAO applied reconfiguration the active power loss reduced to 12.25 kW representing a 38.67% reduction of the active power loss. From the above test scenarios, it is observed that the SAO algorithm can improved voltage profile and obtain lower active power loss, thus resulting in higher quality solution.

REFERENCES

[1] Ahmadi, H., & Martí, J. R. (2015). Minimum-loss network reconfiguration: A minimum spanning tree problem. *Sustainable Energy, Grids and Networks, 1*, 1-9.

[2] Ali A. R., Medhat O. F. (2017) Modelling and Reconfiguration of middle Egypt Distribution Network. *Nine tenth International Middle East Power Systems Conference, Menoufia University,Egypt. 19 – 21 December 2017*

[3] Cruz, M. R. M. (2016). Benefits of coordinating distribution network

[4] reconfiguration with distributed generation and energy storage systems.

[5] Dahalan W. M., Mokhlis H., Ahmad R., Abu Bakar A. H., and Musirin I. (2014) "Simultaneous network reconfiguration and DG sizing using evolutionary programming and genetic algorithm to minimize power losses," Arab. J. Sci. Eng., vol. 39, no. 8, pp. 6327–6338, 2014.

[6] Esmaeilian, H. R., Fadaeinedjad, R., & Attari, S. M. (2013). Distribution network reconfiguration to reduce losses and enhance reliability using binary gravitational search algorithm, 385.

[7] Fathy, A., El-Arini, M., & El-Baksawy, O. (2017). An efficient methodology for optimal reconfiguration of electric distribution network considering reliability indices via binary particle swarm gravity search algorithm. Neural Computing and Applications, 1-16.

[8] Jahani, M. T. G., Nazarian, P., Safari, A. & Haghifam, M., (2019) Multi-objective optimization model for optimal reconfiguration of distribution networks with demand response services. Sustainable Cities and Society, Volume 47, pp. 1-11.

[9] Kalambe S. and Agnihotri G. (2014) "Loss minimization techniques used in distribution network: bibliographical survey," Renewable and Sustainable Energy Renewable and Sustainable Energy Reviews, vol. 29, pp. 184–200, 2014.

[10] Kansal, S., Kumar, V., & Tyagi, B. (2016). Hybrid approach for optimal placement of multiple DGs of multiple types in distribution networks. International Journal of Electrical Power & Energy Systems, 75, 226-235.

[11] Kaur, M., & Ghosh, S. (2016). Network reconfiguration of unbalanced distribution networks using fuzzy-firefly algorithm. Applied Soft Computing, 49, 868-886.

[12] Kunya, A. B., Shehu, G. S., Hassan, U. M. & Lawan, A. U., (2019) Simultaneous Distribution Network Reconfiguration and Optimal Placement of Distributed Generation. Journal of Applied Materials and Technology, Volume 1, pp. 46-53.

[13] Meneses P., de Quevedo, Contreras J., Rider M. J., and Allahdadian J. (2015) 'Contingency Assessment and Network Reconfiguration in Distribution Grids Including Wind Power and Energy Storage', IEEE Trans. Sustain. Energy, vol. 6, no. 4, pp. 1524–1533, Oct. 2015.

[14] Nguyen, T. T., Nguyen, T. T., Truong, A. V., Nguyen, Q. T., & Phung, T. A. (2017). Multi-objective electric distribution network reconfiguration solution using runner-root algorithm. Applied Soft Computing, 52, 93-108.

[15] Pathan, M. I., Al-Muhaini, M. & Djokic, S. Z., 2020. Optimal reconfiguration and supply restoration of distribution networks with hybrid microgrids. Electric Power Systems Research, Volume 187, pp. 1-10.

[16] Rani, D. S., Subrahmanyam N., & Sydulu, M. (2015). Multi-objective invasive weed optimization–an application to optimal network reconfiguration in radial distribution systems. International Journal of Electrical Power & Energy Systems, 73, 932-942.

[17] Savier, J., & Das, D. (2007). Impact of network reconfiguration on loss allocation of radial distribution systems. *IEEE Transactions on Power Delivery*, *22*(4), 2473-2480.

[18] Tripathy, S.,Prasad, G. D., Malik, O., & Hope, G. (1982). Loa-flow solutions for ill-conditioned power systems by a Newton-like method. IEEE Transactions on Power Apparatus and systems (10), 3648-3657.

[19] Vasudevan, B., & Sinha, A. (2017). Reliability improvement of reconfigurable distribution system using GA and PSO. Electrical Engineering, 1-13.

[20] Yang, F., Stoupis, J., Donde, V.: (2012) Feeder automation for an electric power distribution system. US Patent 8121740, 21 Feb 2012

[21] Yuvaraj T., Ravi K., Devabalaji K. R. (2017a) Optimal Allocation of DG and DSTATCOM in Radial Distribution System using Cuckoo Search Optimization Algorithm Hindawi Publ. Corp. Model Simul. Eng. 2017.