Smart Power Distribution Network Reconfiguration based on the Graph Theory and Particle Swarm Optimization

Hassan Chahi[1],Javad MashayekhiFard[2*], Ghasem Faezian[3]

Abstract–Distribution system reconfiguration occurs with switching operation. It is a simple and low-cost method that reduces system losses without adding additional equipment to the system. Radial structure, connection to the very high power transmission, microgrids, and distributed generation sources in the smart distribution network adds to the complexity of the problem. The Particle Swarm Optimization algorithm is suitable for a multi-objective and non-linear problem. This paper proposes a novel method for reconfiguration of distribution networks. The proposed method is based on Particle Swarm Optimization and Graph theory. The objective functions of the optimization problem are loss reduction, voltage profile, and Reliability improvement of the network. The proposed method has been conducted under consideration distributed generation and micro-grid on Esfarayen medium voltage distribution network. Three different scenarios without/with a distributed generation unit are investigated in this paper. The results also demonstrate that the proposed method is capable of finding the best solution.

Keywords: Distribution System Reconfiguration, Graph Theory, Losses Reduction, Reliability, Smart Network

1. Introduction

Over time, the quantitative and qualitative dimensions of the electricity industry were added, and it can be said nearly all residents of earth use from this clean and efficient energy in their lives at the various mode. The energy transmission division has high potential to optimize and increase the efficiency of the network, because the concepts such as losses and reliability of power energy supply are more relevant to this division. The losses of the energy distribution network are more than 60% of the total losses of the energy transmission system. 20% of generated energy is lost in the energy transmission system from the generation to consumption division. Therefore, it is necessary to operate the distribution network in an optimal mode. Reducing losses will release some of the system capacity, which can be used to supply other loads, and many problems of network can be solved, such as weak voltage and voltage oscillation of the subscribers [1].

There are several methods to reduce losses, such as capacitor installation, conductor cross section variation, voltage level variation, transformer load management, determining the feeder feed pattern, load adjustment of feeder phase, load management, the Reconfiguration of the distribution network, and use the advanced SCADA system. Applying many methods require installing and setting up new equipment in the system. This additional equipment, in addition to the financial burden for corporations, may cause new errors on the network which disrupts customer service. Among the mentioned solutions to reduce losses, the Reconfiguration method does not require the installation and setting up of new equipment in the network, and with the same elements and switches on the network in a simple and low-cost way reduces losses. The distribution networks are always used radially. The Reconfiguration must be such that the radial structure of the network is maintained. So far, many studies have been done on the Reconfiguration of the distribution network. The Civanlar et al. Begins with a radial arrangement of the network. So that one of the

1 Department of Electrical Engineering, Sabzevar Branch, Islamic Azad University, Sabzevar, Iran. Email:h.chahi58@gmail.com
2* Corresponding Author : Department of Electrical Engineering, Sabzevar Branch, Islamic Azad University, Sabzevar, Iran. Email:mashayekhi@iaus.ac.ir
3 Department of Electrical Engineering, Sabzevar Branch, Islamic Azad University, Sabzevar, Iran. Email:faezian@iaus.ac.ir
Received: 2023.03.05; Accepted: 2023.04.30

created switches in the normally open mode of the loop will open and create. In this way, the network gains its radial structure again. In a loop created by closing a normally open switch using exploratory and experimental methods, and a series of approximate formulas, the losses amount was calculated by opening each of the closed switches, and the switch that has the highest loss reduction is chosen as the appropriate switch. This is done for all switches in the normally open network mode [2].In [3] the objective function of the Reconfiguration in the form of network losses. In addition, voltage and current limitations were considered as constraints. In this way, the voltage angle is also involved in the calculation. In [4], the Reconfiguration problem of the distribution network is formulated as a transport problem with square costs. Therefore, the nonlinear function of losses is approximated as linear transportation cost, and for this purpose, losses of power can be estimated approximately as the cost of current transportation. In [5] like [4], they first open all the switches. Then, at each step, the switch closes which causes the least increase in the objective function. The objective function is the ratio of increasing the loss to the load added to the system. In the Haque method [6], the important losses are divided into active and reactive divisions, and initially, the losses of the active division were minimized through network Reconfiguration, then in the resulting network of the Reconfiguration operations, reactive losses minimized by using capacitor insertion. In[7] is similar to that of the [3], except that it uses a series of indices to find the appropriate switch to open in each loop. Authors have published another article in this field [8]. Chin and Huang [9] in addition to network Reconfiguration, is also able to retrieve the network and, in retrieval mode, it also finds the arrangement with the least losses. First, all normally open switches were closed and a sieve network was created. Then, on the sieve network, the AC load flow is considered, and using the information of the same load flow and a rating formula, the appropriate switch for each loop were found to open it. By doing this for all loops, the network becomes radial again. In [10] several steps were optimized by fuzzy logic simultaneously. These steps including various stored arrangements, the extraction of efficiency indices, the use of experiences of expert operators and fuzzy logic. Souza et al [11] depicts the application of the specialized genetic algorithm of Chu-Beasley to fathom the Distribution Framework Reconfiguration, DSR, issue considering distinctive request scenarios. This algorithm is an approach propelled within species' characteristic choice and advancement. The reconfiguration issue of distribution systems taking into consideration diverse request scenarios points of distinguishing the foremost satisfactory radial topology of a distributed framework, expecting that this topology is utilized for all request scenarios beneath consideration. In [12] a neural network approach for ideal reconfiguration of the distribution network is displayed which utilizes feeder reconfiguration as a planning and simple time control apparatus in arranging to rebuild the essential feeders for loss minimization. The scientific detailing of the proposed strategy is given; the arrangement method is outlined with a case. Cadenovic et al. [13] presents novel cycle-break (traversing tree era) calculations that can be utilized to discover the ideal distribution organize topology. These calculations (contiguousness matrix/top-down/bottom-up cycle break) speak to a novel way of getting radial to arrange topology by cycle regrouping utilizing contiguousness lattice or rudimentary cycle data. In [14] a method is proposed based on graph theory and linear algebra in order to the network analysis. In this method, the feeders that should be selected as maneuver points were determined using the graph analysis rules and finally the optimal arrangement was determined. In each of the decomposed divisions, the Reconfiguration distribution network is carried out by [2]. The objective function of this method is only loss, and has constraints such as the nodes voltage and the lines current. In [15] proposed a modern heuristic approach to reconfiguration issues actualized by the PSAT computer program in which is that, the choice of which switch is to be closed is based on the voltage distinction over NO switch. In [16] displayed a comparative think about between diverse determinations approaches connected to the issue of power distribution. After formulating the problem, the PSO algorithm and the graph theory were presented and then the proposed algorithm of this paper was investigated. After that, the proposed algorithm is implemented on the actual sample network and finally conclusions and references were given.

2. Problem Formulation

In this paper, the objective is to minimize the losses and improvement the voltage profile and improvement the reliability of the system. Therefore, the objective function of the problem was introduced as equation (1). Where k_1, k_2 and k_3 are the losses factors, expected energy not supplied costs and improvement the voltage profiles. In this equation, P is the probability of failure, EENS is Expected energy not supplied, and U is the annual *off time* period [6].

$$Min \quad COST = k_1 \times P_{Loss} + k_2 \times EENS \times P + k_3 \times V_{reg} \tag{1}$$

$$EENS = \sum_{i=1}^{N_{Load}} U_i^T \times P_i^{Load} \tag{2}$$

$$P_{Loss} = \sum_{i=1}^{N_B} R_i \left|I_i\right|^2 \tag{3}$$

Equations (4) to (7) show the constraints of the distribution network operation.

$$\left|I_l^{\min}\right| \le \left|I_l\right| \le \left|I_l^{\max}\right|, l \in L_{en} \tag{4}$$

$$\left|V_k^{\min}\right| \le \left|V_k\right| \le \left|V_k^{\max}\right|, k \in B_{en} \tag{5}$$

$$P_j^2 + Q_j^2 \le (S_j^{\max T})^2, j \in F \tag{6}$$

$$P_m \le P_m^{\max}, Q_m \le Q_m^{\max} \tag{7}$$

Equation (4) shows the thermal limitations of the network lines. In this equation, I_l ،$I_l^{\min}$ ، $I_l^{\max}$ and L_{en} are the amplitude of the current in line l, the minimum and maximum range of the passing current through line l and the set of lines in the circuit. Equation (5) also shows the voltage limitation of the buses. In this equation, V_k ،$V_k^{\min}$ and $V_k^{\max}$ are the k-bass voltage and the minimum and maximum range of the bus voltage amplitude at the time of *operation*. Equation (6) shows the thermal limitations of the network transformers. In this equation, P and Q are passing power through the transformer and $S_j^{\max T}$ is the capacitance of the j-transformer. In this equation, F is a set of transformers in the circuit. Finally, equation (7) shows the generation power limitations of micro grids. In this equation, P_m and Q_m, are the active and reactive power of the micro grids respectively, $P_m^{\max}$ and $Q_m^{\max}$ are the maximum active and reactive power of the micro grids.

A. PSO Algorithm

Particle swarm algorithm is one of the meta-heuristic optimization techniques that works based on population. The main idea of this method was originally introduced in 1995 by Russell Eberhart and James Kennedy [17]. The optimization of nonlinear capacities utilizing particle swarm strategy is portrayed. The usage of two ideal models is examined and compared, counting an as-of-late created locally arranged worldview. The PSO is one of the population-based search algorithms that starts with a group of random responses (particles) then continues to find for the optimal response in the problem space by updating the location of the particles. The global best PSO (or gbest PSO) may be a strategy where the position of each particle is affected by the best-fit molecule within the whole swarm. Each particle is identified by two vectors X_{ij} and V_{ij}, where $X_{ij}(t)$ is the position vector of particle i in dimension j at time t, $V_{ij}(t)$ is the velocity vector of particle i in dimension j at time t. At each step of population movement, the position vector of each particle is updated with two best values. P_{besti} is the individual best position of molecule i in measurement j found from initialization through time t, Gbest is the worldwide best position of molecule i in measurement j found from initialization through time t. In each repetition, after finding two values of P_{best} and g_{best}, the algorithm updates the new particle position based on equations (8) to (9). Where W is the inertial coefficient that is in the range 0 to 1. C_1 and C_2 are positive speeding up constants that are utilized to level the commitment of the cognitive and social components separately within the run to 2. r_1 and r_2 are irregular numbers from uniform distribution at time t within the run to 1.After obtaining V_{ij} value and putting in equation (9), the new position vector of the particle was obtained [18].

$$V_{ij}(t+1) = W.V_{ij}(t) + C_1.r_1(P_{best\,ij} - X_{ij}(t)) + C_2.r_2(g_{best\,ij} - X_{ij}(t)) \quad i,j = 1,2,\dots,n \tag{8}$$

$$X_{ij}(t+1) = X_{ij}(t) + V_{ij}(t+1) \quad i,j = 1,2,\dots,n \tag{9}$$

B. Graph Theory

A graph is a triple G = (V,E,φ) where V is a finite set, called the vertices of G, E is a finite set, called the edges of G, and φ is a function. The function φ is now and then called the rate function of the chart. The two components of φ(x) = {u,v}, for any x ∈ E, are called the vertices of the edge x, and we say u and v are joined by x. We moreover say that u and v are adjoining vertices which u is adjoining to v or, identically, v is adjoining to u.For any v ∈ V, in case v may be a vertex of an edge x at that point we say x is incident on v. Moreover, we say v may be a part of x, v is on x, or v is in x. Of course, v could be a part of x really implies v may be a part of φ(x).**Depth-first Search (DFS)** is a calculation for looking at a chart or tree information structure. The calculation begins at the root (beat) hub of a tree and goes as distant because it can down a given branch (way), and after that backtracks until it finds an unexplored way, and after that investigates it [19].

Algorithm 1. Depth-First Search

1. Input: an associated graph G, a beginning vertex v ∈ VG.
2. Output: a requested traversing tree T of G with root v.
3. Initialize tree T as vertex v.
4. Initialize S as the set of legitimate edges occurrence on v.

5. Whereas S ≠∅
Let e = dfs-next Edge(G,S).
Let w be the non-tree endpoint of edge e.
Include edge e and vertex w to tree T.
Upgrade Frontier (G, S).
6. Return tree T.

The distribution framework has a radial structure. So the Newton-Raphson and quick decoupled strategies are fizzled with the distribution framework. The proposed strategy presents a stack stream thinking about utilizing a backward/forward clear strategy.

Algorithm 2. Backward/forward clear strategy [20]

1. Studied line information and stack information
2. Set level voltage (1 p.u) for all hubs
3. Compute compelling genuine and receptive control streams of all branches utilizing backward propagation
4. Overhaul hub voltages and stage points utilizing forward propagation
5. In case the stack stream is focalized at that point go to 6 else go to 2
6. Compute department power loss, add up to framework loss, and print the result

3.The Proposed Algorithm

In this paper, a hybrid algorithm will be presented for Power Distribution Network Reconfiguration. Particle swarm algorithm is used to optimize the Reconfiguration problem with the objective of minimizing losses and improving the voltage profile and improving the reliability of the system. In the proposed algorithm, the algorithm creating spanning tree were used in order to establish a radial condition of the network and the feed all the loads. In order to create a spanning tree in the network graph [21], basic loops were used. The algorithm.3 proposed for solving the Reconfiguration problem in a smart network environment using the hybrid method of particle swarm optimization and graph theory. In the mentioned algorithm, the network graph and other network information for carrying out the load flow, as well as micro grid information including the maximum generation power at the moment of the error and the location of the micro grids as inputs of the problem were presented. In forming the network graph, each of the network loads as a node and network lines as the edges of the graph enters the problem. In the next step, by determining the parameters of the PSO algorithm, the initial populations of the particles were generated. The initial population was performed using the fundamental loops and graph theory. By calculating the cost function for all particles, the best position experienced for each particle and the best particle was selected. After generating the initial population for each repetition of the PSO algorithm, the velocity of each particle was updated using equation (8) and the new position of each particle was selected with new switches. By obtaining of new switches, the cost function was calculated and if the cost function was improved, the best position experienced for each particle and the best particle was updated. Algorithm.4 used to generate the initial position of the particles (including selected switches) based on the fundamental loops and graph theory. In the algorithm used to calculate the cost function by entering the network information and selected switches, by removing the corresponding edges with selected switches, the network graph was updated and the network spanning sub-graph was created. In the next step, using the first DFS algorithm, the connectivity components of the network were presented as a stack cell array. The length of the created cell array is equal to the number of connectivity components of the spanning sub graph. The connectivity components of the network sub graph were presented as a stack cell array. The length of the created cell array is equal to the number of connectivity components of the network spanning sub graph. Also, the connectivity components of the network spanning represent the islands created during the Reconfiguration. The algorithm.5 was used to compute the stack cell array. By identifying the connectivity components of the created islands, the balance constraint of generation and consumption in each island was investigated, and in the case of a violation of the constraint, the objective function was considered to be infinite. In the next step, by performing a load flow of the backward/forward sweep in each of the sub-graph connectivity components, the network voltage constraint was examined, and in the case of a violation of the constraint, the objective function was considered to be infinite. In order to calculate reliability indices in distribution network in the presence of scattered resources, the algorithm.6 was used. Due to the presence of distributed generation units in the network and the possibility of micro grid formation in the event of an error, the calculating reliability indices are simply not possible. In order to achieve this objective, it is first assumed that there is only one occurrence *probability* of an event and two simultaneous events will not occur. By the occurrence of each event, first, by using the graph theory, the created islands will be continued and in the created islands, it will examine the balance constraint of the generation and consumption.

Algorithm 3. The particle swarm algorithm for solving the Reconfiguration problem

1. Enter the Graph
2. Enter Information
3. Determine Parameters
4. I=1
5. Random Determine Switcher with Fundamental Loop and Graph Theory
6. Evaluate the Fitness Function of Particle
7. Apply Position Update
8. If the Particle is better than of the Best Particle go to 9 Else go to 10
9. Evaluate the Best State
10. if the last Particle go to 11 Else I=I+1 and go to 5
11. I_T=1
12. I=1
13. Apply Velocity Update
14. Substitute the New Position to Switchers
15. Evaluate the Fitness Function of Particle
16. If the Particle is better than of the Best Particle go to 17 Else go to 18
17. Evaluate the Best State
18. if the last Particle go to 19 Else I=I+1 and go to 13
19. if the last Iteration go to 20 Else I_T=I_T+1 and go to 12
20. Evaluate the Best Strategy

Algorithm 4. Random selected switches based on the fundamental loops and graph theory

1. Evaluate Fundamental Loop of Graph Network
2. Evaluate the common Route in Fundamental Loop
3. I=1
4. Random Evaluate the Tie Branch
5. J=I
6. Evaluate Loop of Graph Network
7. If Tie Branch common between Loop I and Loop j go to 8 else go to 9
8. Remove the common Route of Loop j
9. If the last Loop of j go to 10 Else J=J+1 and go to 6
10. If the last Loop of i go to 11 Else I=I+1 and go to 4
11. Evaluate the Random of Open Switchers

Algorithm 5. Evaluate Cost Function

1. Enter Information
2. Enter opened switches
3. network graph was updated (removing the corresponding edges with selected switches)
4. The connectivity components of the network were presented as a stack cell array.
5. If the generation rate on an island is less than the consumption rate, the load flow program will be executed.
6. Evaluate load flow study using backward/forward sweep method.
7. Operation Constraints
8. Evaluate Reliability factors
9. Evaluate the cost Function

Algorithm 6: Evaluate Reliability Factors

1. Enter the Graph
2. Enter Load Information
3. I=1
4. Occurrence(i-th)
5. Run the DFS
6. Load connection points analysis
7. Update FMEA
8. If the last Loop Occurrence, then Evaluate Reliability Factors Else I=I+1 d go to 4

If the generation rate on an island is less than the consumption rate, the load elimination program will be executed. The load elimination program depending on the priority of loads available on an island, it shut down loads with the least significant value, so that the constraints of the generation and consumption were established on an island. According to the definite determination of loads after the occurrence of events, the Failure Modes and Effects Analysis (FMEA) table was updated and in this way, reliability calculations were performed. The features of the proposed algorithm include its high capabilities in finding the optimal strategy and escaping from the local optimal. Also, the capability to calculate a Reconfiguration strategy in the presence of distributed generation resources and micro grids, as well as a traditional distribution network without distributed generation resources, are important features of this algorithm, which added flexibility.

4. The Implementation of The Proposed Algorithm on a Real Network

In order to implement the proposed method on the distribution network, the distribution network of Esfarayen was considered as case study. The overall schema of this network is shown in Fig. 1. The sample network includes 424 loads and 445 lines. The total loads are 9661 KW. This network has 27 switches that can open and close in normal mode. The implementation of the proposed algorithm on the sample network was performed by the MATALB software. In the following, the discussed scenarios were analyzed.

A. Scenario 1

In this scenario, a sample network is used without a distributed generation unit. The proposed algorithm is applied each time to reduce each of the objective functions, that is, losses, reliability, and voltage profiles, and the results of this algorithm including the switches status and the value of each of the objective functions were presented in Table 1. In the normal mode of the network, in the case of open switches only are 5-8-21-10-15-27, the losses, the expected loss- energy and the voltage profile are 528 KW, 16080 KW and 1,09 respectively.

B. Scenario 2

In this scenario, a distributed generation unit with a capacity of 100 KW and 50 KW is located between the 11 and 12 switches. The results of this algorithm including the switches status and the value of each of the objective functions were presented in Table 2.

C. Scenario 3

In this scenario, a distributed generation unit with a generation capacity of 700 and 300 kW is located between the 11 and 12 switches, and a distributed generation unit with a similar capacity is located between the switches of 4 and 20. In this scenario, the objective function is the total losses and reliability and voltage profile. The k_1 ، k_2 and k_3 coefficients and the results of this algorithm including the switches status and the value of each of the objective functions were presented in Table 3.

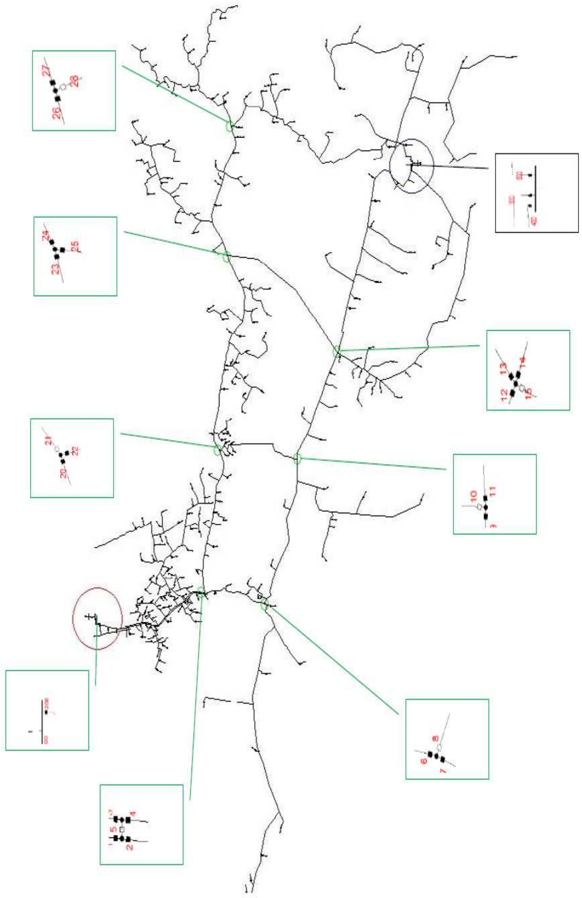

Fig.1 Case Study

Table1. Proposed algorithm results in scenario 1

Cost Function	losses	reliability	Voltage Profile
open switches	15-24-21-8-5-20	20-5-8-10-28-15	21-5-8-22-25-15
losses(KW)	101	281	104
expected loss- energy (KWh)	17671	15938	20314
Voltage Profile (P.U)	0.24	0.689	0.234

Table2. Proposed algorithm results in scenario 2

Cost Function	losses	reliability	Voltage Profile
open switches	21-5-2-10-24-15	20-5-8-10-28-15	21-5-8-22-25-15
losses(KW)	105	271	102
expected loss- energy (KWh)	18039	15729	20104
Voltage Profile (P.U)	0.2637	0.673	0.2304

Table3. Proposed algorithm results in scenario 3

Cost Function Coefficient	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
k_1	1	0.5	0.5	1	0	0
k_2	0.005	0.01	0.005	0	1	0
k_3	200	200	500	0	0	1
open switches	21-5-22-8-24-15	21-5-6-10-26-15	21-3-8-20-24-15	15-24-10-6-3-21	15-28-21-8-1-4	15-25-22-8-1-21
losses(KW)	75	78	69	72	180	74
expected loss-energy (KWh)	14416	13604	14416	14876	12075	17059
Voltage Profile (P.U)	0.16484	0.1859	0.181	0.182	0.53	0.15

5. CONCLUSIONS

This paper proposes a novel method for distribution network reconfiguration. Novel method includes 6 algorithms. First, the graph of network in order to the load flow as well as the micro grid information, including the maximum productive power at the occurrence moment of the error and their installation location are given as inputs of the problem. In forming the network graph, each of the network loads as a node and network lines as the edges of the graph enters the problem. By calculating the cost function including losses and improving the voltage profile and improving system reliability for all particles, the best position experienced for each particle and the best particle was selected. After generating the initial population in each repetition of the PSO algorithm, the velocity of each particle is updated and the new position of each particle such as new switches is selected. The proposed algorithm implemented on the distribution network of Esfarayen. The efficiency of the proposed algorithm was investigated. Improvement of voltage profile, reduction of power losses and an improving the voltage profile are result of best DG placement and sizing.

REFERENCES

[1] A. Onen, "Energy Saving of Conservation Voltage Reduction Based on Load-Voltage Dependency," *Sustainability*, Vol.8, 2016.

[2] S. Civanlar, J.J. Grainger, H. Yin, S.S.H. Lee, "Distribution feeder reconfiguration for loss reduction," *IEEE Transactions on Power Delivery*, vol.3, Issue.3, pp.1217 – 1223, 1988.

[3] D. Shirmohammadi, H.W. Hong, "Reconfiguration of electric distribution networks for resistive line losseseducation," *IEEE Transactions on Power Delivery*, vol.4, Issue.2, pp.1492-1498, 1989.

[4] V. Glamocanin, "Optimal loss reduction of distributed networks," *IEEE Transactions on Power Systems*, vol.5, Issue.3, pp.774-782, 1990.

[5] T. McDermott, I. Drezga, R.P.Broadwater, "A heuristic nonlinear constructive method for distribution system reconfiguration. Power Systems," *IEEE Transactions on power systems*, vol.14, Issue.2, pp.478-483, 1999.

[6] M.H. Haque, "Improvement of power delivery efficiency of distribution systems through loss reduction," *IEEE power Engineering Society Winter Meeting*, Singapore, pp.2739-2744, 2000.

[7] W.M. Lin, H.C. Chin, "A new approach for distribution feeder reconfiguration for loss reduction and service restoration," *IEEE Transactions on Power Delivery*, vol.13, Issue.3, pp.870-875, 1998.

[8] W.M. Lin, H.C. Chin, G.D. Yu., "An effective algorithm for distribution feeder loss reduction by switching operations", *IEEE Transmission and Distribution Conference*, New Orleans, LA, USA, 1999.

[9] H.C. Chin, K.Y. Huang, "A simple distribution reconfiguration algorithm for loss minimization. in Power System Technology," *International Conference on Power System Technology*, Australia, pp.607-611, 2000.

[10] A. Ebrahimi, S. Mohseni, "Multipurpose reconfiguration of distribution systems using fuzzy reasoning approach. in Electricity Distribution," *16th International Conference and Exhibition on Electricity Distribution*, Netherlands, 2001.

[11] S.S. Souza, R. Romero, J. Pereira, "Specialized genetic algorithm of Chu-Beasley applied to the Distribution System Reconfiguration problem considering several demand scenarios," *IEEE Eindhoven Power Tech, Eindhoven, Netherlands*, 2015.

[12] R.Rajaram, K.S. Kumar, S.P. Karthikeyan, J.E. Belwin, "Distribution System Reconfiguration for Loss Minimization Using Modified Artificial Neural Network Approach of 16 Bus and 33 Bus Standard Test Systems with an Compensator," *Applied Mechanics and Materials*, vol. 573, pp. 767-776, 2014.

[13] R. Cadenovic, D. Jakus, P. Sarajcev, J. Vasilj, "Optimal Distribution Network Reconfiguration through Integration of Cycle-Break and Genetic Algorithms," *Energies*, vol.11, No.5, 2018.

[14] A. Shang, S.Yan, "Power System Reconfiguration Using Graph Trace Analysis and Multi-Agent System," *International Conference on Logistics Engineering, Management and Computer Science*, China, pp.501-505, 2015.

[15] E. Dolatdar, S. Soleymani, B. Mozafari, "A New Distribution Network Reconfiguration Approach using a Tree Model," *International Journal of Computer and Information Engineering*, vol.3, No.10, pp.2480-2487, 2009.

[16] A. Moura1, J. Salvadorinho, B. Soares, J. Cordeiro," Compatitive study of distribution networks reconfiguration problem approaches," *RAIRO Operations Research,vol 55, 2021.*

[17] R.C. Eberhart, J. Kennedy, "A new optimizer using particle swarm theory," *Proceedings of the Sixth International Symposium on Micro Machine and Human Science*, Nagoya, Japan, pp. 39-43, 1995.

[18] S. Talukder, "Mathematical Modelling and Applications of Particle Swarm Optimization," *Master's Thesis*, Blekinge Institute of Technology, 2011.

[19] J. Li, "Reconfiguration of power networks based on graph-theoretic algorithms," Ph.D. Dissertation, Iowa State University, 2010.

[20] J.A.M. Rupa, S. Ganesh, "Power Flow Analysis for Radial Distribution System Using Backward/Forward Sweep Method," *International Journal of Electrical and Computer Engineering*, vol.8, No.10, pp.1628-1632, 2014.

[21] H. Ahmadi, J.R. Marti, "Mathematical representation of radiality constraint in distribution system reconfiguration problem," *International Journal of Electrical Power & Energy Systems,* Volume 64, pp. 293-299, 2015.