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UNIFIED PARTICLE SWARM OPTIMIZATION BASED FEEDER RECONFIGURATION FOR RADIAL DISTRIBUTION SYSTEMS

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***Abstract*-This paper exhibits a novel technique to take care of the optimal feeder reconfiguration problem in radial power distribution system with the guide of unified particle swarm optimization algorithm. Typically, an electrical power system's financial aspect essentially depends on the conductor line losses. Henceforth in the proposed study, the network active power loss is picked as the minimization problem, and it is diminished by executing optimum feeder reconfiguration in radial power distribution system using unified particle swarm optimization algorithm. The system power loss is handled as the cost function for every particle in a swarm. The investigation of the purposed method is effectively executed for various radial distribution systems in MATLAB software. The prosperous results accomplished from the case studies show that the high state of system loss reduction and attractive bus voltage profile, when analyzed against prior existing strategies, for example, genetic algorithm, particle swarm optimization, and parameter improved particle swarm optimization.**

Keywords: Feeder reconfiguration, particle swarm optimization, radial distribution system, real power loss, unified particle swarm optimization

1. INTRODUCTION

The power generated from the power station is dispersed to the various load consumers through transmission and distribution systems. It is substantially notable that the electrical power produced at the generating stations not levels with the load devoured by the customers, because of the small extent of energy loss occurred while the electrical power is sent to end customers. The most extreme rate of energy loss in an electric grid is due to transmission and distribution line losses. The apparent power loss of an AC transmission and distribution line is expressed in complex form $I^2(R+jX)$. On account of substantial resistance (R) to reactance (X) ratio characteristics of the radial distribution system (RDS) [1], the primary component of the apparent power loss in an AC distribution line is real power loss. Since the resistance is a real portion of AC distribution line impedance, the resistive loss in an AC system equivalent to active power loss. The power line resistive loss reduction in an AC distribution system presumes an essential part in economic operation and planning of a complete power system. Thus the objective of the presented study is to reduce the real power loss of RDS.

One approach in conformity with minimizing the real power loss of the power distribution network is by feeder reconfiguration. Feeder reconfiguration in radial powe of nations. The feeder reconfiguration of radial power distribution network is a complicated engineering problem directed at determining a best radial topology that reduces the line losses while meeting the system requirements. The reconfiguration on a system structure is made with the aid of modifying the tie lines switch position either by opening or closing. Since lots of tie line switching combos are available in a RDS, determining a best feeder configuration will turn into a complicated task. Typically, the loss minimization problem in an electrical power network is a very critical and difficult task to solve. In this proposed study, an optimal feeder reconfiguration can reduce the power loss of the AC distribution network. Because of the fact that the active power loss of an electrical system is directly proportional to the real part of the line current, an optimal feeder reconfiguration can reduce the system loss.

At present, the idea of integrating optimal feeder reconfiguration in RDS has been increased in greater extent due to its smooth implementation and enhanced network performances [2-10]. In light of the various favorable circumstances of reconfigured radial power distribution networks, the optimum feeder reconfiguration in a distribution system with the aid of naturally propelled artificial algorithms turn out to be more energizing and popular vogues in the domain of radial distribution network optimization and enhancement. For the first time, Merlin and Back presented the feeder reconfiguration to minimize the active power loss in distribution network, and they utilized a combination of optimization and heuristic technique to identify the best reconfiguration structure for system loss minimization in RDS operated with normal loads [2]. The effectiveness of the presented technique is that a best feeder reconfiguration can be achieved which is autonomous to the initial switch position. During planning phase of the feeder reconfiguration, the load profile of various consumers are regarded to make sure that the proposed reconfiguration is reliable, secure, and has an enough power to meet the load demand. The distribution line loss and stresses on the feeder section can be reduced by optimal reconfiguration of the tie lines switch. The system voltage quality can also be enhanced by implementing the optimal feeder reconfiguration.

A lot of load flow based heuristic techniques have been proposed to reduce the system power loss by finding the optimum feeder reconfiguration of radial distribution network [3-5]. There was a technique presented in [3], in which any tie line switch closing position is balanced by opening the another equivalent tie lie switch to maintain the radial nature of the distribution system. However this approach is desirable for small RDS, this turns out to be a ıe to the large number of calculations required to solve the feeder reconfiguration problem. In [4], the feeder configuration problem is formulated as linear programming model and approximated the conductor loss as piecewise linear function. This technique converges quick, and effective for small sized power distribution networks. Although the solving of large scale distribution systems with more than 1000 nodes using this approach can result in unreasonable computational difficulties for online execution.

A compensation based load flow solution has been employed to model the weakly meshed RDS correctly [5]. The disadvantages of compensation based approach are that, it is efficient only in reconfiguring the single phase systems but unsuitable for poly-phase systems, and it's ineffective seeking scheme that consumes more time to achieve best configuration. Genetic algorithm (GA) was introduced to minimize the distribution network losses by implementing the optimal network reconfiguration [6-7]. The GA based optimal feeder reconfiguration in RDS has lots of serior advantage over the conventional methods, and it takes care of most essential problem limitations such as node voltage limits, security limits and generation limits. In this method, chromosomes are framed and each gene in a chromosome represents the opening status of the distribution line switch, an objective function comprising of distribution line loss, and weighted parameters of bus voltage constraints and line thermal limits. Test outcomes manifest that, despite fact that the minimum distribution line loss were achieved, computational time was very high even for a 97-bus radial distribution network which is more than 15 minutes.

Simulated annealing (SA) technique was presented as a solution strategy for feeder reconfiguration by a few researchers [8-10] to look through a worthy non-substandard optimal result. Eventhough it was scientifically complex, the technique can exceptionally consuming more time to achieve the solution for any dimensional optimization problems. The heuristic rules and fuzzy multi objective technique was introduced to optimize the distribution feeder reconfiguration. In this approach, four different multi objectives were considered such as power balancing between the feeders, distribution line loss, bus voltage profile and line thermal limits. The simulation outcomes achieved are empowering, however the conditions for choosing a membership function for the objective functions are not given and specified clearly. In spite of the fact that the techniques specified above doesn't have greater convergence characteristics, the majority of the methods are utilized because of consuming very minimal computational time to obtain the optimal solutions only for small scale distribution networks. For bigger sized distribution networks, these methods consume very huge computational time to solve the feeder reconfiguration problems, and thus it cannot be desirable for online and real time applications.

The differential evolution algorithm has been employed to identify the most suitable network reconfiguration for minimizing the power loss and balancing the demands in the power distribution system [11]. In this approach, multi objective functions such as power losses, node voltage deviation and line current limits were considered. These objective functions were integrated into a single optimization problem via weighted parameters and the reconfiguration with minimal fitness function was chosen for tie line switch position. The multi objective particle swarm optimization (MPSO) technique has been formulated to discover the optimum feeder reconfiguration with minimization of three fitness functions such as system losses, tie line switch positions and node voltage deviation [12]. Graph theory and stochastic heuristics methods are implemented to enhance the probabilistic random search of the technique self tuning during the minimization stage. Improved meta-heuristic programming method has been employed to identify the optimum distribution system reconfiguration and DG in power system with cost function as active power loss minimization.

For the past two decades, many power system optimization problems have been solved with the application of artificial intelligence (AI) algorithms [13-18]. Some of the analysts have executed the use of AI methods to reduce the active power loss in RDS by incorporating optimal feeder reconfiguration [15,16]. The active power loss minimization has been considered as the fitness function to reconfigure the large-scale RDS using improved tabu search algorithm (TSA) [15]. Ant colony search optimization (ACO) technique based radial network reconfiguration has been developed to minimize the system real power loss [16]. A novel two staged technique based fuzzy logic and harmony search algorithm (HSA) for the optimal capacitor placement in power distribution systems with a fitness function to minimize the network loss and to enhance the bus voltage quality was proposed [17]. The optimum location and rating of DGs have been determined by utilizing both particle swarm optimization (PSO) and parameter improved PSO (PIPSO) techniques with real power loss as swarm cost function and the minimization problem considers power balance constraint, DG generation limit and node voltage limit [18]. Besides, it has been proved that the optimum feeder reconfiguration in power distribution systems using PSO and PIPSO algorithms have better loss reduction and fast convergence properties [18]. PSO algorithm has pulled many investigators' sights due to its effectuality and simplicity. PSO algorithm animated from the bird flocking and fish schooling, is a flexible, robust, population based optimization technique that are implemented by many researchers to solve the engineering problems as well as various power system problems [19-21]. A novel technique based on PSO for the optimal DG placement in power distribution systems with multi objective approach by considering economical and technical factors was presented [20]. Numerous advantages and usefulness of the PSO algorithm can be seen in many research studies when solving the engineering optimization problems [19-24]. Unified Particle Swarm Optimization (UPSO) is an advanced method of PSO algorithm that harnesses the local and global variant of PSO, compounding their exploration and exploitation abilities without imposing additional requirements in terms of function evaluations. Preliminary studies have shown that UPSO can tackle efficiently different optimization problems [23,24]. The performance of UPSO has been first analysed on four different engineering constrained optimization problems with the fitness function similar to the power loss function of the electrical power distribution system. The framework which have been analysed with UPSO are design of a tension/compression spring, design of a welded beam, design of a gear train, and design of a pressure vessel [23].

Hence in this paper, by considering the advantages of both the feeder reconfiguration in distribution systems and the application of intelligent PSO technique in engineering optimization, an extended version of PSO algorithm called unified particle swarm optimization is employed to find the desirable feeder reconfiguration in 33-bus and 69-bus power distribution systems. UPSO is a particular version of PSO algorithm that controls the local and global parameters of PSO by compounding their discovery and development skills without enforcing extra duties when computing fitness functions. The proposed UPSO technique based feeder reconfiguration for real power loss minimization problem in power distribution system is formulated and the obtained results are compared to that of the GA, PSO and PIPSO algorithms, providing useful conclusions considering the effectiveness and proficiency of the proposed unified method.

After the introduction, a brief description of the feeder reconfiguration problem colligated with its mathematical formulation is presented in Section 2, while the Section 3 explains the standard PSO, proposed UPSO, and its algorithmic steps to find the optimal feeder reconfiguration in radial power distribution systems. Simulation studies are presented in Section 4. Finally, the conclusion is drawn in Section 5.

2. PROBLEM FORMULATION

It is showed that the ideal feeder reconfiguration can enough reduce the active power loss of a RDS [15]. Along this, the objective of the presented work is gestated as active power loss minimization of distribution system, whose exact active power loss P_L is given as [25].

$$\text{Minimize} P_L = \sum_{i=1}^{n}\sum_{j=1}^{n}\left[\alpha_{ij}\left(P_iP_j + Q_iQ_j\right) + \beta_{ij}\left(Q_iP_j - P_iQ_j\right)\right] \quad (1)$$

where

$$\alpha_{ij} = \frac{r_{ij}}{V_iV_j}\cos\left(\delta_i - \delta_j\right) \quad (2)$$

$$\beta_{ij} = \frac{r_{ij}}{V_iV_j}\sin\left(\delta_i - \delta_j\right) \quad (3)$$

$$Z_{ij} = r_{ij} + jx_{ij} \quad (4)$$

where r_{ij} & x_{ij} is the resistance and reactance of the power line connecting nodes i & j respectively; Z_{ij} is the impendence of the power line connectingnodes i & j; V_i & δ_i is the bus voltage magnitude & angle at node i respectively; V_j & δ_j is the bus voltage magnitude & angle at node j respectively; P_i and Q_i the real & reactive power injected at node i respectively; P_j & Q_j is the real and reactive power injected at node j respectively; n is the number of nodes in the system.

Subjected to constraints,

Real and reactive power balance

$$P_i = \sum_{j=1}^{n} V_iV_j\left[G_{ij}\cos\left(\delta_i - \delta_j\right) + B_{ij}\sin\left(\delta_i - \delta_j\right)\right] \quad (5)$$

$$Q_i = \sum_{j=1}^{n} V_iV_j\left[G_{ij}\sin\left(\delta_i - \delta_j\right) - B_{ij}\cos\left(\delta_i - \delta_j\right)\right] \quad (6)$$

where P_i & Q_i is real & reactive power at node i respectively; G_{ij} & B_{ij} is the conductance & susceptance of the power line connecting nodes i & j respectively.

Bus voltage limits

$$V_{i\min} \le V_i \le V_{i\max} \quad (7)$$

where V_{imin} & V_{imax} is minimum & maximum voltage limits of bus i respectively.

3. PROPOSED METHODOLOGY

A new strategy has been defined in this section to discover the optimal feeder reconfiguration in RDS. This technique uses the development of normally invigorated optimization algorithm called UPSO for real loss reduction in the radial power system by finding the best suitable feeder reconfiguration. In addition to UPSO algorithm, a backward-forward sweep power flow calculation has been used to estimate the line power flows and bus voltage of the radial power system facilitated with the feeder reconfiguration [26]. The origination and algorithmic steps of the proposed UPSO for active power loss reduction in radial power system outfitted with ideal feeder reconfiguration is exemplified in the progressive sections.

Unified particle swarm optimization algorithm (UPSO)

PSO algorithm is fundamentally admonished from the behavioral properties of natural drift developed individual in fledgling rushing or fish tutoring. In 1995, the idea of PSO algorithm to solve the optimization problem was introduced by Eberhart and Kennedy [19].

PSO strategy examines for worldwide best solutions in an engineering optimization problem by cooperating with the particle in a swarm. Each particle in a population has prominent properties of particle position and velocity. Hypothetically in an optimization problem, the particle's position 'x' and velocity 'v' is symbolized as working solution and step length for successive iterations respectively.

For an optimization problem with 'N' decision variables, let 'm' be the particle's population size, then the i^{th} particle's position and velocity can be signified as $x_i = [x_{i1}, x_{i2}, \ldots, x_{iN}]$ and $v_i = [v_{i1}, v_{i2}, \ldots, v_{iN}]$ respectively. For every iteration, the position of i^{th} particle is examined against its earlier optimal position. If the current position is better than the earlier optimum one, then it is officially appointed as the optimal local position for the corresponding particle, and it can be signified as $p_i = [p_{i1}, p_{i2}, \ldots, p_{iN}]$. The overall optimal solution between all individuals in a swarm is perceived as the optimal global solution with position vector $p_g = [p_{g1}, p_{g2}, \ldots, p_{gN}]$. The i^{th} particle's position and velocity for the successive iterations are modified by utilizing its present velocity and its step length between the optimal global position, and the optimal local position. The formula to amend the new position and velocity of the i^{th} particle can be expressed as,

$$v_{id}^{t+1} = \omega v_{id}^{t} + \varphi_1(p_{gd} - x_{id}^{t}) + \varphi_2(p_{id} - x_{id}^{t}) \quad (8)$$

$$x_{id}^{t+1} = x_{id}^{t} + v_{id}^{t+1} \quad (9)$$

where ω is inertia weight; d is variable index; $\varphi_1=c_1r_1$ & $\varphi_2=c_2r_2$; c_1 & c_2 are two positive acceleration coefficients called social and cognitive agents respectively; both r_1 & r_2 are uniform distribution random variables on the interval [0, 1]; t is the iteration count.

By extending the degree and idea of PSO technique, UPSO technique, first figured by Parsopoulos and Vrahatis [23,24], is an extraordinary variant of PSO technique that controls the local and global parameters of PSO by aggravating their revelation and improvement powers without upholding additional obligations when processing the fitness functions. This updated version of UPSO procedure can better both the local and global positions towards the end of the iteration. Accordingly the proposed method requires less number of iterations to accomplish the global best solution for any kind of engineering problems. The two parameters are utilized in UPSO technique to accomplish both the advantages of global and local particle's position updates. These two parameters can be formulated as,

$$G_{id}^{t+1} = \chi(v_{id}^{t} + \varphi_1(p_{gd} - x_{id}^{t}) + \varphi_2(p_{id} - x_{id}^{t})) \tag{10}$$

$$L_{id}^{t+1} = \chi(v_{id}^{t} + \varphi_1^{'}(p_{hd} - x_{id}^{t}) + \varphi_2^{'}(p_{id} - x_{id}^{t})) \tag{11}$$

where, G_{id}^{t+1} & L_{id}^{t+1} represents the global and local parameter of particle's velocity update for particle i respectively; $\varphi_1^{'}=c_3r_3$ & $\varphi_2^{'}=c_4r_4$; where c_3 & c_4 are two positive acceleration coefficients, r_3 & r_4 both are uniform distribution random variables on the interval [0, 1]; d is the dimension of the problem.

The two explore steps Eq. (11) and Eq. (12) are thus aggregated into a single form as,

$$V_{id}^{t+1} = rG_{id}^{t+1} + (1-r)L_{id}^{t+1} \tag{12}$$

$$x_{id}^{t+1} = x_{id}^{t} + V_{id}^{t+1} \tag{13}$$

where, *r* is uniform distribution random variable on the interval [0, 1], which adverted to unification factor that identifies the shapes of both local and global explore steps. Evidently, $r = 0$ and $r = 1$ corresponds to local and global parameters of PSO algorithm. The aim of the presented paper is the optimal feeder reconfiguration in RDS with the aid of UPSO. The implementation of the proposed method is described in the following section.

Algorithmic procedure

The algorithmic steps to find the optimal feeder reconfiguration in distribution system are detailed in this section. Let 'm' be the population size and 'N' be the number of variables in an optimization problem. For optimal feeder reconfiguration, the number of open switch in a radial system is 'N'.

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

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

Step 3: Arbitrarily arrange workable solution for all 'm' particles in vector $x_i = [x_{i1}, x_{i2},\ldots, x_{iN}]$, i = 1 to m; where x_{i1} to x_{iN} denotes the open switch position of feeder lines on the interim [2, n].

Step 4: For particle i, open the switch position x_i in the power distribution system.

Step 5: For particle i, execute backward/forward sweep power flow calculation on radial distribution with open switch position x_i to estimate the line power flows, node voltage and active power loss using Eq. (1). Assign the calculated active power loss as fitness value to i^{th} particle. Again go to Step 4 for every single particle.

Step 6: Find the local optimum position p_i for i^{th} particle and the global optimum position p_g among all particles on the premise of the minimal cost function.

Step 7: Modify UPSO global and local parameters using Eq. (10) and Eq. (11).

Step 8: Carry out particle's velocity and position update using Eq. (12) and Eq. (13) individually.

Step 9: Verify the altered particle's position meets the system constraints Eq. (5) to Eq. (7); if any particles violate the constraints, arbitrarily allocate the random solution for the violated position as like in Step 3; otherwise move to Step 10.

Step 10: Whether the halting conditions are met? i.e., is t == t_{max}?; 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 two distinctive test systems are analyzed, and the results are discussed in the accompanying section to demonstrate the skilfulness and ability of the proposed work.

4. SIMULATION RESULTS

The presented procedure has been evaluated in two power distribution systems, and the outcomes are compared against the existing techniques, for example, GA, PSO, and PIPSO. The first test network is 33-bus IEEE RDS with the active power load of 3.72 MW and reactive power load of 2.3 MVAR [27]. The next test network is 69-bus IEEE distribution system with the active power load of 3.8 MW and reactive power load of 2.69 MVAR [28].

Parameters utilized for simulation studies are,

- Population size, m = 10
- Maximum iteration count, tmax = 100
- Inertia weight, ω is randomly selected between 0.9 and 0.4
- Social agent, c1 = 2 and c3 = 2
- Cognitive agent, c3 = 2 and c4 = 2.

33-bus distribution system

The proposed strategy is simulated and evaluated in 33-bus radial distribution network to locate the ideal feeder reconfiguration according to the algorithmic steps portrayed in the past section. The simulation outcomes obtained from the MATLAB software is depicted in Table 1. It is seen that the presented strategy demonstrates the quality and merits over the early techniques in purpose of active power loss minimization, voltage profile improvement and simulation time. The bus voltage correlation chart between the radial distribution network with and without feeder reconfiguration is portrayed in Fig. 1. The convergence property of the proposed UPSO applied in 33-bus radial distribution network is display in Fig. 2.

69-bus distribution system

The UPSO algorithm is evaluated for power loss minimization in 69-bus radial distribution network by implementing optimal feeder reconfiguration. The simulation results in Table 2, demonstrates the optimal feeder reconfiguration switch open position and level of real power loss decrease in 69-bus radial distribution network. It is shows that the introduced strategy gives better outcomes and takes less simulation time to discover the optimal feeder reconfiguration when compared against the existing strategies. In this way, the utilization of the proposed method can also be extended to bigger radial power systems. The bus voltage correlation diagram between the 69-bus radial distribution network with and without feeder reconfiguration is shown in Fig. 3. The convergence property of the proposed UPSO utilized in 69-bus radial distribution network is shown in Fig. 4.

Table 1. Simulation result of 33-bus system

Technique	Base case	GA	PSO	PIPSO	UPSO
Open Switches	33,34,35, 36,37	7,10,14,2 8,31	7,10,14,3 2,37,	7,9,14,2 8,32	7,9,14,3 2,37
Active power loss (kW)	210.99	145.69	140.28	139.98	139.55
% Reduction in active power loss	-	30.95	33.51	33.65	33.86
Reactive power loss (kVAR)	143.13	115.25	102.93	104.98	102.40
% Reduction in reactive power loss	-	19.48	28.09	26.65	28.46
Computational time (s)	-	5.67	4.96	4.72	4.57

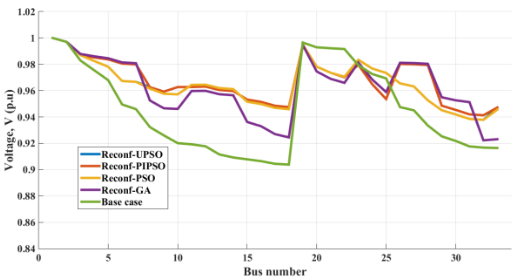

Figure.1 Comparison of bus voltage for 33-bus system

Since the introduced version of UPSO method has enhanced local and global positions at every iteration, the proposed method takes exceptionally least number of iteration counts to achieve the optimal feeder reconfiguration in both 33-bus and 69-bus distribution systems. This can also clearly concluded from the table 1 and 2, the computational time taken to achieve the best solution of the proposed UPSO strategy is significantly faster than that of the existing methods, for example, GA, PSO and PISO. For both 33-bus and 69-bus test systems, the real power loss is also comparatively reduced in proposed UPSO technique when compared to existing methods. Similarly, the bus voltage profile of the system is also improved well in proposed UPSO method.

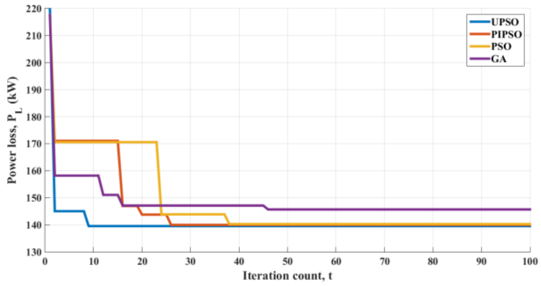

Figure.2 Convergence property for 33-bus system

Table 2. Simulation result of 69-bus system

Technique	Base case	GA	PSO	PIPSO	UPSO
Open Switches	69,70,7 1,72,73	18,43,56, 61,69	13,55,63, 69,70	13,57,61, 69,70	14,58,61, 69,70
Active power loss (kW)	224.89	122.46	99.65	98.66	98.57
% Reduction in active power loss	-	45.55	55.69	56.13	56.17
Reactive power loss (kVAR)	102.12	95.87	93.58	92.20	92.02
% Reduction in reactive power loss	-	6.12	8.36	9.72	9.89
Computational time (s)	-	7.82	6.25	6.08	5.97

5. CONCLUSION

A strategy has been proposed to discover the optimal feeder reconfiguration in 33-bus and 69-bus IEEE radial power distribution systems with the guide of UPSO technique. The m-script has been coded and tested in MATLAB software. The results acquired from the case studies show that the introduced strategy has been predominant in node voltage improvement and active power loss minimization. It has been seen that the proposed strategy utilizing UPSO demonstrates its master quality and advantages against the prior existing calculations, for example, GA, PSO, and PIPSO in the perspective of active power loss minimization, voltage improvement and computational time. In this way, the exhibited strategy can also be stretched out to greater power distribution network to locate the ideal feeder reconfiguration. Likewise, the proposed method can also be extended to simultaneous placement of DG and feeder reconfiguration for better loss reduction.

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