

Controlling the Power Loss in Radial Distribution Network by Optimally Placing UPQC through Reconfiguration Using Evolutionary Algorithms

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Abstract

In this paper, real power loss reduction in radial distribution system is accomplished through reconfiguration and placement of a custom power device. Unified Power Quality Conditioner (UPQC) is the custom power device employed. The main objective of this paper is to control the power loss in the radial distribution system thereby maintaining voltage stability. Non dominated sorting genetic algorithm (NSGA II) is used for feeder reconfiguration. In the reconfigured distribution system, UPQC is placed to reduce power loss. The placement, sizing and cost evaluation of UPQC is done using Evolutionary Algorithms like

Particle Swarm Optimization (PSO), Harmony Search Algorithm (HSA) and Bacterial Foraging Optimization Algorithm (BFOA). The results are compared and it is found that BFOA gives better power loss reduction than PSO and HSA.

Key Words :Reconfiguration, Unified Power Quality Conditioner (UPQC), Reactive power management, Harmony Search Algorithm (HSA), PSO, NSGA-II, BFOA

1 Introduction

A radial distribution system consists of a number of feeders connected together through tie lines and tie switches. The foremost problem in distribution system is the reduction of power loss. This is achieved by injecting the active power or real power to the network or by compensating the reactive power in the network. Conventional methods that are being practiced to alleviate this problem are reconfiguration and capacitor placement. In addition to placement of capacitors, FACTS devices and DGs are also placed in the distribution network in recent times to reduce power loss. The location and size of these devices are found using Evolutionary Algorithms [1-3]. In this paper, reconfiguration and placement of UPQC in the reconfigured network reduces the power loss ensuring voltage stability of the distribution system. Optimization algorithms are used for both reconfiguration and optimal sizing and placement of UPQC.

Feeder reconfiguration is a methodology employed in which the topology of the system is altered by changing the status of the switches. There are two kinds of switches namely normally open (N.O) and normally close (N.C). By changing the status of these switches the length of the closed loop or the distance travelled by the current to reach from one end to the other end of the feeder is decreased. This reduces the resistance of the topology, decreasing the power loss. The order of opening and closing these tie line switches is effectively implemented using optimization algorithms.

The branch exchange heuristic method for reconfiguration is proposed in [4]. In [5], optimal power flow method is used to determine the minimum current. Power loss reduction in distribution system is also accomplished by conventional techniques like

quadratic programming [6], network partitioning technique [7], and heuristic non linear constructive method [8]. These conventional methods are found more suitable for medium size systems and are not suitable for large systems. With the evolution of optimization algorithms and evolutionary algorithms, the problem of power loss reduction in the distribution system for large systems is made simpler and easier. Genetic Algorithms [9-12] are used for reconfiguration and power loss reduction. Optimization and Evolutionary algorithms like Non Dominated Sorting Genetic Algorithm (NSGA) [13], genetic algorithm using matroid theory [14], plant growth simulation algorithm [15], Discrete particle swarm optimization algorithm [16], Bacterial Foraging Algorithm [17] and Improved Binary Particle Swarm Optimization Algorithm [18] are employed for power loss reduction in distribution system. Different methods of reconfiguration are discussed [19-24] to reduce power loss in radial distribution system. In [25], an undirected simplified graph of distribution network is obtained by spanning tree algorithm concept for reconfiguration is proposed. An improved genetic algorithm is proposed to improve calculation speed. In [26], the problem of reverse power flow while using Distributed generation in a distribution system is overcome and the malfunction of protective devices are prevented. In [27], a novel algorithm called Sifting algorithm is used for reconfiguration in radial distribution system.

Custom power devices are mainly employed in power systems to improve power quality. The custom power devices used in power systems are Interline Power Flow Conditioner (IPFC), Dynamic Voltage Restorer (DVR) and Unified Power Quality Conditioner (UPQC). In this paper, UPQC is used to reduce power loss in the distribution system by managing the reactive power. But the placement of UPQC in the distribution system plays a vital role in power loss reduction.

This paper investigates the possibilities of placing UPQC for compensating the reactive power in distribution network to improve the efficiency of the network by reducing the power loss. To get better results five cases are analyzed such as

- Case 1: Base case
- Case 2: Placement of UPQC alone
- Case 3: Reconfiguration alone
- Case 4: Placement of UPQC in reconfigured network

Case 5: Reconfiguration after placing UPQC

2 Reconfiguration of Radial Distribution System

Minimize the Power loss in the radial distribution system thereby improving voltage stability of the network. This problem is formulated as a minimization function. The minimization functions formulated are minimization of power loss and minimization of voltage deviation and is mathematically expressed as [28]

$$\min f1 = \sum_{l=1}^m P_L^1 + jQ_l^1 \quad (1)$$

$$\min f2 = \sum_{i=1}^{mb-g} V_{D_i} \quad (2)$$

Where

P_L^1 - Real power in a line l

ml - Number of network branches

mb - Number of network nodes

g - Number of generator nodes in a network

V_{D_i} - Voltage deviation of load bus i

It is given as,

$$V_{D_i} = (1 - V_i)^2 \quad (3)$$

where

V_i - Voltage at bus i

2.1 Real power and bus voltage constraints

Real power limit of distribution feeders for the network should not be exceeded. [28]

$$P_{pq} \leq P_{pq}^{max} \quad (4)$$

where

P_{pq} - Actual Real power flow of the feeder between buses p and

q

P_{pq}^{max} - Maximum thermal limit for the feeder between buses p and q

Voltage magnitude at each bus must lie within their permissible ranges and it is given by,

$$V_b^{max} \leq V_b \leq V_b^{min} \quad (5)$$

where

V_b - Voltage at bus b

V_b^{max} - Maximum voltage at bus b

V_b^{min} - Minimum voltage at bus b

2.2 Radiality constraints

Under this constraint the radial structure of network should not be affected and all the nodes should be energized.

3 Non-Dominated Sorting Genetic Algorithm-II for Reconfiguration

The reconfiguration of the distribution system is done using NSGA II algorithm. The pseudo code of NSGA II for reconfiguration is given below [29]

BEGIN

While generation count is not reached

Begin Loop

Generate a parent population Pt of size N

Generate an offspring population Qt of size N

Combine the population of parent Pt and Offspring Qt

Obtain a population Rt of size 2N

Non dominate sorting is performed on Rt

Assign ranks to each pareto front

Form a new parent population Pt+1 of size N

Apply Selection, crossover and mutation to obtain a new offspring population Qt+1

Increment generation count

END loop

END

Table 1: NSGA-II Parameters

Parameter	Value
Number of population	20
Number of,generation	200
Cross over probability	0.9
Mutation probability	0.2
Crossover index	20
Mutation index	20

The parameters for NSGA-II used in this paper are given in Table 1.

4 Problem Formulation

The Objective function of this work is to minimize the power loss, improve the voltage profile, optimal placing and sizing of the UPQC as well as to optimize the investment cost for the UPQC. [30]

$$\min f1 = \sum_{l=1}^n P_L^1 + jQ_L^1 \quad (6)$$

$$\min f2 = \sum_{i=1}^{n-g} V_{D_i} \quad (7)$$

where

P_L^1 - Real power in a line l

V_{D_i} - Voltage deviation of load bus i, which is given by,

$$V_{D_i} = (1 - V_i)^2 \quad (8)$$

where

V_i - Voltage at bus i

$$\min f3 = Cost_{UPQC} \quad (9)$$

$$Cost_{UPQC} = 0.003S^2 - 0.2691S + 188.22 \quad (10)$$

where

S is the difference between the reactive power flow after placing UPQC and reactive power flow before placing UPQC.

4.1 Line current and bus voltage constraints

Bus voltage and line current is having some limitation that is formulated as mathematical formula and is given below.

$$OC = 1 \text{ if } I_j \leq I_{jmax} \quad (11)$$

$$OC = e^{\lambda|1-\frac{I_j}{I_{jmax}}|} \text{ otherwise} \quad (12)$$

where

I_j - Actual current flow in line j

I_{jmax} - Maximum current flow limit for line j

$$OV = 1 \text{ if } 0.9 \leq V_j \leq 1.1 \quad (13)$$

$$OV = e^{\mu|1-V_j|} \text{ otherwise} \quad (14)$$

V_j - Voltage at bus j

4.2 UPQC Ratings Constraint

$$0 \leq Q_{UPQC} \leq 1000kVar \quad (15)$$

5 Optimization Algorithms for Placing UPQC

The load flow of the radial distribution system is obtained using Forward/backward sweep load flow algorithm [31]. UPQC is a custom power device which is mainly used for reactive power management. In this paper, the objective of sizing and placing UPQC is to reduce real power loss in the distribution system. The main assumption considered here in this problem is No active power is exchanged between UPQC and the distribution system.

5.1 Particle Swarm Optimization (PSO)

Particle swarm optimization algorithm is an evolutionary algorithm that resembles the schooling behavior of fishes or flocking behavior of birds. In this a population of particles is generated and each particle move towards the global best by getting information from the neighboring particles. The position of the particles and its velocity changes from time to time. Particles with minimum fitness are able to survive and move towards the optimum global best solution. [32]

Velocity of each particle can be modified by the following equation

$$V_i^{k+1} = w * V + C_1 * rand_1 * (P_{best_i} - S_i^k) + c_2 * rand_2 * (G_{best_i} - S_i^k) \quad (14)$$

where

V_i^{k+1} - Velocity of particle i at iterations

W - Weight function which is given by,

$$w = w_{max} - \frac{w_{max} - w_{min}}{iter_{max}} * iter \quad (15)$$

W_{max} - Initial inertia weight

W_{min} - Final inertia weight

$iter_{max}$ - Maximum iteration number

$iter$ - Current iteration number

C_1, C_2 - Weight coefficient

$rand_1, rand_2$ - Random number between 0 and 5

S_i^k - Current position of particle i at iteration k

P_{best_i} - Best position of particle i upto current iteration

G_{best_i} - Best overall position found by the particle upto current iteration

Now the new position can be obtained using,

$$S_i^{k+1} = S_i^k + V_i^{k+1} \quad (16)$$

The parameters of PSO used in this paper are given in Table 2.

Table 2: PSO Parameters

Parameter	Value
No. of particles	30
No. of iterations	100
C1	1
C2	3
Initial inertia weight	0.9
Final inertia weight	0.8

5.2 Bacterial Foraging Optimization Algorithm (BFOA)

The bacterial foraging algorithm is based on the foraging behavior of *E. coli* bacteria. It is based on the concept of survival of the fittest. The strategy behind this algorithm is bacteria with good foraging capability only exists and with poor foraging capability perishes [31]. The steps that are carried out in identifying the optimal solution is given below:

Chemotaxis: All the bacteria in the population are capable of moving and on its way towards the food it avoids noxious substances and its movement is given by

$$\theta^i(j+1, k, l) = \theta^i(j, k, l) + C(i) \frac{\Delta(i)}{\sqrt{\Delta^T(i) \cdot \Delta(i)}} \quad (17)$$

where,

$\theta^i(j, k, l)$ - i^{th} bacterium at j^{th} chemotactic, k^{th} reproductive, and l^{st} elimination-dispersal step

C (i) - Size of the unit step taken in the random direction

Δ (i) - Random vector

Swarming: In this step the bacteria moving towards the nutrient releases a substance aspartate. Cell to cell signaling is done on its movement towards the food. Some cells will readily attract and some will repel. In this manner concentric patterns of swarm with high bacterial density are formed. Some bacteria swim towards the nutrient rich area and some tumble across while moving. The path of the bacteria moving towards the nutrient rich area is given by,

$$J_{cc}(\theta(i, j, k, l)) = \sum_{i=1}^s J_{cc}(\theta, \theta^i(i, j, k, l)) = \sum_{i=1}^s [-d_{attractant} \exp(-w_{attractant} \sum_{m=1}^p (\theta_m - \theta_m^i) \sum_{i=1}^s [-h_{repellant} \exp(-w_{repellant} \sum_{m=1}^p (\theta_m - \theta_m^i)^2)])] \quad (18)$$

Where

$J_{cc}(\theta, \theta^i(i, j, k, l))$ - The objective function value to be added to the actual objective function

S - Total number of bacteria in the population

P - Number of variables to be optimized,

$\theta = [\theta_1, \theta_2, \dots, \theta_p]^T$ is a point in the p-dimensional search domain.

$d_{attractant}, w_{attractant}, h_{repellant}, w_{repellant}$ are various coefficients

Reproduction: The health of i_{th} bacterium is calculated using equation (19).

$$J_{health}^i = \sum_{j=1}^{N_c+1} J^i(j, k, l) \quad (19)$$

The least healthy bacteria are eliminated and each of the healthier bacteria split up into two, which are then occupies the same position and thus the population remains constant.

Elimination and dispersal: In this step some bacteria get eliminated and dispersed with small probability P_{ed} after N_{re} number of reproductive events in order to ensure that the bacteria do not get fascinated into a local optimum instead of the global optima. The parameters of BFOA are given in Table 3.

Table 3: BFOA Parameters

Parameter	Value
No. of Bacteria	30
No. of steps, N	3
No. of chemotactic steps, Nc	30
No. of reproduction steps, Nr	3
No. of elimination and dispersal steps, Ned	2
Dispersal probability	0.25

5.3 Harmony Search Algorithm (HSA)

Harmony search algorithm find the optimal solution of the problem by finding the best harmony among various components in orchestra music. In orchestra music instruments are played by the musicians based on their experience and random improvisation process. HSA is used for both continuous and discontinuous functions. [30]

The parameters used in Harmony Search Algorithm are given in Table 4.

Table 4: HSA Parameters

Parameter	Value
Harmony Memory Size	500
Harmony Memory Considering Rate (HMCR)	0.9
Pitch Adjustment Rate (PAR)	0.9
Band width	0.2
Number of Improvisation	1000

6 Results and Discussion

The performances of proposed methods are tested on IEEE 33 bus radial distribution system using MATLAB. The single line diagram of test system is shown in Figure 1. The test system consists of 33 buses, 32 sectionalizing switches and 5 tie line switches. In this network, sectionalizing switches which are normally closed are numbered from 1 to 32 and tie-switches which are normally opened are numbered from 33 to 37. Simulation is carried by considering four cases.

6.1 Case: 1 Base case

In this paper, forward and Backward Sweep Algorithm is used for load flow analysis since it is reliable and gives accurate results for distribution system [29]. The load flow is performed on test system without connecting tie line switches and without any UPQC. From the load flow results, the total real power loss obtained is 210.0594 kW.

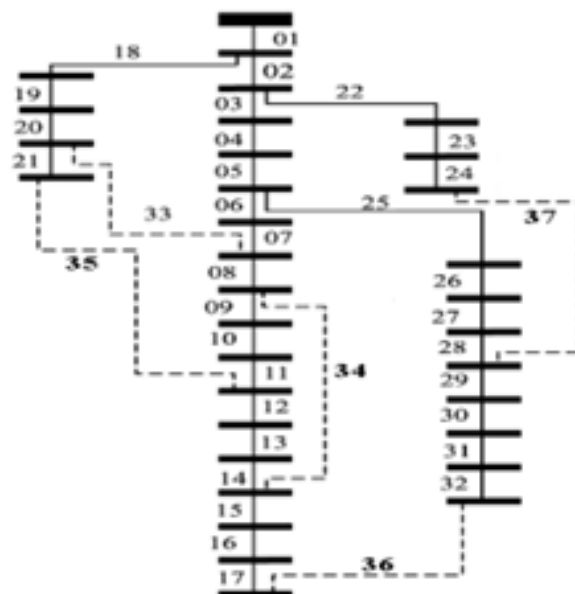


Fig. 1. Single line diagram of IEEE 33 bus radial distribution system

6.2 Case: 2 Placement of UPQC alone

In this case, the BFOA, HSA and PSO algorithms are used to place the custom power device UPQC in the test system without reconfiguration. The optimal location and ratings of UPQC are optimized simultaneously by the BFOA, HSA and PSO algorithms. Cost of the UPQC and the power loss are also calculated. Among all the algorithms BFOA gives the minimized power loss as shown in Table 5. The power loss obtained using BFOA is 146.03 kW. The cost of UPQC is also optimized and reduced using BFOA when compared to other two algorithms and is given as 16739.61 \$/kVAR.

6.3 Case 3: Reconfiguration alone

In this case, Non-dominated Sorting Genetic Algorithm (NSGA-II) is used to reconfigure the test system. The NSGA-II results shows that switches 7, 8, 12, 15, 23 are to be in open condition to minimize the loss to 154.93kW.

Table 5 Location, Rating & Effect of UPQC in IEEE 33 bus radial distribution system Before Reconfiguration

<u>S</u> <u>N</u> <u>o</u>	Algorithm	Location	<u>Rating</u> <u>kVAR</u>		Real power loss (kW)	Reactive power loss (kVar)	Cost of UPQC \$/kVar
			Shunt	Series			
1	PSO	28	726.092	4.6783	155.94	138.4963	17645.15
2	HSA	29	928.426	3.5147	148.88	122.9014	16899.34
3	BFOA	28	911.332	4.0613	146.03	119.9800	16739.61

6.4 Case 4: Placement of UPQC in reconfigured network

In this case, PSO, HSA, BFOA algorithms are used to find the optimal location and rating of the UPQC in the reconfigured network which is obtained in case 3 i.e. Network with switches 7, 8, 12, 15, 23 opened. (Normally 33, 34, 35, 36, 37 are in open condition). In this case also, BFOA provides the better performance in the power loss minimization and minimized cost evaluation of UPQC which is shown in the table 6.

Table 6 Location, Rating & Effect of UPQC in Reconfigured IEEE 33 Bus Radial Distribution Systems

<u>S</u> <u>N</u> <u>o</u>	Switches Opened	Algori thm	Lo cati on	<u>Rating</u> <u>kVAr</u>		Real power loss (kW)	Reacti ve power loss (kVA R)	Cost of UPQC \$/kVAr
				Shunt	Series			
1	[7 8 12 15 23]	PSO	20	863.1158	2.5984	129.03	126.08	18365.76
2		HSA	12	834.6347	3.4366	120.60	123.32	18161.08
3		BFOA	18	866.3533	3.7764	113.22	120.54	18009.28

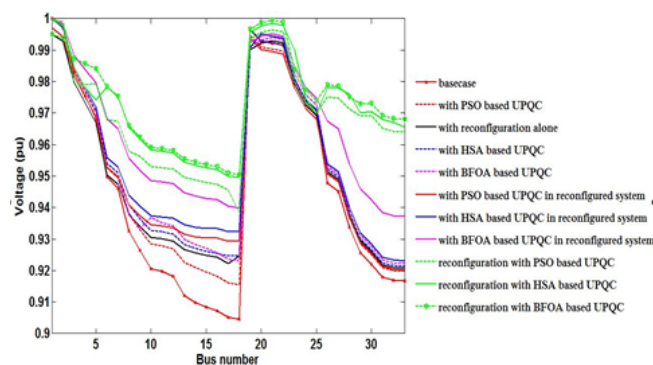
6.5 Case 5: Reconfiguration after placing UPQC

The reconfiguration is done using NSGA-II after placing UPQC in optimal location with optimal rating which is obtained in case 2 using PSO, HSA and BFOA. The results obtained are shown in table 7. From that, it is inferred that by having BFOA based UPQC, the switches 7, 14, 11, 15 and 28 are to be in open condition so that the loss value will be minimized to 99.81 kW. The graph showing the

voltage profile for all the five cases and with different algorithms is shown in Figure 2. This graph witnessed that, the better voltage profile is obtained by performing reconfiguration after placing UPQC by BFOA.

Table 7 Reconfiguration Results after Placement Of UPQC Using NSGA-II

S. No	Case	Switches Opened	Real power loss (kW)	Reactive power loss (kVAR)
1	Without UPQC	[7 8 12 15 23]	154.93	140.9033
2	PSO based UPQC	[7 12 14 17 28]	108.43	111.0831
3	HSA based UPQC	[8 10 17 15 28]	105.11	102.5516
4	BFOA based UPQC	[7 14 11 15 28]	99.81	100.8540



7 Conclusion

In this paper, an optimization method to reconfigure the distributed system with the optimized placement of custom power device UPQC is proposed. A Non-dominated Sorting Genetic Algorithm (NSGA-II) is used for feeder reconfiguration considering voltage, power loss, and radial condition constraints. Bacterial Foraging Optimization Algorithm, Harmony search algorithm and Particle swarm optimization algorithms are used for the placement, sizing and to optimize the investment cost of the UPQC. These algorithms are applied and tested in IEEE 33 standard bus system. Five different

cases are considered such as Case: 1 Base case, Case: 2 Placement of UPQC alone Case 3: Reconfiguration alone, Case 4: Placement of UPQC in reconfigured network. Case 5: Reconfiguration after placing UPQC. Test results have shown that of all the five cases better real power loss reduction is achieved in case 5 with minimum investment cost of UPQC. This shows that first UPQC size, placement and investment cost are optimized using these algorithms and then reconfiguration is done using NSGA II. In case 5, when comparing with algorithms BFOA based UPQC, i.e., size, placement and investment cost optimized by BFOA with reconfiguration using NSGA II gives better real power loss reduction.

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