International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 13 (2017) pp. 3708-3713

Optimal Placement of Unified Power Quality Conditioner using Ant Lion Optimization Method

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Abstract

This paper acquaints us with the problem of Unified Power Quality Conditioner (UPQC) placement in radial distribution systems. The objective of UPQC placement is to reduce the real power losses and improve the voltage profile. The problem is formulated as a nonlinear single objective problem. The voltage compensation is done by injecting active and reactive power with the aid of series compensator of UPQC. The shunt compensator provides the required load reactive power along with the series compensator. The optimal placement of UPQC is unraveled using the latest optimization method known as Ant Lion Optimization (ALO) method. The proposed method is tested using standard distribution systems.

Keywords: Ant Lion Optimization; distribution systems; reactive power compensation; Unified Power Quality Conditioner.

INTRODUCTION

The introduction of computer controlled devices in the distribution system has deteriorated the quality of power supply. The integration of renewable energy sources in the form of Distributed generation units at the customer end has worsened the problem of power quality. The existing power quality improving equipments are not reliable to tackle multiple issues. Hence it is necessary to develop devices which can handle multiple issues of power quality. This requirement has led to the integration of series and shunt compensating devices. UPQC [1]-[3] is one such device which can solve current and voltage related problems simultaneously. UPQC is a versatile device. There are different classifications of UPQC based on the structure, supply, etc. Based on voltage compensation capability, the types of available UPQC's are UPQC-P, UPQC-Q and UPQC-S**.**

In UPQC-P, the series part of UPQC injects active power. The rating of the DVR is low as it requires minimum voltage injection by the series compensator. The shunt compensator, DSTATCOM, is used for all current-based compensation with unity power factor at the load end.

In UPQC-Q, the series compensator of the UPQC injects only reactive power. The shunt compensator is connected across the consumer's load end as the right shunt UPQC and is used for all current-based compensation at the load end.

In UPQC-S, the series compensator of the UPQC injects real and reactive power with the minimum VA rating. The shunt compensator is used for all current-based compensation. In UPQC-S both the compensators are utilized for reactive power compensation. The concept of optimum operation of UPQC is evidently visible in case of UPQC-S. The digital signal processor-based experimental study [4] based on optimal utilization of UPQC is proposed by Khadkikar et.al. The direction of research for UPQC placement in a large distribution system utilizing the concept of optimal utilization of both the series and shunt compensators is evident in [5]-[8].

S. A. Taher et.al [5] has detailed the problem of UPQC allocation in the distribution system with the differential evolution algorithm. M. Boutebel et.al [6] has solved the UPQC placement problem by using Particle Swarm Optimization based Hybrid Differential Evolution (PSO-HDE) method. S. Ganguly et.al [7] has adopted Particle Swarm Optimization (PSO) method for solving UPQC placement problem. UPQC is modeled in the load flow method [8] and the bus which is having minimum power loss is adopted for UPQC placement. The disadvantage with this method is for large distribution system finding the loss at each and every bus is time consuming. Hence, in this paper a new optimization method known as Ant Lion Optimization method is implemented to solve the UPQC placement problem. The voltage injected by the series compensator and the reactive power injected by the shunt compensator is incorporated in the load flow method. The losses in the radial distribution system and voltages are found by using the load flow method described. UPQC model realized in the load flow method is presented. A brief description of ALO algorithm and its implementation to find the optimal location and rating of UPQC is given. The conclusion from the results are presented.

LOAD FLOW METHOD

Load flow is a significant tool to evaluate the performance of the system parameters well in advance. The Newton Raphson method is the most powerful load flow method. But the computational complexity is inevitable. The other methods available in the distribution system are identifying the nodes beyond branches [9], formation of bus-injection to branch-current (BIBC) and branch-current to bus-voltage (BCBV) matrices [10]. The load flow steps involved are finding the load currents, development of BIBC matrix and Forward sweep.

Finding the load currents: Consider real and reactive load on the radial distribution system as P_L and Q_L, voltage at the load bus as V. The load current I_L at the m^th bus is calculated as given in equation (1)

$$I_L(m) = \left(\frac{P_L(m)+jQ_L(m)}{V(m)}\right)^* \quad (1)$$

Development of BIBC matrix: This step involves building BIBC matrix. The matrix dimension is [n x n]. Here n is the number of branches. The element in the matrix is one if there exists a path from the source to the load else the element is zero. BIBC matrix relates the load current with the branch current. The related equation is given in equation (2)

$$[I_b] = [BIBC]\,[I_L] \quad (2)$$

Forward sweep: This step involves finding the voltage drop across the i^th branch and the new node voltages. The related equations are given by equation (3) and (4)

$$\Delta V(i) = I_b(i).\ Z_b(i) \quad (3)$$

$$V_L(i) = V_s(i) - I_b(i).Z_b(i) \quad (4)$$

The difference between the new and old voltages is calculated. If the error is less than tolerance, then the load flow steps is repeated else the load flow is said to be converged.

The real and reactive power losses for n number of branches with branch resistance R_b and branch reactance X_b in a distribution system are given by (5) and (6) respectively.

$$P_{Loss} = \sum_{i=1:n} I_b(i)^2 * R_b(i) \quad (5)$$

$$Q_{Loss} = \sum_{i=1:n} I_b(i)^2 * X_b(i) \quad (6)$$

UPQC

The UPQC mainly includes a series and a shunt compensator connected back to back by a DC link capacitor. Series compensator connects grid-side with series transformer. Shunt compensator connects load-side with inductance. Series compensator solves grid-side voltage quality problems, including voltage sags, swells, interruptions, and imbalance and so on. Shunt compensator solves load reactive power compensation, current harmonics, and imbalance and so on. The conceptual structure of UPQC is shown in Fig 1.

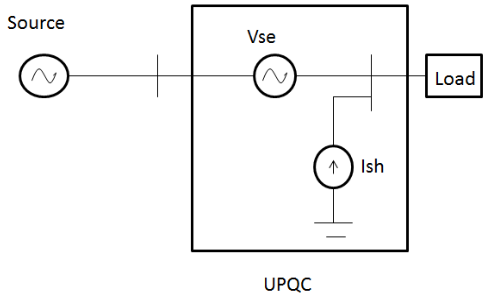

Figure 1: UPQC structure

A. Modeling of UPQC

The voltage compensation can be done by using active power as well as reactive power. Here the series compensator is modeled as a voltage source injecting active as well as reactive power and shunt compensator is modeled as the source of reactive power.

The series compensator injects voltage in series with the line nearer to the receiving end bus and the shunt compensator provides reactive power.

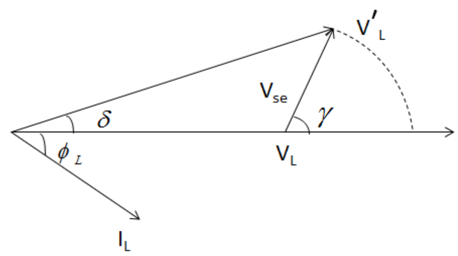

Figure 2: Phasor diagram for series voltage injection

The new load bus voltage V_L' obtained after adding the voltage V_{se} injected by the series compensator at the load bus V_L is calculated as given in equation (7)

$$V_L' \angle \delta = V_L + V_{se} \angle \gamma \quad (7)$$

The complex power injected by the series compensator is obtained as follows:

$$S_{se} = V_{se}.I_b^* \quad (8)$$

Calculate the shunt compensating current I_c' [11]. The reactive power injected by the shunt compensating device is given by equation (9)

$$Q_{sh} = V_L' I_c' \quad (9)$$

ANT LION OPTIMIZATION METHOD

The ALO algorithm [12] is motivated from the hunting performance of antlions. The main phases of hunting include random walk of ants, building traps, entrapment of ants in traps, catching preys, and re-building traps.

i. Random walks:

This phase models the ants' movement. The movement of ants' in nature is selected as a random walk since their search for food is stochastic in nature.

ii. Trapping in antlions pits:

This phase models the effect of antlions traps on random walks of ants.

iii. Building trap:

In order to model the antlion hunting capability, a roulette wheel is employed. The ALO algorithm is obligated to develop a roulette wheel operator for choosing antlions based on their fitness during optimization. This method offers a higher probability to the fitter antlions for grasping ants.

iv. Sliding ants towards antlions:

Antlion shoots sand outwards the center of the pit so that the ant slips in the trap and does not escape the trap.

v. Catching prey and re-building the pit:

An antlion improves its chance of catching new prey by updating its position to the newest position of the hunted ant.

vi. Elitism:

Elitism is an important characteristic which allows maintaining the best solution obtained at any stage of the optimization process. The best antlion achieved in each of the iteration is saved and considered as elite.

A. Algorithm to find the optimal location and rating of UPQC in radial distribution system

Step 1: Initialization of the antlions and ants: Generate the positions of antlions and ants randomly. The positions of antlions and ants are locations and real and imaginary part of the voltage injected by the series compensator.

Step 2: Fitness Evaluation: By compensating the voltage at the corresponding location by using equation (7) and reactive power by using equation (9), run the load flow. Find the fitness values. Here the fitness function is defined by equation (5). Discard the antlions which violate the constraint which states that the voltage at the desired location should not exceed 1 p.u. Sort the antlions fitness and the best antlion is assumed as the elite.

Step 3: Set the iteration count to 2.

Step 4: Sliding ants towards antlions phase: Choose an antlion with the help of the Roulette wheel. Consider w as a constant based on the current iteration, t as the current iteration number, T as the maximum number of iterations, the ratio I is given by equation (12). c, d define the random walks of ants in a hyper-sphere around the selected antlion. Update c and d using equation (10) and (11)

$$c^t = \frac{c}{I} \tag{10}$$

$$d^t = \frac{d}{I} \tag{11}$$

$$I = 10^w \frac{t}{T} \tag{12}$$

Step 5: Random walks phase: Consider the movement of ants as a stochastic function r(t), a_i and b_i as the minimum and maximum of random walk for the i[th] variable , c_i^t and d_i^t as the minimum and maximum of i[th] variable for t[th] iteration. Create random walks using equation (14) and normalize the random walks using the equation (15)

$$\left.\begin{array}{l} r(t) = 1\ if\ random > 0.5 \\ r(t) = 0\ if\ random < 0.5 \end{array}\right\} \tag{13}$$

$$X(t) = [0, cumsum(2r(t_1) - 1), cumsum(2r(t_2) - 1, .. cumsum(2r(t_T) - 1] \tag{14}$$

$$X_i^t = \frac{(X_i^t - a_i) * (d_i - c_i^t)}{b_i^t - a_i} + c_i \tag{15}$$

Step 6: Consider R_A^t as the random walk around the antlion selected by the roulette wheel, R_E^t as the random walk around the elite. Update the position of i[th] ant for t[th] iteration using equation (16)

$$Ant_i^t = \frac{R_A^t + R_E^t}{2} \tag{16}$$

Step 7: Check whether the newly generated ants are within the limits. Run the load flow by compensating the voltage and reactive power at the desired location using equation (7) and equation (9). Find the fitness of ants.

Step 8: Catching prey and re-building the pit:

Update the position of selected j[th] antlion if position of i[th] ant fitness is better than antlion fitness

$$Antlion_j^t = Ant_i^t\ if\ f(Ant_i^t) < f\left(Antlion_j^t\right) \tag{17}$$

Step 9: Update elite if an antlion becomes fitter than the elite.

Step 10: Check for convergence. If the solution does not converge, then repeat the steps from 4 to 9.

Step 11: The elite gives the location and complex voltage. Print the results for real and reactive power injected by the series compensator and reactive power injected by the shunt compensator.

RESULTS

The standard distribution systems used to validate the proposed approach are 33 and 69 bus radial distribution systems.

A. 33 Bus System:

The data of the system is acquired from [13]. The network configuration of the system is shown in Fig. 3.The base voltage is 12.66 kV. The real and reactive load of the system is 3715 kW and 2300 kVAr respectively. It has 33 buses and 32 branches. 21 out of 33 buses of the distribution system have under voltage problem. The results of UPQC installation are detailed in Table I.

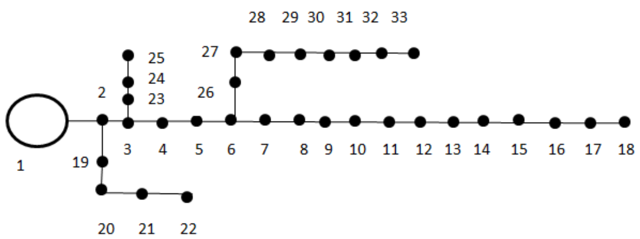

Figure 3: Network configuration of 33 bus system

Table I: Results of 33 bus system

Sr No.	33 Bus system		
	Description	***Without UPQC***	***With UPQC***
1	Location	-	31
2	Total real power loss (kW)	202.6771	123.4237
3	Total reactive power loss (kVAr)	135.141	83.6298
4	Voltage injected (p.u.)	-	0.3080i
5	Injected real power by series compensator (kW)	-	256.39
6	Injected reactive power by series compensator (kVAr)	-	59.241
7	Injected reactive power by shunt compensator (kVAr)	-	954.2685
8	Minimum voltage (p.u.)	0.9131 @bus 18	0.9273 @bus 18
9	Nodes with under voltage problem	21	10

The shunt compensation required after UPQC placement is 954.2685 kVAr. The minimum voltage has increased from 0.9131 p.u. to 0.9273 p.u. at 18th node. The reduction in real power loss is 39.1%.

Comparative results for 33 bus system are presented in Table II. The comparative results indicate that the proposed method has significant reduction of 39.1% in real power losses as compared with Differential Evolution and the method available in [8].

Table II. Comparative Results of 33 bus system

33 Bus system			
Description	***Ref [5]***	***Ref [8]***	***Proposed Method***
Optimal Location	29	30	31
Real Power Loss (kW)	150.1	151.94	123.4237
Minimum voltage (p.u.)	-	0.9177	0.9273
Real power loss reduction (%)	25.84	27.99	39.10

The voltage profile without and with consideration of UPQC is shown in Fig 4.

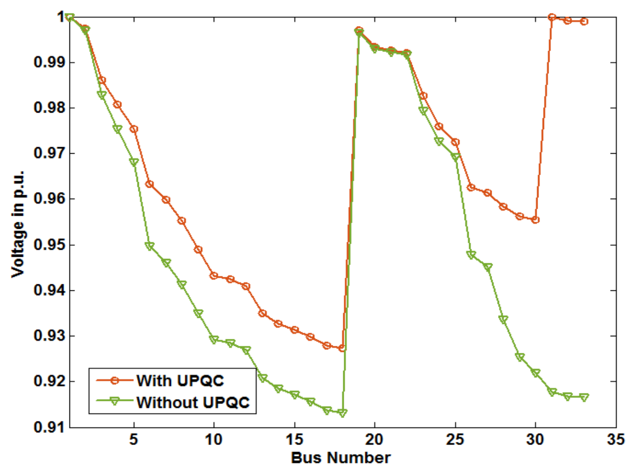

Figure 4: Voltage Profile for 33 bus system without and with consideration of UPQC

B. 69 Bus System:

The data of the system is obtained from [14]. The network configuration of the system is shown in Fig.5.The base voltage is 12.66 kV. The total load on the system is 3802.19 kW and 2694.6 kVAr. It has 69 buses and 68 branches.

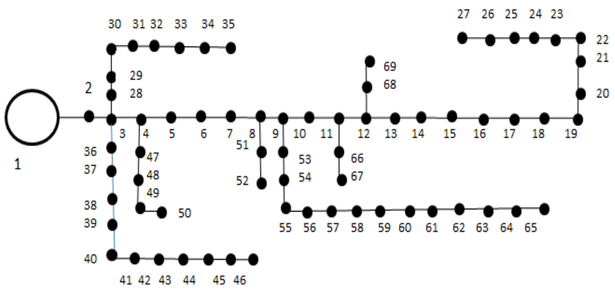

Figure 5: Network configuration of 69 bus system

9 nodes out of 69 nodes of distribution system (13.04%) have under voltage problem. The results of UPQC installation for 69 bus radial distribution system are detailed in Table III.

The voltage profile without and with consideration of UPQC is shown in Fig 6.

Table III. Results of 69 bus system

Sr No.	69 Bus system		
	Description	***Without UPQC***	***With UPQC***
1	Location	-	62
2	Total real power loss (kW)	225.0044	107.5717
3	Total reactive power loss (kVAr)	102.2057	51.784
4	Voltage injected (p.u.)	-	0.3302i
5	Injected Real power by series compensator (kW)	-	337.94
6	Injected reactive power by series compensator (kVAr)	-	0
7	Injected reactive power by shunt compensator (kVAr)	-	1194.4
8	Minimum voltage (p.u.)	0.9092 @bus 65	0.9448 @ bus 61
9	Nodes with under voltage problem	9	2

The shunt compensation required after UPQC placement is 1194.4 kVAr. The minimum voltage has increased from 0.9092 p.u. at 65th node to 0.9448 p.u. at 61st node. The reduction in real power loss is 52.19%.

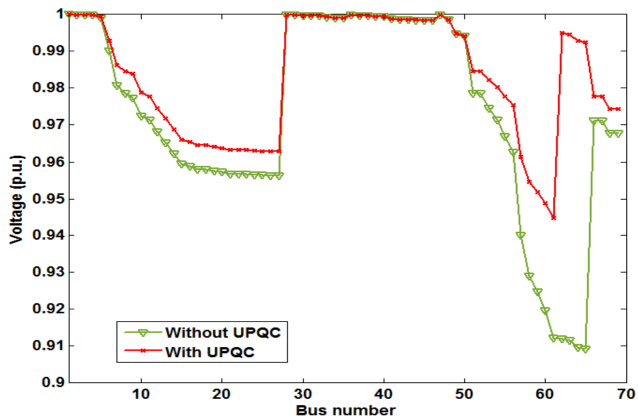

Figure 6: Voltage Profile for 69 bus system without and with consideration of UPQC

The comparative results of 69 bus system are presented in Table IV.

The proposed method is compared with Differential Evolution method, Particle Swarm Optimization method, hybrid method and the method in [8].The proposed method has significant reduction of 52.19% in real power losses.

Table IV. Comparative Results of 69 bus system

69 Bus system					
Description	***Ref [5]***	***Ref [6]***	***Ref [8]***	***Ref [7]***	***Proposed method***
Optimal Location	62	57-58	61	61	62
Real Power Loss (kW)	155.1	163.13	153.96	137	107.57
Minimum voltage (p.u.)	-	-	0.9275	0.941	0.9448
Real power loss reduction (%)	31.06	27.5	31.6	39.10	52.19

CONCLUSION

The optimal location and rating for the Unified Power Quality Conditioner are determined using Ant Lion Optimization. The salient outcomes are: The series compensator takes part in reactive power compensation by injecting the voltage at the receiving end of the bus in the steady state. Results indicate that there is a significant reduction in power losses and substantial improvement in voltage profile. The effectiveness of Ant Lion Optimization method is validated using standard radial distribution systems.

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