



# A new method based on fuzzy system and gravitational optimal detector for capacitor placement, considering nonlinear loads

Hossein Dehghan Dehnavi<sup>1</sup>, Yaghoub Azizi<sup>2</sup>, Mohammad shafiyi<sup>3</sup>

<sup>1</sup>Department of Electrical Engineering, Shahid Beheshti University, Tehran, Iran, Email:y.azizi@aut.ac.ir

## Abstract

This paper describes an advantageous method for using the capacitor banks in the distribution network, optimally. The aim is to determine the count, location and capacitor values in order to minimize the annual cost resulting from energy losses and capacitor bank's installation cost. Besides, in the case of having nonlinear loads in the network, by installing capacitors in appropriate locations, the possibility of occurring a resonance at harmonic frequencies originating from nonlinear loads, could be reduced. Therefore, in capacitor placement, power quality constraints, including the maximum harmonic deviation value, are taken into account. The case study is a nonlinear problem that a new algorithm based on the gravitational optimal detector and fuzzy system has been used to solve it. In comparison with other intelligent search methods, the proposed algorithm has appropriate precision and convergence rate. The proposed method has been performed on a 69-buss network and a part of the distribution network of city YAZD, and the results confirmed the performance and efficiency of the proposed algorithm.

*Keywords:* Gravitational Optimal Detector; Fuzzy System; Capacitor Placement; Power Loss; Harmonic Distortion

© 2014 IAUCTB-IJSEE Science. All rights reserved

## 1. Introduction

For the time being, in the design of power networks, the distribution is of much importance. The optimization in distribution networks may be studied aiming at minimizing the losses [1], reducing the voltage deviation in the consumer feeding point (improving the voltage profile) [2], or increasing the network reliability [3]. Among the aforementioned goals, energy losses in the power network waste a great deal of electrical energy, annually; this way, it imposes enormous costs to the power companies. A large share of the power network losses, comes from the losses in the distribution.

Most important reasons for distribution network losses are: 1) Low-level voltage which necessitates a large electrical current, 2) Passing reactive power through the feeders, 3) Radial structure of the network, 4) Imbalance of the current of the feeders,

5) Harminc pollution, 6) Equipment exhaustion, 7) Illegal branches. Different ways have been developed to reduce losses in the distribution networks, including capacitor placement [4, 5], using distributed generation resources [6], transformers load management [7] and reconfiguration of the network [8]. Increasing use of nonlinear loads such as power electronics equipment, Houseware and electro magnetic equipment, caused the injection of a huge amount of harmonic current into the network. Harmonics occurrence in power networks is the first consequence of the nonlinear loads.

The harmonic issues have been very popular to researchers and their studies have released many standpoints regarding power quality. Some researchers believe that harmonic distortion is the most important problem of power quality [10]. Harmonic issues contradict most of the general power system design rules and its performance under

the main frequency. Therefore, designer encounters phenomena to which he/she is not familiar with and needs complicated and professional equipment to cope with them [11].

Fortunately, in the recent years, researchers recognized that harmonic problems would be reduced if the distribution network has been appropriately designed. For example, appropriate capacitor bank placement can effectively reduce the networks harmonics [9]. Since, the impedance of shunt capacitors depends on the different frequencies (harmonic frequencies) of the network, inappropriate capacitor value and location, increases the possibility of creation of resonance circuits and consequently amplifying harmonic current and voltage [12].

In [13, 14], this problem was formulated as a nonlinear program taking the value and location of these capacitors into account. In [15], capacitor values were assumed as discrete variables and dynamic programming has been used to optimally solve the problem. In order to find the capacitor's optimal location, sensitivity-based methods were introduced in [16, 17]. In [18], a method based on the Birds Algorithm has been used to determine the optimal location and value of capacitors.

In [19, 20], a GA-based method was introduced. In [21] and [22], Bee algorithm and Evolutionary algorithms were used, respectively, to attribute the optimal location and value of capacitors. Although, harmonic issues in the capacitor placement, were not taken into account in most of the developed methods, but some of them have studied both important harmonic issues, simultaneously [12, 23].

In this paper, the problem of determining the count, location and value of capacitors, has been modeled so as to minimize the annual cost resulting from energy losses and capacitor banks installation. Then, in order to avoid the harmonic difficulties, optimization was performed with the constraints of harmonics, taken into account. Since the presented optimization problem has a nonlinear and discontinuous nature, the Gravitational algorithm was used. To avoid the local minima, Fuzzy system was used in order to determine the control parameters of the Gravitational algorithm. The combined algorithm resulting from Gravitational method and Fuzzy systems, which is called Fuzzy Gravitational, has been introduced for the first time, in this paper. It was applied to the standard 69-buss networks and a part of the distribution network of the city YAZD.

The rest of the paper is organized as follows. Section 2 presents the mathematics of the problem, determining the objective function and problem constraints. Section 3 discusses the intelligent algorithms used in this paper, such that the

Gravitational search algorithm, Elitist Gravitational search algorithm and then the fuzzy system would have been studied. In Section 4 we apply the proposed algorithm to the case studies and discuss the results. We conclude the paper in Section 5.

### 1. Mathematical Background

In order to solve the problem of determining the optimal count, value and location of capacitors, it should be modeled as mathematical equations. This way, optimization could be performed using intelligent algorithms. Therefore, the problem objective function is mathematically formulated.

#### A. Objective Function

Objective function consists of the minimum cost of active power losses and investment cost for capacitor placement. To simplify the calculations, the costs of the losses and capacitor installation, expressed in the form of a general cost function as shown in equation (1).

$$Fit = K_p(Ploss) + \sum_{i=1}^{n_c} K_{ci}Q_{ci} \tag{1}$$

In equation (1),  $K_p$  is the coefficient of the power cost, bought from the distribution network, which is assumed 168 dollars per kilowatt [24].

$K_{ci}$  is the annual cost of injection a reactive power,  $Q_{ci}$  is the value of reactive power injected into the  $i$ th buss and  $n_c$  is the number of capacitors, used in the network. Table 1, presents the standard and commercial values of capacitors alongside their costs. The active power losses could be measured using equation (2).

Table.1.  
Standard Capacitor Values with Corresponding Costs

$Q_c$ (kVAr)	150	300	450	600	750
$K_c$ (\$/kVAr)	0.5	0.35	0.253	0.22	0.276
$Q_c$ (kVAr)	900	1050	1200	1350	1500
$K_c$ (\$/kVAr)	0.183	0.228	0.17	0.207	0.201

$$Ploss = Ploss_i + \sum_{h=h_o}^{h_{mm}} Ploss_h \tag{2}$$

In equation (2),  $Ploss_i$  is the loss in the main frequency and  $Ploss_h$  is the loss in harmonic frequencies.

**Problem Constraints:**

In real problems, there exist constraints that affect the parameters. These constraints include, voltage value, harmonic deviations, and capacitor installation constraints.

**1) Buss Voltage Constraint:**

During the optimization process, the voltage of busses should be in permitted range.

$$V_{min} \leq |V_i| \leq V_{max} \quad (3)$$

$$V_i = \sqrt{|V_i^{(1)}|^2 + \sum_{h=h_0}^{h_{max}} |V_i^{(h)}|^2} \quad (4)$$

**2) Harmonic Deviation Constraint:**

In order to improve the power quality, it is necessary to minimize the harmonics. The index by which network harmonics can be calculated, is called TDH and is represented in equation (5).

$$THD_V = \left( \sqrt{\sum_{k \neq 1} (V_i^k)^2 / V_i^1} \right) \times 100 \quad (5)$$

Regarding the standard IEEE-519, the maximum TDH acceptable value is %5.

**3) Capacitor Installation Constraints:**

The capacitors cannot have arbitrary values; their values should be integer multiples of base values. In addition, the overall reactive power generated by the installed capacitors, should be less than the network's overall reactive power.

$$\sum_{i=1}^{n_c} Q_{ci} \leq Q_T \quad (6)$$

In equation (6), QT is the total reactive power generated by the network.

**2. Intelligent Algorithm to Solve the Problem**

Evolutionary algorithms solve many optimization problems [25]. Some algorithms result in a better solution in some problems. Hence, evolutionary algorithms are still popular for researchers [26]. Rashedi and NezamAbadi [2007] proposed an optimization method called Gravitational Search Algorithm (GSA), based on the Gravitational Force [27, 28].

**A. Gravitational Search Algorithm:**

In this section, an optimal detector algorithm based on the law of gravity is introduced [28]. In this algorithm, agents are assumed as objects and their

performance are measured by their weights. All of these objects attract each other using the gravity force. This force causes a global motion of all the objects toward the larger ones. All the objects, directly exchange the data, using the gravity force. Large objects correspond to the desired solutions. Heavy objects have slower velocities rather than light ones, which guarantee the efficiency of the algorithm.

**1) Law of Motion:**

The system is supposed as a set of "n" objects and the location of these objects is a point of the search space that is the solution to be obtained. The location of the i<sup>th</sup> object is calculated using equation (7).

$$V_i = (X_i^1, \dots, X_i^d, \dots, X_i^n) \text{ for } i = 1, 2, \dots, N \quad (7)$$

The location of the dimension "d" of the i<sup>th</sup> object is represented by  $X_i^d$ . At the time "t", the force originated from object "j" and affected the object "i" is calculated using equation (8).

$$F_{ij}^d = G(t) \frac{M_{aj}(t) \times M_{pi}(t)}{R_{ij}(t) + 4} (X_j^d(t) - X_i^d(t)) \quad (8)$$

In Gravitational Search Algorithm, every object has four characteristics; location, inertial weight, active gravitational weight and inactive gravitational weight. The object's location is a point in the search space which is a solution of the problem. The weight of gravitational and inertial objects is determined based on their fitness. In other words, every object is a representation of a solution and the algorithm is conducted by tuning the gravitational and inertial weight parameters. As the algorithm works, all the objects are expected to be attracted by the heavier object. This object represents the optimal solution in the search space.

**2) Law of gravity:**

Parameter "Maj" is the active gravitational weight corresponding to the j<sup>th</sup> object and Mpi is the inactive gravitational weight corresponding to the i<sup>th</sup> object. Parameter "G(t)" is the gravity constant at a time "t" and Rij is the Euclidian distance (norm 2) between i<sup>th</sup> and j<sup>th</sup> objects; the parameter "ε" is a very small number.

$$R_{ij}(t) = \|X_i(t), X_j(t)\|^2 \quad (9)$$

To keep the algorithm, random, suppose that the overall force affecting ith object in the jth dimension, equals the sum of random shares of forces, affecting it.

$$f_i^d(t) = \sum_{j=1, j \neq i}^n rand_j \times F_{ij}^d(t) \quad (10)$$

In equation (10),  $rand_j$  is a random number with a uniform distribution in the range [0, 1]. Based on the Newton law of Motion, every object accelerates in the  $j^{th}$  dimension that is proportional to the force affecting it in the  $j^{th}$  dimension and also to the inverse inertial weight. This is represented in equation (11). The acceleration of the  $i^{th}$  object in the  $j^{th}$  dimension at time "t", is represented by  $a_i^d(t)$  and inertial weight of the  $i^{th}$  object is represented by  $m_i$ .

$$a_i^d(t) = f_i^2(t)/M_{i_i}(t) \quad (11)$$

The velocity of any object equals the sum of its current acceleration and a random share of its current velocity. Hence, the object's location and velocity are calculated using equations (12), (13).

$$V_i^d(t+1) = rand_i \times V_i^d(t) + a_i^d(t) \quad (7)$$

$$X_i^d(t+1) = X_i^d(t) + V_i^d(t+1) \quad (8)$$

The parameter  $rand_i$  is the uniform random variable in the range [0, 1]. This random variable causes the search to be random.

### 3) Gravity constant "G":

At the beginning, the gravity constant "G" starts with an initial value and decreases with time. Because of the gravity decrement phenomenon, the actual value of the gravity constant depends on the actual age of the world. The gravity constant is represented in equation (14). Based on equation (14), the gravity constant is a function of the initial value "G<sub>0</sub>" and the time "t", and is represented in equation (15).

$$G(t+1) = G(t_0) \times \left(\frac{t}{t_0}\right)^B \quad (7)$$

$$G(t) = G(G_0, t) \quad (8)$$

The "G" constant is used to control the precision of the search algorithm. The inertial and gravitational weights could be updated using the equation (17).

$$Ma_i = Mp_i = Mi_i = Mi = Z \text{ for } i = 1, 2, \dots, N \quad (7)$$

$$Z(t) = \frac{Fit_i(t) - Worst(t)}{best(t) - Worst(t)} \quad (8)$$

In equation (17),  $fit_i(t)$  is the fitness of the  $i^{th}$  object in time "t". In minimization problems, one may use equations (18), (19) to calculate the best and worst fitness value, respectively.

$$best(t) = \min Fit_i(t) \quad i \in \{1, 2, \dots, N\} \quad (9)$$

$$Worst(t) = \max Fit_j(t) \quad i \in \{1, 2, \dots, N\} \quad (10)$$

In maximization problems, equations (18) and (19) may be used to calculate the worst and best fitness value, respectively.

### Elitist Gravitational Search Algorithm:

In [28], there is an advantageous method introduced to solve the optimization problems. In most the problems, one way to make a compromise between the exploration and exploitation is to decrease the number of agents, with time, according to equation (10). Therefore, only a set of larger objects that affect the other ones would be taken into account. This method should be used very carefully because it may tend to reduce in exploration power and an increase in exploitation ability. In order to avoid from the local optimal traps, after several iterations the exploration should be less used and the exploitation should become more important and used. In order to reach this goal which is to increase the search ability, object selection influence should be used. To do this, only the "K" superior objects of the population, have the capability of affecting the other objects. In other words, in every iteration of the algorithm, any individual object is affected by a force which is the consequence of the forces originated from the individual "K" superior objects. Therefore, the equation (10) is modified as equation (20).

$$f_i^d(t) = \sum_{j \in K_{best}, j \neq i}^n rand_j \times F_{ij}^d(t) \quad (20)$$

In equation (20),  $K_{best}$  is the "K" superior objects of the population that have the best fitness and heavier weight. The " $K_{best}$ " is a function of time which begins with the  $K_0$  as the initial value and decreases with time. This decrement is linear and eventually there is just one agent, affecting the others. The aforementioned method somehow reduces the required mathematics.

### Adaptive Fuzzy Optimal Detector

The inertial and gravitational weights which are two tuneable parameters have great influences on the performance of the Gravitational Search Algorithm.

By taking the equations (21) and (22) into account and adaptive fuzzily tuning the weight coefficient, desirable solution could be achieved.

$$Ma_i = Mp_i, M_{ii} = Mi \text{ for } i = 1, 2, \dots, N \quad (21)$$

$$\left(\frac{2+W}{2.5}\right) M_{ii}(t) = \left(\frac{3-W}{2.5}\right) Ma_i(t) = Z(t) \quad (22)$$

A large weight coefficient increases the algorithm's capability of global search whereas a small weight coefficient tends to a faster convergence. Therefore, it is impossible to find a special weight coefficient that works well in all circumstances. Making the weight coefficient,

adaptive, using a fuzzy technique, is an appropriate way to solve this problem. Based on this method, a fuzzy system is designed to adapt the inputs and outputs. In the membership function used in this paper, input variables are “AF” and “DP” and output variable is “w”. The parameter “AF” is the global variation of the optimal point rather the previous iteration, the parameter “DP” is the population distribution and the parameter “w” is the weight coefficient.

$$AF = (Fit_{best}^k - Fit_{best}^{k-1}) / Fit_{av} \quad (23)$$

$$DP = \frac{var(Fit_i)}{Fit_{av}} \text{ for } i = 1, 2, \dots, N_p \quad (24)$$

$fit_{best}^k$  : The global optimal point value in  $k^{th}$  iteration.

$fit_{best}^{k-1}$  : The global optimal point value in  $k-1^{th}$  iteration.

$fit_{av}$  : The mean fitted value of all points

$fit_i$  : The fitted value of  $i^{th}$  population

$N_p$  : The number of population

In this fuzzy system, the following agents are used: minimal turning, maximal item, cut deducment and center of gravity defuzzifier. The membership functions for inputs and outputs are depicted in figure 1, figure 2 and figure 3. The fuzzy rules are represented in table (2). In figure 1, figure 2 and figure 3, the parameters B, M, G, VB, V2B, VG, V2G and EX stand for bad, medium, good, very bad, very very bad, very good, very very good and excellent linguistic variables.

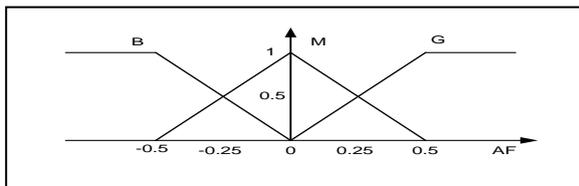


Fig. 1. Membership function for “AF”

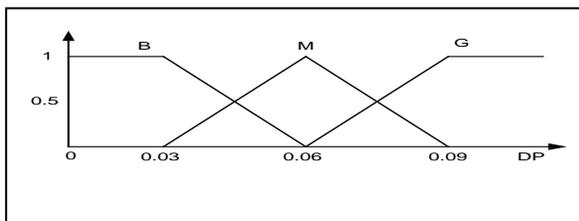


Fig. 2. Membership function for “DP”

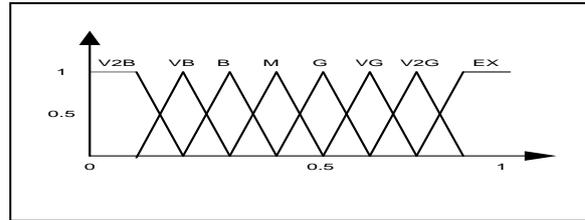


Fig. 3. Membership function for the output

Table.1.  
Fuzzy Rules

		AF		
		G	M	B
DP	G	EX	G	B
	M	V2G	M	VB
	B	VG	VB	V2B

### 3. Simulations and Results:

Based on the aforementioned discussions, one of the best and implementable methods to reduce the loss, harmonics and in better words, to improve the network’s performance, is the capacitor placement. In order to have an optimal use of the capacitors, Fuzzy Theory and the Gravitational Optimal Detector, are used. The latter one is a new search algorithm. Regarding the model used and the objective function defined in (1), simulation was performed for a real network and the results were analysed. In order to show the importance of network harmonics, firstly, the optimizing process was fulfilled without taking this constraint into account and then the process was fulfilled by taking it into account. Overall, the simulations were performed in three following scenarios:

First scenario: no network harmonics, no capacitor placement.

Second scenario: no network harmonics, the capacitor banks mounted.

Third scenario: having network harmonics, the capacitor banks mounted.

To do the simulations, the MATLAB 2011b and the distributed load algorithm introduced in [9] were used. The simulation results in different scenarios for two testbenches and real networks are then discussed. In the gravitational algorithm used, the initial population was 250 and the other parameters were the same those of [27].

#### A. Case Study 1: The 69-buss distribution network

In order to evaluate the proposed algorithm, it has been applied to a 69-buss network. This network has a 12.66kV voltage and an overall load of 3.8MW and 2.694MVar. Its single-line diagram is depicted in figure 4. The other characteristics of this network are available in [29]. In this network three loads of

the network, (13, 25, and 30), are considered as nonlinear loads. The nonlinear load characteristics are provided in table (3).

The buss current disturbances caused by harmonic current in nonlinear load, and the buss voltage disturbance caused by harmonic current in network impedances, may affect the other loads connected to the same buss. Therefore, having some loads polluted, may result in the other loads polluted, too. The simulation results are represented in table 4. Performing the second scenario showed improvement in the overall cost, active loss, reactive loss and network minimum voltage with the values of 34.40%, 35.75%, 35.48% and 2.50%, respectively. In spite of the objective functions' more improvement in this scenario, the index of the maximum harmonic deviations has been almost doubled; and due to the harmonic resonance phenomenon, the number of busses with harmonics more than standard value, has increased from 14 in the first scenario to 39 in the second one. This shows the inappropriateness of the network condition in the sense of harmonic index value.

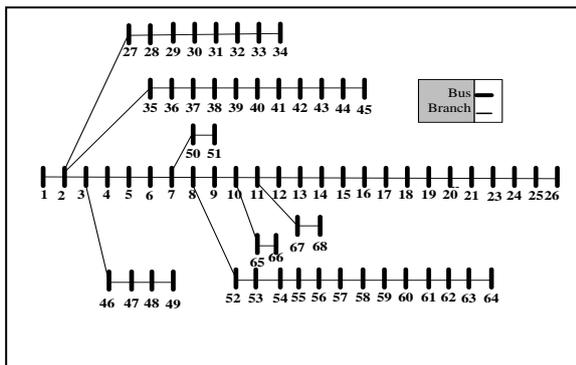


Fig. 4. Single-line diagram of 69-buss distribution network

Regarding the results of the second scenario, it is apparent that network harmonics must be taken into account, while designing the distribution networks. Therefore, in the third scenario the optimization process fulfilled by taking the harmonic deviations into account. The simulation results of the third scenario showed improvement in the overall cost, active loss, reactive loss and network minimum voltage with the values of 34.22%, 35.78%, 35.55% and 2.21%, respectively. The third scenario in comparison with the second one, has increased the overall cost function by 0.53%, but the most harmonic deviation has a vast decrement and the number of harmonically troubled busses has decreased from 39 to 6. The results show that the capacitor placement and installation could reduce the network harmonics.

Undoubtedly, in order to have less harmonics, the network characteristics should be changed, which

increases the network cost. But it could be understood from the simulation results that a small change in the cost could numerously reduce the harmonics. Network voltage profile in various simulation scenarios is depicted in figure 5.

Figure 5 shows that, capacitor installation, increases the voltage of weak busses. However, in the optimization process the voltage profile was not taken into account. If the designer aims at further increasing the network voltage, this term could be added to the objective function. The simulation results of the second scenario are compared with those of other articles, in table (5). It is clear that the Gravitational Fuzzy search algorithm has reached a more appropriate solution rather than the Birds algorithm and Honeybee algorithm, which emphasizes its excellence over the other algorithms.

#### Case Study 2: The network of west Yazd

The network of the west YAZD, has 120 main load busses and its overall load is 4.86 MW and 2.152 MVar. The data were gathered in the 20 KV voltage level, in 2008. The simulation of this network performed to optimize the objective function of equation (1). Similar to the first case study, capacitor placement and installation was fulfilled in three scenarios. The simulation results are represented in table (6).

Using capacitors in the second scenario led to less overall cost and network loss, but, because of ignoring the power quality constraints, the network harmonics increased and many network busses have been harmonically polluted. In the third scenario, by taking the power quality constraints into account, the count, location and the optimal capacitor values calculated and the problem of harmonics has been removed.

The simulation results of the Gravitational Fuzzy algorithm in the second scenario, are compared with the Gravitational algorithm and the Elitist algorithm and represented in table (7). Figure 6 represents the average convergence profile of the aforementioned algorithms in the second scenario for 10 iterations. Based on figure 6, the Gravitational Fuzzy algorithm has reached the optimal solution, after 103 iterations; however, the Gravitational algorithm and Elitist Gravitational algorithm reached the less optimal solutions, after 171 and 154 iterations, respectively. This shows the excellence of the Gravitational Fuzzy algorithm over other studied intelligent algorithms.

#### 4. Conclusion

In this paper, the problem of optimal capacitor placement in the presence of nonlinear loads, by

taking the power quality parameters and constraints into account, has been formulated. In the proposed model, minimization of the annual cost of losses and, capacitor installation, was the optimization purpose. To do this, the Gravitational Fuzzy optimization algorithm was proposed. The proposed algorithm, was performed on a 69-buss network and the network of the west Yazd. The simulation results showed that, the capacitor installation, has a large influence on the improvement of the network condition and decrement of the annual costs. Moreover, by increasing the annual cost, a little bit, the harmonic deviations could be reduced to an acceptable amount. In order to evaluate the performance of the proposed search algorithm, the simulation results have been compared with other intelligent search algorithms, and it proved the more appropriate precision and convergence rate of the proposed algorithm.

Table.2.  
Harmonic Spectrum of nonlinear loads

Buss 13	Buss 25	Buss 30	H			
Phase (Degree)	Value (%)	Phase (Degree)	Value (%)	Phase (Degree)	Value (%)	
0	100	0	100	0	100	1
111	23.52	-135	82.8	0	42	5
109	6.08	69	77.5	0	14.3	7
-158	4.57	-62	46.3	0	7.9	11
-178	.2	139	41.2	0	3.2	13
-94	1.8	9	14.2	0	3.7	17
-92	1.37	-155	9.7	0	2.3	19
-70	0.75	-158	1.5	0	2.3	23
-70	0.56	98	2.5	0	1.4	25
-20	0.49	0	0	0	0	29
-7	0.54	0	0	0	0	31

Table.3.  
Simulation results of the first scenario

Third Scenario	Second Scenario	First Scenario	
24.87	24.80	37.81	Overall Cost Function (×103\$)
4.13	38.42	12.48	Maximum Harmonic Deviation (%)
144.53	144.59	225.06	Active Power Loss (kW)
65.82	65.90	102.14	Reactive Power Loss (kVAr)
24.28	24.29	37.81	Loss Cost (×103\$)
0.59	0.51	-	Capacitor's Installation Cost (×103\$)
0.92	0.93	0.91	Minimum Voltage (p.u)
6	39	14	Number of Harmonically ill Busses
61, 49, 16, 51, 67	22, 11, 49, 61	-	Capacitor's Locations (Buss)
8,4,2,1,1	1, 3, 3, 8	-	Capacitor's Value (×150kVAr)

Table.4.  
Simulation results of the second scenario, case study 1

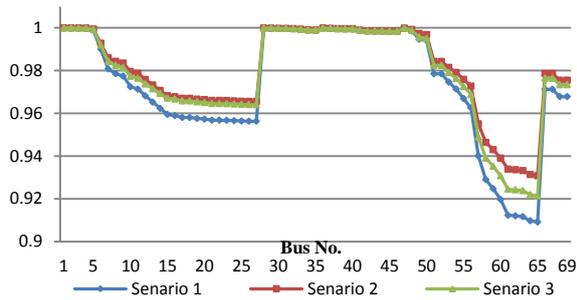
Honey Bee	Birds [18]	Gravitational Fuzzy	
27.83	29.57	24.80	Overall Cost Function (×103\$)
146.75	156.66	144.59	Active Power Loss (kW)
0.93	0.93	0.93	Minimum Voltage (p.u)
59, 64, 61	50, 47, 46	22, 11, 49, 61	Capacitor's Location (Buss)
100, 700, 600	1015, 365, 241	150, 450, 450, 1200	Capacitor's Value (kVAr)

Table.5.  
Simulation results of the second case study

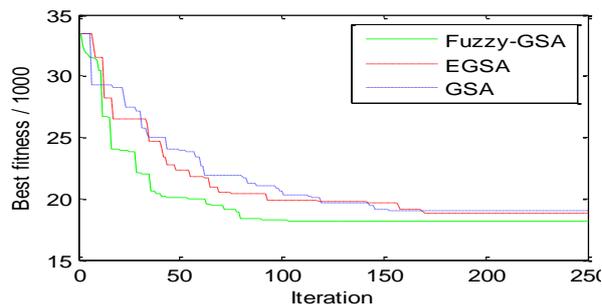
Third Scenario	Second Scenario	First Scenario	
18.67	18.15	30.55	Overall Cost Function (×103\$)
4.70	36.23	2.57	Maximum Harmonic Deviation (%)
104.12	102.31	181.85	Active Power Loss (kW)
174.87	161.02	290.41	Reactive Power Loss (kVAr)
17.49	17.19	30.55	Loss Cost (×103\$)
1.179	0.962	0	Capacitor's Installation Cost (×103\$)
0.95	0.95	0.91	Minimum Voltage (p.u)
0	31	0	Number of Harmonically ill busses
118, 108, 79, 72, 53, 31, 22	111, 94, 72, 53, 39, 29	-	Capacitor's Locations (Buss)
1, 5, 9, 8, 4, 1, 5	2, 9, 1, 4, 7, 4	-	Capacitor's Value (×150kVAr)

Table.6.  
Simulation results of the second scenario, case study 2

Gravitational	Gravitational Elitist	Fuzzy Gravitational	
18.98	18.76	18.15	Overall Cost Function (×103\$)
109.61	105.14	102.31	Active Power Loss (kW)
0.94	0.95	0.95	Minimum Voltage (p.u)



Network voltage profile in various scenarios



Average convergence profile in second case study

## References

- [1] H. Dehghan, S. Esmaeli, "Optimal rearrangement in radial distribution systems in the presense of reactive power compensators using the mobile Frog search algorithm", the 16th Conference on Distribution Networks, 2012.
- [2] E. Gençtürk, T. Gökçek, G. Güneş, "Reliability and validity study of the technology proficiency self-assessment scale", *Procedia - Social and Behavioral Sciences*, Volume 2, Issue 2, pp. 2863-2867, 2010.
- [3] H. Dehaghn, M. Rashidinezhad, "Reliability improvement using the rearrangement in the intelligent distribution networks", the 17th Conference on Distribution Networks, 2013.
- [4] A.M.Sharaf, S.T.Ibrahim, "Optimal capacitor placement in distribution networks," *Electric Power System*, pp. 181-187, 1996.
- [5] J. Grainger and S. H. Lee, "Optimal size and location of shunt capacitors for reduction of losses in distribution feeders," *IEEE Trans. Power App. Syst.*, vol. PAS-100,, pp. 1105–1118, Mar. 1981.
- [6] El-Khattam W., Salama M.M.A., "Distributed generation tech, definitions and benefits," *Electric Power System Res* 71, 2004.
- [7] W.M. Ritchie et al, " Loss Reduction, an Overview of the Problems and Solutions" , *Power Technology International*, 1988.
- [8] Ching-Tzong Su, Chung -Fu Chang, Ji-Pyng Chiou "Distribution network reconfiguration for loss reduction and by ant colony search algorithm," *Elsevier*, pp. 190-199, 2005.
- [9] J. -H. Teng, C.-Y. Chang, "Backward/Forward Sweep- Based Harmonic Analysis Method for Distribution Systems," *IEEE Transactions on Power Delivery*, vol. 22, No.3, 2007.
- [10] Task Force on Harmonics modeling and Simulation, "Modeling and Simulation of the Propagation of Harmonics in Electric Power Networks, Part 2: Sample System and Examples", *IEEE Trans, on Power Del.*, Vol, 11, No, 1, pp. 466-468, 1996.
- [11] M. A. S. Masoum, A. Jafarian, M. Ladjevardi, E. F. Fuchs, and W. M. Grady, "Fuzzy Approach for Optimal Placement and Sizing of Capacitor Banks in the Presence of Harmonics," *IEEE Trans. on Power Delivery*, vol.19, No.2, pp. 822-829, 2004.
- [12] Seyed Abbas Taher, Ali Karimian, Mohammad Hasani , "A new method for optimal location and sizing of capacitors in distorted distribution networks using PSO algorithm", *Simulation Modelling Practice and Theory* 19 .pp. 662–672, 2011.
- [13] J. J. Grainger and S. H. Lee, "Optimum size and location of shunt capacitors for reduction of losses on distribution feeders," *IEEE Trans. Power App. Syst.*, vol. PAS-100, pp. 1105–1118, Mar. 1981.
- [14] J. J. Grainger and S. H. Lee, "Capacity release by shunt capacitor placement on distribution feeder: A new voltage-dependent model," *IEEE Trans. Power App. Syst.*, vol. PAS-101, no. 5, May 1982.
- [15] H. Duran, "Optimum number, location, and size of shunt capacitors in radial distribution feeder: A dynamic programming approach," *IEEE Trans. Power App. Syst.*, vol. PAS-87, no. 9, pp. 1769–1774, Sep. 1968.
- [16] Y. Baghzouz and S. Ertem, "Shunt capacitor sizing for radial distribution feeders with distorted substation voltages," *IEEE Trans. Power Del.*, vol. 5, no. 2, pp. 650–657, Apr. 1990.
- [17] J. L. Bala, P. A. Kuntz, and R. M. Taylor, "Sensitivity-based optimal capacitor placement on a radial distribution feeder," in *Proc. Northcon 95 IEEE Technical Application Conf.*, pp. 225–230, 1995.
- [18] Prakash K. and Sydulu M, "Particle swarm optimization based capacitor placement on radial distribution systems", *IEEE Power Engineering Society general meeting 2007*, pp. 1-5, 2007.
- [19] A. Mendes, P. M. Franca, C. Lyra, C. Pissarra, and C. Cavellucci, "Capacitor placement in large-sized radial distribution networks," *Proc. Inst. Elect. Eng., Gen., Transm. Distrib.* vol. 152, no. 4, Jul. 2005.
- [20] M. A. S. Masoum, M. Ladjevardi, A. Jafarian, and E. F. Fuchs, "Optimal placement, replacement and sizing of capacitor banks in distorted distribution networks by genetic algorithms," *IEEE Trans. Power Del.*, vol. 19, no. 4, pp. 1794–1801, Oct. 2004.
- [21] R. Srinivasa Rao, "Capacitor Placement in Radial Distribution System for Loss Reduction Using Artificial Bee Colony Algorithm", *world academy of science, engineering and Tech*, 68 2010.
- [22] B. Venkatesh and R. Ranjan, "Fuzzy EP algorithm and dynamic data structure for optimal capacitor allocation in radial distribution systems," *Proc. Inst. Elect. Eng., Gen., Transm. Distrib.* vol. 153, 2006.
- [23] Seyed Abbas Taher, Mohammad Hasani, Ali Karimian, "A novel method for optimal capacitor placement and sizing in distribution systems with nonlinear loads and DG using GA", *commun nonlinear sci numer simulate*, pp.851–862. 2011.
- [24] Y. Baghzouz and S. Ertem, "Shunt capacitor sizing for radial distribution feeders with distorted substation voltages," *IEEE Trans. Power Del.*, vol. 5, no. 2, pp. 650–657, Apr. 1990.
- [25] A.P. Engelbrecht, "Fundamentals of computational swarm intelligence", *wiley*, 2005.
- [26] K.S. Tang, K.F. Man, S.Kwong and Q.He, "Genetic algorithms and their applications", *IEEE Signal Processing Magazine* 13(6), 1996.
- [27] A. Rashedi, H. Nezamabadi-pour, S. Saryazdi, "GSA: A Gravitational Search Algorithm", *Information Sciences*

- 179,pp. 2232–2248,1999.
- [28] A. Rashedi, H. Nezamabadipour, “Gravitational Optimal Detection”, the 15th Conference on Electrical Engineering, Iran, Tehran, 2007.
- [29] B. Venkatesh, R. Ranjan, H.B. Gooi, “Optimal reconfiguration of radial distribution systems to maximize loadability”, IEEE Trans. Power Syst. 19 , Pages 260–266,2004.
- [30] H. Dehghan, S. Esmaeeli, “Determination of the optimal count and location of the power quality monitors using the harmonic search algorithm”, the 26th Conf. on Elec. Eng., PSC, Iran, Tehran, 2011.