

# Quantify the Loss Reduction with Optimization of Capacitor Placement Using ICA Algorithm- A CASE STUDY

Mahdi Mozaffari Legha<sup>1</sup>, Moein Khosravi<sup>2</sup>, Milad Askari Hashemabadi<sup>3</sup>, Naser Amirtaheri<sup>4</sup>  
Mohammad Mozaffari Legha<sup>5</sup>

**Abstract-** Increasing application of capacitor banks on distribution networks is the direct impact of development of technology and the energy disasters that the world is encountering. To obtain these goals the resources capacity and the installation place are of a crucial importance. Line loss reduction is one of the major benefits of capacitor, amongst many others, when incorporated in the power distribution system. The quantum of the line loss reduction should be exactly known to assess the effectiveness of the distributed generation. In this paper, a new method is proposed to find the optimal and simultaneous place and capacity of these resources to reduce losses, improve voltage profile too the total loss of a practical distribution system is calculated with and without capacitor placement and an index, quantifying the total line loss reduction is proposed. To demonstrate the validity of the proposed algorithm, computer simulations are carried out on actual power network of Kerman Province, Iran and the simulation results are presented and discussed.

**Keywords-** Distribution systems, Loss reduction index, Capacitor placement, Imperialist Competitive Algorithm

## 1. Introduction

The loss minimization in distribution systems has assumed greater significance recently since the trend towards distribution automation will require the most efficient operating scenario for economic viability variations. The power losses in distribution systems correspond to about 70% of total losses in electric power systems (2005). To reduce these losses, shunt capacitor banks are installed on distribution primary feeders. The advantages with the addition of shunt capacitors banks are to improve the power factor, feeder voltage profile, Power loss reduction and increases available capacity of feeders. Therefore it is important to find optimal location and sizes of capacitors in the system to achieve the above mentioned objectives. Since, the optimal capacitor placement is a complicated combinatorial optimization problem, many different optimization techniques and algorithms have been proposed in the past. H. Ng et al (2000) proposed the capacitor placement problem by using fuzzy approximate reasoning. Ji Pyng Chiou et al (2006) proposed the variable scale hybrid differential evolution algorithm for the capacitor placement in distribution system. Both Grainger et al (1981) and

Baghzouz and Ertem (1990) proposed the concept that the size of capacitor banks was considered as a continuous variable.

However, considered only the losses in the lines and the quantification were defined for the line losses only. These indices, therefore, do not indicate the loss reduction of the system itself. A practical distribution system consists of several distribution transformers, supplying consumers at low voltage on the secondary side. The losses occurring in these transformers and the line losses of the secondary low voltage distribution system should also be considered to arrive at the overall loss reduction of the system.

In this paper, a new method is proposed to find the optimal and simultaneous place and capacity of these resources to reduce losses, improve voltage profile too the total loss of a practical distribution system is calculated with and without capacitor placement and an index, quantifying the total line loss reduction is proposed. To demonstrate the validity of the proposed algorithm, computer simulations are carried out on actual power network of Kerman Province, Iran and the simulation results are presented and discussed.

## 2. Objective Function

The objective of capacitor placement in the distribution system is to minimize the annual cost of the system, subjected to certain operating constraints and load pattern. For simplicity, the operation and maintenance cost of the capacitor placed in the distribution system is not taken into consideration. The three-phase system is considered as balanced and loads are assumed as time

- **Mahdi Mozaffari Legha**, Department of Power Engineering, Javid University, Jiroft, Iran. (E-mail: [Mahdi\\_mozaffari@ymail.com](mailto:Mahdi_mozaffari@ymail.com)).
- **Moein Khosravi**, Department of Power Engineering, Islamic Azad University of science and Research, Sirjan, Iran. (E-mail: [moeinkhosravi69@gmail.com](mailto:moeinkhosravi69@gmail.com)).
- **Milad Askari Hashemabadi**, Department of Power Engineering, Rafsanjan Branch, Islamic Azad University, Rafsanjan, Iran. (E-mail: [miladaskari65@yahoo.com](mailto:miladaskari65@yahoo.com)).
- **Naser Amirtaheri**, Department of Power Engineering, Islamic Azad University of science and Research, Hormozgan, Iran. (E-mail: [Naser.amirtaheri68@yahoo.com](mailto:Naser.amirtaheri68@yahoo.com)).
- **Mohammad Mozaffari Legha**, Department of Power Engineering, Kerman Branch, Science and Research, Islamic Azad University, Iran. Mobile: (E-mail: [Mozaffari50@gmail.com](mailto:Mozaffari50@gmail.com)).

invariant. Mathematically, the objective function of the problem is described as:

$$\text{Minimize } f = \text{Min} (\text{COST})$$

Where COST includes the cost of power loss and the capacitor placement. The voltage magnitude at each bus must be maintained within its limits and is expressed as:

$$V_{\min} \leq |V_i| \leq V_{\max}$$

Where  $|V_i|$  is the voltage magnitude of bus  $i$ ,  $V_{\min}$  and  $V_{\max}$  are bus minimum and maximum voltage limits, respectively.

### 3. Formulation

The power flows are computed by the following set of simplified recursive equations derived from the single-line diagram depicted in Figure. 1.

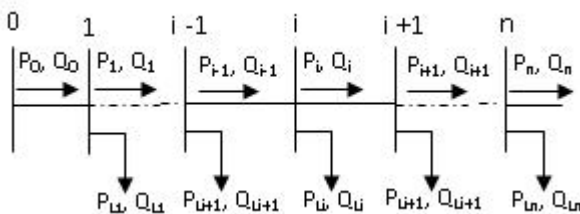


Figure 1: Single line diagram of main feeder

$$P_{i+1} = P_i - P_{Li+1} - R_{ij+1} \frac{P_i^2 + Q_i^2}{|V_i|^2}$$

$$Q_{i+1} = Q_i - Q_{Li+1} - X_{ij+1} \frac{P_i^2 + Q_i^2}{|V_i|^2}$$

$$|V_i|^2 = |V_j|^2 - 2(R_{ij+1} P_i + X_{ij+1} Q_i) + (R_{ij+1}^2 + X_{ij+1}^2) \times \frac{P_i^2 + Q_i^2}{|V_i|^2}$$

Where  $P_i$  and  $Q_i$  are the real and reactive powers flowing out of bus  $i$ , and  $P_{Li}$  and  $Q_{Li}$  are the real and reactive load powers at bus  $i$ . The resistance and reactance of the line section between buses  $i$  and  $i+1$  are denoted by  $R_{i,i+1}$  and  $X_{i,i+1}$  respectively. The power loss of the line section connecting buses  $i$  and  $i+1$  may be computed as

$$P_{Loss}(i, i + 1) = R_{i,i+1} \frac{P_i^2 + Q_i^2}{|V_i|^2}$$

The total power loss of the feeder,  $P_T^{LOSS}$  may then be determined by summing up the losses of all line sections of the feeder, which is given as

$$P_T^{LOSS} = \sum_{i=0}^{n-1} P_{Loss}(i, i+1)$$

Considering the practical capacitors, there exists a finite number of standard sizes which are integer multiples of the smallest size  $Q_0$ . Besides, the cost per Kvar varies from one size to another. In general, capacitors of larger

size have lower unit prices. The available capacitor size is usually limited to

$$Q_c^{max} = LQ_c$$

Therefore, for each installation location, there are  $L$  capacitor sizes  $\{1Q_c, 2Q_c, 3Q_c, \dots, LQ_c\}$  available. Given the annual installation cost for each compensated bus, the total cost due to capacitor placement and power loss change is written as

$$\text{COST} = K_p \times P_T^{LOSS} + \sum_i^c (K_{cf} + K_i^c Q_i^c)$$

Where  $n$  is number of candidate locations for capacitor placement,  $K_p$  is the equivalent annual cost per unit of power loss in  $\$/(\text{Kw-year})$ ;  $K_{cf}$  is the fixed cost for the capacitor placement. Constant  $K_i^c$  is the annual capacitor installation cost, and,  $i = 1, 2, \dots, n$  are the indices of the buses selected for compensation. The bus reactive compensation power is limited to

$$Q_i^c \leq \sum_{i=1}^n Q_{Li}$$

Where  $1Q_c$  and  $LQ_c$  are the reactive power compensated at bus  $i$  and the reactive load power at bus  $i$ , respectively.

### 4. Power Flow Analysis Method

The methods proposed for solving distribution power flow analysis can be classified into three categories: Direct methods, Backward-Forward sweep methods and Newton-Raphson (NR) methods. The Backward-Forward Sweep method is an iterative means to solving the load flow equations of radial distribution systems which has two steps. The Backward sweep, which updates currents using Kirchoff's Current Law (KCL), and the Forward sweep, which updates voltage using voltage drop calculations [5].

The Backward Sweep calculates the current injected into each branch as a function of the end node voltages. It performs a current summation while updating voltages. Bus voltages at the end nodes are initialized for the first iteration. Starting at the end buses, each branch is traversed toward the source bus updating the voltage and calculating the current injected into each bus. These calculated currents are stored and used in the subsequent Forward Sweep calculations. The calculated source voltage is used for mismatch calculation as the termination criteria by comparing it to the specified source voltage. The Forward Sweep calculates node voltages as a function of the currents injected into each bus. The Forward Sweep is a voltage drop calculation with the constraint that the source voltage used is the specified nominal voltage at the beginning of each forward sweep. The voltage is calculated at each bus, beginning at the source bus and traversing out to the end buses using the currents calculated in previous the Backward Sweep [5].

### 5. Imperialist Competitive Algorithm (ICA)

ICA mimics the social-political process of imperialism and imperialistic competition. ICA starts with an initial population of individuals, each called a country. Some of the best countries are selected as imperialists and the rest form colonies which are then divided among imperialists based on imperialists' power. After forming the initial empires, competition begins and colonies move towards the irrelevant imperialists. During competition, weak empires collapse and powerful ones take possession of more colonies. At the end, there exists only one empire while the position of imperialist and its colonies are the same [4,12].

### 6. Loss Reduction Analysis

The total loss of the distribution system without capacitor is given by

$$Loss_{without\ cap} = \sum_{i=1}^{N-1} I_i^2 \times r \times L_i + \sum_{i=1}^{N-1} (P_{ci} + P_{Lv_i})$$

Where  $I_i$  is the current flowing through  $i$ th section,  $r$  is the resistance of line in ohms per unit length,  $L_i$  is the length of  $i$ th section,  $P_{ci}$  is the core loss of  $i$ th transformer,  $P_{Lv_i}$  is the Losses on the low voltage side of the  $i$ th transformer and  $N$  is the number of busses in the system.

In order to determine the losses of the system, the core loss of each transformer and the LV side losses on each transformer must be known. It is evident from the above equation that the total losses can be reduced only by reducing the first term which represents the feeder line losses, since the other term representing the core loss and the LV side loss of each transformer remain same independent of the presence of capacitor. If a capacitor is inserted at  $K$ th bus, the feeder segments up to bus  $K$  will carry the difference of the initial current and the injected current by the capacitor. Where  $I_{cap}$  is the current injected by the capacitor and  $I_i$  remains the same at earlier value. The total loss of the distribution system with capacitor is now

$$Loss_{with\ cap} = \sum_{i=1}^{K-1} (I_i - I_{cap})^2 r L_i + \sum_{i=K}^{N-1} I_i^2 r L_i + \sum_{i=1}^{N-1} (P_{ci} + P_{Lv_i})$$

A factor, loss reduction index (LRI), which quantifies the loss reduction with the insertion of capacitor, is defined as

$$LRI = \frac{Loss\ in\ the\ system\ with\ capacitor}{Loss\ in\ the\ system\ without\ capacitor}$$

The LRI is now obtained as

$$LRI = \frac{Loss_{System\ without\ Cap} + K_{Loss} I_{Cap}}{Loss_{System\ without\ Cap}}$$

Where  $K_{Loss}$  is the loss factor given by

$$K_{Loss} = \sum_{i=1}^{K-1} (I_{Cap} - 2I_i) \times r \times L_i$$

### 7. Test Results

To study the proposed method, actual power network of Kosar feeder of Kerman Province, Iran is simulated in Cymedist. Figure 2 illustrates the single-line diagram of this network. The base values of the system are taken as 20kV and 20MVA. The system consists of 20 distribution transformers with various ratings. The details of the distribution transformers are given in table 1. The details of the distribution conductors are given in table 2. The lengths of the feeder segments are given in table 3. The total connected load on the system is 2550 KVA and the peak demand for the year is 2120 KVA at a PF of 0.8 lag. The connected loads on the transformers are listed in table 4.

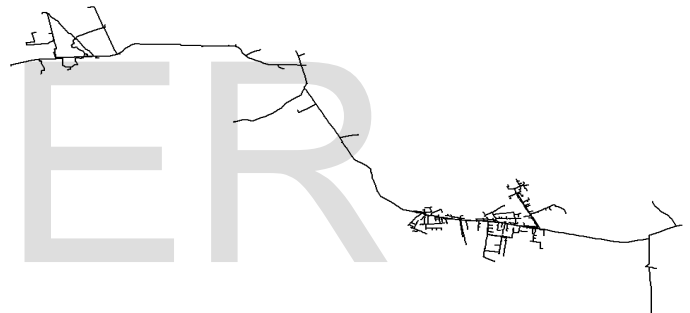


Figure 2: Single-line diagram of actual power network of Kosar feeder of Kerman Province in Cymedist

Table 1: Details of transformers in the system

Rating [KVA]	50	100	250
Number	5	9	6
No load losses [watts]	150	250	480
Impedance [%]	4.5	4.5	4.5

Table 2: Details of conductors in the system

Type	R [Ω/km]	X [Ω/km]	Cmax [A]	A [mm <sup>2</sup> ]
Hyena	0.1576	0.2277	550	126
Dog	0.2712	0.2464	440	120
Mink	0.4545	0.2664	315	70

Table 3: Distribution System Line Data

from	To	Length (meters)
1	2	80
2	3	80
3	4	80
4	5	60
5	6	60
6	7	60
7	8	60
8	9	60
9	10	60
10	11	60
11	12	60
12	13	60
13	14	60
14	15	60
14	16	60
16	17	60
17	18	60
18	19	60
19	20	60

Table 4: Details of the connected loads

Transformer no	Load [Kva]
1	35
2	245
3	85
4	165
5	50
6	85
7	180
8	35
9	35
10	90
11	85
12	75
13	200
14	73
15	35
16	85
17	98
18	230
19	220
20	85

Table 5: Results of power flow before installation of capacitor

Bus Number	V (pu)
1	1.0
2	0.9999
3	0.9998
4	0.9988
5	0.9988
6	0.9987
7	0.9985
8	0.9889
9	0.9879
10	0.9849
11	0.97
12	0.93
13	0.89
14	0.9849
15	0.9849
16	0.91
17	0.92
18	0.95
19	0.94
20	0.89

Table 6: Optimal place and capacity of capacitor banks

Location [#bus]	Capacity [Mvar]
2	0.1
6	0.025
7	0.1
13	0.25
15	0.1

In addition the total network loss, which was 10.05MW before installing capacitor, has diminished to the 4.55MW which shows 45.81% decrease. Table 7 shows the impact of installing capacitor on THD of buses.

Table 7: Results of power flow after installation of capacitor banks

Bus Number	V (pu)
1	1.0
2	0.9999
3	0.9999
4	0.9999
5	0.9999
6	0.9988
7	0.9988
8	0.9888
9	0.9881
10	0.9885
11	0.99
12	0.97
13	0.91
14	0.988
15	0.988
16	0.95
17	0.96
18	0.98
19	0.95
20	0.93

Initially, a load flow was run for the case study in both fundamental frequency and harmonics frequencies without installation of capacitor. Table 5 depicts the results of power flow for determination voltage and harmonic before installation of capacitor. Table 6 depicts the locations and capacity of capacitor banks using artificial bee colony algorithm. As it is clear, all the obtained values confines with all the considered constraints. The obtained penetration lever is 0.27, which is less than the assumed allowable value.

The detailed pu voltages profile and Percentage of loss of all the nodes of the system before and after capacitor

placement are shown in the Figure 3 and Figure 4. The simulation results are given in Table 8. The simulation results are given in Table 8. These results reveal that the inclusions of capacitor reduce the line losses as expected. It can be shown from the graphs that, LRI decreases

marginally, since the core losses of the transformers and the LV side losses remain constant being independent of the presence of v. It can also be seen that with the increase in the reactive power of capacitor, LRI, decrease.

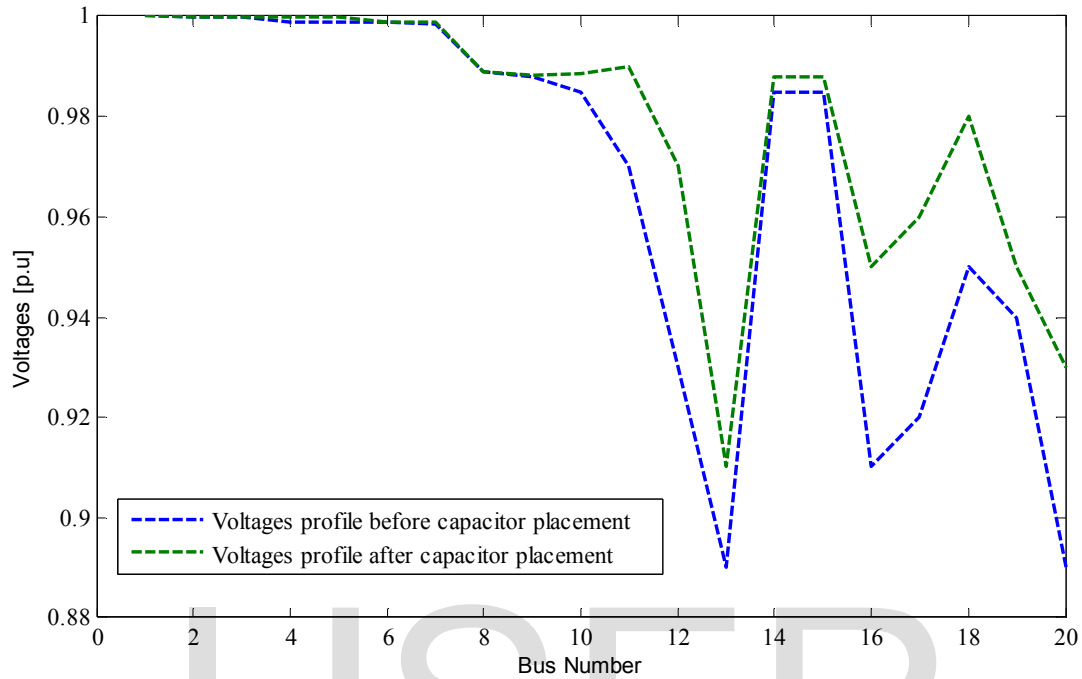


Figure 3: Voltage profile of 20 bus system before and after capacitor placement

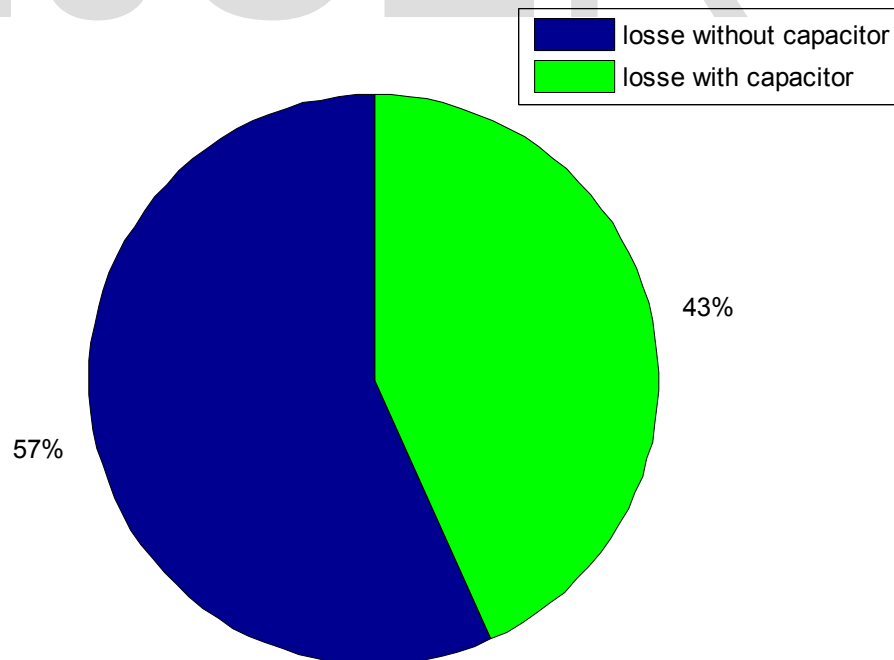


Figure 4: Percentage of loss before and after capacitor placement

Table 8: Variation of LRI and capacity & number of capacitor banks

Number	3	3	5	5	7	7
place	2,12,16	7,13,15	2,6,7,13,15	7,8,9,11,20	5,7,13,15,16,18,20	2,4,9,10,14,18,20
Picked capacity [Mvar]	0.02	0.02	0.575	0.35	2.1	2.25
Presumable Capacity Range [Mvar]	0.025 0.05 0.1 0.2 0.25 0.4 0.5	0.05 0.1 0.2 0.4 0.5 0.8 1	0.025 0.05 0.1 0.2 0.25 0.4 0.5	0.05 0.1 0.2 0.4 0.5 0.8 1	0.025 0.05 0.1 0.2 0.25 0.4 0.5	0.05 0.1 0.2 0.4 0.5 0.8 1
LRI [%]	0.9296	0.8866	0.7627	0.6649	0.7026	0.9754

### 8. Conclusion

In the present paper, a new population based artificial bee colony algorithm (ABC) has been proposed to solve capacitor placement problem and quantifying the total line loss reduction in distribution system. Simulations are carried on actual power network of Kerman Province, Iran. The simulation results show that the inclusion of capacitor, marginally reduce the losses in a distribution system. This is because; the line losses form only a minor part of the distribution system losses and the capacitor can reduce only the line losses. The other losses viz. the transformer losses and the LV side distribution losses remain unaltered. Hence this fact should be considered before installing a capacitor into a system. The results obtained by the proposed method outperform the other methods in terms of quality of the solution and computation efficiency.

### 9. References

[1] C. Lyra, C. Pissara, C. Cavellucci, A. Mendes, P. M. Franca (2005), "Capacitor placement in large sized radial distribution networks, replacement and sizing of capacitor banks in distorted distribution networks by genetic algorithms", *IEE Proceedings Generation, Transmission & Distribution*, pp. 498-516.

[2] Ng H.N., Salama M.M.A. and Chikhani A.Y (2000), "Capacitor allocation by approximate reasoning: fuzzy capacitor placement", *IEEE Transactions on Power Delivery*, vol. 15, No. 1, pp. 393-398.

[3] Sundharajan and A. Pahwa (1994), "Optimal selection of capacitors for radial distribution systems using genetic algorithm", *IEEE Trans. Power Systems*, vol. 9, No.3, pp.1499-1507.

[4] Ji-Pyng Chiou et al(2006), "Capacitor placement in large scale distribution system using variable scaling hybrid differential evolution", *Electric Power and Energy Systems*, vol. 28, pp.739-745.

[5] M. Mozaffari Legha, (2011) Determination of exhaustion and junction of in distribution network and its loss maximum, due to geographical condition, MS.c Thesis. Islamic Azad University, Saveh Branch, Markazi Province, Iran.

[6] J. L. Bala, P. A. Kuntz, M. Taylor (1995), "Sensitivity-based optimal capacitor placement on a radial distribution feeder", *Proc. Northcon 95, IEEE Technical Application Conf.*, pp. 225230.

[7] D. Karaboga, B. Basturk (2007), "A powerful and efficient algorithm for numerical function optimization: artificial bee colony (ABC) algorithm", *Journal of Global Optimization*, vol. 39, pp. 459-471.

[8] D. Karaboga, B. Basturk(2008), "On the performance of artificial bee colony (ABC) algorithm", *Applied Soft Computing*, vol. 8 pp. 687-697.

[9] Prakash K. and Sydulu M (2007), "Particle swarm optimization based capacitor placement on radial distribution systems", *IEEE Power Engineering Society general meeting 2007*, pp. 1-5.

[10] D. Das (2002), "Reactive power compensation for radial distribution networks using genetic algorithms", *Electric Power and Energy Systems*, vol. 24, pp.573-581.

[11] K. S. Swarup (2005), "Genetic Algorithm for optimal capacitor allocation in radial distribution systems", *Proceedings of the 6th WSEAS Int. Conf. on EVOLUTIONARY COMPUTING*, Lisbon, Portugal, June 16-18, pp152-159.

[12] P. Chiradeja, "Benefit of distributed generation: A line loss reduction analysis," in *Proc. IEEE-Power Eng. Soc. Transmission and Distribution Conf. Exhib.: Asia and Pacific*, Dalian, China, Aug. 15-17, 2005.

[13] Chiradeja, Ramkumar, "An Approach to quantify the Benefits of Distributed Generation Systems", *IEEE trans. On Energy Conversion*, Vol. 19, Dec 2004, pp 764 – 773.

[14] B. Basturk, D. Karaboga (2006), "An artificial bee colony (ABC) algorithm for numeric function optimization", *IEEE Swarm Intelligence Symposium 2006*, May 12-14, Indianapolis, IN, USA.