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POWER QUALITY IMPROVEMENT VIA OPTIMAL CAPACITOR PLACEMENT IN ELECTRICAL DISTRIBUTION SYSTEMS USING SYMBIOTIC ORGANISMS SEARCH ALGORITHM

Yesim A. Baysal[1*], Ismail H. Altas[2]

[1,2]Department of Electrical and Electronics Engineering, Karadeniz Technical University, 61080, Trabzon, Turkey
yabaysal@ktu.edu.tr, ihaltas@ktu.edu.tr

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*Corresponding author

Abstract

In this paper, the location and the size of capacitors to be installed in radial distribution systems are determined by using the Symbiotic Organism Search (SOS) algorithm which is a new and powerful metaheuristic optimization technique in order to increase the efficiency by reducing the power losses in distribution systems and to deliver energy more economically with high quality by improving the voltage profile. In the process of determining the capacitor value, the value of the capacitors is taken as commercially available discrete values not as continuous values. The power flow analysis is performed using Forward and Backward Sweep (FBS) algorithm. IEEE 9 bus radial distribution system is used as test system. Performance of the proposed approach is evaluated by comparing the obtained results with the other studies found in the literature for the optimal capacitor placement and sizing (OCPS) problem and the superiority and effectiveness of the method by reducing the power losses in the system and annual cost to the optimum level is shown.
Keywords: Symbiotic Organism Search Algorithm, Optimal Capacitor Placement, Loss Reduction, Annual Cost, Radial Distribution Feeder

SİMBİYOTİK ORGANİZMALAR ARAMA ALGORİTMASI İLE DAĞITIM ŞEBEKELERİNDE GÜÇ KAYIPLARININ AZALTILMASI

Öz

Bu çalışmada, dağıtım şebekesindeki güç kayıplarını azaltarak verimliliği arttırmak ve gerilimi düzenleyerek enerjiyi yüksek kalite ile daha ekonomik olarak iletebilmek için dağıtım şebekesine yerleştirilecek şönt kapasitörlerin optimum yeri ve değeri, yeni ve etkili bir üst sezgisel optimizasyon yöntemi olan simbiyotik organizmalar arama algoritması kullanılarak belirlenmiştir. Kapasitör değerini belirleme işleminde, kapasitörlerin değeri sürekli değer olarak değil de ticari olarak mevcut olan ayrık değerler olarak göz önüne alınmıştır. Güç dağıtım sistemindeki yük akış analizi için ise Forward and Backward Sweep (FBS) algoritması kullanılmıştır. Önerilen yöntem 9 baralı standart IEEE dağıtım şebekesinde test edilmiştir. Elde edilen sonuçlar literatürdeki bazı çalışmalarla karşılaştırılarak önerilen yöntemin performansı değerlendirilmiş ve sistemdeki güç kayıpları ve yıllık maliyet optimum düzeye indirgenerek yöntemin uygulanabilirliği ve üstünlükleri gösterilmiştir.
Anahtar Kelimeler: Simbiyotik Organizmalar Arama Algoritması, Şönt Kapasitörler, Güç Kayıplarını Azaltma, Radyal Dağıtım Şebekeleri

1 Introduction

The power quality is always one of the priority topics in power systems. One of the most important factor affecting power quality is the power losses. The distribution system is the mainly responsible for the losses. Studies have demonstrated that approximately 13% of total power generated is wasted as losses at the distribution level [1]. The reactive component of the current causes the power losses and voltage drops in an electrical line. Reduction of losses to meet power demand is more charming than increasing generation because of more economical. However, it is not possible to reduce power losses to zero in a power system, only they can be kept to a minimum. The capacitor placement is one of the most effective and useful method in reducing the power losses produced by the unnecessary reactive power flow because capacitor has economic advantages such as lower installation and operating costs despite of technical limits. Capacitor placement in radial distribution feeders ensures some benefits like total power loss reduction, voltage profile enhancement, power factor correction and feeder capacity release. Nevertheless, capacitors must be optimally placed to achieve these benefits. Optimal placement means choosing the proper location and sizing of the capacitors. If the reactive power optimization can be performed correctly, the system acquires a longer operating life and an increased performance.

In order to solve OCPS problem in distribution system, a wide range of methodologies have been proposed and reported in the literature over the last decades. These techniques can be classified into four categories as analytical, numerical programming, artificial intelligence (AI) based and heuristic techniques [2]. Among them, the analytical methods were used in the earliest works for optimal capacitor location [3]. Although analytical methods are easy to understand and practice, obtained results may not guarantee an optimal solution because of the modelling of the capacitor locations and sizes as continuous variables. Moreover, some non-realistic assumptions such as radial feeder without any laterals and uniform loading are deficiencies of analytical methods. However, the latter analytical methods modelled radial distribution feeders more realistically by considering non-uniformly distributed loads [4]. As a result of these studies, analytical methods present more accurate results but require more distribution system data and time to implement. With the developed computing ability and increased memory of computer, numerical programming methods began to improve and are used to maximize or minimize an objective function in optimal capacitor location problems [5]. Despite the fact that some of the numerical programming methods are superior to analytical methods by virtue of considering capacitor locations and sizes as discrete variables, numerical techniques require more time than analytical methods in the data preparation. In time, expanding size of optimization problem caused to increase the complication of the programming methods. Therefore, AI based techniques have been investigated by many researchers in OCPS problem to overcome the difficulties [6-11]. The results obtained using these techniques are usually near optimal solution. Especially in recent years, many researches have focused on various types of heuristic and metaheuristic optimization techniques to find the optimal solution for capacitor allocation problem. Heuristic algorithms minimize search space using fast and practical strategies and so better solution is achieved. Genetic algorithm [12], tabu search [13], particle swarm optimization algorithm [14], ant colony search [15,16], artificial bees colony based algorithm [17], plant growth simulation algorithm [18], harmony search algorithm [19, 20], cuckoo search algorithm [21] and group search algorithm [22] are some of the heuristic techniques used in OCPS problem. Although there are considerable amount research work in the area of optimal capacitor placement, more suitable and effective methods are still required for determining the best location and sizing of capacitor.

In this paper, a new metaheuristic algorithm called symbiotic organism search (SOS) developed by inspiration from symbiotic interaction among organisms in the ecosystem is preferred for solving the OCPS problem because it requires no specific algorithm parameters and is easy to implement, unlike most other metaheuristic algorithms. The used objective function aims to maximize the annual net saving from the loss reduction with the proper capacitor installation by minimizing capacitor costs while keeping the voltage profile within required limits. Although the commercially available capacitors are discrete, the capacitors are usually assumed as continuous variables. Selecting integer capacitor sizes closest to the optimal values found by the continuous variable approach may not guarantee an optimal solution [23]. For this reason, discrete capacitors are considered in this paper. The Forward and Backward Sweep (FBS) load flow algorithm is used for computing power losses and bus voltages due to its suitability for radial distribution systems and effectiveness in speeding up the computing time without difficulties in getting converged solutions. The proposed approach is applied to IEEE 9 bus radial distribution system and the results are compared with previous method in literature and the contribution in terms of the quality of solution is reported.

2 Symbiotic Organism Search Algorithm

The SOS algorithm is a new and effective metaheuristic method developed by Cheng and Prayago in 2014 and based on the symbiotic interaction strategies that organisms use to survive in the ecosystem [24]. The algorithm simulates the symbiotic interactions between two organisms in order to search for the most suitable organism that an organism might be in relation. As in other population-based algorithms, SOS uses iteratively the candidate solutions forming search space when searching for the optimal global solution and begins with a randomly generated initial population called the ecosystem. Each organism in the ecosystem represents a candidate solution and has a certain fitness value reflecting degree of adaptation to the desired objective.

In SOS, new solutions are produced by simulating the biological interaction between two organisms in the ecosystem. The algorithm using biological interactions in the real world as a model consists of three steps. These are mutualism phase, commensalism phase, and parasitism phase. Each phase operates by considering the character of interaction and each organism interacts with another organism randomly chosen in all phases. The procedure is repeated until termination criteria are met.

2.1 Mutualism Phase

Mutualism is a symbiotic relationship between two different species where both organisms benefit from the association. In this phase, X_i is considered as *i*th organism in the ecosystem and X_j is the another organism selected randomly from the ecosystem to interact with X_i. These two organisms engage with each other to increase mutual survival advantage in the ecosystem. New candidate solutions for X_i and X_j are calculated using Equation (1) and Equation (2) modelled according to mutualistic relationship between two organisms.

$$X_i{}' = X_i + rand(0,1) * (X_{best} - MV * BF_1) \quad (1)$$

$$X_j{}' = X_j + rand(0,1) * (X_{best} - MV * BF_2) \quad (2)$$

$$MV = \frac{X_i + X_j}{2} \quad (3)$$

BF_1 and BF_2 parameters in the equations are called the benefit factors and used to determine level of benefit of each organism from the association. In the algorithm, the benefit factors are selected randomly as 1 or 2. The X_{best} also reflects the highest degree of adaptation. MV called as mutual vector is a vector representing characteristic of relation between organisms X_i and X_j and calculated as shown in Equation (3).

The fitness value is calculated for each new candidate solutions and if their fitness values is better than the previous fitness values, the old organisms replace with the new solutions.

2.2 Commensalism Phase

This phase of SOS is modelled according to commensalism which is a symbiotic relationship between two different species in which one benefits from the other without affecting it. As in the mutualism phase, X_j is an organism selected randomly from the ecosystem to interact with X_i. While only X_i is benefited from the interaction, X_j is not affected. The new candidate solution of X_i is calculated using Equation (4) modelled according to the commensalism relation between organism X_i and X_j [24].

$$X_i{}' = X_i + rand(-1,1) * (X_{best} - X_j) \quad (4)$$

Finally, organism X_i is updated if the new fitness value is better than the previous fitness value.

2.3 Parasitism Phase

Parasitism is a symbiotic relationship in which one of the two different species benefits from the other by damaging it. In this phase, X_i is used to create an artificial parasite called parasite vector. While the parasite vector is creating, firstly X_i is duplicated and then modified randomly in the search space. Similar to previous phases, X_j is selected randomly from the ecosystem and used to serve as a host to the parasite vector. Parasite vector tries to replace X_j in the ecosystem.

The fitness value of both organisms is evaluated and if the fitness value of parasite vector is better, it takes over position of X_j in the ecosystem by killing it. Otherwise, X_j develops immunity to the parasite vector and the parasite can no longer live in the ecosystem.

3 Objective Function Formulation

The objective function used in this study is a saving function formulated mathematically in Equation (5). The saving is maximized by minimizing power loss and capacitor costs.

$$S = K_P \Delta_P - K_C Q_C \quad (5)$$

where S is obtained net annual saving ($), K_P is the yearly cost of power loss reduction ($/ kW), Δ_P is the power loss reduction (kW), K_C is the cost of the installed capacitor ($/kVar) and Q_C is the size of the installed capacitor (kVar).

After the capacitor installation, the voltage magnitude at each bus must be kept within permissible limits to provide quality electrical supply as expressed in Equation (6).

$$V_{min} \leq V_i \leq V_{max} \quad i = 1, \dots, N \quad (6)$$

where N is the bus number and V_i is the voltage at bus i.

4 Implementation of SOS for OCPS Problem

In the solution of OCPS problem using SOS algorithm, at first the total power loss (P_{loss}) and bus voltages are calculated by performing the load flow program [11] and n random organisms with dimension n_d are generated as in Equation (7) according to the commercially available capacitor values given in Table 1 between the upper and lower bounds. Therefore, the search space is an ecosystem matrix with dimensions of $n \; x \; n_d$ as shown in Equation (8). While each row of the matrix represents an organism (solution), each element of the row vector represents a capacitor value (Q_C) to be installed the bus.

$$organizma = 150 * \text{round}(L_b + (\text{U}_b - L_b).* \, rand) \quad (7)$$

$$Q_C = \begin{bmatrix} (Q_C)_1{}^1 & \cdots & (Q_C)_{n_d}{}^1 \\ \vdots & \ddots & \vdots \\ (Q_C)_1{}^n & \cdots & (Q_C)_{n_d}{}^n \end{bmatrix} \quad (8)$$

The reactive power values at each buses are updated by using the generated organisms in Equation (7) and new total power loss $(P_{loss})'$ and bus voltages are calculated again with the updated Q. Then the fitness value for each organism is evaluated by using the objective function. While the fitness value is determining, bus voltages in the distribution system are considered. If the bus voltages are within limits for each organism, fitness value of the organism is determined as objective function, otherwise, it is determined as zero. Afterwards, the organism (solution) which has maximum fitness value is determined as the best organism (Q_{best}) and by beginning from the first organism in the ecosystem, three phases of SOS are performed respectively for each organism. The process is repeated until iteration number reach maximum value. If not, the best organism is updated and SOS phases are repeated with updated organisms.

Table 1. Commercially available capacitor sizes and their costs.

	1	2	3	4	5	6	7	8	9
Capacitor size (kVar)	150	300	450	600	750	900	1050	1200	1350
Capacitor cost ($/kVar)	0.500	0.350	0.253	0.220	0.276	0.183	0.228	0.170	0.207
	10	11	12	13	14	15	16	17	18
Capacitor size (kVar)	1500	1650	1800	1950	2100	2250	2400	2550	2700
Capacitor cost ($/kVar)	0.201	0.193	0.187	0.211	0.176	0.197	0.170	0.189	0.187
	19	20	21	22	23	24	25	26	27
Capacitor size (kVar)	2850	3000	3150	3300	3450	3600	3750	3900	4050
Capacitor cost ($/kVar)	0.183	0.180	0.195	0.174	0.188	0.170	0.183	0.182	0.179

5 Determining the Parameter

The initial parameters of the algorithm are set as follows. The parameters are summarized in Table 2.

- The dimension of the problem is determined as 9 because there are 9 candidate bus where capacitor can be placed.
- There is not a general rule in determining the number of organisms in the ecosystem. Therefore, the parameter is set to 27 in this study.
- The maximum iteration number is empirically determined as 5000 by considering its effect on the problem solving.
- The upper and lower bounds of the search space are determined by the minimum and maximum values that the capacitor can get. For the test system used in the article, these values are setted as 0 and 4050, respectively.
- Since discrete capacitor values are used in the solving the problem, the random organisms produced must be at these values. When we look at Table 1, it is seen that capacitor values increase at 150 intervals. For this reason, L_b and U_b parameters in the Equation (7) should be determined 0 and 27, respectively. Therefore, the search space is produced according to the commercially available capacitor values between the upper and lower bounds.

Table 2. The initial parameters of the algorithm.

Dimension of organism (n_d)	9
Number of organism (n)	27
The upper and lower bounds of the search space	0- 4050
L_b and U_b	0-27
Maximum iteration number	5000

6 Simulation Results

The test system used in this article is IEEE 9 bus radial distribution system which has a radial structure as shown in Fig.1. The rated voltage of the system is 23 kV. The load data and the line data for the system are given in Table 3. K_P is selected as 168 $/kW with the purpose of making better comparison with other research works in this topic and voltage limits are determined as V_{min}= 0.9 and V_{max}= 1.04 pu.

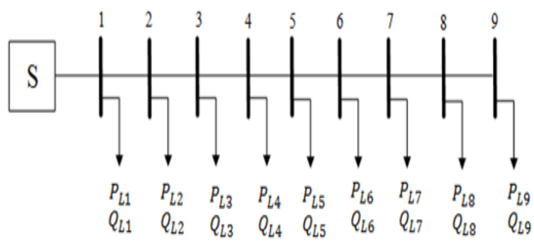

Figure 1. IEEE 9- bus distribution test system

Table 3. Line and load data of the test system.

	Bus no								
	1	2	3	4	5	6	7	8	9
Load									
P(kW)	1840	980	1790	1598	1610	780	1150	980	1640
Q (kVar)	460	340	446	1840	600	110	60	130	200
Line									
i. bus	0	1	2	3	4	5	6	7	8
İ+1. bus	1	2	3	4	5	6	7	8	9
R(Ω)	0.1233	0.0140	0.7463	0.6984	1.9831	0.9053	2.0552	4.7953	5.3434
X(Ω)	0.4127	0.6051	1.2050	0.6084	1.7276	0.7886	1.1640	2.7160	3.0264

Total power loss and annual cost before compensation are 783.8 kW and 131675 $, respectively. After the proposed method is applied to the test system, the values are reduced to 675.40 kW and 115101 $, respectively. Furthermore, the minimum voltage level at the buses is improved from 0.8375 pu to 0.9000 pu. The capacitor sizes to be installed to determined buses and the obtained results are presented in Table 4. From this table, it is seen that the bus voltages are within the required limits.

Table 4. The obtained results for 9 bus radial distribution system bus after the proposed method.

Bus no	**Capacitor size (kVar)**	**Bus voltages (pu)**
1	---	1.0009
2	4050	1.0070
3	2100	0.9976
4	1800	0.9875
5	1200	0.9653
6	150	0.9573
7	150	0.9419
8	150	0.9169
9	450	0.9000
Total losses (kW)	**Annual cost ($)**	**Net saving ($)**
675.40	115101	16574

The voltage profile of the system before and after compensation is shown in Fig. 2. As shown in the figure, the voltage profile of the system is significantly improved after the SOS algorithm is applied to the system.

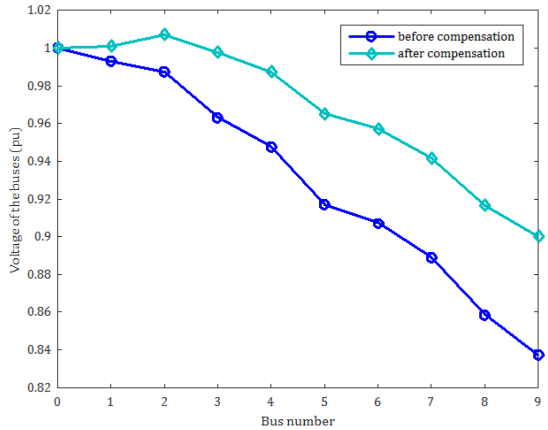

Fig. 2. Voltage profile versus bus number before and after compensation.

The obtained results are compared with the results of the other methods applied to 9 bus system given in Table 5. From the results, it is seen that the proposed method has outperformed the other methods in terms of the power loss and the annual cost.

Table 5. Comparison of results of the proposed method with the other works.

	Reactive power of added capacitor in kVar				
Bus no	**Before Compensation**	**[11]**	**[16]**	**[8]**	**Proposed method**
1	---	---	1800	---	---
2	---	---	1650	4050	4050
3	---	---	1200	1650	2100
4	---	4050	1800	2550	1800
5	---	1200	1200	1050	1200
6	---	---	450	---	150
7	---	---	---	---	150
8	---	450	450	300	150
9	---	---	450	450	450
Total losses(kW)	783.8	684.97	678.73	675.64	**675.40**
Annual cost ($)	131675	116117	115768	115490	**115101**
Net Saving ($)	---	15557	15907	16185	16574

7 Conclusion

The performance and applicability of the symbiotic organism search algorithm for solving the optimal capacitor placement and sizing problem in radial distribution systems which is a discrete problem is investigated in this paper. It is shown that the quite satisfactory simulation results are obtained with the installation of capacitors at the proper locations by using SOS. Moreover, when compared with the similar research works found in the literature, the superiority of the SOS algorithm is clearly demonstrated in terms of achieving maximum net saving and reducing power losses by keeping the bus voltages within permissible limits.

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9 References

[1] Tamilselvan, V., Muthulakshmi, K. and Jayabarathi, T., "Optimal Capacitor Placement and Sizing in A Radial Distribution System using Clonal Selection Algorithm", *ARPN Journal of Engineering and Applied Sciences*, vol.10, no.8, pp.3304-3312, 2015.

[2] Ng, H. N., Salama, M. M. A. and Chikhani, A. Y., "Classification of Capacitor Allocation Techniques", *IEEE Transactions on Power Delivery*, vol.15, no.1, pp.387–392, 2000.

[3] Schmill, J. V., "Optimum size and location of shunt capacitors on distribution feeders", *IEEE Transactions Power Apparatus and Systems*, vol. 84, no. 9, pp. 825–832, 1965.

[4] Grainger, J. J. and Lee, S. H., "Optimum size and location of shunt capacitors for reduction of losses on distribution feeders", *IEEE Transactions Power Apparatus and Systems*, vol. 100, no. 3, pp. 1105–1118, 1981.

[5] Duran, H., "Optimum number, location, and size of shunt capacitors in radial distribution feeders, A dynamic programming approach", *IEEE Transactions Power Apparatus and Systems*, vol.87, no.9, pp.1769–1774, 1968.

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

[7] Mekhamer, S.F., Soliman, S.A., Moustafa, M.A., and El-Hawary, M.E., "Application of fuzzy logic for reactive power compensation of radial distribution feeders", *IEEE Transaction Power Systems*, vol.18, no.1, pp.206–213, 2003.

[8] Bhattacharya, S. K. and Goswami, S. K., "A New Fuzzy Based Solution of The Capacitor Placement Problem in Radial Distribution System", *Expert Systems with Applications*, vol. 36, no. 3, pp. 4207-4212, 2009.

[9] Siddiqui, A. S. and Rahman, M. F., "Optimal Capacitor Placement to Reduce Losses in Distribution Systems", *WSEAS Transactions on Power Systems*, vol.7, no.1, pp.12-17, 2012.

[10] Ravichandran, K. S., Alsheyuhi, S. S. S. and Chitra, V., "A Novel Approach for Optimal Capacitor Placement Model in Power Distribution Systems", *Research Journal of Applied* Sciences, Engineering and Technology, vol.4, no.4, pp.334-341, 2012.

[11] Baysal, Y.A. and Altas, I.H., "A Fuzzy Reasoning Approach for Optimal Location and Sizing of Shunt Capacitors in Radial Power Systems", *IEEE Energy Conversion Congress and Exposition (ECCE)*, Montreal, Canada, pp. 5838 – 5842, 2015.

[12] Ghose, T., Goswami, S. K. and Basu, S. K., "Solving capacitor placement problems in distribution systems using genetic algorithms", *Elect. Mach. Power Syst.*, vol. 27, no. 4, pp. 429–441, 1999.

[13] Gallego, R. A., Monticelli, A. J. and Romero, R., "Optimal capacitor placement in radial distribution networks using tabu search", *IEEE Trans. Power Syst.*, vol.16, no.4, pp. 630–637, 2001.

[14] Prakash, K. and Sydulu, M., "Particle swarm optimisation based capacitor placement on radial distribution systems," *IEEE PES General Meeting*, Tampa, FL, , pp.1–5, 2007.

[15] Chang, C. F., "Reconfiguration and capacitor placement for loss reduction of distribution systems by ant colony search algorithm", *IEEE Trans. Power Syst.*, vol. 23, no. 4, pp. 1747–1755, 2008.

[16] Sirjani, R. and Hassanpour, B., "A New Ant Colony-Based Method for Optimal Capacitor Placement and Sizing in Distribution Systems", *Research Journal of Applied Sciences, Engineering and Technology*, vol.4, no.8, pp. 888-891, 2012.

[17] Zakka, S., Reddy, M. B., and Palepu, S. B., "Optimal capacitor placement using fuzzy and artificial bee colony algorithm for maximum loss reduction", *Int. J. Scient. Eng. Res.*, vol.3, no.10, pp. 1–7, 2012.

[18] Srinivasa Rao, R. and Narasimham, S.V.L., "Optimal capacitor placement in a radial distribution system using plant growth simulation algorithm", *World Academy of Science, Engineering and Technology*, vol.2, pp. 715-722, 2008.

[19] Sirjani, R., Mohamed, A. and Shareef, H., "Optimal capacitor placement in a radial distribution system using harmony search algorithm", *J. Appl. Sci.*, Vol. 10, No. 23, pp. 2996–3006, 2010.

[20] Reddy, M. D. and Kumar, N.V., "Optimal capacitor placement for loss reduction in distribution systems using fuzzy and harmony search algorithm", *ARPN J. Eng. Appl. Sci.*, vol.7, no. 1, pp. 15–19, 2012.

[21] El-Fergany, A. A. and. Abdelaziz, A. Y., "Capacitor allocations in radial distribution networks using cuckoo search algorithm", *IET Generat. Transm. Distrib*, vol.8, pp.223-232, 2014.

[22] Nivethitha, S., Shuaib Y. M. and Saleem A. S., "Optimal Capacıtor Placement for Power Loss Minimization in Radial Distribution System using Group Search Optimization Algorithm", *International Journal of Infinite Innovations in Engineering and Technology*, vol.2, no.1 pp.42-53, 2015.

[23] Baghzouz, Y. and Ertem, S., "Shunt capacitor sizing for radial distribution feeders with distorted substation voltages", *IEEE Trans Power Delivery*, vol. 5, pp.650–657, 1990.

[24] Cheng, M.Y. and Prayogo, D., "Symbiotic Organisms Search: A new metaheuristic optimization algorithm," *Computers and Structures*, vol.139, pp. 98-112, 2014.