1. S.K.B.Pradeep Kumar Ch[1*], 2. G. Balamurugan[1], 3. Y. Butchi raju[2]

Annamalai University (1), Sir CR Reddy College of Engineering (2), India
OrcID: 1. 0000-0002-2237-7998; 2. 0000-0003-3186-0700; 3. 0000-0003-4255-9614

doi:10.15199/48.2021.12.03

Optimal Infusion and Grading of Combined DGs and Capacitor Banks for Line Loss Minimization and Enhancement of Voltages in Radial Circuit System

***Abstract**. Enhancement of voltage profile of the radial distribution network's (RDN) is seen as a debatable subject because it is one of the factors that influence the system's performance. The power distribution system suffers significant losses as a result of the lower voltage and higher currents. As a result, experts are paying more attention to reduce power losses in the RDN. It is feasible to enhance voltage level of RDN by realizingcombined performance of Distribution Generation (DGs) and capacitor placements. This loss minimization technique tends to lower power flow through lines, which invariably improves system reliability and allows same lines to be used for growing load demand. The practice of optimum positioning and sizing the DGs and capacitors may improve system stability while also minimizes system losses. This article presents a simple and distinct way for determining best point and magnitude of integrated DGs and capacitor units in RDS. The fundamental goal of this project is to restore voltage profile and reduce losses by using Moth Flame Optimization (MFO) algorithm, a well-known and recently created meta-heuristic technique, is used. The algorithm is based on moths' natural behaviour when exposed to light, and it includes two key elements: moths and flames. The proposed methodology has been tested on both IEEE 12 and IEEE 33 node test systems to demonstrate its practicality. The simulated results are compared to ways described in the literature to illustrate the difference between prescribed method and others in terms of enhancing the voltage profile and reducing losses.*

Streszczenie.** Poprawa profilu napięciowego promieniowej sieci dystrybucyjnej (RDN) jest postrzegana jako temat dyskusyjny, ponieważ jest jednym z czynników wpływających na pracę systemu. System dystrybucji energii ponosi znaczne straty w wyniku niższego napięcia i wyższych prądów. W rezultacie eksperci zwracają większą uwagę na zmniejszenie strat mocy w RDN. Możliwe jest zwiększenie poziomu napięcia RDN poprzez realizację połączonych osiągów Generacji Dystrybucyjnej (DG) i rozmieszczenia kondensatorów. Ta technika minimalizacji strat ma tendencję do obniżania przepływu mocy przez linie, co niezmiennie poprawia niezawodność systemu i pozwala na wykorzystanie tych samych linii przy rosnącym zapotrzebowaniu na obciążenie. Praktyka optymalnego pozycjonowania i wymiarowania DG i kondensatorów może poprawić stabilność systemu, jednocześnie minimalizując straty systemu. W tym artykule przedstawiono prosty i wyraźny sposób określania najlepszego punktu i wielkości zintegrowanych DG i jednostek kondensatorów w RDS. Podstawowym celem tego projektu jest przywrócenie profilu napięcia i zmniejszenie strat za pomocą algorytmu Moth Flame Optimization (MFO), znanej i niedawno stworzonej techniki metaheurystycznej. Algorytm opiera się na naturalnym zachowaniu ciem pod wpływem światła i zawiera dwa kluczowe elementy: ćmy i płomienie. Zaproponowana metodologia została przetestowana w systemach testowych węzłów IEEE 12 i IEEE 33 w celu wykazania jej praktyczności. Symulowane wyniki porównuje się ze sposobami opisanymi w literaturze, aby zilustrować różnicę między zalecaną metodą a innymi pod względem wzmocnienia profilu napięcia i zmniejszenia strat.* (Optymalna infuzja i stopniowanie połączonych DG i baterii kondensatorów w celu minimalizacji strat linii i poprawy napięć w systemie obwodów radialnych***)

Keywords: Capacitor and DG placement, Distribution system, MFO algorithm, Power loss minimization, Voltage stability.
Słowa kluczowe:sieci dystrybucyjne, bank kondensatorów, generator

Introduction

Distributed Generations (DG) are bridged with radial distribution system with the idea of curtailing the losses and to improve the characteristics of voltages. DGs can be preferred as a source of generation of electrical power from the amenities that are available in smaller capacity than the conventional power generating systems, which permits to tap the power at any stage in the power system network. Moreover, these plants are planned and designed such that it can be instantly connected to the distribution system. Some of the importance of DGs penetration in to the network systems is (i) minimized real power loss, (ii) improved efficiency, (iii) enhanced voltage profile, (iv) induct renewable resources and to avoid environmental issues [1]. The subject of voltage stability is to manage the voltage of all buses in a power system within the tolerable limits. But in practice, the power system networks are operated always nearer to its critical limits which lead to the stability problems. Therefore, researchers and academicians have turned their attention towards the exploitation of benefit of Distributed generations and capacitor banks in to the distribution network. Literature survey reveals that the injection of reactive power by capacitors considerably minimizes the system losses. Effective placement and sizing of capacitors must be examined thoroughly for avoiding voltage stability problems [2, 3].

By estimating the real and reactive power losses, exact locations for the installation of DGs and capacitor are identified. Thereafter quadratic curve fitting method has been adopted to calculate the optimal capacity of the distribution system [4]. The specific points of location for connecting the DGs and reactive power support has been analyzed by sensitivity analysis. The LSF of each and every bus are arranged in decreasing order and first three critical busses were chosen as specific locations. BFOA algorithm is adopted for curtailing the target function by computing the optimal capacity of Distributed generations and capacitors at specific positions [5].

Network restructuring is the other approach for the limitation of loss in radial distribution network. It is done with the network topology of the system using breakers and the other components with a view to realize exceptional topology for minimizing the loss of power. In this paper, network reconfiguration has been executed by the process of combination of HSA with PSO embedded artificial bee colony algorithm [6].

Similarly, optimal scheme of DGs and capacitor banks in the distribution systems has been performed by applying the optimization algorithm like Firefly Algorithm (FFA) and backward search algorithm and results were analyzed with another optimization algorithm [7]. Fuzzy and GA based terminology for the placement were identified by the method of sensitivity analysis and multi-objective functions such as loss minimization and branch current limits are converted into fuzzy domain membership function. Then a target function is combined to form a single target function and is computed by Genetic Algorithm [8].

Growing line losses in the distribution network happened to be the debatable topic which is to be addressed by the researchers. While the necessity for the electrical power may aggravate in the coming days, the power systems are constrained to foresee the modification to minimize the power losses. Moreover, this condition / situation will drive the system losses to operate at its saturated level which leads the system to stability problem. Modernizing the entire power system is not a practical solution because it involves huge financial burden. Thus, researchers have adopted various methodologies which can be attempted without involving major revamping of the actual power system. Network Reconfiguration (NR) is a method which works on the principle of ON/OFF conditions of switches of the distribution system. ABC algorithm has been suggested to minimize the power losses by introducing DG and capacitors with a single computation [9].

An analytical method for optimally placing the renewable DG and capacitor bank with a view of reducing the cost has been suggested. The reliability of the distribution system has been analyzed from the voltage stability analysis. Evolutionary search algorithm has been exercised for the location and sizing of DG and capacitors [10].

By combining fuzzy and GA, an approach has been developed for the simultaneous application of DGs and capacitors in the distribution network to reduce active and reactive power supply, active power loss and refinement in the capacity of branch currents. The functioning of the distribution system was analyzed by the combined operation of shunt capacitors with UPF DG and lagging pf DG unit [11].

An intelligent system which identifies the voltage instability and analyses the output voltage of a power distribution network as safe or unsafe. This work exploits the output voltage patterns as input to the neural network for the testing purpose and formulates rapid instability identification system which simulates a skilled operator to monitor and control the assumed power distribution network [12].

An optimal routing algorithm has been used for minimizing the losses and to improve stability of the voltages in radial distribution system. In the algorithm, voltage stability index (VIS) for the real time analysis is prescribed from the usual critical transmission path. Moreover, this algorithm is able to identify critical paths which lead to voltage collapses when further real and reactive loads are added [13].

In this article, an uncomplicated methodology has been proposed for optimally placing and sizing of the combined DG and capacitor units in RDS. The work is focused to improve the characteristic nature of voltage profile and to minimise the network losses. A metaheuristic algorithm namely Moth Flame Optimization algorithm is employed to figure out this problem. The algorithm works on the basis of natural behavior of moths against lights and it has two essential components of moth and flames. The viability of the proposed method has been demonstrated by the test case analysis on IEEE 12 and 33 node systems and the observations are correlated with that of different methods reported in literatures.

Roblem formulation

VSI of the RDS

The VSI offers the data for a stable operation of all buses in the system. The variation in this index is considered as a measure of sensitivity of the nodes with respect to the voltage levels. The mathematical equation for computing the VSI is formulated as [4]

$$VSI(q) = \left|V_p\right|^4 - 4\left[P_q^F \cdot X_{pq} - Q_q^F \cdot R_{pq}\right]^2 - 4\left[P_q^F \cdot R_{pq} - Q_q^F \cdot X_{pq}\right] \cdot \left|V_p\right|^2$$

(1)

Objective function

The implementation of scheme of combined DGs and capacitors in the distribution network with their optimal size and location decides the stability of the system. Improper selection and application may leads to loss of power, operational cost besides reducing the efficiency factor. The prime intention of the proposed exercise is to minimize the total active power loss at a point of full load condition of the distribution system as suggested by the following equation

(2) $$MinP_L = \sum\nolimits_{(\forall p,q|p,q\in S_B)} {I_{pq}}^2 R_{pq}$$

Where\\\; P_L = Power Loss; I_{pq}= Current passing through the section connected across p and q is specified as

$$I_{pq} = \sqrt{\frac{P_{pq}^2 + Q_{pq}^2}{V_p^2}}$$

R_{pq} = Series resistance; *Equality and Inequality Constraints*

The various equality and inequality constraints are presented from equations (2) – (9). While implementing the DGs, the voltage of different buses and current through the lines are to be kept at safer limits for the stable functioning of distribution system.

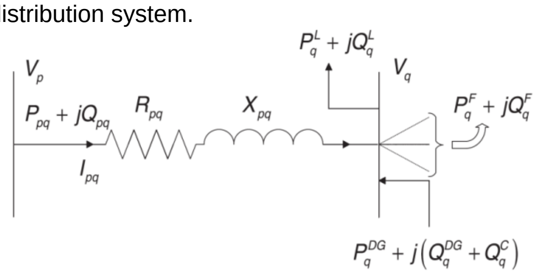

Fig. 1. Model of structure of RDS system

Real and reactive power flow limit

The mathematical representation of active and reactive power flow over the line m is defined using equations:

(3) $$P_{pq} = P_q^F + P_q^L - P_q^{DG} + \frac{R_{pq}}{V_p^2}\left(P_{pq}^2 + Q_{pq}^2\right)$$

(4) $$Q_{pq} = Q_q^F + Q_q^L - Q_q^{DG} - Q_q^C + \frac{X_{pq}}{V_p^2}\left(P_{pq}^2 + Q_{pq}^2\right)$$

Magnitude of the Voltage

The sending and receiving point voltage magnitude of the RDS must satisfy equation (5)

$$V_q^2 = V_p^2 - 2\left(P_{pq}R_{pq} + Q_{pq}X_{pq}\right) + \frac{R_{pq}^2 + X_{pq}^2}{V_p^2}\left(P_{pq}^2 + Q_{pq}^2\right)$$

(5)

Voltage profile

Bus voltage of each bus must lies between minimum and maximum limits of the tolerable limits.

(6) $$V_q^{min_{qq}^{\max}}\ q \in S_B$$

Line current

The line current in each branch must lie within the thermal limit.

(7) $$I_{pq} \le I_{pq}^{rated} \forall pandq \in S_B$$

Capacity of DG unit

The capacity of DG unit should be less than or equal to some percentage of total feeder load.

$$\sum_{q\in S_B}\sqrt{\left(P_q^{DG}\right)^2+\left(Q_q^{DG}\right)^2}\le 0.5\times\sum_{q\in S_B}\sqrt{\left(P_q^{L}\right)^2+\left(Q_q^{L}\right)^2} \tag{8}$$

Size of the Capacitor

Size of the capacitor must be within the sum of reactive power load of the system.

$$\sum_{q\in S_B}Q_q^c\le 1.0\times\sum_{q\in S_B}Q_q^L \tag{9}$$

Solution methodology

Moth – Flame Optimization (MFO) Technique

Generally, optimization algorithms have been confined to the local optimum which curtails the algorithm from attaining their original optimal solution and other flaws are huge computational burden and time consumption [18, 19]. One of recently introduced evolutionary algorithm, namely Moth fly optimization algorithm which was introduced by Mirjalili during 2015. It has received wider attention among the researchers and has been applied to solve multi objective optimization algorithms. It exhibits a competitive performance over other algorithms because of its good convergence attitude. This technique is formulated on the basis of biological behaviour of moth fighting flames in field. The MFO technique uses a community of moths in order to do the optimization process and each and every moth is needs to upgrade their position with reference to the flame. It protects the moth to evade from the entrapment of local optima and to regain its inspection process in the search space. More specifically, its performance is on the virtue of the transverse orientation process. The navigating nature of the moth has inspired the researchers to carry out this kind of optimization problem.

Functions of MFO

Basically, MFO based on its biological nature of moths and its flame around the field. The moth strengthens its place by navigating around its light.Moth adopts exclusive flying methods for transverse adaptation during the hours of darkness. Moth used to fly during the hours of darkness by following a certain angle with reference to moon. This exceptional mechanism is highly helpful for the moths to move in straight line whenever the source of light faraway. However, once the origin of light is nearby, moth used to move in spiral path surrounding it. Here the search agents are the moths which shift its position closer to search space and the best position of the updated flame. It is illustrated in the figure 2, where the light is the prime source and convergence of moths be exercised by preserving a fixed angle. The exclusive characteristics of moth is formulated [17- 19].

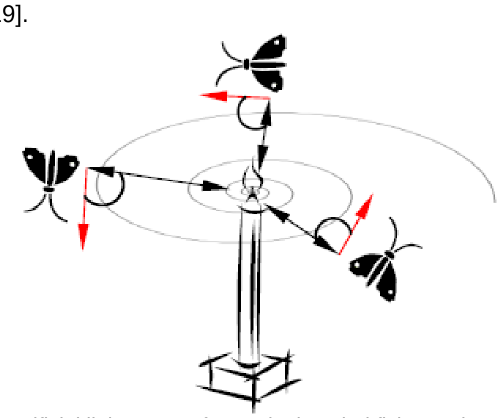

Fig. 2. Artificial light source for moths in spiral flying path

Modelling of MFO Algorithm

Generating the initial population of Moths

In this algorithm, the moth is treated / considered as the candidate solution to the subject of matter, and the position of the moth in the field is considered as the variable to be solved.As MFO technique is basically swarm based optimization module, the population of moth can be expressed as

$$M=\begin{bmatrix} m_{1,1} & m_{1,2} & \cdots & m_{1,d}\\ m_{2,1} & m_{2,2} & \cdots & m_{2,d}\\ \vdots & \vdots & \cdots & \vdots\\ m_{n,1} & m_{n,2} & \cdots & m_{n,d}\end{bmatrix} \tag{10}$$

While 'n' indicates amount of count of moths and'd' refers dimension size of the optimization problem in this solution space. Further, it is also pretended that there is a proportionate series of fitness vectors, and it can be described as

$$OM=\begin{bmatrix} OM_1\\ OM_2\\ \vdots\\ OM_n\end{bmatrix} \tag{11}$$

It is necessary for every moth to renew its place with respect to the flame relevant over it, in order to avert the technique slipping in the local optimal point. This processes support the technique moving towards the global searching mode. Here the location of the moth and flame is the search area and become variable matrices of the equal dimension.

$$M=\begin{bmatrix} F_{1,1} & F_{1,2} & \cdots & F_{1,d}\\ F_{2,1} & F_{2,2} & \cdots & F_{2,d}\\ \vdots & \vdots & \cdots & \vdots\\ F_{n,1} & F_{n,2} & \cdots & F_{n,d}\end{bmatrix} \tag{12}$$

The fitness value vectors are assumed as,

$$OF=\begin{bmatrix} OF_1\\ OF_2\\ \vdots\\ OF_n\end{bmatrix} \tag{13}$$

Upgradation of the Moths' Positions:

The suggested MFO implements three types of operations for achieving the global best optimal values and the tasks are outlined as,

$$MFO=(I,P,T) \tag{14}$$

The random distribution of moth is formulated as

$$M\left(i,j\right)=\left(ub\left(i\right)-lb\left(j\right)\right)*rand\left(\ \right)+lb(i) \tag{15}$$

The Logarithmic spiral, space about a flame and the position with regards to 't' is shown in fig. 3 and fig. 4 depicts spiral path around the flame and the moths update their positions [18].

Hence, the logarithmic spiral of the MFO algorithm may be formulated as

$$S\left(Mi,Fj\right)=Die^{bt}\cos\cos(2\pi t)+Fj \tag{16}$$

The space among the *i-th* moth and the *j-th* flame represented in the form of

(17) $$Di = |Fi - Mi|$$

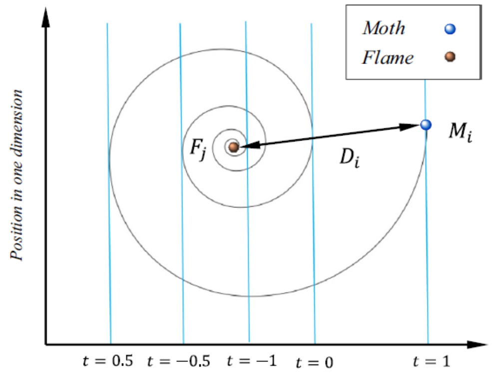

Fig. 3. Logarithmic spiral, space about a flame, and the location with response to ‘t’

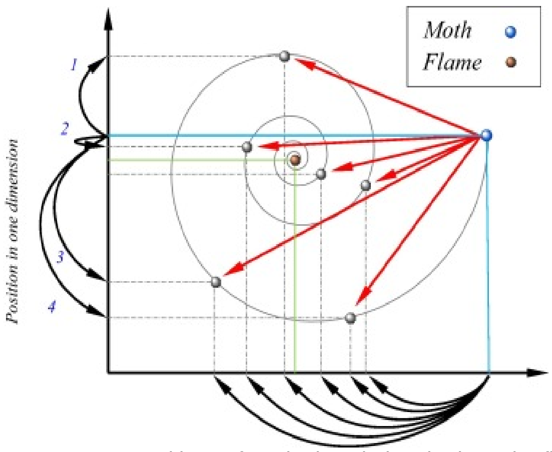

Fig. 4. Temporary positions of moths in spiral path about the flame using theLogarithmic spiral

Updating the count of Flames

During the course of iteration process, the number of flames gets decreased so as to keep the equilibrium in exploration and exploitation process. This balanced decrement in the count of flames stabilises the activities in the exploration space. For the best moth position, the best flame has to be identified from the previous iteration and the best objective function value is obtained using equation:

(18) $$Flame\ no = round\left(N - l * \frac{N-l}{t}\right)$$

Implementation of MOTH FLAME optimization algorithm

The MFO algorithm has been applied for the computation of best solution by using the following steps

1. Read the system information
2. Execute distribution load flow for base case.
3. Fix number of DG and Capacitor areto be used to in RDS...
4. Initialize count of moths (Population), maximum no of iterations, dimension, lower bound and upper bound (node and size of DG and Capacitor respectively)
5. Set iteration=1.
6. Calculate fitness (i.e. loss in network) for each moth by placing DG and Capacitor at their respective buses using eqn. (15).
7. Update the position of flame and save the best fitness values in an array corresponding to eqn. (16)
8. Update the record of flames and the flames are arranged using eqn. (17) based on their fitness values
9. Compute the present position of moths.
10. Check the all constrains are satisfied, if yes move to next step, else go to step 6.
11. Check If the number of iteration process is equal to maximum number of iterations, go to step 12. Otherwise go to step 5.
12. Display the optimal solution and STOP the program.

The flow diagram of proposed MFO technique for optimal location and sizing of DGs and capacitor in RDS is given in fig.5.

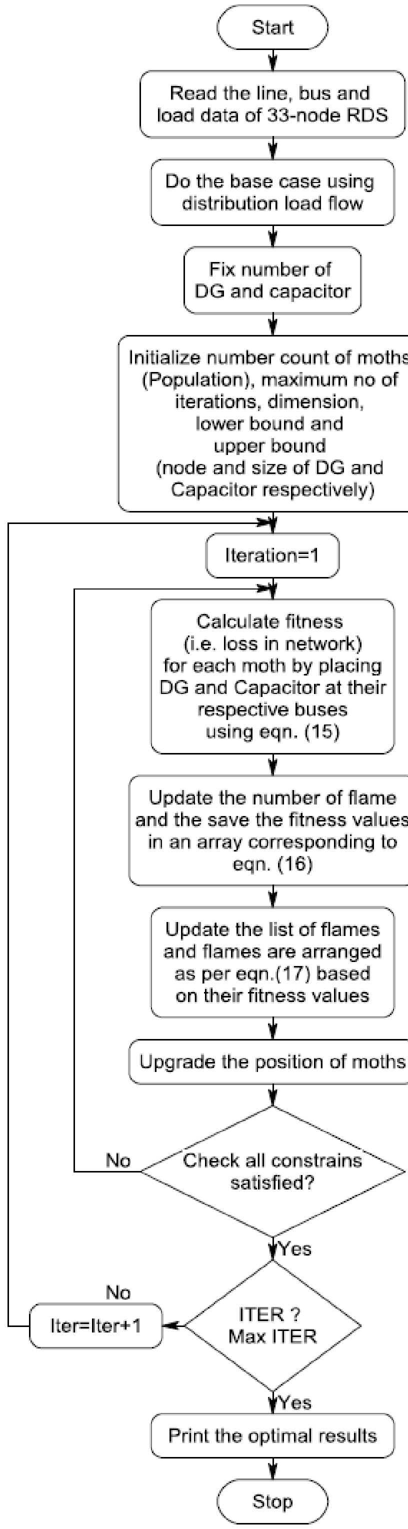

Fig. 5. Flow chart of the proposed MFO technique

Case study and results

In the present investigation, two standard test systems such as 12 and 33 nodes are taken in to account to illustrate the validity of devised algorithm. The simulations are performed on MATLAB 14.0 platform. The solution has been obtained with different test cases.

Test system 1: 12- node RDS

In this test case, total capacity of the system is 11 KV, it contains 12 node and 11 lines with total real and reactive load of 435 kW and 395 KVAr. The line and bus data, real and reactive loads of are taken from the reference [4]. The proposed MFO is a parameter less algorithm and it has only common control parameters. It includes agents or number of moth = 30, Most extreme number of iterations = 100, Number of variables = 11. The following three different test cases are analysed by MFO approach

- Optimal allocation of capacitor alone with its best size and placement
- Optimal allocation of simply DGs operating at unity PF at best location
- Optimal allocation both capacitor and DGs operated at unity PF with best size.

Distribution power flow method is proposed to do the base case power flow. The voltage profile of the 12 bus system with dissimilar cases are reported in Table 1 and graphically represented in fig. 6. From the table, the voltage profiles are highly improved by optimal placement of combined DG and capacitor compared with base case, single capacitor and sing DG. The VSI with various cases are presented in table 2 and also graphically displayed in figure 7.

Table 1. Voltage profile for 12-node RDS

Bus No.	Base Case	Capacitor	DG	Capacitor with DG
1	1.0000	1.0000	1.0000	1.0000
2	0.9943	0.9952	0.9966	0.9976
3	0.9890	0.9908	0.9937	0.9957
4	0.9806	0.9839	0.9895	0.9935
5	0.9698	0.9755	0.9852	0.9920
6	0.9665	0.9731	0.9841	0.9919
7	0.9637	0.9710	0.9833	0.9921
8	0.9552	0.9647	0.9837	0.9950
9	0.9471	0.9595	0.9869	0.9983
10	0.9442	0.9567	0.9841	0.9956
11	0.9433	0.9559	0.9832	0.9947
12	0.9431	0.9556	0.9830	0.9945

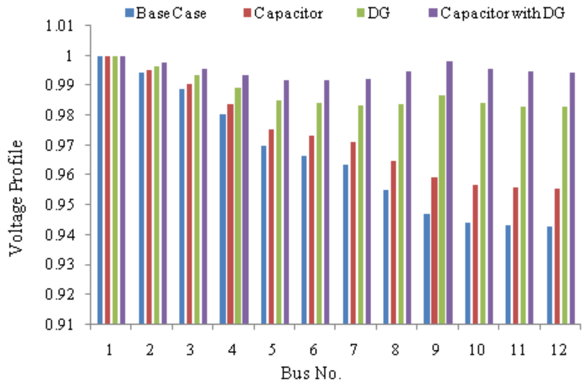

Fig. 6. Voltage profile for 12 bus system with different cases

Table 2. VSI for 12- Bus radial distribution system

Bus No.	Base Case	Capacitor	DG	Capacitor with DG
1	1.0000	1.0000	1.0000	1.0000
2	0.977305	0.980671	0.986215	0.990236
3	0.956650	0.963464	0.974889	0.983085
4	0.924073	0.936863	0.958529	0.974062
5	0.883900	0.905269	0.942180	0.968533
6	0.872648	0.896502	0.938503	0.968158
7	0.862645	0.889009	0.935716	0.968659
8	0.832376	0.866058	0.937471	0.980195
9	0.804778	0.847510	0.950408	0.992810
10	0.795627	0.838024	0.940342	0.982507
11	0.792651	0.834969	0.937102	0.979194
2	0.791954	0.834254	0.936344	0.978419

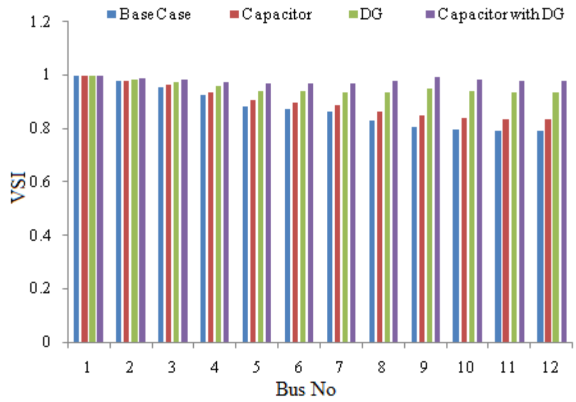

Fig. 7. VSI for 12-node system with different cases

Table 3. Simulation results of 12-node RDS

	Capacitor	DG	Capacitor with DG
Optimal Location	9	9	9, 8
Optimal Size	0.2	0.2355	0.23296, 0.25
Power Loss (KW)	12.6028	10.7744	3.1693

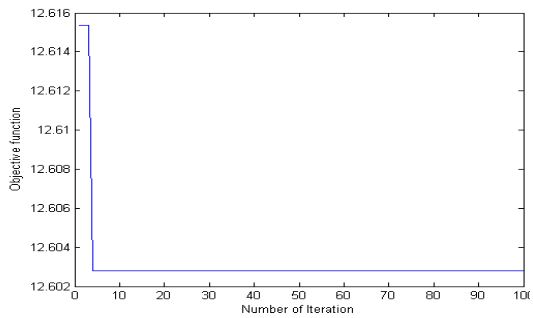

Fig. 8. Convergence curve of Capacitor placement

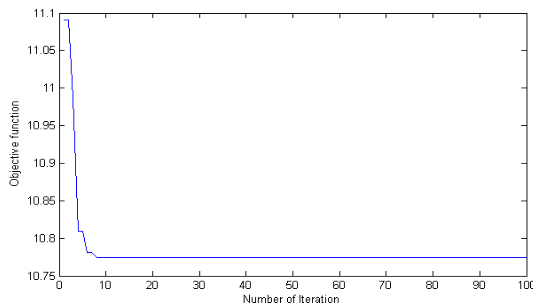

Fig. 9. Convergence curve of DG placement

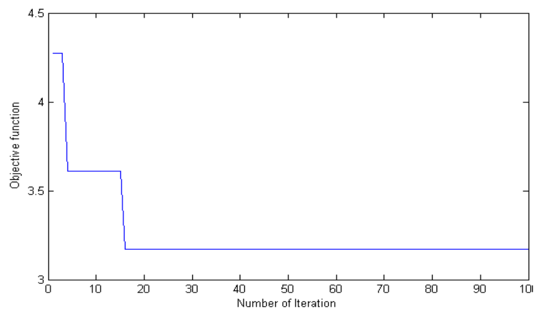

Fig. 10. Convergence curve of DGs with Capacitor placement

Table 4. Optimal location, size and minimum voltage for proposed with existing method

Particulars	Conventional Method [4]		MFO (Proposed)	
	Location and size	Min voltage (p.u.)	Location and size	Min voltage (p.u.)
Base case	-	0.94414 at bus 12	-	-
Capacitor	0.16 MVAr capacitor at bus 12	0.95596 at bus 11	0.2 MVAr capacitor at bus 9	0.9556at bus 12
DG at UPF	0.2MW DG bus 12	0.98032 at bus 8	0.2355 MW DG bus 9	0.9830 at bus 12
Both DG and Capacitor	0.12MW DG at bus 12 and 0.24 MVAr capacitor at bus 12	0.9815 at bus 8	0.23296 MW DG at bus 9 and 0.25 MVAr capacitor at bus 8	0.9919at bus 6

Table 5. Network losses and loss reduction for proposed with existing method

Particulars	Conventional Method		MFO (Proposed)	
	Network loss (kW)	% Loss reduction	Network loss (kW)	% Loss reduction
Base case	198.9	-	-	-
Capacitor	134.3	32.47	12.6028	36.6375
DG at UPF	109.2	45.09	10.7744	45.8301
DG and Capacitor	71.93	63.8	3.1693	84.0659

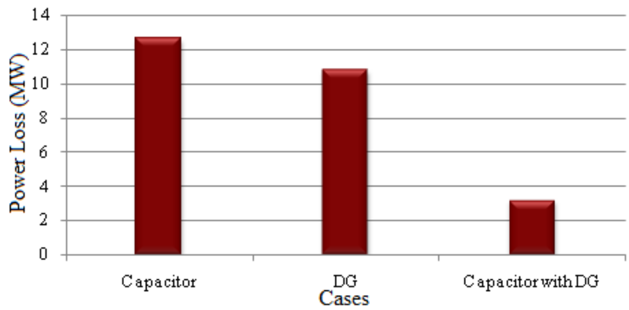

Fig. 11. Power loss for 12-node system

The numerical results are clearly reported in Table 3, it includes optimal location, size and network losses of the RDS with different cases. The convergence characteristics of three different cases are displayed in fig. 8, fig. 9 and fig. 10. The power loss of the three different cases is graphically displayed in fig. 11. The comparative review has also been done to assess the applicability and superiority of planned MFO. Comparison of optimal location, size and minimum voltage for proposed with prevailing practices are presented in Table 4. The system losses and curtailment of losses are also compared with accepted methods are recorded in Table 5. From the table 1 and 5, it is established that the proposed MFO enhances the voltage profile besides reducing the network losses of the system.

Test system 2: 33 Bus RDS

In second case, the large scale system of 33 node system is taken into account in order to demonstrate the efficacy of the devised MFO methodology. The system and load data of the 33-node network is adapted from [1]. The voltage rating is 12.66 KV with a absolute load of 3.72 MW and 2.3 MVAR are considered in this test system. The MFO algorithmic specification includes count of search operators or count of moth = 40, Maximum iterations = 100, total variables = 11. The proposed system has been analysed on the following five different test cases.

- Optimal allocation of capacitor alone with its best size and placement
- Optimal allocation of simply DGs operating at unity PF at best location
- Optimal allocation of both capacitor and DGs operated at unity PF with best size
- Optimal allocation of both DGs and capacitor at 0.9 Pf lag with economical size
- Optimal allocation of both DGs and capacitor at 0.85 Pf lag with economical size

Table 6. Voltage profile for 33-Bus RDS

Bus No.	DG	Capacitor	DGs with Capacitor	0.9pf	0.85pf
1	1.0000	1.0000	1.0000	1.0000	1.0000
2	0.9977	0.9976	0.9981	0.9981	0.9980
3	0.9869	0.9863	0.9894	0.9894	0.9894
4	0.9820	0.9809	0.9860	0.9860	0.9859
5	0.9771	0.9757	0.9828	0.9828	0.9826
6	0.9644	0.9651	0.9758	0.9757	0.9754
7	0.9622	0.9616	0.9736	0.9723	0.9720
8	0.9601	0.9481	0.9716	0.9590	0.9587
9	0.9606	0.9419	0.9722	0.9528	0.9525
10	0.9617	0.9361	0.9733	0.9471	0.9468
11	0.9621	0.9352	0.9738	0.9463	0.9459
12	0.9631	0.9337	0.9747	0.9448	0.9445
13	0.9572	0.9276	0.9689	0.9388	0.9385
14	0.9551	0.9253	0.9668	0.9365	0.9362
15	0.9537	0.9239	0.9655	0.9351	0.9348
16	0.9524	0.9225	0.9642	0.9338	0.9335
17	0.9505	0.9205	0.9622	0.9318	0.9315
18	0.9499	0.9199	0.9617	0.9312	0.9309
19	0.9971	0.9970	0.9975	0.9975	0.9975
20	0.9936	0.9935	0.9940	0.9940	0.9939
21	0.9929	0.9928	0.9933	0.9932	0.9932
22	0.9922	0.9921	0.9926	0.9926	0.9926
23	0.9834	0.9827	0.9859	0.9859	0.9858
24	0.9767	0.9761	0.9793	0.9792	0.9792
25	0.9734	0.9728	0.9759	0.9759	0.9759
26	0.9625	0.9643	0.9747	0.9760	0.9756
27	0.9600	0.9634	0.9734	0.9765	0.9761
28	0.9487	0.9622	0.9695	0.9796	0.9791
29	0.9406	0.9617	0.9670	0.9824	0.9817
30	0.9371	0.9584	0.9656	0.9818	0.9812
31	0.9330	0.9543	0.9616	0.9779	0.9773
32	0.9321	0.9534	0.9607	0.9770	0.9765
33	0.9318	0.9531	0.9604	0.9768	0.9762

Table 7. VSI for 33-Bus RDS

Bus No.	DG	Capacitor	DG with Capacitor	0.9pf	0.85pf
1	1.000000	1.000000	1.000000	1.000000	1.000000
2	0.990658	0.990260	0.992234	0.992223	0.992179
3	0.948083	0.945563	0.957993	0.957918	0.957642
4	0.929628	0.925749	0.945122	0.945004	0.944569
5	0.911621	0.906312	0.932961	0.932798	0.932195
6	0.864250	0.867220	0.906301	0.906090	0.904886
7	0.857393	0.855922	0.898642	0.893643	0.892454
8	0.849914	0.808267	0.891004	0.844982	0.843824
9	0.852187	0.788058	0.893334	0.824305	0.823162
10	0.856275	0.768963	0.897526	0.804779	0.803649
11	0.857948	0.766341	0.899237	0.802093	0.800965
12	0.861449	0.761471	0.902823	0.797112	0.795987
13	0.840432	0.741699	0.881313	0.776887	0.775777
14	0.832976	0.734704	0.873676	0.769725	0.768619
15	0.828275	0.730290	0.868861	0.765206	0.764104
16	0.823721	0.726013	0.864197	0.760828	0.759730
17	0.816986	0.719689	0.857300	0.754355	0.753261
18	0.815009	0.717836	0.855274	0.752456	0.751364

19	0.988595	0.988202	0.990159	0.990147	0.990103
20	0.974411	0.974020	0.975963	0.975951	0.975907
21	0.971732	0.971341	0.973282	0.973270	0.973227
22	0.969241	0.968851	0.970789	0.970777	0.970734
23	0.935082	0.932685	0.944636	0.944563	0.944295
24	0.909875	0.907510	0.919301	0.919229	0.918964
25	0.897799	0.895451	0.907162	0.907090	0.906827
26	0.858406	0.865741	0.902720	0.907430	0.906143
27	0.849428	0.862451	0.897744	0.909307	0.907895
28	0.809630	0.858874	0.883649	0.921062	0.918845
29	0.782710	0.858405	0.874972	0.931568	0.928724
30	0.771404	0.846519	0.870080	0.929431	0.927186
31	0.757998	0.832475	0.855804	0.914726	0.912512
32	0.755169	0.829506	0.852793	0.911609	0.909399
33	0.754270	0.828563	0.851838	0.910620	0.908412

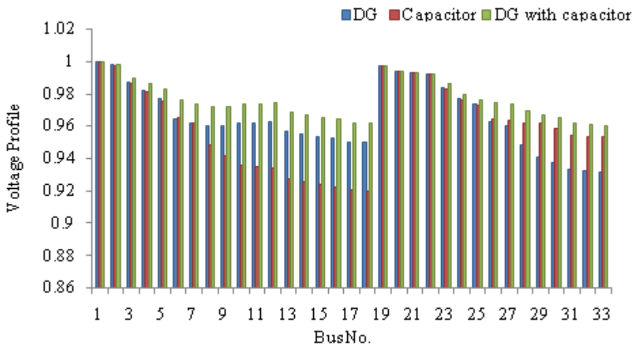

Fig. 12. Voltage profile for 33 node RDS (Case1, 2 and 3)

The proposed MFO algorithm precisely optimizes the best location and value of capacitor and DG units. The voltage contour of the 33-node test system under five different studies are tabulated in Table 6 and graphically reported in fig. 12 and fig. 13. The minimum VSI is located at bus 18 and VSI for different cases are presented in Table 7. The graphical representation of VSI for different cases is displayed in fig. 14 and fig. 15. From the Table 6 and 7, the voltage profile and VSI are highly improved by combined operation of both DGs and capacitor in the RDS. In case 4 and case 5 the voltage level and VSI has been improved at 0.9 power factor than the 0.85 power factor.

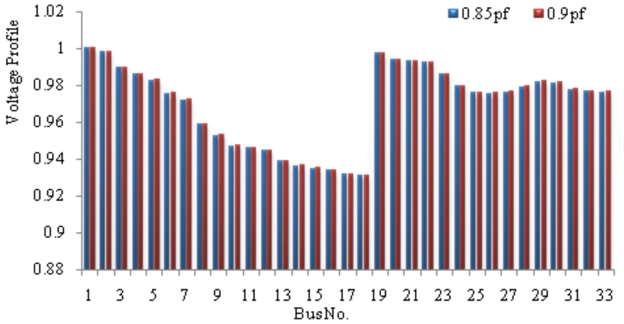

Fig. 13. Voltage profile for 33 node RDS (Case 4 and 5)

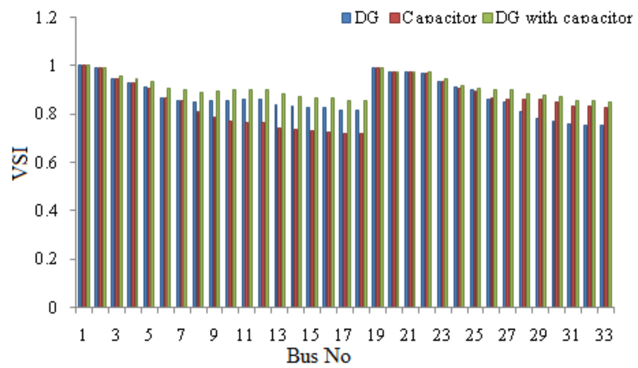

Fig. 14. VSI for 33 node RDS (Case 1, 2 and 3)

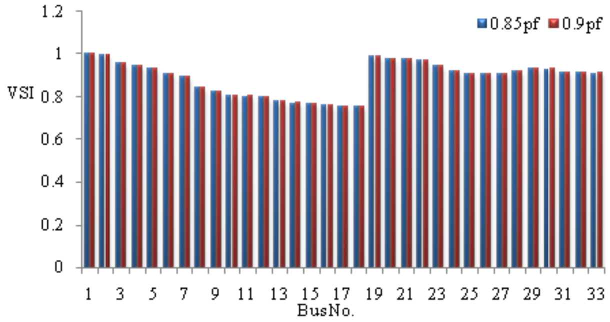

Fig. 15. VSI for 33 node RDS (Case 4 and 5)

Table 8. Numerical results for 33 node RDS

Components	Optimal location	Optimal Size	Power Loss (kW)
Capacitor	29	1.7	157.6864
DG at UPF	12	1	129.9648
DG and Capacitor	12, 30	1,1. 2	75.0069

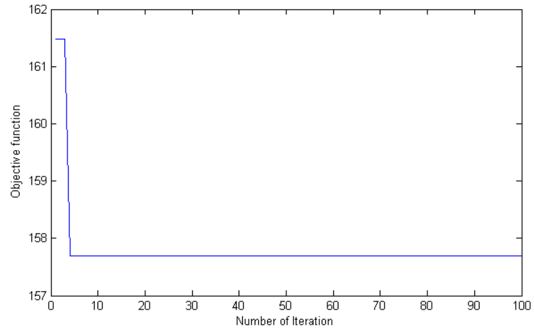

Fig. 16. Convergence curve for Single Capacitor placement

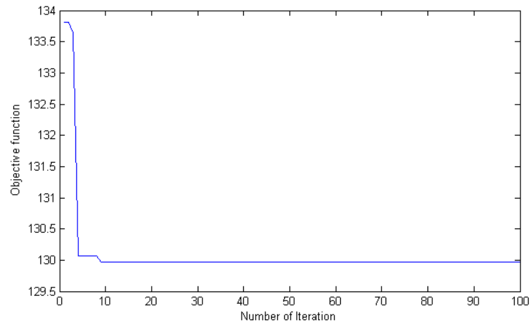

Fig. 17. Convergence curve for Single DG placement

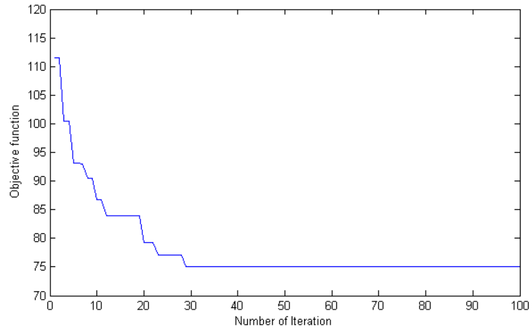

Fig. 18. Convergence curve for combined DG (UPF) with Capacitor placement

Table 9. Numerical results of 33 node RDS with low power factor

Cases		Optimal location	Optimal Size	Power Loss (kW)
0.85pf	Capacitor	29	1	84.3753
	DG	30	1.8	
0.9pf	Capacitor	29	1	83.5144
	DG	30	1.7	

The simulated outcomes are provided in Table 8 and 9. It includes the optimal placement, size and power in KW of capacitor, DG unit and combined capacitor and DG units. From Table 8, it is seen that the power loss is extremely reduced under the combined operation of capacitor and DG units (case 3) which is connected at the node 12 and 30. The optimal value of the DG and capacitor is 1.1 MW and 2 MVAr. The minimized power loss of both combinations is 75.0069 KW. The power loss in case 3 is effectively reduced than the case 1 and case 2. From Table 9, it is obvious that the combined action of DG and capacitor with 0.9 power factor provides minimum power loss compared with 0.85 power factor (case 5) with power loss of 83.5144 KW. The convergence characteristics of different cases are displayed in fig. 16, fig. 17 and fig. 18.

Table 10. Comparison of optimal location, size and minimum voltage for proposed with existing method

Particulars	Conventional Method [1]		MFO (proposed)	
	Location and size	Min voltage (p.u.)	Location and size	Min voltage (p.u.)
Base case	-	0.9065 at 18	-	-
Capacitor	1.0 MVAr at 33	0.91654 at 18	1.7 MVAr at 29	0.9499 at 18
DG at UPF	1.0 MW, at 18	0.9311 at 33	1MW at 12	0.9199 at 18
DG and Capacitor	1.0 MW at 18 and 1.0 MVAr at 33	0.96003 at 30	1.0 MW at 12 and 1.2 MVAr at 30	0.9617 at 18
0.9 PF lag	1.0 MW at 18 and 1.0 MVAr at 33	0.9646 at 30	1.8 MW at 30 and 1.0 MVAr at 29	0.9312 at 18
0.85 PF lag	0.8 MW at 18 and 0.8 MVAr at 33	0.9566 at 30	1.7 MW at 30 and 1.0 MVAr at 29	0.9309at 18

Table 11. Comparison of power loss and loss reduction for proposed with existing method

Particulars	Conventional Method [1]		MFO (proposed)	
	Network loss (kW)	% Loss reduction	Total real power loss (kW)	% Loss reduction
Base case	213.3	-	-	-
Capacitor	164.6	22.83	157.6864	26.0729
DG at UPF	142.34	33.29	129.9648	39.0695
DG and Capacitor	96.70	54.66	75.0069	64.8350
0.9 PF lag	90.9	57.38	83.5144	60.8465
0.85 PF lag	89.72	57.94	84.3753	60.4429

Comparative study has been made to show the performance of suggested MFO technique. The simulated outcomes are compared with conventional mathematical approach and given in Table 10 and Table 11. The capacity, optimal location and minimum voltage for dissimilar cases are compared in Table 10. Table 11 depicts simulation results of network losses and reduction of losses inpercentage of conventional and proposed method. From the comparison, it is evident that the proposed MFO provides the minimum power loss, suitable size of the capacitor and DGs, for the enhanced voltage profile with minimum running time than the conventional method.

Conclusion

In this assignment, a novel MFO has been suggested for improving the voltage profile and to minimize the power losses of distribution systems. The algorithmic concept revolves around the natural behaviour of moths against light and it involves two fundamental components of moths and flames. The algorithm imbibes the potential of global search capacity and a dynamic balance among the global and local searching practice. Moreover, it has only fewer parameter settings when compared with other nature inspired algorithms, conducive to implement and showing faster convergence. The proposed methodology distinctively identifies the optimal locations and sizing of components for the improvement of voltage stability and to minimise the line losses. The work has been subjected to various case studies with different configurations under two bench mark test systems to substantiate the excellence of the projected algorithm. The outcome of the problem has been compared with the other conventional approach in order to validate the results. The solution of the case studies demonstrates the strength of this algorithm in distribution systems.

Authors: *S.K.B Pradeep Kumar Ch, Research Scholar, Annamalai University, India, Email: skbpradeepkumarch@gmail.com, Dr.G.Balamurugan, Professor, Annamalai University, India, Email: abi_senthil10@rediffmail.com, Dr.Y.Butchi Raju, Professor, Sir, C.R.Reddy College of Engineering, India, Email: butchiraju.y@gmail.com*

REFERENCES

[1] Rajeswaran, Sivasangari, and Kamaraj Nagappan. "Optimum simultaneous allocation of renewable energy DG and capacitor banks in radial distribution network." *Circuits and Systems,* Vol.7, no. 11, pp.3556-3564, 2016.
[2] Yadav, Purushottam Singh, and Laxmi Srivastava. "Optimal location of combined DG and capacitor for real power loss minimization in distribution networks." *Int. J. Electr. Electron. Eng,* Vol.7, pp.222-233, 2015.
[3] Roy, Kingshuk, and Shishir Dixit. "Optimal Placement and Sizing of Distributed Generation and Capacitors: A Review.", International Journal of New Innovations in Engineering and Technology, Vol.2, No.4, pp.101-106, 2020.
[4] Naik, S.G., Khatod, D.K. and Sharma, M.P., "Optimal allocation of combined DG and capacitor for real power loss minimization in distribution networks". *International Journal of Electrical Power & Energy Systems*, Vol.53, pp.967-973, 2013.
[5] Kowsalya, M.I.A.M., "Optimal Distributed Generation and capacitor placement in power distribution networks for power loss minimization". In *2014 International Conference on Advances in Electrical Engineering (ICAEE),* Jan., pp. 1-6, IEEE, 2014.
[6] Muthukumar, K., and S. Jayalalitha. "Integrated approach of network reconfiguration with distributed generation and shunt capacitors placement for power loss minimization in radial distribution networks." *Applied Soft Computing*, Vol.52, pp.1262-1284, 2017.
[7] Kumar Injeti, Satish, Sd Meera Shareef, and T. Vinod Kumar. "Optimal allocation of DGs and capacitor banks in radial distribution systems." *Distributed Generation & Alternative Energy Journal*, Vol.33, no. 3, pp.6-34, 2018.
[8] Gampa, Srinivasa Rao, and Debapriya Das., "Fuzzy GA based Multiobjective Methodology for DGs and Shunt Capacitors Placement in Distribution Networks." In *2018 20th National Power Systems Conference (NPSC)*, pp. 1-6. IEEE, 2018.
[9] Muhtazaruddin, Mohd Nabil Bin, Nurul Aini Bani, Siti Armiza Mohd Aris, Hazilah Mad Kaidi, Abdul Yasser Abd Fatah, Jasrul Jamani Jamia, Firdaus Muhammad-Sukki, and Siti Hawa Abu-Bakar. "Distribution power loss minimization via distributed generation, capacitor and network reconfiguration." *Indonesian journal of electrical engineering and computer science*, Vol.5, no. 3, 2017.
[10] Pradeepa, Ha, T. Ananthapadmanabha, Sandhya Rani DN, and C. Bandhavya. "Optimal allocation of combined DG and

capacitor units for voltage stability enhancement." *Procedia Technology,* Vol.21, pp.216-223, 2015.
[11] Gampa, Srinivasa Rao, and Debapriya Das. "Simultaneous optimal allocation and sizing of distributed generations and shunt capacitors in distribution networks using fuzzy GA methodology." *Journal of Electrical Systems and Information Technology* , Vol.6, no. 1, pp.1-18.
[12] Ouali, Saad, and Abdeljebbar Cherkaoui. "Optimal Allocation of Combined Renewable Distributed Generation and Capacitor Units for Interconnection Cost Reduction." *Journal of Electrical and Computer Engineering,* Vol.2020, pp.1-11, 2020.
[13] Lalitha, M. Padma, P. Suresh Babu, and B. Adivesh. "Optimal distributed generation and capacitor placement for loss minimization and voltage profile improvement using Symbiotic Organisms Search Algorithm." *International Journal of Electrical Engineering,* Vol.9, no. 3, pp.249-261, 2016.
[14] M. Chakravorty, D. Das, "Voltage stability analysis of radial distribution networks" *Electrical Power and Energy Systems*, Vol.23, pp.129-135, 2001.
[15] Khatod, D.K., Pant, V. and Sharma, J., "Evolutionary programming based optimal placement of renewable distributed generators" *IEEE Transactions on Power systems*, Vol.*28* (2), pp.683-695, 2012.
[16] Haque, M. "Efficient load flow method for distribution systems with radial or mesh configuration". *IEE Proceedings-Generation, Transmission and Distribution*, Vol.*143* (1), pp.33-38, 1996.
[17] Shehab, M., Abualigah, L., Al Hamad, H., Alabool, H., Alshinwan, M. and Khasawneh, A.M., "Moth–flame optimization algorithm: variants and applications". *Neural Computing and Applications*, Vol.*32* (14), pp.9859-9884, 2020.
[18] Mirjalili, S., "Moth-flame optimization algorithm: A novel nature-inspired heuristic paradigm".*Knowledge-based systems*, Vol.*89*, pp.228-249, 2015.
[19] R. Ng Shin Mei, M.H. Sulaiman, Z. Mustaffa and H. Daniyal, "Optimal reactive power dispatch solution by loss minimization using moth-flame optimization technique", *Applied Soft Computing,* vol. 59, no. 2 , pp. 210-222, 2017.