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Power loss minimization with simultaneous location and sizing of distribution generation units using artificial algae algorithm

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ABSTRACT

Power loss is one of the important pointers used to measure the performance of distributions networks. Many optimization algorithms have been proposed to solve various optimal power flow problems in Electrical Engineering. In this paper, a novel technique, artificial algae algorithm is developed to robustly detect the optimal location and size of distributed generation (DG) units for minimization of total power losses without violating the equality and inequality constraints. The main objective of optimal power flow (OPF) is to maximize or minimize the objective function using various constraint so that steady-state operation point is achieved. The concept of optimal power flow in power system helps to minimize real power loss. In the proposed approach, various control variables like generator bus, voltage magnitudes, and transformer tap settings are considered. The proposed algorithm is simulated in MATLAB and effectiveness is carried on IEEE 33 bus radial distribution system and satisfactory results are achieved when compared with other optimization techniques. A notable improvement in reduction of active power losses with 3 DG operating at different power factors are 65.5%, 42.4%, and 77.8% respectively, were achieved in comparison to the system without DGs and as compared with other research papers.

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1. INTRODUCTION

In recent years, the penetration of intermittent renewable energy sources such as wind and solar into the India’s energy profile has increased significantly. The Government of India (GoI) has set ambitious renewable electricity targets for the short to medium term. By 2022 the country aims to shave 175 GWs of installed renewable electricity capacity. Energy sources utilized in this manner are known as distributed generation (DG) units. Distributed generation (DG) refers to relatively small generation systems that are designed, installed and operated in distribution networks or distributed at the customer side to meet special customers’ needs and support the operation of distribution networks based on economic, efficient, convenient, and reliable generation [1].

Several methods have been addressed by researchers to study the effect of DG on the power system losses. Wong *et al.* [2] proposed that from the perspective of utilities, integration of DG units can bring multiple technical benefits to distribution networks such as loss reduction, voltage profile improvement, voltage stability, network upgrades and reliability while supplying energy sales as a primary task [2], [3]. The distribution system is well-known for its high R/X ratio and significant voltage drops that could cause substantial power losses along the feeders. It is added that the distribution system incurs a power loss which is normally higher than the transmission system. Consequently, distribution loss reduction has been one of the greatest challenges to power distribution utilities worldwide, both in matured and growing power systems. Hassan *et al.* [4] presented in his work that loss reduction at the distribution system level is one of the major benefits due to its impact on the utilities revenue. In addition, as a key consideration for DG planning, the loss reduction can lead to positive impacts on system capacity release, voltage profiles and voltage stability.

The study of Ghosh *et al.* [5] shows that renewable energy-based DG units are developing fast all over the world in recent years due to its promising potential to minimize power losses and harmful carbon emissions. In this work, researchers explained the the challenges in DG applications for loss reduction are appropriate location, appropriate sizes, and operating strategies [5], [6]. Even if the location is fixed due to some other reasons, improper size would increase the losses in the system beyond the losses for case without DG. Hence, optimal location and size of DG in the RDS is most important to harness the maximum benefits from the DG when connected with the RDS [7]. Further, optimal location and sizing depend on the type of DG as well. The study shows that most of the techniques currently available in the literature to determine the optimal location and size of DG units for loss reduction are based on the assumption that DGs can only deliver real power [8] his assumption is unrealistic because there are many types of DGs that provide and/or consume both active and reactive powers. The most significant work dealing with all types of DGs has been presented in literature [9]. Optimal location can only be obtained after determining the optimal size. To bridge this gap, this paper contributes to develop an artificial algae algorithm for solving the simultaneous placement [10]-[12] of different types of multiple DG units to reduce the losses in the RDS.

In this paper, a novel nature inspired algorithm called artificial algae algorithm explored with ability of differential evolution (DE) algorithm is integrated to enhance the performance of both algorithms in searchings of optimal minimum objective function [13]. This method is a newly adopted method applied with DG penetration in radial disttibution system. The effectiveness of the proposed algorithm is validated on IEEE 33 bus RDS. The results show that in terms of optimality of the solution, artificial algae algorithm (AAA) has outstanding performance in attaining the simultaneous optimal location and sizing of different types of DG units in the distribution network for power losses reduction as compared to other methods, thereby suggesting that the solution is a globally optimal.

The rest of the paper is organized as follows. In section 2 detailed explaination of the algorithm and different DG types are highlighted. Section 3 discusses the particularities related to implementation of algorithm; in section 4, the results and discussion are presented. Finally in section 5, conclusions are drawn.

2. PROPOSED METHOD: ARTIFICIAL ALGAE ALGORITHM

The research work proposes novel bio-inspired metaheuristic optimization algorithm developed by Sait Ali Uymaz, Gulay Tezel, Esra Yel known as artificial algae algorithm (AAA). The algorithm is based on evolutionary process, adaptation process and the movement of microalgae. The AAA is based on algal reproduction, adaptation, and their swimming which emerges with the motion of being close to light as a photosynthetic organism. In case of insufficient light and nutrient conditions, species either die or adapt to the changing conditions in the environment. Algae are good swimmers because they continuously swim and try to stay close to water surface to get adequate light [14]. In AAA the global optimum of the objective function was defined as the point on which algae can receive optimum light for photosynthesis. Artificial algae algorithm has three main phases “Evolutionary phase”, “Adaptation phase” and “Helical phase”.

a) Evolutionary process: In this process, the algae receive sufficient nutrients and enough sunlight to grow and reproduce. But if the circumstances are not supportive, for example if the sunlight is not enough, then the algae may die. This process can mathematically be expressed by:

$$G_i^{t+1} = u_i^t G_i^t$$
for i=1,2, 3, N

where, G is the size of the jth algal in time t and N is the colony in the system. Of all N colonies, the colonies that provide better solutions grow bigger because they get enough sunlight to row. The colonies which do not give good solutions become smaller. D is the problem dimention.

$\text{biggest t} = \max \text{Gi t}$ $\quad i = 1,2, \ldots. N$
smallest t = min Gi ^{t} $\quad$ i=1, 2, N
Smallest tm^t = biggest m^t $\quad$ m= 1,2…D

b) Adaptation: In this process the insufficiently grown algal colony tries to adapt to the environment. The insufficiently grown algal colony tries to resemble itself to the biggest algal colony. The initial starvation value is assumed to zero for each algal and it is increases with time t. The starvation value of jth algal colony in time t is Ai ^{t}.

starving t = max Ai ^{t}, i= 1, 2,…N
starving t+1 = starving t + (biggest t – starving t) x rand

c) Helical Movement: The algal cells generally swim helically to stay close to the water surface. Movement restriction due to gravity is displayed as 0 and viscous drag is displayed as shear force which is proportional to the size of the algal cell.

$$\tau(x_i) = 2\pi r^2$$
$$\tau(x_i) = 2\pi\left(3\sqrt{\frac{3G_i}{4\pi}}\right)^2$$

Where $\tau(x_i)$ is the friction surface,

$$x_{im}^{t+1} = x_{im}^{t} + \left(x_{jm}^{t} - x_{im}^{t}\right)\left(\Delta - \tau^t(x_i)\right)p$$
$$x_{ik}^{t+1} = x_{ik}^{t} + \left(x_{jk}^{t} - x_{ik}^{t}\right)\left(\Delta - \tau^t(x_i)\right)\cos\alpha$$
$$x_{il}^{t+1} = x_{il}^{t} + \left(x_{jl}^{t} - x_{il}^{t}\right)\left(\Delta - \tau^t(x_i)\right)\sin\beta$$

where x_{im}^t, x_{ik}^t and x_{il}^t are x, y and z coordinates of the ith algal cellat time t; α and β ε [0,2 π],p ε [-1,1]; Δ is shear force.

In artificial algae algorithm, the colonies are shorted as per their size at a particular time t. The assumption is smallest colony dies and biggest colony reproduce. The smallest algae colony which is finding it difficult to survive in the current environment tries to adapt them self to the current environment to survive. In this process they try to replicate the behaviour of large algae colony. This process changes the starvation level of the algae colony trying to adapt to the new environmental condition. Initially for all algae the starvation value is zero. With sufficient light and good condition starvation level increases and with insufficient condition the starvation level decreases. Algae colony tries to stay close to the water surface so that they can get the maximum sunlight for their photosynthesis process. They stay close to the water surface by swimming helically. The movement of algae is proportional to its energy level. The energy level of an algae at any time t depends on the amount of nutrients taken by those algae at that time. The more energy an algae is having the deeper it can go in water. They swim helically in the liquid to restrict gravity and drag force of liquid. Various parameters like shear force, loss of energy, and adaptation are considered. The helical movement pattern [13] is shown in Figure 1.

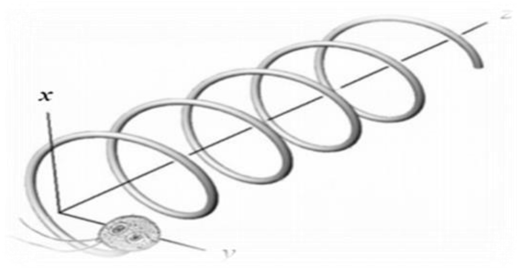

Figure 1. Helical movement

Group of algae cells form an algae colony and they live together. If the conditions are satisfied; single algae cell splits into two and starts living together [15]. So, under suitable condition with adequate nutrients available the algal colony grows and reproduces itself. On the other hand, with not enough sun light and nutrients the algal colony may die also. This process can me mathematically represented by Monod function:

$$\mu = \frac{\mu_{max} S}{K + S}$$

where,
μ specifies the growth rate,
μ_{max} specifies the maximum specific growth rate,
S specifies the nutrient concentration,

DG can be classified into four major types based on their terminal characteristics in terms of real and reactive power delivering capability as follows [10]:
a) Type 1: DG capable of injecting P (i.e. real power) only.
b) Type 2: DG capable of injecting Q (i.e. reactive power) only.
c) Type 3: DG capable of injecting both P and Q.
d) Type 4: DG capable of injecting P but consuming Q.

3. RESEARCH METHOD

Artificial algae algorithm is one of the new developed algorithms, inspired by nature. The implementation of the algorithm is illustrated with the following steps:
a) Randomly select DG
b) Perform load flow analysis of the system.
c) From the obtained result of step 2, calculate the value of the objective function.
d) Select the minimum value of the objective function as the best algae solution.
e) Update the algae colony using helical movement.
f) Perform the operation of reproduction and adaptation.
g) Repeat steps 2-4.
h) Compare the two outputs. If the stopping condition is achieved then stop, else repeat the same process again. Figure 2 shows the general flowchart of AAA Algorithm [13].

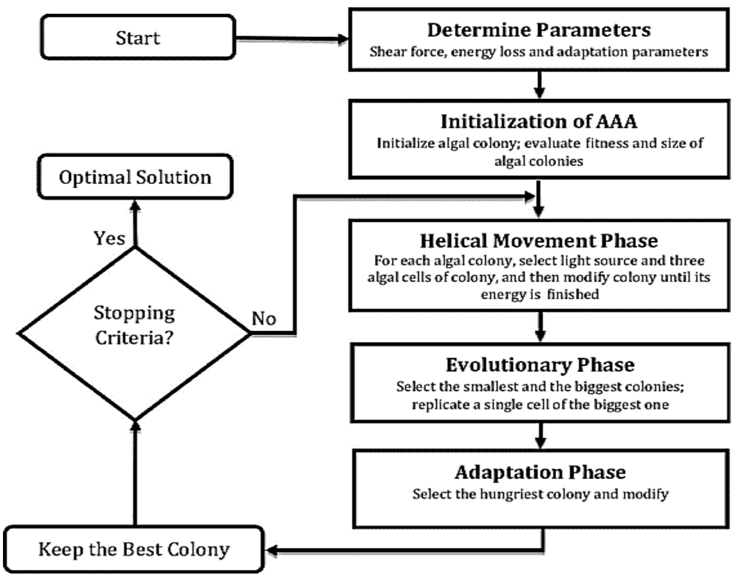

Figure 2. General flowchart of AAA Algorithm

4. RESULTS AND DISCUSSIONS

To verify the effectiveness of the proposed AAA algorithm, the IEEE 33 is considered in the different scenario for different test cases. Also, the results are compared with the results obtained from other methods. The proposed AAA algorithm is implemented in MATLAB 2019 and is executed on Intel core TM i3 PC with 2.66-GHz speed and 4GB RAM.

4.1. Test system

The Single line diagram of the IEEE -33 bus system is shown in Figure 3 [12]. For all the three scenarios that are mentioned in literature review, the following three test cases are considered. Base kV= 12.5, MVA =100 is taken into consideration. Other information of the test system is summarized in Tables 1 and 2.
– Test case -1: One numbers of DGs in each type.

– Test case -2: Two numbers of DGs in each type.
– Test case -3: Three numbers of DGs in each type

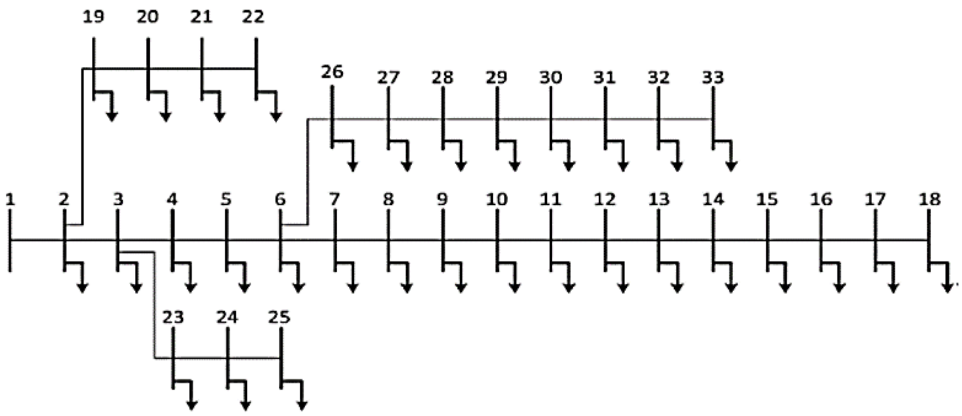

Figure 3. Single line diagram of the IEEE 33-node test system

4.2. Simulation results for 33 buses

In this section, the simulation results for optimal placement and sizing of different types of DG are obtained by using AAA. In this paper, AAA explored with ability of differential evolution (DE) algorithm is integrated to enhance the performance of both algorithms in searchings of optimal minimum objective function. Table 1 shows the results of the AAA algorithm in the standard IEEE 33 Bus system without DG at different operating power factor of unity, 0.85 and 0.95 respectively. Without installation of DG, real power losses at unity, 0.85 and 0.95 are 211 Kw, 70.25 Kw and 50.14 Kw respectively. Table 2 shows the results of algorithm in the standard IEEE 33 Bus system with DG. A considerable amount of reduction in power losses is obtained with penetration of DG in the system. Table 3 gives comparison of results with other methods using 1,2 and 3 DG operating at different power factors respectively and clearly shows that the proposed technique has the ability to find global optimization value in all the study cases [16]-[18]. The maximum loss reduction with better voltage profile is obtained using the proposed AAA technique by optimal siting and sizing of different types of multiple DG units simultaneously than optimal placement and sizing of DGs independently in the RDS. If DG is implemented on non optimal places, it can result in an increase in system losses and cost [19]. As size of DG is increased, losses at a particular bus starts to decrease but if size is increased beyond a limit, the losses starts to increase. Active power losses in the distribution system are high due to radial structure of these systems, hence it is very essential to reduce the power loss.

Table 1. Results of proposed algorithm in the standard IEEE 33 bus system (Without DG)

Algorithm	Ref	Power factor	Reduction of Power Loss (Kw)
AAA	Proposed	Unity	211.11
		0.85	70.25
		0.95	50.14

Table 2. Results of proposed algorithm in the standard IEEE 33 bus system (With DG)

Algorithm	Ref	No. of DG	DG Sizes (kW)	DG Locations	Power factor	Reduction of active power loss (Kw)	%Reduction of active power loss (Kw)
AAA	Proposed	1	2589.9	6	Unity	110.99	47.7%
			2636	7	0.85	68.36	2.7%
AAA	Proposed	2	852,1156.98	12,30	Unity	87	58.7%
			791,1300	12,30	0.85	31.2	55.5%
AAA	Proposed	3	780,1081.83,1068.66	18,28,31	Unity	72.81	65.5%
			830.12,1124.76,1247.34	13,24,31	0.95	28.84	42.4%
			742.12,1005.34,1120.1	13,24,30	0.85	15.574	77.8%

Table 3. Comparison of results of the standard IEEE 33 bus system -1,2 & 3 DG

Method & Year	No. of DG	P.f.(unity/0.85/0.95)	Location	Size (MW/KW)	Power Loss (KW)
Proposed	**1**	**Unity pf**	**6**	**2589.9**	**110.99**
Proposed	**1**	**0.85**	**7**	**2636**	**68.36**
Proposed	**2**	**Unity**	**12,30**	**852,1156.98**	**87**
Proposed	**2**	**0.85**	**12,30**	**791,1300**	**31.2**
Proposed	**3**	**Unity**	**18,28,31**	**780,1081.83,1068.66**	**72.81**
Proposed	**3**	**0.95**	**13,24,31**	**830.12,1124.76,1247.34**	**28.84**
Proposed	**3**	**0.85**	**13,24,30**	**742.12,1005.34,1120.1**	**15.574**
MRFO, 2021 [16]	1	Unity pf	6	2590.217	111.02
GA, 2018 [10]	1	Unity pf	6	2593.6	111.03
WOA, 2018 [17]	1	Unity pf	6	2600	111.03
HPSO, 2014 [17]	1	Unity pf	8	3623.9	131.85
ANALYTICAL APPROACH, 2015 [17]	1	Unity pf	6	2968.46	139.16
AEO, 2020 [14]	1	Unity pf	6	2590.21	111.01
EAEO, 2020 [14]	1	Unity pf	6	2590.21	111.01
EA-0PF, 2016 [14]	1	Unity pf	6	2590	111.02
EAEO, 2020 [14]	1	0.85	6	2637.55	68.557
IA, 2013 [20]	1	0.85	6	3103	68.70
MRFO, 2020 [16]	2	Unity pf	30,13	1157.6,851.5	87.16
GA, 2017 [10]	2	Unity pf	13,30	840,1134	87.19
GA, 2012 [10]	2	Unity pf	11,29,30	1.5000,0.4230,1.0710	106.30
AEO, 2020 [14]	2	Unity pf	13,30	851.62	87.16
EAEO, 2020 [14]	2	Unity pf	13,30	1157.58	87.16
BSOA, 2015 [20]	2	Unity pf	13,30	880,924	89.34
HGWO, 2020 [20]	2	Unity pf	13,30	852,1150	87.164
MINLP, 2014 [21]	2	Unity pf	13,30	850,1150	87.167
IDBEA, 2021 [22]	3	Unity pf	13,24,30	1.0980,1.0970,1.7250	94.8514
PSO, 2012 [23]	3	Unity pf	8,14,32	1.1770,0.9820,0.8300	105.300
BSOA, 2015 [24]	3	Unity pf	12,28,31	632,487,550	89.05
HGWO, 2017 [25]	3	Unity pf	13,24,30	802,1090,1050	72.84
Hybrid, 2016 [26]	3	Unity pf	13,30,31	830,1110,1210	87.28

4.3. Power loss minimization

The impact of DG integration on active power loss were calculated on each branch [15]. Figure 4 shows reduction of power loss without impact of DG. A considerable reduction in power loss were noticed when Type -1 DG were placed in the distribution system, which are shown in Figure 5. Figure 6 shows a comparison of reduction of power loss between without DG and impact of DG penetration. The results clearly shows that power loss is minimized to a large extent when DG is injected into the system, establishing the advantages of the DG penetration in the optimization problem of optimal power flow. Figures 7-9 shows sample of convergence curves of AAA with 1, 2 and 3 DG. Figure 9 shows the minimum value of objective function appears in case 3 in comparison to other cases. As can be seen from the results of various systems, the location and size of DG play an important role in reduction of primary distribution systems. From the results obtained for the three systems, one can conclude that by placing DG of optimum size at optimum location, significant reduction in loss can be achieved.

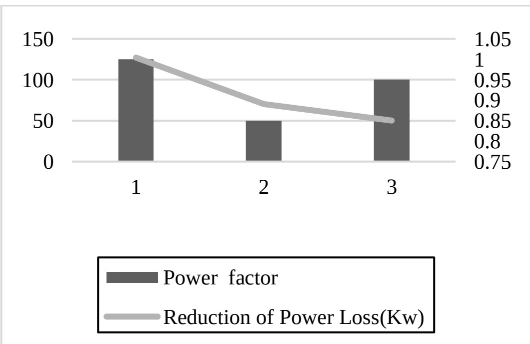

Figure 4. Without DG on power loss

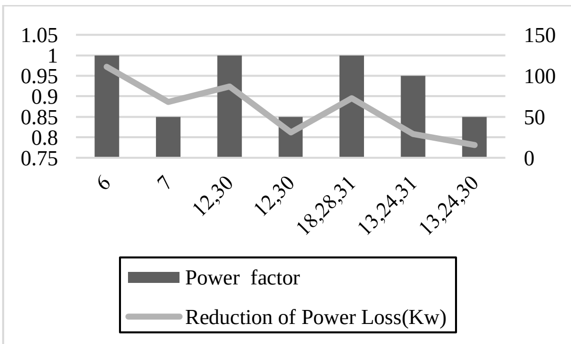

Figure 5. Impact of DG Integration on power loss

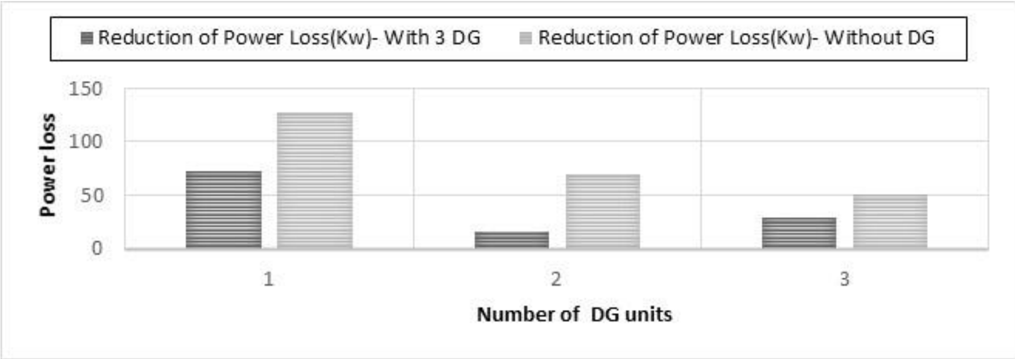

Figure 6. Reduction of power loss with 3 DG/without DG

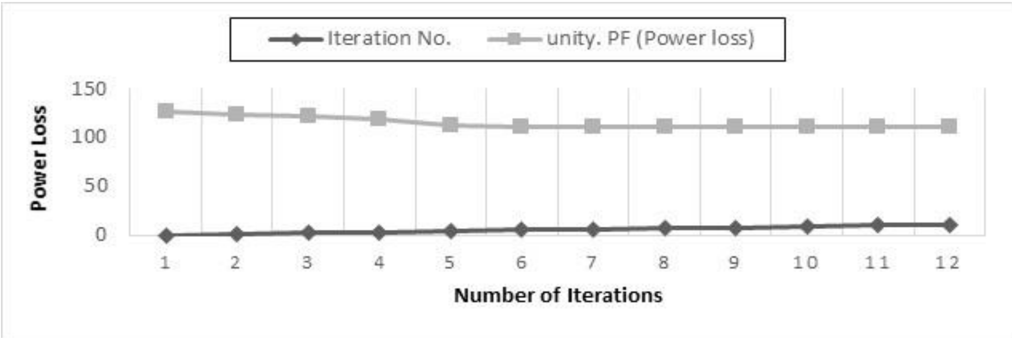

Figure 7. Convergence curve of AAA single DG

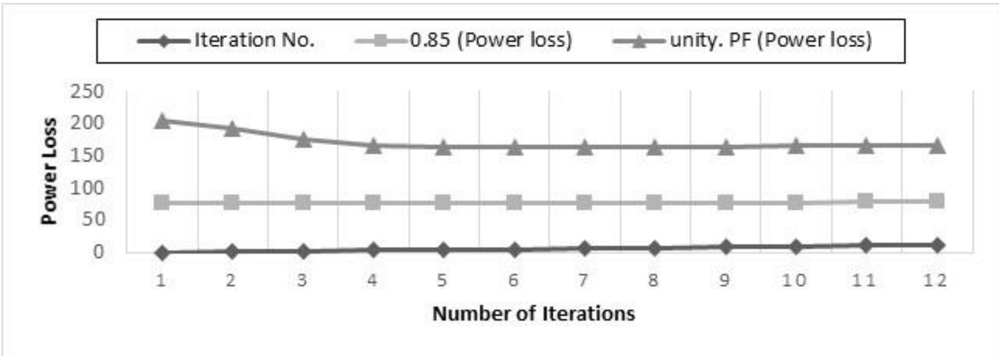

Figure 8. Convergence curve of AAA double DGs

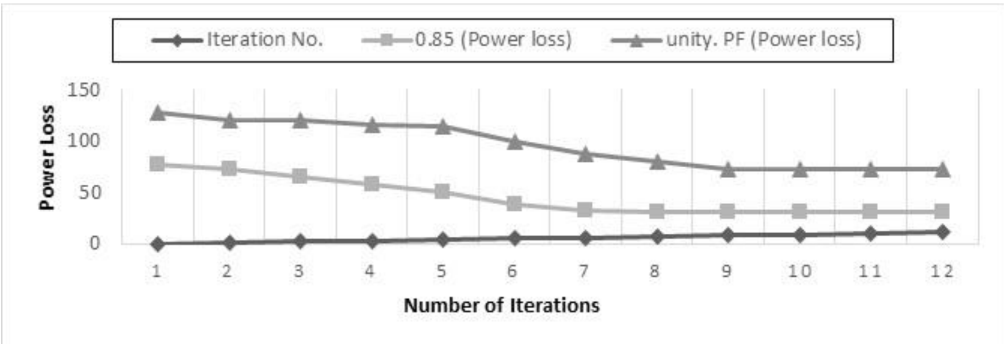

Figure 9. Convergence curve of AAA three DGs

5. CONCLUSION

In this paper, Artificial algae algorithm is proposed for optimal placement and sizing of different types (Type I, II & III) of DGs with their objective for power loss minimization. The proposed technique is implemented on IEEE 33 bus RDS in order to demonstrate the efficacy and performance as compared with those of other compete methods. The experiential findings reveal that the proposed technique exhibits better results in terms of real power loss reduction and convergence speed. The maximum loss reduction with better voltage profile is obtained using the proposed AAA technique by optimal siting and sizing of different types of multiple DG units simultaneously than optimal placement and sizing of DGs independently in the RDS. In view of this, the proposed AAA optimizer can provide better locations for distributed generation sources and better management of real and reactive power deployment. The results show that power loss is minimized to a large extent when DG is injected into the system, establishing the advantages of the DG penetration in the optimization problem of optimal power flow. The obtained results clearly show that the proposed technique has the ability to find global optimization value in all the study cases. It is also observed from the simulation results that, Test case 3 is more effective to decrease line losses associated with all other cases. A notable improvement in reduction of active power losses with 3 DG are 65.5%, 42.4%, and 77.8% respectively, were achieved in comparison to the system without DGs. The simulation results confirm that the proposed algorithm is the best and efficient among the others reported in the literature, in terms of reliability, robustness, consistency and rate of convergence in solving the optimal power flow problem for all the case studies. The proposed algorithm gives consistent results under any condition without violating any equality and inequality constraint. In future work, it would be more interesting to enhance the maximum allowable DG penetration of the distribution system through smart inverter and other techniques.

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