Exchange Market Algorithm for Multiple DG Placement and Sizing in a Radial Distribution System

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Optimal placement and sizing of distributed generation (DG) is one of the important issues in the radial distribution system, playing a vital role in the reduction of power losses and total cost of the system. Optimal placement and sizing of DG has many advantages for the radial networks, which some of the important of them are the reliability and voltage stability improvement, power loss reduction, and emission reduction. In this paper, Exchange market algorithm (EMA) as a new heuristic algorithm is used for solving the multiple DG placement and sizing problem in the radial distribution system. EMA is consisted of two powerful searcher operators, which are used to create and organize the random numbers of the initial population and it can be employed in the optimization problems to find the optimum point. In order to evaluate the purposes of this study, EMA is applied on three test systems, including 33, 69 bus IEEE test system and 94 bus Portuguese radial distribution system. The obtained numerical results of the optimization procedure are compared with recent studies in this regard and the resulting analyses indicated that the power losses in the radial network reduced to the minimum amount. The results also prove the effectiveness of the EMA as one of the powerful optimization tools in solving the DG placement problem.

keywords: *Distributed generation placement, exchange market algorithm, radial distribution system, power loss reduction, distributed generation size.*

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NOMENCLATURE

A. Indices:

m Index of bus

n Index of branch

j Index of group members

B. Parameters and variables

k Number of buses

N Number of branches

$Iter$ Number of iterations

Kdg Number of DG units

$Iter_{Max}$ Maximum number of iterations

P_D^m Active injected power

Q_D^m Reactive injected power

S^m Apparent injected power

V_m^{Iter-1} Voltage at bus m at $(Iter-1)^{th}$ iteration

I_N^{Iter} Current value at branch N

V_{N2}^{Iter} Voltage bus at N2

V_{N1}^{Iter} Updated voltage at bus N1 at (Iter)th iteration

Z_N^{Iter} Series impedance of branch N at (Iter)th iteration

S_1^{inj} Power injection at bus 1

V_1^{inj} Injected/Input voltage at bus 1

I_1^{inj} Branch current at bus 1

P^{inj} Slack power

P_{LOSS} Real power loss

P_m^D Total electricity demand

P_m^{DG} Total real power generated by the DGS

V_m Bus voltage magnitude

V_m^{max} Upper voltage limits

V_m^{min} Lower voltage limits

$P_m^{DG,min}$ Minimum allowable limit of DG generation

$P_m^{DG,max}$ Maximum allowable limit of DG generation

r Random number [0 or1]

$POP_{1,i}^{group(1)}$ First members of the first group

$POP_{2,i}^{group(1)}$ Second members of the first group

$POP_j^{group(2)}$ jth member of the second group

r_1 **and** r_2 Random numbers

n_k nth member of the third group

$POP_k^{group(3)}$ kth member of the third group

S_k Share variation of the kth member of the third group

Δn_{t1} Amount of shares

n_{t1} Total shares of member before applying the share changes

δ nformation of exchange market

r Random number in interval (0,1)

μ Constant coefficient for each member

η_1 Risk level related to each member of the second group

t_{pop} Number of the member in exchange market

n_{pop} Number of the last member in exchange market

S_{ty} Number of the last member in exchange market

g_1 Common market risk amount

k Number of program iteration

$g_{1,max}$ Maximum value of risk in the market

$g_{1,min}$ Minimum value of risk in the market

η_2 Risk factor related to each individual of third group

r_2 Random number within (-0.5 0.5)

g_2 Market variable risk in third group

n_i nth person of the first group

n_j nth person of the second group

DG_{loc} DG location buses

1. INTRODUCTION

In recent years, the power system is faced with several basic challenges related to the energy supply, which some of the most important ones, including reduction of non-renewable energy resources, increasing power consumption, and increasing costs of energy transmission and distribution. These challenges drive the power system to use a new and effective technology, which is called distributed generation (DG) [1]. The DG systems can generate power in about 3 to 10 MW and it is also called on the other terms such as embedded generation, dispersed generation, and decentralized generation [2,3]. In the radial networks, one of the complex problems is finding the optimal placement and sizing of DGs with some nonlinear equations, which the heuristic and robust algorithms can be a good choice for setting DGs in size and place [4]. Optimal DG allocation can improve performance of devices and network status in terms of reduce system losses and costs, increase reliability, reduce greenhouse gas emissions, and improve more items such as power qualify, voltage profile, and etc [1–3]. DG placement not only depends on decision's investors and owners, but also it depends on fuel costs and greenhouse gas emissions. These issues drive researchers to attempt the different kinds of DG in the network [2,3]. Presently, there are two technologies of DGs in the network, which are renewable energy and non-renewable energy [1]. The renewable energy resources technology such as wind turbines, photovoltaic cells and etc., which have not fuel costs for the owners and have not greenhouse gas emissions to the environment, but the non-renewable technology such as internal combustion engine, gas turbines, and micro turbines have not above features [4,5].

Until recently, many studies are conducted with various simplified assumptions to solve the optimal DG placement and several optimization techniques based on the artificial intelligence are proposed for optimal DG placement and sizing in the radial networks. Some of these technologies are weed algorithm [6], bacterial foraging algorithm (BFOA) [7], modified BFOA [8], hybrid genetic optimization algorithm [9], particle swarm optimization algorithm [10], and cuckoo search algorithm [11]. In addition, some reviews are accomplished in fields of optimal DG placement comprehensively. For example, the comprehensive review has been conducted about the optimal DGs allocation in [12]. In this research, all methods, algorithms, constraints, and objectives in optimal DG placement problem along with the results analysis of them are covered and highlighted effectively. All proposed methods in this regards have near solutions for optimal DG location [2]. A comprehensive optimization based technique is presented in [13] for optimal allocation of DGs in the radial distribution systems with the aim of improvement of some key factors, including annual energy savings, voltage prole, and network loss reduction. In [14], the network reconfiguration with optimal placement of DGs are investigated in 33 bus and 69 bus radial distribution networks to minimize the power losses using the genetic algorithm (GA) technique. The particle swarm optimization method is applied to the proposed objective function in [15]. In this study, the objective function is maximization of distribution system reliability after the natural disasters, which fuzzy multi criteria decision making (FMCDM) method is employed for load points ranking in the realization of this goal. Achieving convergence with few iterations and inappropriate for unbalanced distribution system are two main features of the method used in [16]. Stud Krill herd (SKH) algorithm as an intelligent algorithm based on the krill movement is used in reference [2] to minimize power losses and determine the optimal location and size of DG in the radial distribution systems. The GA is applied to optimal DG placement problem not only to minimize the power and energy losses, but also improve the reliability index in [17]. Rank evolutionary particle swarm optimization (REPSO) is used to evaluate the DG placement problem in [18], which numerical results indicated that, this algorithm has the low convergence speed. The water drop algorithm is employed to find the size of DG and loss factor (LF) is also used to determine the optimal DG location in [19]. Symbiotic organism search algorithm (SOSA) is one of the heuristic techniques, which is applied to solve the DG placement problem in [20]. In order to maximize social welfare and profit, locational marginal price (LMP) and consumer payment (CP) are proposed as two methodologies for optimal DG placement in [21]. One of the suitable algorithm for multi-objective problems, which can find a solution near the optimal value is a GA that is used in [22] to determine the optimal DG location. The firefly algorithm is employed in [23] to minimize power losses, improve the voltage profile, and minimize generation cost while the slow convergence is a main disadvantage of this algorithm. In [5], IA method as an efficient methodology is proposed to determine the optimal location of DG along with focusing on the power loss reduction, especially in large scale systems. In [24], the multi objective performance index (MOPI) is engaged to increase voltage stability in radial distribution systems. In order to obtain voltage improvement and voltage stability, references [25, 26] have proposed special methods to locate DG units optimally and the modified firefly algorithm is applied to find the optimal location and size of DG in [27]. Voltage deviation index (VDI), line loading index (LLI), and active power loss index (APLI) are the three significant objectives, which are considered in [28] for optimal siting and sizing of DGs. In this research, the fuzzy satisfying and point estimate methods are applied for solving the multi objective problem and probabilistic load flow, respectively. Flower pollination algorithm and index vector method are used in [29] to determine the size and location of DG, respectively. Obtained index vector from the load flow numerical results depends on the reactive component of power load and current.

Each of the above methods has some advantages and disadvantages, but all of them have two common drawbacks, which include near optimal solution and slow convergence speed. Heuristic algorithms are used to find optimal points in the optimization problems with the random generated numbers [30]. They can be used to solve the complex optimization problems with a many constraints, which mathematical methods not able to solve them [31]. Evolutionary algorithms have randomized structure and this structure may be faced them with some problems such as slow convergence, trapped during program execution, convergence to non-optimal solutions of each iteration, and inability to determine optimum-neighborhood point [30].

Therefore, in order to consider the above problems, exchange market algorithm (EMA) as a new heuristic algorithm is proposed in 2014 [31]. EMA is inspired by the two main items, which include shares traded based on the market conditions and human intelligence. In this algorithm, stock prices are increased when the demand of shares is increased, and they are decreasing by declining the market demand. In order to earn the most possible profit in the stock market, shareholders try to trade stocks on the best possible way based on the market framework. Generally, there are price oscillations in most moment and it depends on the economic and political measures taken by countries and organizations. Trading stocks in no oscillated market have lower risk in comparison with oscillated market and it may be harmful or profitable for shareholders [31].

This paper is aimed to reduce all defects of the above methods by implementing a new human intelligence-inspired, meta-heuristic technique, EMA as a powerful method to solve the optimization problem with considering power loss reduction as purpose of this study subjected to inequality constraints like real power limits, DG capacity limit, DG location, and voltage limit constraint. In this paper, EMA is used for multiple DG placement with different load patterns and it is also applied and evaluated in 33, 69 IEEE standard test systems and 94 bus Portuguese radial distribution systems. The obtained results from the three above test systems are compared with the results of other developed methods like a krill herd (KH) and stud krill herd (SKH) algorithm, firefly algorithm, bacterial foraging optimization algorithm (BFOA), intelligent water drop algorithm, QOTLBO and other analytical methods. The evaluation of the results indicated that EMA can be provided the minimum power loss than other algorithms. In general, the main goal of this paper is to demonstrate the capabilities of the EMA as a new heuristic algorithm in searching and finding the optimal solution in the optimization problems in comparison with other existing algorithms, which minimization of active and reactive power losses is considered for this aim in the different test systems of radial distribution systems.

This paper consists of the six sections, which include introduction, problem formulation, exchange market algorithm, test cases and numerical results, conclusion, and lastly future work is the final section of this paper.

2. PROBLEM FORMULATION

A. power flow formulations

Currently, classical power flow techniques and several schemes in the field of load flow are available [32, 33], but in all of them, the ratio R to X is high, thus they are not suitable for solving problems in the radial distribution systems. Therefore, the forward–backward sweep algorithm based on equation of Kirchhoff's laws as an efficient algorithm is employed to extract output the load flow in the radial system [2, 34].

The forward–backward sweep algorithm as a solution method for this study consists of some operationally steps as follows:

1. Read input data system.
2. Initialized the bus voltage which is assumed as follows:

$$\begin{aligned} &V_m^{Iter} = 1.p.u. \\ &m = 2, 3, \cdots, k; Iter = 1, 2, \cdots, Iter_{\max} \end{aligned} \tag{1}$$

3. Calculate power injection at bus by the equation (2) and determine the terminal bus.

$$S^m = P_D^m + jQ_D^m \tag{2}$$

4. Calculate the bus currents by the equation (3).

$$I_m^{Iter} = \left(\frac{S^m}{V_m^{Iter-1}}\right)^* \tag{3}$$

5. Backward Sweep: calculate branch currents by the equation (4).

Starting from the terminal bus and then moving towards the first bus, the current value at branch N is computed by using KCL,

$$i_N^{Iter} = -I_{N2}^{Iter} + \sum \text{Currents in branches originating from bus N2} \quad (4)$$

where, $N = n, n-1, ..., 1$.
Note that the bus current equal to the line current for the terminal bus.

6. Forward Sweep: calculate the bus voltage from the source to the end buses (equation (5)).
Starting from the first bus and then moving towards the end buses, for each branch N, the bus voltage at N2 is computed by using KVL,

$$V_{N2}^{Iter} = V_{N1}^{Iter} - Z_N^{Iter} \quad (5)$$

7. Increment the iteration count $Iter = Iter + 1$ until $Iter$ reaches to $Iter_{max}$.

8. Calculate the power injection at bus 1 (equation (6)).

$$S_1^{inj} = V_1^{inj}(I_1^{inj})^* \quad (6)$$

9. Calculate the two terms of S, total real and reactive power injected by the equation (7).

$$p^{inj} = \text{real}(S^{inj}); Q^{inj} = \text{imag}(S^{inj}) \quad (7)$$

10. Calculate the total system power loss (equation (8)).

$$P^{loss} = p^{inj} - \sum p^D; Q^{loss} = Q^{inj} - \sum Q^D \quad (8)$$

11. Finally, print the results.

B. Objective function

Minimizing the total power loss in the distribution network is a main objective of studying the optimal placement and sizing of multiple DGs subjected to some equality and inequality constraints such as power balance limit, voltage magnitude limit, DG location constraint, and DG real power limit.

Generally, the objective function of DG placement for power loss minimization is defined as follows:

$$P_{LOSS} = P^{slack} + \sum_{m=2}^{kdg} P_m^{DG} + \sum_{m=1}^{k} P_m^D \quad (9)$$

C. Constraints

C.1. Power balance limit

In the radial distribution systems, the sum of the real power loss and total demand except the slack bus should be greater than the total real power generated by the DGS.

$$\sum_{m=2}^{kdg} P_m^{DG} \le \sum_{m=2}^{k} P_m^D + P_{LOSS} \quad (10)$$

C.2. Voltage magnitude limit

After and before the DG placement, the voltage magnitude for each bus should be within the allowable range. Therefore, this constraint is shown as follows:

$$V_m^{\min} \le V_m \le V_m^{\max} \quad (11)$$

where, $V_m^{\min}$ and $V_m^{\max}$ are equal to 0.95 and 1.05 p.u, respectively.

C.3. DG location limit

All buses on the network can be a candidate for DG placement, thus the DGs should be examined and placed within the total number of buses.

$$1 < DG_{loc} < k \quad (12)$$

C.4. DG real power limit

The amount of real power generated by DG has a limit, which is illustrated by P_m^{DG} the and can be formulated as follows:

$$P_m^{DG,\min} \le P_m^{DG} \le P_m^{DG,\max} \quad (13)$$

where,
$P_m^{DG,\min} = 0$ kw
$P_m^{DG,\max} = \sum_1^m P^D$ /number of DG units.

3. EXCHANGE MARKET ALGORITHM

EMA is a meta-heuristic algorithm, which is inspired by the procedure of trading of shares by stockholders for solving the optimization problems [30]. In this algorithm, absorbent operators are used as two searcher operators to search in the simulation environment and around the optimum point in a wide range [35]. In the EMA, stockholders carry trade and risks, and they try to nominate themselves as the successful individuals in procedure the market and then the stockholders have less profit tend to experience greater risks [31]. There are a specific number of shares in the EMA, which each individual tries to sell or buy a number of them to gain the maximum profit at the end of each iteration by calculating the credibility of his own total shares [35].

In the stock market, the performance of shareholders varies with balanced and oscillation markets. In the EMA, there are two different and major market situations. In each iteration, this assumption is used to assess the performance and behavior of stockholders to improve their situation when their level of assets is variable. In the first situation, the market has a normal condition and considerable event are not happened during the process of the market and under this condition, the shareholders try to trade their selling and buying in the intelligent manner to gain maximum profit and earn a better rank between the all stockholders using the experiences of the successful participant members without adoption hazardous risks in trading market (searching toward the optimal point). In the second situation, the market experiences abnormal conditions and unbalanced and different oscillations make the shareholders for identifying ways to reach the better conditions and perform intelligent risk during their trading to gain maximum possible benefit [35]. The shareholders' fitness is evaluated after each operation and individual shareholders will be divided based on the amount of their assets. In other words, after each iteration, the shareholders with low, medium, and high assets will be divided into three different groups, which means the initial, median, and the end individuals of the stockholders population [30,31].

A. Exchange Market in normal mode

In this situation, existence normal status and non-oscillation conditions are two advantages, which provide suitable mode for all stockholders to gain the maximum possible benefit from their trading in the exchange market using the experiences of the successful stockholders without being forced to do dangerous risk to increase their profit. Therefore, they corrival with each other to earn better rank between all shareholders so they are ranked according to their operation and fitness in a group [31].

First group: stockholders with high fitness

This group of members performs risk to change their shares and trade with each other to keep their ranks. These stockholders constitute 10-30% of the all members. Stockholders of this group do not require to change their behavior because all members in this group are the elite shareholders or the best response to problems.

Second group: stockholders with average fitness

These stockholders perform the lowest possible risk to change their shares. This group of members constitute 20-50% of the all members. In this group, stockholders use successful experiments of the elite shareholders to trade shares in the exchange market.

$$POP_j^{group(2)} = r \times POP_{1,i}^{group(1)} + (1-r) \times POP_{2,i}^{group(1)} \\ i = 1,2,3,\cdots,n_i, \quad \mathrm{j} = 1,2,3,\cdots,\mathrm{n_j} \tag{14}$$

Third group: stockholders with weak fitness

This group of members constitute 20-50% of the all members. Stockholders of this group use the differences of share value between themselves and the first group to change their shares based on the equation (15). In this group, members are bottommost rank of stockholders. Stockholders of this group really search the optimal point in a wider space in comparison with the stockholders of the second group.

$$S_k = 2 \times r_1 \times (POP_{i,1}^{group(1)} - POP_k^{group(3)}) + \\ 2 \times r_2 \times (POP_{i,2}^{group(1)} - POP_k^{group(3)}) \tag{15}$$

$$POP_k^{group(3),new} = POP_k^{group(3)} + 0.8 \times S_k, k = 1,2,3,\cdots,n_k \tag{16}$$

B. Exchange market in oscillation mode

In this situation, after stockholder reevaluation and determining the rank of them, first, stockholders consider to their rank and profits and then they adopt risks based on the intelligent manner. By this manner, stockholders, not only increase their profits to the maximum amount, but also they can have better rank in comparison to the past. In this mode, in order to find an unknown optimal point, the EMA should increase the space of search to provide appropriate conditions for the stockholders through finding the optimal point for them. Here, each of stockholders employs some efficient financial policies due to their profit conditions and ranking to improve their rank among the all members in the exchange market. By considering to the member performances, they can be classified into three different groups.

First group: stockholders with high fitness

These shareholders constitute 10-30% of the all members. Shareholders of this group are the best response to problems or the elite shareholders, which tend to keep their suitable situation and do not attempt to trade and gain more profit [31].

Second group: stockholders with average fitness

In this group, people held shares in the market region that the sum of them tend to be constant and only some types of shares decrease and some of them increase in a certain manner to maintain total shares constant.

At first, the number of shares held by each trader increases based on the equation (17), which defined as follows:

$$\Delta n_{t1} = n_{t1} - \delta + (2 \times r \times \mu \times \eta_1) \tag{17}$$

$$\mu = \left(\frac{t_{pop}}{n_{pop}}\right) \tag{18}$$

$$n_{t1} = \sum_{y=1}^{n} |s_{ty}|, y = 1,2,3,\cdots,n \tag{19}$$

$$\eta_1 = n_{t1} \times g_1 \tag{20}$$

$$g_1^k = g_{1,\max} - \frac{g_{1,\max} - g_{1,\min}}{iter_{\max}} \times K \tag{21}$$

Where, Δn_{t1} should be added randomly to some shares and g_1 decreases with the increase in iteration number.

In the next part of this section, it is obligatory that traders sell their shares randomly being equal to the number, which they have purchased in a certain manner that the sum of each of them remain constant. In this section, it is essential that each trader reduce the number of his/her shares in Δn_{t2} amount. In this state, the Δn_{t2} of each trader equals:

$$\Delta n_{t2} = n_{t2} - \delta \tag{22}$$

where, Δn_{t2} is the amount of shares are to be decreased randomly from some shares and n_{t2} is the sum share amount of shareholder after applying the share variations.

Third group: stockholders with weak fitness

In this section, the risk percentage of members is variable so that reduction of their fitness makes them to increase their risk. In this group of stockholders, unlike group 2, each member purchases or sells a number of shares and changes some of hisshares based on the following equation:

$$\Delta n_{t3} = (4 \times r_s \times \mu \times \eta_2) \tag{23}$$

$$r_s = (0.5 - \mathrm{rand}) \tag{24}$$

$$\eta_2 = n_{t1} \times g_2 \tag{25}$$

$$g_2^k = g_{2,\max} - \frac{g_{2,\max} - g_{2,\min}}{iter_{\max}} \times k \tag{26}$$

Where, Δn_{t3} is totally of the share amount, which should be applied in each individual share of the third group randomly. In this group, each stockholder trades a part of his/her shares randomly by changing the total number of his/her shares.

C. Exchange market algorithm implementation pattern in solving DGs placement problem

The DGs placement problem is solved using the EMA through the following steps:

1. Selecting initial numbers and values and attributing share to the initial stockholders.

2. Calculating stockholder fitness by equation (9), ranking them, and dividing stockholders in three different groups. (Starting balanced mode).

3. Applying changes on the stocks of the second group individuals in normal market condition by equation (14).

4. Applying changes on the stocks of the third group stockholders in normal market condition by equation (16).

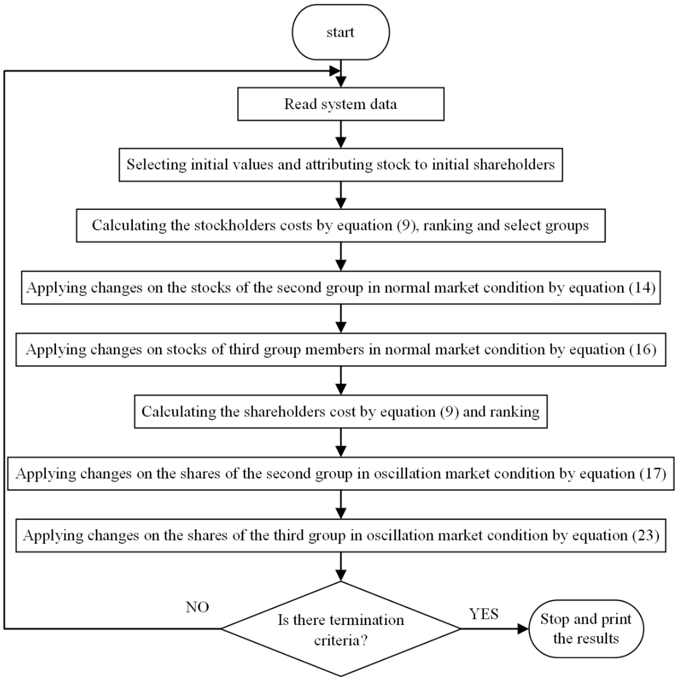

Fig. 1. Program implementation flowchart of exchange market algorithm

5. Recalculating stockholder fitness by equation (9), ranking and dividing stockholders in three different groups (Starting oscillation mode).

6. Trading the stocks of the second group stockholders using equation (17) in oscillated market condition.

7. Trading the stocks of the third group stockholders using equation (23) in oscillated market condition.

8. Going to step 2 until the program ending conditions is satisfied.

With the completion of the market oscillation condition in this step, the optimization program starts to evaluate the stockholders from step 2 if end up conditions are not satisfied. If end up conditions are satisfied, the program operation is ended up. A flowchart of the EMA for solving the DG placement problem is shown in Fig. 1.

4. TEST CASES AND NUMERICAL RESULTS

In order to evaluate the effectiveness of EMA and extract optimal location and sizing of DGs, this algorithm is implemented successfully on the 33 bus, 69 bus IEEE radial test systems and 94 bus Portuguese radial distribution system. The EMA can also be implemented effectively for any number of DGs. In this study, bus 1 is taken to account as a slack bus for all test systems. This study has evaluated three load level i.e. light, nominal, and peak load with 0.5, 1 and 1.6 of peak load conditions and the results are extracted from all the test systems and then completely tabulated.

A. 33-bus test system

The first test system is a 33-bus with 3-lateral radial distribution system and 32 branches, which is shown in Fig. 2. In this case study, the base voltage and total load are 12.66 KV and (3.715+j2.3) MVA, respectively. Before DG placement, the total active and reactive losses of the system are 202.6771 KW and

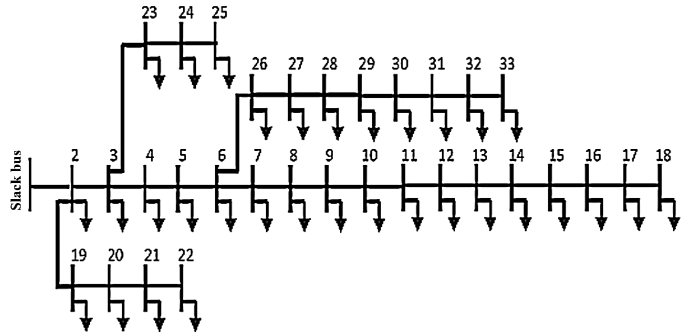

Fig. 2. Single line diagram of 33-bus system

135.1409 KVAr, respectively. EMA is used to find the optimal location and sizing of DG and the results of simulation are tabulated in Table 1. In this study, number of DG is varied between one and three units, which are considered to evaluate the system loss reduction. Numerical results illustrated that the implementation of one, two, and three DG units reduce the system losses to 48.7036%, 57.6014%, and 64.3276% respectively. Comparison of the obtained results by the EMA with the results of the other algorithms indicated that power loss magnitude is reduced to the minimum amount by using the EMA.

In this case study, the effectiveness of DGs placement in system loss minimization is shown in Fig. 3. Fig. 4 shows the voltage profile variations with consider to the number of DG units. In this regard, voltage profile is analyzed in the three different states of DG implementation include one, two, and three then the obtained results are compared with the results of the before applying DG units. After applying DG units, the total real power compensation magnitude of three units DG is 943.54852 KW at bus 12, 1169.0983 KW at bus 24 and 976.60554 KW at bus 30 and the minimum voltage amount is 0.96848 at bus 32. By considering to the Table 1, the results assessment demonstrated that the voltage profile is improved in the three states of DG operation and stayed on the acceptable range. In addition, the suitable candidate buses for DG location in terms of power loss reduction are determined along with their optimal capacity. All of this information can provide appropriate conditions for the system developers to adopt the best decisions to improve the operation of radial distribution systems.

In this regard, in order for more evaluation of the EMA capabilities, the optimal location and sizing of DG is determined at different load levels-light (0.5), nominal (1.0), and peak (1.6) at full load and the numerical results are tabulated in Table 2. The results of this evaluation illustrated that after the applying the EMA, the minimum voltage is improved at the all load levels and power loss is reduced to the minimum amount in comparison with other methods.

Finally, all obtained results of the EMA are compared with various recently methods, which are developed to improve the voltage magnitude and reduce power losses in the system from the literature in Table 3. It is indicated that the EMA gives an optimal solution in comparison with other methods. Finally, the obtained results of this study indicated that the EMA can be applied effectively for the optimal placement and sizing of DG problem and it can be extracted the optimal results in comparison with the other developed optimization algorithms.

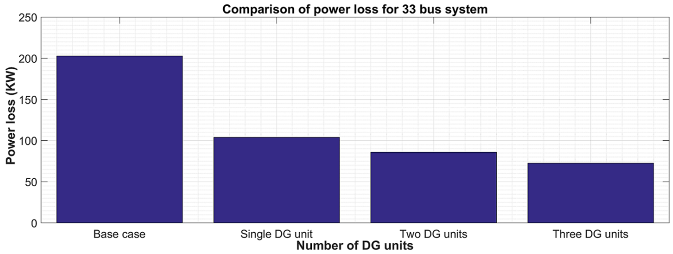

Fig. 3. Comparison of power loss for 33 bus system

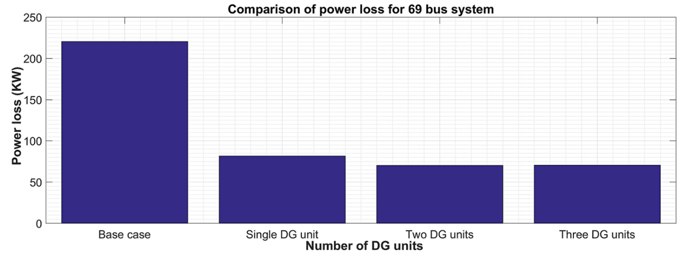

Fig. 6. Comparison of power loss for 69 bus system

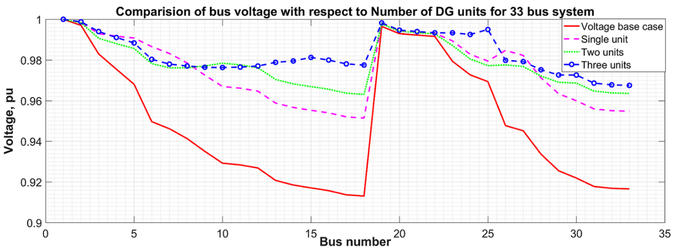

Fig. 4. Comparison of bus voltage with respect to number of DG units for 33 bus system.

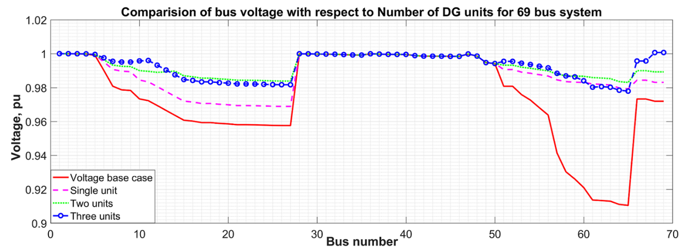

Fig. 7. Comparison of bus voltage with respect to number of DG units for 69 bus system.

B. 69-bus test system

The second test system is a 69-bus with 6-lateral radial distribution system, which is shown in Fig. 5. In this case study, the base voltage and total load are 12.66 KV and (3.80+j2.69) MVA, respectively. Before applying DG units, the total active and reactive losses of the system are 220.5175 KW and 100.0158 KVAr respectively. EMA is employed to find the optimal location and sizing of DG and the results of simulation are tabulated in Table 4. By considering the results of Table 4, the implementation of one, two, and three DG units reduce system losses to 63.1763%, 68.0689%, and 69.3092% respectively. Comparison of the obtained results by the EMA with the results of the other algorithms depicted that the power loss magnitude is reduced to the minimum amount in the all states of DG operation by using the EMA. Power loss reduction with high percentage have some positive effects for the investors and distribution company. For example, reducing the power losses in the radial distribution systems has been led to the reduction of the fuel consumption by the power plants for more power generation to compensate the less power caused by the system power losses. In the other hands, reduction of fuel consumption will also be led to the reduction of the greenhouse gas emissions along with the harmful effects of them for the environment.

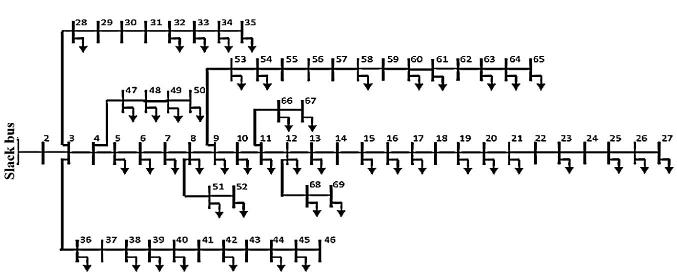

Fig. 5. Single line diagram of 69-bus system

In this case study, Fig. 6 shows the efficiency of DGs placement in the system loss minimization and Fig.7 shows voltage profile variations along with consideration of the number of DG units. After applying DG units, the minimum voltage magnitude is 0.98147 at bus 26 and the real power magnitude of three units of DG compensation is 689.06899 KW at bus 50, 910.72492 KW at bus 68, and 1263.9633 KW at bus 69. By considering the information of Table 4, evaluation of the results concluded that the voltage profile is improved in the three states of DG operation and the voltage limits is satisfied, too. This study continues with an evaluation of the three different load levels and simulation results for the all load levels are given in Table 5. The assessment of the results of this table demonstrated that after the applying the EMA, the minimum voltage is improved at the all load levels and power loss is reduced to the minimum amount in comparison with the results of the before applying DG units.

At the end, total results of the EMA are compared with other various methods from literature and are tabulated in Table 6. By analyzing the information on this table, numerical results showed the effectiveness of EMA in the improvement of results.

Table 1. Summary of results after DG placement with EMA for 33 bus system

Item	Load flow Results	EMA		
Number of DG unit	-	Single DG unit	2 DG units	3 DG units
Optimal Bus no. /DG size in kW	-	6/2526.9826	11/816.38475	30/976.60554
	-	-	33/1000.5825	24/1169.0983
	-	-	-	12/943.54852
Bus no /Vmin p.u.	17/0.91309	17/0.95104	17/0.96311	32/0.96848
Bus no /Vmax p.u.	2/0.99703	2/0.99859	2/0.99825	2/0.99891
Ploss, kW	202.6771	103.9659	85.9323	72.2997
Qloss, kVAr	135.1409	74.7857	58.7754	49.8124
% Loss reduction	-	48.7036	57.6014	64.3276

Table 2. Summary of results after applying DG using EMA for 33 bus system

Parameters		EMA		
Load level		Light load (0.5)	Nominal load (1.0)	Peak load (1.6)
Load flow results	Ploss in KW	47.0707	202.6771	575.3616
	Qloss in kVAr	31.35040	135.1409	384.2627
	bus no/Vmin in pu	17/0.95826	17/0.91309	17/0.85284
	bus no/Vmax in pu	2/0.99856	2/0.99703	2/0.99506
Optimal Bus no. /DG size in kW	-	33/846.47654	30/976.60554	11/1015.2049
	-	13/883.28602	24/1169.0983	24/977.52302
	-	24/1227.4433	12/943.58852	33/860.6553
Bus no /Vmin p.u.	-	17/0.98274	17/0.91309	32/0.94798
Bus no /Vmax p.u.	-	2/0.99934	2/0.99703	2/0.99791
Ploss, kW	-	17.4987	72.2997	191.2714
Qloss, kVAr	-	12.5068	49.8124	133.6353

Table 3. Comprison of results of EMA with other develop methods for 33 bus test system

Method	Power loss without DG, kw	single DG		Two DG		Three DG			Power loss, kw
		Bus no/Size of DG, kw	Power loss, KW	Bus no/Size of DG, kw	Power loss, KW	Bus no/Size of DG, KW			
Firefly alg. [23]	277.7	30/1190.4	116.7	30/1013.1,14/612.8	96.9	-			-
BFOA [36]	210.98	-		-		-			-
Invasive weed opt. [37]	202.771	-		-		14/652.1	18/198.4	32/1067.2	89.9
Rank Evol. PSO(REPSO) [18]	202.7	-		-		6/1260.7	12/609.6	25/1579.2	98.8
QOTLBO [38]	210.998	-		-		13/1083.4	26/1187.6	30/1199.2	103.409
Backtracking search [39]	210.84	8/1857.5	118.12	13/880, 31/924	89.34	13/632	28/487	31/550	89.05
Golden section search [39]	211	6/2590.2	111	-		-			-
Grid search alg. [39]	211	6/2600.5	111	-		-			-
Analytical [39]	211	6/3150	115.29	-		-			-
Analytical [39]	211	6/2490	115.15	-		-			-
Analytical [39]	211.2	6/2490	111.24	-		-			-
Int. water drop alg. [16]	211.27	6/2490	111.01	-		9/600.3	16/300	0/1011.2	85.78
Fuzzy + Clonal Alg. [19]	203.9088	32/1931	127.0919	32/383.6, 30/1150.6	117.3946	32/2071	0/1113.8	31/150.3	117.358
Craziness based PSO [40]	202	6/2575	103	29/1158,12/846	86	-			-
KHA [2]	210.9876	6/2590	111.0188	29/1242, 13/825	87.426	24/915	14/750	30/1142	73.2968
SKHA [2]	210.9876	6/2590	111.0188	13/851.6, 30/1157.6	87.1656	30/1054	24/1091	13/802	72.7853
EMA	202.6771	6/2526.9826	103.9659	11/816.3847, 33/1000.5825	85.9323	30/976.60554	24/1169.0983	12/943.54852	72.2997

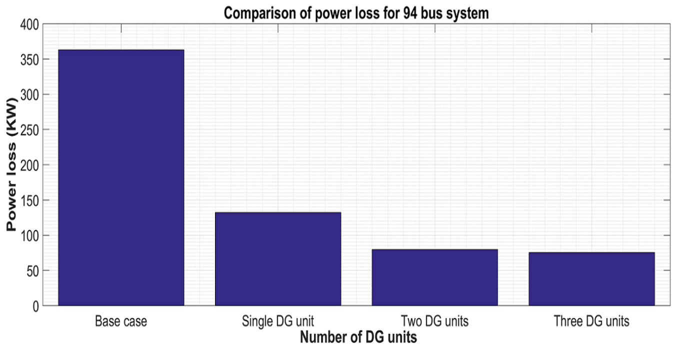

Fig. 8. Comparison of power loss for 94 bus system

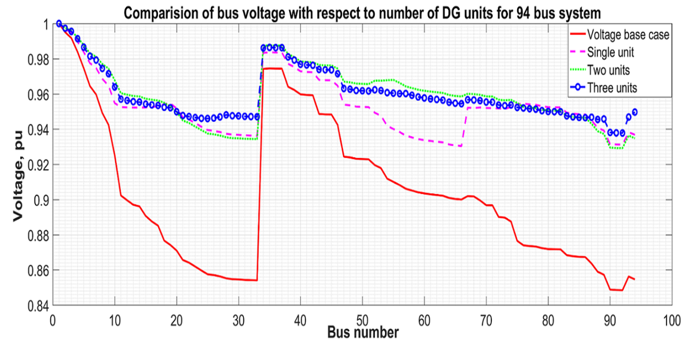

Fig. 9. Comparison of bus voltage with respect to number of DG units for 94 bus system

Table 4. Summary of results after DG placement with EMA for 69 bus system

Item	Load flow Results	EMA		
Number of DG unit	-	Single DG unit	2 DG units	3 DG units
Optimal Bus no. /DG size in kW	-	57/1910.3461	61/1886.9142	68/910.72492
	-	-	69/649.30133	69 /1263.9633
	-	-	-	50/689.06899
Bus no /Vmin p.u.	64/0.91048	26/0.9689	64/0.9794	26/ 0.98147
Bus no /Vmax p.u.	2/0.99997	2/0.99997	2/0.99997	2/0.99998
Ploss, kW	220.5175	81.2026	70.4136	67.6784
Qloss, kVAr	100.0158	39.5174	37.0136	35.8549
% Loss reduction	-	63.1763	68.0689	69.3092

Table 5. Summary of results after applying DG using EMA for 69 bus system.

Parameters		EMA		
Load level		Light load (0.5)	Nominal load (1.0)	Peak load (1.6)
Load flow results	Ploss in KW	50.65036	220.5175	638.0442
	Qloss in kVAr	23.0922	100.0158	287.3444
	bus no/Vmin in pu	64/0.95727	64/0.91048	64/0.84689
	bus no/Vmax in pu	2/0.99998	2/0.99997	2/0.99994
Optimal Bus no. /DG size in kW	-	5/907.80066	68/910.72492	69/770.46271
	-	63/1243.4018	69 /1263.9633	61/1088.9141
	-	11/277.03103	50/689.06899	20/318.1942
Bus no /Vmin p.u.	-	26/0.98625	26/0.98147	26/0.96023
Bus no /Vmax p.u.	-	2/0.99999	2/0.99998	2/0.99996
Ploss, kW	-	17.1579	67.6784	191.6475
Qloss, kVAr	-	8.3568	35.8549	97.5082

C. 94-bus test system

A third test system, which is evaluated by this paper is a 94 bus Portuguese. In this case study, the base voltage and total load are 15 KV and (4.797+j2.324) MVA, respectively and the single line diagram is illustrated in Fig. 10. The total active and reactive losses of the system without DGs unit are 362.8578 KW and 504.0419 KVAr, respectively. The EMA is employed to find the optimal location and sizing of DG and the results of simulation are tabulated in Table 7. Numerical results showed that the implementation of one, two, and three DG units reduces system losses to 63.5130%, 78.1755%, and 80.0420%. After applying DG units, the minimum voltage magnitude is 0.9387 at bus 91 and the real power magnitude of three units of DG compensation is 1574.8156KW at bus 21, 650.85461KW at bus 63 and 1503.0821KW at bus 72.

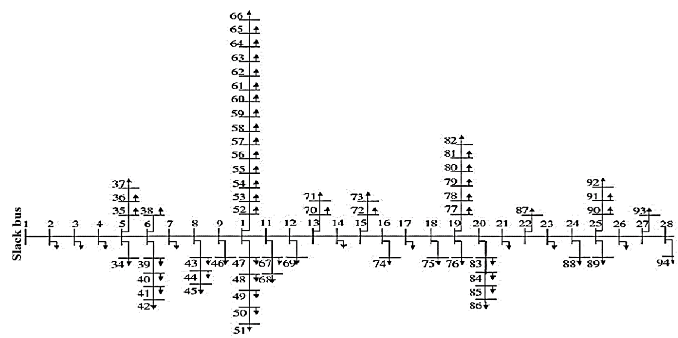

Fig. 10. Single line diagram of 94-bus system

In this study, Fig. 8 shows the efficiency of DGs placement in the system loss minimization and voltage profile variations along with consideration of the number of DG units is illustrated in Fig.9. Simulation results for the different load levels are tabulated in Table 8 and total results are compared with the results of the before DG placement. This comparison showed that the system power loss is reduced to the minimum amount and voltage profile is improved and stayed in the satisfactory range by employing the EMA as a solving algorithm. In addition to the mentioned conclusions, improvement of the voltage profile can be reduced the system requirements for the capacitor banks for the voltage profile improvement if the aim of this work is the voltage profile improvement. All of these positive results will be removed the extra expenses for the distribution companies and it will increase the profit of the investors and encourage them for more attention to the power loss reduction issue.

In the end step of the experiment, total results of the EMA are compared with other various methods from literature and are structured in Table 9. In this case study, numerical results show the effectiveness of EMA in the improvement of results, too. The capabilities of the EMA are achieved by several statistical measuring factors after 25 tests and tabulated in Table 10. Nominal load condition with three DG units is studied for this analysis and considering to the results showed that, the best solution comes near to the average value.

Table 6. Comparison of results of EMA with other developed methods for 69 bus test system

Method	Power loss without DG, kw	single DG		Two DG		Three DG			Power loss, kw
		Bus no/Size of DG, kw	Power loss, KW	Bus no/Size of DG, kw	Power loss, KW	Bus no/Size of DG, KW			
BFOA [36]	-	-				27/295.4	65/446	61/1345.1	75.23
MBFOA [41]	225.4	61/1879.2	83.4	-		-			-
QOTLBO [38]	224.7	-		-		15/811.4	61/1.1470	63/1.0022	80.585
Analytical [16]	225	61/1800	83.37	-		-			-
Analytical [16]	224.88	61/1830	83.19	-		-			-
Analytical [16]	219.28	61/1810	81.44	-		-			-
MINLP [16]	225.27	61/1870	83.49	-		-			-
Int. water drop alg [16]	225	61/1870	80.12	-		17/2999	60/1320	63/438.8	73.55
GA [16]	-	-	-	-		21/929.7	62/1075.2	64/992.5	89
PSO [16]	-	-	-	-		61/1199.8	63/796	17/992.5	83.2
GA+PSO [39]	-	-	-	-		63/884.9	61/1196	21/910.5	81.1
Craziness based PSO [40]	317	61/1891.4	112	60/1786, 13/610	97	-			-
KHA [2]	220.534	61/1865	81.6003	51/972.1609, 61/1726.9813	77.0354	15/549.10	61/1768.48	49/1013.9697	69.1977
SKHA [2]	220.534	61/1846.6	81.6003	17/5229.1, 61/1778.9	70.4092	61/1719.0677	17/370.8802	11/527.1736	68.1523
EMA	220.5157	57/1910.3461	81.2026	61/1886.9142, 69/649.30133	70.4136	68/910.72492	69/1263.963	50/689.06899	67.6784

Table 7. Summary of results after DG placement with EMA for 94 bus system.

Item	Load flow Results	EMA		
Number of DG unit	-	Single DG unit	2 DG units	3 DG units
Optimal Bus no. /DG size in kW	-	19/2368.9275	59/1569.5323	21/1574.8156
	-	-	86/2303.0292	63/650.85461
	-	-	-	72/1503.0821
Bus no /Vmin p.u.	91/0.84848	65/ 0.93041	91/0.92922	91/0.9378
Bus no /Vmax p.u.	2/0.99508	2/0.99681	2/0.99754	2/0.99732
Ploss, kW	362.8576	132.3956	79.1915	72.419
Qloss, kVAr	504.0419	164.0405	101.1177	95.7671
% Loss reduction	-	63.5130	78.1755	80.0420

Table 8. Summary of results after applying DG using EMA for 94 bus system

Parameters		EMA		
Load level		Light load (0.5)	Nominal load (1.0)	Peak load (1.6)
Load flow results	Ploss in KW	79.6035	362.8576	115.54831
	Qloss in kVAr	110.9393	504.0419	159.5157
	bus no/Vmin in pu	91/0.92988	91/0.84848	91/0.72418
	bus no/Vmax in pu	2/0.99771	2/0.99508	2/0.99119
Optimal Bus no. /DG size in kW	-	60/1515.5688	21/1574.8156	58/1598.9384
	-	18/1206.5265	63/650.85461	15/343.34359
	-	94/692.74117	72/1503.0821	79/1598.9484
Bus no /Vmin p.u.	-	91/0.97134	91/0.84848	91/0.90301
Bus no /Vmax p.u.	-	2/0.99866	2/0.99508	2/0.99566
Ploss, kW	-	17.9089	72.419	150.0329
Qloss, kVAr	-	24.3819	95.7671	278.1751

Table 9. Comparison of results of EMA with other developed methods for 94 bus test system

Method	Power loss without DG, kw	single DG		Two DG		Three DG			Power loss, kw
		Bus no/Size of DG, kw	Power loss, KW	Bus no/Size of DG, kw	Power loss, KW	Bus no/Size of DG, KW			
Backtracking search Algorithm [39,42]	362.86	21/2399	153.86			-			-
KHA [2]	362.8578	19/2636.0175	132.3957	56/1940.2177, 83/1752.4332	86.6475	10/955.1033	58/1285.2885	20/1833.7965	74.4197
SKHA [2]	362.8578	19/2636.018	132.3957	58/1726.6598, 20/1978.5448	79.2549	25/498.7761	19/1575.7066	58/1638.3085	73.1022
EMA	362.8576	19/2368.9275	132.3956	59/1569.5323, 86/2303.0292	79.1951	21/1574.8156	63/650.85461	72/1503.0821	72.419

Table 10. Statistical Performance Analysis of EMA

Measuring factor	Test Systems		
	33 bus test System	69 bus test system	94 bus test system
Best (Ploss/kW)	72.2997	67.6784	72.419
Worst(Ploss/kW)	74.3129	80.3478	75.419
Average	74.1818	76.1891	74.38054
Median	74.3129	78.0217	75.419
Variance	5.36115	13.19652	2.03698
Standard deviation	2.31541	3.63270	1.42722

5. CONCLUSION

In this paper, optimal placement and sizing of DG is studied and power loss reduction and voltage profile improvement as two objectives of this paper are evaluated using the heuristic algorithm as a solving tool. EMA as a metaheuristic technique is employed to solve the optimal DG placement problem with considering the goals of this study subjected to inequality constraints. In other words, EMA is used to the multiple DG placement with different load patterns and it is also applied and evaluated in 33, 69 IEEE standard test systems and 94 bus Portuguese radial distribution systems. The obtained results from the three test systems are compared with the results of the other developed methods. In this research, the recently methods such as PSO, GA, BFOA, KHA, SKHA, and other developed analytical algorithms are considered for comparison with EMA. The evaluation of the results indicated that the other algorithms is faced with some problems such as slow convergence, trapped during program execution, convergence to non-optimal solutions in each iteration, and inability to determine the optimum-neighborhood point, while EMA can provide the optimal solution in comparison with the other algorithms. In addition, numerical results illustrated that, the EMA improves the voltage magnitude and reduces both the real and reactive power losses in the radial distribution system.

6. FUTURE WORK

Optimal DG placement and sizing is taken into account as one of the important problems in the radial distribution networks. In general, this work is accomplished with various objectives and constraints in the distribution systems. However, this research has an enough potential to extend the more effective researches, especially for the new power grids. Todays, because of the non-renewable energy resource problems for the environment, the renewable energy based DG technologies can be more applicable for the electrical networks to clean energy supply for the consumers. Therefore, optimal allocation and sizing of these types of DGs in the system can be taken into account for various objectives such as greenhouse gas emission reduction, maximizing the investor profits, minimizing the dependency of the electricity generation to the conventional power plants with fossil fuels in the future researches of the researchers.

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