Impact of Optimal DG Placement and Sizing on Power Reliability and Voltage Profile of Radial Distribution Networks

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ABSTRACT:
Nowadays, energy supplied by the reliable manner is one of the important challenges of the distribution company in the radial distribution system. Therefore, this paper considers these challenges by the optimal DG placement to minimize power losses with considering the analysis related to the reliability and voltage profile. In this paper, exchange market algorithm (EMA) is used as a powerful tool to solve the optimization problem. In order to extract the global optimum point, EMA uses two searching operators and two absorbent operators based on the generation of random numbers. To evaluate the goals of this paper, EMA is successfully implemented on 10, 33, and 69 bus IEEE test systems. Simulation results have illustrated that power losses are reduced by the optimal DG placement and size. Finally, the analysis of obtained results has shown the system's reliability; voltage profile can be improved if the DGs are allocated optimally in the radial network.

KEYWORDS: Distributed Generation, Power Loss Reduction, Reliability Improvement, Exchange Market Algorithm, Voltage Profile Improvement.

1. INTRODUCTION

In the power system, one of the important worries for the consumer is the cost of the electricity. For attention to consumer worries in the distribution systems, distribution company tries to use different solutions to provide reliable and economical electricity for consumers. On the other hand, power loss reduction, reliability and voltage profile improvement are the three critical challenges for distribution company in the electricity supply process. In this regards, if the distribution companies do not consider the above challenges, they not only face with the severe cost of the power losses, but also the more amount of the energy not supplied makes consumers not convenience. Therefore, many technologies are proposed and tested to reduce power losses with considering the reliability and voltage profile improvement in the radial distribution systems.

With recent advances in technology, distributed generation (DG) as a powerful and proper solution is introduced to the distribution company to reduce power losses, improve system reliability and subsequently reduce the cost of energy not supplied, and keep the voltage level in the acceptable range. In recent years, many researches have been performed to propose an efficient methodology for the optimal DG placement and sizing.

In this regards, many authors only have considered the power loss reduction factor in their research and reliability analysis are not evaluated in their studies. The literature contains several researches on the optimal DG placement and sizing. These researches can be divided into concentrating on power loss reduction only, such as [1-3], or focusing on voltage and reliability improvement, such as [4-7]. Load flow analysis is one of the approaches for solving the DG placement problem, which is used by [8]. The authors in [4] have applied the Genetic Algorithm (GA) for the optimal DG placement and sizing in the presence of time varying loads with considering of the annual load duration curve. The heuristic approach and analytical method are applied to solve the DG problem by the authors of [9, 10], respectively. In [11], the authors have used a novel chaotic symbiotic organisms search (CSOS) algorithm to find the optimal location and sizes of DG units. These authors have solved the DG placement problem to reduce the system power losses and improve the voltage stability. An improved non-dominated sorting genetic algorithm–II (INSGA-II) has been applied by the authors of the [12] to find an optimal DG location based on the line loss reduction, voltage stability maximization, and voltage deviation minimization. The authors of [13] proposed the Particle Swarm Optimization algorithm (PSO) with its updated code to determine the optimum location and size of DG, not only for minimizing line losses, but also for maximizing voltage profile in distribution systems. In order to optimize the DG placement and sizing, a multi-objective index-based approach has been proposed by the authors of [14] and the voltage profile, power losses of the system, and the line loading are three main factors, which have been considered by them. The authors of [15] have employed an analytical approach to determine the optimal size and location of DG units with considering the power loss minimization in the radial distribution system. Multi-objective function is an efficient approach, which is used by the authors of [16] to optimal DG placement and sizing to achieve the voltage and reliability improvement and power loss minimization. An analytical method is employed by the authors of [17] to find the optimal places and capacities of two DGs for minimizing the power loss in the radial distribution systems. In [18], the authors have applied simple analytical approach to evaluate the system power losses, network reliability, and power quality by finding the optimal size and locate of DG units. In order to solve the DG allocation problem with considering the reliability index and loss reduction, the authors of [19] have employed the multi-objective function, which is solved by a novel approach based on dynamic programming.

This paper uses the exchange market algorithm (EMA) to optimal DG allocation and sizing to evaluate the reliability improvement along with minimize power losses in the radial network. After determining the optimal DG location and sizing, the reliability and voltage profile analysis are applied to the obtained results to evaluate the effects of the optimal DG placement on the reliability and voltage improvement.

The remaining paper is organized as follows: section 2 presents the problem formulation. The ENS calculation is demonstrated in section 3. Exchange market algorithm is described in sections 4 and 5. Section 6 illustrates the simulation results. Finally, the conclusions of this paper is summarized in section 7.

2. PROBLEM FORMULATION

2.1. Load Flow Formulations

This paper has used backward-forward sweep as the appropriate method for solving the radial distribution system problem. This algorithm consists of several parts to solve the load flow problems, which are addressed as follows:

Part 1. First, system data enters to the load flow algorithm and then read by it to analysis next steps. In the next step, the voltage amount, which should be applied in each bus in the first iteration equal 1. With starting from end node, this algorithm computes the node current by (1).

$$I_n = \left(\frac{S_n}{V_n}\right)^* \quad (1)$$

$$S_n = P_n + jQ_n \quad (2)$$

Where, P_n and Q_n are injection active and reactive power at node *n*, respectively. S_n is injected power at node *n*. V_n is the voltage magnitude at node *n*.

Part 2. Backward sweep: In this part, by using the KCL law in (3), the current flowing from node *n* towards node *n+1* will be determined.

$$I_{(n,n+1)} = I_{n+1} + \sum \begin{pmatrix}\text{current in branches} \\ \text{emanating from node n+1}\end{pmatrix} \quad (3)$$

Where, $I_{(n,n+1)}$ is the line current between *n* and *n+1*th node.

Part 3. Forward sweep: In this part, node voltage is calculated with considering the obtained current in the part (2) and then it is computed using the KVL law in (4).

$$V_{n+1} = V_n - Z_{(n,n+1)}.\mathrm{I}_{(n,n+1)} \quad (4)$$

Where, V_{n+1} and V_n are the voltage magnitude at node *n+1* and *n*, respectively. $Z_{(n,n+1)}$ is the line series impedance between *n* and *n+1*th node.

Part 4. In this part, the iteration counter increases to *iter+1* until the counter reaches to *itermax*. Then, the power injection will be calculated for each bus using the (5) and then, using the power injection amount, the total real and reactive power injected will be determined in (6). Finally, the amount of power loss will be computed in (7) and then the results of the load flow process will be printed.

$$S_{inj}^n = V_{inj}^n (I_{inj}^n)^* \quad (5)$$

Where, V_{inj}^n is a voltage magnitude, which is injected at bus *n*. I_{inj}^n is a branch current at bus *n*.

$$P_{inj}^n = real(S_{inj}^n); \qquad Q_{inj}^n = imag(S_{inj}^n) \quad (6)$$

$$\begin{aligned} ploss &= P_{inj}^n \text{ - (sum of the active power demand);} \\ Qloss &= Q_{inj}^n \text{ - (sum of the reactive power demand)} \end{aligned} \quad (7)$$

Where, *Ploss* and *Qloss* are the active and reactive power losses, respectively.

2.2. Objective Function

In this paper, the power loss minimization is a main objective function, which is realized by the optimal DG placement and sizing. In addition, this paper after the DG placement for minimizing the system power loss, it considers the reliability and voltage profile analysis for the DG placement problem.

Minimize $OBJ = \min(P_{Loss})$

$$P_{Loss} = P_{inj} + \sum_{n=2}^{nDG} P_{DG}^{n} - \sum_{n=1}^{n} P_{D}^{n} \tag{8}$$

Where, *nDG* is a number of DG units, which is connected at bus *n*.

2.3. Constraints

In this study, real power limit, voltage and location limit, and power balance are four constraints in relation to the DG placement problem. Therefore, the DG placement problem is solved with considering that mentioned and below constraints have acceptable ranges. These constraints are illustrated as follows:

2.3.1. Voltage Limit

The voltage magnitude must be kept in the acceptable range in all buses at the all times. This limit is shown as follows:

$$V_{\min}^{n} \leq V^{n} \leq V_{\max}^{n} \tag{9}$$

Where, $V_{\min}^{n}$ and $V_{\max}^{n}$ are the minimum and maximum voltage limits, which generally equal to (0.95 p.u) and (1.05 p.u), respectively.

2.3.2. Real Power Limit

The real power injected by DG unit should be have standard amount. This amount should be kept in the standard range, which is shown as follows:

$$P_{DG,MIN}^{n} \leq P_{DG}^{n} \leq P_{DG,MAX}^{n} \tag{10}$$

Where, $P_{DG,MAX}^{n}$ and $P_{DG,MIN}^{n}$ are the maximum and minimum permissible limit, which generally equal to (0 kW) and ($\sum_{1}^{n}(\frac{\text{real power demand}}{nDG})$), respectively.

2.3.3. Power Balance Constraint

The power generated by DG units should have a permissible range, which is demonstrated as follows:

$$\sum_{n=2}^{nDG} P_{DG}^{n} \leq \sum_{n=2}^{n} P_{D}^{n} + P_{Loss} \tag{11}$$

2.3.4. DG Location Limit

Number of nodes, which DGs can be placed in it, has a constraint as follows:

$$1 < \text{DG location} < N \tag{12}$$

Where, *N* is the number of nodes in the radial network.

3. ENS CALCULATION IN RADIAL DISTRIBUTION NETWORK

In the power system, all sectors try to supply energy from energy generation sector to the consumers by reliable manners. In this regards, the energy supplied to the consumers at every time is one of the important challenges for the distribution company. Therefore, one of the suitable manners to reliable supply energy is the use of distributed generation (DG) in radial distribution systems. To bridge these research gaps, the reliability analysis is evaluated in this paper. Since, all the elements in radial networks such as switches, cables, etc. stay on the series state with each other, the series laws can be applied to radial distribution systems [20]. In order to do reliability analysis, reliability parameters will be calculated to evaluate the reliability improvement in radial networks.

In this regards, average outage time (r_s), average failure rate (λ_s), and average annual outage time (U_s) are the three basic parameters, which are used to reliability analysis. These parameters are shown as follows:

$$\lambda_s = \sum_j \lambda_j \tag{13}$$

$$U_s = \sum_j \lambda_j r_j \tag{14}$$

$$r_s = \frac{U_s}{\lambda_s} = \frac{\sum_j \lambda_j r_j}{\sum_j \lambda_j} \tag{15}$$

Where, *j* illustrates the load point number. In addition to the above parameters, energy not supplied (ENS) is one of the important parameters, which is used to reliability analysis. In order to calculate the ENS, the amount of average load (L_a) is needed, which is computed by (16).

$$L_a = \frac{E_d}{t} \tag{16}$$

Where, E_d is the total energy demand in period of interest and t is the period of interest, which are shown in Fig. 1.

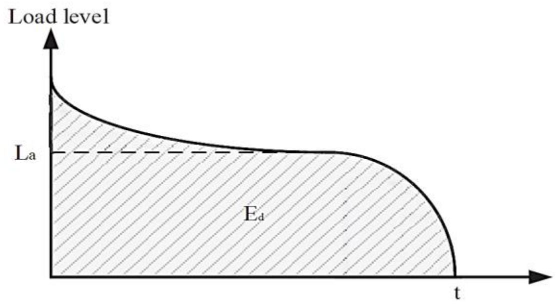

Fig. 1. Total energy demand E_d with average load L_a in period t.

Therefore, the ENS and AENS (average energy not supplied) parameters can be computed as follows:

$$ENS = \sum_j L_a(j) \times U_j \tag{17}$$

$$AENS = \frac{\sum_j L_a(j) \times U_j}{\sum_j N_j} \tag{18}$$

In this research, the total cost of energy not supplied after and before DG placement are also calculated by the following equation.

Total cost= cost of DG + cost ENS-After (19)

Where, the cost of DG is consisted of the investment, operation, and maintenance cost of DG unit. Cost ENS-After is the cost of energy not supplied after the DG placement in the radial network.

4. EXCHANGE MARKET ALGORITHM

Exchange market algorithm is one of the optimization algorithms, which is inspired by the trading stocks in the share market. This algorithm operates based on the how the shares are exchanged in the share market. Therefore, EMA is divided into the two modes, which are named as an oscillation and not oscillation markets. In the market with oscillation mode, the price of shares oscillates, but it is almost constant in the not oscillation mode. In this algorithm, the assessment of the individuals' fitness is performed at the end of each mode [21]. Two absorbing operators are the powerful tools for EMA that are used to search optimal point in the search space. In this algorithm, the market has two situations based on the stockholder behaviors. After each iteration, the stockholders are ranked based on their stock's value and will be divided to the three high, medium, and low levels that are called group 1, group 2, and group 3, respectively. In this regards, stocks are not traded by the shareholders of group 1. Stockholders of the two another group will be traded their stocks under the special conditions [22, 23].

4.1. The exchange Market in Balanced Condition

In this mode, the market has not oscillation and each of the stockholders tries to search optimum point by mainly considering the experience of the succeeded shareholders and not performing risk actions in the market process. In this situation, shareholders are ranked based on their state of the traded stocks in the market.

4.1.1. Shareholders with high ranks

The members of this group are composed of the shareholders with successful experience. These members want to keep their ranks in the market. Therefore, they try as far as possible to have no risk in their exchanges.

4.1.2. Shareholders with mean ranks

The members of this group are consisted of the approximately one-third percent of the stockholder population. In this group, shareholders use the experiences of the successful members of group 1 to perform a little risk in their trades to gain the better ranked in the stock market. In this regards, a comparison between the shares of the stockholders is addressed by (20). Therefore, the number of stockholder shares change as follows:

$$\begin{aligned} &M_j^{group\,2} = r \times M_{1,i}^{group\,1} + (1-r) \times M_{2,i}^{group\,1}; \\ &i = 1, 2, 3, \ldots, m_i; \\ &j = 1, 2, 3, \ldots, m_j \end{aligned} \tag{20}$$

Where, m_i is the mth member of the first group, m_j is the member of the second group, r is random number, which have the amount between zero and one. $M_{1,j}^{group1}$ and $M_{2,j}^{group1}$ are the individuals of the first group. $M_i^{group\,2}$ is the jth member of the second group.

4.1.3. Shareholders with low ranks

Stockholders of this group have the worst position among the other stockholders in the market. They have high risk than the members of the first group. In this group, stockholders use the differences between the stocks of the first group and themselves shares to change their shares to get the better position. They change the number of their stocks to earn more profit based on the (22).

$$\begin{aligned} S_e = {} & 2 \times r_1 \times (M_{i,1}^{group\,1} - M_e^{group\,3}) + \\ & 2 \times r_2 \times (M_{i,2}^{group\,1} - M_e^{group\,3}) \end{aligned} \tag{21}$$

$$M_e^{group3,\ new} = M_e^{group3} + 0.8 \times S_e;\ e = 1, 2, 3, \ldots, m_e \qquad (22)$$

Where, r_1 and r_2 are random number, which have the amount between zero and one. m_e is the mth individual of the third group. M_e^{group3} is the eth individual. Finally, stock variations of the eth individual of the third group is shown by the S_e.

4.2. The Exchange Market in Oscillated Condition

In this mode of the market, the stockholders will be ranked based on their fitness value. With considering their fitness value, they are divided into the three different groups.

4.2.1. Shareholders with high ranks

In this group, elite stockholders make the members of the group. Since these members have best rank between other stockholders, they do not want to have trade based on the risk. Members of this group include 10-30 percent of the all members in the market.

4.2.2. Shareholders with mean ranks

Shareholders of this group tend to keep the sum of their stocks in the constant amount. In other words, only some of the stocks decreases and some of them increases, which causes total stocks remains in constant amount. In this group, the first step is that each shareholder increases their number of stocks as following equation:

$$\Delta m_{t1} = m_{t1} - \delta + (2 \times r \times \eta_1 \times \mu) \qquad (23)$$

$$\mu = \left(\frac{t_M}{n_M} \right) \qquad (24)$$

$$m_{t1} = \sum_{y=1}^{m} |s_{ty}| \quad y = 1, 2, 3 \ldots, m \qquad (25)$$

$$\eta_1 = m_{t1} \times g_1 \qquad (26)$$

$$g_1^{\,k} = g_{1,\max} - \frac{g_{1,\max} - g_{1,\min}}{iteration_{\max}} \times k \qquad (27)$$

Where, Δm_{t1} demonstrates the amount of shares, which is added randomly to some shares. Before the share changes, total shares of the tth individual are illustrated by the m_{t1}. The stocks of the tth individual are demonstrated by the s_{ty}. The information of the stock market is shown by δ. In second group, risk level of each individual is shown by η_1. The number of the tth individual in stock market is shown by t_M. The number of the last individual in stock market is shown by n_M. μ is a constant coefficient for each member. g_1 is the market risk, which is a common amount between the members and decreases when the iteration number increases. In addition, last iteration number and number of program iteration are illustrated by $iter_{max}$ and k, respectively. Maximum and minimum amount of risk are shown by $g_{1,\ max}$ and $g_{1,\ min}$, respectively.

In the next step, in order to establish balance between purchased and sold stocks, the shareholders should sell some of their shares to keep their trading in the constant amount. In this regard, the number of stocks should be reduced in Δm_{t2} amount by the members. Therefore, the Δm_{t2} will be calculated using the following equation.

$$\Delta m_{t2} = m_{t2} - \delta \qquad (28)$$

Where, m_{t2} is the sum of the stock amount after stocks variations.

4.2.3. Shareholders with low ranks

In this group, the amount of risk for stockholders is variable. The amount of risk increases when the shareholder's fitness decreases. Unlike the group 2, the sum of the number of stockholder's shares in this group will be changed after each trade. In this regards, the shares of the stockholders will be changed by the following equations.

$$\Delta m_{t3} = (4 \times r_s \times \mu \times \eta_2) \qquad (29)$$

$$r_2 = (0.5 - rand) \qquad (30)$$

$$\eta_2 = m_{t2} \times g_2 \qquad (31)$$

$$g_2^{\,k} = g_{2,\max} - \frac{g_{2,\max} - g_{2,\min}}{iteration_{\max}} \times k \qquad (32)$$

Where, Δm_{t3} demonstrates the amount of shares, which is added randomly to some shares. r_s is random number, which have the amount between zero and one. In third group, risk level of each individual is shown by η_2. In the third group, g_2 is the variable risk in the stock market. μ is the coefficient in relation to risk, which forces the shareholders with low rank to perform more risk to increase their finance.

5. EXCHANGE MARKET ALGORITHM IMPLEMENTATION PATTERN IN SOLVING MULTIPLE DGS PLACEMENT PROBLEM

The DG allocation problem is solved using the EMA according the following steps:

1- In the first step, the initial values are selected and stocks are allocated to the shareholders.
2- Shareholders fitness is calculated in (8) and then they are ranked based on the fitness values, and

classified in the three groups (balancing mode started).

3- The stocks of the second group of individuals are variated by (20).
4- The stocks of the third group of individuals are variated by (22).
5- Shareholders fitness are recalculated in (8) and then they are ranked based on the fitness values in new state, and classified in the three groups (oscillation mode started).
6- The stockholders of the second group trade their stocks using the (23) in oscillation market.
7- The stockholders of the third group trade their stocks using the (29) in oscillation market.
8- This process continues with jumping to step 2 until the program constraints and ending criterion are satisfied.

In this step of algorithm, the oscillation mode is finished and evaluating stockholders from step 2 is started if the market conditions are not satisfied. However, if the market conditions are satisfied, the program will be executed until the iteration counter reaches to $iter_{max}$. Fig. 2 shows the flowchart of the DG problem, which is solved by the EMA.

6. TEST CASES AND SIMULATION RESULTS

In order to evaluate the influence of DG implementation on the system reliability in radial distribution system, the exchange market algorithm is applied effectively on the 33 bus, 69 bus IEEE test system and 94 bus Portuguese radial distribution system. Although the proposed method can be used for any number of DG unit, but for reliability issues the number of DG unit, which is evaluated in this study is three. In this study, the control parameters used for EMA are common for all part of the simulation. All of the load levels as light with coefficient 0.5, medium with coefficient 1, and peak with coefficient 1.6 are covered by this study. Bus 1 is the slack bus for all the test systems.

With the aim to reliability analysis, the failure rate is considered as 2 (fail/year) and the outage time is assumed as 194.66 (hours) for all test systems [24]. In this study, the total cost of DG placement and the cost of energy not supplied are 31($/KWh) and 1.148 ($/KWh), respectively [25]. For all test systems, the results of the simulation are tabulated and analyzed. In order to analysis the objectives of this paper, we consider the three test system, which is evaluated as follows.

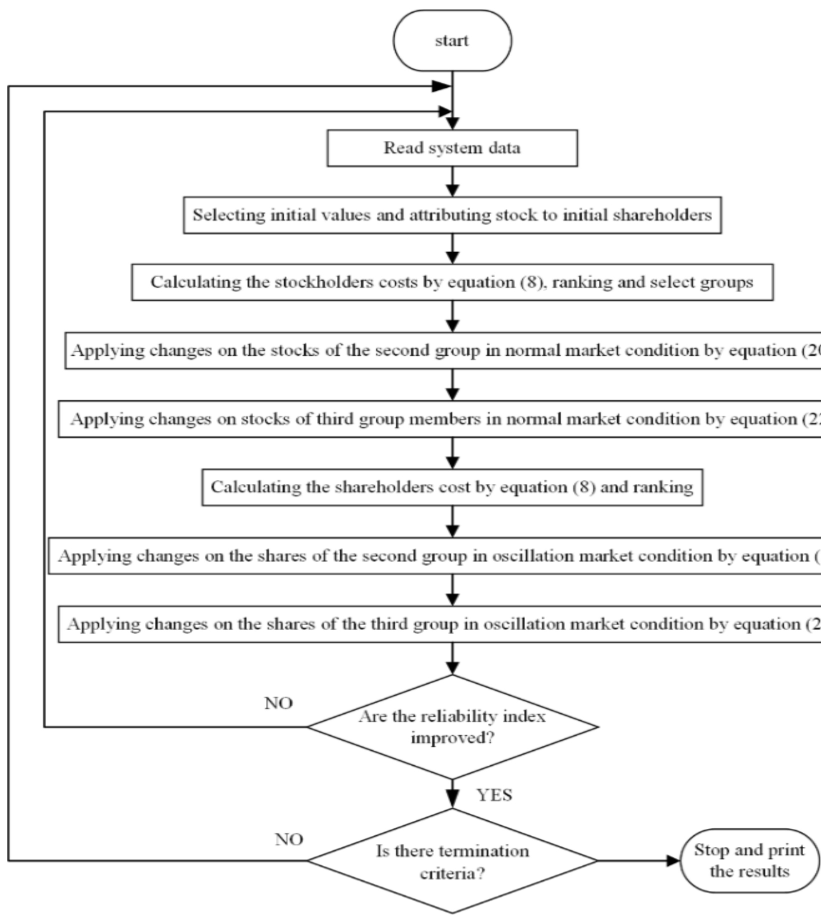

Fig. 2. Flowchart for solving DG problem using the EMA.

6.1. 33-bus Test System

In this section, the test system consists of the 32 branches. The single line diagram of 33 bus radial distribution system is illustrated in Fig. 3. The amount of the total load and base voltage are (3.715+j2.3) MVA and 12.66 KV, respectively. Before the DG allocation, the total system loss is 202.6764 KW. The power loss minimization, reliability and voltage improvement are the goals of this research, which is realized by the optimal DG placement and sizing.

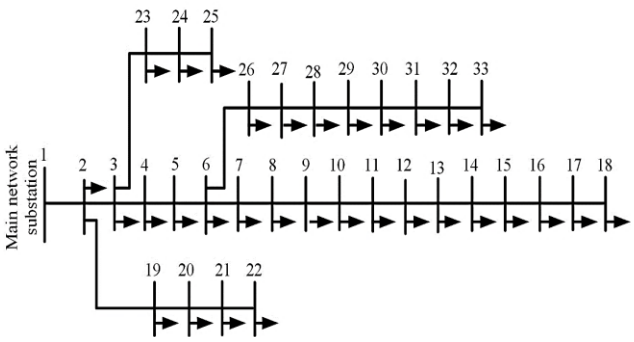

Fig. 3. Single line diagram of 33 bus system.

The simulation results for the DG allocation on radial network are tabulated in Table 1. The test system is evaluated in three state of DG implementation as one, two, and three DG unit. The results analysis indicate that the system power loss is reduced by 64.32 % with three DG units. The effect of DG placement in the loss minimization and voltage profile improvement for the three states of the DG implementation are shown in Fig. 4 and Fig. 5, respectively. To confirm the effectiveness of the proposed algorithm, the DG problem is solved for the different load levels (light, nominal, and peak) and the results are listed in Table 2. Numerical results indicated that the voltage profile improved by the optimal DG placement. Finally, the ENS index is computed for all of the state of DG implementation, which is addressed in the Table 1 and Table 2 and then the results are tabulated in Table 3.

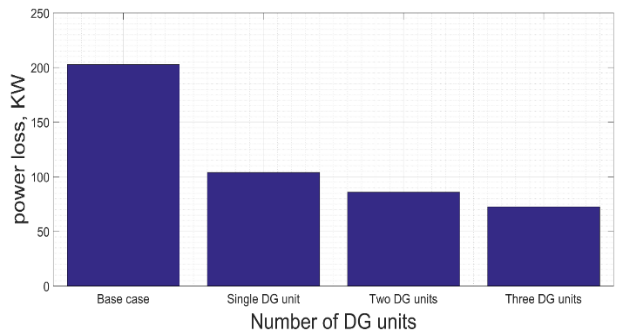

Fig. 4. Comparison of power loss for the various numbers of DG unit for 33 bus system.

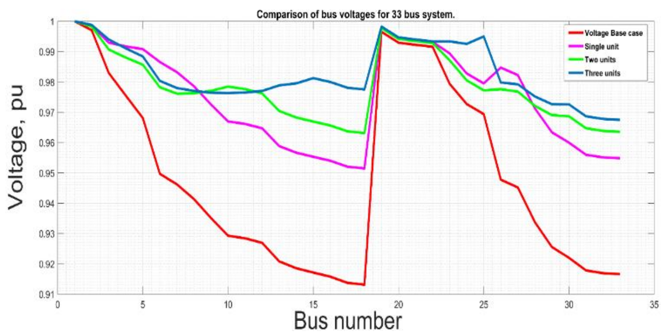

Fig. 5. Comparison of bus voltages for 33-bus system.

Table 1. The simulation results after DG placement 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	-	6/2528.244	11/816.385	30/976.606
	-	-	33/1000.583	24/1169.098
	-	-	-	12/943.549
Bus no /Vmin p.u.	17/0.913	17/0.951	17/0.963	32/0.969
Bus no /Vmax p.u.	2/0.997	2/0.999	2/0.998	2/0.999
Ploss, kW	202.676	103.955	85.932	72.299
Qloss, kVAr	135.141	74.785	58.775	49.813
% Loss reduction	-	48.709	57.601	64.328

Table 2. The simulation results for 33-bus system after DG placement with load variation.

Parameters		EMA		
Load level		Light load (0.5)	Nominal load (1.0)	Peak load (1.6)
Load flow results	Ploss in KW	47.071	202.676	575.361
	Qloss in kVAr	31.350	135.141	384.260
	bus no/Vmin in pu	17/0.958	17/0.913	17/0.853
	bus no/Vmax in pu	2/0.999	2/0.997	2/0.995
Optimal Bus no. /DG size in kW	-	33/846.477	30/976.606	11/1015.205
	-	13/883.286	24/1169.098	24/977.523
	-	24/1227.443	12/943.588	33/860.655
Bus no /Vmin p.u.	-	17/0.983	17/0.913	32/0.948
Bus no /Vmax p.u.	-	2/0.999	2/0.997	2/0.998
Ploss, kW	-	17.499	72.299	191.2718
Qloss, kVAr	-	12.507	49.813	133.635

Table 3. Comparing cost of ENS and total cost after and before DG placement for 33 bus system.

cost	1-DG	2-DG	3-DG	Light Load	Nominal Load	Peak Load
ENS-B (KWh/year)	165105.45	165105.45	165105.45	165105.45	165105.45	165105.45
cost ENS-B ($/year)	5118.269	5118.269	5118.269	5118.269	5118.269	5118.269
ENS-A (KWh/year)	77594.38	79355.62	40619.62	50789.79	54585.29	63877.52
cost ENS-A ($/year)	2405.426	2460.024	1259.208	1574.483	1692.114	1980.203
Total cost ($/year)	4665.914	4675.018	4474.787	4527.358	4546.977	4595.010

6.2. 69-bus Test System

This test system has features that consists of the 69 branches. The amount of the total load and base voltage are (3.80+j2.69) MVA [3] and 12.66 KV, respectively. The single diagram of this test system is demonstrated in Fig. 6. In this test system, the power loss without DG allocation is 220.5174 KW. We applied EMA for this test system and the results of it are listed in Table 4. The evaluation results indicated that after the DG placement, the system power loss with three DG units is minimized and reduced to 67.6783 KW and its diagram is shown in Fig. 7. In addition, the voltage profile is also improved to 0.98145 at bus 26, which is illustrated in Fig. 8. This study continued for different load levels and the numerical results is tabulated in Table 5. In the final stage, reliability analysis is performed by the ENS index calculation for this test system and their results are reported in Table 6. The reliability analysis indicated that after DG placement both the energy not supplied and cost of it are reduced.

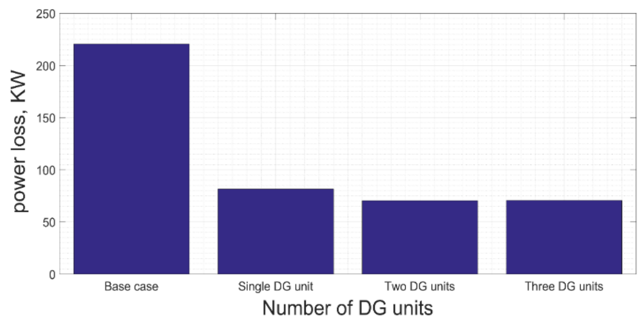

Fig. 7. Comparison of power loss for the various numbers of DG unit for 69 bus system.

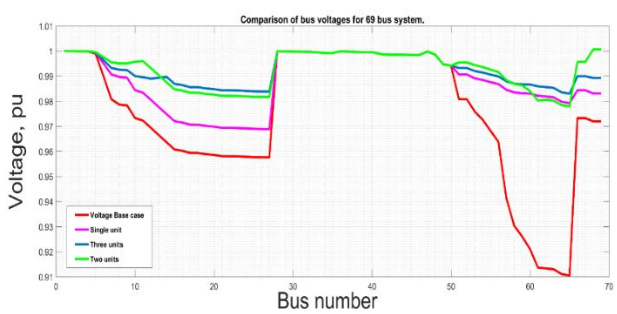

Fig. 8. Comparison of bus voltages for 69 bus system.

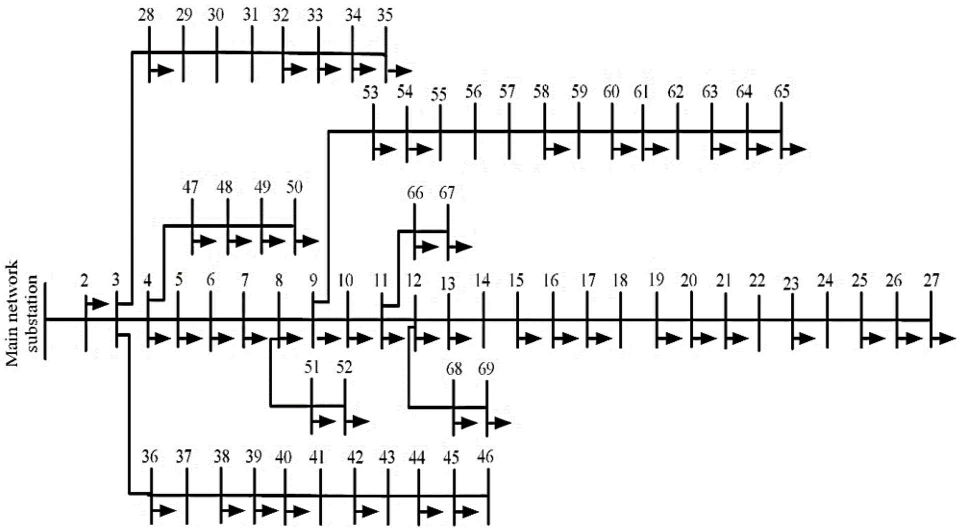

Fig. 6. Single line diagram of 69 bus system.

Table 4. The simulation results after DG placement 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	-	57/1910.346	61/1886.914	68/910.725
	-	-	69/649.301	69 /1263.963
	-	-	-	50/689.069
Bus no /Vmin p.u.	64/0.911	26/0.969	64/0.979	26/ 0.982
Bus no /Vmax p.u.	2/0.999	2/0.999	2/0.999	2/0.999
Ploss, kW	220.517	81.202	70.414	67.678
Qloss, kVAr	100.016	39.518	37.013	35.854
% Loss reduction	-	63.176	68.069	69.309

Table 5. The simulation results for 69 bus system after DG placement with load variation.

Parameters		EMA		
Load level		Light load (0.5)	Nominal load (1.0)	Peak load (1.6)
Load flow results	Ploss in KW	50.650	220.517	638.044
	Qloss in kVAr	23.093	100.016	287.344
	bus no/Vmin in pu	64/0.957	64/0.911	64/0.847
	bus no/Vmax in pu	2/0.999	2/0.999	2/0.999
Optimal Bus no. /DG size in kW	-	5/907.801	68/910.725	69/770.463
	-	63/1243.402	69 /1263.963	61/1088.914
	-	11/277.031	50/689.069	20/318.194
Bus no /Vmin p.u.	-	26/0.986	26/0.982	26/0.960
Bus no /Vmax p.u.	-	2/0.999	2/0.999	2/0.999
Ploss, kW	-	17.158	67.678	191.647
Qloss, kVAr	-	8.357	35.854	97.508

Table 6. Comparing cost of ENS and total cost after and before DG placement for 69 bus system.

Cost	1-DG	2-DG	3-DG	Light Load	Nominal Load	Peak Load
ENS-B (KWh/year)	168522.67	168522.67	168522.67	168522.67	168522.67	168522.67
cost ENS-B ($/year)	5224.202	5224.202	5224.202	5224.202	5224.202	5224.202
ENS-A (KWh/year)	96271.25	45382.89	6263.565	5115.89	6614.16	6786.98
cost ENS-A ($/year)	2984.408	1406.869	1941.705	1585.928	2050.390	2103.964
Total cost ($/year)	4850.726	4587.679	4676.860	4617.536	4694.983	4703.916

6.3. 94-bus Test System

The single line diagram of this test system is illustrated in Fig. 8, which represents that it has 94 branches. The EMA is applied to solve the DG problem and the results is listed in Table 7. The base voltage amount and total load, which are used for this test system is 15 KV and (4.797+j2.3247) MVA, respectively. Consideration of the results specified that after the DG allocation, the system power loss is reduced from 362.8580 KW to the 72.422 KW and the graphical representation of the system power losses is shown in Fig. 9.

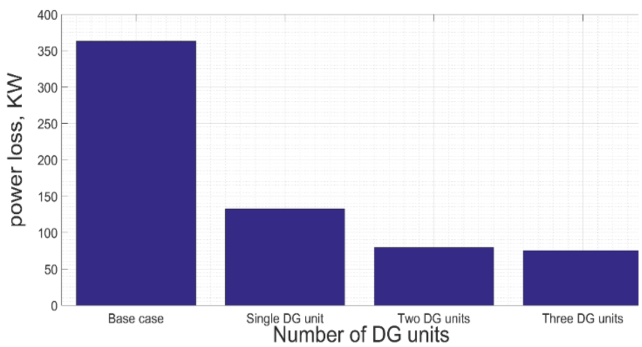

Fig. 10. Comparison of power loss for the various numbers of DG unit for 94 bus system.

The voltage profile is improved to 0.9379 KV at bus 91, which is demonstrated in Fig. 10. The performance of the system for different load levels is given in Table 8. The ENS index is calculated for all state of the DG implementation and the results are tabulated in Table 9. Considering the amount of ENS after the DG placement, one can conclude that the cost of ENS is reduced, which represents the improvement of the reliability index.

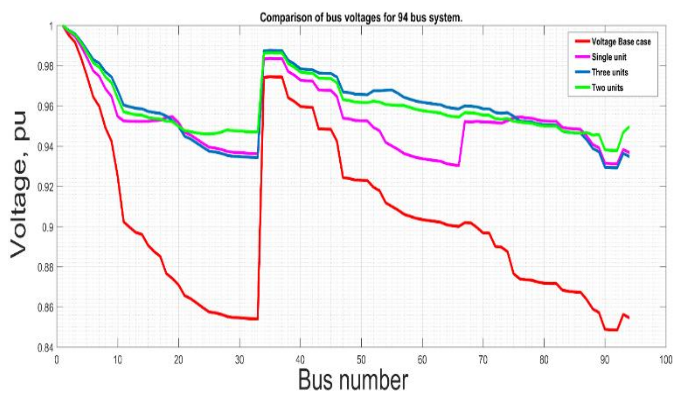

Fig. 11. Comparison of bus voltages for 94 bus system.

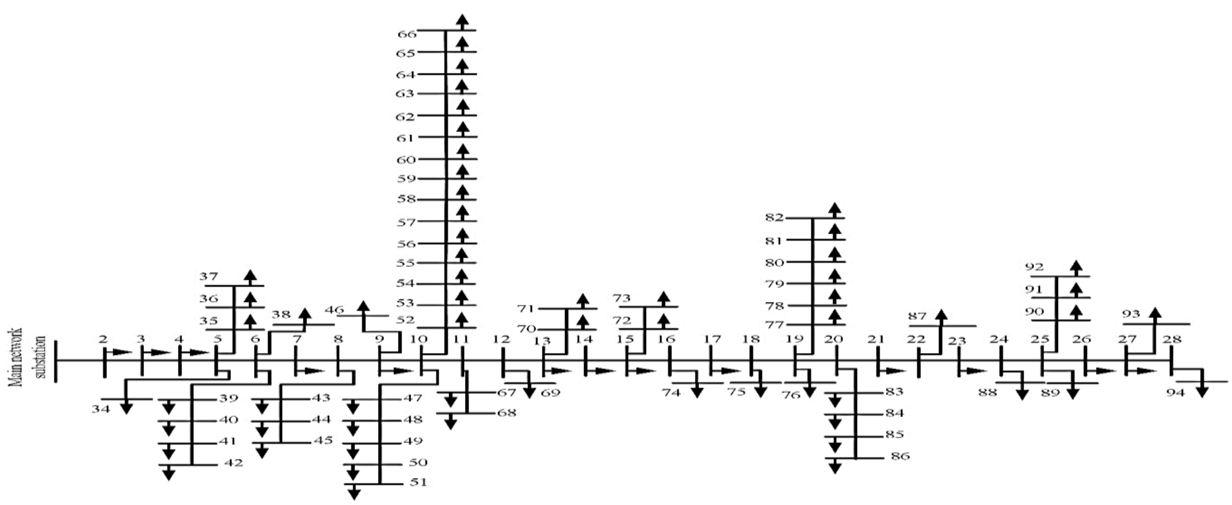

Fig. 9. Single line diagram of 94 bus system.

Table 7. The simulation results after DG placement 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	-	19/2368.928	59/1569.532	21/1574.816
	-	-	86/2303.030	63/650.855
	-	-	-	72/1503.083
Bus no /Vmin p.u.	91/0.849	65/ 0.931	91/0.930	91/0.938
Bus no /Vmax p.u.	2/0.996	2/0.997	2/0.998	2/0.997
Ploss, kW	362.858	132.396	79.192	72.422
Qloss, kVAr	504.042	164.041	101.118	95.768
% Loss reduction	-	63.513	78.176	80.041

Table 8. The simulation results for 94 bus system after DG placement with load variation.

Parameters		EMA		
Load level		Light load (0.5)	Nominal load (1.0)	Peak load (1.6)
Load flow results	Ploss in KW	79.603	362.858	115.548
	Qloss in kVAr	110.940	504.042	159.517
	bus no/Vmin in pu	91/0.929	91/0.849	91/0.724
	bus no/Vmax in pu	2/0.998	2/0.995	2/0.991
Optimal Bus no. /DG size in kW	-	60/1515.568	21/1574.816	58/1598.939
	-	18/1206.527	63/650.855	15/343.344
	-	94/692.741	72/1503.083	79/1598.948
Bus no /Vmin p.u.	-	91/0.971	91/0.849	91/0.903
Bus no /Vmax p.u.	-	2/0.999	2/0.995	2/0.996
Ploss, kW	-	17.909	72.422	150.033
Qloss, kVAr	-	24.382	95.768	278.175

Table 9. Comparing cost of ENS and total cost after and before DG placement for 94 bus system.

cost	1-DG	2-DG	3-DG	Light Load	Nominal Load	Peak Load
ENS-B (KWh/year)	213192.69	213192.69	213192.69	213192.69	213192.69	213192.69
cost ENS-B ($/year)	6608.973	6608.973	6608.973	6608.973	6608.973	6608.973
ENS-A (KWh/year)	73997.23	66968.20	61944.00	48398.47	74317.111	90101.052
cost ENS-A ($/year)	2293.914	2076.014	1920.264	1500.352	2303.830	2793.132
Total cost ($/year)	5889.456	5853.122	5827.151	5757.133	5891.109	5972.698

7. CONCLUSION

In this study, the exchange market algorithm is applied to solve the DG placement and sizing problem on the three test systems effectively that includes: 33 bus, 69 bus IEEE test system and 94 bus Portuguese radial distribution system. In order to do more evaluation of the goals of this study, different load levels are examined for DG placement problem by this research, too. In the all part of the simulation, the system power losses, reliability and voltage profile improvement are analyzed effectively. The numerical results indicated that after the optimal DG allocation in the system, the system power loss is minimized, the voltage profile is improved, and the cost of energy not supplied is minimized, which represents that the reliability is improved in the radial distribution systems.

REFERENCES

[1] D. Q. Hung and N. Mithulananthan, **"Multiple Distributed Generator Placement in Primary Distribution Networks for Loss Reduction,"** *IEEE Transactions on industrial electronics*, Vol. 60, No. 4, pp. 1700-1708, 2013.

[2] S. Elsaiah, M. Benidris, and J. Mitra**, "Analytical Approach for Placement and Sizing Of Distributed Generation on Distribution Systems,"** *IET Generation, Transmission & Distribution*, Vol. 8, No. 6, pp. 1039-1049, 2014.

[3] S. ChithraDevi, L. Lakshminarasimman, and R. Balamurugan, **"Stud Krill Herd Algorithm for Multiple DG Placement and Sizing in A Radial Distribution System,"** *Engineering Science and Technology, an International Journal*, Vol. 20, No. 2, pp. 748-759, 2017.

[4] Z. Boor and S. M. Hosseini, **"Optimal Placement of DG to Improve the Reliability of Distribution Systems Considering Time Varying Loads using Genetic Algorithm,"** *2012, Distributed Generation; Genetic Algorithm; Reliability; Time Varying Loads*. Vol. 7, No. 1, 2012-10-08 2012.

[5] L. Han, R. Zhou, and X. Deng, **"An Analytical Method for DG Placements Considering Reliability Improvements,"** *in Power & Energy Society General Meeting, 2009. PES'09. IEEE,* 2009, pp. 1-5: IEEE.

[6] M. Tadayon and S. Golestani, **"A New Method For Optimal RCS Placement in Distribution Power System Considering DG Islanding Impact on Reliability,"** in *Transmission & Distribution Conference & Exposition: Asia and Pacific*, 2009, 2009, pp. 1-4: IEEE.

[7] K. M. Muttaqi, A. D. Le, M. Negnevitsky, and G. Ledwich, **"An Algebraic Approach for Determination of DG Parameters to Support Voltage Profiles in Radial Distribution Networks,"** *IEEE Transactions on Smart Grid*, Vol. 5, No. 3, pp. 1351-1360, 2014.

[8] S. Ghosh, S. P. Ghoshal, and S. Ghosh, **"Optimal Sizing and Placement of Distributed Generation in A Network System,"** *International Journal of Electrical Power & Energy Systems*, Vol. 32, No. 8, pp. 849-856, 2010.

[9] S. Porkar, P. Poure, A. Abbaspour-Tehrani-fard, and S. Saadate, **"A Novel Optimal Distribution System Planning Framework Implementing Distributed Generation in A Deregulated Electricity Market,"** *Electric Power Systems Research*, Vol. 80, No. 7, pp. 828-837, 2010.

[10] T. Gözel and M. H. Hocaoglu, **"An Analytical Method for the Sizing and Siting Of Distributed Generators in Radial Systems,"** *Electric Power Systems Research*, Vol. 79, No. 6, pp. 912-918, 2009.

[11] S. Saha and V. Mukherjee, **"Optimal Placement and Sizing of DGs in RDS using Chaos Embedded SOS Algorithm,"** *IET Generation, Transmission & Distribution*, Vol. 10, No. 14, pp. 3671-3680, 2016.

[12] W. Sheng, K.-Y. Liu, Y. Liu, X. Meng, and Y. Li, **"Optimal Placement and Sizing Of Distributed Generation Via An Improved Nondominated Sorting Genetic Algorithm II,"** *IEEE Transactions on Power Delivery*, Vol. 30, No. 2, pp. 569-578, 2015.

[13] M. Vatankhah and S. M. Hosseini, **"PSO Based Voltage Profile Improvement and Line Loss Reduction by Optimizing Size and Location of DGs,"** *Majlesi Journal of Electrical Engineering*, Vol. 6, No. 2, 2012.

[14] A. El-Zonkoly, **"Optimal Placement of Multi-Distributed Generation Units Including Different Load Models Using Particle Swarm Optimisation,"** *IET generation, transmission & distribution*, Vol. 5, No. 7, pp. 760-771, 2011.

[15] S. N. G. Naik, D. K. Khatod, and M. P. Sharma, **"Analytical Approach for Optimal Siting nd Sizing of Distributed Generation in Radial Distribution Networks,"** *IET Generation, Transmission & Distribution*, Vol. 9, No. 3, pp. 209-220, 2014.

[16] R. Baghipour and S. M. Hosseini, **"Placement of DG And Capacitor for Loss Reduction, Reliability And Voltage Improvement In Distribution Networks and BPSO,"** *International Journal of Intelligent Systems and Applications*, Vol. 4, No. 12, p. 57, 2012.

[17] M. H. Ranjbari, **"Determination of Contributions Of Several Distributed Generation for Reduction Of Losses Simultaneously,"** *Majlesi Journal of Energy Management*, Vol. 2, No. 3, 2013.

[18] H. Hamedi and M. Gandomkar, **"A Straightforward Approach to Minimizing Unsupplied Energy nd Power Loss through DG Placement and Evaluating Power Quality in Relation To Load Variations Over Time,"** *International Journal of Electrical Power & Energy Systems*, Vol. 35, No. 1, pp. 93-96, 2012.

[19] N. Khalesi, N. Rezaei, and M.-R. Haghifam, **"DG Allocation With Application of Dynamic Programming for Loss Reduction and Reliability Improvement,"** *International Journal of Electrical Power & Energy Systems*, Vol. 33, No. 2, pp. 288-295, 2011.

[20] H. Yip, G. Weller, and R. Allan, **"Reliability Evaluation of Protection Devices in Electrical Power Systems,"** *Reliability engineering*, Vol. 9, No. 4, pp. 191-219, 1984.

[21] N. Ghorbani and E. Babaei, **"Exchange Market Algorithm,"** *Applied Soft Computing*, Vol. 19, pp. 177-187, 2014.

[22] N. Ghorbani,**"Combined Heat and Power Economic Dispatch using Exchange Market Algorithm,"** *International Journal of Electrical Power & Energy Systems*, Vol. 82, pp. 58-66, 2016.

[23] N. Ghorbani and E. Babaei, **"Exchange Market Algorithm for Economic Load Dispatch,"** *International Journal of Electrical Power & Energy Systems*, Vol. 75, pp. 19-27, 2016.

[24] H. Saboori, R. Hemmati, and M. A. Jirdehi, **"Reliability Improvement in Radial Electrical Distribution Network by Optimal Planning of Energy Storage Systems,"** *Energy*, Vol. 93, pp. 2299-2312, 2015.

[25] (July 11, 2017). Typical Calculation of Running Cost per unit (kWH) for DG set Available: https://www.apollopowersystems.com/