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Effect of Multi-DG Installation to Loss Reduction in Distribution System

Since last decade, Artificial Intelligence (AI) methods have been used to solve complex DG problems because in most cases, they can provide global or near global solution. The major advantage of the AI methods is that they are relatively versatile for handling various qualitative constraints. AI methods mainly include Artificial Neural Network (ANN), Expert System (ES), Genetic Algorithm (GA), Evolutionary Programming (EP), Ant Colony Optimization (ACO) and Particle Swarm Optimization (PSO). The purpose of this paper is to present a new technique, namely Adaptive Embedded Clonal Evolutionary Programming (AECEP). The objective of the study is to employ AECEP optimization techniques for loss minimization. This technique was developed to optimally determine the location and sizing of DG. The IEEE 41-Bus RTS was implemented for testing several cases in terms of loading conditions..

Keywords: Artificial intelligence; Adaptive Embedded Clonal Evolutionary Programming; loss minimization.

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1. Introduction

One of the power distribution system activities is contrived with the power distribution arrangement to address the growing demand for electrical power is increasing from year to year. Among these plans is to furnish a dependable and low cost to the consumer while ensuring power quality and potential drop are within the standard scope. To achieve this plan, the strengthening of existing lines and substations, or make a new installation should be carried out. Today, distributed generation is becoming the choice of new capacity has arisen in the system operating environment over economic power. The importance of distributed generation power systems is an advantage in terms of technical, economic and operational characteristics change [1]. However, the penetration of renewable energy-based distributed generation in power distribution will be increased in the hereafter by a variety of factors. Models of distributed generation such as wind and solar energy can affect voltage regulation in power distribution organizations. To overcome this problem, the location and size of distributed generation are essential before any installation is carried out [2]. Therefore, how to comprehensively analyze the impacts of the different types of distributed generators on the distribution system reliability is a critical issue to be addressed [3].

There has been an increased interest in installing distributed generation of the distribution systems due to considerable advantages such as power loss reduction, cost reduction, environmental friendliness, voltage improvement, postponement of system upgrades and increasing reliability. To achieve one of these advantages, Abu-Mouti and El-Hawary [4] finds the optimal location and size of the DG to minimise the total system power loss for radial distribution feeder systems. For this reason, different methodologies and tools have been developed and discussed by many researchers to identify the optimal place and sizing to install DG. These methodologies are based on analytical and AI optimization techniques. Lee and Park, [5] proposed the method for selecting the optimal locations and sizes of multiple distributed generations (DGs). In this study, a method to

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determine the optimal locations of multiple DGs is proposed by considering power loss. The optimal sizings are determined by using the Kalman filter algorithm. The objective is to minimize the total power loss of system in a steady state operation. The proposed procedure based on the Kalman filter algorithm which took only few samples, and therefore reduced the computational requirement dramatically during the optimisation process. Sizing, sitting and scheduling distributed generators using Evolutionary Programming (EP) algorithm was suggested by [6]. For the purpose of comparative study of EP, Abdul Rahim et al. [7] presented another AI technique based Artificial Immune System (AIS) in their study. The result shows that the AIS technique was capable to simulate with the minimum number of iteration compared to EP. In the further study in 2010, Abdul Rahim et al [8] proposed the AIS for the purpose of determining the optimal sizing of DG. Sedighizadeh and Rezazadeh, [9] presented the application of Genetic Algorithm (GA) to the optimal allocation of DGs in distribution network. Sulaiman, M.H. et al, [10] in their paper presents a new technique from GA namely the continuous GA. This technique proposed to find the optimal sizing and location of EG units in the distribution system to minimize the total loss in the system. An Immune Algorithm (IA) based optimisation approach for solving the distributed generation (DG) placement problem is proposed by Aghaebrahimi et al. [11].
Inspiration through the observation on the AI techniques that has been discussed from the literature review in this section first, to enhance the original EP performance. This paper suggested a new technique, namely Adaptive Embedded Clonal Evolutionary Programming (AECEP). The technique devised the search space reduction strategy to accelerate the mutation process. The results obtained from the proposed techniques are compared with the first analysis obtained by EP and AIS optimisation techniques. It has shown superiority to the conventional techniques and also obtains precise solutions compared to analytical methods.

2. Notation

The notation used throughout the paper is stated below.

Indexes:

P_{loss}	active power loss
I	current through line
R	resistance through the line
P_{DGi}	active dg generated power
P_{Gi}	generate power source
P_D	power load demand
S_{DGi}	apparent dg generate power
pf_{DGi}	power factor of dg
V_i^{min}	minimum voltage at bus i
v_i^{max}	maximum voltage at bus i

3. Problem formulation

3.1. Objective function

There are two main aspects to the optimal DG installation problem, i.e. the optimal DG location and sizing. The search for appropriate placement of the DG to be installed is performed via the AI technique. Optimal DG sizing is a highly nonlinear constrained optimization problem represented by a nonlinear objective function subjected to nonlinear equality and inequality constraints; and boundary restrictions imposed by the system planner. The detailed formulation of the DG optimization problem is presented in the following sections.

A. Objective Function

The objective function to minimize the system losses given by:

$$\mathrm{F}=P_{loss} = Min(\sum_{n=1} I^2 R) \tag{1}$$

B. Equality Constraint

The equality constraints are the nonlinear power flow equations which state that all the real and reactive powers at any DS bus must be conserved. The loss is optimized with the following power balance equation,

$$\sum_{i=1}^{n} P_{DGi} + \sum_{i=1}^{n} P_{Gi} = P_L + P_D \tag{2}$$

The active P_{DG}, DG generated powers are respectively modelled as,

$$P_{DGi} = -S_{DGi} pf_{DGi} \tag{3}$$

C. Inequality Constraint

One inequality constraint is to be satisfied for this study. The inequality constraint is the bus voltage magnitude. The bus voltage magnitudes are bounded between two extreme levels imposed by physical limitations. It is customary to tolerate the variation in the voltage magnitudes in the distribution level to be in the vicinity of $\pm 10\%$ of its nominal value [12]. In this research, the power factor is assumed as unity power factor. The inequality constraint on voltage of each bus is expressed as shown in equation (4).

$$|V_i|^{min} \leq V_i \leq |V_i|^{max} \tag{4}$$

4. Adaptive Embedded Clonal Evolutionary Programming (AECEP)

The EP advantage is that the calculation time short and fast operation. EP can reduce computation time to reach the optimal solution. EP has proven superior in terms of fast computation time, especially in solving power system optimally in most cases in the study. Ref [13] reported that the number of iterations result of the EP usually short at less than 10 iterations.

However, the EP also has disadvantages such as inability to reach a settlement as appropriate. It is called as nearly optimal. Similarly,the technique AIS. This is due to inherited traits AIS EP. The only difference between AIS and the EP is, AIS through the process of cloning without fusion, while the EP only has the combination process but does not have cloning process.

Having worked with EP and AIS, in this study Adaptive Embedded Clonal Evolutionary Programming abbreviated as AECEP is proposed. This idea is to incorporate the element of randomised search step, denoted as β into the embedded AIS-EP. β is the scalar value ranging from 0 to 1 which exists in the mutation mathematical formulation in which it is able to search the best search step. A clonal process in AIS is embedded in the original EP algorithm, while β is added as a randomised factor which has the capability to control the search step. Improper selection of β value will lead to exhaustive optimisation process causing inaccurate solution and possible computation burden.

4.1. Algorithm of AECEP in DG installation

In this study, AECEP is implemented in order to minimise the total losses in the distribution system; while monitoring voltage at all buses in the system to be within the acceptable limit. The flowchart of the proposed AECEP is shown in Figure 1. The algorithm for AECEP is explained as follows:

Step 1: Initialization
In this process, random numbers are generated using the uniformly distribution random number generators. These candidates are also known as parents. The random number is denoted as x. The general equation for x is given as follows:

$$x_{nk} = \begin{bmatrix} x_{11} & x_{12} & x_{1k} & x_{1,k+1} & x_{1,k+2} & \cdots & x_{1,2k} \\ \vdots & \cdots & \cdots & \cdots & \cdots & \cdots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nk} & x_{n,k+1} & x_{n,k+2} & x_{n,2k} \end{bmatrix} \tag{5}$$

Matrix size= n x $2k$
where ; n = population number is 20
k = number of control variables
The population size is normally chosen between 10 to 20. Based on the experience and past researches [13], 20 is the suitable population size to achieve optimal solution.

Step 2: Fitness computation and cloning process
Fitness computation is conducted in order to perform the optimization. In this study, losses in power system will be the fitness which needs to be minimized. This can be referred to objective function in equation 1. The total losses are computed by running the load flow. On the other hand, cloning process is a process to duplicate the parents. The cloned population:

Matrix size of cloned population: mn x $2k$
where : n = population number
m = cloning number
k = number of control variables

$$\Gamma_{nmk} = \begin{array}{c} \begin{array}{cc} \longleftarrow \; k \; \longrightarrow & \longleftarrow \; k \; \longrightarrow \end{array} \\ \begin{bmatrix} x_{11} & \cdots & x_{ik} & \cdots & x_{1,k+1} & x_{1,k+2} & \cdots & x_{1,2k} \\ \vdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \vdots \\ x_{n1} & \cdots & x_{nk} & \cdots & x_{n+1,k} & x_{1,k+2} & \cdots & x_{n,2k} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ x_{21} & \cdots & x_{2k} & \cdots & x_{2,k+1} & x_{2,k+2} & \cdots & x_{2,2k} \\ \vdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \vdots \\ x_{n1} & \cdots & x_{nk} & \cdots & x_{n,k+1} & x_{n,k+2} & \cdots & x_{n,2k} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ x_{31} & \cdots & x_{n2} & \cdots & x_{n,k+1} & x_{1,k+2} & \cdots & x_{n,2k} \\ \vdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \vdots \\ x_{n1} & \cdots & x_{n2} & \cdots & x_{n,k+1} & x_{1,k+2} & \cdots & x_{n,2k} \end{bmatrix} \end{array} \begin{array}{c} \updownarrow m \\ \\ \updownarrow m \\ \\ \updownarrow m \end{array} \tag{6}$$

Step 3: Adaptive mutation

Mutation is a process to produce offspring (children). The mutation process is performed using equation (7) and (8).

$$x_{i+m,j} = x_{i,j} + N(0, \gamma^2) \tag{7}$$

$$\gamma^2 = \beta\left(x_{j\max} - x_{j\min}\right)\left(\frac{f_i}{f_{\max}}\right) \tag{8}$$

β is a scalar value, generated randomly to control the mutation process. β controls the movement of candidates from the valley to hill within the chosen bell-curve. This curve can be the Gaussian, Cauchy or Levy. The matrix sizing for the offspring is similar with that for the cloned population, τ_{mnk}.

Step 4: Fitness 2 computation

In this phase, fitness values are recalculated using the offspring. In this study, Gaussian mutation technique is employed.

Step 5: Combination

Combination is a process to connect the whole population and population after the cloned process in cascode form. It can be conceptually represented as in equation (9), (10) and (11). From the parent population, A_1

$$A_1 = \begin{bmatrix} no & x_1 & x_2 & \cdots & x_k & x_{k+1} & x_{k+2} & \cdots & x_{2k} & F_1 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ n & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & F_{20} \end{bmatrix} \tag{9}$$

and offspring population, A_2. Therefore, the combined population can be written as *C*.

$$A_2 = \begin{bmatrix} n0 & x_{1new} & x_{2new} & \cdots & x_{3new} & x_{1k+new} & \cdots & F_1 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ n \times m & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & F_{20} \end{bmatrix} \quad (10)$$

$$C = \frac{A_1}{A_2} \quad (11)$$

Step 6: Tournament Selection

Tournament selection is a process to prescribe the candidates for the next iteration. If the cloning multiplier *m* is 10, therefore F1 and F2 will have 20x10=200 populations. Only 20 best members or individual are prescribed from this population. There are many techniques for the selection process such as pair wise comparison, elitism and roulette wheel. Any suitable technique can be adopted for this purpose. But in this study, pair wise comparison was used.

Step 7: Stopping Criterion

The stopping criterion for AECEP is determined by evaluating the difference between maximum fitness or minimum fitness which is supposed to be less than Ɛ. Ɛ is the accuracy level set in the beginning of optimisation process. The typical value is 0.0001 [18]. The general equation can be given by:

$$\Delta f = f_{\max} - f_{\min} \leq 0.0001 \quad (12)$$

If Δf does not achieve the desire Ɛ value, the optimization process will repeat.

5. Results and discussion

The application of the proposed technique to power system has been examined on three different cases as single, two and three DG installation. To determine the robustness of the proposed technique, the cases were tested on IEEE 41-Bus radial distribution system (RDS). For each example, comparative studies were taken with regard to the results obtained using EP and AIS.

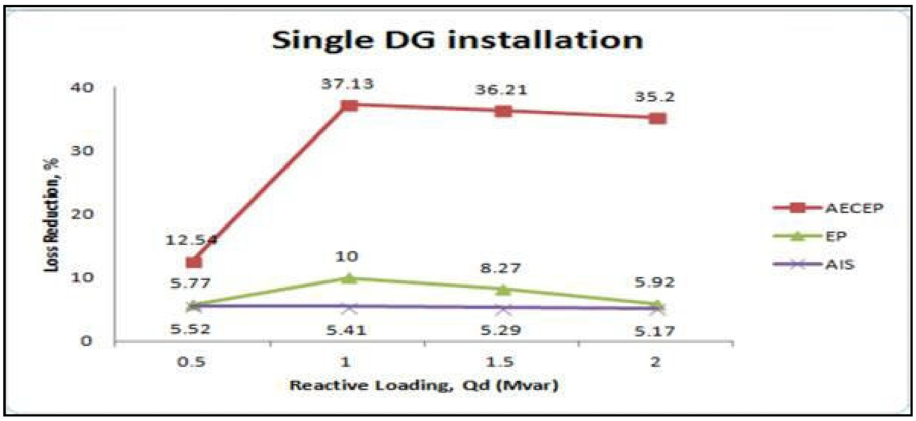

Figure 2: Single DG installation when bus 23 was reactively loaded using AECEP, EP and AIS technique in the IEEE 41-Bus RDS

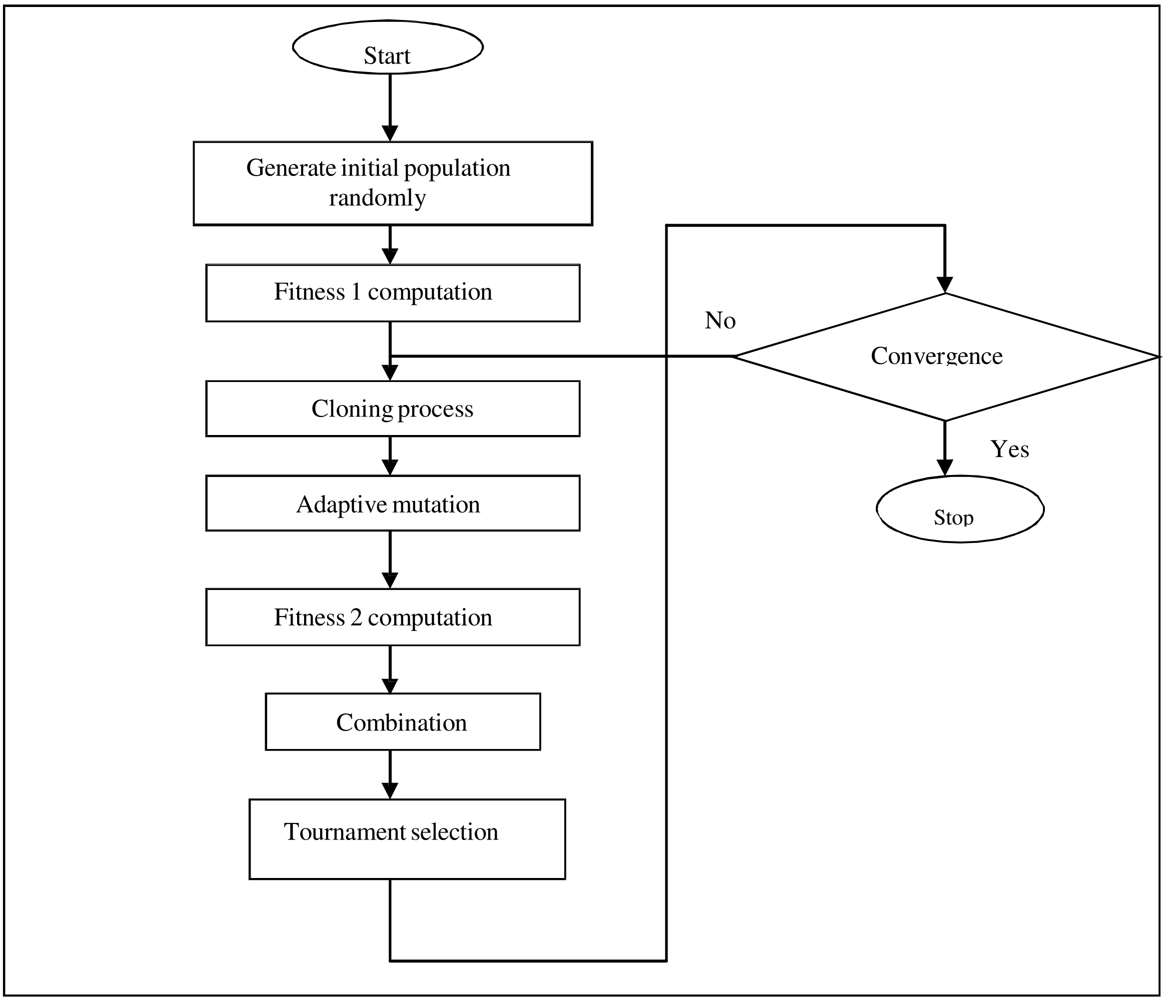

Figure 1: Flowchart of AECEP algorithm

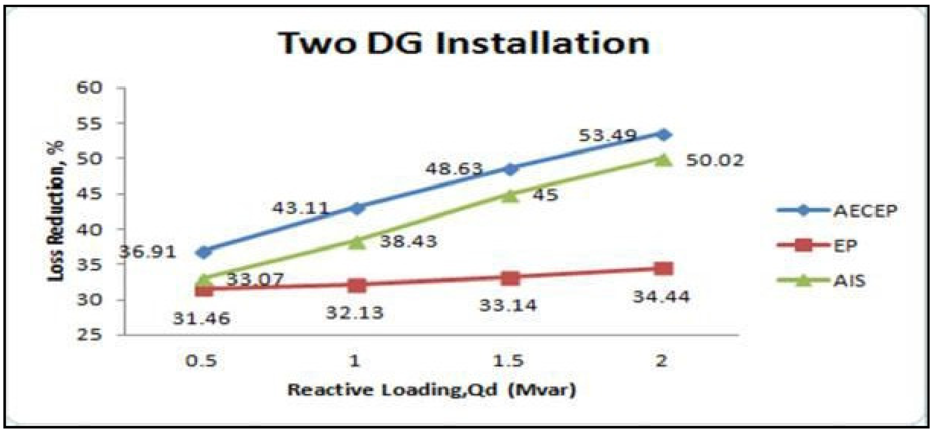

Figure 3: Two DG installation when bus 23 was reactively loaded using AECEP, EP and AIS technique in the IEEE 41-Bus RDS

From the figure 2, overall the result for AECEP shows the best performance in percentage of loss reduction compared to the EP and AIS technique. When bus 23 was reactively loaded (1.0Mvar), the AECEP depicted the highest loss reduction, 37.13%. At the same time, the EP and AIS only get the lower loss reduction, 10% and 5.41%

respectively when single DG was installed in the system.

Figure 3 depicted the results for two DG installation when bus 23 was reactively loaded using AECEP, EP and AIS technique. The percentage of loss reduction, increased when the reactive loading increased. It shows the same pattern for increment of reactive loading to loss reduction. The proposed AECEP technique shows the highest percentage of loss reduction, 53.49% at 2.0Mvar reactive loaded. While, the EP and AIS show lower values than AECEP, 50.02% and 34.44% respectively.

Figure 4 shows the results for three DG installation when bus 23 was reactively loaded using AECEP, EP and AIS technique. Same observation can be seen in this figure. The AECEP against to perform the highest loss reduction from the beginning increment of reactive loaded. While the EP and AIS reached at 25.15% and 24.47%, respectively, the result of the proposed AECEP was found in a good agreement with 37.93% at 2.0Mvar reactively loaded.

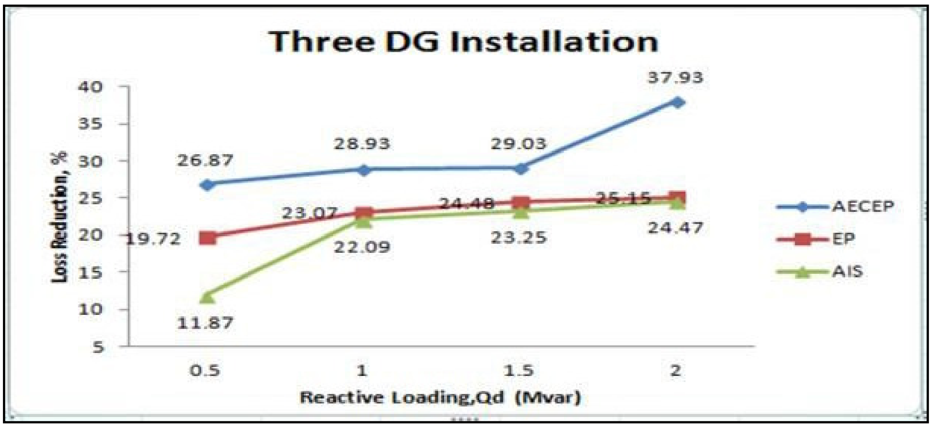

Figure 4: Three DG installation when bus 23 was reactively loaded using AECEP, EP and AIS technique in the IEEE 41-Bus RDS

5.1. Effect of Number of DG installation of the distribution system

The results for the effect of number of DG installation in the distribution system are discussed in details in this section. Numerous experiments were conducted with the system, as to gain the effect of number of DG installation, adequate to converge to a solution with minimized solution. The results are presented in the comparison table for the proposed AECEP technique only.

Table 1 presents the results for effect of number of DG installation when bus 23 was reactively loaded using the AECEP technique in the IEEE 41-Bus RDS. From the table, when the system was installed with two DG units, the loss shows the good reduction compared to one and three DG unit installation. The percentage of loss reduction is achieved at highest; 53.49% when the reactive loading condition is up to 2.0MVar. The voltage profile also shows the best improvement with the increment of load variations. The voltage is within the acceptable limit which is 0.956p.u. These results observed that the most desirable number of DG unit to install in the IEEE 41 Bus RDS is two DGs units.

Table 1: Results for the effect of number of DG installation when bus 23 was reactively loaded using the AECEP technique in the IEEE 41-Bus RDS.

Reactive Loading, Qd (MVar)	1 DG		2 DG		3 DG	
	Loss Red.(%)	Voltage (pu)	Loss Red.(%)	Voltage (pu)	Loss Red.(%)	Voltage (pu)
0.5	12.54	0.9001	36.91	0.900	26.87	0.919
1.0	37.13	0.9032	43.11	0.913	28.93	0.922
1.5	36.21	0.9117	48.63	0.937	29.03	0.934
2.0	35.20	0.9230	53.49	0.956	37.93	0.948

Table 2 tabulates the result for the location and size of DG when bus 23 was reactively loaded using AECEP, EP and AIS. As mentioned in the table 1, when two DG installed in the system, the percentage of loss reduction shows the highest value compared to others. The optimal location for 2 DG installation are at bus 9 and bus 30, while the optimal size is 0.1471MW and 0.5146MW.

Table 2: Results for the location and sizing of DG installation when bus 23 was reactively loaded using AECEP, EP and AIS technique in the IEEE 41-Bus RDS

Number of DG installation	Optimization Techniques					
	AECEP		EP		AIS	
	Location (Bus)	Sizing (MW)	Location (Bus)	Sizing (MW)	Location (Bus)	Sizing (MW)
1 DG	38	0.5455	20	0.1652	20	0.1652
2 DG	9 30	0.1471 0.5146	35 8	0.3287 0.8656	35 8	0.3287 0.8656
3 DG	10 18 35	0.3674 0.2336 0.3502	17 32 21	0.3552 0.5943 0.1346	7 37 16	0.3834 0.5042 0.3421

6. Conclusion

This paper presents the effect of number of DG installation in the distribution system. The results are shown in the comparison table for the proposed AECEP technique only. After a numerous experiments were conducted with the system, it is discovered that the most suitable number of DG to be installed for IEEE 41 Bus RDS in order to minimize losses and voltage profile improvement is two DGs units. On the other hand, for IEEE 41 Bus RDS the most suitable number of DG to be installed is a single DG unit. However, the results are both showing good indicator to engineer, planner to realize the effect of number of DG installation, adequate to converge to a solution with minimized solution.

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