

Multi Objective Allocation of Distributed Generations and Capacitor Banks in Simultaneous

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ABSTRACT

This paper has developed a novel multiobjective function for optimal sizing and siting of Distributed Generation (DG) units and capacitor banks in simultaneous mode to improve reliability and reduce energy losses. The proposed function consists of four objectives: Cost of Energy Not Supplied (CENS), System Average Interruption Duration Index (SAIDI), costs of energy loss and investment. A novel structure has been suggested for Differential Evolutionary Algorithm (DEA) to solve this nonlinear complex problem and its results compared with related values of genetic algorithm and simple DEA. In addition to the novel objective function, the other contribution of this work is proposing a new model for load and energy cost. Three types of DGs, i.e., wind turbine, solar cell and diesel generator have been employed in placement process. To verify the comprehensiveness of the proposed function, three scenarios have been introduced: Scenario i) First, placement of DGs, then capacitor banks, Scenario ii) First, placement of capacitor banks, and then DGs, and Scenario iii) simultaneous placement of DGs and capacitor banks. Simulations have been carried out on one part of practical distribution network in Metropolitan Tabriz in North West of Iran. The results of simulations have been discussed and analyzed by using of the five novel indices. The obtained simulation results using proposed function shows that the simultaneous placement of distributed generations and capacitor banks results in more reduction of the energy losses, and increase improvements of reliability indices as well as voltage profile.

KEYWORD: Capacitor banks placement, Distributed generation placement, Differential evolutionary algorithm, Reliability improvement, Practical radial distribution network.

1. INTRODUCTION

Main contributions of shunt capacitor banks are mainly power loss and reactive power consumption reduction, voltage profile and power quality improvements and power factor

correction [1-2]. Also, it has been found that if Distributed Generations (DGs) are placed appropriately, it can reduce the total active power loss, improve the voltage profile and increase the reliability of consumer service.

[3]. obviously, placement of both the capacitor banks and DGs has the advantages of the both system simultaneously.

1.1 Literature Survey

Only a few works have been performed in simultaneous placement of DGs and capacitor banks, the conducted works have been classified in three categories: optimal placement of DG and capacitor banks, multiobjective DG placement, and multiobjective capacitor banks placement.

In [4-6], DG and capacitor allocation has been proposed. Authors in [4] have placed capacitor in the presence of DG in radial distribution networks with nonlinear loads to improve power quality. Zou *et al.* have integrated DG and capacitor to improve the system voltage and reduce system losses, and solved the problem using Particle Swarm Optimization (PSO) algorithm. Authors have identified target voltage support zones by reducing the large search space [5]. The core objective function in [6] is minimizing voltage profile and reducing power/energy loss by simultaneous placement of DG sources and capacitor banks. For this purpose, voltage stability has been considered as a criterion in placement process.

In [7-11], optimal capacitor placement has been done for voltage profile improvement, reconfiguration, and reliability enhancement. Authors in [7] have used fixed and switching capacitors as well as network reconfiguration

to save annual cost using a joint strategy and taking advantage of the installed resources of the network by GA with special crossover and mutation operators. Chang has solved combined problems of reconfiguration and the optimal capacitor placement using Ant Colony Search Algorithm (ACSA). The results of the work have been compared with obtained results of Simulated Annealing (SA) and GA methods [8]. Etemadi and Fotuhi-Firuzabad in [9] have suggested a novel multiobjective function to improve reliability and reduce annual cost. Authors have employed Composite Customer Damage Function (CCDF) as an index for reliability improvement and solved the complex problem by PSO technique. One of the main advantages of capacitor banks in distribution networks is improving voltage profile which has been considered as a constraint in many works while in [10-11] it has been integrated in objective function.

In [12-15], DG units have been allocated considering voltage sag, voltage improvement and reliability improvement. Objective function in [12] has been coded by combination of genetic algorithm to evaluate impacts of DG placement in reliability enhancement and loss reduction as well as voltage profile improvement. In formulation of objective function in [13], technical factor (e.g. minimization of the line loss, reduction in the voltage sag) and economical factor

(installation and maintenance cost of the DGs) have been considered. The multiobjective function has been solved using GA and tested on 14, 30 and 34 distribution networks. The proposed objective function in [14] is based on nodal pricing which has been employed to find optimal size and location of DG units for loss reduction, and voltage profile improvement including voltage rise phenomenon. In [15] objective function has been formulated as the weighted sum of reliability indices and power loss, whereas load models, investment costs and DG types have not been considered.

1.2 Drawbacks of the mentioned studies

Drawbacks of the reviewed paper should be categorized in two groups; i.e. formulation and solution technique.

In Refs.[8, 12], the objective function has not been defined and power loss and voltage profile have been analyzed, separately. The objective function of Refs.[7, 10, 11, 13] has been formulated as classic mode (only function of power loss) and in [10-11], the voltage deviation added to the objective function. In [4], capacitor placed in the presence of DG units by ignoring impact of DG on reliability of network. Main terms of the objective function of Ref.[5] are investment costs of DG and capacitor and voltage profile improvement and power loss reduction have been studied separately. The used reliability indices in [6] are only

improving reliability from customer point of view.

The reviewed works have also some weak points in their solution techniques. Main disadvantage of GA which has been proposed in [1,6,7,10, 12] is low convergence velocity. In [5,9], PSO has been suggested to solve the problem but the main weakness of PSO is high possibility of lying in the local optimum points in most cases especially in problems with large scattering mistakes. The main drawbacks of ACSA [8] are: difficulty of theoretical analysis and probability distribution changes by iteration as well as uncertainty of convergence velocity

1.3 Main contributions of this work

In this paper, a novel multiobjective function is suggested with load modeling to improve network reliability and reduce the annual cost of network. Main contributions of the work are listed as follows:

- Objective function: Unlike [4-6] in which DG and capacitor placement has been implemented in non-simultaneous fashion, and capacitor allocation is performed in the presence of DG and vice versa, however, in this paper, optimal capacitor and DG placement was performed simultaneously.
- Modeling of load and energy cost: In the load modeling process, load has been modeled in two stages which are

necessary and required together. These stages are: load modeling based on time and load modeling based on voltage. Another contribution of this work is to model energy cost as novel equations which are function of load types changed in each load levels.

- Source diversity: In most works involved in DG placement, only one type of DG units have been used while in this study three types of DG units have been considered.
- Solution technique: In this paper, Differential Evolutionary (DE) algorithm has been improved in two stages; i.e. using a bi-strategy technique in mutation and self-adapting cross-over rate. Impact of these modifications has been confirmed by comparing its results with simple DEA and GA.
- Results: Three scenarios for prioritization of the presence of DG units and capacitor banks have been defined, in the first and second scenarios, DGs and capacitors are not allocated in simultaneous mode, however in third scenario DG and capacitor are placed simultaneously. Results of the scenarios are compared to confirm superiority of third scenario. Other contribution of this work is introducing five novel indices to analyze obtained results from simulations.

2. PROPOSED MULTIOBJECTIVE PROBLEM FORMULATION

Main goal of this work is simultaneous placement of DG units and capacitor banks to reduce network annual cost and improve network reliability. For this purpose, a novel multiobjective function is presented which consists of four terms. Two terms of the objective function are reliability indices and the other two terms are costs of investment and energy loss.

2.1 DG placement function

The presence of DG units leads to improve reliability of network. Different indices have been employed to illustrate network reliability improvement. In this study, Cost of Energy not Supplied (CENS) and System Average Interruption Duration Index (SAIDI) have been considered as the reliability improvement indices which calculation method of these indices presented in App.A. Another contribution of DG units is reducing cost of energy loss, ELC_{DG} , in kWh . Finally, DG(s) has investment cost, IC_{DG} in \$. Then DG placement problem is formulated by the four terms as F_{DG} ,

$$F_{DG} = \text{Min} \left\{ \begin{array}{l} CENS + SAIDI \\ +ELC_{DG} + IC_{DG} \end{array} \right\} \quad (1)$$

2.2 Capacitor bank placement formulation

Capacitor bank placement has a great impact on energy loss reduction, EL_{cap} , in distribution networks, however capacitor banks have

investment costs, IC_{cap} in \$. Eq. (2) shows objective function of capacitor placement to reduce energy loss,

$$F_{cap} = \text{Min} \{ ELC_{cap} + IC_{cap} \} \quad (2)$$

2.3 Classic multiobjective function

To present a novel function, objective function of DG and capacitor allocations (i.e. F_{DG} and F_{cap}) are integrated. The presence of both DG and capacitor banks reduces energy loss, therefore in multiobjective function the energy loss reduction has been introduced to objective function as one of the terms, EL_{all} . The SAIDI and CENS, in single objective case, are based on reliability module while in multiobjective case they should be expressed in terms of economical parameters, thus CSAIDI and ELCall are introduced as related costs of SAIDI and EL . The conversion reliability indices, such as SAIDI, to economic coefficients in [16-19] has been proposed and employed. By applying these two modifications, the proposed multiobjective function, MOF , is,

$$MOF = \text{Min} \left\{ \begin{array}{l} CENS + CSAIDI \\ +ELC_{all} + IC_{all} \end{array} \right\} \quad (3)$$

where, $IC_{all} = IC_{DG} + IC_{cap}$

3. LOAD AND ENERGY COST MODELS

To implement the proposed multiobjective function, appropriate models for load should be used. Two types of modeling are

introduced for load in terms of time and voltage. The obtained results from modeling process have been used to load flow suggested in [20].

3.1 Load modeling in terms of time

The load of system is changing continuously. The changes are the function of consumption pattern for hourly, daily, monthly and annual time duration. In modeling process, it is assumed that load is fixed in duration of one hour.

$$P = P_{h,d,m,y} \quad (4)$$

$$Q = Q_{h,d,m,y} \quad (5)$$

where, h , d , m and y representing hour, day, month and year, respectively. $P_{h,d,m,y}$ and $Q_{h,d,m,y}$ are the related consumed active and reactive powers, respectively, which are obtained using load forecasting. Thus to calculate energy loss of feeder by the model in a given hour, active and reactive powers are obtained using Eqs.(4-5), and then load flow is implemented. Energy loss of network is computed as the sum of loss at each hour, $loss_{h,d,m,y}$, by Eq.(6),

$$EL = \sum_{y=1}^u \sum_{m=1}^{12} \sum_{d=1}^v \sum_{h=1}^{24} loss_{y,m,d,h} \quad (6)$$

where, u and v are the number of studied years and days of m^{th} month, respectively.

It is observed that to obtain energy loss in duration u year(s), the load flow should be carried out for $u \times 12 \times v \times 24$ times for each feeder for each DG and capacitor placement process. Then to reduce the computation, the

followings are suggested: instead of hourly model, load variations in each day have been classified in three levels; i.e. peak, off-peak and medium, Also, in a given month, load variation is assumed to be fixed.

The above approximations do not lead to significant changes in power loss, because load behavior is fixed for a given month. Hence, Eq. (7) changes as follows,

$$EL = \sum_{y=1}^u \sum_{m=1}^{12} \sum_{l=1}^3 V_m h_l loss_{y,m,l} \quad (7)$$

where, $loss_{y,m,l}$ is feeder loss at year y , month m and level l . v_m and h_l are the number of days of month m and hours of l , respectively.

3.2 Load modeling based on voltage

Load is different in each distribution substation based on its type in terms of industrial, commercial, residential and agricultural loads, and the consumed power value for each load type is depending to the voltage magnitude of each substation based on Eqs. (8-9),

$$P_i = P_{0i} V_i^\alpha \quad (8)$$

$$Q_i = Q_{0i} V_i^\beta \quad (9)$$

where, α and β are coefficients of active and reactive powers variation, respectively. P_0 is power in Ipu voltage. Q_0 are power in Ipu voltage.

In [21], the loads of networks have been classified in three types; i.e. industrial, commercial and residential loads while in the study, in addition to these levels, loads of agricultural, general and fixed-power are

considered. The values of α and β for each load types have been listed in Table 1.

Table 1. Load variation factors

The novel equations have been suggested to load model in a mixed case,

$$P_i = P_i^{res} V_i^{\alpha,res} + P_i^{ind} V_i^{\alpha,ind} + P_i^{com} V_i^{\alpha,com} + P_i^{agr} V_i^{\alpha,agr} + P_i^{gen} V_i^{\alpha,gen} \quad (10)$$

$$Q_i = Q_i^{res} V_i^{\alpha,res} + Q_i^{ind} V_i^{\alpha,ind} + Q_i^{com} V_i^{\alpha,com} + Q_i^{agr} V_i^{\alpha,agr} + Q_i^{gen} V_i^{\alpha,gen} \quad (11)$$

where, *res.*, *ind.*, *com.*, *agr.* and *gen.* indicate indices for residential, industrial, commercial, agricultural and general loads, respectively.

3.3 Energy cost modeling

By considering the difference of energy cost for industrial, commercial, residential, agricultural, general and fixed-power loads, it is required to determine the values for each load in each feeder and mean energy cost for feeder. Thus, energy cost model is defined as,

$$CE_{y,m,l} = AIC^{res} .Pe^{res} + AIC^{com} .Pe^{com} + AIC^{ind} .Pe^{ind} + AIC^{agr} .Pe^{agr} + AIC^{gen} .Pe^{gen} \quad (12)$$

where, $AIC(res)$, $AIC(com)$, $AIC(ide)$, $AIC(agr)$ and $AIC(gen)$ are energy cost per kWh for loads of residential, commercial, industrial, agricultural and general, respectively. Pe^{res} , Pe^{com} , Pe^{ind} , Pe^{agr} and Pe^{gen} are percentage of residential, commercial, industrial, agricultural and general loads, respectively. It is clear, different load percentage is influenced by time which is expressed in Eq. (14)

$$\begin{aligned}
 CE_{y,m,l} = & AIC^{res} \cdot Pe_{y,m,l}^{res} + AIC^{com} \cdot Pe_{y,m,l}^{com} \\
 & + AIC^{ind} \cdot Pe_{y,m,l}^{ind} + AIC^{agr} \cdot Pe_{y,m,l}^{agr} \\
 & + AIC^{gen} \cdot Pe_{y,m,l}^{gen}
 \end{aligned} \quad (13)$$

In Eq. (13), energy cost for different loads (i.e., AIC^{res} , AIC^{com} , AIC^{ind} , AIC^{agr} and AIC^{gen}) can be changed in each time period. For example, multi-tariff meters register the energy consumption in different time periods, separately, and energy costs are considered for each time period. The time period can be, for example, in three time period: peak, off-peak and medium. Then for accurate calculation of energy loss cost, it can be considered in different levels, separately.

$$\begin{aligned}
 CE_{y,m,l} = & AIC_{y,m,l}^{res} \cdot Pe_{y,m,l}^{res} + AIC_{y,m,l}^{com} \cdot Pe_{y,m,l}^{com} \\
 & + AIC_{y,m,l}^{ind} \cdot Pe_{y,m,l}^{ind} + AIC_{y,m,l}^{agr} \cdot Pe_{y,m,l}^{agr} \\
 & + AIC_{y,m,l}^{gen} \cdot Pe_{y,m,l}^{gen}
 \end{aligned} \quad (14)$$

For simplicity, energy loss is same for weekdays and weekends.

3.4 Investment cost

Investment cost is different for various DG and capacitor banks. Investment is changed based on nominal power. The changes are not linear. Based on different data of DG and capacitor banks prices, it was observed that investment cost has a direct relationship with squared nominal power, approximately. Thus investment cost for various DG and capacitor banks are modeled as,

$$COST_{DG,n} = a_n \sqrt{S_{DG,n}} \quad (15)$$

$$COST_{cap} = a_{cap} \sqrt{Q_{cap}} \quad (16)$$

where, n is 1, 2 and 3 for diesel generator (DGen) and wind turbine (WT) as well as solar cell (SC), respectively. $COST_{DG,n}$ and $COST_{cap}$ are investment costs of installing DG and capacitor banks, respectively. $S_{DG,n}$ and Q_{cap} are nominal capacities of DG and capacitor banks, respectively. a_n and a_{cap} are constant factors of DG and capacitor, respectively. It is assumed produced power of DGs is 1.25 times theirs nominal power.

It is worth noting that solar cells single handedly only active power but nowadays manufacturers have built a perfect pack product consists of solar cells and controlled capacitor by power electronic devices. This pack generates active and reactive powers. Similarly, wind turbines can generate reactive power. Considered included in wind turbine pack can supply the required reactive power of induction generators, too.

4. SOLVING PROBLEM

4.1 The proposed technique

In this paper, a novel approach has been proposed for optimal DG units and capacitor banks placement to minimize power loss and improve reliability indices. Evolutionary Algorithms (EAs) are of the most famous branches of artificial intelligence. It uses some operators like crossover, mutation and other operators to obtain optimal solution from initial population. DEA is among EAs which was proposed in 1997 [23].

DEA and GA are same in basis and performance; however, DEA advantages are fast velocity in convergence and reaching to global solution in less iteration. SA is also similar to DE, starting from a randomly generated initial population and moves to the final solution using several operators. One of the drawbacks for SA is that this algorithm needs vast search space and even though it has been observed. Despite that the mentioned drawback also seen in DEA, in this paper it is been improved by employing various improvements on DE. Linear programming is essentially used for problems their objective functions are linear, but, DEA is used both for linear and non-linear problems.

To reach better solution than simple DEA, several improvement techniques have been suggested; these techniques mainly are categorized in two groups. Goal of first group is to adapt control parameters of DEA. Second category has focused on changing structure of simple DEA operators and/or adding new operator.

Improvement i. A novel structure for mutation operator

In this paper, to apply improvement on simple DEA, structure of mutation operator has been changed. In mutation process, there are two important features; search space and convergence velocity. To increase search space, diversity of genes are increased, this state may be due to decrease in the

convergence velocity decrease. In proposed mutation operator structure, a trade off has been compromised between larger search space and higher convergence velocity.

By proposed technique, two scenarios are defined for mutation operator. In classic DEA, three vectors, Z_1 and Z_2 as well as Z_3 are selected from initial population, while in iDEA, among these selected vectors, Z_1 is vector corresponding to the best solution and Z_2 and Z_3 are two rest vectors. This technique is first scenario of proposed mutation structure,

$$\bar{Z}_{m,i}^{G+1} = \bar{Z}_{1,select}^G + F(\bar{Z}_{2,select}^G - \bar{Z}_{3,select}^G) \quad (17)$$

Second scenario is applied to keep genes diversity and proper search space. For this purpose; four vectors ($Z_{1,rand}$, $Z_{2,rand}$, $Z_{3,rand}$ and $Z_{4,rand}$) are selected randomly, and a vector corresponding to the best possible solution, Z_{best} , is applied to this scenario, thus, maintains trajectory toward optimal point,

$$\bar{Z}_{m,i}^{G+1} = \bar{Z}_{best}^G + F(\bar{Z}_{1,rand}^G + \bar{Z}_{2,rand}^G + \bar{Z}_{3,rand}^G - \bar{Z}_{4,rand}^G) \quad (18)$$

Then main duty of first and second scenarios is to increase convergence velocity and produce proper search space, respectively.

Main problem in this stage is that how many of the population are mutated by first scenario (17) and how many by the second scenario (18). For this, the number of population is mutated by first scenario, and then second scenario is applied on population by

considering the best vector. Thus, (19) is defined for mutation operator of iDEA,

$$\bar{Z}_{m,i}^{G+1} = \begin{cases} \bar{Z}_{1,select}^G + F(\bar{Z}_{2,select}^G - \bar{Z}_{3,select}^G) \\ \quad \text{if } i \leq Pop / MSF \\ \bar{Z}_{best}^G + F \begin{pmatrix} \bar{Z}_{1,rand}^G + \bar{Z}_{2,rand}^G \\ + \bar{Z}_{3,rand}^G - \bar{Z}_{4,rand}^G \end{pmatrix} \\ \quad \text{otherwise} \end{cases} \quad (19)$$

where, MSF is mutation selection factor and a real value. Trial and error technique is utilized to calculate MSF .

The various scenarios have been used in mutation based on how to select vector among initial population, the number of differential vectors and how to combine them. For this, the term $DE/x/y/z$ has been used to express scenario types. Where, x specifies the vector to be mutated (which can be random or the best vector); y is the number of difference vectors used; and z denotes the crossover scheme, binomial or exponential.

Then, the strategy of proposed mutation for (14) is described as follows [1],

$$\bar{Z}_{m,i}^{G+1} = \begin{cases} \text{Modified} \{DE / rand / 1 / bin\} \\ \quad \text{if } i \leq Pop / MSF \\ \text{Modified} \{DE / best / 1 / bin\} \\ \quad \text{otherwise} \end{cases} \quad (20)$$

Improvement ii. Adapting crossover rate

In simple DEA, the CR is initialized by user in $[0,1]$ and this initial value affects on the algorithm solution, directly. Choosing suitable control parameter values are, frequently, a problem-dependent task. The trial-and-error method used for tuning the

control parameters requires multiple optimization runs. In this improvement, a self-adaptive approach is used for choosing control parameters. For this, CR is adaptive and initialized as follows (21),

$$CR^{G+1} = \begin{cases} rand & \text{if } rand < \tau \\ CR^G & \text{otherwise} \end{cases} \quad (21)$$

where, τ represents probability to adjust CR , and considered 0.1 [22].

4.2 Coding problem

The iDEA has been used to solve the nonlinear and discrete problem which has been proposed in [23]. Fig.1 shows the coding of problem. Three scenarios have been introduced for simulation; Scenario i: first, DG placement, and then capacitor placement, Scenario ii: first capacitor placement, and then DG placement, and Scenario iii: simultaneous placement of DGs and capacitor banks.

In the first scenario, the location and size of DG units have been considered as variable based on Fig.1 (a) and are optimized using iDEA. Then, the obtained locations and sizes are assumed as installed in network and based on the assumption, the locations and sizes of capacitors are optimized as Fig.1 (b). In second scenario, the locations and sizes of capacitors are considered variable and are optimized by iDEA then it is assumed obtained capacitors have installed in test system. Based on the assumption and Fig.1

(a), the location and size of DG units are optimized. In scenario iii, the location and size of DG units and capacitor banks are assumed as varying, simultaneously, and all variables are optimized by iDEA.

Fig.1. Coding problem in three scenarios

To start placement process, initial population has been generated based on the number of chromosomes, N_c , and generation, N_g . First step in optimization process is calculation of energy loss cost. The mentioned process is enclosed by dashed lines in the problem solving flowchart presented in Fig. 2. The active and reactive powers have been considered to be P_0 and Q_0 , in year y , month m and level l in 1 pu voltage. Load flow program proposed in [20] is implemented using values of P_0 and Q_0 to obtain bus voltages, and the obtained bus voltages have been used to model loads formulated in Eqs. (10-11). By rerunning load flow program, feeder loss in year y , month m and level l , and ELC_{all} are computed by Eq.(8). If the number of years, months and load levels are not terminated, the process is repeated. The values of $CENS$, $CSAIDI$, $COST_{DG,n}$ and $COST_{cap}$ are calculated. The process of obtaining energy loss cost and $CENT$, $CSAIDI$, $COST_{DG,n}$ and $COST_{cap}$ are repeated until the number of chromosomes reach to maximum number, N_{rc} . After analyzing the number of chromosomes, the number of generation is evaluated and if the number of

generation is less than its maximum number, the generation number is increased by one unit and GA implemented again. The flowchart of solving proposed multiobjective function using GA has been shown in Fig.2.

Fig.2. problem solving using iDEA

5. CASE STUDY

A 115 bus practical distribution network of Tabriz City has been used as the test system. The single line diagram of the network in medium voltage level (20 kV) has been shown in Fig.3. There are three maneuver points TS2, TS3 and TS4, two auto-recloser, one overhead sectionalizer, and two cutout fuses then this test system consists of six sections which have been marked by numbers 1 to 6. The maximum and minimum voltages of the system are 1.05 and 0.95 pu and the maximum and minimum currents are 1 and 0.1 pu in 12.660 kV and 1000 kVA.

Given that load forecasting for more than 5 years is not practical, then duration of study is considered to be five years ($y=5$). Also, it is assumed that network configuration is fixed in the mentioned duration. The numbers of generation and chromosome are 1000 and 12, respectively. In [11], an analytical method has been introduced to calculate SAIDI and CENS and the technique used in this paper.

Fig.3. 115 bus network of Tabriz City

Load model data of the test system has been included in Table 2. In this table, the first

three columns present hours of off-peak, medium and peak levels of each months while columns 4 to 6 show related value of load; e.g. in January the value of medium load level is 0.7 of peak load in same month and 12.5 h. As it was mentioned, it is assumed that the load pattern do not change during the month. This assumption is close to reality in the test system (Fig.3). The values of a_n for DGen, WT and SC are 250000, 750000 and 1000000 $\$/MVA^{0.5}$ as well as the value of a_{cap} is 750 $\$/MVA^{0.5}$.

Table .2 Load model of Tabriz City network

5.1 Simulation results by the proposed iDEA

In this subsection, values of objective function and its terms as well as the locations and capacities of DG units and capacitor banks have been reported. The number of population and generation are 40 and 200 respectively. Value of MSF is 2 [1].

5.1.1 Objective function

By applying proposed objective function on three introduced scenarios in practical test system, the results obtained are given in Table 3. In this table, the values of objective function, energy loss cost, cost of SAIDI, investment cost and CENS have been listed in columns 2 to 6th respectively. All values of Table 3 are multiplied by 10^6 . For all cases, in

all tables, the best solution has been bolded, while the worst are crossed.

Table .3 Results of multi objective function and its parameters in three scenarios

By focusing on results of Table 3, DGs and capacitor bank placement in simultaneous mode presents better results than the other scenarios except in investment cost, while the value of objective function that is the sum of the cost of energy losses, cost of reliability indices and cost of investment, MOF , in simultaneous case, scenario iii, is less than other scenarios. First scenario presents worse solution than second and third scenarios. MOF of scenario i is more than related parameter of scenario ii and scenario iii by 7.2946% and 6.8438%, respectively. The energy loss cost of proposed multiobjective function is less than ELC_{all} of first and second cases by 36.2384% and 32.2525%, respectively. CSAIDI of 3rd scenario is less than related parameters of 1st and 2nd scenarios by 9.6289% and 8.7999%, respectively. Investment cost of first scenario is 4.5996% less than IC_{all} of second scenario, and investment cost of first scenario is less than IC_{all} of scenario ii by 5.7574%. CENS of scenario-i is less than CENS of second and third scenarios by 2.5187% and 4.0097%. The optimal location and generated active and reactive powers by three DG units in three scenarios have been listed in Table 4. In this

table, active and reactive powers are in kW and $kVAr$.

Table .4 Optimal location and generated active and reactive powers by three DG units

5.1.2 Diesel Generator location/capacity

By considering listed values in columns 2 to 4 of Table 4, from viewpoint of the number of installed DGen units these three scenarios can be classified as follows (from lowest to highest), i, ii and iii, respectively. Two locations for DGen units installations of 2nd and 3rd scenarios are same; i.e. buses 101 and 106. In all scenarios, generated active power value is more than produced reactive power value. Active power of DGen units of scenario-i is the least value and which is less than related parameter of scenarios ii and iii by 775 kW and 845 kW , respectively. The reduction for reactive power is 800 and 210 $kVAr$.

5.1.3 Wind turbine location/capacity

By focusing on results given in columns 5 to 7 of Table 4, the minimum and maximum capacity of wind turbine is presented in 1st and 3rd scenarios, respectively. Active and reactive powers of installed wind turbine for scenario iii is 800 kW and 395 $kVAr$ more than related parameters of scenarios i, respectively. These values are increased 175 kW and 10 $kVAr$ respect to second scenario, respectively. The number of installed wind turbine in scenarios i and ii are equal, 6 units, which are one unit more than first scenario.

5.1.4 Solar cell location/cost

By considering presented values in columns 8 to 10 of Table 4, in all scenarios three wind turbines have been installed. Despite the two aforementioned DG types, in solar cell, installed capacity of scenario iii is less than two other scenarios. The active power of third scenario is less than active power of first and second scenarios by 70 and 95 kW , respectively. Reactive power of scenario iii is less than related parameter of scenarios i and ii by 5 and 10 $kVAr$, respectively. Candidate buses for locating solar cell units are 47, 11, 2, 106, 101 and 36.

5.1.5 Capacitor banks location/cost

Ten candidate buses for capacitor placement are: 2, 75, 72, 47, 105, 36, 92, 101, 11, 55, 106, 111, 61, 115, 103, 5 and 80. Table 5 shows optimal location and size of installed capacitor banks in test system in three scenarios.

Table.5 Optimal size/location of capacitor banks

Regarding the listed values in Table 5, second scenario has the maximum number of installed capacitor banks which has two and one banks more than first and third scenarios, respectively. The installed capacity of scenarios i and ii are the minimum and maximum among the three scenarios, respectively.

5.1.6 Voltage profile

One of the main contributions in the presence of capacitor banks and DG units is improving voltage profile. Fig. 4 illustrates voltage profile improvement using three scenarios.

Fig.4 Voltage profile of test system

According to the Fig. 4, simultaneous placement of DGs and capacitor placement presents the best solution in respect to the other two scenarios, the result of first capacitor and then DGs placement scenario is better than first DGs and then capacitor banks placement. In terminal buses that the voltage drop is considerable, improvement of simultaneous scenario is significant.

5.2 Comparison of results

In this subsection, the results of the iDEA have been compared with related values of GA and simple DEA.

5.2.1 Techniques comparison

To confirm superiority of the proposed algorithm, its results have been compared with related values of GA and simple DEA. The number of population and generation of simple DEA are 40 and 200, respectively and CR is 0.1. Also, the numbers of population and generation of GA are 12 and 10000, respectively. Crossover rate and mutation factor of GA are 0.5 and 0.2, respectively.

For this, Tables 6-7 have been formed. The results of objective function and its parameters by three techniques have been listed in Table 6.

Table .6 Comparisons of results of objective function by three techniques

By focusing on results of Table 6, the proposed technique presents the best solutions in respect to the other algorithms. This improvement is considerable in third scenario. Optimal location and capacity of the installed DG sources and capacitor banks have been listed in Table 7.

Table .7 Optimal location and capacity of DGs and capacitor by three techniques

5.2.2 Comparison of parameters value for before and after load modeling

In this subsection, results of load modeling on system have been studied. Thus, the values of non- simultaneous optimization without load and cost modeling (NS without L) and non-simultaneous optimization with load and cost modeling (NS with L) as well as simultaneous optimization with load and cost modeling (S with L) have been listed in Table 8.

Table .8 Values of before and after load modeling

By considering results of Table 8, impact of modeling has been confirmed. The NS without L technique has the minimum and maximum installed capacity and parameters values. In all cases, modeling with simultaneous placement presents better solution respect to other techniques. This improvement, in installed capacity by

capacitor and DGs and objective function is considerable.

6 ANALYSIS AND DISCUSSION

From simulation results the simultaneous allocation presents better results in respect to non-simultaneous placements. This can be verified mathematically by a discussion on a simple objective function.

A nonlinear function is considered as $y = F(x_1, x_2, \dots, x_n)$. The goal is to minimize this function. The following three optimization methods are presented for minimizing the function.

A. It is assumed that the variables x_1 to x_m ($m < n$) are zero and the optimal values of the variables $x_{m+1}, x_{m+2}, \dots, x_n$ are determined according to a certain algorithm. Then the optimal values of the variables $x_{m+1}, x_{m+2}, \dots, x_n$ are assumed to be constant, and then the algorithm determines the optimal values of x_1, x_2, \dots, x_m .

B. The above state is conversely implemented, in other words the variables $x_{m+1}, x_{m+2}, \dots, x_n$ ($m < n$) is assumed zero and the optimal values of the variables x_1, x_2, \dots, x_m is determined by the algorithm, and then the optimal values of the variables x_1, x_2, \dots, x_m are assumed to be fixed and then by using the same algorithm, the optimal values of the variables $x_{m+1}, x_{m+2}, \dots, x_n$ is achieved.

C. Optimal values of the variables x_1, x_2, \dots, x_n are achieved simultaneously by the use of a specific algorithm.

Methods A and B are not reliable and the results from these two methods may not be the optimal solution, while method C reaches a definitive solution: $F_c \leq F_b$ and $F_c \leq F_a$

Assuming that the variables x_1 to x_m are related to DG while x_{m+1} to x_n are related to Capacitor, it can be said that optimization of objective function in simultaneous state can lead to a solution equal/less than that of non-simultaneous optimization.

Main challenge of this section is detailed discussion on obtained results of the case study. For this purpose, five criteria are introduced to analyze the results of previous section. Accordingly, two indices are introduced for discussing generated powers by DGs and capacitors which are called RGRCD and RRADG. A novel index is defined for the relationship between reliability improvement and generated active power by DG units. This index confirms the capability of scenario in simultaneous mode in respect to the other scenarios (see subsection 6-3). Finally, in subsection 6-4 and 6-5, two indices have been presented to analyze voltage profile.

6.1 Ratio of generated reactive power by capacitor to DGs (RGRCD)

DGs generate active and reactive power while the network planners use these sources to

generate active power, because DG installations impose more investment cost than capacitor banks, also the capacitor produces reactive power with less cost. Therefore, higher ratio of generated reactive power by capacitor compared to DGs in each scenario means that share of capacitor in reactive power generation is more than DGs. The RGRCD of scenarios i, ii and iii are 82.80, 50.70 and 60.09, respectively. The maximum and minimum RGRCD are presented by first and second scenarios while third scenario is a tradeoff between first and second scenarios. Consequently, it is revealed that although the simultaneous scenario uses reactive power injected by capacitor banks, however, appropriate share of reactive power production are considered for DGs to obviate any problems aroused from deterioration of investment.

6.2 Ratio of reactive to active power of each DG (RRADG)

To discuss about share of each DG in active and reactive power generation in three scenarios, RRDG has been used. The less this index value is, the better improvement is achieved for the system. It indicates that most of DGs' power share is for real part resulting in better investment. Fig.5 presents the ratio of reactive power to active power DGs in three scenarios.

Fig.5 Ratio of reactive to active power of DGs

By considering the results of Fig. 5, it is clear that 3rd scenario has suggested the least RRADG in DGen and WT DGs except in solar cell. This fact confirms that the investment cost of DG in third scenario has more shares on active power generation than reactive power. The maximum and minimum RRADG indices are presented by DGen and SC, respectively.

6.3 Reliability improvement for generated active power

The generated active power by DG led to reliability improvement. In this paper, two indices have been selected as reliability improvement index: i.e., CENS and cost of SAIDI. Thus, the ratios of these indices to generated active power in three scenarios are studied. The ratios of CENS to active power are 0.0323, 0.0193 and 0.0189 for scenarios 1, 2 and 3, respectively. The generated active power in scenario iii is more than related values of first and second scenarios by 38.9696% and 7.2411%, respectively.

6.4 Percentage of Sum of Voltage Deviation (PSVD)

Improving voltage profile is one of the main objectives of DG/capacitor placement. Main target from the viewpoint of voltage profile improvement is the voltage magnitude close to ideal value: i.e. 1 pu. The SVD index is sum of voltage deviation of network buses from 1 pu in three scenarios. The values of SDV for scenarios i, ii and iii are 1.824, 1.250

and 0.8411, respectively. These values show the ability of simultaneous placement to improve voltage profile.

6.5 The number of bus voltage less than a certain value

The study system includes 116 buses for which the voltage drop in buses are noticeable. Thus, not only sum of voltage deviations of network should be minimized but also the numbers of these buses are decreased. For this purpose, three states are defined in which the buses should be regarded that their values in three scenarios are less than 0.97, 0.98 and 0.99 pu. The numbers of bus voltage of three cases has been depicted in Fig.6.

Fig.6 The number of bus which its voltage is less than certain value (i.e. 0.97, 0.98 and 0.99 pu)

By considering results of Fig.6, none of buses in simultaneous placement has no value less than 0.97 and 0.98 pu. In third scenario, only thirty-five buses have value less than 0.99. Second scenario reaches best solutions if disregard simultaneous scenario.

7. CONCLUSION

In this paper, a novel multiobjective function has been formulated for simultaneous DGs and capacitor banks placement. In objective function, four terms have been applied to reduce costs of energy loss and investment, and improve reliability indices and the

objective solved by a novel DEA. Other contribution of this work is proposing a novel model for load (based on time and voltage) and energy cost. Simulations in three scenarios based on priority placement have been implemented on a portion of Tabriz City distribution network and results of the proposed algorithm compared with related values of GA and simple DEA approaches. The results of simulations in six contexts have been analyzed and studied. Main inference from simulation is that the simultaneous placement is better solution in respect to non-simultaneous. Other deductions are:

- i. By considering the obtained results in Table 3, it can be claimed that in simultaneous mode, in addition to reduction of the objective function, four parameters forming objective function are much lower than the two other scenarios. Indeed, optimization of the proposed method is performed simultaneously and relatively and not specific to a group of parameters.
- ii. Based on the ratio of generated reactive power to the active power, the three DGs are arranged from higher to lower as solar cell, diesel generator and wind turbine.
- iii. In all cases, the reactive power produced by three types of DG units is less than the active power. Among the three types of DG units, solar cells units and diesel generators have the highest and lowest

ratio of active power to reactive power, respectively.

- iv. First DG and then capacitor banks placement, and first capacitor and then DG placement scenarios offer the lowest and highest sizes of capacitors, respectively.
- v. The location of installing wind turbine in first DG and then capacitor banks placement are different from the other scenarios while location of wind turbine in 2nd and 3rd scenarios are the same.
- vi. In case of using solar cell units, active and reactive powers in the third scenario is lower than the two other scenarios, while by using diesel generators and wind turbines the actions are reversed.
- vii. From subsection (6-3), improving reliability per 1 MW of third scenario is better than two other scenarios.
- viii. The voltage profile and voltage deviation as well as the number of buses which its voltage is less than certain value of simultaneous placement is better than non-simultaneous placement (see subsections 6-4 and 6-5).

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Appendix A. Calculation of CENS and CSAIDI

To calculate reliability indices, SAIDI and CENS, analytical method based on error modes and their effects (FMEA) is used [11]. Accordingly the mentioned parameters are calculated using Eqs. (A.1) to (A.4).

$$SAIDI_i = \left(\lambda_{sys} \frac{l_i}{l_t} \right) \left[\left(r_{loc} \frac{l_{loc,i}}{l_t} \right) \left(\frac{N_{loc,i}}{N_t} \right) + r_{rep} \frac{N_{rep,i}}{N_t} \right] \quad (A.1)$$

$$CENS_i = \left(C_{ns} \lambda_{sys} \frac{l_i}{l_t} \right) \left[\left(r_{loc} \frac{l_{loc,i}}{l_t} \right) (P_{loc,i}) + r_{rep} P_{rep,i} \right] \quad (A.2)$$

$$SAIDI_{sys} = \sum_{i=1}^k SAIDI_i \quad (A.3)$$

$$CENS_{sys} = \sum_{i=1}^K CENS_i \quad (A.4)$$

where:

$CENS_i$: Cost of Energy Not Supplied due to an error in the i th region

$SAIDI_i$: System Average Interruption Duration Index due to an error in the i th region

λ_{sys} : Annual failure rate of system

l_i : Length of the i th region

l_t : Total length of feeder

r_{loc} : Average time for locating the fault

$l_{loc,i}$: The length of region which is de-energized for locating the fault due to an error in the i th region

$N_{loc,i}$: Total number of customers who are de-energized for locating the fault due to an error in the i th region

N_t : Total number of system customers

r_{rep} : Average time to repair a fault

$N_{rep,i}$: The number of customers who are de-energized for repairing the fault due to an error in the i th region

C_{ns} : The average cost of a 1 kWh outage

$P_{loc,i}$: The average outage active power for repairing the fault due to an error in the i th region

$P_{rep,i}$: The average outage reactive power for repairing the fault due to an error in the i th region.

In Eqs.(7) and (8), load and cost models can not be used. $P_{loc,i}$ and $P_{rep,i}$ are calculated using annual average active power. C_{ns} is not related to the energy costs, and fixed for a year. $SAIDI_{sys}$ and $CENS_{sys}$ are constant for a given year and for u years studied, CSAIDI and CENS are multiplied u .

Figures of Multi objective Allocation of Distributed Generations and Capacitor Banks in Simultaneous Mode

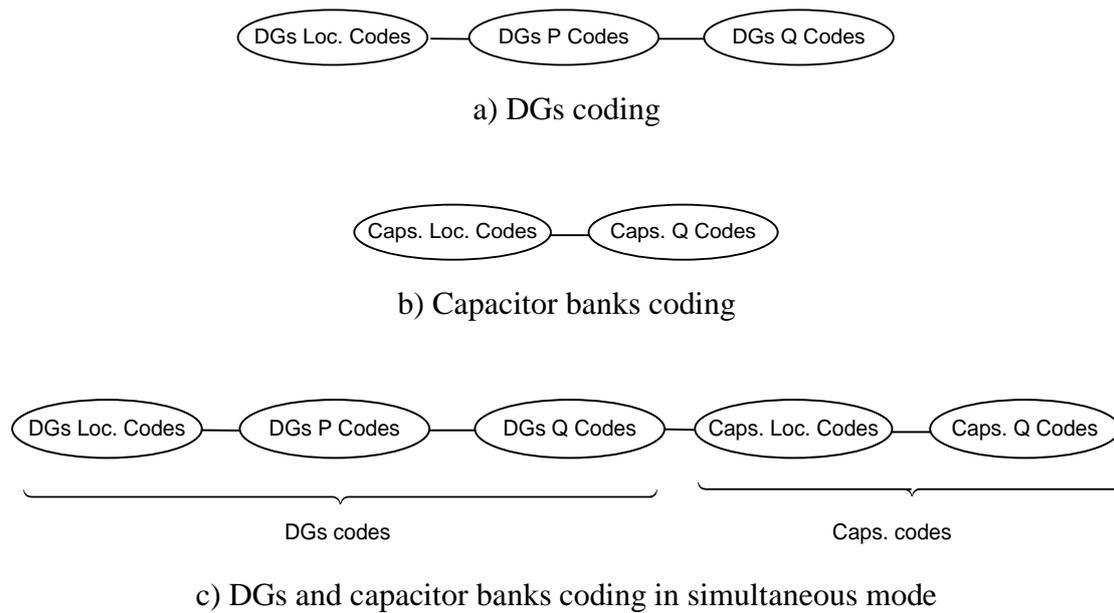


Fig.1. Coding of problem in three scenarios

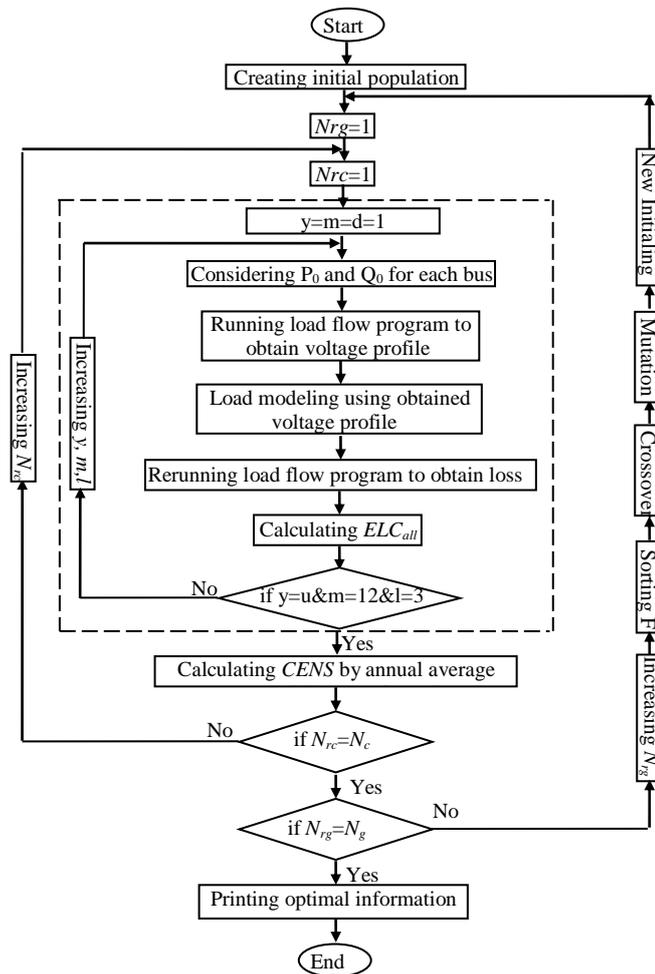


Fig.2. problem solving using iDE algorithm

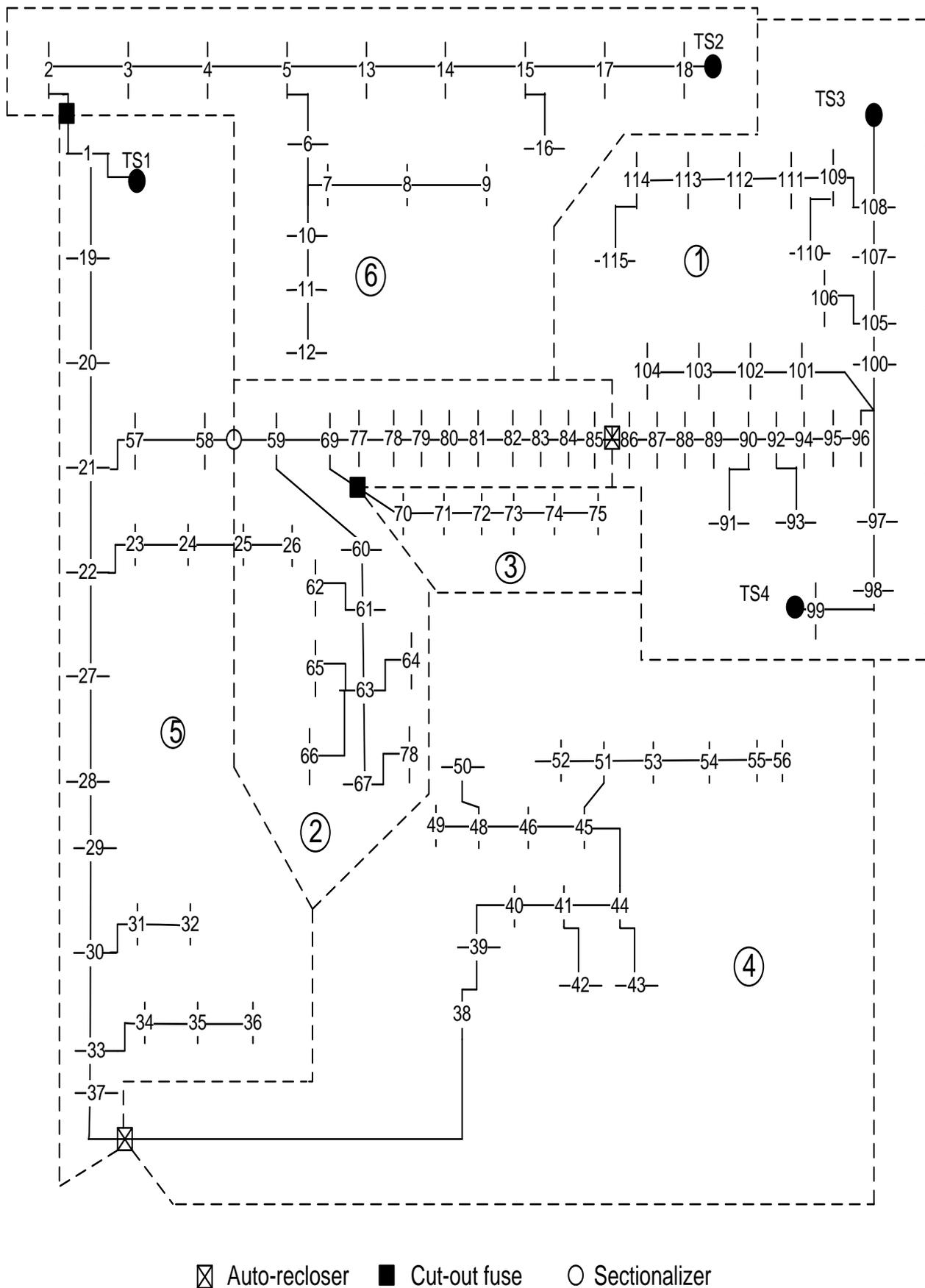


Fig.3. 115 bus distribution network of Tabriz City

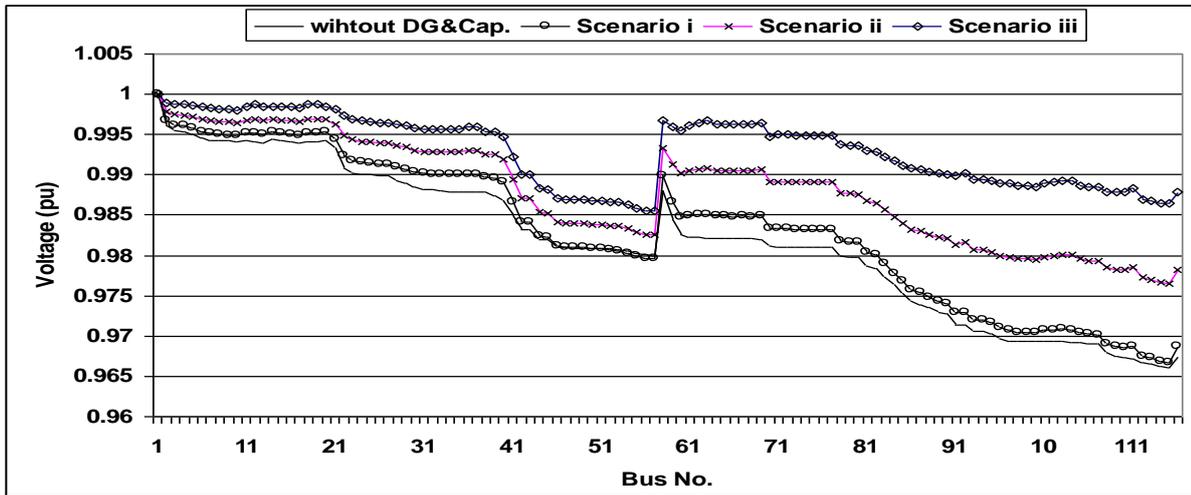


Fig.4. Voltage profile of test system

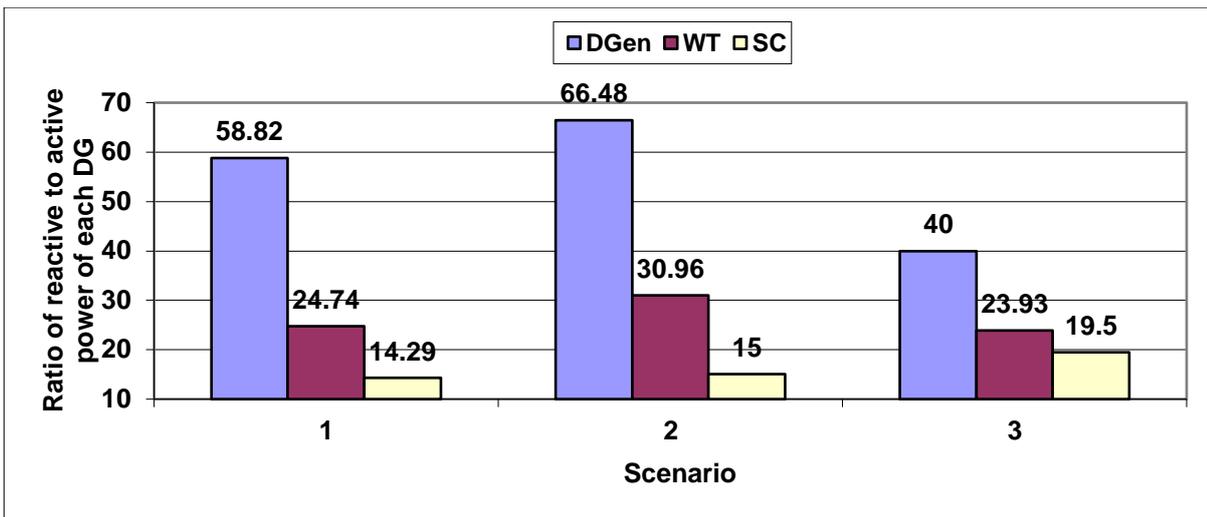


Fig.5. Ratio of reactive to active power of DGs

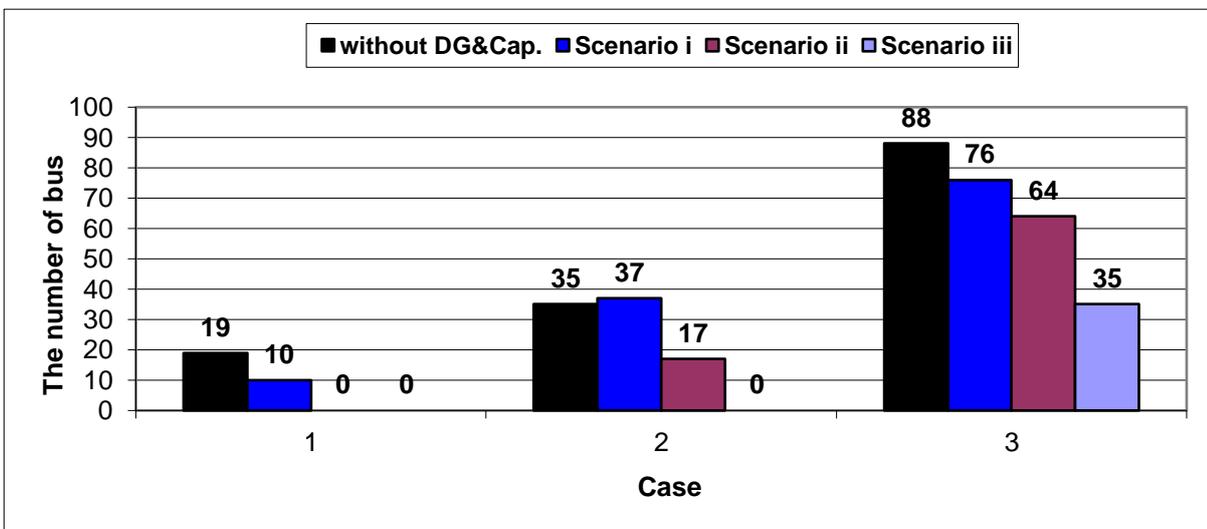


Fig.6. The number of bus which its voltage is less than certain value

Table 1. Load variation factors

Load type	residential	commercial	industrial	agricultural	general	fixed-power
α	0.92	1.51	0.18	0.92	0.92	0
β	4.04	3.4	6	4.04	4.04	0

Table 2. Load model of Tabriz City distribution network

Month	model of Load(Time in hour)			model of Load(Level in hour)		
	off peak	medium	peak	off peak	medium	peak
January	12.5	8	3.5	0.3	0.7	1
February	13	8	3	0.3	0.7	1
March	13.5	8	2.5	0.3	0.7	1
April	13.5	8	2.5	0.3	0.7	1
May	13	8	3	0.3	0.7	1
Jun	12.5	8	3.5	0.3	0.7	1
July	12	8	4	0.3	0.7	1
August	11.5	8	4.5	0.3	0.7	1
September	11	8	5	0.3	0.7	1
October	11.5	8	4.5	0.3	0.7	1
November	12	8	4	0.3	0.7	1
December	12.5	8	3.5	0.3	0.7	1

Table 3. Results of multi objective function and its parameters in three scenarios

Scenario	MOF	ELC _{all}	CSAIDI	IC _{all}	CENS
i	91.9202	2.3006	4.5239	6.0114	74.6934
ii	85.2150	1.4669	4.0883	5.7349	72.8121
iii	85.6294	1.5586	4.1258	6.3575	71.6984

Table 4. Optimal location and generated active and reactive powers by three DG units

	Diesel generator			Wind turbine			Solar cell		
	Loc.	Active	Reactive	Loc.	Active	Reactive	Loc.	Active	Reactive
Scenario i	2	150	110	38	300	55	47	80	10
	106	250	80	41	255	80			
	92	150	100	101	350	100	11	15	5
	101	130	110	36	200	75			

	sum	680	400	106	250	50	2	80	10
	sum	1355	360	sum	175	25			
Scenario ii	61	280	250	75	250	75			
	106	325	280	12	310	100	106	110	10
	111	350	200	92	350	90			
	55	350	250	106	255	90	47	45	10
	47	330	220	11	310	80			
				55	285	110	11	35	10
sum	1455	1200	sum	1760	545	sum	200	30	
Scenario iii	92	250	100	47	350	55			
	41	300	100	11	445	80	101	55	5
	103	100	80	106	300	90			
	47	260	90	92	300	110	36	30	10
	55	280	120	12	410	105			
	2	335	120	2	350	95	11	20	5
	sum	1525	610	sum	2155	535	sum	105	20

Table 5.Optimal size and location of the installed capacitor banks (in *kVAR*)

Sce. i	Loc.	2	75	72	47	105	36	92	101	-	-	650	Sum
	Reactive	100	100	50	50	50	100	100	100	-	-		
Sce. ii	Loc.	11	75	55	106	111	61	115	103	5	80	900	
	Reactive	100	50	100	100	100	50	100	100	100	100		
Sce. ...	Loc.	75	55	11	92	106	36	115	2	80	-	700	
	Reactive	100	50	100	50	50	100	100	50	100	-		

Table 6.Comparisons of results of objective function by three techniques

Technique	GA			DE			iDE		
	i	ii	iii	i	ii	iii	i	iii	iii
MOF	93.637	88.385	87.77	93.178	87.510	86.173	91.920	85.215	85.629
	5	2	1	7	2	6	2	0	4
ELCall	2.3561	2.0020	1.602	2.3436	1.5841	1.5778	2.3006	1.4669	1.5586
		0							
CSAIDI	4.8124	4.2870	4.210	4.7898	4.1304	4.1435	4.5239	4.0883	4.1258

			0						
ICall	6.1410	7.6652	8.0664	6.1091	5.9869	7.9865	6.0114	5.7349	7.8575
CENS	79.328	74.431	73.893	78.9393	73.8366	72.5851	74.6934	72.8121	71.6984

Table 7. Optimal location and capacity of DGs and capacitor by three techniques

Technique		GA			DE			iDE		
Scenario		i	ii	iii	i	ii	iii	i	ii	iii
DGen	Active	800	1580	1600	750	1570	1580	680	1805	1525
	Reactive	430	1270	655	440	1310	640	400	1200	610
WT	Active	1370	1825	2340	1380	1850	2300	1455	1760	2155
	Reactive	360	540	560	375	360	550	360	545	535
SC	Active	170	205	115	170	170	110	175	200	105
	Reactive	30	25	20	30	25	20	25	30	20
Capacitor		700	1000	800	750	1000	900	650	900	700

Table 8. Values of before and after load modeling

Technique		NS without L	NS with L	S with L
MOF		1250.9813	1198.5959	85.6294
ELCall		23.0221	22.5557	1.5586
CSAIDI		60.0233	58.9448	4.1258
ICall		113.5477	108.6791	7.8575
CENS		1054.3882	1008.4163	71.6984
Diesel generator	Active	-	4820	1525
	Reactive	-	1900	610
Wind turbine	Active	2450	5610	2155
	Reactive	750	1680	535
Solar cell	Active	189	125	105
	Reactive	38	27	25
Capacitor		0	3000	700