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Optimal determination of island boundaries besides the optimal placement of D-STATCOM devices and DG units

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Abstract: In this study, integration of three important concepts of distributed generation, D-FACTS devices, and microgrids are evaluated. The performance of a microgrid is dependent on its location, capacity, and placement of DG units and D-FACTS devices. In this paper a new method is proposed to simultaneously determine the optimal number, location, and capacity of DG units and D-STATCOM devices and optimal boundaries of electrical islands in the independent mode of microgrids. The main objective is to minimize the economic costs. The optimal locations of DG units and D-STATCOM devices should be determined to maximize the DG capacities with minimum loss in the best voltage profile and in the grid-connected mode of microgrids. Moreover, this locating besides simultaneous determination of island boundaries makes it possible to supply the maximum load in the islanded mode operation. To meet the mentioned goals, the PSO algorithm and MATLAB software are used. Analyzing the obtained results shows that the proposed method has suitable capability in optimal operation and cost management of distribution network planning.

Key words: D-STATCOM device, island boundaries, microgrid, DG unit, economic cost

1. Introduction

One of the main concepts of smart grids is the microgrid (MG), which has great potential to increase applications of distributed generation (DG) units under different operation conditions. MGs are operated in islanded mode or grid-connected mode. Transferring from conventional power systems to smart systems is inevitable for the following reasons: the need for highly reliable energy, demand increase, problems of reduction in fossil fuel sources, and environmental issues. Moreover, actual implementation and control of smart systems is one of the main concerns of researchers and industrialists. The amount of load that could be supplied by DG in MGs is dependent on different factors such as the capacity and location of DG, possibility of active and reactive power control, and the present load pattern. One of the main control tools and active and reactive power management approaches in power systems is flexible AC transmission system (FACTS) devices that are operated in distribution networks as distributed flexible AC transmission systems (D-FACTS) [1]. With the increase of D-FACTS and DG applications and the increasing development of MGs in distribution networks, integration of these three concepts could provide a suitable framework for novel studies that could serve specific purposes. For the desired operation of DG units and distributed static synchronous compensators (D-STATCOMs), among the main and most applicable D-FACTS devices, some factors such as the number, location, and optimal capacity

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of these units have an important role in network operation. The above-mentioned factors have great effects on system losses, voltage profile, reliability, and power quality.

Several studies were conducted for the optimal placement of these devices and units. For example, in [2–4] the determination of the optimal location and capacity of DG units was evaluated for different purposes such as economic costs and environmental pollution minimization, voltage profile improvement, network loss reduction, and restoration operation of network-equipped DG. Moreover, in [5–7] the modeling and simulation of D-STATCOMs was presented and their operation in the network and the optimal placement problem were evaluated. In [8,9] the optimal location problem of FACTS devices was evaluated for different purposes such as real power flow performance index reduction and voltage stability improvement. In [10] D-STATCOM placement was investigated for different purposes such as voltage profile improvement, network loss reduction, and energy saving. With the progress of smart grids and MG applications, several studies have addressed these topics. For example, in [11,12], modeling, control, operation, and protection solutions of MGs were studied. In addition, in [13] the optimal placement and capacity determination of DG units were evaluated by considering the procedure of intentional islanding and controllability in power systems. In [14] the islanding operation of MG systems was studied for different purposes such as maximization of system loadability and minimization of power losses. In addition, the static voltage stability index was evaluated for different cases of operation. The main purpose of this paper is to integrate D-FACTS devices, DG units, and MG systems in order to operate distribution networks optimally. Therefore, a new method is proposed to determine the optimal number, location, and capacity of D-STATCOM and DG units besides optimal boundaries of islands by the capability of operation as independent MGs are determined. To obtain our goals, normal operation of the whole network, the possibility of intentional islanding of some parts of networks, and the operation of them as independent MGs are considered. To optimize the mentioned problem, the PSO algorithm is employed. The IEEE 118-bus standard distribution network is used to verify the performance of the proposed method. Results are given and compared to evaluate the capabilities of the proposed method.

2. Mathematical modeling

In this paper, to execute power flow in the network and calculate the required parameters such as losses, the voltage of each bus, and the current of each branch, the forward/backward sweep method is employed. This method has several advantages such as simplicity, linearity of equations, and fast convergence as compared to other methods. Because of these advantages, most studies have used this method in distribution networks [15]. In the following sections, the mathematical modeling of DG units and the D-STATCOM device is presented.

2.1. DG modeling for load flow analysis

Here a DG unit is considered to have the both capability of only active power injection and simultaneous injection of active and reactive power to network. In the following subsections, different used models of DG are explained [16].

2.1.1. Modeling of DG unit with constant power factor

The commonly used DG model is the constant power factor model. It can be used for controllable DG units, such as synchronous generator-based DG. For this model, active power and power factor are specified values.

Its reactive power and injected current to the network are calculated as follows:

$$Q_{i,g} = P_{i,g}\tan(Cos^{-1}(PF_{i,g})) \tag{1}$$

$$I_{i,g} = \left(\frac{P_{i,g} + jQ_{i,g}}{V_{i,g}}\right)^{*} \tag{2}$$

Here, $P_{i,g}$, $Q_{i,g}$, $V_{i,g}$, and $I_{i,g}$ are active power, reactive power, injected voltage, and current of DG to bus i respectively. $PF_{i,g}$ is the DG power factor.

2.1.2. Modeling of DG unit as PQ bus

In this case, the DG unit is modeled as a source of constant active power and reactive power, as follows:

$$P^{new}_{load,i} = P_{load,\,i} - P_{i\,,\,g} \tag{3}$$

$$Q^{new}_{load,i} = Q_{load\,,\,i} - Q_{i\,,\,g} \tag{4}$$

Here, $P_{load,i}$ and $Q_{load,i}$ are the active and reactive power of primary load in bus i. $P^{new}_{load,i}$ and $Q^{new}_{load,i}$ are new loads of bus i.

3. D-STATCOM modeling

The D-STATCOM device is one of the main and most applicable D-FACTS devices. This device plays an important role in load ability, stability, and reactive power compensation. A single-line diagram of the conventional D-STATCOM model is shown in Figure 1 [17]. To calculate the power flow, steady-state losses of the D-STATCOM model should be considered. The losses consist of three terms of power losses in the DC capacitor, switching losses, and conductivity losses. The equivalent circuit of the D-STATCOM is shown in Figure 2. In this figure, X_S is the transformer leakage inductance. To model the conductivity and switching losses series resistance r_S is used. In addition, to model the DC capacitor power losses the parallel resistance r_P is employed.

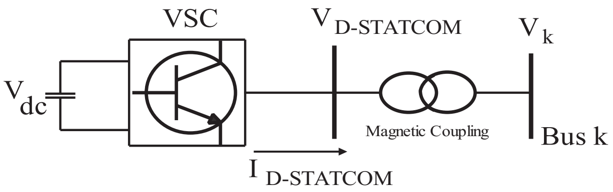

Figure 1. Single-line diagram of the D-STATCOM.

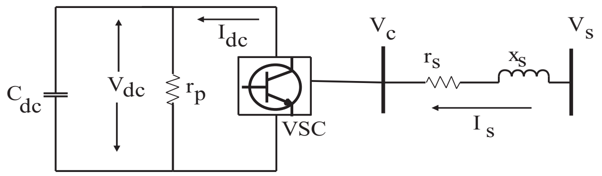

Figure 2. Equivalent circuit of the D-STATCOM.

According to Figure 2, the VSC, which is placed behind the equivalent impedance of the transformer (Z_S), is operated as an AC voltage source with controllable amplitude and phase. Using KVL, equations of reactive and active power injection of the D-STATCOM to the AC system are obtained as follows [17]:

$$S_{D-STATCOM} = V_s I_s^{*} \tag{5}$$

$$P_{D-STATCOM} = Re(V_S I_S^{*}) = \frac{k_s k_t m V_{dc} V_s \cos(\theta_s - \alpha + \beta) - V_s^2 \cos\beta}{Z_s} \tag{6}$$

$$Q_{D-STATCOM} = Im(V_S I_S^*) = \frac{V_s^2 \sin\beta - k_s k_t m V_{dc} V_s \sin(\theta_s - \alpha + \beta)}{Z_s} \tag{7}$$

The parameters are as follows:

$$Z_S = |Z_S|\,\beta = r_S + jX_S;\ V_C = k_S k_t m V_{dc}\alpha;\ V_S = |V_S|\,\theta_S;\ V_{dc}\alpha;\ I_S = \frac{V_S - V_C}{Z_S}$$

Here, $Q_{D-STATCOM}$ is the reactive power injection of the D-STATCOM. Vs is the bus voltage of the AC system. k_S is the gain of converter DC to AC. V_C is the VSC voltage with m modulation index in pulse with modulation (PWM) control. k_t is the coupling transformer rate and V_{dc} is the DC voltage of the capacitor with control angle of α. I_S is the flow current of the AC system to the VSC. Since the DC power supply has been removed from the VSC circuit and the DC capacitor is replaced, the D-STATCOM will not have any active power exchange with the AC system and the active power of device will be zero. In this case, the VSC charges the DC capacitor and keeps the required voltage level. Thus, the exchange of power between the network and the D-STATCOM is only reactive power and Eq. (7) is used in the calculations.

4. Formulation of the problem

In this paper, the optimization problem is evaluated by proposing a new economic cost function and a method for simultaneous determination of optimal island boundaries (by capability of operation as independent MGs) is presented. In the following, the optimization method and cost function are described and the implementation steps of the proposed method are explained completely.

4.1. Objective function description

In this paper, cost function is proposed as a summation of investment and operation costs of DG and D-STATCOMs and the costs of network ohmic losses. This cost function is defined as in Eq. (8):

$$\begin{aligned} C.F &= Cost_{Investment} + Cost_{Operation} + Cost_P = \\ &\sum_{t=1}^{T}\left(\left[\sum_{m=1}^{M_{D-STATCOM}} Cost_{D-STATCOM}^{m} + \sum_{n=1}^{N_{DG}} \text{Price}_{DG} \times S_{DG}^{n}\right] \times T\right) \\ &+ \sum_{t=1}^{T}\left(\left[\sum_{m=1}^{M_{D-STATCOM}} OC_m^{D-STATCOM} + \sum_{n=1}^{N_{DG}} OC_n^{DG}\right] \times B^T\right) \times T \\ &+ \sum_{t=1}^{T}\left(8760 \times P_{loss-ij}(1+y)^T \times R \times B^T\right) \end{aligned} \tag{8}$$

Here, $Cost_P$ is the cost of network ohmic losses in the total study period [18]. $P_{loss-ij}$ is the network ohmic losses that are calculated as follows [2]:

$$P_{loss-ij} = \frac{1}{2}\left(\sum_{i=1}^{N}\left(\sum_{j=1}^{N} R_{ij} \times |I_{ij}|^2\right)\right),\ i \neq j \tag{9}$$

Here, R_{ij} is ohmic resistance between the i and j buses, I_{ij} is injected current from bus i to bus j, N is the number of network buses, and R is energy cost per kWh (here it is assumed \$0.016). In addition, B is the investment return rate, which is calculated by $B = \frac{1+F}{1+\mu}$. F is the inflation rate and μ is the interest rate. In this study, inflation and interest rates are 15% and 10%, respectively. $y$is the load growth rate per year (here it is assumed as 5%) and T is the planning horizon (here it is assumed as 5 years). $Cost_{Investment}$ is the total investment costs of the DG and D-STATCOMs including installation costs. S_{DG}^{n} is the rating capacity of n DG units, $Price_{DG}$ is cost per rating MVA of each DG, and $Cost_{D-STATCOM}^{m}$ is the m D-STATCOM investment cost, which is calculated as [19]:

$$Cost_{D-STATCOM} = C_D \times S_D \times 1000(\$) \tag{10}$$

$$C_D = 0.0003\,S_D^2 - 0.305\,S_D + 127.38\left(\frac{\$}{MVAR}\right) \tag{11}$$

Here, S_D is D-STATCOM capacity per MVAR and C_D is the cost function of the used FACTS device in parallel with the system. Approximate total value of investment and operation costs per MVAR reactive power of the D-STATCOM is considered as \$105,834.42. Moreover, $Cost_{Operation}$ is the total operation cost of the DG units and D-STATCOM devices. It also includes the maintenance cost of these units. $OC_{m}^{D-STATCOM}$is the operation cost of m D-STATCOM devices, $OC_{n}^{DG}$is the operation cost of n DG units, N_{DG} is the number of DG units, and $M_{D-STATCOM}$ is the number of D-STATCOMs. In the following, the constraints of the optimization problem are described:

$$I_{feeder,\,i} \leq I_{feeder\,,\,i}^{\max} \tag{12}$$

$$P_{DG}^{\min} \leq P_{DG} \leq P_{DG}^{\max} \tag{13}$$

$$Q_{DG}^{\min} \leq Q_{DG} \leq Q_{DG}^{\max} \tag{14}$$

$$Q_{D-STATCOM}^{\min} \leq Q_{D-STATCOM} \leq Q_{D-STATCOM}^{\max} \tag{15}$$

$$V_j^{\min} \leq V_j \leq V_j^{\max} \tag{16}$$

Here, $I_{feeder,i}$ is the current of line i, P_{DG} and Q_{DG} are the injected active and reactive power of the DG, $Q_{D-STATCOM}$ is the reactive injected power of the D-STATCOM, and V_j is the voltage of bus j.

4.2. Optimization technique

In this paper, to optimize the proposed cost function and obtain the goals, the PSO algorithm is used because of its wide range of applications, calculation performance, accurate and fast searching, capability of simple understanding, and capability of simultaneous evaluation of several variables. In this algorithm, movement toward the optimum point of the objective function is based on the data of the obtained point depending on the current factors in the initial population and the best found point by neighboring points. In the search area under study, some points are selected as the initial population. The points are placed in different groups based on the geometrical distance. Having these data, each factor moves along the position and velocity vector of Eqs. (17) and (18) [20]:

$$V_i(t+1) = wV_i(t) + r_1c_1\left[P_i(t) - X_i(t)\right] + r_2c_2\left[G_i(t) - X_i(t)\right] \tag{17}$$

$$X_i(t+1) = X_i(t) + V_i(t+1) \tag{18}$$

Here, X_i is the position vector, V_i is the velocity vector, c_1 and c_2 are local and global learning factors, w is the inertia factor, and P_i and G_i are the best local and global values. In addition, r_1 and r_2 are random numbers in (0,1).

4.3. Proposed method for determination of optimal electrical islands boundaries

In this section, the proposed method for determination of optimal electrical boundaries of islands with capability of operation as a MG is described by considering D-STATCOM devices and DG units.

4.3.1. Initial population generation for island i_S formation

In the optimization procedure by PSO technique, each island is considered as a particle i_S. Each particle includes n subsets, which indicates the number of buses in each island. For generation of the initial population, the entire case study network is considered as an island i_s by choosing bus number 1 as the slack bus. In addition, n is assumed as 118.

4.3.2. Evaluation of required condition for island formation

First condition: Considering at least one DG unit in each island.

Second condition: Checking the radial structure and continuity of buses in each island.

Existence of at least a DG unit in each specified island is required because of the independence of islands. If this condition is not met, the determined boundaries will not be verified and they must be changed. Therefore, Eq. (19) is imposed in the optimization procedure:

$$\sum N_{DG,i_S} \geq 1 \tag{19}$$

Here, $N_{DG,is}$ is the number of DG units in each island i_s. To obtain the second condition, the graph theory and concept of minimal spanning tree (MST) are employed. To investigate the condition of Shane continuity and find the possible optimal graph while keeping the radial structure of the grid, graph theory and the MST method are used. To use the application associated with the MST, line information, feeders, and buses of the test network are applied as input. To illustrate, suppose that an island, having the first condition as in Figure 3, is one of the choices to optimize the algorithm. According to this figure, if Shane 29 is not in the range, discontinuity between bus 30 and bus 45 causes this choice to be removed from the optimization process and the PSO algorithm looks for a new particle and range. Considering any range, a bus matrix is created in which, if discontinuity is observed in two items of the series i_S, the island is diagnosed as undesirable [21].

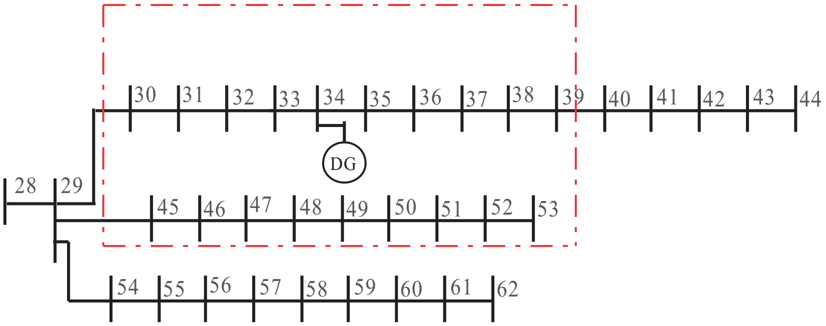

Figure 3. An island chosen by the algorithm.

4.3.3. Execution of load flow program in each island

In this step, in each island, a load flow program is executed independently. The bus in which the DG unit is placed optimally is considered as the slack bus. If more DG units are placed in an island proportional to its load and losses, the bus that has a DG unit with higher capacity will be considered as the slack bus. Losses, amplitude, and phase of voltage in each bus of each island are calculated. Moreover, here constraints are considered for each island according to Eqs. (20) and (21):

$$\sum_{i=1}^{N} P_{DG,i} \geq \sum_{i=1}^{N} (P_{L,i} + P_{loss,i}) \tag{20}$$

$$\sum_{i=1}^{N} (Q_{DG,i} + Q_{D-STATCOM,i}) \geq \sum_{i=1}^{N} (Q_{L,i} + Q_{loss,i}) \tag{21}$$

Here, $P_{L,i}$ and $Q_{L,i}$ are active and reactive power of the load, and $P_{loss,i}$ and $Q_{loss,i}$ are active and reactive losses of each island.

4.3.4. Evaluation of objective function

In this section, the total cost function (Eq. (8)) is evaluated for each island. If no particle can satisfy any constraints of Eqs. (12)–(16) and (20) and (21), a cost value is considered as a penalty. The penalty function is:

$$P.F = \sum \left(\sum (S_p - L_p) \leq 0 \right) \tag{22}$$

Its parameters are given as:

$$S_p = \sum_{i=1}^{N} (S_{DG,is} + S_{D-STATCOM,is}) \tag{23}$$

$$L_p = \sum_{i=1}^{N} (S_{feeder,is} + S_{loss,is}) \tag{24}$$

Here, $S_{DG,is}$ is the DG injection capacity, $S_{D-STATCOM,is}$ is the D-STATCOM injection capacity, $S_{feeder,is}$ is the total feeder load, and $S_{loss,is}$ is the total losses of each island i_S. Finally, the value of the penalty function is added to the total cost and Eq. (25) is used:

$$C.F_{new} = (C.F) + (R \times (P.F) \times 1000) \tag{25}$$

The parameter R is set by 0 or 1. $R = \mathit{0}$ means that the considered constraints are satisfied and $R = \mathit{1}$ means that the constraints are not satisfied by particle i_S.

5. Simulation and case studies

In this paper, to examine the proposed method's performance, the IEEE 118-bus standard distribution network is employed [17]. Network parameters in the beginning of the study period are given in Table 1. Neither the DG nor the D-STATCOM is installed at the beginning. Moreover, the voltage profile of the base case is shown in Figure 4. The used optimal parameters of PSO in this study are provided in Table 2. Simulation and optimization of the problem and result analysis are evaluated for two scenarios:

Table 1. Network data at the beginning of the study period.

$P_{load}^{total}(MW)$	$P_{loss}^{total}(MW)$	$Q_{load}^{total}(MVAR)$	$Q_{loss}^{total}(MVAR)$
22.91	1.6798	17.041	1.1047

Table 2. The used optimal parameters of PSO in this study.

PSO parameters	C_1	C_2	W_{Max}	W_{Min}	$N_{Population}$	$N_{Iteration}$
Amount	1.85	1.85	0.9	0.4	180	300

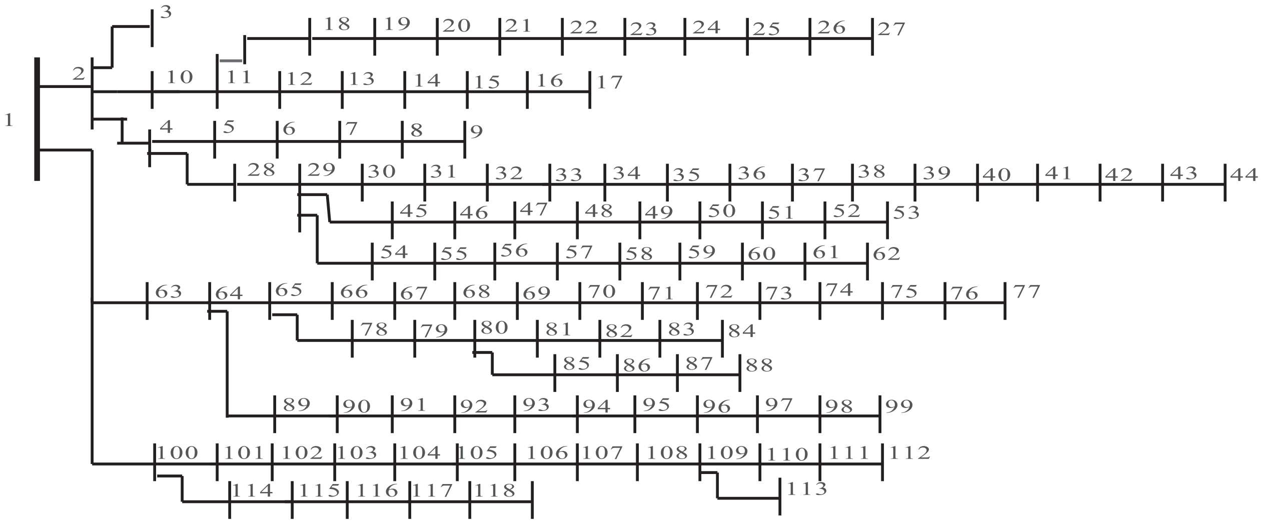

Figure 4. Single-line diagram of the 118-bus IEEE standard test system.

- Optimal placement of DG units and D-STATCOMs under normal operation of the system
- Optimal placement of DG units and D-STATCOMs besides determination of electrical island boundaries

5.1. First scenario

In this scenario, an optimization procedure is performed by considering DG and D-STATCOM placements as the problem variables. By changing the number of DG units and D-STATCOMs, the simulation procedure is evaluated. The DG unit is modeled by the capability of only active power injection to the network. Simulation results of the scenario are given in Table 3, in which *state* is the number of optimization states. BS_{DG}, BS_{D-S}, Loc_{DG}, DOC_{D-S}, N_{DG}, and N_{D-S} are optimal capacity, location, and number of DG units and D-STATCOMs, respectively. In order to determine the optimal number of DG units and D-STATCOMs and acceptable losses, the values of the cost function and active losses obtained by optimization (columns 8 and 12 of Table 3) are normalized by changing the number of components and using the normalization method of Eq. (26) [13].

$$F_{norm} = \left(1 + \left(\frac{(F_x - F_{\min}) \times (b - a)}{(F_{\max} - F_{\min})}\right)\right) \tag{26}$$

Table 3. Placement results of the first scenario.

State	N_{DG}	N_{D-S}	Loc_{DG} ($Bus\ No\#$)	BS_{DG} (MW)	Loc_{D-S} ($Bus\ No\#$)	BS_{D-S} ($MVAR$)	P_{loss}^{before} (MW)	P_{loss}^{after} (MW)	Q_{loss}^{before} ($MVAR$)	Q_{loss}^{after} ($MVAR$)	Best cost ($)
1	2	1	39	2.42	74	2.1	1.6798	1.068	1.1047	0.7898	1,491,171.20
			110	1.987							
2	3	1	39	1.98	2	1.954	1.6798	0.8485	1.1047	0.6551	2,128,658.30
			72	1.856							
			115	1.874							
3	4	2	27	1.741	39	1.843	1.6798	0.6707	1.1047	0.5087	2,915,139
			28	1.6521							
			73	1.536	110	1.654					
			100	1.705							
4	5	2	2	1.7021	2	1.754	1.6798	0.3685	1.1047	0.2712	3,527,732.90
			39	1.465							
			63	1.7980							
			85	1.4501	62	1.361					
			110	1.2025							
5	6	2	20	1.653	2	1.67	1.6798	0.2997	1.1047	0.21125	4,112,449.60
			39	1.4020							
			46	1.7501							
			63	1.053	74	1.2521					
			85	1.0977							
			110	0.981							
6	7	3	27	1.5609	2	1.6021	1.6798	0.102	1.1047	0.08502	4,956,243.60
			45	1.3012							
			62	1.0601							
			72	1.0234	110	1.065					
			88	0.99541							
			99	0.8751	118	1.4131					
			103	1.2653							

Here, F_x is the actual value of each function, F_{min} and F_{max} are the minimum and maximum of the function, a and b are the minimum and maximum of the normalization bound (1 and 10, respectively), and F_{norm} is the value of the normalized function. Values of F_{cost} and F_{loss} are defined for the cost function and active losses of the network. The obtained diagram of the normalization is shown in Figure 5. Using Eq. (26) and Figure 5 in network planning, the desired cost could be obtained by an optimal number of DG units and acceptable losses. For this purpose, Eq. (27) is introduced. In this equation, ε is a fixed number that is determined according to system planning.

$$|F_{Cost} - F_{Loss}| \leq \varepsilon \tag{27}$$

According to the obtained results of this scenario, in the first state with two DG units and one D-STATCOM, the optimal cost value is $1,491,171.20. This value in the sixth state with seven DG units and three D-STATCOMs is $49,566,243.60. The loss value is reduced from 1679.8 kW at the beginning of the study period to 102 kW in the sixth state. Simultaneous or independent determination of the optimal location and capacity of any number of DG units and D-FACTSs in every standard test network with different purposes could be obtained using the written program in this scenario. By setting an arbitrary $\varepsilon = 4$, the fourth state is an appropriate selection from the perspective of optimal cost and loss minimization. The voltage profile and the flowchart of the proposed approach in this state are shown in Figures 6 and 7.

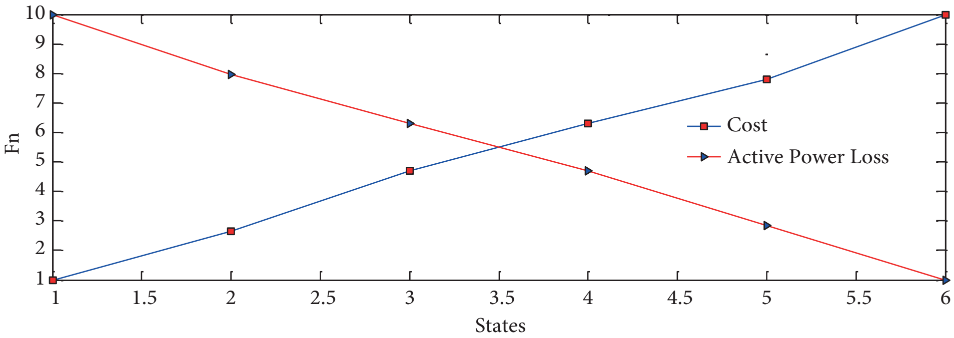

Figure 5. Normalized diagram of the first scenario.

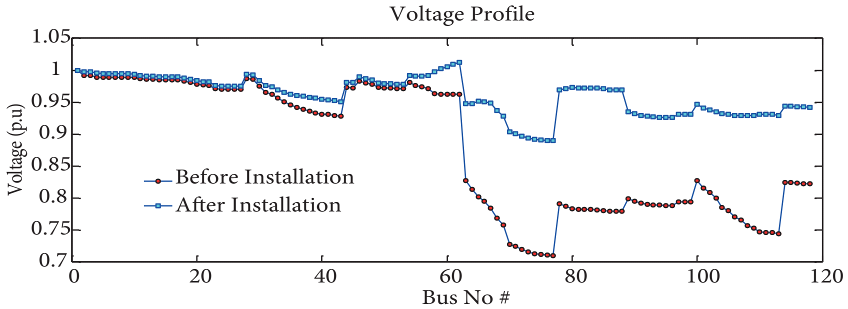

Figure 6. Voltage profile in the first scenario after the installation of components.

5.2. Second scenario

In this scenario, in order to supply the faulty loads by DG units in the case of fault occurrence and intentional island formation, the optimal location of units should be suitably determined. In this case, fault occurrence possibility is considered in the whole of the network. In the optimization procedure the number of electrical islands with their optimal boundaries, their number, and optimal capacity of DG units and D-STATCOMs are the optimization variables. Table 4 shows the optimal boundaries of electrical islands with the present number of buses in each island. Moreover, results of DG and D-STATCOM placement in each island are given in Table 5. The optimized value of total cost in this scenario is obtained as $6,371,715.521. The flowchart of the proposed approach in this scenario and the voltage profile of the network before and after the installation of DG units and D-STATCOMs are shown in Figures 8 and 9. In addition, Tables 6 and 7 show the total losses of network and each island's losses before and after the installation of DG units and D-STATCOMs.

Table 4. Optimal boundaries of electrical islands in the second scenario.

Particles (islands)	Bus numbers in each particle i_s (island)
i_{S1}	2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27
	i_{S2}28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 4546, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62
i_{S3}	65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88
i_{S4}	1, 63, 64, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100, 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111, 112, 113, 114, 115, 116, 117, 118

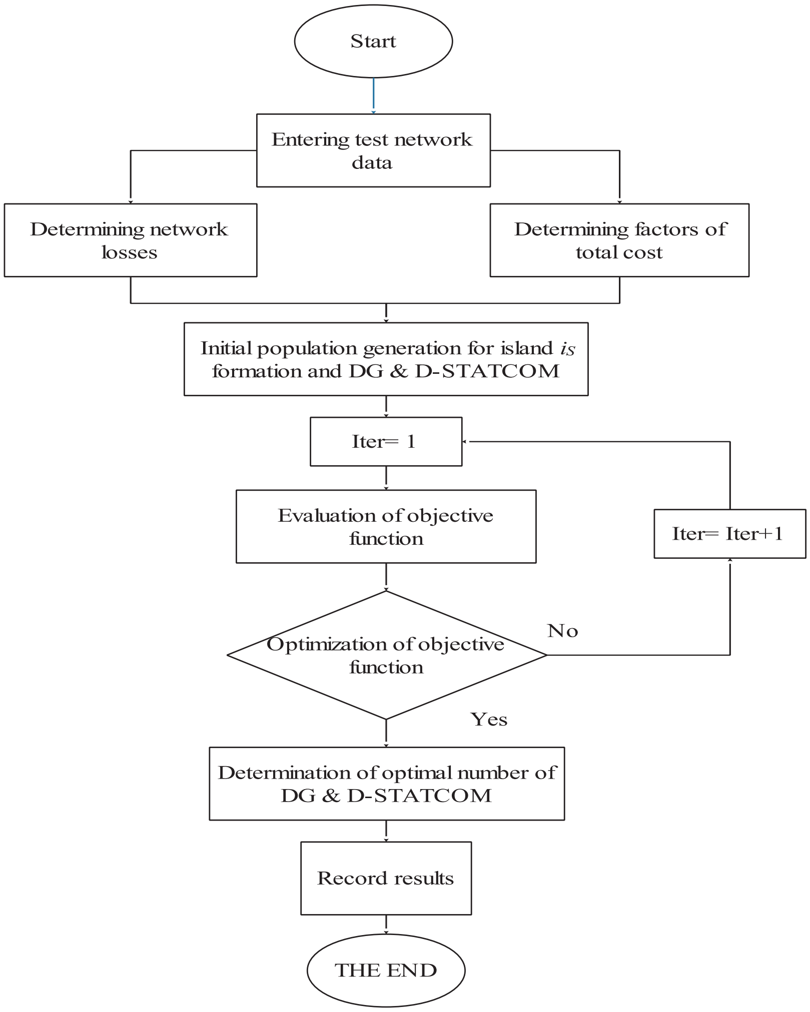

Figure 7. The flowchart of the proposed approach in the first scenario.

Table 5. Results of DG and D-STATCOM placement in the second scenario.

Optimal island #	D-STATCOM		DG		
	Bus #	Size (MVAR)	Bus #	size (MW)	Size (MVAR)
i_{S1}	---	---	2	1.85	0.86
i_{S2}	28	2.45	39	2.52	1.26
			46	2.5	1.2
i_{S3}	---	---	71	2.2	0.85
			80	2.3	0.76
i_{S4}	110	2.6	89	1.951	0.45
			101	2.85	1.2
			113	1.56	0.58
Min cost = $6,371,715.521					

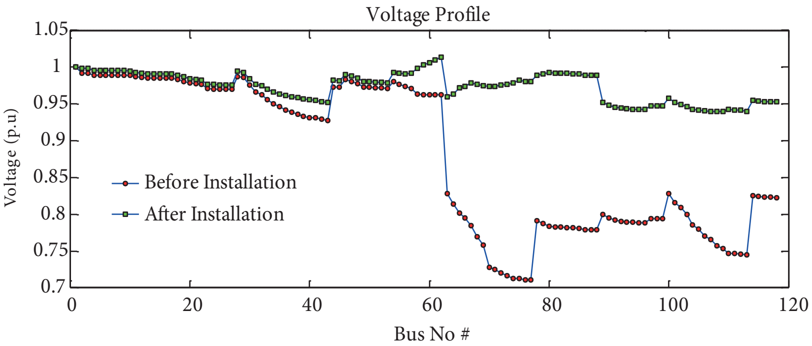

Figure 8. Voltage profile after installation of components in the second scenario.

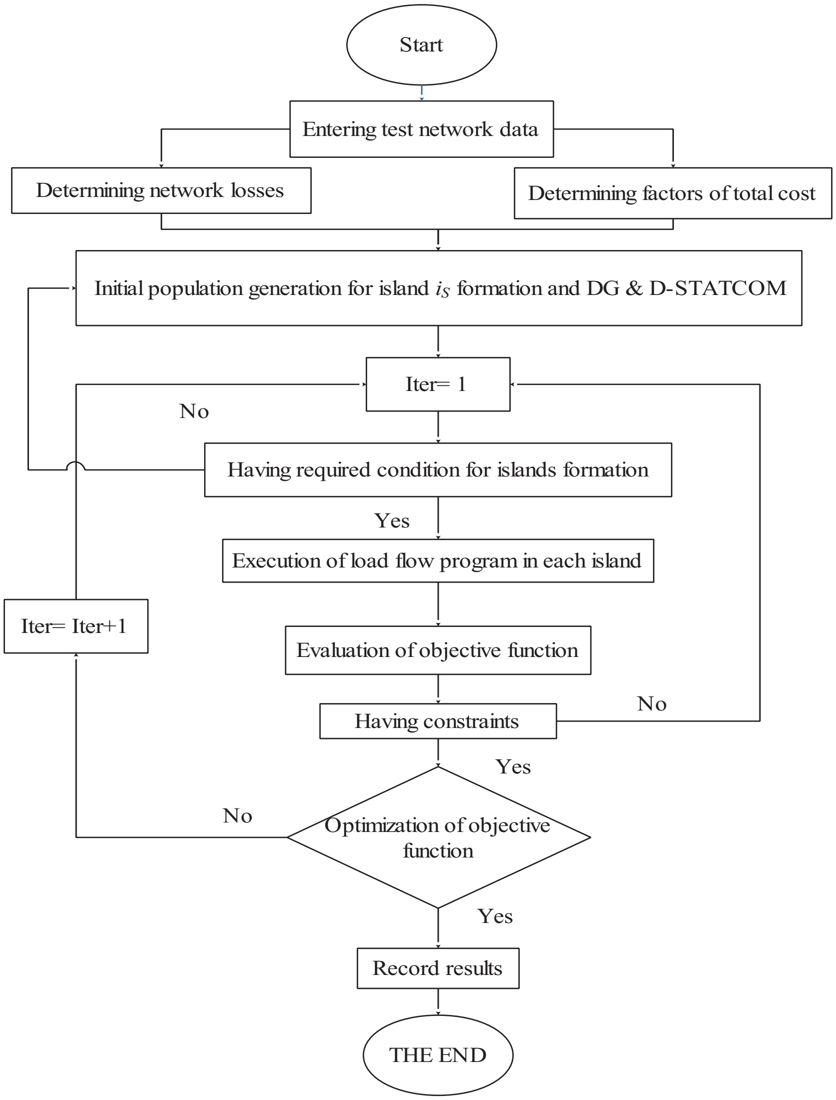

Figure 9. The flowchart of the proposed approach in the second scenario.

Table 6. Total losses of network after installation of components in the second scenario.

$P_{loss}^{before}(MW)$	$P_{loss}^{after}(MW)$	$Q_{loss}^{before}(MVAR)$	$Q_{loss}^{after}(MVAR)$
1.6798	0.243	1.1047	0.186

Table 7. Losses of each island after installation of components in the second scenario.

Island #	$P_{loss}^{before}(MW)$	$P_{loss}^{after}(MW)$	$Q_{loss}^{before}(MVAR)$	$Q_{loss}^{after}(MVAR)$
i_{S1}	0.263	0.0354	0.149	0.0348
i_{S2}	0.2734	0.0886	0.355	0.0852
i_{S3}	0.4145	0.0444	0.2206	0.0241
i_{S4}	0.483	0.048	0.272	0.0195

6. Conclusion

In this study, the problem of optimal placement of DG units and D-STATCOMs is evaluated by considering the condition of islanding in some parts of the network and operation as independent MGs and with the purpose of economic cost function minimization. In addition, a new method is proposed to determine the optimal electrical islands' boundaries. The proposed cost function includes the network ohmic losses costs, investment, and operation costs of DG units and D-STATCOMs. In order to optimize the proposed cost function, the PSO algorithm is employed and the IEEE 118-bus standard distribution network is used for simulation and case studies. The optimization progress is evaluated by considering the following two scenarios:

- Optimal placement of components under normal operation of the system
- Optimal placement of components besides determination of island boundaries

In each scenario, results of optimization are analyzed to verify the performance of the proposed method. In the proposed method, it is possible to determine the optimal location and capacity of any number of different DG units and D-FACTSs in every standard test network with different purposes simultaneously or independently. For further study, issues like effectiveness of reliability indices on economic costs and estimation of the network state considering various D-FACTSs are proposed.

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