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A state-of-the-art decentralized structure for unit commitment in restructured power systems

Ali Rasouli[1], Mehdi Bigdeli[2*], Soheil Malekshah[3] and Javad Ansari[4]

[1]Zanjan Regional Electric Company, Zanjan, Iran
[2] Department of Electrical Engineering, Zanjan Branch, Islamic Azad University, Zanjan, Iran
[3]Department of Electrical Engineering, South Tehran Branch, Islamic Azad University, Tehran, Iran
[4]Electrical Engineering Department, Iran University of Science and Technology, Tehran, Iran

[*]Corresponding author: m.bigdeli@srbiau.ac.ir

Abstract

In a restructured power system, different parts of the network are dedicated to the private sector and each of these sectors seeks to maximize their profits. Therefore, it cannot be traditionally planned and managed by the network and a new framework needs to be used. In this paper, a decentralized framework for the planning of generation units is presented. In this framework, the power system is divided into several subsets and each of these subsets has a physical relationship involving the exchange of active and reactive power and the transmission of information as well as economic information with each other. Thus, a hierarchical bi-level optimization method is used to implement the decentralized decision method to solve the security constraints unit commitment (SCUC) problem. Considering dispersed generation (DG) units in calculations will reduce the total cost of generation. Generally, the cost of generating power in such units is less than that of large units. The proposed method is implemented on a sample 6-bus network, which has an active and passive distribution network. The results indicate the correctness and accuracy of this method.

Keywords: Security constraints unit commitment (SCUC), decentralized framework, active distribution grid (ADG), dispersed generation (DG).

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1. Introduction

Today, the structure of the power system has moved from monopoly to competitive markets in many countries of the world in which economic principles form the basis of the electricity market with free access. In this case, the issue of orbiting units is divided into two separate optimization problems. From the generation side, the optimization problem is aimed at maximizing the profit of the firm. On the other hand, the central operator (CO) of the network receives the generation offer and selects units, in addition to meeting the network security constraints; the cost of network utilization will be as low as possible. In modern power systems, each of the electric power companies is responsible for planning the generation of their covered units. In such systems, each of the generation companies, based on their technical-economic constraints, as well as considering the uncertainty and fluctuation of the load, and forecasting the price in the market and others, provide their own curves with the aim of maximizing profits to central operator. It should be noted that the central operator, in the process of determining the planning of generation companies, in addition to considering the demand and the offer price of each generation unit, selects units for generation that do not violate the provisions of the network security and transmission system. The aim is to achieve unit commitment to power plants with security constraints, which refers to the planning of generation resources to establish the minimum cost for satisfying the demanded load, which is subject to the security constraints. This is an important tool in exploiting power systems. In restructured power systems without ADGs, the central operator runs the hourly scheduling of conventional and traditional generation connected to the transmission network. As a result, there is no coordination and cooperation between distribution networks. However, the extension of DG in power systems requires a decision-making model for operation, as well as for the unit commitment power plants and the coordination between traditional generation units with distributed products throughout the power system. The participation of ADGs in the marketplace creates economic and technical benefits not only for the central operator but also for the owners of the DG units. The reference [1] provides a centralized optimization method for assessing the impact of DG with reliability limits on orbiting power plants. The formulation of a power plant for distribution systems consisting of DG formulated storage and control units is also provided [2]. A two-step algorithm for distribution networks is provided in [3]. This algorithm finds the hourly generation of dispersed sources of resources (DER) from the electricity market. The SCUC issue provides for the daily generation planning in ADGs, including the costs of DG units, as well as the cost of fines for carbon dioxide emissions (emission of pollutants) [4]. An algorithm is presented to unit commitment for coordination between the exit for medium term maintenance and scheduling with short-term security constraints in the ADGs [5]. The reference [6] presented a multiple optimization problem to solve the multi-cycle electric energy model of distribution companies with dispersed products and unbroken quantities on the daily electricity market. We note that in traditional power systems, non-active distribution systems cannot be separated from the transmission network. However, the most important issue in restructured electricity networks, transmission and distribution levels can be operated and controlled independently. Uncertainty in DER has created a new challenge for the SCUC issue and the economic load distribution that has been paid [7-8]. Affine policy is successfully applied with improvements in calculations [9-12]. It should also be noted that in [13], using imperialist competitive algorithm, optimized the cost function to determine the optimal linked Microgrids clustering boundary in distribution networks.

In this paper, a decentralized framework for the planning of generation units is presented. In this framework, each power system is divided into several sub-systems, and each of these sub- systems has a physical relationship, including the exchange of active, reactive power and power information, as well as economic (financial) information. In this decentralized framework, a hierarchical bi-level optimization method is used to implement a decentralized decision-making method for solving the SCUC problem. To validate this method, we implemented it in several scenarios for the experimental network and analyzed its results.

2 SCUC problem for independent systems

In general, the SCUC is an optimization problem with the goal of minimizing system operating costs, which includes the cost of power generation and on/off of units. Equal and unequal constraints of this problem are the power balance constraints, the capacity of the generation unit, the slope of the unit's power increase/decrease, the load flow equations, the transmission network security constraints, and so on. The normal SCUC problem can be applied to each independent system (CO and DISAGs). This problem is resolved separately in DISAG and CO. To date, various methods have been proposed to solve the SCUC problem, such as the Lagrange liberation method and mixed integer programming (MIP). In this paper, the proposed MIP model is used to solve the SCUC problem of each independent system.

If there is no connection between the transmission network and ADGs, the SCUC problem related to COs and DISAGs can be solved individually and can determine the operating schedule of the units at different hours of the day. While the transmission networks and ADGs are connected to each other, an optimal operating point in each of them will affect the other performance point. To model this relationship between systems in SCUC problem based on decentralized system method and to find the optimal system performance point, a decentralized decision method can be used that desirably compares DG resources and ADGs in the electricity market. For this purpose, in this paper, a hierarchical binary level optimization method is used to implement a decentralized decision-making method for solving the SCUC problem based on a decentralized system approach.

3 The problem of binary level hierarchical optimization

Compared to conventional power systems, restructured power systems will be activated as distribution networks using DG units in distribution power systems. As shown in Figure Figure 1, in a power grid, electricity and data are transmitted bilaterally, in such a way that electrical information/energy is exchanged from the transfer grid to the distribution grid and vice versa, and this makes the system analysis complicated. Figure Figure 2 shows an ADG that is physically connected to the transmission network.

Constraints of the SCUC problem for CO are presented as follows:

$$
\begin{aligned}
& Minf(y) \\
s.t.\ \ & h(y) \leq 0 \qquad\qquad (1) \\
& I(y) = 0
\end{aligned}
$$

Where y denotes decision variables for CO, *f*, the objective function of problem, I and h are the equality and inequality constraints for CO. The problem is similarly defined for DISCO as follows:

$$
\begin{aligned}
& Minf(x) \\
s.t.\ \ & h(x) \leq 0 \qquad\qquad (2) \\
& I(x) = 0
\end{aligned}
$$

Where x is the decision variable for DISAG, f is the objective function of the problem, I and h are the equality and inequality constraints for DISAG.

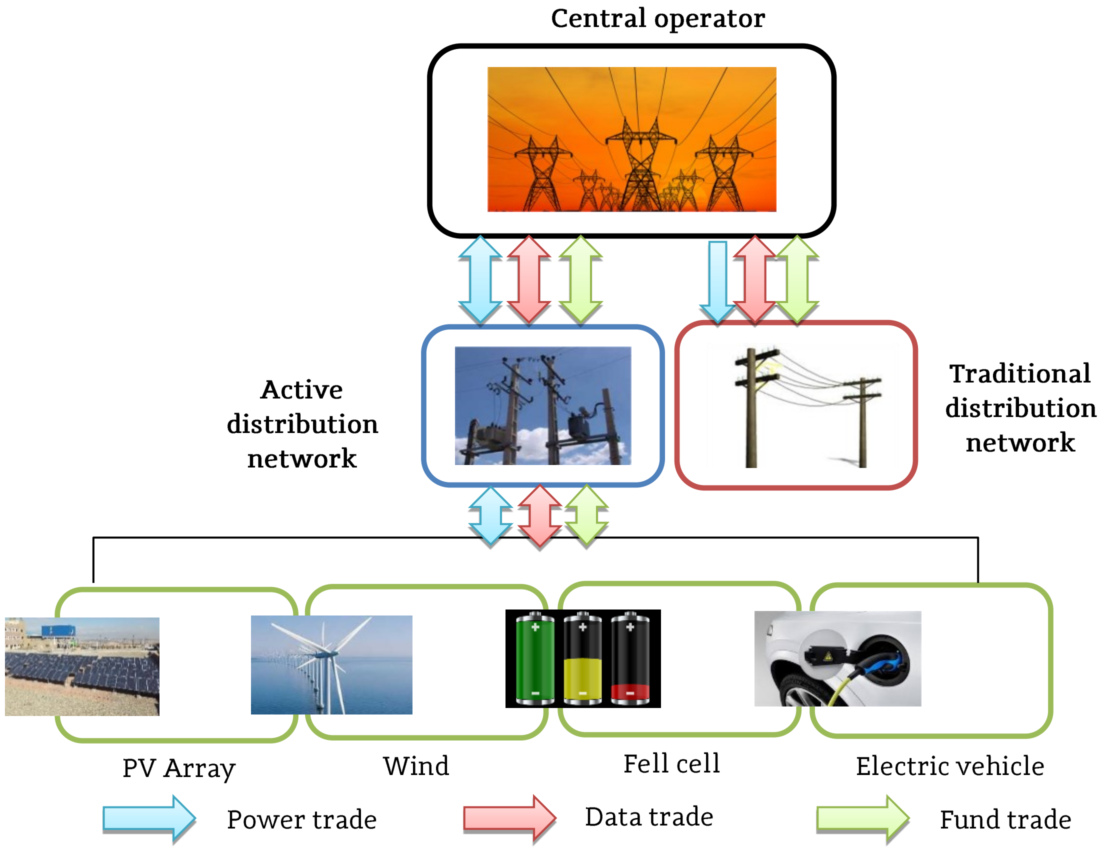

Figure 1: Fund, data and power trade in electrical power system

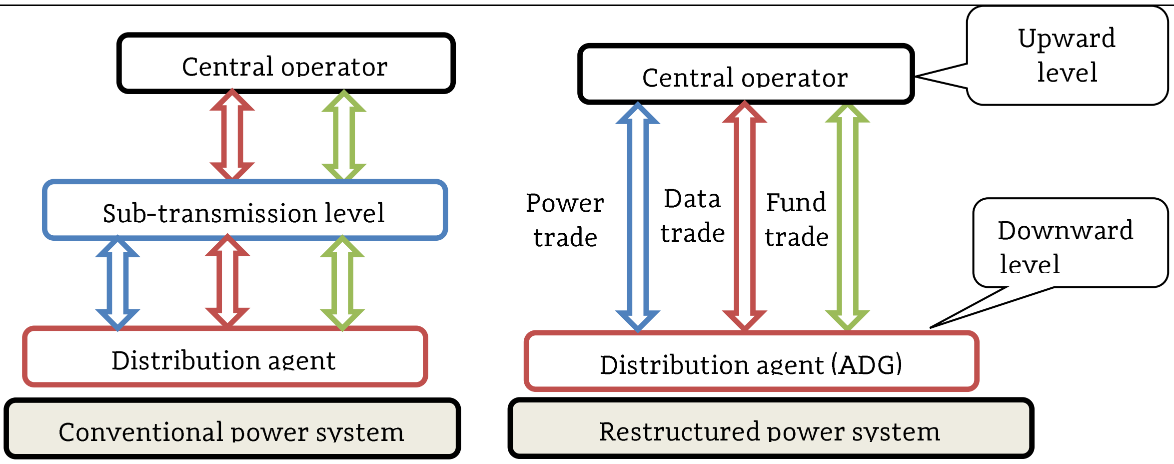

Figure 2: ADG in restructure and conventional power system

Whenever ADG and ADs are connected to each other, they always share the variables. In the proposed model, local variables are defined as, $\tilde{x}$ and $\tilde{y}$ which are related to CO and DISAG respectively. Also, common variables between them are defined by z. Therefore, equations (1), and (2) can be rewritten as follows:

$$\begin{aligned} & Min f(\tilde{x},z) \\ s.t.\ \ & h(\tilde{x},z) \le 0 \\ & I(\tilde{x},z) = 0 \end{aligned} \tag{3}$$

$$\begin{aligned} & Min f(\tilde{y},z) \\ s.t.\ \ & h(\tilde{y},z) \le 0 \\ & I(\tilde{y},z) = 0 \end{aligned} \tag{4}$$

Due to the existence of common variables z, equations (3), and (4) cannot be solved individually. To solve the defined optimization problems independently, they must be separated into two distinct problems; for this purpose, a hierarchical binary level systematic decentralized structure is proposed, in which CO is compared to DISAG at a level higher. Two different sets of variables are defined for modeling common variables and the objective function and constraints of each system are independently formulated. The first variable, ∂, is named as the objective variable, which is one of the common variables between the two systems that are sent from CO to DISAG. In fact, ∂ is sent from the higher-level system to the lower-level system. The response variable, ρ, is the second common variable between CO and DISAG. This variable is sent from DISAG to CO. Given the objective and response variables, the integrity constraint is introduced as follows:

$$c = \sigma - \rho = 0 \tag{5}$$

Constraint 5 should be considered in the optimization of CO and DISAG. Using the penalty function, the integrity constraint can be met. Hence, the local optimization problems for CO and DISAG are rewritten in the form of equations 6, and 7, respectively:

$$\begin{aligned} & Min f(\tilde{x},z) + \pi(c) \\ s.t.\ \ & h(\tilde{x},z) \le 0 \\ & I(\tilde{x},z) = 0 \\ & \forall z \in \{\eta, \mu\} \end{aligned} \tag{6}$$

$$\begin{aligned} & Min f(\tilde{y},z) + \pi(c) \\ s.t.\ \ & h(\tilde{y},z) \le 0 \\ & I(\tilde{y},z) = 0 \\ & \forall z \in \{\sigma, \rho\} \end{aligned} \tag{7}$$

4 Modeling the response and objective variables

In this section, two objective and response variables are defined as common variables between systems, based on the physical connection between the transmission network and ADGs. As shown in Figure Figure 2, the power exchange through a physical connection is the same as the common variable between two independent systems. The SCUC problem for CO and DISAG is related to each other through this variable. Suppose that the power from CO to DISAG has been transmitted. Objective and response variables can be modeled as Figure Figure 3, where CO is the independent system 0 and DISAG is System 1.

From DISAG's point of view, the line is modeled as a hypothetical generator that feeds DISAG. From CO's point of view, the current line is modeled as a hypothetical load fed by the CO; therefore, ∂ is equal to the hypothetical production for DISAG and ρ is equal to the assumed load for CO. It should be noted that it is possible that hypothetical production would be negative. This means that the power is delivered from DISAG to CO. This is also true for ∂.

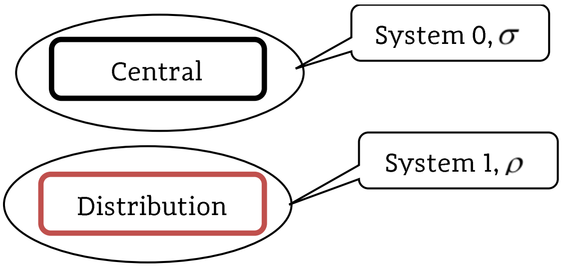

Figure 3: The power exchange and physical connection between two independent systems

In this section, the power provided by CO and consumed by DISAG is defined in DISAG optimization problem (Eq. 8). The power generated by CO and sent to DISAG in the CO optimization problem is defined as Eq (9). Additionally, the value of the two PGD and PDS variables should not exceed the minimum and maximum communication link capacity between the ADG and the transmission network.

$$\rho = PG_D \tag{8}$$

$$\sigma = PG_S \tag{9}$$

The proposed model for a period of time and with the presence of several ADGs by increasing the number of ADGs connected to the transmission network, Figure Figure 2 can be expanded as Figure Figure 4. In this case, CO is at a higher level and all ADGs are at a lower level.

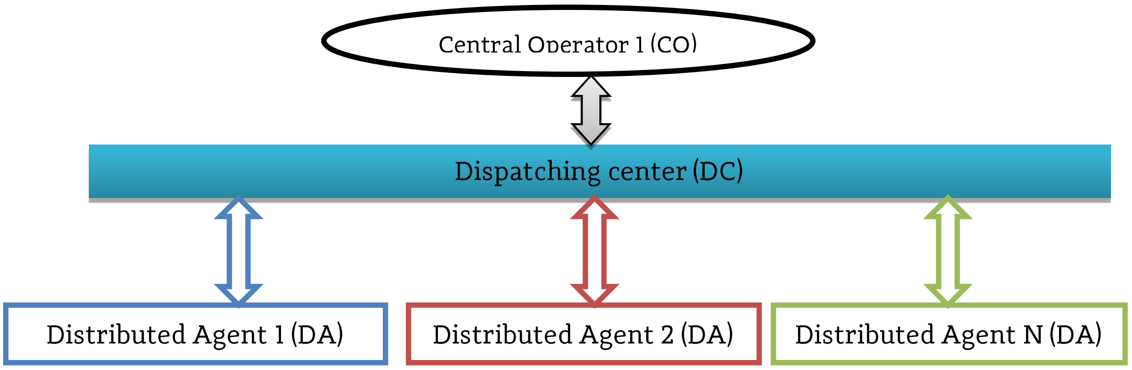

Figure 4: A power system in the form of a hierarchical binary level systematic decentralized structure

The CO system always shares variables with DISAGs. Thus, the optimization problem (Eq. 6) can be rewritten as Eq (10), which includes a penalty function for modeling constraints between CO and all DISAGs controller.

Considering several time intervals and using a second order function for modeling the penalty function π, the CO optimization problem (Eq. 10) is rewritten as Eq. (11), in this case, the symbol o represents the multiplication of the corresponding elements of two matrices.

$$\begin{aligned} & Minf(\tilde{x}, z_1, z_2, \dots, z_j) \\ & \qquad\qquad + \pi(c_1, c_2, \dots, c_j) \\ & s.t. h(\tilde{x}, z_1, z_2, \dots, z_j) \le 0 \\ & I(\tilde{x}, z_1, z_2, \dots, z_j) = 0 \\ & \forall z_j \in \{\sigma, \rho_j\}; \ \ \forall_j = 1,2, \dots, NA \end{aligned} \tag{10}$$

$$
\begin{aligned}
&Min\sum_{t=1}^{NT} f(\tilde{x}\,, z_{1t}, z_{2t}, \dots, z_{jt})\\
&\sum_{t=1}^{NT}\ \ \sum_{j=1}^{NA}\Big(\beta_{jt}(\sigma_{jt}-\rho_{jt})\\
&\qquad\qquad - \left\|\varepsilon_{jt} o(\sigma_{jt}\right.\\
&\qquad\qquad \left.- \rho_{jt})\right\|_2^2\Big) \qquad (11)\\
&s.t.\, h(\tilde{x}, z_{1t}, z_{2t}, \dots, z_{jt}) \le 0\\
&\quad I(\tilde{x}, z_{1t}, z_{2t}, \dots, z_{jt}) = 0\\
&\quad \forall z_{jt} \in \{\sigma_{jt}, \rho_{jt}\}\ \ \forall_j = 1,2,\dots, NA,\\
&\quad \forall t
\end{aligned}
$$

Similarly, the problem of optimizing DISCOj can be rewritten as follows:

$$
\begin{aligned}
&Min\sum_{t=1}^{NT} f(\tilde{y}, z_{jt}) + \sum\Big(\beta_{jt}(\sigma_{jt}-\rho_{jt})\\
&\qquad\qquad + \left\|\varepsilon_{jt} o(\sigma_{jt}-\rho_{jt})\right\|_2^2\Big) \qquad (12)\\
&s.t.\ h(\tilde{y}, z_{jt}) \le 0\\
&\quad I(\tilde{y}, z_{jt}) = 0\\
&\quad \forall z_{jt} \in \{\sigma_{jt}, \rho_{jt}\}\ \forall t
\end{aligned}
$$

Where, z_{jt}, ∂_{jt} and ρ_{jt} are the common variables, the objective and the response between CO and DISAGj, respectively at time t. The penalty function consists of two linear terms and a second order. The parameters β_{jt} and ε_{jt} are coefficients of linear and quadratic expressions that change their values in the problem-solving process. An important feature of the second-order penalty function is that this function is a convex quadratic curve. Therefore, the problem can be easily solved using a second order optimization method.

5 Controlling constraints in SCUC problems

SCUC problems in independent systems are associated with each other using penalty functions, objective variables and response variables. This connection was created with the aim of finding optimal results for the entire power system. Therefore, the SCUC problem for DISAGj can be shown as follows:

$$
\begin{aligned}
&Min\ \sum_{t=1}^{NT}\quad \sum_{i=1}^{NG_J} D_j(P_{it}) I_{it} +\\
&SUD_{it} + \sum_{t=1}^{NT}\Big(\beta_{jt}(PD_{S,jt}^{*} - PG_{D,jt}) + \qquad (13)\\
&\left\|\varepsilon_{jt} o\big(PD_{S,jt}^{*} - PG_{D,jt}\big)\right\|_2^2\Big)
\end{aligned}
$$

The first expression of equation (13) related to the cost of generating power is to turn on/off the production units of DISAGj. The second term is the penalty function for common variables with CO. It should be noted that in the penalty function PGD,jt response variables must be determined, but the number of objective variables of $PD_{S,jt}^{*}$ from the CO is received. Meanwhile, SCUC constraints should be met. The response variables for modeling the penalty function are obtained from DISAGs. In this regard, PDS,jt is considered as a vector of design variables, while $PG_{D,jt}^{*}$ variables are assumed as constant values.

$$
\begin{aligned}
&Min\sum_{t=1}^{NT}\ \ \sum_{i=1}^{NG} D_j(P_{it}) I_{it} + SUD_{it}\\
&+\sum_{t=1}^{NT}\ \ \sum_{j=1}^{NA}\big(\beta_{jt}(PD_{S,jt} - PG_{D,jt}^{*}) \qquad (14)\\
&+\left\|\varepsilon_{jt} o(PD_{S,jt} - PG_{D,jt}^{*})\right\|_2^2\ \ \big)
\end{aligned}
$$

Similarly, in Eq (14), the first term indicates the cost of production, the switching on/off of production units, and the second term of the penalty function is related to common variables with DISAGs. In this problem, the SCUC's normal constraints should also be considered. In the systematically decentralized SCUC problem, systems may have limitations in relation to the amount of power that can be interconnected. Therefore, in addition to the normal SCUC constraints, the constraint of transferable power limitation must be considered in problems.

$$
\begin{aligned}
max\left\{\underline{PT_{S,jt}}, \underline{PT_{D,jt}}\right\} &\le \{PD_{S,jt}, PG_{D,st}\} \qquad (15)\\
&\le min\left\{\overline{PT_{S,jt}}, \overline{PT_{D,jt}}\right\}
\end{aligned}
$$

Where $\underline{PT_{S,jt}}$ and $\overline{PT_{S,jt}}$ the minimum and maximum amount of power transferable between CO and DISAGj at time t from the CO point of view, and $PT_{D,jt}$ and $\overline{PT_{D,jt}}$ the minimum and maximum amount of power transferable between CO and DISAGj at time t from the DISAGj point of view.

6 Problem-solving process

The following figure illustrates the proposed problem-solving process, which results in the planning of production units for CO and DISAGs. This algorithm has two repetitive loops, which are described below. At first step, the repetitive indices of ψ and L corresponding to the inner and outer loops respectively, are set to zero and the initial value of the $PD^{*\omega}_{S,jt}$, ε^{L}_{jt}, β^{L}_{jt} variables, will be determined. Then, by applying L = L+1, the SCUC problem is solved for each DISAG with considering $PG^{\omega}_{D,jt}$ considered as design variables. In the next step, the $PG^{\omega}_{D,jt}$ variables are considered according to their value in the repetition before ($PG^{\omega-1}_{D,jt}$). Then, the SCUC problem for CO is solved by considering the $PD^{\omega}_{S,jt}$ as design variables and taking into consideration $PG^{*\omega}_{D,jt}$ values calculated in the second step. Meanwhile, using Eq. (16, and 17), the internal loop convergence is checked. If these conditions are not met, one will need to go back to the second stage until the next iteration, otherwise we should go to step 5.

$$PD^{\omega}_{S,jt} - PD^{\omega-1}_{S,jt} \le \varepsilon_1 \ \forall_j, \forall t \qquad (16)$$

$$PG^{\omega}_{D,jt} - PG^{\omega-1}_{D,jt} \le \varepsilon_1 \ \forall_j, \forall t \qquad (17)$$

If these constraints are not met, go to the next step; otherwise, the optimal convergent results will be obtained, and the process of solution will be stopped.

$$PD^{\omega}_{S,jt} - PD^{\omega}_{D,jt} \le \varepsilon_2 \ \forall_j, \forall t \qquad (18)$$

After applying L=L+1, the value of the coefficients β^{L}_{jt} and ε^{L}_{jt} is updated according to the equations (19, and 20):

$$\beta^{(L+1)}_{jt} = \varepsilon^{(L)}_{jt} + 2(\varepsilon^{(L)}_{jt})^2(PD^{\omega}_{S,jt} - PG^{\omega}_{D,jt}) \qquad (19)$$

$$\varepsilon^{(L+1)}_{jt} = \lambda\varepsilon^{(L)}_{jt} \qquad (20)$$

Where, coefficient λ should be equal to or greater than one to obtain convergent optimal results. This method has been proved to update the Lagrangian coefficients for convergence to an optimal result. The next step $PD^{*0}_{S,jt} = PD^{*\omega}_{S,jt}, \forall j, \forall t,\ \ \omega = 0$ and it is placed and returns to the second step. It should be noted that the internal repetition loop of this algorithm is the constant penalty coefficients and only PDS,$_{jt}$ and PGD,$_{jt}$, must be updated. Such method helps to lead the algorithm to a precise answer, especially when the initial guess is not good for the initial values of the common variables.

2 Numerical results and discussion

In this paper, a 6-busbar network is considered as the network studied. All calculations are done using the GAMS software. The 6-busbar network's single-line diagram is shown in Figure Figure 5; this 6-busbar network has 3 production units, 7 branches and 3 loads. To analyse the performance of the proposed method, three different scenarios are considered:

First scenario: Regardless of ADGs.

Second scenario: Considering ADGs, but without regard to the security constraints.

Third scenario: Considering ADGs and incorporating security constraints.

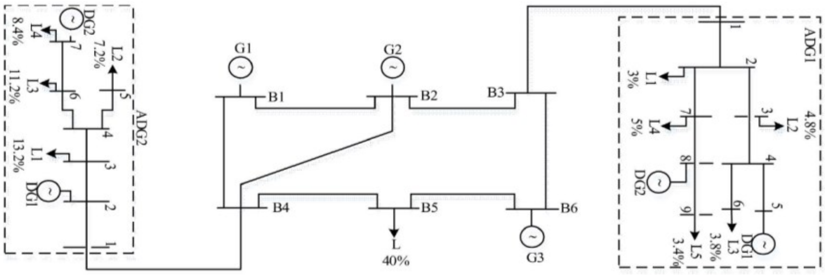

Figure 5: A 6-busbar network single-line diagram

Specifications of production units, transmission network information and network load rates at different hours of the night are shown in Tables Table 1 to Table 3.

Table 1: Transmission network generator information

Min time for on (h)	Min time for off (h)	b (MBtu/MW^{2}h)	b (MBtu/MWh)	a (MBtu)	P_{max} (MW)	P_{min} (MW)	unit
4	4	0.03	7	100	220	40	1
2	3	0.07	10	104	100	10	2
1	1	0.05	8	110	25	0	3

Table 2: Transmission network information

Max power (MW)	X (pu)	To bus	From bus
200	0.170	2	1
200	0.258	4	1
190	0.037	3	2
200	0.197	4	2
180	0.018	6	3
190	0.037	5	4
180	0.140	6	4

Table 3: Hourly load of 24-busbar network in a 24-hour period

Load (MW)	hour	Load (MW)	hour	Load (MW)	hour	Load (MW)	hour
246	1	175	7	173	13	242	19
237	2	169	8	174	14	244	20
237	3	165	9	185	15	249	21
233	4	155	10	202	16	256	22
210	5	155	11	228	17	256	23
210	6	165	12	236	18	247	24

Two ADGs in the 3rd and 4th busbars are connected to this transmission network and a passive ADG is connected to busbar No. 5. ADG1 network consists of 9 busbars, 8 distribution feeders, 5 loads and 2 DGs. ADG2 also includes 7 busbars, 6 distribution feeders, 4 bars and 2 DGs. Data and network specifications and DG units of these distribution networks are presented in Tables Table 4 and Table 5. The amount of ADG in percent of total network load is shown in Figure Figure 5: A 6-busbar network single-line diagram.

Table 4: Distribution network generator information

b (MBtu/MW^{2}h)	b (MBtu/MWh)	a (MBtu)	P_{max} (MW)	P_{min} (MW)	DG	ADG No
0.08	7	100	15	0	1	ADG1
0.03	3	65	18	0	2	
0.04	5	140	25	5	1	ADG2
0.00	25	50	19	0	2	

Table 5: Distribution network layout information

ADG2				ADG1			
Max power (MW)	X (pu)	To bus	From bus	Max power (MW)	X (pu)	To bus	From bus
70	0.2	1	B4	60	0.2	1	B3

70	0.15	2	1	60	0.19	2	1
90	0.20	3	2	30	0.21	3	2
70	0.16	4	3	30	0.21	7	2
40	0.18	5	4	40	0.20	4	3
40	0.18	6	4	20	0.18	5	4
40	0.16	7	6	30	0.18	6	4
-	-	-	-	20	0.19	8	7
-	-	-	-	20	0.19	9	8

In the following, the simulation results have been analyzed. These results are presented for different scenarios. In the first scenario, it is assumed that there is no DG unit in the ADGs, and all the distribution networks are passive. In this case, all ADGs are modeled as a constant load, connected to the 3, 4, and 5 busbars. The usual concentrated SCUC problem is solved to find the optimal operating point of the system. Table Table *6* shows the on / off status of the network transmission units. The amount of power produced by the units per hour is also shown in Table Table *7*. The total cost of generating power over the 24-hour period will be equal to $ 65641.275.

Table 6: On/Off status of transmission network units in the first scenario

	H1	H2	H3	H4	H5	H6	H7	H8
G1	1	1	1	1	1	1	1	1
G2	1	1	1	1	1	1	1	1
G3	1	1	1	1	1	1	1	1
	H9	H10	H11	H12	H13	H14	H15	H16
G1	1	1	1	1	1	1	1	1
G2	1	1	1	1	1	1	1	1
G3	1	1	1	1	1	1	1	1
	H17	H18	H19	H20	H21	H22	H23	H24
G1	1	1	1	1	1	1	1	1
G2	1	1	1	1	1	1	1	1
G3	1	1	1	1	1	1	1	1

Table 7: Production power rate of transmission network units in the first scenario

	H1	H2	H3	H4	H5	H6	H7	H8
G1	120	115	113	106	106	113	118	119
G2	30	28.2	27	24	24	27	29.4	29.7
G3	25	25	25	25	25	25	25	25
	H9	H10	H11	H12	H13	H14	H15	H16
G1	127	138	157	162	166	168	171	176
G2	33	38.1	45.9	48.3	50.1	50.7	52.2	54.3
G3	25	25	25	25	25	25	25	25
	H17	H18	H19	H20	H21	H22	H23	H24
G1	176	170	169	163	164	166	145	145
G2	54.3	51.6	51.3	48.6	48.6	47.4	40.5	40.5
G3	25	25	25	25	25	25	25	25

As shown in Tables Table *6* and Table *7*, all three generators are always in circuit. Another point from Table Table *7* is that generator 3 is always at its minimum. Looking at Table Table 1, it can be seen that the cost coefficients of this generator are higher than the rest. This means that power generation by this unit is more expensive than the other two generators. That is why the generator is always at its lowest (25 MW).

In the second scenario, as shown in Figure Figure 5, the two ADGs are connected to the transmission network via busbars 3 and 4. Regarding the decentralized system concept, CO and DISAGs are modeled as independent systems. The transmitted power between CO and DISAG is limited by the capacity of the lines between CO and DISAG. The initial value of the parameters is considered as follows:

$$PD^{*}_{S,jt} = 0$$

$$\alpha^{0}_{1t} = \alpha^{0}_{2t} = 101$$

$$\beta^{0}_{1t} = \beta^{0}_{2t} = 21$$

The problem of SCUC is based on a decentralized system approach to find the optimal transmission point of the transmission network and ADGs. It should be noted that in this scenario, the security constraints of the transmission network and distribution networks are not considered. In other words, the SCUC problem has become a UC problem by considering ADGs. Table Table *8* shows the on/off status of production units. The amount of power generated by each unit is shown in Table Table *9*. In Tables Table *10* and Table *11*, respectively, the on/off state and output power of ADG1 units are shown. In addition, Tables Table 12 and Table 13 show the data of ADG2 units. As shown here, the ADG1 units are always in the circuit and generate power. Considering the cost coefficients of these units, it can be seen that these units are cheaper than transmission network units; hence these units are always in the circuit and generate power.

Table 8: On/Off status of transmission network units in the second scenario

	H1	H2	H3	H4	H5	H6	H7	H8
G1	1	1	1	1	1	1	1	1
G2	0	0	0	0	0	0	0	0
G3	1	1	1	1	1	1	1	1
	H9	H10	H11	H12	H13	H14	H15	H16
G1	1	1	1	1	1	1	1	1
G2	0	0	0	0	0	0	0	0
G3	1	1	1	1	1	1	1	1
	H17	H18	H19	H20	H21	H22	H23	H24
G1	1	1	1	1	1	1	1	1
G2	1	1	1	1	1	1	1	1
G3	1	1	1	1	1	1	1	1

Table 9: Generation capacity of transmission network units in the second scenario

	H1	H2	H3	H4	H5	H6	H7	H8
G1	112	106	102	94	94	102	110	111
G2	0	0	0	0	0	0	0	0
G3	25	25	25	25	25	25	25	25
	H9	H10	H11	H12	H13	H14	H15	H16
G1	122	133	148.8	153.6	157	158.4	161.4	165.6
G2	0	0	0	0	0	0	0	0
G3	25	25	25	25	25	25	25	25
	H17	H18	H19	H20	H21	H22	H23	H24
G1	130.9	150	149.6	154	154.2	151.8	138	137
G2	34.68	10	10	0	0	0	0	0
G3	25	25	25	25	25	25	25	25

Table 10: On/Off status of ADG1 network units in the second scenario

	H1	H2	H3	H4	H5	H6	H7	H8
G1	1	1	1	1	1	1	1	1
G2	1	1	1	1	1	1	1	1
	H9	H10	H11	H12	H13	H14	H15	H16
G1	1	1	1	1	1	1	1	1
G2	1	1	1	1	1	1	1	1
	H17	H18	H19	H20	H21	H22	H23	H24
G1	1	1	1	1	1	1	1	1
G2	1	1	1	1	1	1	1	1

Table 11: The power generation capacity of the ADG1 network units in the second scenario

	H1	H2	H3	H4	H5	H6	H7	H8
G1	15	15	15	13	13	15	15	15
G2	18	18	18	18	18	18	18	18
	H9	H10	H11	H12	H13	H14	H15	H16
G1	15	15	15	15	15	15	15	15
G2	18	18	18	18	18	18	18	18
	H17	H18	H19	H20	H21	H22	H23	H24
G1	15	15	15	15	15	15	15	15
G2	18	18	18	18	18	18	18	18

Table 12: On/Off status of ADG2 network units in the second scenario

	H1	H2	H3	H4	H5	H6	H7	H8
G1	1	1	1	1	1	1	1	1
G2	0	0	0	0	0	0	0	0
	H9	H10	H11	H12	H13	H14	H15	H16
G1	1	1	1	1	1	1	1	1
G2	0	0	0	0	1	1	1	1
	H17	H18	H19	H20	H21	H22	H23	H24
G1	1	1	1	1	1	1	1	1
G2	1	1	1	0	0	0	0	0

Table 13: Generation capacity of ADG2 network units in the second scenario

	H1	H2	H3	H4	H5	H6	H7	H8
G1	5	5	5	5	5	5	5	5
G2	0	0	0	0	0	0	0	0
	H9	H10	H11	H12	H13	H14	H15	H16
G1	5	10.8	21.2	24.4	25	25	25	25
G2	0	0	0	0	1.8	2.6	4.6	7.4
	H17	H18	H19	H20	H21	H22	H23	H24
G1	25	25	25	24.8	24.8	23.2	14	14.9
G2	7.4	3.8	3.4	0	0	0	0	0

The results obtained in Table Table *11* show that the units of the ADG1 network, with the exception of unit number 1 in two times of 4 and 5 o'clock, produce at their maximum capacity. In connection with the ADG2 network units, it can be seen that Unit 2 of this network, which is a more expensive unit, has entered the circuit only during peak hours, which does not generate much power during these hours. However, compared to Unit 1, this network has been producing at least 25 megawatts of power during these hours.

The cost of generating transmission network power, ADG1, and ADG2 for this scenario is 47092.278 $, 8404.32 $, 6693.55 $, respectively. Taking into account these costs, the total cost of providing network power in this scenario would be $ 62190.148. Comparing this cost with the cost of providing the power in the first scenario ($ 65641.275), it is estimated that the cost of providing power has fallen by 3451.127 $. This reduction was due to the use of cheaper units in distribution networks.

The power exchanged between the ADG1 and ADG2 networks is shown in Tables Table 14 and Table 15, respectively.

Table 14: The amount of power exchanged between the transmission network and the ADG1 network in the second scenario

	H1	H2	H3	H4	H5	H6	H7	H8
Power (MW)	2	0.8	0	0	0	0	1.6	1.8
	H9	H10	H11	H12	H13	H14	H15	H16
Power (MW)	4	7.4	12.6	14.2	15.4	15.8	16.8	18.2
	H17	H18	H19	H20	H21	H22	H23	H24
Power (MW)	18.2	16.4	16.2	14.4	14.4	13.6	9	9

Table 15: The amount of power exchanged between the transmission network and the ADG2 network in the second scenario

	H1	H2	H3	H4	H5	H6	H7	H8
Power (MW)	65	62.6	61	57	57	61	64.2	64.6
	H9	H10	H11	H12	H13	H14	H15	H16
Power (MW)	69	70	70	70	70	70	70	70
	H17	H18	H19	H20	H21	H22	H23	H24
Power (MW)	70	70	70	70	70	70	70	69.1

In the third scenario, the network security constraints (maximum transmittable power by lines) are also included in the calculation. For this purpose, the system load distribution equations are included in the program. The amount of power transmitted from the lines is calculated and the minimum and maximum power transmission is considered. The initial value of the parameters is the same as in the second scenario.

The results obtained in this scenario are presented in Tables Table *16* to Table 23. In Tables Table *16* and Table 17, the units on/off status and the unit power production in any hour of the day is presented.

The results of the tables mentioned show that in this scenario, as in the first scenario, at best, all generators should be on and able to generate power. As you can see, in this scenario, Unit 3 is in circuit at all times of the day with its maximum power (25 MW). In Tables Table *18* and Table *19* respectively, the status of the on/off power and output power of ADG1 units is shown. Tables Table *20* and Table 21 also show the data of ADG2 units. As shown here, the status of ADG1 units in this scenario is like the second scenario. The reason for this is the cheapness of the units of this network, which has led to these units always being in circuit. In this scenario, as in the previous scenario, only at 2 times 4 and 5 o'clock, unit number 1 does not work at maximum power (its production capacity is 13 megawatts, which is 2 megawatts fewer than its maximum capacity).

The results for ADG2 indicate that in this case, the power output of unit number 1 has decreased during peak hours. In the previous scenario, this power was 25 megawatts, while in this scenario it dropped to 20 megawatts. In contrast, the production capacity of unit number 2 has increased. This is due to the consideration of the security constraint of maximum transmittable power of the lines. Another thing is that in this scenario, unit number 2 was in circuit for more hours. In the second scenario, this unit was only in circuit at 13 to 19, while in this scenario, the unit was on from 11 to 22.

Table 16: On/Off status of transmission network units in the third scenario

	H1	H2	H3	H4	H5	H6	H7	H8
G1	1	1	1	1	1	1	1	1
G2	1	1	1	1	1	1	1	1
G3	1	1	1	1	1	1	1	1
	H9	H10	H11	H12	H13	H14	H15	H16

G1	1	1	1	1	1	1	1	1
G2	1	1	1	1	1	1	1	1
G3	1	1	1	1	1	1	1	1
	H17	H18	H19	H20	H21	H22	H23	H24
G1	1	1	1	1	1	1	1	1
G2	1	1	1	1	1	1	1	1
G3	1	1	1	1	1	1	1	1

Table 17: Generation capacity of transmission network units in the third scenario

	H1	H2	H3	H4	H5	H6	H7	H8
G1	93.32044	89.20075	86.37109	80.76986	80.79835	86.36983	91.95713	92.61571
G2	18.6796	16.79926	15.62891	13.23014	13.20165	15.63017	18.04294	18.38422
G3	25	25	25	25	25	25	25	25
	H9	H10	H11	H12	H13	H14	H15	H16
G1	100.3983	108.2403	119.1601	122.5203	125.03	125.8814	127.9794	130.9179
G2	21.60186	24.96	29.63998	31.07993	32.17024	32.51872	33.42059	34.68204
G3	25	25	25	25	25	25	25	25
	H17	H18	H19	H20	H21	H22	H23	H24
G1	130.9187	127.144	126.7196	122.94	122.94	121.26	111.6	111.6001
G2	34.6812	33.05654	32.88104	31.25995	31.26	30.53993	26.40006	26.40009
G3	25	25	25	25	25	25	25	25

Table 18: On/Off status of ADG1 network units in the third scenario

	H1	H2	H3	H4	H5	H6	H7	H8
G1	1	1	1	1	1	1	1	1
G2	1	1	1	1	1	1	1	1
	H9	H10	H11	H12	H13	H14	H15	H16
G1	1	1	1	1	1	1	1	1
G2	1	1	1	1	1	1	1	1
	H17	H18	H19	H20	H21	H22	H23	H24
G1	1	1	1	1	1	1	1	1
G2	1	1	1	1	1	1	1	1

Table 19: Generation capacity of ADG1 network units in the third scenario

	H1	H2	H3	H4	H5	H6	H7	H8
G1	15	15	15	13	13	15	15	15
G2	18	18	18	18	18	18	18	18
	H9	H10	H11	H12	H13	H14	H15	H16
G1	15	15	15	15	15	15	15	15
G2	18	18	18	18	18	18	18	18
	H17	H18	H19	H20	H21	H22	H23	H24
G1	15	15	15	15	15	15	15	15
G2	18	18	18	18	18	18	18	18

Table 20: On/Off status of ADG2 network units in the third scenario

	H1	H2	H3	H4	H5	H6	H7	H8
G1	1	1	1	1	1	1	1	1
G2	0	0	0	0	0	0	0	0
	H9	H10	H11	H12	H13	H14	H15	H16
G1	1	1	1	1	1	1	1	1
G2	0	0	1	1	1	1	1	1
	H17	H18	H19	H20	H21	H22	H23	H24
G1	1	1	1	1	1	1	1	1
G2	1	1	1	1	1	1	0	0

Table 21: Generation capacity of ADG2 network units in the third scenario

	H1	H2	H3	H4	H5	H6	H7	H8
G1	5	5	5	5	5	5	5	5
G2	0	0	0	0	0	0	0	0
	H9	H10	H11	H12	H13	H14	H15	H16
G1	5	10.8	20	20	20	20	20	20
G2	0	0	1.2	4.4	6.8	7.6	9.6	12.4
	H17	H18	H19	H20	H21	H22	H23	H24
G1	20	20	20	20	20	20	14	14
G2	12.4	8.8	8.4	4.8	4.8	3.2	0	0

Table 22: The amount of power exchanged between the transmission network and the ADG1 network in the third scenario

	H1	H2	H3	H4	H5	H6	H7	H8
Power (MW)	2	0.8	0	0	0	0	1.6	1.8
	H9	H10	H11	H12	H13	H14	H15	H16
Power (MW)	4	7.4	12.6	14.2	15.4	15.8	16.8	18.2
	H17	H18	H19	H20	H21	H22	H23	H24
Power (MW)	18.2	16.4	16.2	14.4	14.4	13.6	9	9

The cost of generating transmission power, ADG1 and ADG2 for this scenario is 47809.99$, 8404.32 $, 8510.345 $, respectively. Considering these costs, the total cost of providing network power in this scenario would be 64724.655 $. Comparing this cost with the cost of providing power in the first scenario ($ 65641.275), and the second scenario ($ 62190.148), the cost of power supply compared to the first scenario is reduced by 916.62 $ and compared to the second scenario increased by 2534.507 $. The reason for the increase compared to the second scenario is that, having regard to the security constraints, inevitably expensive units have entered the circuit, and the total cost has increased. The power exchange between the transmission network and ADG1 and ADG2 are respectively presented in Tables Table 22 and Table 23.

Table 23: The amount of power exchanged between the transmission network and the ADG2 network in the third scenario

	H1	H2	H3	H4	H5	H6	H7	H8
Power (MW)	65	62.6	61	57	57	61	64.2	64.6
	H9	H10	H11	H12	H13	H14	H15	H16
Power (MW)	69	70	70	70	70	70	70	70
	H17	H18	H19	H20	H21	H22	H23	H24
Power (MW)	70	70	70	70	70	70	70	70

As shown, the power exchange between ADG1 and the transmission network is similar to the second scenario, since the output power of the units in ADG1 is the same for both scenarios. This is also the case for ADG2. Where, transmitted power is the same for both scenarios. The important point is that in the third scenario, the capacity of unit number 1 in ADG1 has been decreased in some hours but has increased against unit number 2 output. As shown, the power exchange between the transmission network and the ADG2 is not more than 70 MW. The reason for this is that the maximum transmittable power by the connecting line of the two networks is 70 MW. Hence, the network cannot receive more than 70 megawatts from the transmission network, and it has to supply the required power and eliminate the congestion in the case of congestion of some lines, with the help of a unit within its own network. In this scenario, this is done by reducing the power of unit number 1 and increasing the power of unit number 2.

3 Conclusion

In a restructured power system, different parts of the network are allocated to the private sector, and each of these sectors seeks to maximize its profits. Therefore, the network cannot be traditionally planned and managed, and a new framework must be used. In this paper, a systematically decentralized framework for the planning of generation units is presented. The variables between the different systems in this framework are the amount of power transferred between the two systems. The generation planning (SCUC) in the traditional way is better and more suitable for calculation time and computational capacity compared to the proposed method (binary level hierarchical optimization). Considering DG units in calculations will reduce the total cost of production. Generally, the cost of generating power in such units is less than that of large units. Considering the security constraints on the network will increase the total cost of production. This is because the existence of security constraints will always make it impossible to use cheaper units (due to violations of the security constraints) and, inevitably, more units that are expensive should be used.

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