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Security Constrained Unit Commitment in the Simultaneous Presence of Demand Response Sources and Electric Vehicles

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Abstract

Due to the ever-growing load, especially peak load, the increase in the capacity of plants is inevitable for the response to this growth. Peak load causes increases in customer costs and vast investments in generating and transmission parts. Therefore, restructuring in the electrical industry, competition in the electrical market and Demand Response Programs (DRPs) are of special importance in power systems. In DRPs, customers in certain periods, such as peak or times when the price is high, decrease self-consumption. It means profit for costumers and prevention of expensive production in peak time for a generation source. Moreover, to decrease the operation cost of network and ever-growing technology significantly, the power systems operators have employed new sources of energy production as well as thermal units, and it has led to the emergence of Electric Vehicles (EVs) technology as a new source of energy production. This paper studies the simultaneous presence of DRPs and EVs to minimize the total operation cost of a network from one hand and from the other to improve the level of system reserve in Unit Commitment (UC) problem with considering the security constraint. Here, the proposed framework is structured as a Mixed Integer Programming (MIP) and solved using CPLEX solver.

Keywords: Demand response, mixed integer programming, security constrained unit commitment, electric vehicles.
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1. Introduction

UC problem is one of the most important economic problems in power systems. UC planning means optimization of production sources with the purpose of load- demand supply through the minimum cost. In modern and conventional power systems, in addition to being economical, the security in the operation of units is also of great importance, because interrelation between economy and security can result in decreasing of the production costs regarding the total potentials and constraints. If in UC planning the transmission congestion constraint is also considered, it is named as Security Constraint Unit Commitment (SCUC). SCUC problem is one of the most complex problems in the productivity of power systems, in which the constraints of generation, transmission and security must be viewed as well [1, 2, 3, 4]. SCUC is solved by Lagrangian Relaxation (LR) [5,6,7] which has the drawback of perverse relaxations for discrete variables. In [8] bender's decomposition technique has been used to solve SCUC. In recent years, genetic algorithms have also been used to solve the problem. In [9,10] SCUC is solved without reserves, considering only the errors in load forecasting and system contingencies. In [11], SCUC is solved incorporating load shedding for stable and contingency conditions. The methods used to decrease the operational costs of the network in UC include the presence of DRP and utilization of energy storage sources such as EVs on the operation of the power system. World researches show that making load response in the utilization of DR methods has high advantages for customers, market and network [12, 13, 14]. The advantages of the customers include economic advantages, continuity and electrification. Advantages of the market include prevention of leaping price and helping its constancy, and advantages of the network include saving in investment costs, putting off in making new plants, smoothing load curves and increasing the customer factor. A customer can react to the market situation in two ways: the first interruption of the load section, and secondly load transfer from expensive periods to cheap periods. This paper considers the contribution of DR as the first way. Furthermore, to decrease significantly the operation cost of the network and to lessen the amount of the pollution resulted from the consumption of fuel by vehicles is necessary to find the new methods for the change in vehicle energy sources. One of these methods is the utilization of energy storage sources such as Vehicles to Generation (V2G). These vehicles, when connected to the network, have a dual-purpose ability charge. The presence of these vehicles in a parking operates like a small virtual power plant with a very high-velocity startup and without startup cost. This paper proposes the solution for SCUC simultaneously with the presence of DR and V2G under an objective function. In this paper, a six-bus system has been analyzed to show the effectiveness of the proposed approach, and the proposed method is programmed in GAMS software.

2. Methodology

The main objective of the SCUC problem is to minimize the generation cost by satisfying the equality and inequality constraints along with transmission, network and security constraints

A) Objective function

Fuel cost function (F_C) of the thermal units is a quadratic and nonlinear function explained as following:

$$F_c = \alpha(i) + \beta(i)P(it) + \gamma(i)P^2(it) \tag{1}$$

Where *α(i), β (i), γ (i)* are the cost function coefficients and *P (i,t) is* the active power of unit *i* at time *t*.

For the linearization, the piece linear method and the approximation of it with a linear function are used. This is explained as following [15,16]:

$$F_c = \alpha(i) + \beta(i)P(it) + \gamma(i)P^2(it) \tag{2}$$

$$MC_i = FC_{c,i}(P_i^{min}) \tag{3}$$

Where $r_{i,t}$ and $P_{i,t}$ are the ramp and output power unit *i* at time *t* in the linearized curve and P_i^{min} and $P_i^{max}$are minimum and maximum power generation of unit *i*.

The total objective function of the problem, with considering the Demand Response sources (DRs) and V2G, is shown in equation (4).

$$\begin{aligned} &Min\ CF \\ &= \sum_{i=1}^{NG}\sum_{t=1}^{H}\left[FC_{c,i}\left(P_i^{min}\right)I(i,t) + \sum_{k=1}^{kk} r_{i,t}^k P_{i,t}^k + SU_{i,t}\right. \\ &\left. + SD_{i,t}\right] + \sum_{t=1}^{H}\sum_{d=1}^{N_{DRP}}\sum_{r=1}^{N_{SDR}}\left[L_{DR}(r,d,t)\omega(r,d,t)\right] \\ &+ \sum_{t=1}^{H}\left[p_v N_{V2G}\pi_{V2G}\right] \end{aligned} \tag{4}$$

Where $SU_{i,t}$ and $SD_{i,t}$ are the startup and shutdown costs of unit *i* at time *t*, $I_{i,t}$ is on (1) or off (0) unit *i* at time *t*, $L_{DR}(r,d,t)$ is the curtailable load level of block *rth* of a demand provider at period *t*, $\omega(r,d,t)$ is the contribution situation of a customer in point *rth* of demand provider, N_{SDR} is the number of points in demand provider, p_v is the power vehicle, N_{V2G} is the number of vehicles connected to the network, and π_{V2G} is the offer price by V2G.

The first term of the objective function is consists of the fuel cost of generation units, and SU and SD are the costs of startup and shutdown respectively, which is for the standard systems equal to zero. Equations of startup and shutdown costs are formulated in (5) and (6).

$$SU_{i,t} = I_{i,t}\left(1 - I_{i,(t-1)}\right)C_i^{SU} \tag{5}$$

$$SD_{i,t} = I_{i,t}\left(1 - I_{i,(t-1)}\right)C_i^{SD} \tag{6}$$

The second term of the objective function refers to returning the purchasing cost to the consumers who contributed to the demand management program. The third term of the objective function shows the operation cost of V2G.

B) Constraints

Generation power of thermal units

$$P_{i,t}^{min} \le P_{i,t} \le P_{i,t}^{max} \tag{7}$$

– *Units ramp rate*

In every hour, the generation power of thermal units is limited by the ramp rate constraint. The uptime and downtime ensure the time for which the generator stays either in on or off condition.

$$P_{i,t} - P_{i,t-1} \le RUR_i \tag{8}$$

$$P_{i,t-1} - P_{i,t} \le RDR_i \tag{9}$$

Where RUR_i and RDR_i are ramp up and ramp down rate of unit *i*.

– *Power flow of lines*

$$-P_l^{max} \le P_{l,t} \le P_l^{max} \tag{10}$$

$$P_{l,t} = \frac{\delta_b - \delta_{bo}}{x_l} \tag{11}$$

Where $P_{l,t}$ and P_l^{max} are power flowing through line l at time t and maximum power flow for line l, δ_b is bus angle; δ_{bo} is the number of buses and x_l is line reactance.

Equation (11) shows the DC load flow and bus 1 is considered as slack bus [17, 18].

– *Number of the dischargeable vehicles*

It is supposed that only specific and predefined numbers of vehicles are modeled for discharge planning, and thus the total number of vehicles is unchanged [19, 20].

$$\sum_{t=1}^{H} N_{V2G}(t) = N_{V2G}^{max} \tag{12}$$

$$N_{V2G}(t) \leq N_{V2G}^{max} \tag{13}$$

$$N_{V2G}^{max}(t) = \delta\% N_{V2G}^{max} \tag{14}$$

Where $N_{V2G}^{max}(t)$is the maximum number of vehicles in parking at time *t*, maximum existing vehicles in every hour is $\delta\%$ the total number of existing vehicles in parking.

– *Quantity charge rate (SoC)*

Every one of V2Gs must have an agreeable level of charge in the time of connection to the network.

– *Demand management programs*

In every period, the value of interrupted load must be lower than a limit that is identified in every DR provider. It means that the maximum specficed number of customers like to contribute to the DRs.

$$DRR(d,t) \leq \eta(d,t) \qquad \forall d \in N_{DRP}, \forall t \in T \tag{15}$$

Where $\eta(d,t)$ is the maximum level of contribution of customers in demand provider *dth* and time *t* and $DRR(d,t)$ is the total reserve capacity of demand in demand provider *dth* at time *t*.

Daily interrupted load: the amount of interrupted load in the period of the case study in every DRP is limited through the following relation:

$$\sum_{t=1}^{T} DRR(d,t) \leq D_{LC}(d) \qquad \forall d \in N_{DRP} \tag{16}$$

Where $D_{LC}(d)$ is the maximum curtailable load in demand provider *dth*.

– *Balance of the network power*

In every bus, the difference between the generation and the consumption power must be equal with the input and output powers of lines that are connected to the same bus.

$$\sum_{i\in B_b^i} P_{i,t} + \sum_{v\in B_b^v} P_v N_{V2G,t} + \sum_{d=1}^{N_{DRP}} DRR(d,t) - \sum_{b=1}^{N_B} P_D(b,t) = \sum_{i\in l_{f,b}} Pl_{l,t} - \sum_{i\in l_{t,b}} Pl_{l,t} \tag{17}$$

Where $P_D(b,t)$ is the quantity of demand bus b at time t, $\sum_{i\in l_{f,b}} Pl_{l,t}$ and $\sum_{i\in l_{t,b}} Pl_{l,t}$ are the lines that are disconnected/connected from/to bus b.

– *Spinning reserve*

In every time, quantitative spinning reserve is needed for the network security.

$$\sum_{i=1} I_{i,t} P_i^{max}(t) + P_v^{max} N_{V2G}(t) \geq \sum_{b=1}^{N_B} P_D(b,t) + SR_t \tag{18}$$

Where SR_t is the needed system reserve.

3. Case study

In this section, to evaluate the proposed method, a six-bus Reliability Test System (RTS) has been selected and the effect of input vehicles that can be connected to the network and DRP have been studied for 24 hours. Figure 1 shows the six-bus RTS.

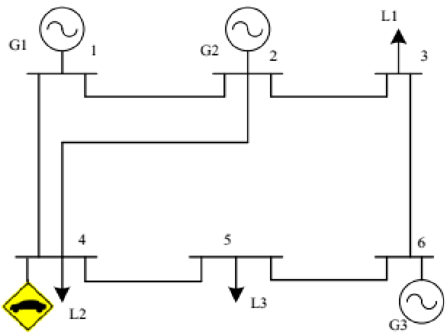

Fig. 1. The six bus test system

This network consists of 3 thermal generation units and 7 transmission lines. The fuel cost curves for generating units given as a quadratic function are approximated by 25 linear segments between the minimum and maximum generating units capacity. Parking for the vehicles that can be connected to the network is installed at bus 4. Table 1 shows the hourly load profile [21], where 20% of the total load is placed on bus 3, 50% on bus 4, and the remaining on bus 5. Data of transmission lines and thermal units have been used according to [6].

The test system was evaluated in three states:

- Modeling the SCUC problem in basic state
- Modeling the SCUC problem in the presence of DRs
- Modeling the SCUC problem in the simultaneous presence of DRs and V2G

Table.1.
Load data in 24 hour

Time (h)	***Load (MW)***	***Time (h)***	***Load (MW)***	***Time (h)***	***Load (MW)***
1	178	9	209	17	261
2	168	10	221	18	251
3	161	11	233	19	250
4	157	12	240	20	242
5	158	13	247	21	242
6	163	14	248	22	231
7	176	15	253	23	205
8	194	16	260	24	200

A) Modeling the SCUC problem in the basic state

In this case, the SCUC problem has been solved without DR and V2G and the total operation cost of the network is $98790.

B) Modeling the SCUC in the presence of DRs

In this state, first, the DR model is described. The way the DRP affects the SCUC leads to the connection between the production plant and virtual generation sources of demand. Here, the necessary information in connection units and Transco is referred to ISO. Moreover, the information about the requested load and the customers' suggestions for the contribution in DRPs is also sent for the ISO. DRPs that are responsible for collecting the customers' suggestions function as a link between the customers and ISO. ISO, after receiving the total information, runs the SCUC. In the proposed method, the energy of generation units to supply the load, the security margin and the contribution of the customers in DRPs are decided in such a way that the cost in the studied period is minimized. Moreover, the minimum level of interrupted load is identified so that in short-term planning it could be used as a virtual source to supply the reserve power system. Bidding strategy of curtailed load that is sent by DRPs to ISO is stated as following: if the level of total DR reaches 33%, 66% and 100% peak load, then the proposed prices would be respectively $11, $12 and $13. In this state, the total operation cost of the network is equal to $94830, which is in comparison with the base state is about 5% decrease.

C) Modeling the SCUC in the presence of DRs and V2G

In the third state, besides DRP, EVs are also taken in when SCUC problem solution is concerned. In this paper, different models are hypothesized for the presence of EVs based on their drivers' behavior. EVs are considered as to be charged by renewable energy sources and there is no cost for the recharge process of the units, and discharged in the day length. In the proposed method the number of EVs in any hour is identified according to the stochastic behavior of the owner of the vehicles in parking. There exists 10000 EVs in the network. Maximally 15% of the existing vehicles are connected hourly to the network based on the drivers' stochastic behavior. Approximate average production power of any vehicles is 15 kWh and the number of charges and discharges is once a day. The amount of charge in every outage time from parking is 50%, charge efficiency 85% and the price offered to the network by the vehicle's owner is $23/MWh. Also, the amount of spinning reserve in every hour is supposed to be 10% of the total load. Figure 2 shows the present behavior of vehicles in every hour.

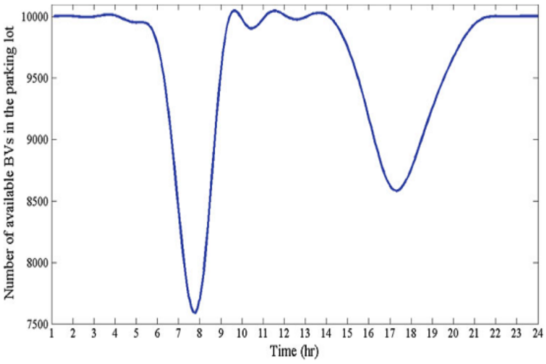

Fig. 2. Vehicles in the parking at every hour

Operation cost in this state is equal to $93250 that is in comparison with the base and previous state about 6% and 2% of decrease respectively. Table 2 shows the generation units, power and number of vehicles in each hour.

Just as observed, due to DRP and the presence of EVs in times 12-21, the generation of unit 3 decreases when compared to two previous states. It causes an increasing of system reserve level and also the decrease of system operation cost. Figure 3 shows the hourly operation cost of the system.

In this curve, a decrease in operating cost in the presence of DRP and EVs is seen. Due to a decrease in the load by DRP in peak hours and dividend production of network power by vehicles, the total operation cost decreases in comparison with the two previous states. Figure 4 shows the reserve curve in different states and 10% of the load demand.

According to this figure, the level of reserve in solving SCUC has reached the maximum limit simultaneously with DRP and EVs in peak hours, because with the vehicles commitment and decreasing the load level in solving the problem, thermal units decrease their production and consequently it leads to increasing the reserve level of plants. Figure 5 shows the transmission line flow in each three states at peak load.

Table.2.
Power of units in the simultaneous presence of V2G and DRs

Time (h)	***U1 (MW)***	***U2 (MW)***	***U3 (MW)***	***Power vehicles (MW)***	***Number of vehicles***
1	178.69	0	0	0	0
2	168.45	0	0	0	0
3	161.85	0	0	0	0
4	157.82	0	0	0	0
5	158.17	0	0	0	0
6	163.68	0	0	0	0
7	176.87	0	0	0	0
8	194.23	0	0	0	0
9	199.60	0	10	0	0
10	207.51	0	13.91	0	0
11	204.21	0	29.24	0	0
12	203.46	0	33.54	3.15	495
13	202.47	0	35.29	6.42	999
14	201.1	0	34.6	4.33	679
15	201.15	0	33.47	9.37	1455
16	198.23	0	35.24	8.71	1365
17	198.38	0	35.14	8.22	1290
18	201.71	0	33.45	6.93	1092
19	201.89	0	33.87	8.92	1395
20	203.04	0	35.22	3.81	597
21	203.26	0	34.83	4.04	632
22	205.6	0	26.57	0	0
23	195.25	0	10	0	0
24	190.74	0	10	0	0

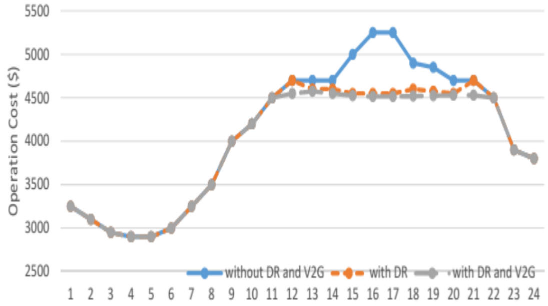

Fig. 3. Hourly operation cost(in a day)

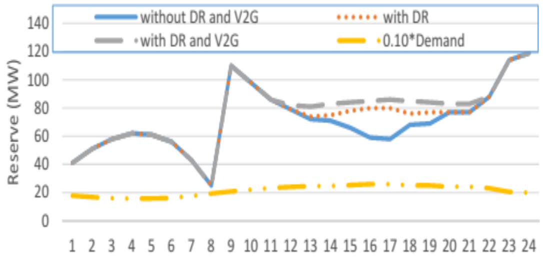

Fig. 4. Hourly of system reserve(in a day)

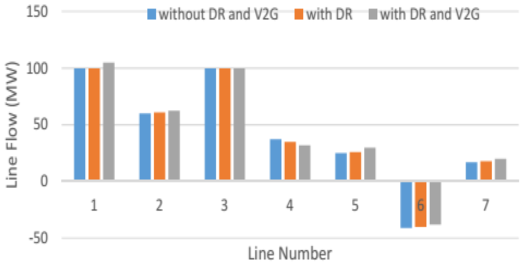

Fig. 5. Lines flow at peak load (17th hour)

Based on the presented results, the cheap price of unit 1, its continual presence in the network and the high reactance of line 3 has led to the increase of power flow of the line and in some hours to the highest amount i.e. 100 MW. One of the effects of EVs is decreasing of the congestion lines. Due to the power flow of lines 4 and 6 and comparing it with two previous states, it shows the decrease of the power flow through these lines, especially in peak times.

One of the most important tasks is the accurate placement of the parking station. The operation cost of grids in the SCUC problem is shown in Figure 6 for different locations of the parking station. Referring to Figure 6, bus 4 is the best option for the installation of the EV charging station because the majority of the load (50%) is located on bus 4. When these loads supplied by EVs satisfy, the unit G2 (an expensive unit) does not commit in the generation schedule, and the operation cost is reduced.

The operation cost of the network is shown in Figure 7 for different EV penetration levels. Referring to Figure 7, along with the increasing involvement of EVs in the power network, the operation cost decreases significantly until 30%, remaining constant beyond this value. This shows that further increase in number of EVs (more than 30%) does not necessarily result in any further decrease in the operation cost.

4. Conclusion

First, the SCUC has been evaluated separately, and then, the SCUC problem has been analyzed with the DRP, and in the end, the problem has been analyzed in the simultaneous presence of DRP and EVs. This paper reveals that the operation cost with the solution of the SCUC problem decreases in the presence of DRP. Moreover, the network reserve that shows its reliability has been improved in accordance with the decrease of generation. What is significant in this study is the load decreases at the peak hours with the DRP and identification of the optimum number of EVs according to their owners' behavior in every hour of parking; the fact that can help the operator in designing, planning and operating of the power system.

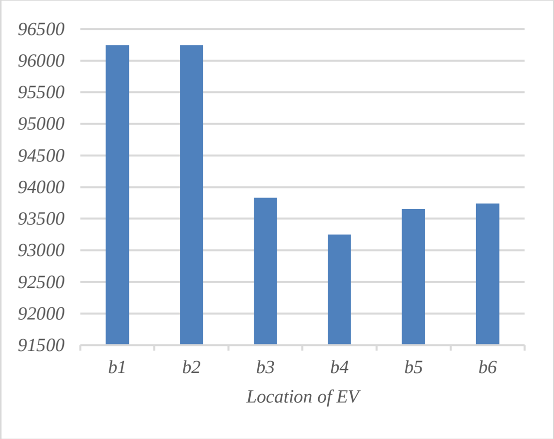

Fig. 6. The operation cost of grids for different locations of the parking station

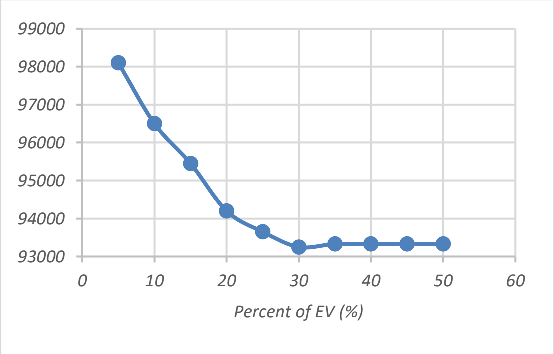

Fig. 7. The operation cost of the network for different degrees of EV penetration

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