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EVALUATING IMPACTS OF ELECTRICAL VEHICLES ON SECURITY CONSTRAINED UNIT COMMITMENT

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Abstract- Security Constrained Unit Commitment (SCUC) problem is contemplated as one of the most significant issue in power system researches. The SCUC problem is provided with an optimized schedule for participation generating units to maximize security and minimize cost. In recent years, rapid development of new technologies caused operators to pay more attention to apply simultaneous renewable energy procedures beside thermal units. Vehicle to Grids (V2Gs) as one of this new technology can reduce dependencies on small expensive units in existing power systems used as energy storage. The storage capacity of V2Gs can decrease operating cost as well as increasing spinning reserve. Moreover, it can efficiently manage load fluctuation. In this paper, the impacts of V2Gs on spinning reserve level as well as operational cost have been investigated. Here, the presented SCUC associated with V2Gs is structured as a mixed-integer linear programming (MILP) problem which is solved using a CPLEX solver. This model determines the commitment status of generating units, values of reserve and dischargeable V2Gs during 24 hours. The presented approach is applied to the IEEE-RTS to demonstrate the effectiveness of the proposed structure.

Keywords: Security Constrained Unit Commitment, Spinning Reserve Assessment, Vehicle to Grid, Mixed-Integer Linear Programming (MILP).

I. INTRODUCTION

Nowadays, reducing the power system operating expenditure is one of the most challenging problems of the electricity sector. Basically, the aim of a Security-Constrained Unit Commitment (SCUC) problem is to obtain the commitment scheme of generating units at minimum operation cost level. In several power markets, the independent system operator (ISO) plans the day-ahead schedule using 'SCUC'. The traditional unit commitment algorithm determines the unit schedules to minimize the operating costs and satisfy the prevailing constraints such as load balance, system spinning reserve, ramp rate limits, fuel constraints, and minimum up and down time limits over a set of time periods.

The scheduled units supply the load demands and possibly maintain transmission flows and bus voltages within their permissible limits. However, in circumstances where most of the committed units are located in a specified region of the system, it becomes more difficult to satisfy network constraints throughout the system .As the system becomes more congested, the ISO would consider the alternative of incorporating the network flow constraints in the unit commitment formulation (i.e., SCUC) to minimize the violation and the related costs of the normal operation of the system. This paper regards the SCUC problem incorporating renewable energy resources [1].

Renewable energy sources 'RES' are going to play an important role in new restructured power systems. Thanks to the increasing environmental awareness and to the will to reduce the dependence of fossil sources, the energy policy of many governments around the world aim to strongly support the use of renewable sources such as Wind, Photovoltaic (PV) and Vehicle to Grid (V2G).

Vehicles to Grid represent hourly distributed and mobile demands in power systems which could also provide distributed storage to power grids [2, 3]. The aggregated storage capability of V2Gs can alter the hourly generation portfolio and reduce grid operation costs. Hence, a dramatic increase in the number of V2Gs could have major impact on power system operations [4].

Unit commitment associated with vehicle to grid (UC-V2G) involves intelligently scheduling existing generating units and optimal number of grid able vehicles for V2G technology in limited and restricted parking lots so that maximum benefit can be achieved [5].The optimal UC-V2G should meet the forecasted load, plus spinning reserve requirements at each time interval such that the total cost is minimized. UC-V2G problem is known as one of the most important and complex programs in power systems optimization which includes optimal methods such as Priority List, Mixed Integer Linear Programing, Branch-and-Bound, Lagrangian Relaxation, and Benders' Decomposition.

A bibliographical survey on UC methods reveals that variation numerical optimization techniques have been employed to approach the UC problem since the last three decades. Amongst these methods, priority list 'PL' methods can be highlighted. Although 'PL' method is a very fast technique, yet they are highly heuristic and generate schedules with relatively higher operation cost [6-8]. Branch-and-Bound (BB) method has the danger of a deficiency of storage capacity and increasing the calculation time enormously for a large scale UC problem [9-12]. Lagrangian Relaxation 'LR' method concentrates on finding an appropriate co-ordination technique for generating feasible primal solution, while minimizing the duality gap [13-17].

The main problem with an LR method is the difficulty encountered in obtaining feasible solution. The meta-heuristic methods are iterative techniques that can search not only local optimal solutions but also a global optimal solution depending on problem domain and execution time limit [18-24]. In the meta-heuristic methods, the techniques frequently applied to the UC problem are genetic algorithm (GA), Tabu Search (TS), evolutionary programming (EP), simulated annealing (SA), etc.

If 'security' is emphasized in UC scheduling, new problem is called security-constrained unit commitment. In this program three parameters of load satisfaction, security maximization, and cost minimization are considered as the final objectives of the problem [1]. This paper investigates the impacts of V2Gs on security constraint UC problem. Therefore, a cost based structure for security-constrained UC associated with V2Gs is presented. Besides the prevailing constraints of security-constrained UC, V2Gs limits are also contemplated.

The proposed framework determines commitment status of generating units, energy scheduling and system spininng reserve level as well as number of dischargeable V2Gs so that the system total expenditure is minimized over the scheduling time horizon. The suggested framework is developed as a combinatorial optimization problem which is linearized and structured as a mixed integer linear programming (MILP) problem. The advantages of MILP method include global optimality, direct measure of the optimality of a solution and more flexible and accurate modeling capabilities. Here, the employed optimization software is General Algebraic Modeling System (GAMS) and CPLEX as a sophisticated and computationally efficient MILP solver is applied for solving the proposed model [25, 31].

The rest of the paper is organized as follows. Section 2 provides the MILP based structure of SCUC problem associated with V2Gs. Section 3 conducts the numerical simulations and finally the concluding remarks are explained in Section 4.

II. PROBLEM FORMULATION

The proposed SCUC-V2G problem is structured as a mixed integer linear programming model. Mixed integer linear programming conveniently lends itself for solving multi-variable optimization problems [26]. The objective function of the SCUC-V2G is minimizing total operating cost which includes mainly fuel cost, startup cost and V2G cost. The cost-based linearized objective function can be presented by Equation (1).

$$\begin{aligned}\min TC = \sum_{i=1}^{NG}\sum_{t=1}^{H}\left[FC_i(P_{i,t}) + SC_i(1 - I_i(t-1))\right]U(i,t) + \\ + \sum_{t=1}^{H}\left[P_v N_{V2G}(t)\right]\end{aligned} \qquad (1)$$

In Equation (1), the first term shows the Fuel cost of a thermal unit is expressed as a second order function of each unit output as follow [27]:

$$FC_i(P_{i,t}) = a(i) + b(i)P(i,t) + c(i)P^2(i,t) \qquad (2)$$

Equation (2) can be precisely approximated by a set of piecewise blocks [28]. The piecewise linear function can't be distinguished from the nonlinear model if enough segments are used. The analytic representation of such linear approximation is:

$$FC_i\left(P_{i,t}, U_{i,t}\right) = F_i\left(P_{i,t}^{\min}\right).U_{i,t} + \sum_{k=1}^{kk} s_{i,t}^k P_{i,t}^k \qquad (3)$$

The second term of the objective function corresponds to Start-up cost for restarting a decommitted thermal unit, which is related to the temperature of the boiler, is included in the model .If the unit is cold, which means it has been shut down for a long time, it is necessary to consume more fuel to warm up the boiler. If the unit has been decommitted for a short while, which satisfies the minimum down time, less energy will be needed to restart the unit [5]. In this study, a step function of time-dependent start-up cost is simplified using transition hour (H_i^{off}) from hot to cold start which is defined in (4) and (5). Start-up cost will be high cold cost '$(c\text{-}\cos t_i)$' when down time duration '(X_i^{off})' exceeds cold start hour '$(c\text{-}s\text{-}hour_i)$' in excess of minimum down time '(MD_i)'. Similarily, it will be low hot cost '$(h\text{-}\cos t_i)$' when down time duration does not exceed '$(c\text{-}s\text{-}hour_i)$' in excess of minimum down time as follows [28]:

$$SC_i(t) = \begin{cases} h\text{-}\cos t_i : MD_i \le X_i^{off}(t) \le H_i^{off} \\ c\text{-}\cos t_i : X_i^{off}(t) > H_i^{off} \end{cases} \qquad (4)$$

$$H_i^{off} = MD_i + C\text{-}S\text{-}hour_i \qquad (5)$$

Also, Shut-down cost is a constant value and the typical value is zero in standard system. The third term of the objective function is V2G - operation cost. Therefore, the objective function of SCUC-V2G is formulated by Equation (1) subjected to unit and network constraints.

Any new type of cost may be included or excluded from the objective function according to the system operators' demand in the deregulated market. The objective function is subjected to the following constraints which must be satisfied during the optimization process [5].

- Electrical vehicle balance in V2G

'Total scheduled vehicles during 24-hour period' is the predefined registered/forecast electrical vehicles for V2G technology.

$$\sum_{t=1}^{H} N_{V2G}(t) = N_{V2G}^{\max} \tag{6}$$

- Spinning reserve

To maintain system reliability, adequate spinning reserve is required.

$$\sum_{i=1}^{NG} U_{i,t}.P_i^{\max}(t) + P_v^{\max}.N_{V2G}(t) \geq D(t) + R(t) \tag{7}$$

- Initial status

At the beginning of the schedule, initial states of all the units and vehicles must be taken into account.

- Generation limits

Each unit has generation range, which is represented as:

$$P_i^{\min} \leq P_i(t) \leq P_i^{\max} \tag{8}$$

- State of charge

Each vehicle should have a desired departure state of charge (SoC) level.

- Vehicle parking limits

Each parking lot has space limit for parking vehicles. This constraint is also valid for current limit.

$$N_{V2G}(t) \leq N_{V2G}^{\max}(t) \tag{9}$$

- Charging-discharging frequency

Frequency of charging-discharging of guidable vehicles is considered as 1 per day. It should vary depending on life-time and type of batteries. Vehicles will be charged either from wind/solar power or from utility grid during off-peak load when price is low (or free for wind/solar power) and will discharge at peak load when price is high.

- Efficiency

Charging and inverter efficiencies should be considered.

- Minimum up/down time

Once a unit is committed / decommitted, there is a predefined minimum time after it can be decommitted / committed again.

$$\begin{aligned} &\left(1 - U_i(t+1)\right) MU_i \leq X_i^{on}(t), \quad \text{if} \quad U_i(t) = 1 \\ &U_i(t+1) MD_i \leq X_i^{off}(t), \qquad \text{if} \quad U_i(t) = 0 \end{aligned} \tag{10}$$

- Ramp rate

For each unit, output is limited by ramp up/down rate per hour as follow:

$$\begin{aligned} &P_i^{\min} \leq P_i(t) \leq P_i^{\max} \\ \text{where} \quad &P_i^{\min}(t) = \max(P_i(t-1) - RDR_i, P_i^{\min}) \\ \text{and} \quad &P_i^{\max}(t) = \min(P_i(t-1) + RDR_i, P_i^{\max}) \end{aligned} \tag{11}$$

The SCUC problem considers transmission flow constraints. In the sub-problem, we would try to minimize violation of these constraints.

- Transmission constraints

Generation must be distributed throughout the system preventing transmission lines from being overloaded. For transmission flow constraints, since we are primarily interested in screening transmission violations in the sub-problem, we could use a dc load flow to expedite the process.

$$-P_l^{\max} \leq P_l(t) = \sum_{t=1}^{NG} \Gamma_{l,i} P_i(t) - \sum_{t=1}^{M} \Gamma_{l,M} D_M(t) \leq P_l^{\max} \tag{12}$$

$l = 1, 2, ..., L$

In DC load flow, the bus #1 is considered as the slack bus. Therefore, the flow of line *l* is:

$$Pl_{l,t} = \left(\frac{\delta_b - \delta_{b0}}{x_l} \right) \tag{13}$$

where 'b_0' is the number of buses.

- System power balance

The generated power from all the committed units and electrical vehicles must satisfy the load demand, which is defined as:

$$\sum_{i \in B_b^i} P_{i,t} + \sum_{v \in B_b^v} P_v N_{V2G,t} - \sum_{D_b} D = \sum_{i \in l_{f,b}} Pl_{l,t} - \sum_{i \in l_{t,b}} Pl_{l,t} \tag{14}$$

Also, the difference between generated power and load demand in the same bus should be equal to input and output power by the lines.

III. SIMULATION RESULTS AND DISCUSSIONS

In this study, an IEEE 6-bus Reliability Test System has been utilized for simulation studies with scheduling period of 24 hours as shown in Figure 1.

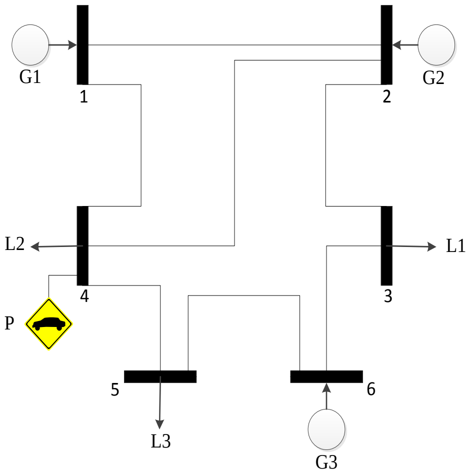

Figure 1. IEEE 6-bus RTS System with parking lot connection [29]

The system includes three units and seven transmission lines as shown in Tables 1 and 2. Unit 1 is coal-fired while unit 2 and 3 are oil-fired and gas-fired, respectively [29]. The last two rows in Table 1 give the mean up time and mean down time of units, which show that the larger the generating capacity, the more frequent is the generating unit's outage. The fuel cost curves for generating units given as a quadratic function are approximated by 50 linear segments between the 'minimum and maximum generating units' capacity.

The hourly load profile over the 24 scheduling time horizon is presented in Table 3, while the peak load is 261.17 MW (17th hours). Also, 20% of the total current load are placed on bus 3, 50% on bus 4, and the remaining on bus 5.

Table 1. Generator data [29]

Unit No	Gen 1	Gen 2	Gen 3
Bus Number	1	2	6
a (Mbtu)	176.95	129.97	137.41
b (Mbtu/MWh)	13.51	32.63	17.69
c (Mbtu/MW2h)	0.00045	0.00100	0.00500
Fuel Price ($/MBtu)	1.2469	1.2461	1.2462
$P_{\max}$ (MW)	220	100	100
$P_{\min}$ (MW)	100	10	10
Ramp Up&Dn (MW/h)	55	50	10
Start Up (Mbtu)	124.69	373.83	0
Min Dn (h)	4	3	1
Min Up (h)	4	2	1

Table 2. Transmission line characteristics [29]

Line	From	To	*X* (pu)	Flow Limit (MW)
1	1	2	0.17	200
2	2	3	0.037	100
3	1	4	0.258	100
4	2	4	0.197	100
5	4	5	0.037	100
6	5	6	0.140	100
7	3	6	0.018	100

Table 3. Hourly load demand data [29]

Hour	Demand	Hour	Demand	Hour	Demand
1	178.69	9	209.67	17	261.12
2	168.45	10	221.54	18	251.68
3	161.84	11	233.18	19	250.89
4	157.83	12	240.82	20	242.1
5	158.16	13	247.03	21	242.05
6	163.69	14	248.47	22	231.68
7	176.86	15	253.83	23	205.07
8	194.21	16	260.9	24	200.69

In this section, the following rated data and parameters: The total number of grid able vehicles is considered 10000 which are charged by renewable resources; maximum battery capacity = 25 KWh; minimum battery capacity = 10 KWh; average battery capacity, $p_v = 15\ \text{KWh}$; maximum parking lot capacity at each hour, $N_{V2G}^{\max}(t) = 15\%$ of total vehicles; charging-discharging frequency = 1 per day; scheduling period = 24 hours; departure state of charge, SoC = 50%; efficiency = 85%. In order to perform simulations on the same condition of, spinning reserve requirement is assumed to be 10% of the load demand, cold start-up cost is double of hot start-up cost [30].

The following case studies are conducted to investigate the impacts of V2Gs on SCUC. In case 1, the SCUC is addressed without considering V2Gs. In the second case, i.e., case 2, the V2Gs is contemplated in proposed problem. The generation pattern of units and the value of system reserve for both case studies are prepared in Tables 4 and 5. Moreover, the optimized number of V2G and the values of their power generation are provided in Table 5.

Applying CPLEX 12.4.0, the system total costs in cases 1 and 2 are computed equal to $98788.848 and $97259.743, respectively. The operation cost and spinning reserve in the aforementioned cases are presented in Table 6. Referring to Table 6, the system reserve has been increased 63 MW in comparison with case 1. In addition, the optimal allocation of parking lot is set to be bus 4 as it appears to have minimized operational cost.

The number of discharging V2Gs over the scheduling time horizon is depicted in Figure 2. It is concluded that during peak hours, i.e. hours #12 to #20, the number of V2Gs is increased considerably to decline the total operating expenditures more.

Table 4. Generation levels and reserve in case 1

Hour	Unit #1	Unit #2	Unit #3	Reserve
1	178.69	0	0	41.31
2	168.45	0	0	51.55
3	161.84	0	0	58.16
4	157.83	0	0	62.17
5	158.16	0	0	61.84
6	163.69	0	0	56.31
7	176.86	0	0	43.14
8	194.21	0	0	25.79
9	199.67	0	10	110.33
10	207.643	0	13.897	98.46
11	204.17	0	29.01	86.82
12	201.889	0	38.931	79.18
13	200.036	0	46.994	72.97
14	199.606	0	48.864	71.53
15	198.007	0	55.823	66.17
16	195.897	0	65.003	59.1
17	195.831	0	65.289	58.88
18	198.648	0	53.032	68.32
19	198.884	0	52.006	69.11
20	201.507	0	40.593	77.9
21	201.522	0	40.528	77.95
22	204.617	0	27.063	88.32
23	195.07	0	10	114.93
24	190.69	0	10	119.31

Table 5. Generation levels and reserve in case 2

Hour	Unit #1	Unit #2	Unit #3	V2G Power	NV2G	Reserve
1	178.69	0	0	0	0	41.31
2	168.45	0	0	0	0	51.55
3	161.84	0	0	0	0	58.16
4	157.83	0	0	0	0	62.17
5	158.16	0	0	0	0	61.84
6	163.69	0	0	0	0	56.31
7	176.86	0	0	0	0	43.14
8	194.21	0	0	0	0	25.79
9	199.67	0	10	0	0	110.33
10	207.64	0	13.89	0	0	98.46
11	204.17	0	29.01	0	0	86.82
12	201.92	0	38.8	0.09	14.46	79.27
13	202.44	0	38.8	5.78	907.53	78.75
14	202.56	0	38.8	7.10	1114.62	78.63
15	201.98	0	42.28	9.56	1500	75.73
16	199.87	0	51.46	9.56	1500	68.66
17	199.81	0	51.74	9.56	1500	68.44
18	202.62	0	39.48	9.56	1500	77.88
19	202.86	0	38.46	9.56	1500	78.67
20	202.03	0	38.8	1.26	198.54	79.16
21	202.22	0	38.13	1.68	264.83	79.63
22	204.61	0	27.06	0.09	14.46	88.32
23	195.07	0	10	0	0	114.93
24	190.69	0	10	0	0	119.31

Table 6. Comparison of the cost and reserve in cases 1 and 2

	Without (V2G)	With (V2G)	V2G Effect
Gen. 1 (MW)	4553.417	4579.955	-26.538
Gen. 2 (MW)	0	0	0
Gen. 3 (MW)	607.033	516.745	90.288
V2G (MW)	-	63.753	-
Cost ($)	98788.848	97259.743	1529.105
Reserve (MW)	1719.55	1783.3	63.75

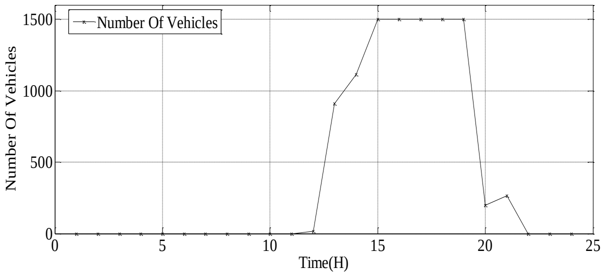

Figure 2. Hourly demand and total number of V2G

The hourly cost of the system with and without considering V2Gs is shown in Figure 3. It's obvious that due to participation of V2Gs in demand satisfaction, the system expenditure is declined during the specified hours, i.e. hours #12-#20.

Obviously, the system reserve level during peak hours is increased due to participating V2Gs in comparison with the base case which causes a more reliable system. This fact is shown in Figure 4.

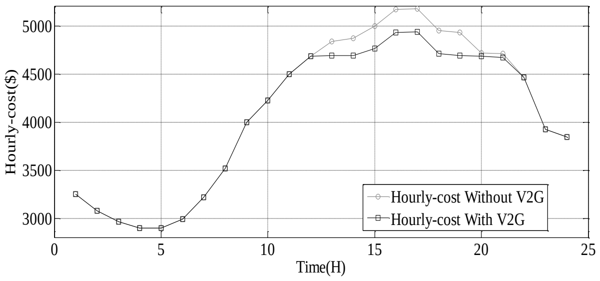

Figure 3. Hourly cost

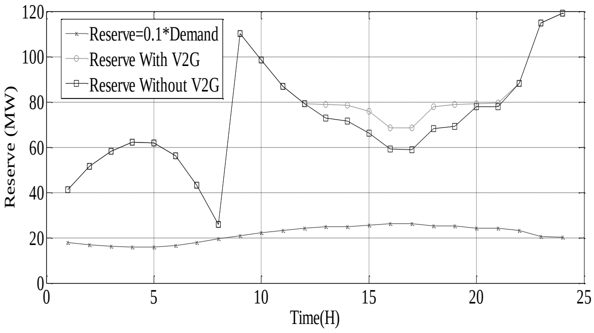

Figure 4. Reserve power in cases 1 and 2

IV. CONCLUSIONS

Security constrained of unit commitment is addressed as one of the most crucial issue in power system studies. In this paper, the impact of vehicle to grids technology on the SCUC problem has been scrutinized. Moreover, an MILP-based structure for security constrained unit commitment associated with V2Gs is presented. The applicability of the model has been illustrated using a 6-bus IEEE reliability test system. It is concluded that V2Gs decrease the operation expenditure as well as increasing system reserve level. Future research is needed to develop the model, considering more complementary constraints of V2Gs.

NOMENCLATURES

$a(i), b(i), c(i)$: Fuel cost coefficients
i : Index of units
b : Bus index.
$s_{i,t}^{k}$: Slope of kth segment in linearized fuel cost curve
NG : Number of units
H : Scheduling hour
M : Number of buses with loads
L : Number of transmission lines
$U_i(t)$: ith unit status at hour t (1/0 for on/off)
$P_i(t)$: Output power of ith unit at time t
$P_i^{\max} / P_i^{\min}$: Maximum/minimum output limit of ith unit
$P_i^{\max}(t) / P_i^{\min}(t)$: Maximum/minimum output unit i at time t
RUR_i : Ramp up rate of unit i
RDR_i : Ramp down rate of unit i
$D(t)$: Load demand at time t
$D_M(t)$: Load at bus Mat time t
$P_{i,t}^{k}$: Output power of kth segment in linearized fuel cost curve
$R(t)$: System reserve requirement at hour t
MU_i / MD_i : Minimum up/down time of unit i
$X_i^{off}(t)$: Duration of continuously off of unit i at time t
$X_i^{on}(t)$: Duration of continuously on of unit i at time
sc_i: Start-up cost function of unit i
FC_i : Fuel cost function
$h\text{-}cost_i$: Hot start cost of ith unit
$c\text{-}cost_i$: Cold start cost of ith unit
$c\text{-}s\text{-}hour_i$: Cold start hour of ith unit
$P_l^{\max}$: Maximum capacity of line
Γ_l : The matrix relating generator output to power flow on transmission line l
$N_{V2G}^{\max}$: Total vehicles in the system
$N_{V2G}^{\max}(t)$: Maximum parking lot capacity at hour t
$N_{V2G}(t)$: Number of vehicles connected to the grid at hour t
p_v : Capacity of each vehicle
SoC: State of charge
TC : Total cost
x_l : Reactance of line l
δ : Bus angle
$P_{l,t}^{l}$: Power flow of line at time t
$L_{f,b}$: A set of lines which is disconnected from bus b
$L_{t,b}$: A set of lines which is connected from bus b
D_b : A set of loads which is connected from bus b
B_b : A set of units which is connected from bus b

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