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EMISSION CONSTRAINED UNIT COMMITMENT COORDINATED WITH VEHICLE TO GRID IN A SMART GRID ENVIRONMENT

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Abstract- Emission constrained unit commitment (ECUC) problem is a key step for power system operation. ECUC involves the optimum scheduling of power generating units as well as the determination of the amounts of power to be generated by each committed unit, so as to meet the forecasted demand at minimum production cost. Intelligent ECUC associated with Vehicle to grid (v2g) in order to scrutinize economic and environment optimization in power system is considered in this paper. The v2g has gained attention in the past few years due to growing public concerns about urban air pollution and other environmental and resource problems. The v2g can be utilized to reduce the undesirable effects of fuel price fluctuations and environmental emissions of greenhouse gases. An IEEE 10-unit test system is employed to investigate the impacts of v2g on generation scheduling. The results obtained from simulation analysis show a significant resulting in reduced operation cost and emissions. Here, the proposed framework is structured as a mixed integer nonlinear programming (MINLP) and solved using DICOPT as a powerful solver in GAMS.

Keywords: Emission Constrained Unit Commitment, V2G, Generating Scheduling, Smart Grid.

I. INTRODUCTION

Unfortunately, fossil fuels harm the global ecosystem by emitting noxious gases, causing greenhouse effect. Reducing emission from fossil-fueled electric power generating plants has received considerable attention in recent years in both regulated and deregulated power markets[1]. Each generator is allocated certain amount of emission expenditures, which they can use to cover emission during energy generation. In this paper the emission constrained unit commitment (ECUC) approach that investigates the effects of emissions on the generation scheduling outcome and electric utility operations is considered. Unit Commitment problem (UCP) plays an important role in the operation of power systems. It involves two processes, determining the on/off state of the generators and distributing the forecasted load demand among the committed generators for each hour of the time horizon[2]. UCP is a nonlinear, mixed integer combinatorial, constrained optimization problem to schedule the operation of the generating units in a cost efficient manner in order to satisfy the demand and reserve requirements. The exact solution to the problem can be obtained only by complete enumeration at the cost of large computational time requirement for power systems. Therefore, over the last two decades, considerable research has been focused on obtaining efficient, near-optimal solutions using AI techniques. The techniques include genetic algorithm (GA) [3, 4], particle swarm optimization (PSO) [5, 6], simulated annealing (SA) [7]and memetic algorithm (MA) [8].

A Vehicle to Grid (v2g) concept has arisen in the last years, v2g systems represent a means by which power capacity in parked vehicles can be used to generate electricity for the grid, researchers have mainly concentrated on inter connection of energy storage of vehicles and grid [9]. Allowing returning back to the grid the energy stored in the battery that has not been used by the vehicle. This operation mode will cause a great impact on the power grid[10]. It could add capacity to the electric grid during peak times without the need for the utility industry to build new power plants. Success of v2g technology greatly depends on the efficient scheduling of vehicles in limited and restricted parking lots. v2g technology should be charged from renewable sources [11]. The v2g has many advantages, as quick response and relatively low capital cost at peak time and it can effect on electricity demand, supply and emissions. As environmental pressure and energy depletion are increasingly severe, more and more attention has been paid to v2g because of their high energy efficiency and no emission compared to conventional units [12].

This paper models an economic-emission constrained UC (ECUC) with focus on the effect of v2g on the generation side. ECUC-v2g is introduced, where ECUC-v2g involves intelligently scheduling existing units and large number of vehicles in limited and restricted parking lots. Moreover, It can reduce operation cost and emission output of the thermal units, while all of these constrains should be satisfied.

The paper will be structured as follows: Section II describes a methodology and the system formulation of ECUC-v2g and also presents the constraints. Section III expresses the solution and simulation results on IEEE 10-unit test system and in Section IV, conclusion of the study is represented.

II. EMISSION CONSTRAINED UNIT COMMITMENT WITH V2G STRUCTURE

A. Objective Function

The two objective functions of the presented framework for the ECUC-v2g can be stated as below. Where, F_1 mainly is comprised of minimizing the total operation cost of the generating units and F_2 is emission minimization, that pertaining to the ECUC with v2g over the entire scheduling periods subject to system and unit constraints.

minimize $FT =$

$$= \sum_{i=1}^{N}\sum_{t=1}^{T}[w \times (C_i^{op}(P_{it}) + C_i^{sup}(1-u_{i(t-1)})) + \quad (1)$$
$$+(1-w)\times \varepsilon_i^{em}(P_{it})]u_{it}$$

$0 \le w \le 1$

- *Fuel cost and startup cost*

The fuel cost of a thermal unit i is generally assumed to be a quadratic function, where P_{it} is the power generation of unit i at hour t.

$$C_i^{op}(P_{it}) = a_i + b_i P_{it} + c_i (P_{it})^2 \quad (2)$$

where a_i, b_i and c_i are positive fuel cost coefficients of unit i, C_{it}^{sup} is the startup cost and defined as:

$$C_{it}^{sup} = \begin{cases} HSC_i, & \text{if } T_{it}^D \le MD_i^{ON} \le T_{it}^D + CST_i \\ CSC_i, & \text{if } MD_i^{ON} > T_{it}^D + CST_i \end{cases} \quad (3)$$

- *Emission*

For environment friendly power production, emission effects should be considered. The emissions have modeled as a second-order Polynomial, where α_i, β_i and γ_i are emission coefficients of unit i.

$$\varepsilon_i^{em}(P_{it}) = \alpha_i + \beta_i P_{it} + \gamma_i (P_{it})^2 \quad (4)$$

Weight factor w is utilized for the accordance of cost and emission, which (w=1) is used to be include and (w=0) for being exclude. It increases flexibility of the system. Different weights may also be possible to assign different precedence of cost and emission in the fitness function. Whatever in Equation (1), w is tended to w=1, accordingly cost minimization is more important than emission reduction. In this paper w is assumed to be w=0.5.

B. Constraints of ECUC-V2G

These constraints are as follows: Power balance constraint and reserve constraint are represented in Equations (5) and (6). Unit generation limits ensures that each generator's production is within its normal operating limit (7). Equations (8) and (9) are ramping constraints, ensuring that the output of each generator does not change too rapidly. Equations (10), (11) are minimum up and downtime constraints and Constraints contributed with the network security are represented in Equations (12) and (13), these latter two constraints guarantee keeping voltage magnitude at each bus and apparent power flow in transmission lines within operational limits.

$$\sum_{i=1}^{NG}(P_{it})u_{it} + P_{v2g,t} = P_{D,t} + P_{Loss,t} \quad (5)$$

$$\sum_{i=1}^{NG}(\overline{P}_{it})u_{it} + P_{v2g,t} \ge P_{D,t} + R_t \quad (6)$$

$$\underline{P}_i u_{it} \le P_{it} \le \overline{P}_i u_{it} \quad (7)$$

$$P_{it} - P_{i(t-1)} \le [1-u_{it}(1-u_{i(t-1)})]UR_i + u_{it}(1-u_{i(t-1)})\underline{P}_i \quad (8)$$

$$P_{i(t-1)} - P_{it} \le [1-u_{i(t-1)}(1-u_{it})]DR_i + u_{i(t-1)}(1-u_{it})\underline{P}_i \quad (9)$$

$$[X_{i(t-1)}^{on} - T_i^{on}]\times[u_{i(t-1)} - u_{it}] \ge 0 \quad (10)$$

$$[X_{i(t-1)}^{off} - T_i^{off}]\times[u_{it} - u_{i(t-1)}] \ge 0 \quad (11)$$

$$\left|P_{ij,t}\right| \le \overline{P}_{ij} \quad (12)$$

$$\underline{v}_i \le v_i \le \overline{v}_i \quad (13)$$

Equation (14) demonstrates each parking lot has a maximum capacity that should be considered. All the vehicles cannot discharge at the same time. Limited number of vehicles will discharge at a time. In order to obtain energy from the v2g parking lot, total number of vehicles discharge to the grid during a predefined scheduling period (24 h), this Constraint consider in Equation (15). Departure state of charge level and efficiency of v2g are presented by ψ and ξ.

$$N_{v2g,t} \le N_{v2g}^{\max} \quad (14)$$

$$\sum_{t=1}^{N} N_{v2g,t} = N^{\max} \quad (15)$$

III. SOLUTION OF THE EMISSION CONSTRAINED UNIT COMMITMENT WITH V2G PROBLEM

Generating units' data associated with the 10-unit test system are listed in Tables 1 and 2. A standard IEEE 10-unit system is considered for simulation study with total number of vehicles, $N_{\max}$ = 50,000, which are charged from renewable sources [11]. According to reference [13, 14], The following parameters are presumed for v2g: maximum battery capacity = 25 kWh; minimum battery capacity =10 kWh; average battery capacity (pv) =15 kWh; maximum number of discharging vehicles at each hour, $N_{v2g}^{\max}$ = 10% of total vehicles; departure state of charge, ψ = 50%; total Efficiency, ξ = 85% . In this case, the spinning reserve requirement is held as 10% of the load in 24 h scheduling time period and charging/discharging frequency =1 per day. Furthermore, the emission coefficients for 10-unit test system are given in Table 6, in Appendix.

Table 1. Unit characteristic of conventional 10-unit test system

Unit	a_i	b_i	c_i	$P_{i,t}^{\max}$	$P_{i,t}^{\min}$
1	1000	16.19	0.00048	455	150

2	970	17.26	0.0031	455	150
3	700	16.6	0.002	130	20
4	680	16.5	0.00211	130	20
5	450	19.7	0.00398	162	25
6	370	22.26	0.00712	80	20
7	480	27.74	0.0079	85	25
8	660	25.92	0.00413	55	10
9	665	27.27	0.00222	55	10
10	670	27.79	0.00173	55	10
Unit	CSC_i	HSC_i	CST_i	MU_i	MD_i
1	9000	4500	5	8	8
2	10000	5000	5	8	8
3	1100	550	4	5	5
4	1120	560	4	5	5
5	1800	900	4	6	6
6	340	170	2	3	3
7	520	260	2	3	3
8	60	30	0	1	1
9	60	30	0	1	1
10	60	30	0	1	1

Table 2. IEEE 10-unit standard system hourly load

Hour	Load	Hour	Load
1	700	13	1400
2	750	14	1300
3	850	15	1200
4	950	16	1050
5	1000	17	1000
6	1100	18	1100
7	1150	19	1200
8	1200	20	1400
9	1300	21	1300
10	1400	22	1100
11	1450	23	900
12	1500	24	800

Two scenarios are studied in this paper. First scenario is consisting of a typical basic ECUC, while in the second one an integration of 50,000 v2g in ECUC is considered. The result of ECUC with absence of v2g is presented in Table 3 and as it can be seen from this Table, that two least expensive units 1 and 2 are committed in 24 h while unit 1 and 2 always generate their maximum power. Additionally, units 9 and 10 are the most expensive units which always generate their minimum power. The other units generate less than unit 1 and 2. In compere with these two units the other units are cheaper.

According to the results from Table 4, integration of 50,000 v2g in ECUC problem can diminish peak load level and dependencies on expensive existing units. As shown, units 9 and 10 are the most expensive units and they are committed only for one or two special hours. The generation level of unit 6, 7 and 8 is less than in scenario 1 with absence of v2g, therefore the cost of generation decreases when v2g is implemented. Unit 1 and 2 are less expensive than other units, for satisfying the load these two units are initiative.

Thus, the total operation costs and emissions decrease. Generation level of units 2 and 4 in scenario 2 is more than scenario 1 because, by considering v2g in this scenario the operation cost and emission in critical point of these two units are low and totally the peak load level decreases accordingly utilization of v2g for reducing numbers of committed unit is so advantageous. The v2g effect on generation scheduling is demonstrated in Figure 1.

Table 3. Unit output power for the10-unit test system without v2g

Hours	Unit (MW)									
	1	2	3	4	5	6	7	8	9	10
1	417.6	282.3	0	0	0	0	0	0	0	0
2	442	307.9	0	0	0	0	0	0	0	0
3	455	370	0	0	25	0	0	0	0	0
4	455	340	130	0	25	0	0	0	0	0
5	455	389.9	130	0	25	0	0	0	0	0
6	455	360	130	130	25	0	0	0	0	0
7	455	403.6	130	130	31.3	0	0	0	0	0
8	455	437.8	130	130	47.1	0	0	0	0	0
9	455	455	130	130	85	20	25	0	0	0
10	455	455	130	130	162	33	25	10	0	0
11	455	455	130	130	162	73	25	10	10	0
12	455	455	130	130	162	80	25	43	10	10
13	455	455	130	130	162	33	25	0	10	0
14	455	455	130	130	85	20	25	0	0	0
15	455	437.8	130	130	47.1	0	0	0	0	0
16	449.3	315.6	130	130	25	0	0	0	0	0
17	424.9	290	130	130	25	0	0	0	0	0
18	455	360	130	130	25	0	0	0	0	0
19	455	437.8	130	130	47.1	0	0	0	0	0
20	455	455	130	130	162	38	0	10	10	10
21	455	455	130	130	100	20	0	10	0	0
22	455	444.6	130	0	50.3	20	0	0	0	0
23	455	410.4	0	0	34.5	0	0	0	0	0
24	455	345	0	0	0	0	0	0	0	0

Table 4. Unit output power for the10-unit test system with v2g

Hours	Unit (MW)									
	1	2	3	4	5	6	7	8	9	10
1	417.6	282.3	0	0	0	0	0	0	0	0
2	442	307.9	0	0	0	0	0	0	0	0
3	455	380	0	0	0	0	0	0	0	0
4	455	444.6	0	0	50.3	0	0	0	0	0
5	455	455	0	0	70	0	0	0	0	0
6	455	455	0	130	55.2	0	0	0	0	0
7	455	403.6	130	130	31.3	0	0	0	0	0
8	455	437.8	130	130	47.1	0	0	0	0	0
9	455	455	130	130	78.1	20	0	0	0	0
10	455	455	130	130	153.1	20	25	0	0	0
11	455	455	130	130	162	51.1	25	10	0	0
12	455	455	130	130	162	80	25	21.1	10	0
13	455	455	130	130	153.1	20	25	0	0	0
14	455	455	130	130	78.1	20	0	0	0	0
15	455	437.8	130	130	47.1	0	0	0	0	0
16	449.3	315.6	130	130	25	0	0	0	0	0
17	424.9	290	130	130	25	0	0	0	0	0
18	455	360	130	130	25	0	0	0	0	0
19	455	437.8	130	130	47.2	0	0	0	0	0
20	455	455	130	130	162	0	0	16.1	10	10
21	455	455	130	130	88.1	0	0	10	0	0
22	455	361	130	130	0	0	0	0	0	0
23	451.7	318.2	130	0	0	0	0	0	0	0
24	455	345	0	0	0	0	0	0	0	0

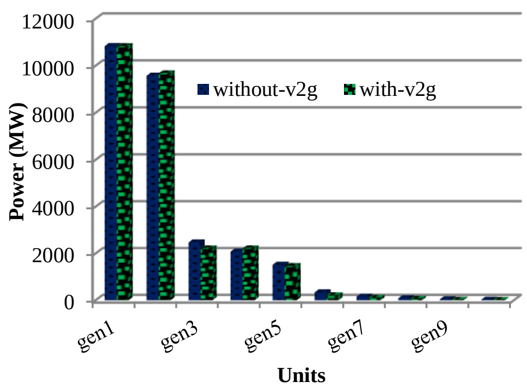

Figure 1. The v2g effect on generation scheduling

Tables 3 and 4 show the results of implementation scenario 1 and 2 by using the GAMS program. Furthermore these two scenarios are solved by employing genetic algorithm (GA) and Particle swarm optimization (PSO). Figure 2 and Table 5 show a comparison between results of scenarios 1 and 2 with GAMS, GA and PSO. The results show that these proposed methods have the following merits in solving ECUC-v2g but results from GAMS are more accurate and forceful than other methods.

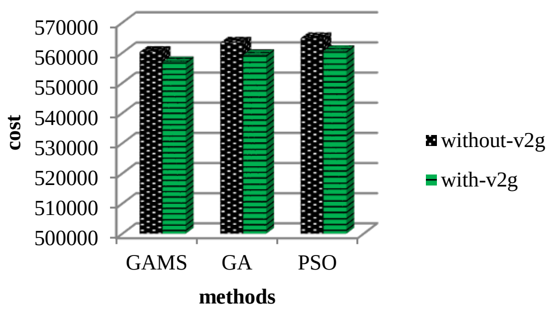

Figure 2. Total cost comparison of different techniques

Table 5. Comparison of total cost and emission for different method

Method	Scenario	Cost	Emission
GAMS	-	560264.03	11447.61
	with-v2g	556841.23	10647.56
GA	-	563357.32	12040.51
	with-v2g	559213.78	11311.71
PSO	-	564842.10	12824.48
	with-v2g	560542.75	11762.26

IV. CONCLUSIONS

Under new deregulated power systems, vehicle to grid technologies can be utilized as a source of energy to satisfy the required demand. ECUC with v2g based on optimal operation cost and reduced emission in power system has been presented. The proposed framework is structured as a mixed integer nonlinear programming (MINLP) and has been solved by using GAMS, which is applicable program for solving optimization problems. From the results it is terminated that integrating v2g to conventional generation scheduling problem significantly the operation costs and emission have been reduced.

Finally, remarkable results from GAMS are compared with two other methods (GA and PSO). The results show that the proposed methods have the following merits in solving ECUC-v2g, but GAMS has more capability to solve complex problem than other methods.

APPENDIX

Table 6. Generators emission coefficients

Unit	A	B	γ
1	10.33908	-0.24444	0.00312
2	10.33908	-0.24444	0.00312
3	30.03910	-0.40695	0.00509
4	30.0390	-0.40695	0.00509
5	32.00006	-0.38132	0.00344
6	32.00006	-0.38132	0.00344
7	33.00056	-0.39023	0.00465
8	33.00056	-0.39023	0.00465
9	35.00056	-0.39524	0.00465
10	36.00012	-0.39864	0.00470

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