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Intelligent Unit Commitment with Vehicle to Grid for Cost and Emission Reduction

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Abstract- In present scenario, increasing electricity demand is mostly met out by thermal power plants. Generating units in the plants have to be properly committed to meet out the load demand and also, to reduce the operating cost of the unit. Reduction in fuel cost is achieved by allocating the units properly. Vehicle to grid (V2G) technology drawn interests in recent years on unit commitment to reduce the running cost of the unit by properly allocating the vehicle in constraint parking slots. The output power of generators will be reallocated in the consideration of Vehicle power to grid. Each vehicle is considered as a Small portable power plant (S3P) for supplying power to grid. Now, the UC become complex constrained problem. This problem is optimized by using Particle swarm optimization (PSO). In this paper, Improved binary PSO (IBPSO) is used to optimize the status of the unit in binary form (on/off) and also, PSO optimizes number of gridable vehicles in constraint parking slots. In, this paper sample 10 unit systems is tested. Results show a considerable amount of cost and emission is reduced and also, Reserve power capacity of the unit increased with intelligent UC with V2G.

Index term: *Unit Commitment, Portable vehicles, vehicle to grid, Improved Binary Particle Swarm Optimization, cost, Emission, Reserve power.*

1. INTRODUCTION

Unit commitment is very significant task in daily operation and planning of power system. The main aim of the unit commitment is to schedule the on/off states of the units to meet out the forecasted load in a day, which includes many constraints to be satisfied and Also, operating cost of the unit has to be minimized. This problem is a non-linear, large-scale, mixed-integer constrained optimization problem, which is quite difficult due to its inherent high dimensional, non-convex, discrete and nonlinear nature [1]. Many optimization techniques were available to solve the unit commitment problem. Some of the methods are priority list (PL)[2] , branch-and-bound (BB) [3] dynamic programming (DP)[4], Lagrangian relaxation (LR)[5, 6], Evolutionary algorithms (EA)[7-9]. PL methods are fast, but the solution obtained might not be close to the optimum, especially when dealing with a great number of generators. Also, this method gives high operating cost. The BB methods have the danger of a deficiency of storage capacity and exponential growth in the execution time with the size of the UC problem. The DP method is able to solve problems of a variety of sizes, But it may lead to more mathematical complexity and increase in computation time, if the constraints are taken into Consideration. The LR methods concentrate on finding an appropriate co-ordination technique for generating feasible primal solutions, while minimizing the duality gap. The main disadvantage with the LR methods is the difficulty encountered in obtaining feasible solutions.

Due to increase in industries, vehicles the air get polluted, leads to global warming. Pollution due to transportation sector is alone increased from 24% to 27% [10].Now governments and industries have investing their, money in environment friendly equipments. Due to increase in load demand fossil fuels were burnt for producing power, which increase the Emission to the environment.

Vehicle to Grid (V2G) technology becoming popular in recent days. V2G technology is regarded as an important application of smart grid technology. By using next generation electric vehicle (EV) for supplying the power to the grid drawn researchers recent years in V2G technology [11] . An EV may be used as energy storage which allows the bi-directional electricity Flow between the vehicle’s battery and the electric power grid. By, considering each EV’s as a mini power generator’s (small portable power plants). Electric vehicles can be used to level the real fluctuating load demand. Efficient V2G scheduling can reduce generation cost. If gridable vehicles are charged from renewable energy source like solar power. During the off load periods like night the vehicles were charged and during the peak load periods vehicles were made to discharge power to grid. This, can be made more efficient by properly placing the vehicles in the constraint parking slots.

In this paper an attempt is made to combine both the generating unit and the gridable vehicles together for making a schedule to meet the load demand. Unit commitment with vehicle to grid technology is complicated than a ordinary unit commitment problem. An Improved Binary Particle swarm optimization [12] is used to solve this complex constrained optimization problem. Improved binary PSO find the optimal placement of the gridable vehicles in the constraint parking slots to meet out the demand. The running cost and emission of the unit is reduced and also spinning reserve capability and profit of the unit is increased. Testing on sample 10 unit system, comparison results between unit commitment with vehicle to grid and without vehicle to grid using IMPROVED binary PSO were much better than the ordinary binary PSO as in [13].

2. PROBLEM FORMULATION

2.1 Nomenclature and acronyms

Fc_i	Fuel cost function of the unit i.
E_{Ci}	Emission cost function of the unit i.
CSH_i	Cold start hour of i^{th} unit.
HST_i	Hot start up cost of i^{th} unit.
CST_i	Cold start up cost of i^{th} unit.
SC_i	Start up cost function of the unit i
$D(t)$	Load Demand of the unit at time t
$I_i(t)$	Status of the unit at the time t.
$P_i(t)$	Output power of the unit at the time t.
MU_i/MD_i	Min up and min down time of the unit at time t.
N	Number of units
$P_i^{min/max}$	Minimum / Maximum output of the unit i
$N_{V2G}^{max}(t)$	Maximum number of vehicle connected to grid at time t.
N_{V2G}^{max}	Maximum number of vehicle available in the system
N_{V2G}	Number of vehicle connected to grid.
Pv	Capacity of each vehicle
$R(t)$	System reserve requirement at hour t
$S3P$	Small Portable vehicles
ψ_i	Emission penalty factor

2.2. Objective Function

Unit commitment problem is complex optimization problem that arranges the starting-up and shutting-down, generating units in sequence to reduce the operating cost of the unit. Scheduling up of the unit is also depends upon the individual unit, Emission and fuel cost of the unit, size of the unit. Vehicle to grid technology introduce gridable vehicle into the power system for reduction of operating cost of the unit. Now the problem involves no of constraints and becomes complex optimization problem. In unit commitment with vehicle to grid the units aims in arranging the sequence of the generating unit and vehicles. The main objective of the unit commitment with vehicle to grid technology is to reduce the running cost and emission of the unit. Running cost of the unit include start-up and shut-down cost. Constraints that have to be included is given below:

2.1.1 Fuel cost

Fuel cost of a thermal unit is expressed as second order function of generated power of the unit.

$$Fc_i(P_i(t))=a_i+b_iP_i(t)+c_iP_i^2(t) \tag{1}$$

Where, a_i,b_i,c_i are cost co-efficient

2.2.2 Emission

Emission curve is expressed as polynomial function and order depends on the desired accuracy.

$$E_{Ci}(P_i(t)) =\alpha_i + \beta_iP_i(t)+ \gamma_i P_i^2(t) \tag{2}$$

Where, α_i ,β_i , γ_i are emission co-efficients.

2.2.3 Start- up cost

The start-up cost for restarting a recommitted thermal unit, which is related to the temperature of the boiler, is included in the model. In this paper, simplified start up cost is applied as follows:

$$\left[SCi\,(t) \;=\; \begin{cases} HST_i & MDi \le X_i^{off}(t) \le H_i^{off} \\ CST_i & X_i^{off}(t) > H_i^{off} \end{cases} \right] \tag{3}$$

Where,

$$H_i^{off} = MD_i + CSH_i \tag{4}$$

2.2.4 Shut-down cost:

Shut-down cost is constant and the typical value is zero in standard systems [13].

Therefore, the Main Objective Function for cost-emission optimization of unit commitment with V2G is given by formula,

$$\text{Min } \pi = W_c*(\text{Fuel} + \text{start\_up})+W_e*\text{Emission}$$

$$= \sum_{i=1}^{N}\sum_{t=1}^{H}[\{Wc(FC_i(P_i(t)) + SC_i(1-I_i(t-1))\} + We(\psi_i EC_i(P_i(t))]I_i(t) \tag{5}$$

Where, ψ_i is the emission penalty factor of unit i [13]. Weight factors Wc and We are used to include (Wc = 1) or exclude (We = 0) cost and emission in the fitness function. It increases flexibility of the system. Different weights may also be possible to assign different precedence of cost and emission in the fitness function. Depending on the operators demand value may be chosen for Wc and We between (0 to 1).

2.3 Constraints of UC with V2G:

A constraint that must be satisfied during optimization procedure is as follows:

2.3.1 Gridable vehicle balance in UC with V2G:

Only registered predefined numbers of vehicles participate in optimal scheduling of unit commitment with vehicle to grid. It is assumed that all vehicles were charged by renewable energy sources and discharge to grid. Number of vehicle going to participate in discharging the power to grid is fixed. There schedule for 24 hours is predefined.

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

2.3.2 Charging–discharging frequency:
Vehicles were charged from renewable energy sources for supplying power to the grid. Depending on the type of batteries used in the vehicle for charging and based on the life time of the batteries multiple charging and discharging facilities of vehicles were considered. If one vehicle is fixed in a schedule of 24 hour for discharging power to grid, only during the corresponding hour vehicle is used. In simple, words a scheduled vehicle is used only one time a day.

2.3.3 System power balance

In this case, power generated from the small portable power plants (S3P's) which is connected to grid with the power generated from the units committed were added together to satisfy the load demand plus losses in the system is given by the equation below,

$$\sum_{t=1}^{N} I_i(t)P_i(t) + Pv\,N_{V2G}(t) = D(t) + \text{losses} \qquad (7)$$

2.3.4 Spinning reserve

Adequate spinning reserve is required, for maintaining the reliability in the system is given as follows:

$$\sum_{t=1}^{N} I_i(t)P_i^{max}(t) + Pv^{max}N_{V2G}(t) \geq D(t) + R(t) \qquad (8)$$

2.3.5 Generation limits

Each unit has generation range, which is represented as follows:

$$\sum_{t=1}^{N} I_i(t)P_i^{max}(t) + Pv^{max}N_{V2G}(t) \geq D(t) + R(t) \qquad (9)$$

2.3.6 Number of discharging vehicles limit

All the vehicles can't discharge the power to the grid at the same time. for, reliable operation of the unit only predefined number of vehicle's discharge at a given time to grid. This limit is given by the equation below:

$$\sum_{t=1}^{N} N_{V2G}(t) = N_{V2G}^{MAX}(t) \qquad (10)$$

2.3.7 Minimum up/down time

Once a unit is committed / uncommitted, there is a predefined minimum time after it can be uncommitted / committed respectively,

$$\left\{\begin{array}{ll} (1 - I_i(t+1))MU_i \leq X_i^{on}(t), & \text{if } I_i(t) = 1, \\ I_i(t+1)MD_i \leq X_i^{off}(t), & \text{if } I_i(t) = 0 \end{array}\right\} \qquad (11)$$

2.3.8 Initial status

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

3. IMPLEMENTATION OF UNIT COMMITMENT WITH VEHICLE TO GRID

The optimization of UC with V2G could be considered as two sub-problems, the first one is unit-scheduled (US) problem which generate a binary matrix (or called 'status matrix').The matrix elements are '0' (unit OFF) and '1' (unit ON). Improved Binary Particle Swarm Optimization (BPSO) is used to calculate the matrix of next generation with the fitness of objective function. The second one is the economic dispatch (ED) problem which decides the power generated by every unit under the schedule coming from the first step , which is calculated by using lambda-iteration method.

3.1. Improved Binary PSO for unit commitment

Ordinary binary PSO [12] can be used to solve unit commitment problem but a drawback of binary PSO for solving UC problem is that the particle's position $X_{i,d}$ is updated by a non-standard form, comparing the new particle's velocity $V_{i,d}$ with a random number, the new value for $X_{i,d}$ is found as 0 or 1. In order to overcome the shortcomings of the binary PSO for solving UC problem, a new improved binary PSO method is proposed to solve UC problem as in [12]. An individual in the improved binary PSO method is a bit string which starts its trip from a random point in the search space and tries to become nearer to the global best position and previous best position of itself. The process of generating a new position for a selected individual in the swarm can be represented by the following equations,

$$V_{i,d}^{k+1} = W_1 \otimes (P_{best\,i,d}^{\;k} \oplus X_{i,d}^{k}) + W_2 \otimes (G_{best\,d}^{\;k} \oplus X_{i,d}^{k}) \qquad (12)$$

$$X_{i,d}^{k+1} = X_{i,d}^{k} \oplus V_{i,d}^{k+1} \qquad (13)$$

Where, $\otimes$ is AND operator, $\oplus$ is XOR operator, + is OR operator, W1 and W_2 are two random binary integer numbers uniformly distributed in the range of [0,1].

The original version of PSO operates on real values. The BPSO was presented to solve optimization problems that are set in discrete space .In BPSO, Xi and P_{best} can take on values of 0 or 1 only. The velocity Vi will determine a probability threshold. If the velocity is higher, the individual is more likely to choose 1, and lower values favour the 0 choice. The threshold is calculated by the sigmoid function which is defined as follows:

$$P(V_{ijt}) = \frac{1}{1 + \exp(-V_{ijt})} \qquad (14)$$

Then a random number from 0.0 to 1.0 is generated. Xi is set to 1 if the random number is less than the value from above. The main difference between IBPSO and PSO is Eq. (14) replacing Eq. (12).

If rand() < $p(v_{ijt})$ then, X_i=1;
Else, X_i=0;

3.2 Proposed algorithm for UC with V2G

In the same algorithm, Improved Binary PSO is applied for the optimization of generating units as below.

Step1 - Set parameters for Improved Binary PSO and Initialize (N+1) *H matrix for each particle randomly.
Step2 - Calculate Fitness for each particles using Eq. (5).
Step3 - Find P_{best} and G_{best} among the particles.
Step4 - Calculate velocity by using G_{best} then update the current position using Eq.(12 -14) and check for constraints if satisfied goto next step else randomly generate feasible solution for particle.
Step 5- Calculate the fitness for updated particles and find P_{best} among them.
Step 6 - If $F(P_{best}) < F(G_{best})$. Then, $G_{best} = P_{best}$.
Step 7 - Get the values of global best (G_{best}) and Goto step 4 until the stopping criteria is satisfied

Where, N × H binary matrix X_i; Vehicle: An H × 1 integer column vector Y_i; Velocity: An (N + 1) × H real-valued matrix V_i

4. RESULTS AND DISCUSSIONS

All the calculations were done in Intel Core^{TM} i3 processor with 2GB RAM in Microsoft windows 7 OS and MATLAB (R2011a). For analysis 10 unit test system is considered. This analysis consists of two parts , first part results for unit commitment with and without V2G [Table 1-3] and second part include comparison between Improved Binary PSO and Binary PSO .The proposed Improved Binary PSO gives better results than the normal binary PSO. The solution obtained was feasible.

For Improved Binary PSO, Swarm Size is taken as 30; Max no of Iterations 1000; Trust parameters were taken as c1=1.5, c2=1.5;

Vehicle Data: Total number of vehicles = 50,000; Departure State of Charge (ψ) = 50%; Frequency=1per day ; scheduling Period = 24 h.

Table 1. Comparison table for running cost, emission and Reserve power between V2G and without V2G using IBPSO

Hrs	WITH VEHICLE CONNECTED TO GRID			WITHOUT VEHICLE CONNECTED TO GRID		
	Generation cost ($)	**Emission (ton)**	**Reserve power (MW)**	**Generation cost ($)**	**Emission (ton)**	**Reserve power (MW)**
1	15501.14	6871.0	264.4	15963.73	7388.3	210.0
2	16678.11	8231.0	175.9	17586.92	8398.2	210.0
3	18138.25	8196.4	224.6	18138.25	7517.9	240.0
4	19919.70	10106	118.5	20168.82	10390.1	90.0
5	21111.62	8284.9	249.1	21510.10	8789.4	201.0
6	22970.78	8544.3	255.1	23168.53	8748.4	231.0
7	23933.65	9311.7	194.1	24039.22	9399.9	181.0
8	24617.75	9918.3	165.6	24911.45	10207.5	131.0
9	25598.66	9098.8	197.6	25604.21	9103.2	197.0
10	26088.80	9507.0	186.3	26388.74	9780.8	151.0
11	26243.23	9645.7	163.7	26301.51	9699.3	157.0
12	26191.90	9656.3	161.6	26197.57	9661.1	161.0
13	25973.41	9406.5	199.6	26388.74	9780.8	151.0
14	25425.31	8966.2	217.5	25604.21	9103.2	197.0
15	24849.67	10145.	264.4	24911.45	10207.5	131.0
16	21937.59	7223.3	175.9	22326.93	7701.5	281.0
17	21300.27	6487.7	224.6	21490.19	6700.6	331.0
18	23134.81	8726.3	118.5	23168.53	8748.4	231.0
19	23028.17	8657.9	249.1	23429.57	8927.5	217.0
20	26383.18	9775.6	255.1	26388.74	9780.8	151.0
21	25168.46	8781.0	247.0	25604.21	9103.2	197.0
22	22774.90	9206.0	190.4	23127.79	9528.8	150.0
23	19123.35	9295.6	158.4	19284.14	9451.6	140.0
24	17311.36	9025.3	151.4	17664.58	9486.3	110.0
Avg value	22641.84	8877.90	200.3	22890.34	9066.888	185.7917

Table 2 . Results for unit commitment of generating units with and without vehicle connected to grid (both cost and emission taken as fitnes function)

Hrs	Power generation of units (MW)										Generation Cost ($)	Emissi -on (ton)	V2G (MW)	No. of vechicle	Maximum Capacity (MW)	Total Load (MW)	Total Reserve (MW)
	1	2	3	4	5	6	7	8	9	10							
1	347	326	0	0	0	0	0	0	0	0	15501.14	6871.0	27.2	4272	964.4	700	264.4
2	383	359	0	0	0	0	0	0	0	0	16678.11	8231.0	8.0	1250	925.9	750	175.9
3	435	268	130	0	0	0	0	0	0	0	18138.25	8196.4	17.3	2714	1074.6	850	224.6
4	455	351	130	0	0	0	0	0	0	0	19919.70	10106	14.3	2235	1068.5	950	118.5
5	439	245	130	0	162	0	0	0	0	0	21111.62	8284.9	23.6	3702	1249.1	1000	249.1
6	450	216	130	130	162	0	0	0	0	0	22970.78	8544.3	11.6	1818	1355.1	1100	255.1
7	455	267	130	130	162	0	0	0	0	0	23933.65	9311.7	6.1	950	1344.1	1150	194.1
8	455	306	130	130	162	0	0	0	0	0	24617.75	9918.3	16.8	2639	1365.6	1200	165.6
9	455	258	130	130	162	80	85	0	0	0	25598.66	9098.8	0.3	50	1497.6	1300	197.6
10	455	286	130	130	162	80	85	55	0	0	26088.80	9507.0	17.2	2697	1586.3	1400	186.3
11	455	295	130	130	162	80	85	55	55	0	26243.23	9645.7	3.3	524	1613.7	1450	163.7
12	455	297	130	130	157	80	85	55	55	55	26191.90	9656.3	0.3	50	1661.6	1500	161.6
13	455	279	130	130	162	80	85	55	0	0	25973.41	9406.5	23.8	3735	1599.6	1400	199.6
14	455	248	130	130	162	80	85	0	0	0	25425.31	8966.2	10.3	1611	1517.5	1300	217.5
15	455	319	130	130	162	0	0	0	0	0	24849.67	10145.2	3.5	555	1339.1	1200	139.1
16	401	204	130	130	162	0	0	0	0	0	21937.59	7223.3	23.3	3647	1378.4	1050	328.4
17	370	197	130	130	162	0	0	0	0	0	21300.27	6487.7	11.4	1782	1354.7	1000	354.7
18	455	221	130	130	162	0	0	0	0	0	23134.81	8726.3	1.9	304	1335.9	1100	235.9
19	455	215	130	130	162	0	85	0	0	0	23028.17	8657.9	23.1	3618	1463.1	1200	263.1
20	455	221	130	130	162	80	85	55	0	0	26383.18	9775.6	0.3	50	1551.6	1400	151.6
21	455	233	130	130	162	80	85	0	0	0	25168.46	8781.0	25.0	3925.0	1547.0	1300	247.0
22	455	285	130	130	0	80	0	0	0	0	22774.90	9206.0	20.2	3173.0	1290.4	1100	190.4
23	455	306	0	130	0	0	0	0	0	0	19123.35	9295.6	9.2	1445.0	1058.4	900	158.4
24	455	377	0	0	0	0	0	0	0	0	17311.36	9025.3	20.7	3254.0	951.4	800	151.4

(with V2G) Total running cost : $ 543404.0707 total emission : 213070.8346 tons total cost : $ 984547.4418
(without V2G) Total running cost :$ 548043.5473 total emission :217605.3188 tons total cost :$ 997071.5001

Efficiency = 85%; Maximum battery capacity P_{EV}^{max}=25 kWh; Minimum battery capacity P_{EV}^{min}= 10 kWh; Average battery capacity, P_{avg} = 15 kwh ; Maximum number of discharging vehicles at each hour, N_{V2G}^{max} (t) = 10% of total vehicles ;Total number of gridable Vehicles in the system N_{V2G}^{max}=50,000 ; Charging-Discharging

Results for the first part of the unit commitment without vehicle connected to grid both *emission* and *cost* is taken as fitness function (W_c =1,W_e =1) is given in the Table I. Total fuel cost of the unit is obtained as $548043.5473, total emission: : 217605.3188 tons and Total Cost of the unit is $997071.5001. Also, Table 1 shows the results for unit commitment with vehicle connected to grid. In this case, Total fuel cost (start up cost plus fuel cost) is obtained as $543404.0707, Total emission: 213070.8346 tons and Total Cost is $984547.4418. From Table I it is observed that value of total emission of the system with V2G is 213070.8346 tons/day and without V2G is 217605.3188 tons/day. Now the difference between the two is 4534.4842 tons/day. Also, for a year amount of emission is reduced to (4534.4842* 365) =1655086.733 tons/ year.

Similarly, it is observed that running cost of the unit without vehicle to grid is $ 548043.5473/day and for with vehicle to grid is $ 543404.0707/day. Hence, total savings of running cost is difference between two, which is $ 4639.47/day. For a year it is approximately$5434040707*365= $ 1693408.959/year is saved. Parallel to this spinning reserve of the unit is increased up to 10%.

Table 2 shows comparison results for reserve power, running cost and emission of 10 unit test system with and without vehicle connected to grid. It is seen from the table that the average running cost of the unit is decreased up to 11%. Also, emission is reduced considerably and spinning reserve capacity of the unit is increased. This reduction of running cost and emission of the unit is due to, addition of vehicle power to the grid. Vehicles are charged from a renewable energy source. Hence, the overall profit of the unit is increased. Solution obtained was feasible.

Table 3 shows results for second part of this paper, comparison between normal Binary PSO, as in [13] and Improved Binary PSO to solve unit commitment with and without vehicle power connected to grid. It is seen that there is a great reduction in emission, running cost and total cost of the unit. Approximately up to **20%** reduction in emission and also, approximately there is **28 %** increase in profit of the unit when comparing the values of unit commitment with V2G using BPSO and IPSO respectively.

5. CONCLUSION

In this paper, unit commitment with V2G scheduling is solved using a new intelligent approach. Gridable vehicles are mainly charged from the grid at off-peak load and discharge to the grid at peak load hours. The problem of UC with V2G is studied in more detail. Also, an introduction to V2G scheduling in constrained parking slots is given. Unit Commitment with V2G by using Improved Binary Particle Swarm Optimization provides better numerical results than the ordinary Binary Particle swarm Optimization. In this case, operating cost and emission of the unit is decreased. Also, spinning reserve capacity of the unit is increased. Numerical study shows that in Micro Grid application, dispatch of traditional generators will be reallocated with the connection of PEVs in order to reduce operating cost. In future, there is much more practical constraints have to be reconsidered, which will lead to more realistic results.

Table 3. Comparison of total emission, running cost and total cost

	IBPSO		**BPSO**	
	With vehicle connected to grid	**Without vehicle connected to grid**	**With vehicle connected to grid**	**Without vehicle connected to grid**
Total emission ($)	2,13,070.83	2,17,605.31	2,57,391.18	2,60,066.35
Total running cost ($)	543404.07	548043.54	559,367.06	565,325.94
Total cost (MW)	984547.441	997071.5001	1089591.89	1102663.28

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