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A Solution to Unit Commitment Problem with V2G Using Improved Harmony Search Algorithm

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ABSTRACT: Unit commitment(UC)is used to determine the system optimization problem in the operation of the generating unit at each and every hour interval varying load under different constraints and environments. In UC problem still researchers are working in this field to found new or hybrid algorithm to make the problem more realistic. The importance of UC is increasing with the constantly varying demands. UC problem become much more complicated when we need to consider power system having several plants each plant having several generating units and the system load to be served has several load steps. The capability of using the energy in micro grid integrated with renewable energy resources (RES) by Electrical vehicle (EV) with Vehicle-to-grid(V2G).The UC problem with V2G cost optimization is presented in this paper. A new solution to the UC problem based on Improved Harmony Search Algorithm (IHSA) is proposed.

KEYWORDS: Unit Commitment (UC), Electrical Vehicle (EV), Vehicle-to-grid (V2G),Harmony Search Algorithm(HSA) and Improved Harmony Search algorithm(IHSA).

I.INTRODUCTION

UC is a large-scale, non convex, nonlinear, mixed-integer optimization problem. The optimal solution to the UC problem can be obtained by complete enumeration, which is prohibitive in practice owing to its excessive computational resource requirements [1][3]. Unit commitment, in regulated or state monopoly power markets, is to schedule the operation of the generating units in order to serve the load demand at minimum operating cost while observing all plant and system constraints over a given scheduling period, ranging from several hours to days ahead[1][2].

Every day regional electricity networks deliver hundreds of GWh of energy from generating units to consumers. Demand varies rather predictably throughout the day, but it can also fluctuate significantly in real time. To ensure that the system remains secure and that power is reliably delivered requires careful planning. The daily on/off scheduling of the system's energy resources is known as unit commitment. It is a large-scale optimization problem that determines the operating status of hundreds of generating units based on a set of complicated constraints. Due to the scale of the problem and the frequency at which it must be solved, unit commitment has become a major research area in the past few decades. This paper aims to provide a better understanding of unit commitment through past and present research. When the load increases the utility has to decide in advance the sequence in which the generator units are to be brought in similarly, when the load decreases the operating engineer need to know in advance the sequence in which the generating units are to be shut down. The problem of finding the order in which the units are to be brought in and the order in which the units are to be shut down over a period of time say one day so the total operating cost involved on the day is minimum is known as Unit Commitment(UC).

A new technology vehicle-to-grid is widely used in smart grid applications. A new technology is used to produce electric energy which is generated by electrical vehicle and it is supplied to the grid. The electrical vehicle is used to store the energy in bi-directional ways such as both electrical grid and electrical vehicle. The electrical vehicle can be used to reduce the generation cost and load demand. Renewable energy sources are used to charge the gridable vehicle

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where used in off load(charging)and peak load(discharging) condition. Electrical vehicle application in vehicle-to-grid technology is more efficient in unit commitment [8].

The methods for solving UC problem are of two types and the one is conventional method exist during 1957 to 1980 and the other is heuristic method which is a advance technique formed from the natural activity. Priority List, Branch-and-Bound, Dynamic Programming, Lagrangian Relaxation, Co-ordination Method, Evolutionary Algorithms, Integer Programming, Mixed Integer Programming, Muller Method, Linear Programming etc.. are the conventional method. Genetic Algorithm, Simulated Annealing , Tabu Search, Fuzzy Logic & Neural Networks Algorithm, BAT Algorithm, Ant Colony Optimization, Artificial Bee Colony, Hybrid Method, Teacher Learning Algorithm, Particle Swarm Optimization, Harmony Search Algorithm, Improved Harmony Search Algorithm etc.. are heuristic method[1].

In this paper a novel structure has been proposed for Improved Harmony Search algorithm (IHSA) to Unit Commitment (UC) problem. Harmony Search (HS) algorithm is based on jazz musical improvisation process. Jazz improvisation, solve this classical optimization problem, called 'harmony search' and when jazz musicians play together they select the musical notes in their instruments to give the best overall harmony with the rest of the group. The running cost and emission of the unit is reduced and also spinning reserve capability and profit of the unit is increased. Unit commitments with vehicle to grid and without vehicle to grid using IMPROVED HARMONY SEARCH ALGORITHM were much than HARMONY SEARCH ALGORITHM [17].

II. PROBLEM FORMULATION

2.1 Nomenclature and acronyms

The following notations are used in this paper.

C_{sci}	Cold start-up cost of unit i	$P_{dis}(t)$	Discharging power of V2G at time t
D_i	Demand power at time t	P_{PEV}	Average rated power of PEV
E_{dis}^{con}	Average daily energy consumption of PEV	P_{bat}	Average battery capacitor of each PEV
E_{char}	Total daily charging energy of PEVs	P_{v2g}	Power generated/consumed by PEVs at t
E_{dis}	Total daily discharging energy of PEVs	R_t	System reserve requirement at time t
$FC_i()$	Fuel cost function of unit i	RDR_i	Ramp down rate of unit i
H	Scheduling hours	RUR_i	Ramp up rate of unit i
H_{sci}	Hot start-up cost of unit i	$SC_i()$	Start-up cost function of unit i
$I_i(t)$	Status of unit i at time t	SoC	Average discharge depth of battery
$N_{v2G}(t)$	Number of vehicles connected to the grid at t	TC	Total cost
$P_i(t)$	Output power of unit i at time t	T_{ioff}^t	Duration of continuous off-line of unit i at t
$N_{v2G}^{max}(t)$	Maximum number of V2G at time t	T_{ion}^t	Duration of continuous on-line of unit i at t
$P_i(t)$	Output power of unit i at time t	T_{idown}	Minimum down time of unit i
$P^{max/min}$	Maximum/minimum output limit of unit i	T_{icold}	Cold start-up time of unit i
$P_i^{max}(t)$	Maximum output power of unit i at time t	λ_i	Lagrange multiplier at time t
$P_i^{min}(t)$	Minimum output power of unit i at time t	Ψ	State of charge
$P_{cha}(t)$	Charging power of V2G at time t	ξ	Efficiency

Objective functions

The objective of UC with V2G is to minimize the total operating cost over the time horizon while the hourly load demand and spinning reserve are met and emission, and to improve system reserve and reliability. The cost includes mainly fuel cost and start-up cost. Usually large cheap units are used to satisfy base load demand of a system. Most of the time, large units are therefore on and they have slower ramp rates. On the other hand, small units have relatively faster ramp rates. Besides, each unit has different cost and emission characteristics that depend on amount of power generation, fuel type, generator unit size, technology and so on. Gridable vehicles of V2G technology will reduce

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dependencies on small/micro expensive units. But number of gridable vehicles in V2G is much higher than small/micro units. So profit, emission, spinning reserve, reliability of power systems vary on scheduling optimization quality. UC with V2G is a large-scale and complex optimization problem. The objective of the UC with V2G is to minimize total operation cost and emission, where cost includes mainly fuel cost and start-up cost.

Fuel cost

Fuel cost of a thermal unit is expressed as a second order function of generated power of the unit and a_i, b_i, c_i are cost co-efficient.

$$F_c(P_i(t)) = a_i + b_i P_i(t) + c_i P_i^2(t) \quad \dots(1)$$

Emission

Emission curve is expressed as polynomial function and order depends on the desired accuracy and $\alpha_i, \beta_i, \gamma_i$ are emission co-efficients

$$E C_i(P_i(t)) = \alpha_i + \beta_i P_i(t) + \gamma_i P_i^2(t) \quad \dots(2)$$

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:

$$\left[\begin{array}{l} S C_i(t) = \left\{ \begin{array}{l} h - \text{cost}_i \quad M D_i \leq X_i^{\text{off}}(t) \leq H_i^{\text{off}} \\ c - \text{cost}_i \quad X_i^{\text{off}}(t) > H_{\text{off}} \end{array} \right\} \\ H_i^{\text{off}} = M D_i + C_{-} S_{-} \text{hour}_i \end{array} \right] \quad \dots(3)$$

Shut-down cost

Shut-down cost is constant and the typical value is zero in standard systems. Therefore, the main objective function for cost-emission optimization of unit commitment with V2G is given by formula,

$$\begin{aligned} \text{Min } \pi &= W_c * (\text{Fuel} + \text{start_up}) + W_e * \text{Emission} \\ &= \sum_{i=1}^N \sum_{t=1}^H [\{ W_c (F C_i(P_i(t)) + S C_i(1 - I_i(t-1))) \} \\ &\quad + W_e (\psi_i E C_i(P_i(t)))] I_i(t) \quad \dots(5) \end{aligned}$$

Where, ψ_i is the emission penalty factor of unit i . Weight factors W_c and W_e are used to include ($W = 1$) or exclude ($W = 0$) 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 W_c and W_e .

Constraints of UC with V2G

The constraints that must be satisfied during the optimization process are as follows

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 are fixed. There schedule for 24 hours is predefined

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

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.

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System power balance

Gridable vehicles are considered as S3Ps. Power supplied from committed units and selected (some percentage of total vehicles) S3Ps must satisfy the load demand and the system losses, which is defined as,

$$\sum_{t=1}^N I_i(t)P_i(t) + P_v N_{v2G}(t) = D(t) + \text{losses} \quad \dots(7)$$

Spinning reserve

To maintain system reliability, adequate spinning reserves are required,

$$\sum_{t=1}^N I_i(t)P_i^{\max}(t) + P_v^{\max} N_{v2G}(t) \geq D(t) + R(t) \quad \dots(8)$$

Generation limits

Each unit has generation range, which is represented as,

$$\sum_{t=1}^N P_i^{\min} \leq P_i(t) \leq P_i^{\max} \quad \dots(9)$$

Number of discharging vehicles limit

All the vehicles cannot discharge at the same time. For reliable operation and control, limited number of vehicles will discharge at a time. This constraint also applies for power transfer, current limit

$$\sum_{t=1}^N N_{v2G}(t) = N_{v2G}^{\max}(t) \quad \dots(10)$$

Minimum up/down time:

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

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

Initial status

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

III. PROPOSED APPROACH

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'

Improved Harmony Search Algorithm

Improved Harmony Search Algorithm (IHSA) is used to obtain better solution from simple HS algorithm, several improvement techniques have been suggested these techniques mainly are categorized in two groups. Goal of first group is adapting of control parameters of DEA. Second category has focused on change structure of simple HS algorithm operators and/or adding new operator. PAR and BW in HS algorithm are very important parameters in fine-tuning of optimized solution vectors and can be potentially useful in adjusting convergence rate of algorithm to optimal solution. So fine adjustment of these parameters are of great interest. The traditional HS algorithm uses fixed value for both PAR and BW. In the HS method PAR and BW values adjusted in initialization step and cannot be changed during new generations. The main drawback of this method appears in the number of iterations the algorithm needs to find an optimal solution. Small PAR values with large BW values can cause to poor performance of the algorithm and

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considerable increase in iterations needed to find optimum solution. Although small BW values in final generations increase the fine-tuning of solution vectors, but in early generations BW must take a bigger value to enforce the algorithm to increase the diversity of solution vectors. Furthermore large PAR values with small BW values usually cause the improvement of best solutions in final generations which algorithm converged to optimal solution vector. The key difference between IHS and traditional HS method is in the way of adjusting PAR and BW. To improve the performance of the HS algorithm and eliminate the drawbacks lies with fixed values of PAR and BW, IHS algorithm uses variables PAR and BW in improvisation step.

IV. RESULT

All calculations have been run on Intel(R) Pentium(R) P62002.66 GHZ CPU, 2GB RAM, Microsoft Window XP OS.A 10 unit system is considered for simulation with 50,000 gridable vehicles, which are charged from renewable sources and they discharged to the grid so that running cost and emission are minimum and the load demand and constraint are fulfilled. The spinning reserve requirement is assumed to be 10% of the load demand, cold start-up cost is double of hot start-up cost, and total scheduling period is 24 h.

Parameter values are Harmony memory size=20, Max Iterations=1000; total number of vehicles = 50,000; maximum battery capacity = 25 kWh; minimum battery capacity = 10 kWh; average battery capacity, $P_v = 15$ kWh; maximum number of discharging vehicles at each hour, $N_{max} V2G(t) = 10\%$ of total vehicles; total number of gridable vehicles in the system, $N_{max} V2G = 50,000$; charging–discharging frequency = 1 per day; scheduling period = 24 h; departure state of charge, $\psi = 50\%$; efficiency, $\xi = 85\%$.

In fitness function, both cost and emission are considered (i.e., $W_c = 1$ and $W_e = 1$) and randomly selected results with and without gridable vehicles are shown in Tables 1 and 2, respectively. The total fuel cost is 5,54,556.49 \$ total emission cost is : 2,78,643.34 ton and total cost is \$11,35,110.09 when 50,000 gridable vehicles are considered in the 10-unit system during 24 h (Table 1). On the other hand, the total fuel cost is \$5,73,113.51 total emission cost is 2,85,694.3860 ton and total cost is \$11,99,654.7044 respectively when gridable vehicles are not considered in the same system (Table 2). Though value of fitness function is continuously decreasing, individual cost and emission are frequently fluctuating (both increasing and decreasing) up to 200 iterations.

Operation cost and schedule for 24 hours																		
Power generation units(MW)											Generation cost	Start-up cost	Emission cost	V2G	No of vehicles	Maximum Demand capacity	Total Demand	Reserve
Hour	1	2	3	4	5	6	7	8	9	10	\$	\$	ton		MW	MW	MW	MW
1	455	225	0	0	0	0	0	0	0	0	13332.77	0.0	6581.8	20.1	3157.0	950.2	700	250.2
2	455	291	0	0	0	0	0	0	0	0	14484.99	0.0	7484.7	4.0	625.0	918.0	750	168.0
3	455	358	0	0	25	0	0	0	0	0	16605.09	900.0	8929.8	11.7	1833.0	1095.3	850	245.3
4	455	443	0	0	25	0	0	0	0	0	18088.23	0.0	10840.6	27.0	4231.0	1125.9	950	175.9
5	455	455	0	61	25	0	0	0	0	0	19996.74	560.0	11389.0	3.8	589.0	1209.5	1000	209.5
6	455	455	130	29	25	0	0	0	0	0	22356.83	550.0	12003.2	5.6	880.0	1343.2	1100	243.2
7	455	455	130	64	25	0	0	0	0	0	22928.59	0.0	12026.0	21.4	3351.0	1374.7	1150	224.7
8	455	455	130	115	25	0	0	0	0	0	23788.75	0.0	12281.0	20.4	3199.0	1372.7	1200	172.7
9	455	455	130	130	72	20	25	0	0	0	26982.04	430.0	12906.4	13.2	2076.0	1523.4	1300	223.4
10	455	455	130	130	162	29	25	10	0	0	29977.93	30.0	13563.5	3.5	550.0	1559.0	1400	159.0

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11	455	455	130	130	162	76	25	10	0	0	31040.94	0.0	13554.5	7.3	1146.0	1566.6	1450	116.6
12	455	455	130	130	162	80	72	10	0	0	32445.06	0.0	13589.4	6.1	963.0	1564.3	1500	64.3
13	455	455	130	130	158	20	25	10	0	0	29669.92	0.0	13551.6	17.5	2737.0	1586.9	1400	186.9
14	455	455	130	130	60	20	25	0	0	0	26751.46	0.0	12898.0	24.6	3864.0	1546.2	1300	246.2
15	455	455	130	121	25	0	0	0	0	0	23900.60	0.0	1333.2	13.8	2167.0	1359.6	1200	159.6
16	455	455	83	20	25	0	0	0	0	0	21400.61	0.0	11699.5	12.0	1883.0	1356.0	1050	360.0
17	455	455	31	20	25	40	10	0	0	0	21476.55	30.0	11933.8	3.5	554.0	1394.1	1000	394.1
18	455	455	121	20	25	0	0	0	0	0	22043.54	0.0	11937.8	24.2	3796.0	1380.3	1100	280.3
19	455	455	130	129	25	0	0	0	0	0	24037.07	0.0	12402.7	5.8	910.0	1343.6	1200	143.6
20	455	455	130	130	162	28	25	10	0	0	29944.97	460.0	13566.2	5.0	778.0	1561.9	1400	161.9
21	455	455	130	130	60	20	25	0	0	0	26742.58	0.0	12897.9	25.1	3933.0	1554.1	1300	247.1
22	455	455	0	0	138	20	25	0	0	0	22589.72	0.0	11868.6	7.0	1098.0	1251.0	1100	151.0
23	455	413	0	0	0	20	0	0	0	0	17433.35	0.0	10121.1	12.1	1898.0	1014.2	900	114.2
24	455	301	0	0	0	0	0	0	10	10	16538.17	60.0	8282.9	24.1	3782.0	1068.2	800	268.2

Table-1 Unit Commitment using IHSA with V2G for 10unit system with 50,000 gridable vehicles

Total Fuel Cost : 5,54,556.49 \$, Total Emission Cost : 2,78,643.34 ton, Total Cost : 11,35,110.09 \$

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.

Operation cost and schedule for 24 hours																		
Hour	Power generation units(MW)										Generation cost	Start-up cost	Emission cost	V2G	No of vehicles	Maximum Demand Capacity	Total Demand	Reserve
	1	2	3	4	5	6	7	8	9	10	\$	\$	ton		MW	MW	MW	MW
1	455	245	0	0	0	0	0	0	0	0	13683.13	0.0	6827.7	0.0	0.0	910.0	700	210.0
2	455	295	0	0	0	0	0	0	0	0	14554.50	0.0	7547.8	0.0	0.0	910.0	750	160.0
3	455	370	0	0	25	0	0	0	0	0	16809.45	900.0	9166.8	0.0	0.0	1072.0	850	222.0
4	455	455	0	0	40	0	0	0	0	0	18597.67	0.0	11123.3	0.0	0.0	1072.0	950	122.0
5	455	455	0	55	25	0	0	0	10	0	20830.09	590.0	11692.6	0.0	0.0	1257.0	1000	257.0
6	455	455	130	25	25	0	0	0	10	0	23221.83	550.0	12324.1	0.0	0.0	1387.0	1100	287.0
7	455	455	130	75	25	0	0	0	10	0	24057.38	0.0	12375.1	0.0	0.0	1387.0	1150	230.7
8	455	455	130	125	25	0	0	0	10	0	24903.48	0.0	12680.6	0.0	0.0	1387.0	1200	187.0
9	455	455	130	130	75	20	25	0	10	0	27985.61	430.0	13225.5	0.0	0.0	1552.0	1300	252.0
10	455	455	130	130	162	23	25	10	10	0	30768.89	30.0	13891.7	0.0	0.0	1607.0	1400	207.0
11	455	455	130	130	162	73	25	10	10	0	31916.06	0.0	13866.2	0.0	0.0	1607.0	1450	157.0
12	455	455	130	130	162	80	68	10	10	0	33275.49	0.0	13894.5	0.0	0.0	1670.0	1500	107.0
13	455	455	130	130	162	23	25	10	10	0	30768.89	0.0	13891.7	0.0	0.0	1670.0	1400	207.0
14	455	455	130	130	75	20	25	10	10	0	27985.61	0.0	13225.5	0.0	0.0	1552.0	1300	252.0
15	455	455	130	125	25	0	0	0	10	0	24903.48	0.0	12680.6	0.0	0.0	1387.0	1200	187.0

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16	455	455	85	20	25	0	0	0	10	0	22372.50	0.0	12023.6	0.0	0.0	1387.0	1050	337.0
17	455	455	35	20	25	0	0	0	10	0	21530.50	0.0	11921.7	0.0	0.0	1387.0	1000	387.0
18	455	455	130	25	25	0	0	0	10	0	23221.83	0.0	12324.1	0.0	0.0	1387.0	1100	287.0
19	455	455	130	125	25	0	0	0	10	0	24903.48	0.0	12680.6	0.0	0.0	1387.0	1200	187.0
20	455	455	130	130	162	25	25	10	10	0	30768.89	460.0	13891.7	0.0	0.0	1607.0	1400	207.0
21	455	455	130	130	75	20	25	0	10	0	27985.61	0.0	13225.5	0.0	0.0	1552.0	1300	252.0
22	455	455	0	0	135	20	25	0	10	0	23465.30	0.0	12167.0	0.0	0.0	1292.0	1100	192.0
23	455	415	0	0	0	20	0	0	10	0	18408.08	0.0	10485.4	0.0	0.0	1045.0	900	145.0
24	455	335	0	0	0	0	0	0	10	0	16195.78	30.0	8561.1	0.0	0.0	965.0	800	165.0

Table-2 Unit Commitment using IHSA without V2G for 10 unit systemTotal

Fuel Cost : 5,73,113.51 \$, Total Emission Cost : 2,85,694.3860 ton, Total Cost : 11,99,654.7044 \$

V. CONCLUSION

In this paper, unit commitment with V2G scheduling is solved using a new advanced technological approach. The problem of UC with V2G is studied using gridable vehicles are mainly charged from the grid at charging and discharging of the peak load hours. Unit Commitment with V2G by using Improved Harmony Search Algorithm (IHSA) provides better numerical results than Harmony Search Algorithm. In this case, operating cost and emission of the unit is decreased. Also, spinning reserve capacity of the unit is increased. In future, there is much more practical constraints have to be reconsidered, which will lead to more realistic results.

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