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

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ABSTRACT: Unit commitment (UC) is a optimization task planning operation in power system and is done by scheduled the generating units in on/off states. The UC problem is to minimize system total operating cost to meet forecasting load and reserve requirement while adhering to generator and transmission constraints to satisfy a given security level. The capability of using load, energy sources and energy storage in micro grid integrated with renewable energy sources (RES) by Electrical Vehicles(EV) with Vehicle-to-Grid. An intelligent UC with V2G for cost optimization is presented in this paper. And this paper presents a new solution to the UC problem based on Harmony Search Algorithm (HSA) is proposed. HS algorithm is based on musical improvisation process has employed to solve several power system problems like reactive power dispatch, power flow, unit commitment, economic dispatch, reconfiguration etc...

KEYWORDS: Unit commitment (UC), Electrical Vehicle (EV), Vehicle-to-Grid(V2G), Harmony search Algorithm(HSA).

I.INTRODUCTION

UC 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]. The 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 [2]. The need for practical, cost-effective UC solutions, led to the development of various UC algorithms that provide suboptimal, but efficient scheduling for real sized power systems comprising hundreds of generators [1].

The “unit commitment” decision involves the determination of the generating units to be running during each hour of the planning horizon, considering system capacity requirements, including the reserve, and the constraints on the start-up and shut-down of units [3]. There are two types of constraints on the unit commitment schedule. The first type consists of a few system or "coupling" constraints resulting from system demand and capacity requirements, which relate to the capacity or output of all generating units during each time period. The second types are at the individual unit level or "local" constraints for each unit. The objective function to be minimized is the summation of unit start-up and shut-down costs, and operating or fuel costs, and maintenance costs over all the units, and for the total planning horizon[4][5].

Transportation sector increases the pollution from 24% to 27% and the industries and vehicles pollute the air which creates global warming [6]. Now-a-days the environment friendly equipment are used by governments and industries to reduce pollution. The emission in the environment increase by load demand fossil fuels were burnt for producing power.

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 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 [7].

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 [9], Lagrangian Relaxation [3], Co-ordination Method, Evolutionary Algorithms [12][14], Integer Programming, Mixed Integer Programming, Muller Method, Linear Programming etc.. are the conventional method. Genetic Algorithm [10-13], Simulated Annealing [13], Tabu Search, Fuzzy Logic & Neural Networks Algorithm, BAT Algorithm, Ant Colony Optimization, Artificial Bee Colony, Hybrid Method, Teacher Learning Algorithm, Particle Swarm Optimization[14-18], Harmony Search Algorithm etc.. are heuristic method.

In this paper 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 HARMONY SEARCH ALGORITHM were much than improved binary PSO [19-21].

II. PROBLEM FORMULATION

Nomenclature and acronyms

The following notations are used in this paper.

C_{sci}	Cold start-up cost of unit *i*
D_i	Demand power at time *t*
E_{dis}^{con}	Average daily energy consumption of PEV
E_{char}	Total daily charging energy of PEVs
E_{dis}	Total daily discharging energy of PEVs
$FC_i()$	Fuel cost function of unit *i*
H	Scheduling hours
H_{sci}	Hot start-up cost of unit *i*
$I_i(t)$	Status of unit *i* at time *t*
$N_{v2G}(t)$	Number of vehicles connected to the grid at t
$P_i(t)$	Output power of unit *i*at time *t*
$N_{v2g}^{max}(t)$	Maximum number of V2G at time *t*
$P_i(t)$	Output power of unit *i*at time *t*
$P^{max/min}$	Maximum/minimum output limit of unit *i*
$P_i^{max}(t)$	Maximum output power of unit *i* at time *t*
$P^{min}(t)$	Minimum output power of unit *i* at time *t*
$P_{cha}(t)$	Charging power of V2G at time *t*
$P_{dis}(t)$	Discharging power of V2G at time *t*
P_{PEV}	Average rated power of PEV
P_{bat}	Average battery capacitor of each PEV
P_{v2g}	Power generated/consumed by PEVs at time
R_t	System reserve requirement at time *t*
RDR_i	Ramp down rate of unit *i*
RUR_i	Ramp up rate of unit *i*
$SC_i()$	Start-up cost function of unit *i*
SoC	Average discharge depth of battery
TC	Total cost
T_{ioff}^t	Duration of continuous off-line of unit *i*at *t*
T_{ion}^t	Duration of continuous on-line of unit *i* at *t*
T_{idown}	Minimum down time of unit *i*
T_{icold}	Cold start-up time of unit *i*
λ_i	Lagrange multiplier at time *t*
Ψ	State of charge
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[8]. 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 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 [6].

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.

$$Fc_i(P_i(t))=a_i+b_iP_i(t)+c_iP_i^2(t) \qquad \ldots(1)$$

Emission

Emission curve is expressed as polynomial function and order depends on the desired accuracy and α_i ,β_i , γ_i are emission co-efficient

$$ECi(P_i(t))= \alpha_i + \beta_iP_i(t)+ \gamma_i P_i^2(t) \qquad \ldots(2)$$

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:

$$\left[\begin{array}{l} SCi\ (t) \;=\; \begin{cases} h-\cos t_i & MDi \le X_i^{\mathrm{off}}(t) \le H_i^{\mathit{off}} \\ \mathrm{c\text{-}cost_i} & X_i^{\mathrm{off}}(t) > H_{\mathrm{off}} \end{cases} \\ H_i^{\mathrm{off}} = MD_i + C\_S\_hour_i \end{array}\right] \qquad \begin{array}{r} \ldots(3) \\ \ldots(4) \end{array}$$

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,

$$\text{Min } \pi = W_c{*}(\text{Fuel} + \text{start\_up}) + W_e{*}\text{Emission} = \sum_{i=1}^{N}\sum_{t=1}^{H}[\{Wc(FC_i(P_i(t))+SC_i(1-I_i(t-1))\} + We(\psi_i EC_i(P_i(t))]I_i(t) \qquad \ldots(5)$$

Where, ψ_i is the emission penalty factor of unit i. Weight factors Wc and We 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

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

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.

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,

$$\sum_{t=1}^{N} \mathrm{I_i(t)P_i(t) + PvN_{V2G}(t) = D(t) + losses} \qquad ...(7)$$

Spinning reserve

To maintain system reliability, adequate spinning reserves are required,

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

Generation limits

Each unit has generation range, which is represented as,

$$\sum_{t=1}^{N} \mathrm{P_i^{min} \leq P_i(t) \leq P_i^{max}} \qquad ...(9)$$

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

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

Minimum up/down time:

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

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

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’

Harmony Search Algorithm

Harmony Search (HS) algorithm has based on musical improvisation process. The HS algorithm has been very successful in a wide variety of optimization problems, presenting several advantages with respect to a traditional optimization technique. As the HS algorithm uses stochastic random searches, derivative information is also unnecessary. In the HS algorithm, musical performances seek a perfect state of harmony determined by aesthetic estimation, as the optimization algorithms seek the best state (i.e., global optimum) determined by the objective function value. Each musician corresponds to each decision variable; a musical instrument’s pitch range corresponds to a decision variable’s value range; musical harmony at certain time corresponds to a solution vector at certain iteration; and audience’s aesthetics corresponds to an objective function. Just like musical harmony is improved with time, the solution vector is improved with iteration. To understand the principle of the HS algorithm, let us first idealize the improvisation process by a skilled musician.

When a musician improvises, he or she has three possible choices are playing any famous tune exactly from his or her memory, playing something similar to the aforementioned tune, thus adjusting the pitch slightly or composing new or random.

A few parameters that are used for the calculation of UC problem by HS algorithm are number of Iterations (IN) which is determined by complexity and nature of problem, number of Decision Variable (DVN) which set of DVN constitutes a harmony, Size of harmony search (SHS) used to specify the number of harmonies that will be stored in the harmony memory, Pitch Adjustment Rate (PAR) determines probability value to give value to decision values, Harmony Memory Considering Rate (HMCR) determines the rate at which decision variables in the harmony are considered as elements of a new harmony.

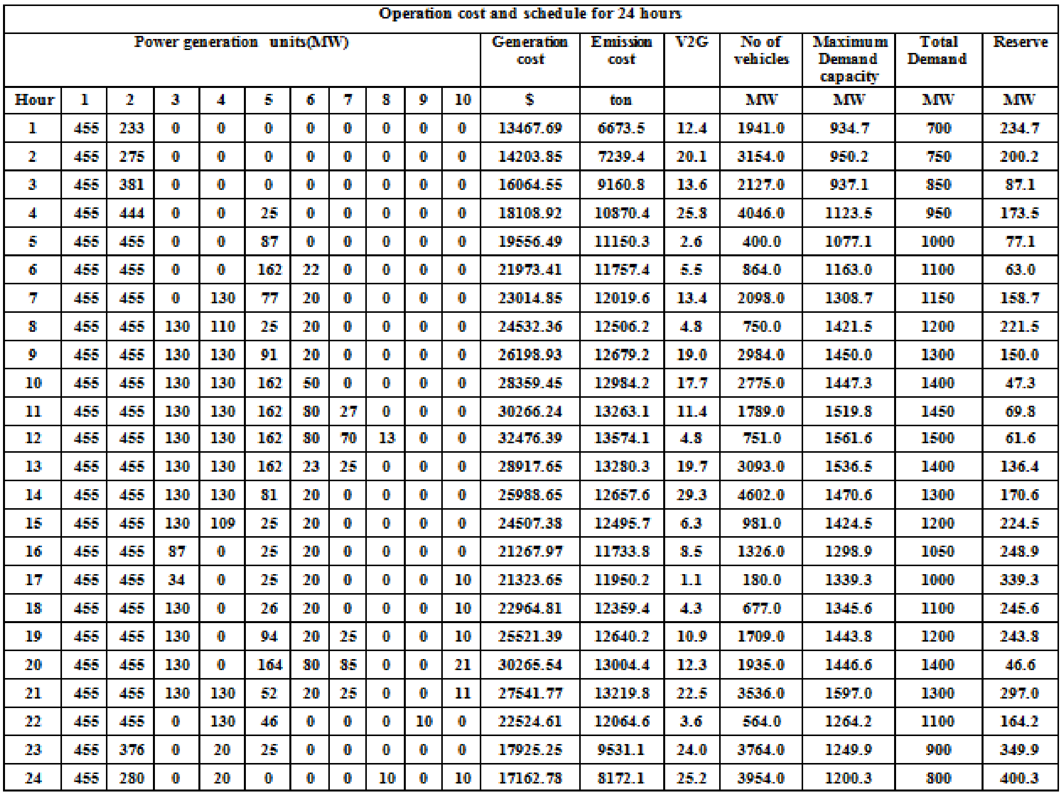
IV. RESULT

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, Pv = 15 kWh; maximum number of discharging vehicles at each hour, NmaxV2G(t) = 10% of total vehicles; total number of gridable vehicles in the system, Nmax V2G= 50,000; charging–discharging frequency = 1 per day; scheduling period = 24 h; departure state of charge, ψ = 50%; efficiency, ξ = 85%.

In fitness function, both cost and emission are considered (i.e., Wc = 1 and We = 1) and randomly selected results with and without gridable vehicles are shown in Tables 1 and 2, respectively. The total fuel cost is $5,54,134.59 total emission cost is 2,76,987.53 ton and total cost is $11,35,323.37 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 $5,73,879.34 total emission cost is 2,84,779.94 ton and total cost is $11,95,083.92 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.

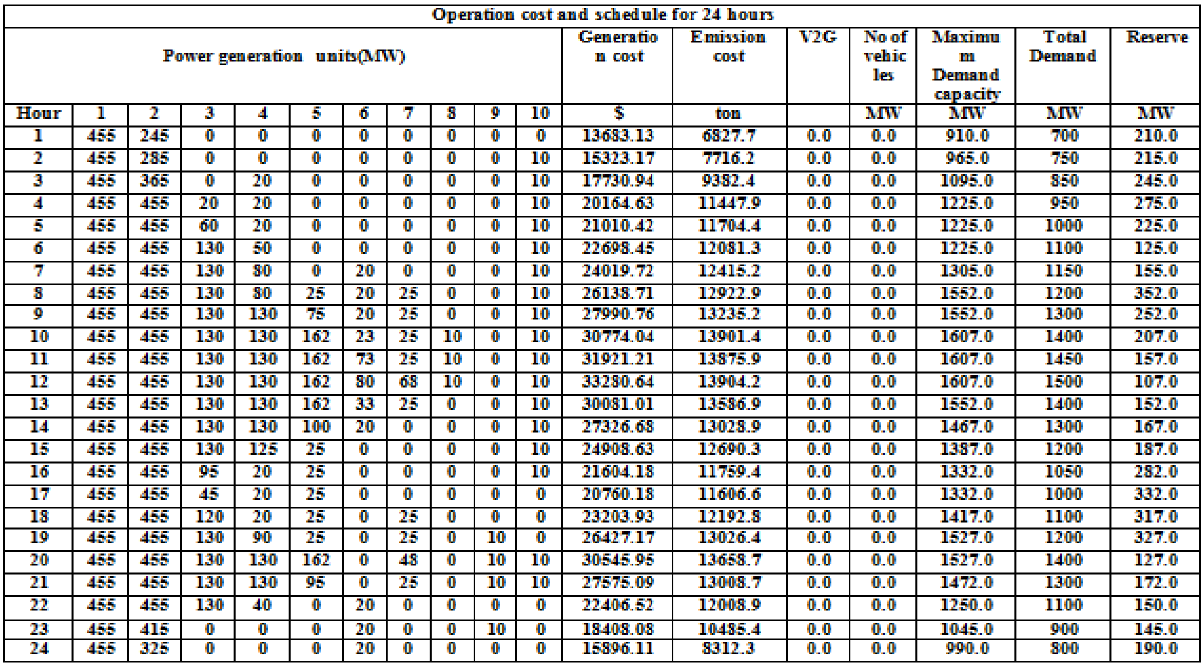
Results for reserve power, running cost and emission of 10 unit test system with and without vehicle connected to grid. It is seen from the table that the average running cost of the unit is decreased up to 11% **.**Also, emission is reduced considerably and spinning reserve capacity of the unit is increased. 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.

Hence the total saving by usingHSA with V2G technology in UC problem the running cost is reduced by ($5,73,879.34−$5,54,134.59)= $19,744.15 and the emission is reduced by (2,84,779.94−2,76,987.53 tons) = 7792.41 tons per day in the 10-unit small system. And for the year running cost is reduced by 72,06,614.75 $ and emission is reduced by 28,44,229.65 ton by using HSA with V2G in UC problems. And the comparison of running cost and emission is made the reference paper[6].



Operation cost and schedule for 24 hours																	
Power generation units(MW)											Generation 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	233	0	0	0	0	0	0	0	0	13467.69	6673.5	12.4	1941.0	934.7	700	234.7
2	455	275	0	0	0	0	0	0	0	0	14203.85	7239.4	20.1	3154.0	950.2	750	200.2
3	455	381	0	0	0	0	0	0	0	0	16064.55	9160.8	13.6	2127.0	937.1	850	87.1
4	455	444	0	0	25	0	0	0	0	0	18108.92	10870.4	25.8	4046.0	1123.5	950	173.5
5	455	455	0	0	87	0	0	0	0	0	19556.49	11150.3	2.6	400.0	1077.1	1000	77.1
6	455	455	0	0	162	22	0	0	0	0	21973.41	11757.4	5.5	864.0	1163.0	1100	63.0
7	455	455	0	130	77	20	0	0	0	0	23014.85	12019.6	13.4	2098.0	1308.7	1150	158.7
8	455	455	130	110	25	20	0	0	0	0	24532.36	12506.2	4.8	750.0	1421.5	1200	221.5
9	455	455	130	130	91	20	0	0	0	0	26198.93	12679.2	19.0	2984.0	1450.0	1300	150.0
10	455	455	130	130	162	50	0	0	0	0	28359.45	12984.2	17.7	2775.0	1447.3	1400	47.3
11	455	455	130	130	162	80	27	0	0	0	30266.24	13263.1	11.4	1789.0	1519.8	1450	69.8
12	455	455	130	130	162	80	70	13	0	0	32476.39	13574.1	4.8	751.0	1561.6	1500	61.6
13	455	455	130	130	162	23	25	0	0	0	28917.65	13280.3	19.7	3093.0	1536.5	1400	136.4
14	455	455	130	130	81	20	0	0	0	0	25988.65	12657.6	29.3	4602.0	1470.6	1300	170.6
15	455	455	130	109	25	20	0	0	0	0	24507.38	12495.7	6.3	981.0	1424.5	1200	224.5
16	455	455	87	0	25	20	0	0	0	0	21267.97	11733.8	8.5	1326.0	1298.9	1050	248.9
17	455	455	34	0	25	20	0	0	0	10	21323.65	11950.2	1.1	180.0	1339.3	1000	339.3
18	455	455	130	0	26	20	0	0	0	10	22964.81	12359.4	4.3	677.0	1345.6	1100	245.6
19	455	455	130	0	94	20	25	0	0	10	25521.39	12640.2	10.9	1709.0	1443.8	1200	243.8
20	455	455	130	0	164	80	85	0	0	21	30265.54	13004.4	12.3	1935.0	1446.6	1400	46.6
21	455	455	130	130	52	20	25	0	0	11	27541.77	13219.8	22.5	3536.0	1597.0	1300	297.0
22	455	455	0	130	46	0	0	0	10	0	22524.61	12064.6	3.6	564.0	1264.2	1100	164.2
23	455	376	0	20	25	0	0	0	0	0	17925.25	9531.1	24.0	3764.0	1249.9	900	349.9
24	455	280	0	20	0	0	0	10	0	10	17162.78	8172.1	25.2	3954.0	1200.3	800	400.3

Table-1 Unit Commitment using HSA with V2G for 10unit system with 50,000 gridable vehicles
Total Fuel Cost : 5,54,134.5980 $ Total Emission Cost : 2,76,987.5333 ton Total Cost : 11,35,323.3713 $



Operation cost and schedule for 24 hours																	
Power generation units(MW)											Generation 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	245	0	0	0	0	0	0	0	0	13683.13	6827.7	0.0	0.0	910.0	700	210.0
2	455	285	0	0	0	0	0	0	0	10	15323.17	7716.2	0.0	0.0	965.0	750	215.0
3	455	365	0	20	0	0	0	0	0	10	17730.94	9382.4	0.0	0.0	1095.0	850	245.0
4	455	455	20	20	0	0	0	0	0	10	20164.63	11447.9	0.0	0.0	1225.0	950	275.0
5	455	455	60	20	0	0	0	0	0	10	21010.42	11704.4	0.0	0.0	1225.0	1000	225.0
6	455	455	130	50	0	0	0	0	0	10	22698.45	12081.3	0.0	0.0	1225.0	1100	125.0
7	455	455	130	80	0	20	0	0	0	10	24019.72	12415.2	0.0	0.0	1305.0	1150	155.0
8	455	455	130	80	25	20	25	0	0	10	26138.71	12922.9	0.0	0.0	1552.0	1200	352.0
9	455	455	130	130	75	20	25	0	0	10	27990.76	13235.2	0.0	0.0	1552.0	1300	252.0
10	455	455	130	130	162	23	25	10	0	10	30774.04	13901.4	0.0	0.0	1607.0	1400	207.0
11	455	455	130	130	162	73	25	10	0	10	31921.21	13875.9	0.0	0.0	1607.0	1450	157.0
12	455	455	130	130	162	80	68	10	0	10	33280.64	13904.2	0.0	0.0	1607.0	1500	107.0
13	455	455	130	130	162	33	25	0	0	10	30081.01	13586.9	0.0	0.0	1552.0	1400	152.0
14	455	455	130	130	100	20	0	0	0	10	27326.68	13028.9	0.0	0.0	1467.0	1300	167.0
15	455	455	130	125	25	0	0	0	0	10	24908.63	12690.3	0.0	0.0	1387.0	1200	187.0
16	455	455	95	20	25	0	0	0	0	10	21604.18	11759.4	0.0	0.0	1332.0	1050	282.0
17	455	455	45	20	25	0	0	0	0	0	20760.18	11606.6	0.0	0.0	1332.0	1000	332.0
18	455	455	120	20	25	0	25	0	0	0	23203.93	12192.8	0.0	0.0	1417.0	1100	317.0
19	455	455	130	90	25	0	25	0	10	0	26427.17	13026.4	0.0	0.0	1527.0	1200	327.0
20	455	455	130	130	162	0	48	0	10	10	30545.95	13658.7	0.0	0.0	1527.0	1400	127.0
21	455	455	130	130	95	0	25	0	10	10	27575.09	13008.7	0.0	0.0	1472.0	1300	172.0
22	455	455	130	40	0	20	0	0	0	0	22406.52	12008.9	0.0	0.0	1250.0	1100	150.0
23	455	415	0	0	0	20	0	0	10	0	18408.08	10485.4	0.0	0.0	1045.0	900	145.0
24	455	325	0	0	0	20	0	0	0	0	15896.11	8312.3	0.0	0.0	990.0	800	190.0

Table-2 Unit Commitment using HSA without V2G for 10 unit system
Total Fuel Cost : 5,73,879.3431 $ Total Emission Cost : 2,84,779.9490 ton Total Cost : 11,95,083.9293 $

Cost	HSA			BPSO			Saving increased
	With V2G	Without V2G	Saving	With V2G	Without V2G	Saving	Percentage (%)
Running Cost ($)	5,54,134.59	5,73,879.34	19,744.15	5,59,367.06	5,65,325.94	5958.88	30.18
Emission Cost (ton)	2.76,987.53	2,84,779.94	7792.41	2,57,391.18	2,60,066.35	2675.17	34.33

Table – 3 Comparision of running cost and emission cost for HSA and BPSO algorithm

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 Harmony Search Algorithm (HSA) provides better numerical results than 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. In future, there is much more practical constraints have to be reconsidered, which will lead to more realistic results.

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