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A Novel Approach for the Unit Commitment with Vehicle-to-grid

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Abstract – The electrical vehicles (EV) with vehicle-to-grid (V2G) capability can be used as loads, energy sources and energy storage in MicroGrid integrated with renewable energy sources. The output power of generators will be reallocated in the considering of V2G. An intelligent unit commitment (UC) with V2G for cost optimization is presented in this paper. A new constraint of UC with V2G is considered to satisfy daily use of EVs. A hybrid optimization algorithm combined Binary Particle Swarm Optimization (BPSO) with Lagrange Multipliers Method (LMM) is proposed. The difference between results of UC with V2G and UC without V2G is presented.

Keywords: Lagrange multiplier, Particle Swarm Optimization (PSO), Unit commitment, Vehicle to Grid (V2G).

1. Introduction

Unit commitment (UC) is a very significant optimization task in the daily operation planning of power systems. The basic goal of the UC problem is to schedule the on/off status of all the units in the systemfor a given time horizon. In addition to fulfill a number of constraints, the optimal UC should meet the predicted load demand which is calculated in advance, plus the spinning reserve requirement at every time interval such that the total operating cost is minimum. The UC problem is formulated as a combinatorial optimization problem with 0-1 variables which represents on/off status and continuous variables which represents unit power.The exact solution to the UC problem can be obtained by complete enumeration, which is prohibitive owing to its excessive computational time requirement for realistic power systems [1]. Several solution methods have been proposed to solve the UC problem, such as priority list (PL) [2],branch-and-bound (BB) [3], dynamic programming (DP) [4],Lagrangian relaxation (LR)[5, 6], Evolutionary algorithms (EA)[7-18]. The PL methods are very fast, but they are highly heuristic and give schedules with relatively high operating cost. The BB methods have the danger of a deficiency of storage capacity and increasing the calculation time enormously for a largescale UC problem.The DP method is able to solve problems of a variety ofsizes. But it may lead to more mathematical complexity andincrease in computation time, if the constraints are taken intoconsideration.The LR methods concentrate on finding an appropriate co-ordination technique for generating feasible primal solutions, while minimizing theduality gap. Themain problem with the LR methods is the difficulty encounteredin obtaining feasible solutions.The EA methods, such as genetic algorithm(GA) and particle swarm optimization (PSO), are iterativesearch technique that can search not only local optimalsolution but also global optimal solution and can deal with variousconstraints. The GA methods have been implemented by variousresearchers for the solution of the UC problem. However, the disadvantageof this method is long execution time, and there isno guarantee it will converge to the optimal solution.In solving the UC problem by PSO, the particles do not requireany repair strategies for satisfying the constraints withoutdisturbing the optimum process. As a result, the algorithmis capable of exploring the search space andgenerating quality solutionsefficiently. The comparison results show thatthe PSO is more efficient than GA, which could obtain the globaloptimum solution with much more possibility[18].

As plug-in hybrid vehicles (PHEVs) and all-electric vehicles (EVs) are getting popular, vehicle-to-grid (V2G) will play an important role in power grid, which can be seen as an energy storage unit [19-21]. The EVs which have the capability of connecting to grid are called Plug-in Electric Vehicles (PEVs). UC is known as one of the most difficult problems in power systems optimization. UC with V2G is Gen more complex than typical UC of conventional generating units [7].

The problem of UC with V2G has been researched on

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several papers [7, 22-24]. Cost and emission reduction, and reliability study of UC with V2G have been published in the past few years. Nevertheless, there are still many problems to be discussed in this area along with the growth of PEV's popularity. In this paper, an extra constraint which considers daily power consumption of PEVs is presented, and a hybrid optimization algorithm combined BPSO with LMM is also proposed. The rest of the paper is organized as follow. In Section II, problem formulation and constraints of UC with V2G are discussed. The proposed algorithm, applied distributions and important operations are explained in Section III. Simulation results are reported in Section IV. Finally, conclusion is drawn in Section V.

2. Problem Formulation

2.1 Nomenclature and acronyms

The following notations are used in this paper.

C_{SCi}	Cold start-up cost of unit i
D_t	Demand power at time t
E_{PEV}^{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 (1/0 for on/off)
N	Number of units
$N_{V2G}(t)$	Number of vehicles connected to thegrid 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
$P_i^{\max/\min}$	Maximum/minimum output limit of unit i
$P_i^{\max}(t)$	Maximum output power of unit i at time t
$P_i^{\min}(t)$	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
$P_{V2G}(t)$	Power generated/consumed by PEVs at time t
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 time t
T_{ion}^t	Duration of continuous on-line of unit i at time t
T_{idown}	Minimum down time of unit i
T_{icold}	Cold start-up time of unit i
λ_t	Lagrange multiplier at time t

2.2 Objective function

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. The cost includes mainly fuel cost and start-up cost.

2.2.1 Fuel Cost

Fuel cost of athermal unit can be expressed as a second orderfunction of each unit output as follows:

$$FC_i(P_i(t)) = a_i + b_i P_i(t) + c_i P_i^2(t) \tag{1}$$

Where a_i, b_i and $c_i$are positive fuel cost coefficients.

2.2.2 Start-up Cost

The start-up cost is a function of the number of hours during which the unit has been down. Hereinafter, a simplified time-dependent start-up cost is adopted:

$$SC_i(t) = \begin{cases} H_{SCi} : T_{idown} < T_{ioff}^t < T_{idown} + T_{icold} \\ C_{SCi} \ : T_{ioff}^t > T_{idown} + T_{icold} \end{cases} \tag{2}$$

The objective function for a cost optimization of UC-V2G could be expressed as:

Min TC = fuel cost + star-up cost

$$= \sum_{i=1}^{N} \sum_{t=1}^{H} [FC_i(P_i(t)) + SC_i(1 - I_i(t-1))] \tag{3}$$

2.3 Constraints

The constraints of UC-V2G must be satisfied during the optimization process. They are described as follows:

2.3.1 Power Balance Constraint

$$\sum_{i=1}^{N} I_i(t)P_i(t) + P_{V2G}(t) = D_t + Losses \tag{4}$$

2.3.2 Spinning Reserve Constraint

$$\sum_{i=1}^{N} I_i(t)P_i^{\max}(t) + P_v^{\max} N_{V2G}(t) \geq D_t + R_t \tag{5}$$

2.3.3 Generation Limit

$$P_i^{\min} \leq P_i(t) \leq P_i^{\max} \tag{6}$$

2.3.4 Minimum up/down time

Once a unit is committed/uncommitted, there is a minimum time before it can be uncommitted/committed.

$$\begin{cases} (1 - I_i(t+1))MU_i \leq X_i^{on}(t), & if\ I_i(t) = 1 \\ I_i(t+1))MD_i \leq X_i^{off}(t), & if\ I_i(t) = 1 \end{cases} \tag{7}$$

2.3.5 Ramp Rate Constraint

For each unit, output is limited by ramp up/down rate at eachhour as follows:

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

Where $P_i^{\min}(t) = \max(P_i(t-1) - RDR_i, P_i^{\min})$ and $P_i^{\max}(t) = \min(P_i(t-1) + RDR_i, P_i^{\max})$.

2.3.6 Availability of the PEVs

Not all the PEVs can charge/discharge at the same time. For reliable operation and control, only a certain number of vehicles will charge/discharge at a time. In this study, the percentage is 10%.

2.3.7 Charging/Discharging Frequency

In view of battery lifetime, charging/discharging frequency of PEV is set to 1.

2.3.8 Efficiency

The convert efficiencies from grid to vehicle and from vehicle to grid should be considered.

2.3.9 PEV Power Balance

In MicroGrid application, the electric power of EV is obtained from the same grid and consumed on daily driving. The total difference between charging and discharging power should meet the daily power consumption of PEVs.

$$\sum_{t=1}^{H} P_{cha}(t) - \sum_{t=1}^{H} P_{dis}(t) = E_{PEV}^{con} \sum_{t=1}^{H} N_{V2G}(t) \tag{9}$$

3. Proposed Novel 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’ (unit ON). 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.Lagrange Multiplier Method (LMM) is used during this process.

3.1 Binary Particle Swarm Optimization

Particle Swarm Optimization (PSO) was introduced by James Kennedy and RusselEberhart in 1995 [25]. PSO is inspired by particles moving around in the search space. The individuals which are called particles in a PSO have own positions and velocities. The PSO refines its search by attracting the particles to positions with better solutions. Each particle remembers its own best position in the process. This position is called personal best and is denoted by *pbest*in (10). Among these *pbests*, there is only one particle that has the best fitness, which is called the global best and is denoted by *gbest*in (10). The velocity and position of *i*thdimensionare calculated as below.

$$\begin{aligned} V_i = c_0 \cdot V_{i-1} + c_1 \cdot rand_1() \cdot (pbest_{i-1} - X_{i-1}) \\ + c_2 \cdot rand_2() \cdot (gbest_{i-1} - X_{i-1}) \end{aligned} \tag{10}$$

$$X_i = X_{i-1} + V_i \tag{11}$$

Where c_0 is the inertia weight, $rand_1()$ and $rand_2()$ are uniform random number between 0 and1, c_1 and c_2 are acceleration constant.

The original version of PSO operates on real values. The BPSO was presented to solve optimization problems that are set in discrete space [26].In BPSO, X_i and *pbest*can take on values of 0 or 1 only. The velocity V_i will determine a probability threshold. If the velocity is higher, the individual is more likely to choose 1, and lower values favor the 0 choice. The threshold is calculated by the sigmoid function which is defined as follows:

$$s(V_i) = \frac{1}{1+\exp(-V_i)} \tag{12}$$

Then a random number from 0.0 to 1.0 is generated. $X_i$is set to 1 if the random number is less than the value from (12). The main difference between BPSO and PSO is equation (13) replacing(11):

$$\begin{aligned} &If\ rand() < s(V_i),\ then\ X_i = 1, \\ &\qquad\qquad\quad else\quad X_i = 0. \end{aligned} \tag{13}$$

3.2 Lagrange Multiplier Method

Lagrange Multiplier Method (LMM) provides a strategy for finding the local maximum/minimum of a function subject to equality constraints.

Consider the optimization problem maximize *f(x, y)*, subject to *g(x, y=c* .A new variable λ called Lagrange multiplier is introduced to define Lagrange function as follows.

$$\Lambda(x,y,\lambda) = f(x,y) + \lambda\cdot(g(x,y)-c) \tag{14}$$

Solve

$$\nabla_{x,y,\lambda}\Lambda(x,y,\lambda) = 0 \tag{15}$$

The solution of (15) is also the solution of the original problem.

3.3 Economic Dispatch

In this study, Lagrange multiplier is calculated as follows:

$$\lambda_t = \frac{2D_t + S_{t,i}\cdot\sum_{i=1}^{N}\frac{b_i}{a_i}}{S_{t,i}\cdot\sum_{i=1}^{N}\frac{1}{a_i}} \tag{16}$$

Where ***S***is the status matrix, $\boldsymbol{S_{t,i}}$represents the *(t,i)*thentry of ***S.***

The output power of unit *i*at time *t* is

$$P_i(t) = S_{t,i}\cdot\frac{\lambda_t - b_i}{2a_i} \tag{17}$$

The Economic Dispatch (ED) would dispatch appropriate power to all committed units in the purpose of minimizing the operating cost in each hour. Considering of constraints, not every status matrix would have a dispatch solution. To optimize ED process, each status matrix would be divided into possible matrix and ill-condition matrix based on whether they satisfier power balance constraint under max/min limit. For the possible matrix, an economic dispatch would be calculated through LMM. For the ill-condition one, a preset ‘large’ fitness value would be assigned to eliminate the particle in next generation of BPSO. Therefore, ED process operates much more efficiently.

The solution of (17) may violate (6). If so, the maximum or minimum output power of unit*i*will be selected to be the actual output depends on which limit does the solution violate.

3.4 Data Structure and Algorithm

In the proposed method, each BPSO particle has the following components for UC-V2G problems,

Particle P_i
{
Status matrix: An $H\times N$ binary matrix;
Vehicle: An $H\times 1$ integer column vector;
Velocity: An $H\times(N+1)$ real-valued matrix;
Fitness: A real-valued cost;
}

The steps of proposed method are showed in Fig. 1 and described briefly as bellow:

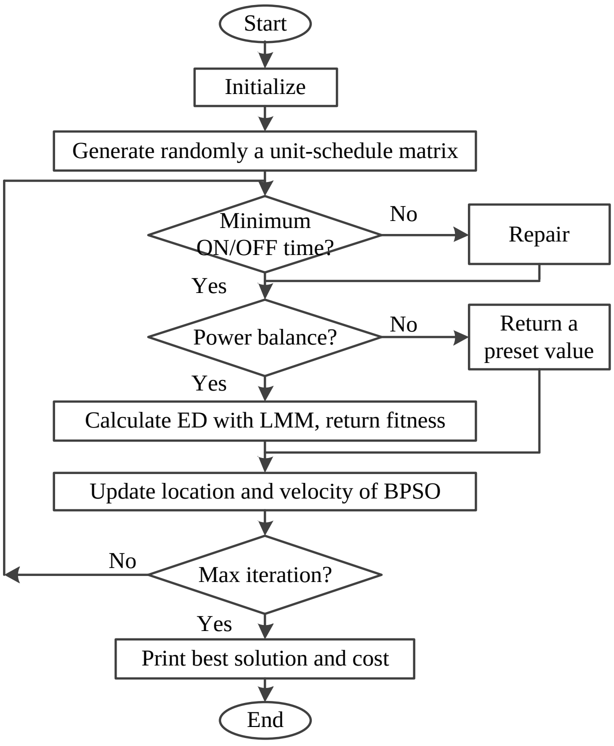

Fig. 1. Flowchart of proposed algorithm

Step1: Initialization

- Initialize parameters of systems, like number of units, schedule hours, swarm size, inertia weight and acceleration constant, etc.
- Generate randomly a status matrix.
- Initialize random velocities for all particles.

Step 2: Transition. Calculate velocity and location in all dimensions of the current swarm and generate status matrix by using (10) to (13).

Step 3: Repair. Repair each particle location if any constraint is violated. For the ill-condition matrix, aforementioned method is applied to accelerate the repairingprocess.

Step 4: ED. ED would be conducted by the presented LMM for each particle. All constraints are satisfied.

Step 5: Evaluate fitness. Evaluate feasible location in the swarm using the objective function. Update location, velocity, *pbest*, and*gbest* of BPSO.

Step 6: Check and stop/continue. Print the best solution and stop if max iteration number is reached; otherwise increase iteration generation number and go back to Step 2.

4. Numerical Studies

All calculations have been run on Intel(R) Core(TM)2 Duo 3.00GHz CPU, 1.99GB RAM, Microsoft Windows XP OS and MATLAB(R2011a).

A 10-unit with 24-hour demand system which was studied in [8, 9] and typicalPEVs discussed in [23] are considered for the numerical studies. Two scenarios are considered in numerical studies. In the first scenario, V2G is considered in UC problem of MicroGrid，both characteristics of charging and discharging are studied. The proposed method optimizes the output power of PEVs and generators in each hour in order to minimize the objective function considering the aforementioned constraints. In the second scenario, no PEV is connected in gird.

The parameter values used in this paper are as follows: the spinning reserve requirement is assumed to be 10% of the load demand, and the scheduling period is 24 hours. Total number of vehicles =50000, $N_{V2G}^{\max}(t)$ =10% of total vehicles,rated power of PEVs, $P_{PEV} = 15\,kW$, battery capacitor, $P_{bat} = 15\,kWh$,daily energy consumption, $E_{PEV}^{con} = 7.5\,kWh$,charging-discharging frequency =1 per day, converter efficiency =85%, average discharge depth of battery, $SoC = 15\%$, total charging energy $E_{char} = 662 MWh$, discharging energy $E_{dis} = 223 MWh$,Swarmsize =30, iteration number =1000, inertia weight c_0 =0.9, acceleration constant $c_1 = c_2$ =1.49618.

Table 1. Dispatch Schedule and Reserve Power of UC with 50,000 PEVs

Time (H)	U-1 (MW)	U-2 (MW)	U-3 (MW)	U-4 (MW)	U-5 (MW)	U-6 (MW)	U-7 (MW)	U-8 (MW)	U-9 (MW)	U-10 (MW)	Vehicles (MW)	Max. Capacitor (MW)	Demand (MW)	Reserve (MW)
1	455.0	305.3	0	0	0	0	0	0	0	0	-60.3	910.0	700.0	210.0
2	455.0	345.1	0	0	0	0	0	0	0	0	-50.1	910.0	750.0	160.0
3	455.0	413.0	0	0	25.0	0	0	0	0	0	-43.0	1072.0	850.0	222.0
4	455.0	455.0	0	0	86.1	0	0	0	0	0	-46.1	1072.0	950.0	122.0
5	455.0	442.4	0	130.0	25.0	0	0	0	0	0	-52.4	1202.0	1000.0	202.0
6	455.0	398.6	130.0	130.0	25.0	0	0	0	0	0	-38.6	1332.0	1100.0	232.0
7	455.0	443.5	130.0	130.0	25.0	0	0	0	0	0	-33.5	1332.0	1150.0	182.0
8	455.0	443.9	130.0	130.0	25.0	0	0	0	0	0	16.1	1348.1	1200.0	148.1
9	455.0	455.0	130.0	130.0	89.4	20.0	0	0	0	0	20.6	1432.6	1300.0	132.6
10	455.0	455.0	130.0	130.0	158.6	20.0	25.0	10.0	0	0	16.4	1568.4	1400.0	168.4
11	455.0	455.0	130.0	130.0	162.0	55.3	25.0	10.0	10.0	0	17.7	1624.7	1450.0	174.7
12	455.0	455.0	130.0	130.0	162.0	75.2	25.0	10.0	10.0	0	48.8	1655.8	1500.0	155.8
13	455.0	455.0	130.0	130.0	159.8	20.0	25.0	10.0	0	0	15.2	1567.2	1400.0	167.2
14	455.0	455.0	130.0	130.0	88.0	20.0	0	0	0	0	22.0	1434.0	1300.0	134.0
15	455.0	447.5	130.0	130.0	25.0	0	0	0	0	0	12.5	1344.5	1200.0	144.5
16	455.0	354.6	130.0	130.0	25.0	0	0	0	0	0	-44.6	1332.0	1050.0	282.0
17	455.0	337.7	130.0	130.0	25.0	0	0	0	0	0	-77.7	1332.0	1000.0	332.0
18	455.0	393.9	130.0	130.0	25.0	0	0	0	0	0	-33.9	1332.0	1100.0	232.0
19	455.0	445.2	130.0	130.0	25.0	0	0	0	0	0	14.8	1346.8	1200.0	146.8
20	455.0	455.0	130.0	130.0	151.6	20.0	25.0	10.0	0	0	24.4	1586.4	1400.0	186.4
21	455.0	455.0	130.0	130.0	70.5	20.0	25.0	0	0	0	14.5	1511.5	1300.0	211.5
22	455.0	455.0	0	0	162.0	35.5	25.0	0	0	0	-32.5	1237.0	1100.0	137.0
23	455.0	455.0	0	0	0	63.3	0	0	0	0	-73.3	1045.0	900.0	145.0
Total operating cost=$568,045														

Table 2. Dispatch Schedule and Reserve Power of UC without PEVs

Time (H)	U-1 (MW)	U-2 (MW)	U-3 (MW)	U-4 (MW)	U-5 (MW)	U-6 (MW)	U-7 (MW)	U-8 (MW)	U-9 (MW)	U-10 (MW)	Vehicles (MW)	Max. Capacitor (MW)	Demand (MW)	Reserve (MW)
1	455.0	245.0	0	0	0	0	0	0	0	0	0	910.0	700.0	210.0
2	455.0	295.0	0	0	0	0	0	0	0	0	0	910.0	750.0	160.0
3	455.0	370.0	0	0	25.0	0	0	0	0	0	0	1072.0	850.0	222.0
4	455.0	455.0	0	0	40.0	0	0	0	0	0	0	1072.0	950.0	122.0
5	455.0	390.0	0	130.0	25.0	0	0	0	0	0	0	1202.0	1000.0	202.0
6	455.0	360.0	130.0	130.0	25.0	0	0	0	0	0	0	1332.0	1100.0	232.0
7	455.0	410.0	130.0	130.0	25.0	0	0	0	0	0	0	1332.0	1150.0	182.0
8	455.0	455.0	130.0	130.0	30.0	0	0	0	0	0	0	1332.0	1200.0	132.0
9	455.0	455.0	130.0	130.0	85.0	20.0	25.0	0	0	0	0	1497.0	1300.0	197.0
10	455.0	455.0	130.0	130.0	162.0	33.0	25.0	10.0	0	0	0	1552.0	1400.0	152.0
11	455.0	455.0	130.0	130.0	162.0	73.0	25.0	10.0	10.0	0	0	1607.0	1450.0	157.0
12	455.0	455.0	130.0	130.0	162.0	80.0	25.0	43.0	10.0	10.0	0	1662.0	1500.0	162.0
13	455.0	455.0	130.0	130.0	162.0	33.0	25.0	10.0	0	0	0	1552.0	1400.0	152.0
14	455.0	455.0	130.0	130.0	85.0	20.0	25.0	0	0	0	0	1497.0	1300.0	197.0
15	455.0	455.0	130.0	130.0	30.0	0	0	0	0	0	0	1332.0	1200.0	132.0
16	455.0	310.0	130.0	130.0	25.0	0	0	0	0	0	0	1332.0	1050.0	282.0
17	455.0	260.0	130.0	130.0	25.0	0	0	0	0	0	0	1332.0	1000.0	332.0
18	455.0	360.0	130.0	130.0	25.0	0	0	0	0	0	0	1332.0	1100.0	232.0
19	455.0	455.0	130.0	130.0	30.0	0	0	0	0	0	0	1332.0	1200.0	132.0
20	455.0	455.0	130.0	130.0	162.0	33.0	25.0	10.0	0	0	0	1552.0	1400.0	152.0
21	455.0	455.0	130.0	130.0	85.0	20.0	25.0	0	0	0	0	1497.0	1300.0	197.0
22	455.0	455.0	0	0	145.0	20.0	25.0	0	0	0	0	1237.0	1100.0	137.0
23	455.0	425.0	0	0	0	20.0	0	0	0	0	0	1045.0	900.0	145.0
Total operating cost=$562,838														

The optimization results of two scenarios are showed in Table I and Table II. According to Table I, the minus value of PEVs indicates charging, and the plus value indicates discharging. PEVs are charged from the grid at off-peak load during the 1st-7th, 16th-18th, and 22nd-24th hours. On the other hand, PEVs are discharged to the grid at peak load during the 8th-15th and 19th-21st hours. Fig.2 shows the distribution of PEVs in 24 hours. The maximum charging and discharging are at 12 P.M. and 5 P.M. The results match the daily life that PEVs will get charged before commute time. Compare Table I and Table II, unit 7 need to generate power at peak load such as 9th and 14th hours without V2G, unit 10 generates at 12th hours. That's because with the help of power from V2G, the output power needed from generators is reduced. Some expensive generator could be shut down.

In 24 hours, the total energy between the PEVs and MicroGrid is -439*MW*, which indicates the PEVs obtaining power from the grid, consuming on the driving and converting process.

With regard to total operating cost of generators (including start-up cost), cost of MicroGrid with V2G is $568,045. Meanwhile, cost of MicroGrid without V2G is $562,838. The 1streason is that in MicroGrid application, the PEVs consume extra electrical energy as mentioned.The 2nd reason is that converting efficiencies from bothdirections are considered. In a word, V2G in MicroGrid needs extra power, and increase the operatingcost. In other paper [7], PEVs areconsidered as pure generating units, so the conclusion is opposite. Fig.3 shows the convergence of the approach for the two scenarios. After 500 interations, the optimization result is stable. Also, we can see the difference of operating cost between the two scenarios intuitively.

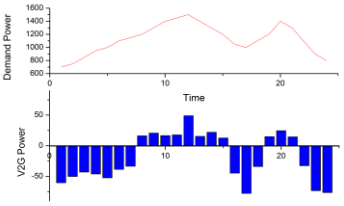

Fig. 2. Power of PEVs charging/discharging in 24 hours in

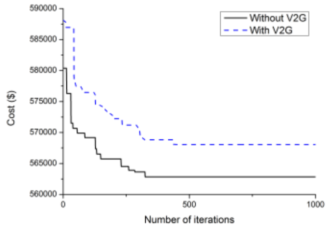

Fig. 3. Convergence of the proposed algorithm for UC with V2Gand UC without V2G

5. Conclusions

A novel approach for implementing the V2G in the short-term UC problem is presented in this paper. A new constraint of UC with V2G in MicroGrid application is considered to satisfy the general usage of PEVs. The approach to solve UC with V2G combines BPSO and Lagrange Multipliers Method. In dealing with power balance constraint, some improvements are applied to accelerate the optimization process. The problem of UC with V2G is studied in more details. Numerical study shows that in MicroGrid application, dispatch of traditional generators will be reallocated with the connecting of PEVs in order to reduce operating cost. Meanwhile, the total cost of generating would increase as the power used to be obtained from gasoline will be supplied from the MicroGrid. In future, there is still much scope to reconsider the problem with other piratical constraints or precise parameters, which will lead to more realistic results.

Reference

[1] A. J. Wood and B. F. Wollenberg, Power Generation Operation and Control. New York: Wiley, 1984.

[2] R. C. Johnson, H. H. Happ and W. J. Wright, "Large Scale Hydro-Thermal Unit Commitment-Method and Results," Power Apparatus and Systems, IEEE Transactions on, vol. PAS-90, pp. 1373-1384, 1971-01-01 1971.

[3] G. S. Lauer, N. R. Sandell, D. P. Bertsekas, and T. A. Posbergh, "Solution of Large-Scale Optimal Unit Commitment Problems," Power Apparatus and Systems, IEEE Transactions on, vol. PAS-101, pp. 79-86, 1982-01-01 1982.

[4] W. L. Snyder, H. D. Powell and J. C. Rayburn, "Dynamic Programming Approach to Unit Commitment," Power Systems, IEEE Transactions on, vol. 2, pp. 339-348, 1987-01-01 1987.

[5] S. Virmani, E. C. Adrian, K. Imhof, and S. Mukherjee, "Implementation of a Lagrangian relaxation based unit commitment problem," Power Systems, IEEE Transactions on, vol. 4, pp. 1373-1380, 1989-01-01 1989.

[6] A. J. Svoboda, T. Chung-Li, L. Chao-An, and R. B. Johnson, "Short-term resource scheduling with ramp constraints [power generation scheduling]," Power Systems, IEEE Transactions on, vol. 12, pp. 77-83, 1997-01-01 1997.

[7] A. Y. Saber and G. K. Venayagamoorthy, "Unit commitment with vehicle-to-Grid using particle swarm optimization," in PowerTech, 2009 IEEE Bucharest, 2009, pp. 1-8.

[8] B. Zhao, C. X. Guo, B. R. Bai, and Y. J. Cao, "An improved particle swarm optimization algorithm for unit commitment," International Journal of Electrical Power & Energy Systems, vol. 28, pp. 482-490, 2006.

[9] T. O. Ting, M. V. C. Rao and C. K. Loo, "A novel approach for unit commitment problem via an effective hybrid particle swarm optimization," Power Systems, IEEE Transactions on, vol. 21, pp. 411- 418, 2006-01-01 2006.

[10] A. Y. Saber, T. Senjyu, A. Yona, and T. Funabashi, "Unit commitment computation by fuzzy adaptive particle swarm optimisation," Generation, Transmission & Distribution, IET, vol. 1, pp. 456-465, 2007-01-01 2007.

[11] S. A. Kazarlis, A. G. Bakirtzis and V. Petridis, "A genetic algorithm solution to the unit commitment problem," Power Systems, IEEE Transactions on, vol. 11, pp. 83-92, 1996-01-01 1996.

[12] J. M. Arroyo and A. J. Conejo, "A Parallel Repair Genetic Algorithm to Solve the Unit Commitment Problem," Power Engineering Review, IEEE, vol. 22, p. 60-60, 2002-01-01 2002.

[13] K. S. Swarup and S. Yamashiro, "Unit commitment solution methodology using genetic algorithm," Power Systems, IEEE Transactions on, vol. 17, pp. 87-91, 2002-01-01 2002.

[14] I. G. Damousis, A. G. Bakirtzis and P. S. Dokopoulos, "A solution to the unit-commitment problem using integer-coded genetic algorithm," Power Systems, IEEE Transactions on, vol. 19, pp. 1165- 1172, 2004-01-01 2004.

[15] K. A. Juste, H. Kita, E. Tanaka, and J. Hasegawa, "An evolutionary programming solution to the unit commitment problem," Power Systems, IEEE Transactions on, vol. 14, pp. 1452-1459, 1999-01-01 1999.

[16] A. H. Mantawy, Y. L. Abdel-Magid and S. Z. Selim, "Integrating genetic algorithms, tabu search, and simulated annealing for the unit commitment problem," Power Systems, IEEE Transactions on, vol. 14, pp. 829-836, 1999-01-01 1999.

[17] C. Y. Chung, Y. Han and P. W. Kit, "An Advanced Quantum-Inspired Evolutionary Algorithm for Unit Commitment," Power Systems, IEEE Transactions on, vol. 26, pp. 847-854, 2011-01-01 2011.

[18] G. Zwe-Lee, "Discrete particle swarm optimization algorithm for unit commitment," in Power Engineering Society General Meeting, 2003, IEEE, 2003, pp. 424 Vol. 1.

[19] W. Kempton and S. E. Letendre, "Electric vehicles as a new power source for electric utilities," Transportation Research Part D: Transport and Environment, vol. 2, pp. 157-175, 1997.

[20] W. Kempton and J. Tomic, "Vehicle-to-grid power fundamentals: Calculating capacity and net revenue," Journal of Power Sources, vol. 144, pp. 268-279, 2005.

[21] W. Kempton and J. Tomic, "Vehicle-to-grid power implementation: From stabilizing the grid to supporting large-scale renewable energy," Journal of Power Sources, vol. 144, pp. 280-294, 2005.

[22] A. Y. Saber and G. K. Venayagamoorthy, "Intelligent unit commitment with vehicle-to-grid --A cost-emission optimization," Journal of Power Sources, vol. 195, pp. 898-911, 2010.

[23] A. Y. Saber and G. K. Venayagamoorthy, "Plug-in Vehicles and Renewable Energy Sources for Cost and Emission Reductions," Industrial Electronics, IEEE Transactions on, vol. 58, pp. 1229-1238, 2011-01-01 2011.

[24] T. Ghanbarzadeh, S. Goleijani and M. P. Moghaddam, "Reliability constrained unit commitment with electric vehicle to grid using Hybrid Particle Swarm Optimization and Ant Colony Optimization," in Power and Energy Society General Meeting, 2011 IEEE, Detroit, Michigan, USA, 2011, pp. 1-7.

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