Genetic Algorithm Based Cost-emission Optimization of Unit Commitment Integrating with Gridable Vehicles

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Abstract
This paper first proposes a multilayer framework of vehicle-to-grid (V2G) system based on the concept of gridable vehicles (GVs). GVs can draw and store energy from the power grid as loads, as well as feed energy back to the grid as resources. Then, unit commitment integrating with GVs is analyzed using the proposed framework. The objective is to minimize the total operating cost and emissions of the V2G system by intelligently scheduling the generating units and GVs based on the use of genetic algorithm. The results illustrate that the operating cost and emissions can be reduced and the system reserves can be enhanced by applying V2G.

Keywords
gridable vehicle, vehicle-to-grid, unit commitment, cost-emission optimization, genetic algorithm

1. INTRODUCTION
With the increase of air pollution, environmental and health problems have increased rapidly since past decades. One major source of air pollution can be attributed to vehicle emissions [Chan and Chau, 2001]. Since electric vehicles (EVs) is one of the most feasible approaches to significantly lower the consumption of oil and reduce the emissions, they will play an important role for the transportation in future [Chau and Chan, 1998; Chau et al., 2000; Chau et al., 1999; Chau and Wong, 2001; Chau and Wong, 2002; Wong et al., 2003; Wong et al., 2005; Wong et al., 2006].

The concept of vehicle-to-grid (V2G) was initially proposed in utility grid to buffer the power disturbance due to load variation and renewable energy sources. It is a bi-directional electrical grid interface that allows a gridable vehicle (GV) to take energy from the grid or feed it back to the grid. At present, V2G is usually applied to level or shave load, provide voltage or frequency regulation services, and improve power system stability. Three kinds of GVs are generally recognized, namely the battery EV, plug-in hybrid EV and range-extended EV [Chan and Chau, 1997; Jiang et al., 2002; Jiang et al., 2003; Chau and Wang, 2005; Chan et al., 2005; Chan et al., 2006; Chan and Chau, 2007].

The unit commitment (UC) problem in a power system involves determining the start up and shut down schedules of thermal generating units to meet forecasted demand over a future short term period. The objective is to minimize the total operating cost while observing the operating constraints. According to the concept of V2G, GVs can be charged from the power grid when power demand is low and discharged to supply the grid at peak hours instead of starting up some generating units. Figure 1 shows the effect of load variation when V2G is applied in the power system. During the off-peak conditions at night, GVs are considered as loads to be charged from the grid, hence leveling the low load [Kempton and Kubo, 2000]. And during the peak conditions at daytime, GVs can deliver power to shave the peak load [Tomic and Kempton, 2007]. Thus, the UC problem in a V2G system is to determine the start up and shut down schedules of generating units and GVs. The objective is not only to minimize the total operating cost, but also to minimize the total emissions at the same time.

This paper introduces a multilayer V2G system. And the UC with GVs will be analysed based on this sys-

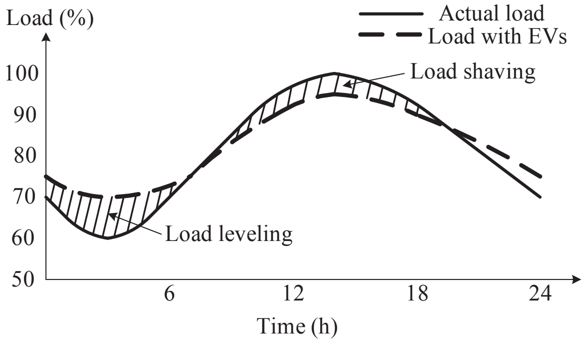

Fig. 1 Daily load with and without EVs

tem. It is to minimize the operating cost and emissions simultaneously by scheduling the operating units and GVs. This cost-emission optimization will be calculated by using the genetic algorithm (GA). The results of cost-emission reduction and spinning reserve improvement will be given.

2. V2G FRAMEWORK

Figure 2 shows the proposed framework of V2G. Generally, a multi-storey parking lot has about 300 parking places and the capacity of each GV is 5-20 kWh. Thus, the maximum energy capacity is up to 6 MWh when the parking lot is fully parked, which is remarkable to the power grid. Since only aggregated GVs can provide considerable energy to the power grid, the V2G framework is established based on the aggregation of GVs.

When the aggregated GVs act as resources, a significant capacity produced by them can affect the grid operator such as the independent system operator (ISO) and regional transmission organization (RTO). The control signal from ISO/RTO which operates the bulk power system delivers the request of power to the aggregated GVs through the aggregator. When the aggregated GVs act as loads, they also send the request of charge to the energy service provider (ESP) through the aggregator [Guille and Gross, 2009].

The aggregator is responsible for collecting a certain number of GVs into a single entity and interacting with the power grid. It contacts with ISO/RTO and ESP directly instead of the aggregated GVs. Moreover, it manages the capacity and energy service collected by the aggregation of GVs, and dispatches the aggregated GVs either to sell their capacity and energy service to the grid or to be charged from the grid.

The aggregator is the executor of the schedules derived from UC with GVs. It makes sure that a specified number of GVs will be connected to the power grid to provide power support. The aggregator also has the function of determining which GVs should participate in the aggregation. In general, the participation depends on their state of charge (SOC) [Shen et al., 2002; Chau et al., 2003; Chau et al., 2004; Chan et al., 2004; Shen et al., 2005], and the time and location that GVs can be connected to serve for the grid. Notice that the aggregation not necessarily consists of the GVs from the same parking lot or service station [Kempton and Tomic, 2005a].

3. COST-EMISSION OPTIMIZATION

Based on the framework of V2G, the total operating cost and emissions can be reduced by intelligently and efficiently scheduling the aggregation of GVs and the generating units. The cost-emission optimization refers to minimize the operation cost and emissions as well as to improve system reserve and reliability.

Due to the characteristic of quick response, V2G can perform instantaneous backup of intermittent renewable power [Kempton and Tomic, 2005b]. It is suitable to save high cost electrical equipment but not appropriate for providing base load power which can be supplied economically by large and continuously running generators. Therefore, the key of cost-emission optimization is to properly scheduling those small generating units and GVs. Although GVs can supersede some small and expensive generators, a large number of GVs may cause high cost [Chau and Chan, 2007; Chau et al., 2008; Zhang et al., 2008]. The objective of the optimization is to make the balance of the costs and emissions.

In this paper, fuel cost, start-up cost and shut-down cost are considered as operation cost of power system. All these costs and emissions can be expressed by the following functions [Saber and Venayagamoorthy, 2010].

- Fuel cost:

$$FC_i(P_i(t)) = a_i + b_i P_i(t) + c_i P_i^2(t) \qquad (1)$$

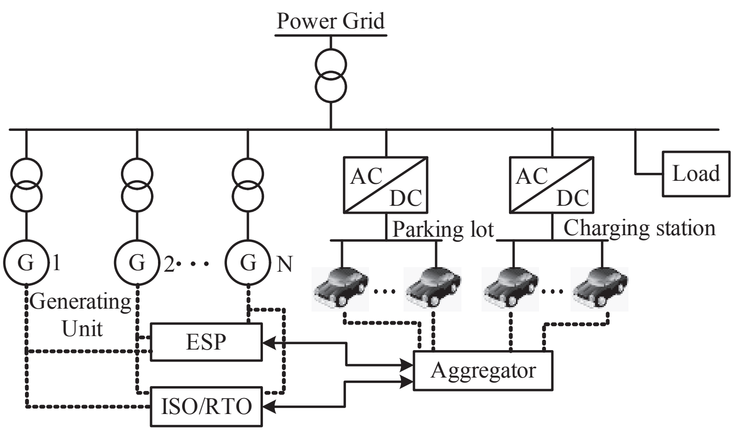

Fig. 2 Proposed V2G framework

- Start-up cost:

$$SC_i(t) = \begin{cases} hcost_i & MD_i \le X_i^{off}(t) \le H_i^{off} \\ ccost_i & X_i^{off}(t) > H_i^{off} \end{cases} \quad (2)$$

$$H_i^{off} = MD_i + cshour_i \quad (3)$$

- Shut-down cost:
  The shut-down cost does not vary with other parameters, and it is usually considered as zero for standard power systems.
- Emissions:

$$EC_i(P_i(t)) = \alpha_i + \beta_i P_i(t) + \gamma_i P_i^2(t) \quad (4)$$

The fuel cost and emissions are expressed as second order functions, where $P_i(t)$ represents the output power of ith unit at time t, $FC_i()$, $SC_i()$, $EC_i()$ represent the fuel cost function, start-up cost function and emissions function of unit i respectively, $hcost_i$ and $ccost_i$ represent the hot start-up cost and cold start-up cost of ith unit respectively, $cshour_i$ represents the cold start hour of ith unit, MD_i represents the minimum down time of ith unit, $X_i^{off}(t)$ represents the duration of continuously off of ith unit at time t, a_i, b_i, c_i are positive fuel cost coefficients of ith unit, and α_i, β_i, γ_i are emission coefficients of ith unit.
The fitness function for the cost-emission optimization of V2G system is given by:

$$\min TC = \sum_{i=1}^{N}\sum_{t=1}^{H}[w_c(FC_i(P_i(t)) + SC_i(1 - I_i(t-1))) + w_e(\psi_i EC_i(P_i(t)))]I_i(t) \quad (5)$$

where N is the number of units, H is the scheduling hours, $I_i(t)$ represents the status of ith unit at time t which is binary (1 for on, 0 for off), w_c, w_e are weight factors which equal 1 when cost or emission are included and equal 0 when they are not included in the fitness function, and ψ_i is the emission penalty factor of ith unit.
Therefore, the UC with GVs is an optimization problem, in which there are limited and restricted parking lots and a large number of GVs.
There are some constraints that must be considered during the optimization. Firstly, the scheduling period is set to 24 hours in this paper. The scheduling plan of the generating units and GVs is calculated at least one day before according to the previous power demand curves. And the total number of GVs can simultaneously connect to the power grid is fixed [Saber and Venayagamoorthy, 2010]. It is expressed as follow:

$$\sum_{t=1}^{H} N_{GV}(t) = N_{GV\max} \quad (6)$$

$$N_{GV}(t) \le N_{GV\max} \quad (7)$$

where $N_{GV}(t)$ is the number of GVs connected to the grid at the time t, and N_{GVmax} is the total number of GVs in the V2G system.
The SOC of each GV should be at a certain desirable level when GVs are plugged out. In fact, the owners can set the desirable SOC and lowest SOC limitation according to their needs. In order to avoid the lack of energy when GVs leave unexpectedly, the lowest SOC limitation is set to 60 % for the owners' convenient driving. Once a GV reaches the lowest SOC limitation, it should never be discharged below this level. And in order to protect the batteries of GVs, GVs are assumed to be discharged once within 24 hours.
On the other hand, the output power of the generating units and GVs must satisfy the load demand. Meanwhile, adequate spinning reserves should be maintained for system reliability:

$$\sum_{i=1}^{N} I_i(t)P_i(t) + P_{GV}N_{GV}(t) = D(t) \quad (8)$$

$$\sum_{i=1}^{N} I_i(t)P_{i\max}(t) + P_{GV\max}N_{GV}(t) \ge D(t) + R(t) \quad (9)$$

where P_{GV} represents the available capacity of each GV, P_{GVmax} is the maximum capacity of a GV, $P_{imax}(t)$ represents the maximum output power of unit i at time t, $D(t)$ is the load demand at time t, and $R(t)$ is the spinning reserve at time t.
In addition, the output power of each generating unit cannot be beyond its extreme boundaries. And the duration of a committed or uncommitted unit should not less than their minimum start up or shut down time, respectively:

$$P_{i\min} \le P_i(t) \le P_{i\max} \quad (10)$$

$$\begin{cases} MU_i \le X_i^{on}(t) \\ MD_i \le X_i^{off}(t) \end{cases} \quad (11)$$

where P_{imin} and P_{imax} represent the minimum and maximum output limits of ith unit, respectively, MU_i represents the minimum up time of ith unit, and $X_i^{on}(t)$ represents the duration of continuously on of ith unit at time t.

4. GENETIC ALGORITHM

In this paper, the GA is used to solve this constrained optimization problem. It is an adaptive search method based on natural selection, reproduction and mutation. Each population of individuals in GA represents a possible solution. A powerful global search is achieved by processing a set of genetic operators of crossover and mutation [Cheng et al., 2000].

4.1 Selection

The purpose of parent selection in GA is to give more reproductive chances to population members which have the global fitness. Figure 3 shows a binary string for each generating unit and GVs in this UC with GVs problem, where 1 and 0 in this string stand for the state of on and off, respectively. The length of the string stands for the scheduling period. GVs are considered as continuously on during the scheduling period.

Time	1	2	3	4	• • • •	T-1	T
Unit 1	1	1	1	0	• • • •	1	0
Unit 2	1	0	1	0	• • • •	0	0
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
Unit N	0	0	0	1	• • • •	0	1
GVs	1	1	1	1	• • • •	1	1

Fig. 3 Schedule of UC with GVs

4.2 Crossover

Crossover is a random process of recombination of strings. The chromosomes from two mating parents' strings are exchanged. Thus, GA is able to acquire more information with the generated individuals.

4.3 Mutation

Mutation is the occasional random alteration of the bits in the string. For the binary strings in UC with GVs, the state of a bit may be changed from 1 to 0 or vice versa.

4.4 Small generating units

Small generating units can be committed or uncommitted to the system in short intervals. However, the operating costs of them are expensive. So the on-time of them should be minimized. The committed order can be set as the ascending order of the operating cost. Namely, the unit of the lowest cost is committed first, and the most expensive unit is committed last. Nevertheless, GVs are able to be committed at anytime if the constraints are satisfied.

At each time period, the best solutions are saved and the relevant population is maintained in the next generation. If there is no feasible solution in some particular period, GA will repeat until at least one feasible combination is found. The optimal solution is obtained after completely calculating the UC-V2G schedules with fitness during the whole time period.

5. RESULTS

Generally, a standard 10-unit model is used to calculate UC. And the available power of GVs should reach the MW rate to affect the power grid. Thus, the cost-emission optimization is carried out on a system including 10 generating units and maximum 50000 available GVs. The time period is 24 hours. And the maximum number of iterations is set to 1000, which is enough to find a global fitness value. The parameters of GVs are shown in Table 1.

Table 1 Parameters of GV

Capacity of each GV: P_{GV}	15 kWh
Maximum No. of GVs at each hour: $N_{GV}(t)$	5000
Total No. of GVs: N_{GVmax}	50000
Lowest SOC limitation: φ	60 %

Figure 4 and Figure 5 show the fitness curves of UC without and with V2G. It can be seen that the fitness value of UC with GVs is less than that of UC without V2G. And the fitness curve of UC with GVs is smoother than that of UC without V2G.

Figure 6 shows the load demand, the maximum capacity of UC without V2G and the maximum capacity of UC with GVs, respectively. Figure 7 shows the spinning reserves of UC with and without V2G. It can be seen that both UC without and with V2G fulfill the load demand as well as maintain the spinning reserves. Moreover, the maximum capacity of UC with GVs is more than that of UC without V2G at almost any hour in a day. It is obvious that the reserve

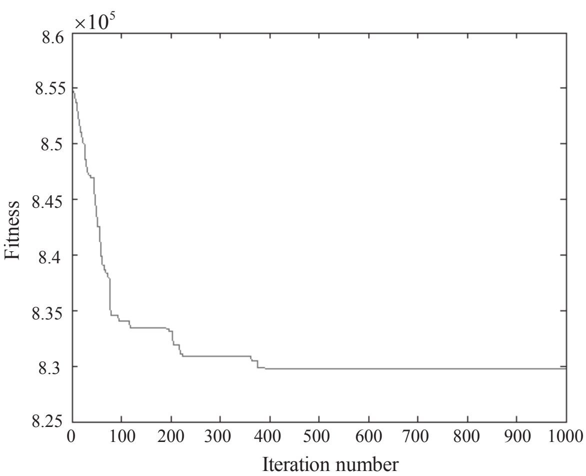

Fig. 4 Fitness of UC

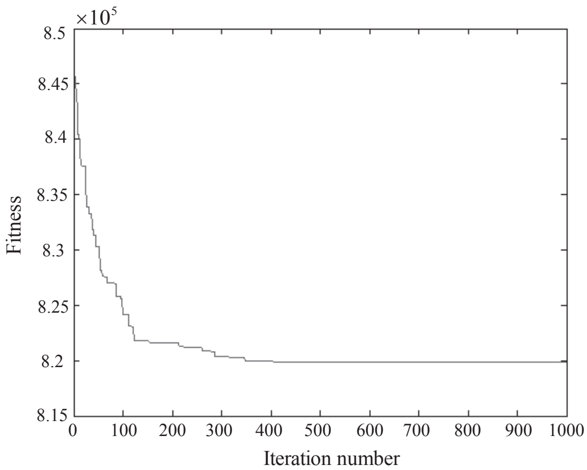

Fig. 5 Fitness of UC with GVs

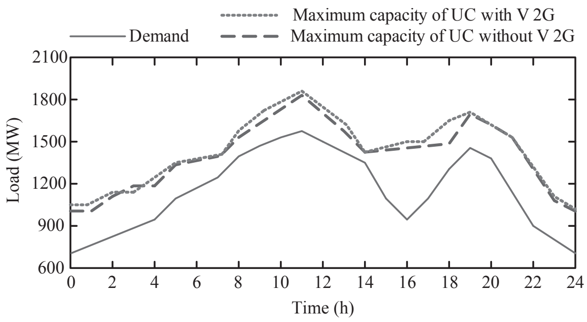

Fig. 6 Maximum capacity of UC with and without V2G

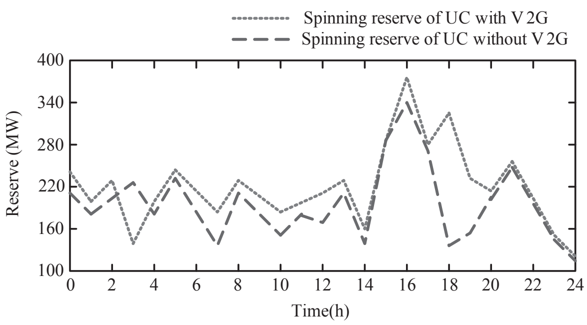

Fig. 7 Spinning reserves of UC with and without V2G

capability of UC with GVs is better than that of UC without V2G. Namely, the reliability of the system is improved when V2G is applied.

Table 2 shows the fitness value of UC with and without V2G, including the values of the operating costs and emissions. It can be seen that both the operating cost and emission are reduced by involving GVs into UC. Thus V2G helps the system save the operating cost of 5665.59 dollars a day. Meanwhile, it also helps the system reduce the emission of 4250.99 tons for one day.

Table 3 shows the output power of generating units and GVs during the scheduling period. It can be found that the output power of some generating units decrease when V2G are applied. It demonstrates that V2G can keep the system work as well as shut down some small and expensive generating units.

From the results, the operating cost and emission of the system are reduced by applying V2G. And the spinning reserves are increased to make the system more reliable.

Table 2 Fitness with and without V2G

	With V2G	Without V2G
Fitness	820071.91	829988.49
Cost ($)	560077.53	565743.12
Emission (ton)	259994.38	264245.37

Table 3 Output power of generating units and GVs during 24 hours

	Without V2G (MW)	With V2G (MW)
Unit 1	10920	10920
Unit 2	9249.8	9070.7
Unit 3	2480	2310
Unit 4	2651.5	2698.5
Unit 5	1225.6	1210.2
Unit 6	330	280
Unit 7	225	225
Unit 8	84.3	70.9
Unit 9	20	20
Unit 10	10	10
GVs	0	380.9

6. CONCLUSION

In this paper, a multilayer framework is proposed based on the concept of V2G. This framework fully utilizes the bidirectional characteristic of GVs. Once GVs are connected to the power grid, charging and discharging can extend to absorbing energy from the grid and delivering energy to the grid, respectively. The aggregator is introduced for collecting a certain number of GVs and artfully controlling the plug-in number and time of GVs. UC of generating units and GVs is analyzed on the proposed V2G system. The objective is to minimize the operating cost and emission of the system as well as improve the system reliability. GVs are committed to reduce the usage of small and expensive generating units. GA is used to implement this cost-emission optimization. And the results indicate that the operating cost and emission can be reduced simultaneously by applying V2G. In the meantime, the spinning reserve and reliability of the system are enhanced.

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