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Cost-Emission Analysis of Vehicle-to-Grid System

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Abstract

In recent years, electric vehicles (EVs) have been widely accepted by general publics due to their low emissions. Particularly, those EVs which are able to be connected to power grid have earned lots of attention. In this paper, a multilayer framework is newly proposed for vehicle-to-grid operation and cost-emission analysis is carried out based on this framework. Hence, operation cost and emissions can be reduced by using these gridable EVs. The key is to introduce particle swarm optimization to find out the optimal scheduling of generating units and gridable EVs.

Keywords: electric vehicle, cost-emission optimization, vehicle-to-grid, smart grid

1. Introduction

At present, vehicle emissions have great impact on air pollution [1]. Since electric vehicles (EVs) can highly reduce the emissions compared with traditional gasoline vehicles, EVs will play an important role for the transportation market [2]-[9].

Vehicle-to-grid (V2G) technology is a bi-directional electrical grid interface that allows a gridable EV to take energy from the grid or put it back on the grid [10]-[17]. Gridable EVs can charge from the power grid when power demand is low and can discharge to supply the grid when power is required. During the off-peak conditions at night, gridable EVs are considered as loads by being charged from the grid, hence leveling the low load [18]. At peak hours, some small and expensive generators have to be started up to fulfill the power demand. At this time, gridable EVs can feed back power to shave the peak load. Moreover, operation cost and emissions of power grid can be reduced by employing V2G. Due to the capability of energy storage and generation of gridable EVs, they can be used during peak hours instead of some small expensive generator, resulting in decreasing operation cost and emissions [19]-[20].

This paper proposes a multilayer framework of V2G concept, and cost-emission optimization analysis is carried out based on this framework.

2. Framework of V2G System

Generally, the capacity of the batteries on gridable EVs is usually 5-20 kWh. A single gridable EV cannot be a storage or generation device to the grid. However, the energy provided by a number of gridable EVs aggregated in a parking lot or service station will be significant to the power grid. Therefore the basic concept of this framework is the aggregation of gridable EVs. The aggregator is introduced in this framework,

which is responsible for collecting EVs and making them maintain a certain level to interact with the grid [21].
Fig.1 shows the proposed multilayer framework of V2G. The intergrid consists of the aggregator, independent system operator (ISO)/ regional transmission organization (RTO) and energy service provider (ESP). The aggregator is responsible for collecting a certain number of gridable EVs into a single entity and plays the role of controlling the power flow inside the intragrid. The aggregation of EVs in this framework is capable of supplying capacity and energy service requested by power grid. Meanwhile it can be connected to ESP to be charged from the grid.
The intragrid consists of these aggregated EVs, which exists for satisfying the electrical energy need inside the entity of aggregated EVs. The request of individual EV will be processed in the intragrid first. This EV should be charged from some other EVs if the collected capacity inside the intragrid allows. Those EVs whose status allows to selling power out can be operated by the aggregator to provide power to the needed EVs inside the intragrid.

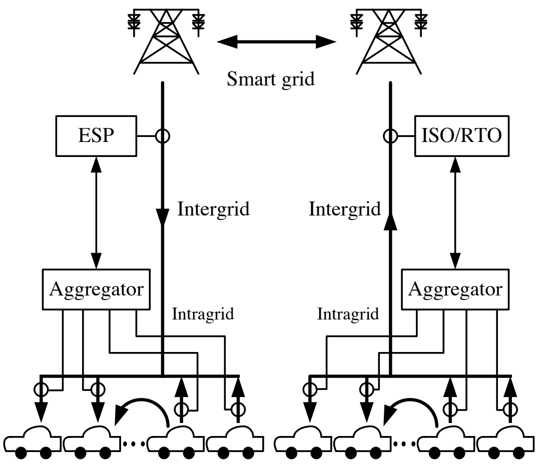

Figure 1: Proposed multilayer framework of V2G

The aggregator also has the function of determining which EVs should participate in the aggregation. In general, the participation depends on their state of charge [22]-[27], and the optimal time and location that EVs can be connected to serve for the grid [28].

Based on this multilayer framework of V2G, operation cost and emissions can be reduced by intelligently and efficiently scheduling the aggregation of gridable EVs and traditional generating units.

3. Cost-Emission Analysis

Usually base load power is provided by large and continuously running generating units and gridable EVs perform instead of some small and expensive generators. But a large number of EVs may cause high cost [29]-[31]. The key is to schedule those small generating units and gridable EVs properly.
In general, fuel cost, start-up cost and shut-down cost are considered as operation cost for standard power systems with V2G. The fitness function for cost-emission optimization is given by the following equation [32]:

$$\begin{aligned} \min TC &= w_c \times (Fuel + Start-up) + w_e \times Emission \\ &= \sum_{i=1}^{N}\sum_{t=1}^{H}[w_c(FC_i(P_i(t)) + SC_i(1-I_i(t-1))) \\ &\quad + w_e(\psi_i EC_i(P_i(t)))]I_i(t) \end{aligned} \tag{1}$$

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, 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 cost-emission analysis of V2G system is an optimization problem with some constraints such as forecast load demand, charging-discharging efficiency, state of charge and spinning reserve requirement.

4. Simulation and Discussion

In this paper, particle swarm optimization (PSO) is used to solve this complicated constrained optimization problem. In PSO, particles are the potential solutions, which fly through the problem space by following the current optimum particles. The fitness value is stored as *pbest*. When a particle takes all the population as its topological neighbors, there is a global best *gbest* [33].

Particle P_i consists of generating unit which is an $N \times H$ binary matrix X_i, gridable EVs which is an $H \times 1$ integer column vector Y_i, velocity which is an $(N+1) \times H$ real valued matrix V_i, and fitness which is a real-valued cost TC.

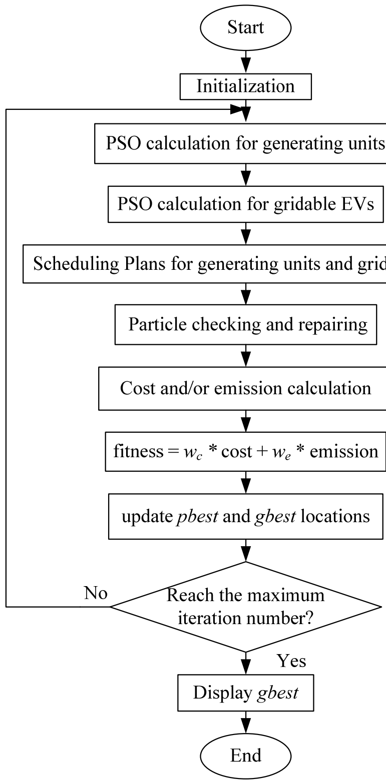

Figure 2: Flowchart of cost-emission PSO of V2G system

The flowchart of the entire system using PSO is shown in Fig.2. Firstly, initialize the $(N+1) \times H$ matrix for each particle randomly, set the parameters of the binary PSO for generating units and the integer number PSO for gridable EVs, and select the locations of *pbest* and *gbest*. Secondly, calculate the PSO of $N \times H$ binary matrix for generating units and $H \times 1$ integer column matrix for gridable EVs respectively for each particle, and obtain the outputs. According to the outputs of these calculations, a scheduling plan of generating units and gridable EVs can be generated. Thirdly, repair each particle if some of constraints are not obeyed perfectly. Finally, calculate the cost and emissions according to the operators' demand, and apply to the fitness function. A round of the algorithm is finished by updating *pbest* and *gbest* locations. Once the maximum iteration number is reached, the program will stop and display *gbest* solution.

In this paper, a system including 10 generating units and maximum 10,000 available gridable EVs are considered for cost-emission optimization simulation. The average battery capacity of gridable EV is 15 kWh. The population size of PSO is set to 30; the maximum number of iterations (epochs) is set to 1000; and the acceleration constants $c1$ and $c2$ are 2.5 and 3 respectively.

Cost-emission optimization simulation is applied to three different conditions. Fig.3 shows the result when cost and emission are considered in the fitness function simultaneously. In Fig.3, the fitness represents the total cost of the system, namely cost plus emission. The total cost decreases and ultimately converges. On the other hand, cost and emission separately fluctuates, but they get stable gradually with the number of iterations increasing. Emission varies more greatly than cost. The possible reason is that the second order coefficients of the emission are higher than those of the cost.

Fig.4 shows the result when only emission is considered in the fitness function. In Fig.4, since the cost is ignored in the fitness function, the fitness directly represents the emission of the system. Compared with the results of the situation cost and emission are considered simultaneously, the emission is reduced faster and does not fluctuate very often. However, the operation cost is higher, which probably illustrates those small and expensive generating units have to work even at off-peak hour while V2G may not be working. For practical systems, this kind of results may not be acceptable.

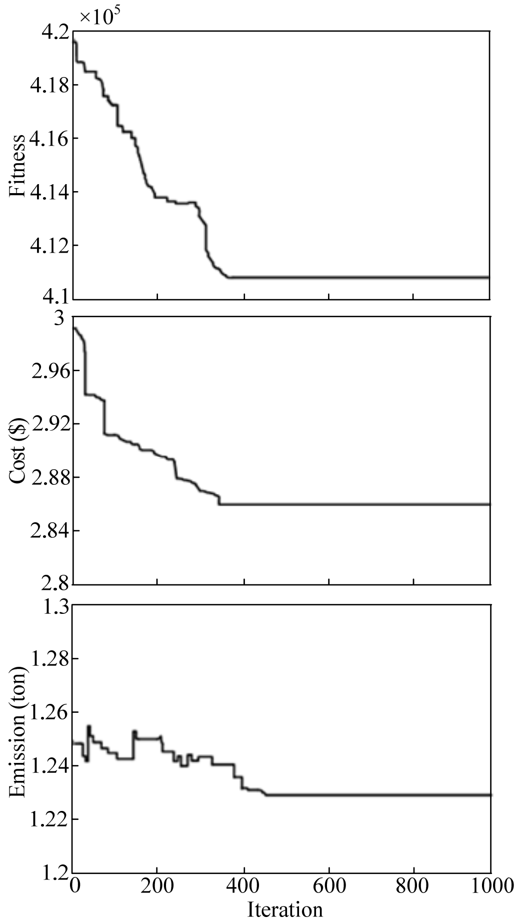

Figure 3: Cost plus emission in fitness function

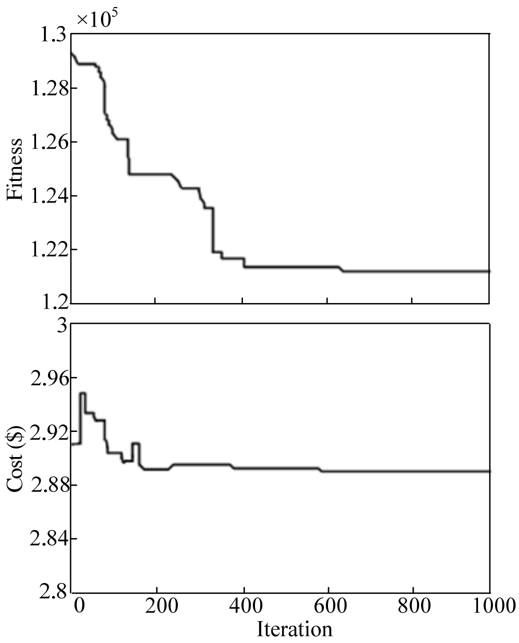

Figure 4: Only emission in fitness function

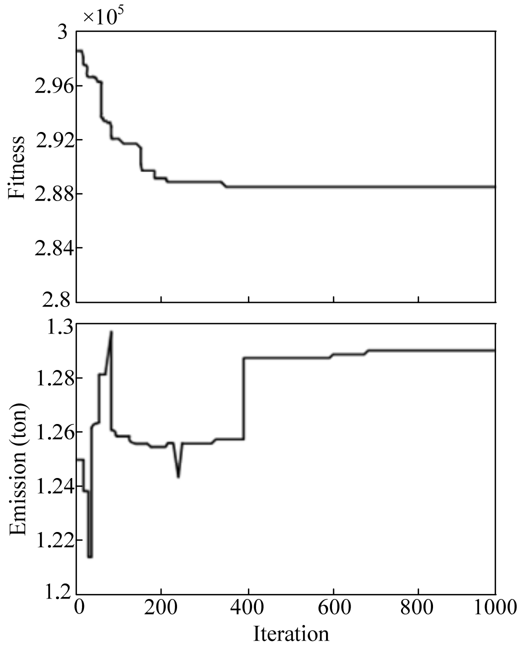

Figure 5: Only cost in fitness function

Fig.5 shows the result when only cost is considered in the fitness function. In Fig.5, since the emission is ignored in the fitness function, the fitness directly represents the operation cost of the system. Compared with the previous results, the operation cost decreases more rapidly and is lower than that of the situation only emission is considered. However, the emission fluctuates fiercely and is very high which definitely cannot be accepted by environment. In this case, gridable EVs are operated to provide energy to the grid as more as possible instead of those small generating units.

The results demonstrate that cost and emission can be balanced when they are simultaneously considered in the fitness function. Namely, generating units and gridable EVs should be simultaneously scheduled properly.

5. Conclusion

In this paper, a new multilayer framework has been developed to implement the concept of V2G. This framework fully utilizes the characteristics of gridable EVs with bidirectional batteries. Once they are connected to the power grid, charging and discharging can be extended to taking energy from the grid and feeding back energy to the grid respectively. Cost-emission optimization analysis is carried out on the proposed V2G framework since V2G can reduce the usage of small and expensive generating units and emissions. PSO is used to achieve the objective of making the balance of profit, emissions and reliability of power system and minimize the cost and emissions. Simulations are performed on three different situations and the results prove that the proposed multilayer grid with V2G is feasible and can reduce operation cost and emission.

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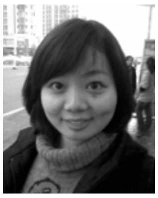

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