ANALAYTICAL ASSESSMENT OF MUTUAL IMPACTS BETWEEN PHEVs AND POWER GRID

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ABSTRACT

In this study, a list of feasible advantages and drawbacks of employing plug-in hybrid electric vehicles (PHEVs) is made. Then, to investigate precisely the mutual impacts of PHEVs and power grid as well as to determine the maximum penetration level of PHEVs various connection scenarios are reviewed. Besides, elaboration of aspects related to the coordinated connection is focused. Moreover, determination of the penetration level of PHEVs and online implementing of the energy management system as the two cases of the assessment objectives is explored. Further, optimizations in the aggregation based systems which are carried out at two levels are examined. At last, the objective functions, the constraints and the expected solutions of the optimization problems related to the coordinated connection as well as the appropriate computational methods to solve them are studied.

INTRODUCTION

Constantly increasing price of fuel, the air and environmental pollution, the negative impacts of greenhouse gas (GHG) emission on the ozonosphere, global warming phenomena, ever-growing consumer expectations, future energy security and knowing petroleum as a limited and finite resource are the most important concerns of the energy legislation and supplying entities. Thus, a great effort has been devoted to optimize the fuel consumption as well as to minimize the emission of toxic gases to let environment be green. Undoubtedly, employing electric vehicles can be considered as a feasible solution to the abovementioned issue [1]. Among the several types of electric vehicles, PHEVs seem to be the most promising that is going to take a noticeable percent of the vehicle market of the near future; thereby, considering the characteristics of the PHEV, the distribution level of power grids would be significantly affected. The capability of energy exchange with the electric power grids can be mentioned as the one of interesting and unique characteristics of PHEV [2].

The scope of this research is to provide a succinct paper that addresses various topics of interest related to PHEV connections to power grid. Among them, planning of connection scenarios to assess the possible effects of PHEVs on the grid is highly critical [3]. The scenario planning is figured out based on numerous conditions. This paper divides the connection scenarios in two categories, namely uncoordinated methods and coordinated methods. The elaboration of various aspects related to the coordinated connection of PHEVs to the grid as well as their impacts on the distribution level of the grid is focused. The coordinated connection is considered in two structures: the direct energy management system and the aggregation-based energy management system.

MERITS AND DRAWBACKS

PHEVs have gained a considerable attention because they contain all the capabilities of HEVs as well as the possibility of being charged through the use of a battery charger that is plugged in power grid. According to the mentioned facility, the battery capacity of PHEVs is augmented and thereby, they have the possibility to travel longer distances with the zero pollution state in comparison with HEVs. The most significant and unique aspect of PHEV is that the power flow in this vehicle can be bidirectional. The vehicle is able to take power from the grid during charging (G2V) and provide power to the grid during discharging (V2G) [4]. Thus, PHEVs are called the energy storages of smart power grids.

On the other hand, uncoordinated and uncontrolled connection of PHEVs to the grid can lead to some side effects like imposing an extra load on the grid as well as occurring voltage dip especially during the peak load hours. The advantages of employing PHEVs can be briefly listed as follow:

- Travelling longer distances under zero emission situation owing to the larger capacity of PHEV batteries
- Possibility of employing batteries included in PHEVs as the energy storages of future smart grids
- Peak shaving
- Preventing base load power plants to shut down during low demand hours
- Substituting for traditional providers of spinning reserves
- Enhancing controllability of the grid voltage
- Providing power quality services through the power electronics based interfaces of PHEVs
- Enhancing power reliability through performing as a backup power source
- Decreasing environmental pollutions
- Making profits through buying energy from the grid during low price hours and selling it back to the grid during high price hours
- Increasing penetration level of sustainable power sources with intermittent generation
- Providing possibility to charge the vehicles at home

The drawbacks of using PHEVs can also be written as:

- Voltage dip occurring in case of connecting the vehicles

to the grid during peak load hours
- Possibility of increasing amount of peak load
- Necessity of expanding power plants; especially the base load power plants
- Necessity of increasing rating of the grid devices such as cables, switches and transformers
- Increasing short circuit power of the grid buses and arising several protection difficulties

CONNECTION SCENARIOS

Because of considerable uncertainty related to PHEVs, various connection scenarios can be taken into account to investigate the mutual impacts of the vehicles and power grid. Generally, the connection scenarios can be divided in two categories, namely uncoordinated methods and coordinated methods. Scenarios of the former category are based on people's interest without any supervisor while scenarios of the latter are organized by a management system. Moreover, scenarios of each category can assume the power flow between PHEVs and power grid to be unidirectional or bidirectional. Some of significant factors in planning the connection scenarios are as follows:
- The understudy area and season
- Habitants' driving behavior
- Traffic and roads conditions
- Start time and duration of working hours
- Pattern of electricity pricing
- Possibility of energy discharging to the grid (V2G)
- Charging rate of batteries
- Efficiency of power electronics interfaces

Uncoordinated hourly connection profiles

In this section, a number of possible hourly connection profiles for plugging vehicles in power grids are provided. Because it is assumed that there is no supervisor, the following scenarios can be classified as uncoordinated connections. The charging time for a completely discharged battery is assumed to be about 6 hours. Besides, it is assumed that the duration of working hours is about 8 hours a day and starts from 8 o'clock in the morning. It should be noticed that positive and negative percentages in Fig. 1 indicate G2V and V2G power flows respectively.

Unidirectional power transfer

- Home charging: charging is exclusively possible at home and the charging begins as soon as the vehicles plugged in (Fig. 1.(a)).
- Tariff-based charging: based on the different electricity tariffs, vehicle charging happens during off-peak low-price hours of a day (Fig. 1.(b)). In addition, the charging possibility can be restricted to be only at home (Fig. 1.(c)).

Bidirectional power transfer

- Home connection: connection is exclusively possible at home (Fig. 1.(d)).
- Tariff-based connection: power exchange between the vehicles and the grid takes place according to the electricity price (Fig. 1.(e)). The vehicles should be plugged in to be charged during the low tariffs (G2V) and to be discharged during the high tariffs (V2G). In addition, the connection can be restricted to be exclusively at home (Fig. 1.(f)).

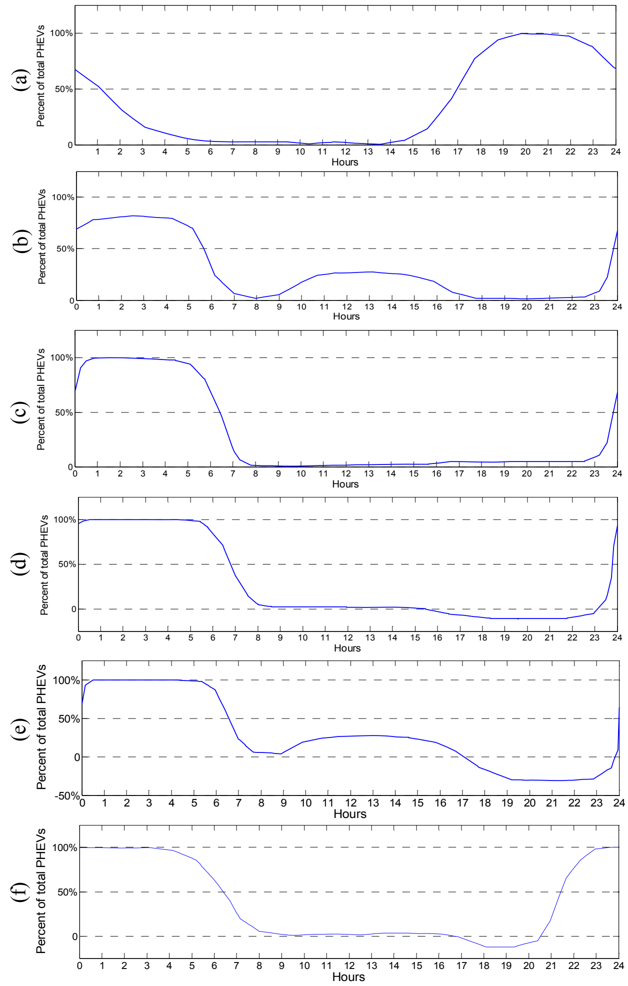

Fig. 1. Some samples of uncoordinated hourly connection scenarios

Evaluation methods

Under the uncoordinated connection scenarios, the step by step method is utilized to analyze the mutual impacts of the PHEVs and the grid besides to examine the maximum penetration level of PHEVs. By starting from the lower percentages of penetration level, this amount is increased step by step to reach the maximum possible that would not violate the considered constraints. Actually, it is essential to determine the special type of vehicle used in the investigation as well as the battery capacity and the rating of the charging current at first. Then, the number of the participated vehicles should be cleared based on the penetration level of the PHEVs and the power rating of the chargers. Afterwards the distribution pattern of the vehicles and connection point of them throughout the grid should be specified. The distribution methods of the vehicles include the following aspects:

- Stochastic distribution: to investigate the impacts of PHEVs on the power grid, under various situations, the distribution of the vehicles and the duration of their connection to the grid are specified in a stochastic manner. In case the considered constraints are not violated, it would be possible to increase the number of vehicles in the next step and then, repeat the mentioned process.
- The worst case study: the worst possible case is considered during each step. In each step, the specified percentage of PHEVs should be plugged-in to the most sensitive points of the grid.

Coordinated connections

In coordinated connection, an appropriate optimization problem is defined and then, an energy management system is carried out based on solutions of the problem. Thus, the vehicle connections to the grid is controlled and coordinated by a central supervisor. Certainly, the mentioned optimization problem would be defined with the aim of minimizing the total cost or maximizing the total profit considering the constraints related to both the power grid and the PHEVs. Several communication and control infrastructures are required to continuously get current states of included variables, to estimate next states of the variables and to examine the essential controlling instructions. By employing the coordinated connection method, PHEVs become the controllable loads of the grid. Additionally, employing the coordinated connection method would impose the minimum possible requirements of the power plant expansions.

It is worthy to mention that the necessary agreements should be made with the vehicle owners to follow the controlling instructions received from the management center. Besides, the minimum state of charge (SOC) of the battery should be mentioned in the contracts. Moreover, it is possible for the included vehicles in a system to have diverse SOCs.

Generally, the coordinated connection can be considered in two structures:

- The direct energy management system
- The aggregation-based energy management system

The direct energy management system

In the direct method, there is just one energy management and control center that applies the controlling instructions directly to the individual vehicles. Having paid attention to the mass number of the vehicles, the controller would be dealt with enormous number of variables. Thus, the objective function of the optimization problem should be defined carefully and ultra speed complicated processors should be employed to solve the problem. In literature, the PHEVs have been considered as small power plants that their generation should be specified besides the conventional power plants by solving a unit commitment problem [5]. Therefore, several factors like the grid demand, voltage profile of the grid buses, SOC of the batteries, estimation of the next traveling distances and traffic condition of the roads would affect start time of the vehicles connection to the grid as well as its duration.

The aggregation-based energy management system

An aggregator should do the aggregation of the available potentials to exploit them in an optimized manner. The aggregator is considered not as a company but as a small computational entity that gathers the required information. As an interface, the aggregator transfers the demanded information in two directions between the grid operator and the individual PHEVs. The power grid operator contracts with the aggregators and the aggregators, in turn, contract with the individual PHEVs. Actually, instead of the large number of individual vehicles, the central energy management system would only faces with the lower number of aggregators. Moreover, from the viewpoint of the grid operator, the aggregator can be assumed as a large scale controllable load which is capable to provide the operator's demand according to the signed contract.

The optimizations are carried out at two levels: first, the grid operator, having paid attention to the grid load, reported conditions of the power plants, the current electricity price and the stated capacity of the aggregators, assigns the demanded powers to the aggregators. Then, each of the aggregators, considering the present and the future conditions of the authorized vehicles as well as the related constraints, communicates the appropriate optimized instructions to the individual PHEVs to fulfill the system operator's demand.

As it is mentioned above, the final objective of the optimizations is to gain the maximum possible profit. At the same time, the grid operator considers minimization of the grid line losses as well as minimization of the voltage violations of the grid buses where, on the other hand, the aggregator takes into consideration supply of the desired SOC of the batteries. The desired SOC is a level of the battery charge that should be reached before plugging out from the grid. This quantity is determined according to the mutual agreement between the vehicle owner and the aggregator. Considering unexpected departure of PHEVs from parking lots (where aggregation are done), SOC of the batteries should not decrease below the desired amount.

Evaluation methods

The assessment method is selected according to the desired objective. Determining the penetration level of PHEVs and the online implementing of the energy management system can be mentioned as two cases of the assessment objectives.

- Case 1. Determining the penetration level of PHEVs

Similar to the previous sections, the charging power of PHEVs and the load profile of the grid during hours of a day are considered at first. Then, distribution of the vehicles is randomly done throughout the assumed grid. Afterwards, the arrival time, the departure time and the desired SOC are set for each of the vehicles. Finally, based on the defined objective function and the related constraints as well as the selected computational method to solve the problem, the charge/recharge starting time and duration for each of the vehicles are examined for one day. It is to be noted that the parked vehicle is not necessarily participated in the charging/recharging processes.

- Case 2. Implementing of the online energy management system

First, an energy management strategy should be adopted. In fact, the objective function and the constraints are similar to the previous case; however, the major difference would be the employed computational method to solve the optimization problem. The main challenge in modeling and analyzing the coordinated method is some uncertainties associated with the arriving time, the parking duration, SOC and the energy capacity of the vehicles as well as the load profile of the grid.

Numerical methods for solving the optimization problems

It is of grave importance to select an appropriate computational method to solve the optimization problem and extract precise solutions. The computational method is adopted according to amount of the available data, number of variables, required time to derive solutions, type of objective functions and related constraints. Generally, the numerical optimization methods can be classified into the deterministic methods and the heuristic methods. Employing each of the mentioned categories has its own advantages and drawbacks. Usually, the deterministic methods result precise and global optimized solutions based on an acceptable mathematical proof; however, their computational processes are complicated and time-consuming with huge memory requirements. On the other hand, although the repeated-based heuristic methods are less complicated, they can not necessarily reach the global optimized solutions. Further, it is almost impossible to express the heuristic methods based on a clear mathematical formula. Dynamic programming and Lagrange relaxation are two instances of the deterministic methods. Genetic algorithm (GA), Tabu search, evolutional programming, simulated annealing, the ant colony optimization and particle swarm optimization (PSO) can be mentioned as some examples of the heuristic methods [5].

The objective functions, constraints and expected solutions

In this section, several terms that can be included in objective functions and constraints as well as expected solutions of the optimization problems are briefly reviewed.

Objective functions:

- minimizing fuel cost of the power plants
- minimizing start-up cost of the power plants
- minimizing environmental pollutions
- maximizing vehicle owner's annual revenue
- minimizing line losses of the grid
- minimizing voltage violations of the grid buses

Constraints:

- Limitations of the parking lots
- Chargers/rechargers efficiencies
- Power ratings of chargers/rechargers
- Power rating of plug-in cables
- Voltage variation of the grid busses
- Power losses of the grid lines
- Rating of the grid transformers
- Congestion of the grid lines
- SOC of the batteries
- Energy capacity of the batteries
- Power rating of the batteries
- Spinning reserve power of the grid
- Number of charging/recharging transactions
- Power balance of the grid
- Limitations of the power plants

Expected solutions:

- Number of the participated PHEVs in energy transfer
- Clarification of the vehicles that are participated in charging/recharging processes
- Start time and stop time of the charging/recharging processes
- Production schedule of the power plants

CONCLUSION

Various topics of interest related to plug-in hybrid electric vehicles (PHEV) connections to the grid have been addressed. Advantages and drawbacks of employing PHEVs have been comprehensively listed. Then, to investigate precisely the mutual impacts of PHEVs and power grids as well as to determine the maximum penetration level of PHEVs in the grid several connection scenarios have been reviewed. Moreover, the coordinated connection has been quite elaborated. Further, optimizations in the aggregation-based systems which are carried out at two levels have been examined. At last, objective functions, constraints and expected solutions of the optimization problems related to the coordinated connection as well as appropriate computational methods to solve them have been studied.

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