Energy retrieval from electric vehicles' discharging through multi-objective optimization

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1 Introduction

While electric vehicles (EVs) have been immensely taking part in the worldwide pollution reduction, their on-board batteries can also be used as means of storage of electrical energy which does not seem to be easily stored in huge quantities. Eventually, the charging and discharging of EVs can be scheduled based on the supply and demand of electricity and their alternative energy needs. Thus, as long as the electricity supply by the electric grid exceeds its demand, the vehicles batteries would be used as storage means. So, the EVs would charge their batteries where energy would be stored. Yet, whenever there's a lack of supply compared to the electricity demand, the discharging of vehicles would be launched, and then, the exceeding energy stored in the batteries could be, besides the vehicles' personal use, retrieved back to the grid or to supply houses. Subsequently, this study focuses on the retrieval of energy process where the EVs would be discharging, aiming to optimize this process in a way that the houses would be purely supplied by the vehicle's stored energy assisted by renewable sources, hence omitting the supply by the grid.

2 Overview

The energy restitution from the EV towards houses seeks, with the assistance of renewable energy sources (the installation of photovoltaic panels and wind turbines for example) to eliminate the supply of energy through the grid to these houses. This restitution also targets the optimization of the flow of energy in the most beneficial ways either environmentally by reducing the greenhouse gases emissions or economically through the establishment of incentives and paybacks. Practically, a prototype system including a fleet of EVs and a household supplied by photovoltaic panels and a windmill has been defined in order to study and optimize the energy flows between the discharging vehicles, the house and the electric grid. So, when the supplies of photovoltaic panels and the wind turbine are not being able to fulfill all the household's needs, the lack of energy would then be covered by the energy already stored within the fleet's batteries [1]. The global energetic model of the vehicles' discharging phase would be as follows:

$$\mathrm{N}_{\mathrm{H}_{\mathrm{j,PV}}} \times \mathrm{P}_{\mathrm{f,PV}} \times k + \frac{0.01328 \times D^2 \times v^3}{365.25} + E_0 \times d < \sum_{home\ appliances} N_{H_j} \times P_f \quad (1)$$

Whereas $\mathrm{N}_{\mathrm{H}_{\mathrm{j,PV}}}$ and $\mathrm{P}_{\mathrm{f,PV}}$ represent the daily number of hours of use of the photovoltaic panels, and their operating power, k is a correction factor, D is the wind turbine's rotor diameter and v is the annual average wind speed. On the other hand, $\mathrm{N}_{\mathrm{H}_{\mathrm{j}}}$ is the daily number of hours of use of the functional home appliances, and P_{f} is their operating power. The system's optimization has been performed through the identification of several objectives to be solved using the genetic algorithm (GA) as a multi-objective optimization approach [2]. The study seeks the following objectives, set during the vehicles' discharging stage:

1. Minimizing the vehicle's state-of-charge *SoC* in order to use the energy confined within its battery, taking into account the amount of energy that should be retained from restitution for the vehicle's personal trips and needs.
2. Minimizing the vehicles discharging time t_d.
3. Maximizing the battery life L_b of the vehicle and controlling its cycles' consumption.
4. Minimizing the losses *l* resulting from the instantaneous power going in to/leaving the vehicle.

Thus, the optimization model has been summarized as follows:

$$\begin{cases} f_1(SoC(t-1), P_d) = SoC(t) = SoC(t-1) - \eta_d \frac{P_d}{E_b} \\ f_2(I_d) = t_d = \frac{E_b}{I_d} \\ f_3(n_c, DoD) = L_b = n_c \times DoD \times E_b \\ f_4(P_p + P_{aux}, P_d) = l = 100 \times \frac{|(P_p+P_{aux}) - P_d|}{P_p+P_{aux}} \end{cases} \quad (2)$$

Whereas η_d, P_d, E_b, Id, n_c, and DoD represent respectively, the discharging efficiency, the discharging power, the nominal capacity of the battery, as well as its discharging current, its number of cycles and depth of discharge. P_p and P_{aux} are respectively the propulsive power of the vehicles and their auxiliary power resulting from the usage of auxiliary electric accessories (such as air conditioning, heating, windshield wipers, radio, headlights, seat heaters, etc…).
As some of the objective functions are interdependent, several scenarios have been studied in order to highlight the optimal solution of all the objective functions taking into account the decision maker's priorities. So, having applied the genetic algorithm, all fitness functions are normalized and the weighted sum approach is performed using randomly assigned weights for different optimization scenarios, in order to find the system's Pareto-front. In order to verify the calculation results, the fitness functions related to the vehicles' discharging have been computed through the gamultiobj solver of Matlab. The simulation of the GA method has been launched for several initial populations of different sizes; particularly for initial populations of 12 and 200 chromosomes.
Consecutively, on a larger scale, the energy restitution is also validated through the application of a regulation algorithm that allows to control the energy flowing between the vehicles and the households and/or electric grid. This algorithm also classifies the available vehicles based on their storage capability and battery lives. Thus, it minimizes the number of discharging vehicles for a convenient energy transfer and a reduced consumption of batteries. A sample set of discharging fleets is assigned and simulated using Matlab to prove the partial or complete fulfillment of energetic needs using the vehicles' energy. Due to the page number's limitation of this abstract, it is impossible to compare the obtained results with those with different parameters and algorithms. Yet, both the theoretical calculations and simulation have proven the efficiency of the outcomes.

3 Conclusion and perspectives

This energy retrieval process has been carried out using a multi-objective optimization model aiming to minimize the battery's state of charge, the vehicles' discharging time and losses, and to maximize the battery's life time. The optimization has been studied using the GA approach, and has been verified by a Matlab simulation through the gamultiobj solver. Consequently, the optimization has contributed into an effective optimal solution for the considered fitness functions that would converge into the calculated theoretical optimum. Yet, in some cases, it was the prioritization of a specific function that leads to a final solution. Besides, a regulation algorithm has been proposed and simulated in order to manage the vehicles' discharging to tighten the difference margin between electricity consumption and production without over-consuming the vehicles' batteries. As a future perspective, it would be interesting to validate the proposed algorithm and obtained results using realistic prototype and confirm the obtained simulation results.

4 References

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