Management and Content Delivery for Smart Networks: Algorithms and Modeling

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L2 - Version B

Simulating a renewable powered charging station for electrical vehicles in a Goods Delivery service scenario

You will simulate the operation of one of the recharging stations that serve a fleet of electric vehicles (EVs) in a urban environment. The vehicles represent the fleet of electric vans belonging to a company that provides **Goods Delivery service**. The energy used to recharge the batteries of EVs can be drawn from the electric power grid. In addition, the charging station can be equipped with a set of **photovoltaic (PV) panels**, from which renewable energy can be produced during the daytime and used to charge the EVs.

1 Electric Vehicles and Charging Stations

The fleet of EVs consists of electric vans, each featuring a battery capacity, denoted C, of 40 kWh. To preserve a good battery lifespan, the charging rate should preferably not exceed half the capacity of the battery per hour, i.e. $\frac{C}{2}$. Furthermore, the charging rate depends on the actual power level of the considered charging station, leading to a battery charging time that may span from 1 hour (fast charging) to 8-12 hours (like in the case of an EV plugged into a standard household wall outlet). In our scenario, an intermediate level of charging power can be reasonably assumed for the considered EV supply equipment, allowing to fully recharge an empty battery in 2-4 hours.
Battery Switching Stations (BSSs) are envisioned to recharge the EV batteries. This type of charging station is suitable for specially designed EVs, from which the discharged battery can be removed and immediately replaced by a fully recharged one, that is already available at the battery switching station since it had been previously recharged. Hence, the EV can immediately leave and continue its trip with the new battery. The swapped battery remains at the BSS to complete the charging process until the full recharge level (or at least the desired target charge level) is achieved, in order to be mounted on another EV that will arrive at the charging station later on. The maximum number of batteries that can be plugged in for simultaneous recharge in a BSS is denoted N_{BSS}.

2 The Goods Delivery service

This scenario envisions a fleet of electric vans belonging to a company that provides goods delivery service:

- **BSSs** are assumed.
- Each BSS is placed in the same location of a company warehouse, representing a last mile hub for the distribution of goods.
- The simulation should consider the arrivals of EVs at the BSS, where the discharged battery is swapped with a recharged unit, hence the EVs can immediately leave. The unmounted battery stays in charge until the full charge level (or the desired charge level) is achieved, hence it becomes available for a new EV. If no EV arrives to pick up the battery, the battery charge process can continue up to the full level.
- In case an EV does not find an available battery at the BSS to perform the battery swap, it can wait for a maximum time of w_{max} minutes. In case no battery is expected to become available with a sufficient charge available in the next w_{max} minutes, the EV looks for another charging station. We consider this situation as a case of missed service.
- We assume that the service operates all day long. During the nighttime, only a small number of EVs circulate, typically to transport goods to the hub warehouse where they are stored, waiting for being delivered to the final destination the day after. Conversely, during the daytime a larger number of electric vans circulate, due to the higher delivery workload, that includes also short distance last-mile deliveries to the final destinations in the urban area.

3 Electricity cost

We consider the electricity cost paid for the energy bought from the grid according to the prices reported by the Italian energy market. In the file ***electricity_prices.csv***, the average daily electricity prices per season, expressed in €/MWh, are reported with a time granularity of 1 hour.

4 Renewable energy generation system

A charging station can be equipped with a set of photovoltaic panels that produce solar energy to recharge the EV batteries. We denote S_{PV} the nominal capacity of the set of PV panels installed at a charging station. The nominal capacity of a PV panel is measured in Watt peak (Wp). A PV panel with nominal power of 1 kWp will produce less than 1 kW of photovoltaic power, since the output depends on the actual radiation and environmental conditions. The file ***PVproduction_PanelSize1kWp.csv*** reports the output power of a PV panel with nominal capacity of 1 kWp for a period of 1 year, expressed in Watts, with a granularity of 1 hour. As the value of the nominal capacity, S_{PV}, increases, the value of the output power grows proportionally. The data are derived considering real irradiation data during the Typical Metereological Year in the city of Turin. In a renewable powered charging station, the solar energy, whenever available, is used to power the EV batteries instead of drawing energy from the electric grid.

5 Investigating the system performance

You must investigate via simulation the operation of a single EV charging station, analysing the system performance under variable settings. You can plot graphs showing relevant performance metrics to highlight your findings. The system performance can be evaluated for example in terms of average waiting delay, missed service probability, energy cost, average battery charge level at departure time from the charging station or other useful performance metrics you may think of.

1. Consider a simple case, setting a small size of the charging station (N_{BSS}) and assuming a fixed average arrival rate for the EVs. Furthermore, assume that that an EV can be picked up only after the battery has been fully recharged. Analyze the average waiting delay or the missed service probability:
   - observe the system behavior during the warm-up transient period and identify the transition to the steady state. Try different methods to remove the warm-up transient in your simulations;
   - observe how the confidence level of the estimated value of the considered performance metric is affected by the simulation settings. How can the confidence be improved? For the considered performance metric, properly configure the simulation settings to obtain a desired target confidence level.
2. Simulate the system operation over a period of 24 hours, considering variable arrival rates of EVs, depending on the time of the day. Assume that, in periods of high demand, we accept that a battery can be picked up from the BSS even if the battery is not fully recharged, as long as it has achieved a minimum charge level, denoted B_{th}. Test different values of B_{th}. What is the impact on the system performance?
3. Assume that the charging station is equipped with a set of PV panels and that the energy to charge the EV batteries is drawn from the electric grid only when solar energy is not produced. Evaluate the system performance in a **summer day** and in a **winter day**:
   - Test different values of the PV panel size, S_{PV}.
   - Consider different combinations of PV panel size and N_{BSS} value.
   - Assume to postpone the charging of a fraction of batteries, denoted f, when the electricity prices are higher and no renewable energy is currently available, in order to resume the charging process later on, buying energy from the grid when the energy cost is lower or some renewable energy is available again. Set a bound on the maximum time by which the charge process can be postponed, denoted T_{max}. Analyse the system performance under different combinations of the values of f and T_{max}, assuming constant values of these two parameters for the whole day.