Simulation assignment Optimization for Sustainability (INFOMOFS): Smart charging in Polderwijk

Problem Description

Introduction

We study Polderwijk[1], a future `green' and very modern neighborhood in Leidsche Rijn on the west side of Utrecht. In Polderwijk there will be modern facilities for charging e-vehicles. Seven parking places will all be equipped with a number of charging stations.

These parking places are owned by the company PolderCharge. PolderCharge is an aggregator company. It offers electricity for charging e-vehicles at a very competitive price, but has the possibility to control the charging at the stations. Since charging at the stations of PolderCharge is cheaper than charging at home, we assume that all the vehicle owners in Polderwijk will charge their cars at the charging stations of the company.

At the beginning of the evening, many inhabitants come home and want to charge their car. It is likely that uncontrolled charging may lead to overload or even blackouts in the electricity network. Therefore PolderCharge considers different methods for smart charging, i.e., controlling the charging process in an effective way. In this assignment, you have to perform a simulation study to analyze these methods. You will start by analyzing a base case, in which cars start charging immediately upon arrival at the charging station. Next, you will study a pricing strategy and scheduling strategies.

Figure 1 Parking for e-vehicles

[1] In this assignment, we use realistic data for arrival hours, charging volume and connection time of e-vehicles and for the availability factors of the solar panels. Polderwijk is of course not a real neighborhood and any correspondence with a real neighborhood is coincidental.

Electricity network

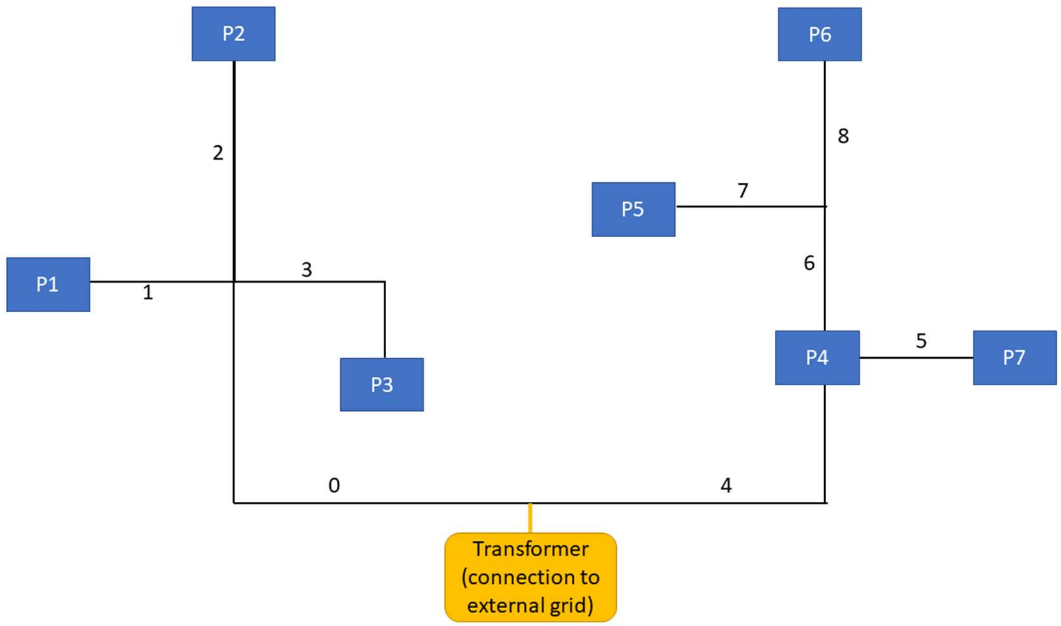

Figure 2: Network layout in Polderwijk

The electricity network in Polderwijk is depicted in Figure 2. The parking places and cables are numbered. The available capacity of the cables (so 0,1,2,.., 8) is equal to 200kW, except for the cable to the transformer which has capacity 1000 kW. This means that the flow through the cable is at most 200 kW. For the sake of simplicity, you may assume that vehicle charging is the only demand in the network. This means that the capacity limits are such that demand of households is already accounted for.

To compute the power flows through the network, you can use the so-called trade-based model. This coincides with the network flow models that you learn in an algorithms course. This means that if the demand/supply of each node are given, you can compute the flow by requiring flow balance (inflow-outflow = net demand) for each node.

The capacity of the parking places is given in the following table.

Table 1: Capacity of parking places

Parking	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Number of charging stations	60	80	60	70	60	60	50

Vehicles

Cars arrive in the neighborhood according to a Poisson process. On average each day 750 cars arrive for charging. The cars divide themselves over the different parking places as follows.

Table 2: Choice of parking places

First choice parking	1	2	3	4	5	6	7
Percentage	15	15	15	20	15	10	10

If a car arrives and it does not find a free charging station, it will look for another parking place. If it did not find a free charging station after checking 3 parking places, it will leave the neighborhood to charge elsewhere.

You can use the following files, which contain realistic data for e-vehicles charging in Utrecht and were provided by Nico Brinkel (Copernicus Institute of Sustainable Development; see [1])

- **arrival_hours.csv:** this file represents the percentage of cars arriving during each hour of the day, where hour 0 is from 24PM until 1AM etc.
- **charging_volume.csv**: this file describing the distribution of the charging volume. Note that charging volume 0 represent a volume in (0,1), charging volume 1 represents a volume in [1,2), etc
- **connection_time.csv** with the distribution of the interval between arrival and departure. Like in the previous files 0 represent a time smaller than 1 hour, 1 represents a time of at least 1 hour but smaller than 2 hours, etc

We assume that all vehicles charge at a constant power of 6 kW. We assume that the minimum required charging time (time needed to get the charging volume at a rate 6kW) is at most 70% of the connection time. The idea is that in the simulation you first generate the charging time, and then the connection time. If the connection time is too short, you should increase it.

Charging strategies

Initially, you may assume that a vehicle does not preempt (interrupt) its charging.

You have to consider four types of charging decisions:

1. **Base:** Immediate charging upon arrival
2. **Price-driven** decisions by vehicles. When price levels vary over the day, a vehicle will choose its starting time such that it can leave on time and the cost are minimal. The price levels are given in Table 3.
3. **First-Come-First-Served (FCFS)** strategy by aggregator. The aggregator avoids overloads by using a FCFS rule when assigning charging capacity to vehicles. The aggregator uses separate queues for the different parking places.
4. **Earliest-Latest-Feasible-Start-time (ELFS)** strategy by aggregator. The Latest Feasible Start time is the latest time at which a vehicle can start charging such that it can leave at its desired departure time. This strategy is similar to FCFS, but aggregator prioritizes the vehicles for which starting charging is most urgent.

Table 3: Price levels

Interval	Price per kWh
00:00-08:00	16
08:00-16:00	18
16:00-20:00	22
20:00-00:00	20

Solar energy

To avoid overloads, PolderCharge considers to install solar panels near the parking places or on a roof over the parking place. For a parking place, it considers a collection of solar panels with a peak power of 200 kW.

The first idea is to install these panels at parking places P6 and P7. In a later stage this may be extended to P1 and P2.

The revenue of the solar panels varies over the day and over the year. The forecasts are given in terms of the so-called availability factor. This factor is defined as the fraction of the peak power of the PV panel that will be generated. A forecast for the availability factor for the solar panels located in the Netherlands in 2025 is given in the file **solar.xls.** In the file hour 0 is from 12 PM until 1 AM, hour 1 is from 1 AM to 2 AM etc. It contains average availability factor over the winter and summer. The numbers originate from the Pan-European Climate Database (see https://www.entsoe.eu/outlooks/midterm/) [2]

You may assume that the actual revenue equals the forecast with a Gaussian (normally distributed) error with a standard deviation of 15% the revenue in the forecast.

In case the power from the solar panels causes overload in the network, you do not have to curtail (lower the produced power) the solar panel.

Optional issue: If solar panels are used, a drop (decrease) in revenue of the solar panels while vehicles are charging may lead to capacity problems in the network. In strategies 3. and 4. the aggregator may want to prevent overload, by preempting charging of vehicles. As optional work, you can define and implement a strategy for that.

Performance measures

Your simulation study should at least contain the following performance measures:

1. Cable load:
   - maximum load of each cable
   - percentage of the time with at least 10% overload (blackout), for each cable
   - percentage of the time with overload of at most 10%
   - for each cable: load over time

2. Departure delays, which is defined as the amount of time that the end of charging time exceeds the planned departure time:
   - percentage of vehicles with a delay
   - average delay over all vehicles
   - maximum delays

[2] Thanks to Rogier Wuijts, PhD student Computer Science/Copernicus Institute for providing these numbers.

3. Percentage of non-served vehicles and average number of non-served vehicles per day. Non-served vehicles are the vehicles that cannot find a free parking place and leave the neighborhood to charge elsewhere.

Required scenarios

In your simulation study you have implement the 4 charging strategies (base, price-driven, FCFS, ELFS) in combination with the following scenarios for generation of solar energy:

- no solar panels
- solar panels at P6, and P7, winter
- solar panels at P6, and P7, summer
- solar panels at P1, P2, P6, and P7 winter
- solar panels at P1, P2, P6, and P7 summer

Optional scenarios and research questions

- Implement a strategy for preempting the charging of certain vehicles to prevent overload in case of drops of solar energy. What is the effect of this terms of performance of the simulation?
- Implement a new aggregator strategy, e.g. order on end of connection time or give priority to parkings with solar panels, and show its effect.
- Implement a strategy to include more flexibility in the pricing strategy to avoid peaks at the time points at which prices decrease, e.g. by choosing randomized starting times within periods of the same price level.
- How should the network be expanded to improve service to e-vehicles and/or to cope with future growth of the number of e-vehicles?
- What are alternative ways for generating the charging volume and connection time, still with the constraint the minimum charging time is at most 70% of the connection time?

Workplan

General

- Work in groups of 2 persons.
- You have to implement a **discrete-event** simulation.
- The simulation has to be implemented in a standard imperative programming language such as Java, C# or Python.
- You have to fully implement the simulation by yourself and are not allowed to use any simulation libraries or frameworks.
- You may use libraries for random number generation
- The devil is in the detail: Experience has learned that programming simulations is prone to nasty bugs; solving these may take a very large amount of time. Therefore pair-programming is strongly advised.

- You have to use continuous probability distributions for connection times and charging volumes. The vehicles arrival process has to be stochastic as well.

Milestone

- There is one intermediate milestone around Tuesday May 10 (form for making appointments will be made available).
- At this milestone you should at least have finished
    - Your simulation model including assumptions
    - Initial implementation of the simulation model: at least strategies 1 (base) without solar energy.
    - Some output numbers concerning the cable overload. Just give some numbers for the base strategy. An output analysis with graphs and statistical analysis is only required for the final report.
- At this milestone you have a feedback discussion and/or demo with the practicum supervisor. You not have to hand-in material beforehand. You should have a written model description and your computer implementation available and explain to the practicum supervisor what you have done.
- If there are still minor bugs, this is acceptable.
- The supervisor marks if you obtain a `pass' for the milestone. A `pass' for the milestones is required for additional examination. You only obtain a pass if you attended the milestone meeting.

Deliverables

- The deliverables consist of (an) implemented simulation model(s) and a report
- The deadline is Sunday May 29, 2022.
- One of you has to hand in the assignment through blackboard, do not forget to mention both your names on the report.
- The report has to be between 8 and 15 pages of 11 pt A4 . This excludes pictures and tables. The report contains at least:
    - Assumptions
    - Event graph
    - Definition of performance measures
    - Input modelling: how do you generate arrivals of vehicles, connection times, charging volumes and revenues of solar panels
    - Output analysis: experimental results from your model:
        - Questions to be answered by the experiments
        - Description of the investigated scenarios including all relevant parameter settings and performance measures
        - Number of runs
        - Tables (at least the most interesting ones)
        - Graphs
        - Observations from your tables and graphs
        - Statistical analysis. The minimum requirement is to find confidence intervals for comparing two different scenarios. You can make a selection of the most interesting combinations (select at least 10). Additional analysis such as Comparisons with a standard', All pairwise comparisons, or Ranking and selection are optional (will improve your grade).
        - Reflection on the content and the working process.

        - Conclusions
        - Statement of the contributions in the individual group members.
- For reporting the standard academic rules with respect to references and plagiarism hold.
- The report has to be in PDF-format.

Grading

- **There is no unique solution leading to the perfect grade.** Note that different assumptions in your model may lead to different results. In an educational setting, this is OK. If you clearly describe your assumptions, they are reasonable and match your computational results, this in general hardly has consequences for your grade. *Disclaimer: Assumptions which are obviously wrong, very impractical or make the assignment extremely easy do have a negative impact.*
- Only complete assignments will be graded, i.e. you should have results for the required scenarios and performance measures.
- The different parts are graded as follows:
    - Model and performance measures: 4 points
    - Code quality: 0.5 point
    - Input modelling: 0.5 points
    - Output analysis: 3.5 points
    - Optional items: 3 points
- In most cases, all group members get the same grade. However, exceptions are possible if there are large differences in quality or quantity of the individual contributions.

Reference

[1] Brinkel, N., AlSkaif, T., & Van Sark, W. (2020, September). The impact of transitioning to shared electric vehicles on grid congestion and management. In *2020 International Conference on Smart Energy Systems and Technologies (SEST)* (pp. 1-6). IEEE.