Computer practical assignment: Utrecht smart district

Part B: Optimal Home Energy Management (HEM) - Multi-objective optimisation of home energy management

Course: Energy in the Built Environment (GEO4-2522) 2021/2022

Date/Version: Oct. 1st, 2021

Contributors/Editors

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Abstract

The tutorials will address the employment of programming and optimisation tools for solving a computer practical assignment. Through this practical assignment, the students are introduced to the concept of distributed generation in the built environment and demand side management for residential customers. The students will perform the computer practical assignment in groups by using Python programming. The assignment consists of two parts:

Part A: Building-integrated photovoltaics (BIPV) - Irradiance and PV performance modelling

Part B: Optimal Home Energy Management (HEM) – Multi-objective optimisation of home energy management

After successfully completing the assignment (both Part A & B), the students are expected to be able to apply Python programming and optimisation tools to solve a practical problem addressing performance modelling of distributed energy resources and energy management in buildings, and to report their results and findings in a clear and understandable manner. In this manual, there are a number of questions, including sub-questions that shall be part of the group's deliverable report.

Recommended pre-requisites and self-study material

Completed Python programming online course (it is highly recommended to the students to complete the Sololearn course: https://www.sololearn.com/learning/1073). See Section 2.2. of the 'Introduction to Python Programming' manual.

To get started with using Gurobi for modelling and optimization. It is highly recommended to follow the Webinar "Introduction to Modelling with Python using Gurobi":

https://www.youtube.com/watch?v=vnLc_3VnVcw&t=4s

For more examples on Gurobi optimizer in Python:

https://www.gurobi.com/documentation/8.1/examples/python_examples.html

Time schedule

The tutorials will take place on Tuesdays and Thursdays including the lectures that are specifically addressing programming techniques with Python (an introduction to Python programming, and optimisation techniques and Python tools), and an introduction to the computer practical assignments. For the detailed time-schedule, please check the course guide. During the tutorials, instructions will be provided about how to complete the assignment, and students will be able to question and/or discuss any issues with the tutorial instructors.

Deadlines

- **Submission of group draft report for Part B by October 25th, 2021 at 17:00**. Instructions about the submission will be provided via Blackboard before the deadline.
- **Submission of peer-review feedback by October 29th, 2021 at 17:00**. Each group will review the draft report and results of their fellow students and provide feedback. Specific guidelines for the peer-review process will be provided via Blackboard before the deadline for the submission of the reports. The responsible tutorial instructor will check the received peer-review comments, add any additional comments and send the comments to the students prior to the final report submission deadline (at least 2 days in advance).
- **Submission of group final report for Part B by November 5th, 2021 at 17:00**. Instructions about the submission will be provided via Blackboard before the deadline.

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1. Part B: Optimal Home Energy Management

1.1 Introduction

This assignment will provide hands-on practice for optimisation applicable to the management of energy resources in households. The assignment is organised in a tutorial fashion, thereby allowing you to practice optimisation techniques on a real-life energy system case.

1.2 Learning objectives

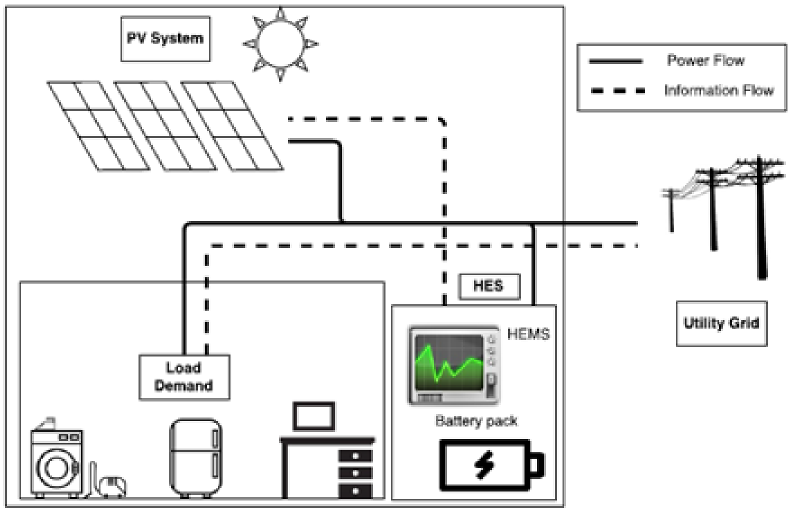
- To model and solve optimisation problems using Python-Gurobi
- Demonstrate the importance of home energy management systems for managing and optimising the power flows from different energy resources based on economic principles and subject to technical constraints

1.3 Description

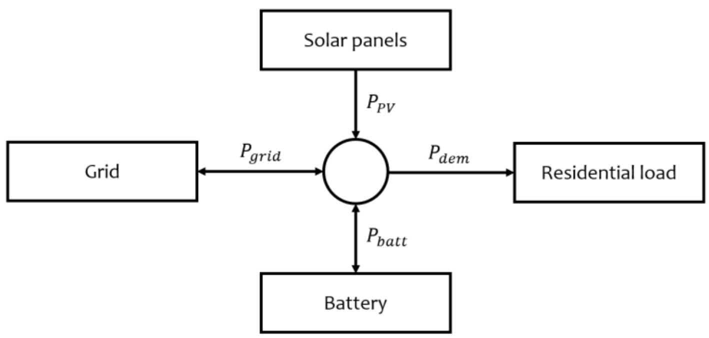
Consider a household with several power sources supplying its needed power demand. We assume that the household is equipped with a small-scale rooftop Photovoltaics (PV) system and a Battery-based Energy Storage System (BESS). Household's electricity demand can be satisfied by a grid connection, the rooftop PV system installation and the BESS. A Home Energy Management System (HEMS) is used to determine the optimal day-ahead scheduling of the household's demand based on a day-ahead grid electricity prices signal, deciding when to charge/discharge the battery and whether to absorb power from PV, BESS or the grid.

The optimisation horizon is day-ahead and each day is divided to a number of time slots T, indexed as $t \in \{0, 1, \ldots, T\}$. Electricity prices are assumed to be positive and time-varying. The objective is to minimise the total cost of electricity consumed over one day. Locally produced PV electricity can be directly self-consumed with zero costs and the surplus PV energy can be stored temporarily in the BESS to be used later as a supply source for household's demand. In addition, surplus PV can be injected to the electricity grid.

The BESS can also be charged from the grid in periods that have a low pricing signal. The power from the grid is limited by a grid capacity constraint. This capacity constraint is active for bidirectional power flows, i.e. both energy taken from the grid, and power injected into the grid. The battery is characterised by the following parameters: Battery capacity, charging/discharging efficiency, maximum and minimum state of charge (SoC) and maximum charging/discharging power. It is assumed that the household has perfect information on its PV generation and power demand the day-ahead. The considered system architecture is illustrated in **Figure 1**.



(a)



(b)

Figure 1. The system architecture.

Question 1: Formulation of the economic optimisation of home energy management

Formulate an optimisation problem to minimise household's electricity costs over one day subject to constraints, while supplying sufficient power to meet its power demand. Provide the following:

1. Assign symbols to all variables and parameters that are going to be used in the optimization problem, including the power from PV, grid and storage, electricity cost, battery state of charge, and power demand. Make a distinction between variables and input parameters.

2. Write down the objective function, using the notation from (1).

3. Write down all the constraints, using the notation from (1), in a complete and correct fashion (see lecture 'Optimisation techniques and Python tools' by Nico Brinkel). Clarify the physical meaning of each constraint.

4. Define the class of your optimization problem, according to the classification categories discussed in the lecture. Explain why your optimization problem belongs to this class.

1.4 Input data and instructions

The input data for Question 1 can be downloaded from the Blackboard environment. Download the files *AssB_Skeleton.py,* *AssB_Input_Group<GROUPNUMBER>_summer.csv* and *AssB_Input_Group<GROUPNUMBER>_winter.csv* from Blackboard. The csv data files provide the time of the day [hour], electricity price at each time-slot [€/kWh], emission factor at each time-slot [kgCO_2eq/kWh], PV power generation data [kW] and corresponding residential power demand [kW]. The provided hourly electricity prices resemble the day-ahead market clearing prices of the European Power Exchange (EPEX) in the Netherlands, that is the Day-Ahead auction, where trading takes place one day before the delivery of electricity the next day[1]. The power demand profiles of residential customers are represented based on available statistical data from the Dutch Energy Data Exchange (NEDU) which is the platform for administrative connections between the various different market parties within the energy sector[2]. Note that the electricity demand profile of an average residence in the Netherlands is provided for two days, one for summer and one for winter, with an hourly resolution. Each group of students will select and run the optimization for the two average days in different seasons (summer/winter).

Question 2: Optimisation results

1. Solve the problem that you have formulated in Python using Gurobi modelling package. Provide the value of the objective function (total cost) and the values of the optimization variables at the optimum.

2. Describe qualitatively the optimal solution. Which constraints are active? For each day, present your results using appropriate plots, which explain the most important trends and observations in a clear way to outside readers. Make sure you make use of the subplot function. Use appropriate line styles, axis labels, font sizes, etc. Include the figures in your report.

Question 3: Multi-objective optimization.

In some cases, the battery owner considers multiple objectives when scheduling the charging and discharging of the battery system through multi-objective optimization. There are different methods for multi-objective optimization. In this exercise, you will determine the battery schedule for multi-objective optimization of charging costs and charging emissions using the ε-constraint method. The ε-constraint method presents the trade-off between cost and emissions when determining the charging schedule of the battery system. First, the cost optimization and emission optimization are performed separately, in order to find the possible range in costs and

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[1] EPEX Day-Ahead Auction: https://www.apxgroup.com/trading-clearing/day-ahead-auction/
[2] Nederlandse EnergieDataUitwisseling (NEDU) consumption profiles: http://www.nedu.nl/portfolio/verbruiksprofielen/

emissions. Afterwards, different trade-offs between costs and emissions can be studied by adding a constraint on the charging costs, and minimize charging emissions (or vice versa). Results of this trade-off are normally presented using so-called Pareto frontiers. Examples of studies explaining and using the ε-constraint method are:

- W. Schram, T. AlSkaif, I. Lampropoulos, S. Henein and W. Van Sark, "On the trade-off between Environmental and Economic Objectives in Community Energy Storage Operational Optimization," in *IEEE Transactions on Sustainable Energy*, doi: 10.1109/TSTE.2020.2969292.
- N. Brinkel, W. Schram, T. AlSkaif, I. Lampropoulos, and W. van Sark, "Should we reinforce the grid? Cost and emission optimization of electric vehicle charging under different transformer limits, "Applied Energy, vol. 276, no. October, 2020, doi: https://doi.org/10.1016/j.apenergy.2020.115285

In this exercise, you are going to use the ε-constraint method to set up a Pareto-frontier for the studied battery system showing the trade-off between costs and emissions.

1. Present this Pareto frontiers for both the summer and winter day, using 10 equally spaced-bins. When reporting the Pareto frontiers, please consider the following:
    a. Determine the costs and emissions for the most extreme points of the Pareto-frontier (i.e., the points with pure cost and emission minimization).
    b. Determine and report the used values of the ε-constraint.
    c. Shortly outline the steps taken in setting up the Pareto frontiers.
    d. Discuss alterations to the model (i.e., extra constraints/objective functions/variables etc.)
    e. Discuss your observations.
    f. Use appropriate line styles, axis labels, font sizes, etc. in your figures.
    g. **Tip:** Convert your model from question 2 to a function, and call this function when running the model for different points in the Pareto frontier. This will save you a lot of time in coding! Feel free to ask the teaching staff for support in this step.

Question 4: Reflection on your model.

1. Think of two aspects that are not included in the model, which could lead to more-realistic battery schedules. Use provided literature for inspiration. Shortly(!) discuss how including these aspects in your model could affect your results.