Requirement Specification

TSRT10, Project Group 7

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Project Identity

Group E-mail:
Orderer: Jan Åslund, Linköpings universitet
Phone: (+46)13-28 16 92
E-mail: jan.aslund@liu.se

Supervisor: Daniel Jung
Phone: (+46)13-28 57 43
E-mail: daniel.jung@liu.se

Course Responsible: Daniel Axehill
Phone: (+46)13-28 40 42
E-mail: daniel.axehill@liu.se

Participants of the group

Name	Responsible	E-mail
Pontus Karlsson	Project Leader (PL)	ponka602@student.liu.se
Algirdas Bartkevicius	Head of Testing (TEST)	algba880@student.liu.se
Elis Sandberg	Head of Documentation (DOC)	elisa519@student.liu.se
Filip Leijonhufvud	Head of Simulation (SIM)	fille526@student.liu.se
Simon Saber	Head of Software (SW)	simsa393@student.liu.se
Tanja Nyberg	Head of Design (DES)	tanny054@student.liu.se

CONTENTS

DOCUMENT HISTORY

Version	Date	Changes made	Sign	Reviewer
0.2	2022-xx-xx	First revision	Sign2	Name2
0.1	2022-09-16	First draft.	PK	Daniel Jung

1 INTRODUCTION

The accelerating pace of electrification leads to an increasing demand on the commercial power grid. Simultaneously, the growing amount of electric vehicles and domestic solar power alters the behaviour of the household energy consumption. Previously the grid fed the homes with electricity, now the homes are able to produce their own electricity and feed the grid which produces greater voltage fluctuations. These fluctuations may be small when there are only a minority electricity producing homes, but the impacts on the low-voltage grid will be significant when every household in an area has solar power. The same problem occurs with the increasing amount of electric vehicles. The impact is small with only a few but increases to a major problem if every household has one.

A key method to control the electricity consumption of households are price models called electricity rate. The end customer wants to minimise the expenses of electricity and the grid owners want to have a stable grid, in order to avoid having to rebuild and expand the power grid which can be expensive.

In this project, it will be investigated how a real time control system of the charging of an electric vehicle battery and usage of an heat pump with accumulator tank can be designed and what impact such solution can have on power grid stability. The project will produce a simulation environment that mimics real time control of power distribution in a residential area and it's effects on the low-voltage grid using historic data.

In this document, all requirements are described with the table format shown below, see *Table 1*. The requirements are running number throughout the document, column two specifies if the requirement has been changed and the priority specifies the importance of the requirement, if it is base requirement or an optional requirement.

- Base - requirements that must be met upon final delivery.
- Optional - requirements that can be implemented if time and resources are available.

Table 1: *Description of how requirements will be written through out the project*

Requirement	Version	Description	Priority
1	Updated	A brief description of the project	Base/Optional

1.1 Partners

The project is carried out in the Project Course - Automatic Control; TSRT10, accounted by the department of Electrical Engineering (ISY) at Linköping University. The project scope is based on a collaboration between the department of Vehicular Systems (FS) at Linköping University and the local energy company Tekniska Verken. The involved members are:

- The producers are six students who are studying a M.Sc, either in Applied Physics and Electrical Engineering, Mechanical Engineering, or Environmental Engineering.
- The supervisor, Daniel Jung at Vehicular Systems (FS) at Linköping University.
- The orderer, Jan Åslund at Vehicular Systems (FS) at Linköping University.
- The client, Christofer Sundström at Vehicular Systems (FS) at Linköping University.
- Some data regarding electricity usage has been presented by Tekniska Verken, Linköping.

1.2 Aims and goals

The goal of the project is to study how a single household can reduce energy expenses by utilizing an electric car battery and a heat pump with an accumulator tank for energy storage. A bigger residential area with several houses will be simulated to analyze the effects on low-voltage grid. The aim is to solve this by further developing a pre-existing simulation environment and implementing an algorithm for optimization of energy consumption.

This will be carried out by implementing various algorithms and strategies for optimal control, mainly for the houses in a residential area in Linghem, Östergötland. Included components will be power transformers, grid cables, residential buildings, electric vehicles, heat pumps and photovoltaics.
The research questions are:

- How can the energy consumption be optimised in a low voltage distribution system in order to decrease peak loads?
- How can different electricity price tariffs contribute to voltage stability?

The long term goal is to implement smart control in every household, making them as self sufficient as possible regarding energy consumption. In the electricity grid of the future, charging of all electric components in the household and the time of use is optimized so that the impact on the power grid is minimal.

1.3 Application

The delivered product is intended to be used to test various energy loads in residential areas, both existing and planned. It can be used to discover when problems on the electricity grid may start to arise in terms of voltage stability, and how to prevent this by using optimal control. Additionally, it can be used to predict the energy demand in a single household and indicate potential energy savings by avoiding the peak loads. In the long term, this project can contribute to creating a basis for how a smart control system are realized in hardware.

1.4 Background information

The current situation on the energy market have created higher voltage fluctuations in the electrical grid. This can be harmful. Earlier projects have studied the phenomenon and made applications for simulating how a modern suburban residential area affects the low-voltage power grid. This serves as a background to the current project.

Furthermore, previous studies have been done in the field. A paper on optimal energy management by using MPC [1], and another one analyzing the effect of price tariffs on the low-voltage power grid [2]. These papers will serve as a background and source of information for this project.

1.5 Definition of terms

In this chapter, shorts that will be used in the project are defined, see *Table 2*.

Table 2: *Definition of terms*

Short	Definition
LV	Low-voltage
HV	High-voltage
AC	Alternating Current
DC	Direct Current
PV	Photovoltaics
EV	Electric Vehicle
HP	Heat Pump
AT	Accumulator Tank
GUI	Graphical User Interface
V2G	Vehicle to Grid

2 SYSTEM OVERVIEW

This chapter will firstly present an overview of the system. In *Figure 1* there is a block diagram of how the overall system will work. It shows the simulation running on a computer hard drive, being fed data and running it through an optimization algorithm. Lastly data will be returned to the user, which in turn can give input to the system. Further on this chapter will also describe in detail how the system and its components work and interactive with each other.

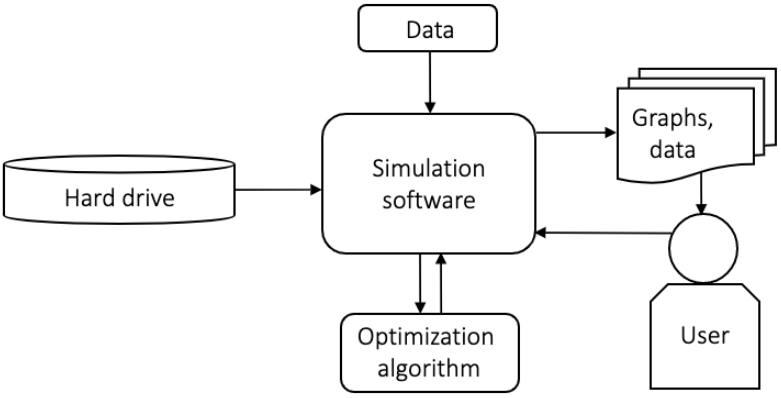

Figure 1: An overview of the system.

2.1 Description of the delivery

The electric grid stands before an extensive change as the usage of electric vehicles and photovoltaics becomes widespread. To avoid expensive reconstruction of the current power grid an investigation will be carried out to see if it is possible to reduce the load on the grid by stabilizing the power usage (without having to expand the current grid).
The final product will be based on the previously mentioned papers regarding optimal energy management using MPC [1] and tariff's impact impact on the stability on the low-voltage grid [2]. The objective with this product is to simulate and optimize charging of electric vehicles, production from photovoltaics and storage by using heat pumps for households in a residential area. The objective with the optimization is to stabilize domestic low-voltage grids without having to expand or renovate the current system.

2.2 Delivery components

The product consists of;

- A technical report
- A function which online controls the EV-charging and potentially accumulator tanks (or other forms of energy storage)
- MATLAB code or graphical interface which allows the user to adjust the household configurations
- The results visualized graphically in MATLAB and interesting values described and printed in the terminal
- User manual
- Documented results from the analyses

2.3 Dependency of other systems

The product shall work independently given that the MATLAB version is correct and the used additional MATLAB packages are installed.

2.4 Included subsystems

- Subsystem 1 - the residential building including photovoltaics, an electric vehicle, a hot water tank and a thermodynamic model of the building.
- Subsystem 2 - the low-voltage grid that connects the small residential area Linghem in Sweden.

2.5 Delimitations

- The simulations will be based on energy usage from one residential area in Linköping during a year. The project will not look at other residential areas nor for other time periods.
- The residential area will be represented by an average household in which the simulations will be based upon.
- The project scope will not include the high-voltage grid.

2.6 Design philosophy

To ensure a smooth and time effective work process without unnecessary confusion the group has agreed upon certain design philosophies. The following philosophies will be implemented:

- All development in code will be version managed in GitLab repository
- Model and script files must be named according to the function they fulfill
- Scripts must be continuously commented for easy readability
- Scripts and models must strive to be minimalistic
- Files must be saved in organized folders for easy access

2.7 General requirements on the system

In this chapter, general requirements of the system will be described, see table below. Base requirements are the ones that must be fulfilled throughout the project while optional requirements are fulfilled if there is enough time.

Requirement	Version	Description	Priority
1	Original	A comparison of results from simulations of a real time control approach using MPC, presented in the report	Base
2	Original	Evaluate different models for the power grid tariff, present at least two in the report	Base
3	Original	Simulations and optimizations will be made to evaluate the solutions for different real time control approaches	Optional

3 SUBSYSTEM 1

The subsystem 1 will consist of models for a connected electric vehicle, from which energy can be stored and used, a model for photovoltaic, providing energy while the sun shines, a model for usage of a heat pump and accumulator tank to store energy for later use. The main algorithm will use historic data to balance the different energy sources to minimize cost for the household.

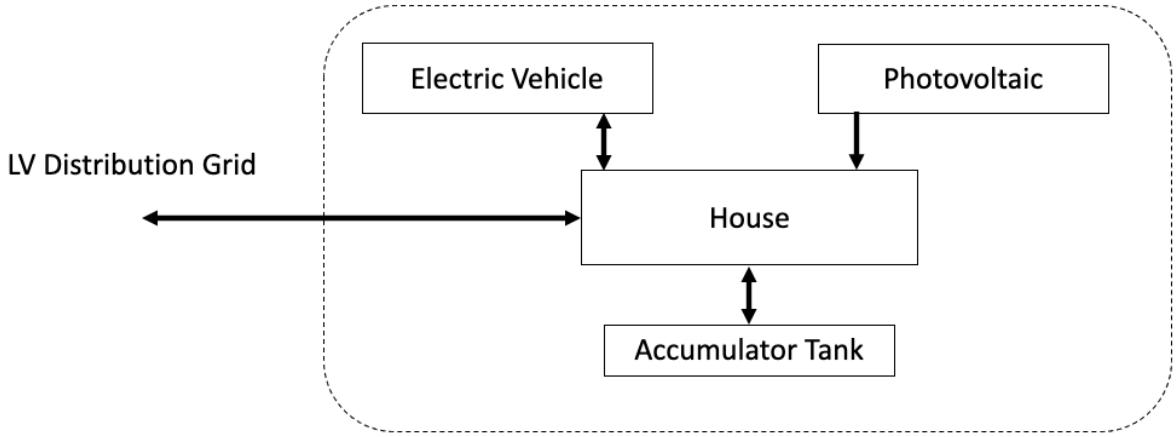

Figure 2: Subsystem including residential house, electric vehicle, photovoltaics and an accumulator tank.

3.1 Introductory description of subsystem 1

Subsystem 1 consists of a house, an electric vehicle, solar panels and an heat pump with accumulator tank. The interconnections are illustrated by the arrows. The electric vehicle encloses a battery that serves as an electrical energy storage component. The accumulator tank serves as a storage for thermal energy. Both of these energy storage systems will be used to optimize the household's energy consumption cost.

3.2 Interfaces

The requirements presented below are connected to facilitate user experience of the system. Base requirements must be fulfilled throughout the project while optional requirements are completed if there is enough time.

Requirement	Version	Description	Priority
4	Original	It shall be possible to make adjustments for activities related to the electricity consumption of the living residence (i.e. photovoltaics, electric vehicle, accumulation tank)	Base
5	Original	It shall be possible to monitor the impact of activities related to electrical consumption of the living residence on the low-voltage grid	Base
6	Original	It shall be possible to make adjustments for input data (i.e. spot price, outside temperature, sun radiation)	Optional

3.3 Design requirements

The requirements presented below are connected to computers, programming language, methods of manufacturing etc. Base requirements must be fulfilled throughout the project while optional requirements are completed if there is enough time.

Requirement	Version	Description	Priority
7	Original	The optimization shall be performed in Matlab, including visualisations of the result	Optional
8	Original	A model of an accumulator tank with simplified calculations for a heat pump shall be developed and integrated with the low-voltage grid	Base
9	Original	A model of an stationary battery should be developed	Base
10	Original	Develop a thermodynamic model of a house	Base
11	Original	A dimensional analysis shall be made on energy storage regarding stationary battery and accumulator tank with respect to solar energy production	Base
12	Original	A simplified model of water usage in household shall be developed and integrated with the low-voltage grid	Base
13	Original	A model of PV production shall be developed and integrated with the low-voltage grid	Base

3.4 Functional requirements

The requirements presented below are connected to the functionality of the system. Base requirements must be fulfilled throughout the project while optional requirements are completed if there is enough time.

Requirement	Version	Description	Priority
14	Original	A sensitivity analysis shall be preformed examining the power voltage levels of the power grid to determine the impact of a single household	Base
15	Original	A real time optimization shall be implemented to control the energy storage activities of an electric vehicle battery	Base
16	Original	A real time optimization shall be implemented to control the storage and consumption activities of hot water accumulation tank	Base
17	Original	Sensitivity analysis shall be performed examining the cost for the single household with respect to the low-voltage grid stability	Base
18	Original	A different optimization shall be implemented to control the energy storage activities of an electric vehicle	Optional
19	Original	A different optimization shall be implemented to control the energy storage and consumption activities of hot water accumulation tank	Optional
20	Original	Evaluation and comparison of different optimization algorithms shall be documented	Optional

4 SUBSYSTEM 2

Subsystem 2 consists of a low-voltage grid that connects a local residence area. The purpose of the subsystem is to see how the energy consumption of multiple single households affects the local grid at large. As can be seen in *Figure 3*. The end nodes illustrate domestic establishments while the interconnecting nodes represent power transformers. The main step-down transformer reduces the voltage to approximately 230 V.

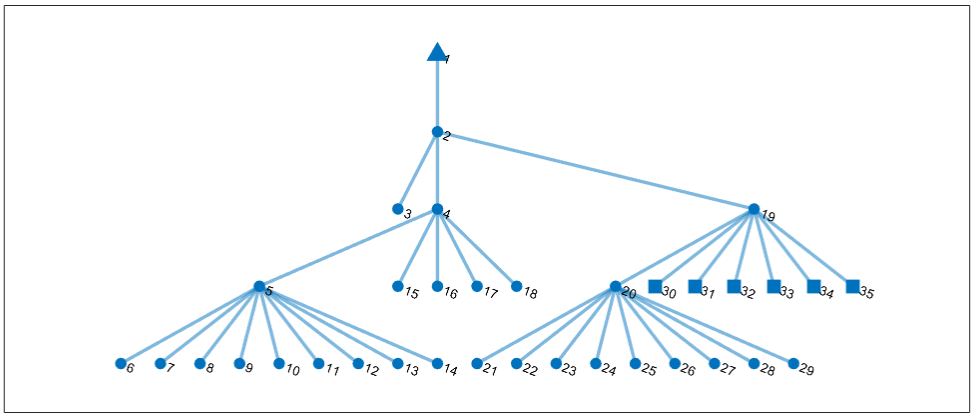

Figure 3: Overview of a the local distribution grid.

4.1 General description of subsystem 2

The requirements presented below are connected to facilitate user experience of the system. Base requirements must be fulfilled throughout the project while optional requirements are completed if there is enough time.

Requirement	Version	Description	Priority
21	Original	The voltage fluctuations shall be visible at every time instance for the single house	Base
22	Original	The power flows shall be visible between the living residences and the grid	Optional

4.2 Design requirements

The requirements presented below are connected to programming language, methods of manufacturing etc. Base requirements must be fulfilled throughout the project while optional requirements are completed if there is enough time.

Requirement	Version	Description	Priority
23	Original	The calculations and visual representations shall be performed using Matlab	Optional
24	Original	Develop an alternative electric price model	Optional

4.3 Functional requirements for subsystem 2

The requirements presented below are connected to the functionality of the system. Base requirements must be fulfilled throughout the project while optional requirements are completed if there is enough time.

Requirement	Version	Description	Priority
25	Original	It shall be possible to detect when the voltage is outside the acceptable range	Base
26	Original	Results of spot price and peak effect tariffs shall be investigated, compared and documented to observe the stresses on the grid	Base
27	Original	Identify and recommend tariff parameters to influence the price models for stabilizing grid	Optional

5 PERFORMANCE REQUIREMENTS

In this chapter the requirements of the performance of the product are presented. Base requirements must be fulfilled throughout the project while optional requirements are completed if there is enough time.

Requirement	Version	Description	Priority
28	Original	The optimization shall be designed to be compatible with the data sets provided by Tekniska Verken	Base
29	Original	A model shall be developed to predict energy consumption based on historic data	Base

6 POSSIBILITIES TO FURTHER DEVELOPMENT

In this chapter the requirement for upgrade of the product is described. Base requirements must be fulfilled throughout the project while optional requirements are completed if there is enough time.

Requirement	Version	Description	Priority
30	Original	Documented manual on how the implemented software could be easily developed to increase performance shall be written	Optional
31	Original	Results and discussion of possibilities on realising the implemented software in a physical product shall be documented	Base

7 RELIABILITY

In this chapter requirements of reliability are described. Base requirements must be fulfilled throughout the project.

Requirement	Version	Description	Priority
32	Original	The data regarding technical devices shall be obtained from commercial sources to the greatest extent possible	Base
33	Original	General assumptions should be conservative, i.e. the behaviour of the consumers	Base

8 ECONOMY

In this chapter requirements regarding economy are described. Base requirements must be fulfilled throughout the project.

Requirement	Version	Description	Priority
34	Original	1440 hours distributed over 6 group members	Base

9 SAFETY AND SECURITY REQUIREMENTS

Since the project will be implemented via software and no physical product will be developed, no safety measurements are required.

10 DELIVERY

In this chapter all deliverables are presented. Base requirements must be fulfilled throughout the project.

Requirement	Version	Description	Priority
35	Original	BP2: Requirement specification, Project plan, Time plan and draft of design specification will be delivered latest 21/9	Base
36	Original	BP3 will be delivered 2-3 weeks after BP 2	Base
37	Original	BP5 will be delivered about half a week before delivery of project (12/12)	Base
38	Original	Delivery of project about 2 weeks before project conference (latest 12/12)	Base
39	Original	After study about a week before project conference (latest 12/12 kl 13.15)	Base
40	Original	Ready to print poster to the deliverer about a week before project conference (latest 13/12 kl 12.00)	Base
41	Original	BP6 and belonging deliverables latest by project conference 19/12 kl 13.15	Base

11 DOCUMENTATION

Table 15 lists all documents that shall be produced in the project and delivered.

Table 15: Documents to be produced and delivered.

Document	Language	Aim	Target	Format
Project plan	English	Initiate project, deadlines, roles etc	Project partners	PDF
Requirement specification	English	Set project scope	Project partners	PDF
Design specification	English	Describe complex system	User	PDF
Meeting Protocols	Swedish	Afterlife	Future partners	PDF
Technical report	English	Overview of project	Everyone	PDF
After study	English	Reflection	Group members	PDF
Product Manual	English	Afterlife of product	Future partners	PDF

12 TRAINING

No training will be needed to implement the project since the group already has sufficient experience and knowledge in the field.

13 QUALITY

Requirements presented below are concerning the quality of the project to avoid bad practice. Base requirements must be fulfilled throughout the project.

Requirement	Version	Description	Priority
42	Original	The code will be developed according to best practice, i.e. variable naming conventions, indentations, reusability etc	Base
43	Original	Tests shall be performed to detect any anomalies	Base
44	Original	Results from test which show that different requirements have been accomplished shall be documented	Base

14 MAINTAINABILITY

Requirements presented below are concerning the maintainability of the project. Base requirements must be fulfilled throughout the project.

Requirement	Version	Description	Priority
45	Original	The code will have clear and concise comments to make it easy for an external party to understand and further contribute to it.	Base

REFERENCES

[1] C. Sundström, D. Jung, and A. Blom, "Analysis of optimal energy management in smart homes using mpc," in *2016 European Control Conference (ECC)*, 2016, pp. 2066–2071. DOI: 10.1109/ECC.2016.7810596.

[2] D. Jung and C. Sundström, *Analysis of tariffs and the impact on voltage stability in low-voltage grids with smart charging and renewable energy*, 2022. [Online]. Available: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4203231.