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FP7-SMARTCITIES-2013

OPtimising Hybrid Energy grids for smart citieS

WP4 System Modelling and Simulation for the Evaluation of the OrPHEuS Control Strategies

Deliverable 4.3.2

Technical evaluation of the OrPHEuS control strategies with future business model

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Deliverable Description

Abstract: This deliverable provides the technical evaluation of the OrPHEuS control strategies co-simulation results enabling hybrid grid optimization using future business models, from the perspective of WP4. The deliverable first introduces an investigation methodology for a continuous enhancement of the control strategies developed in WP5, and then provides the technical indicators assessment for the two demo sites with different scenarios and variations: 1) removal of peak oil boiler usage and integration of waste heat from additional industrial customers for the district heating network of Skellefteå, Sweden and 2) storing and distributing heat produced with surplus photovoltaic power through the district heating network in Ulm, Germany. An additional scenario involving power-to-gas solution for the city of Ulm has been investigated only from the technical point of view, without the involvement of a dedicated control strategy from WP5. The final evaluation results contribute towards the holistic evaluation analysis task in WP7.

Key Words: smart cities, hybrid energy grid, co-simulation based evaluation, hybrid grid control strategy, smart grid, surplus photovoltaic power, E-rods, waste heat, power-to-gas, ICT

Document History

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0.1	14.10.2016	AIT	D4.3.2 Draft of deliverable outlining
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Dissemination Level

Dissemination Level		
PU	Public	**X**
PP	Restricted to other program participants (including the Commission Services)	
RE	Restricted to a group specified by the Consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Executive Summary

The OrPHEuS project explores hybrid energy network control system for smart cities implementing novel cooperative local grid and inter-grid control strategies for the optimal interactions between multiple energy grids. This is achieved by enabling simultaneous optimization for individual response requirements, energy efficiencies and energy savings as well as coupled operational, economic and social impacts. Starting from existing system setups in two cities, enhanced operational scenarios are demonstrated for today's market setup, as well as for future market visions. The deliverable supports the achievement of the STO3: Extended hybrid energy network modeling of cities' Hybrid Energy Networks, and of the objective results: Advances respecting different time horizons and time operational needs.

The main scope of the deliverable D4.3.2 (Task 4.3) is the technical evaluation and validation of the OrPHEuS collaborative control strategies for hybrid grids, developed in WP5, under **future business** models. The assessment and validation of the control strategies' simulation results is performed for the two demo sites, respectively Skellefteå (Sweden) and Ulm (Germany) for different scenarios and variations. The technical evaluation has been considered part of an iterative process for the definition/enhancement of the control strategies. The technical evaluation aimed at validating the scenarios' results from a technical operation point of view, in which operational limits, violations and/or possible technical impacts on the systems, according to the defined thermal and electrical KPIs in D4.2, have been investigated. It has also to be reported that deliverable D4.3.2 differs from deliverable D5.3.2 which evaluates the control strategies' performance, assessing achievements based on control strategy functionalities, targets and goals.

An additional scenario involving a power-to-gas solution for the city of Ulm has been investigated only from the technical point of view, without the involvement of a dedicated control strategy from WP5.

The technical evaluation of the different scenarios and variations contributes to the assessment of the control strategies' potential for the enhancement of hybrid grids. The evaluation methodology and the analysis of the simulation results for the single domains for both demo sites is described in Section 2. The evaluation of the control strategies for both demo sites from a hybrid grid prospective is reported in Section 3. The needed enhancement for the control strategies are coupled within the analysis of the results in an iterative process as feedback to WP5.

Administrative Overview

Task Description

Task 4.3: OrPHEuS control strategies evaluation in simulation environment

Input from: Task 5.3, Task 2.3, WP3

The control strategies developed in WP5 task 5.3 are modelled and integrated in the simulation and evaluation environment of Task 4.3. The different load and generation models from Task 4.1 and 4.2, including historical data from the demo sites (WP3), deliver the input parameter for the model-based predictive OrPHEuS control strategies.

The analysis of the capability of the control strategies to overcome possible technical constraints is done in task 4.3, taking into consideration the interaction of the different energy carriers based on different use cases and scenarios developed in cooperation with WP2 (thermal-electrical coupling), which will be evaluated in a second step.

The simulations give input for requirements of the monitoring system in WP3. Additionally the evaluation of the necessary data flows to run the control strategies gives input for ICT requirement and gap analysis of the demo sites in WP3. An iterative enhancement of the OrPHEuS control strategies will be done in WP5 according to the analysis of the simulation results.

Relation to the Scientific and Technological Objectives

This deliverable is related to the achievement of the STO3 – "Extended hybrid energy network modeling of cities' Hybrid Energy Networks" and of the objective / expected results: "Advances respecting different time horizons and time operational needs".

It is related to the Performance Indicator:

No.	**Objective/expected result**	**Indicator name**	**STO**	**Deliverable**	**MS**	**Expected Progress**		
						Year 1	**Year 2**	**Year 3**
15	Validation of the control strategies in the Simulation Environment	Simulation environment	STO3	D4.3.2	MS3			Due: M30 Draft: M27

Relations to activities in the Project

Relationship to previous and future tasks in the WP

- Inputs:
    - WP2 Task 2.3: different use cases and scenarios
    - WP3: historical data from the demo sites
    - WP5 Task 5.3: cooperative control strategies for both demo sites using current business model

- Outputs:
    - WP2: provides simulation evaluation results for evaluation/validation

- WP3: requirements of the monitoring system, ICT requirements and gap analysis of demo sites
- WP5: further improvement and enhancement of the control strategies
- WP7: control strategies technical evaluation results as an holistic analysis for the final recommendations

Terminologies

Definitions and abbreviations

The definitions and abbreviations are reported directly in the text.

Table of Contents

1 Introduction

1.1 Scope of the document

The scope of this document is to support the overall aim of OrPHEuS on the development of collaborative hybrid grid control strategies on a simulation basis, by applying new control strategies in an enhanced multi-domain simulation environment (focusing on electricity and district heating domains). In the document, under the future business model boundary conditions, different variations for the demo site Skellefteå (Sweden) and Ulm (Germany) have been investigated and with the help of the technical indicators defined in the deliverable D4.2 the related control concepts have been evaluated. The detailed description of control strategy algorithms, scenarios and variations is provided in the deliverable D5.3.2. Additionally it has to be reported that deliverable D4.3.2 does provide only the technical evaluation of results (operational limits violations and/or possible technical impacts on the system) and differs from deliverable D5.3.2 in which the evaluation of the control strategies performances is reported, e.g. including achievements based on control strategies' functionalities, targets and goals.

The document includes additionally the power-to-gas scenario involving power-to-gas solutions for the city of Ulm, investigated only from the technical point of view, without the involvement of a dedicated control strategy from WP5.

This deliverable is related to the achievement of the STO3 – "Extended hybrid energy network modeling of cities' Hybrid Energy Networks" and of the Objective / Expected result: - "Advances respecting different time horizons and time operational needs".

1.2 Structure of the document

This document is structured as follows:

Chapter 2 presents a **general description of the methodology** used to evaluate and enhance the proposed control strategies from WP5 in both demo sites from the point of view of the electric and the thermal grid systems. Additionally it describes the effects of the control strategies for the two demo sites while analysing the technical KPIs under different boundary conditions. Furthermore, it introduces a possible alternative with power to gas and the analysis of the results done by project partner HSU.

Chapter 3 introduces and **evaluates control strategies from the hybrid aspects** point of view, for the demo sites of Skellefteå (Sweden) and Ulm (Germany). This chapter presents the analysis of the interconnections between technical KPIs from both domains, respectively the electrical and thermal networks.

2 Single domains: technical evaluation of the control strategies

2.1 Methodology

The simulation set-up developed in Task 4.1 and described in the deliverable D4.1 serves as a real-life simulation-based testing lab for the OrPHEuS project and key performance indicators, defined in the deliverable D4.2, are used to test and compare the various scenarios and variations developed within WP5 and described in the deliverable D5.3.2. In this section the technical indicators from the D4.2 process are used for the evaluation of the simulation runs in order to assess the influence of the control strategies on the specific domains (electricity and thermal). The mutual interdependencies between the thermal and electricity domains are analyzed separately in Section 4. As a result from the evaluation of the single domains as well as from the hybrid grids point of view, enhancements have been provided to the control strategy concepts of WP5 as well as to the monitoring concepts of WP3. The details of the single domains control strategy evaluation are reported for the Skellefteå demo site in Section 2.2. The details of the single domains control strategy evaluation are reported for the Ulm demo site in the Section 2.3.

Moreover it has to be stated that the evaluation process has been serving the enhancement and improvement of both thermal and electrical models and control strategies development. This evaluation process takes into account not only technical operation limitations and technical KPIs for both electricity and thermal domains but also the possible application of these strategies using the capabilities of the existing and new devices. The continuous enhancement includes the added elements' design, their operation limitations and also the operation conditions and limits of both domains. Meanwhile the scenarios correspond to different seasons to reflect the real possible thermal and electrical consumption and production.

In order to investigate the sensitivity of control strategies to boundary condition variations (e.g. electricity demand increase, thermal demand increase, etc.) the OrPHEuS consortium agreed on testing a number of variations as described in detail in D5.3.2.

For the Skellefteå demo site as reported in the Sections 2.2.2 and 2.2.3, the evaluation of the simulation results has been performed for two different electricity tax conditions, since it is expected in the future that they will be significantly decreased from the current value, allowing power-to-heat solutions to enhance energy grid performances. Additionally, variations including different electric boiler sizes, electric battery capacities, different industrial load demands and heating demand conditions have been investigated. The simulations are visualized, when required, in a matrix scheme as showed for example in Figure 3.

For the Ulm demo site as reported in Sections 2.3.2 and 2.3.3 evaluation of the simulation results has been separately performed for the 2 main control strategies using one central electric boiler and one heat storage. As for the Skellefteå demo site, also for the Ulm2 scenario different system setting variations (limitations of heat overproduction export to Einsingen) as well as two PV penetration variations have been investigated.

A detailed description of the control strategies as well as parametric variation is reported in the deliverable D5.3.2.

2.2 Skellefteå demo site

2.2.1 Introduction

The evaluation of the KPIs from the simulation results for the Skellefteå demo site has been divided into the thermal and electricity domains and is reported respectively in the Sections 2.2.2 and 2.2.3. A short summary of the parametric variations is reported in the following paragraph.

- **Size of the electric battery (4)** –0MW/0MWh, 1MW/1MWh, 5/5MWh, 10MW/10MWh (peak load/capacity): on the basis of the analysis of the performance data of the electricity grid and the preliminary economic evaluation from WP3, WP4 recommended the investigation to start with these four sizes.
- **Additional industrial customer electric load (4)** – 10-20-30-40 MW: WP3 recommended the investigation to start with these four sizes.
- **Heat demand conditions (4)** – 0-5-10-20%: increase of the demand as compared to the typical winter conditions defined in D4.3.1. Four demand conditions have been chosen and the co-simulation investigations are limited to the winter season, which is defined as November to March. The 5 months were set by selecting the months most likely to require peak heating.
- **Control strategies (2)** – baseline and “Control-R” (detailed description provided in D5.3.2): From the requirements of the stakeholders, WP5 set two practical control goals. One is the baseline (extension of the concept for the baseline defined in D5.3.1) for which the assumption that oil is not used anymore for heating is considered; “Control-R” considers to optimize the operation of the DH and electricity systems from a cost point of view (including CO_2 taxes and all operational costs).
- **Electricity tax conditions (2)**: Two electricity tax conditions: respectively 0.5 €/MWh (based on possible future regulations to support electricity usage) and 19.5 €/MWh (as today conditions) on top of the electricity price.

In total, the simulation-based investigation delivered 64 baseline variations and 64 Control-R variations (as combinations of the abovementioned parameters). The evaluation of the simulation runs for the Skellefteå demo site in the case of the Scenario 1 is reported in the Sections 2.2.2 and 2.2.3 respectively for the thermal domain and the electricity domain.

A detailed description of the control strategies as well as parametric variation is reported in the deliverable D5.3.2.

2.2.2 Thermal domain

The analysis of the simulation runs under different boundary conditions (e.g. size of the electric battery, size of the additional industrial customer, etc.) is performed also considering the KPIs defined in the deliverable D4.2. The results, as shown for example in Figure 3, are visualized in a matrix approach by dividing them into 8 groups for which the columns are the size of the industrial customer (10 MW, 20 MW, 30 MW, 40 MW), and rows are the electricity tax conditions (0,5 €/MWh and 19.5 €/MWh). Results are presented by comparing the baseline with the alternative control strategy.

As explained in deliverable D5.3.2 in the description section of the Ulm Future Scenario, the baseline assumes no heat pump for the usage of waste heat from the industrial customer.

Figure 1 and Figure 2 show two single representative days in order to evaluate the effects of the control strategy on the heat production distribution (scenario with an electric boiler of 100 MW, electricity tax condition of 19.5 €/MWh, battery size 10MW/10MWh, additional industrial customer of 40MW, additional heating load of 20% and control R setup). On the representative day in January, see Figure 1, the target (from the district heating point of view reducing operational costs) is achieved by charging overnight the storage tank (and partly using heat from it) and during the day discharging the storage tank (until around 18:00) and using the biomass boiler, the CHP and the heat pump.

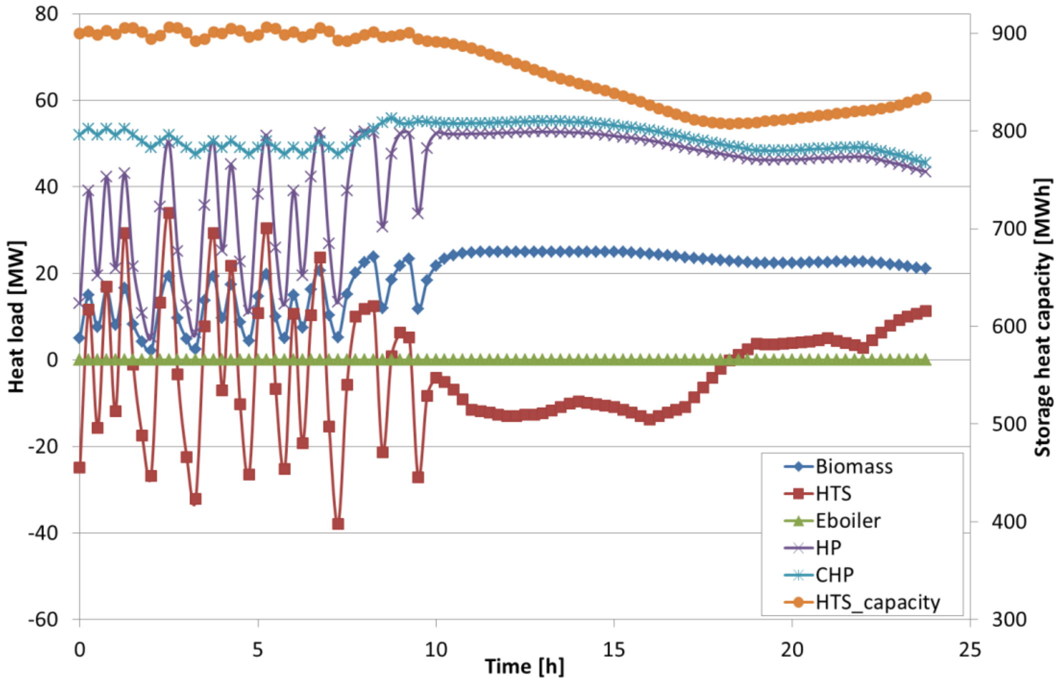


Figure 1: SKR2, Heat load distribution (representative day in January with control R)

On the representative day in March, see Figure 2, the target of reducing operational costs is achieved by using the CHP, the heat pump and the electric boiler. The storage tank buffers only heat produced from the electric boiler in the timeframe between 9:00 and 15:00. The biomass boiler is not operated for long periods (on the representative day in March for one full day).

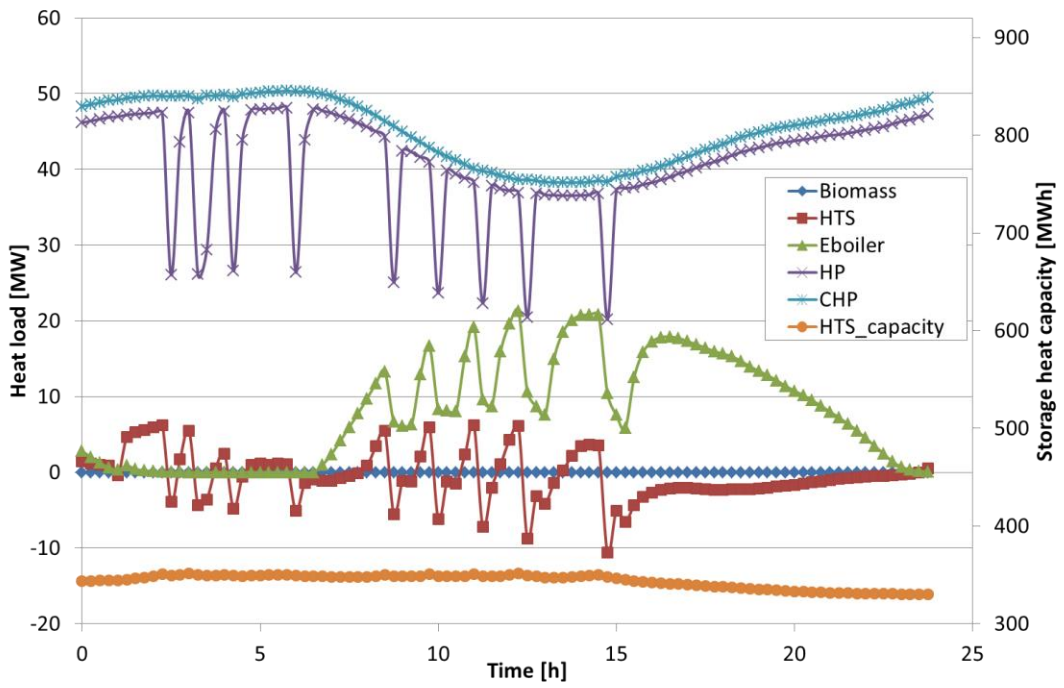


Figure 2: SKR2, Heat load distribution (representative day in March with control R)

Figure 3 visualizes heat production distribution in a matrix approach for which the columns are the size of the industrial customer variations (10 MW, 20 MW, 30 MW, 40 MW), and rows are the electricity tax condition variations (0.5 €/MWh and 19.5 €/MWh). From the analysis of the results, it can be stated that there is no effect of the electricity tax conditions on the decisions of the operation conditions, meaning the heat production distribution is similar with low and high electricity taxes.

Large variation in heat production from heat pump (using the waste heat from the additional industrial customer) and e-boiler occurs when varying the additional industrial customer electricity demand (available waste heat is coupled to the electricity demand of the industrial customer). The heat pump operation hours is for the industrial customer of 10 MW about 2900h, while for the case of an industrial customer of 40 MW is about 2100h with a reduction of about 800h. The heating demand increase (variations with 0, 5, 10 and 20%) shows a difference in the usage of both electric boiler and heat pump with a difference between 0 and 20% of 17% more usage of heat pump and 45% more electric boiler and no difference with different sizes of electric boilers.

Figure 4 visualizes heat distribution losses for the district heating network in a matrix approach for which the columns are the size of the industrial customer variations (10 MW, 20 MW, 30 MW, 40 MW), and rows are the electricity tax condition variations (0.5 €/MWh and 19.5 €/MWh). From the analysis of the results, it can be stated that there is no effect of the electricity tax conditions on the decisions of the operation conditions, meaning the heat distribution losses is similar with low and high electricity taxes. Moreover the control strategy and the electric battery variations don't influence the heat distribution losses (no effect on the supply and return network temperatures). Heating demand variations have an effect with is a minimum value of heat distribution losses of 12300 MWh for the 0% heat demand increase scenario and 14800 MWh for the 20% heating demand increase scenario.

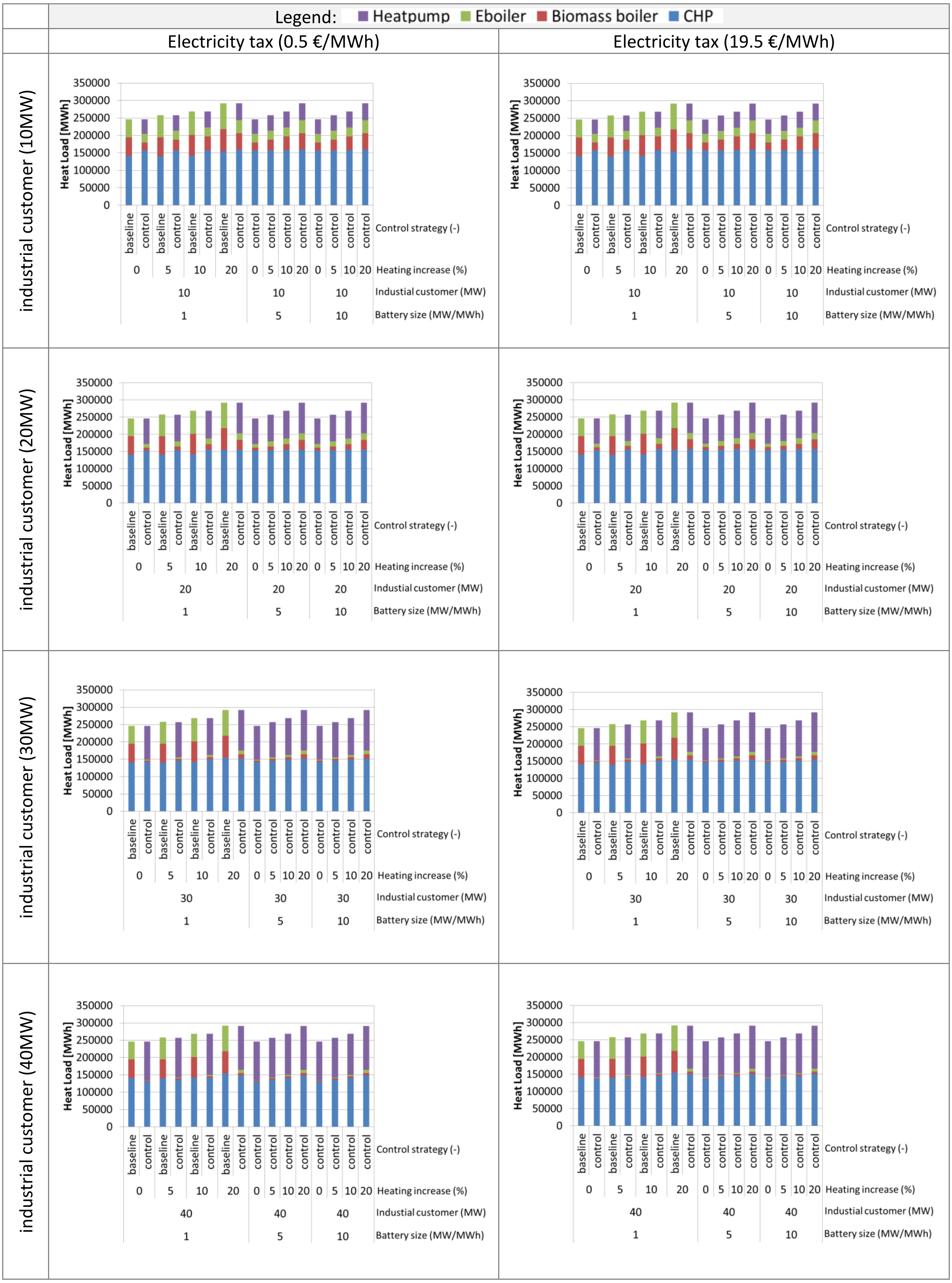


Figure 3: SKR2, Energy heat production distribution split in industrial customer variations (rows) and electricity tax conditions (columns)

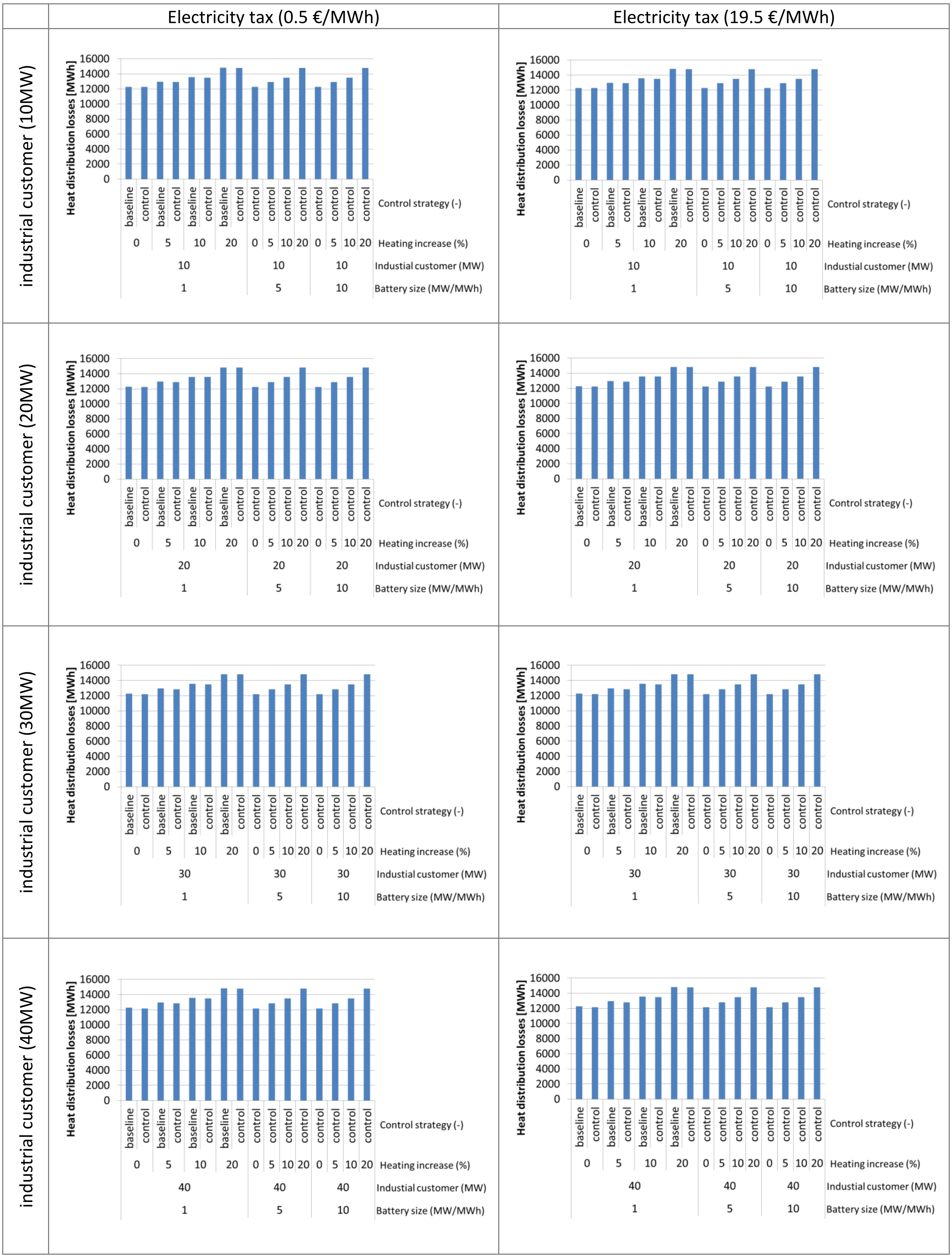
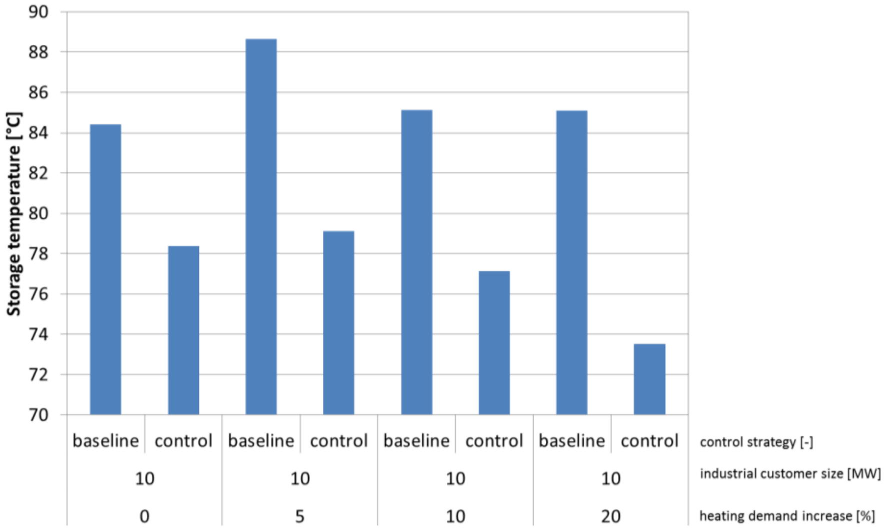


Figure 4: SKR2, Heat losses split in industrial customer variations (rows) and electricity tax conditions (columns)

Figure 5 shows storage temperature average results for the industrial customer of 10MW. No large differences are occurring for other sizes of industrial customer (20 MW, 30MW and 40MW) and for different size of electric battery and therefore they are not represented in Figure 5. The tabular form of the complete dataset is reported in the Annex I. Moreover from the analysis of the results it can be stated that the control strategy reduces the usage of the storage tank with lower average storage temperatures compared to the baseline for all variations (decrease from 85°C to about 73°C for the case of heating demand increase of 20% by using directly more the heat pump.



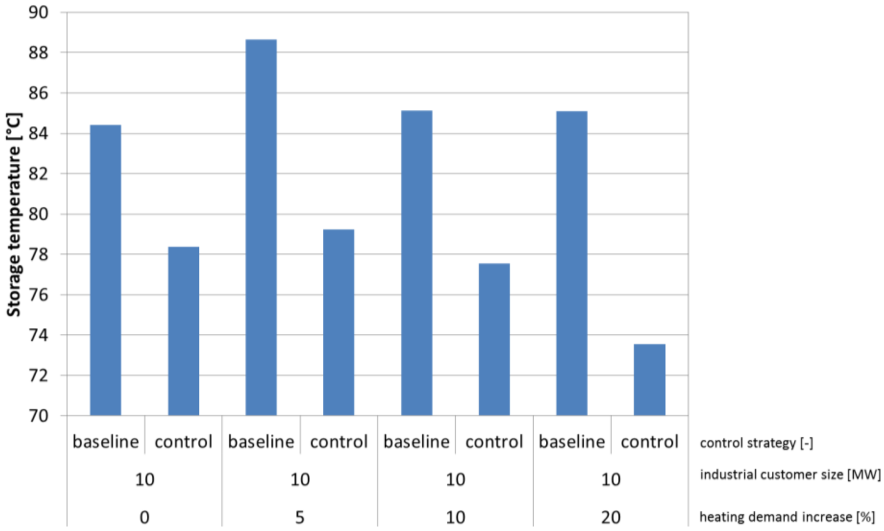


Figure 5: SKR2, average temperature levels of the top layer for the electricity tax condition 0.5€/MWh (top) and 19.5 €/MWh (bottom)

2.2.3 Electricity domain

The analysis of the simulation runs under different boundary conditions (e.g. size of the electric battery, size of the additional industrial customer, etc.) is performed also considering the KPIs defined in the deliverable D4.2. The results, as shown for example in Figure 6, are visualized in a matrix approach by dividing them into 4 groups for which the columns are the size of the industrial customer (10 MW, 20 MW, 30 MW, 40 MW), and rows are the electricity technical KPI's (network losses, maximum voltage spread, etc.). Comparison are done for different scenarios and variations such as electricity tax conditions (epr1 corresponding to 0.5 €/MWh and epr2 corresponding to 19.5 €/MWh), different heat demand increase from 0% to 20% (named hd0, hd5, hd10, and hd20) and different electric storage sizes (Eb1, Eb5, and Eb10), see Section 2.2.1. The developed control strategies results are compared with the baseline. As explained in deliverable D5.3.2 in the description section of the Ulm Future Scenario, the baseline assumes no heat pump for the usage of waste heat from the industrial customer.

Figure 6 shows a comparison of network losses of all scenario variations and control strategies, which demonstrates a reduction of about 14% in network losses for no heat demand increase scenario with epr2 (electricity price 19.5 Euro/MWh) and Eb1 (electric storage size 1 MW) (electrical industrial customer electricity load 10 MW). The same variation shows a voltage spread reduction of about 5%. The voltage spread reduction of the other different scenarios is between 16% and 42%, reflecting under voltage violations problems.

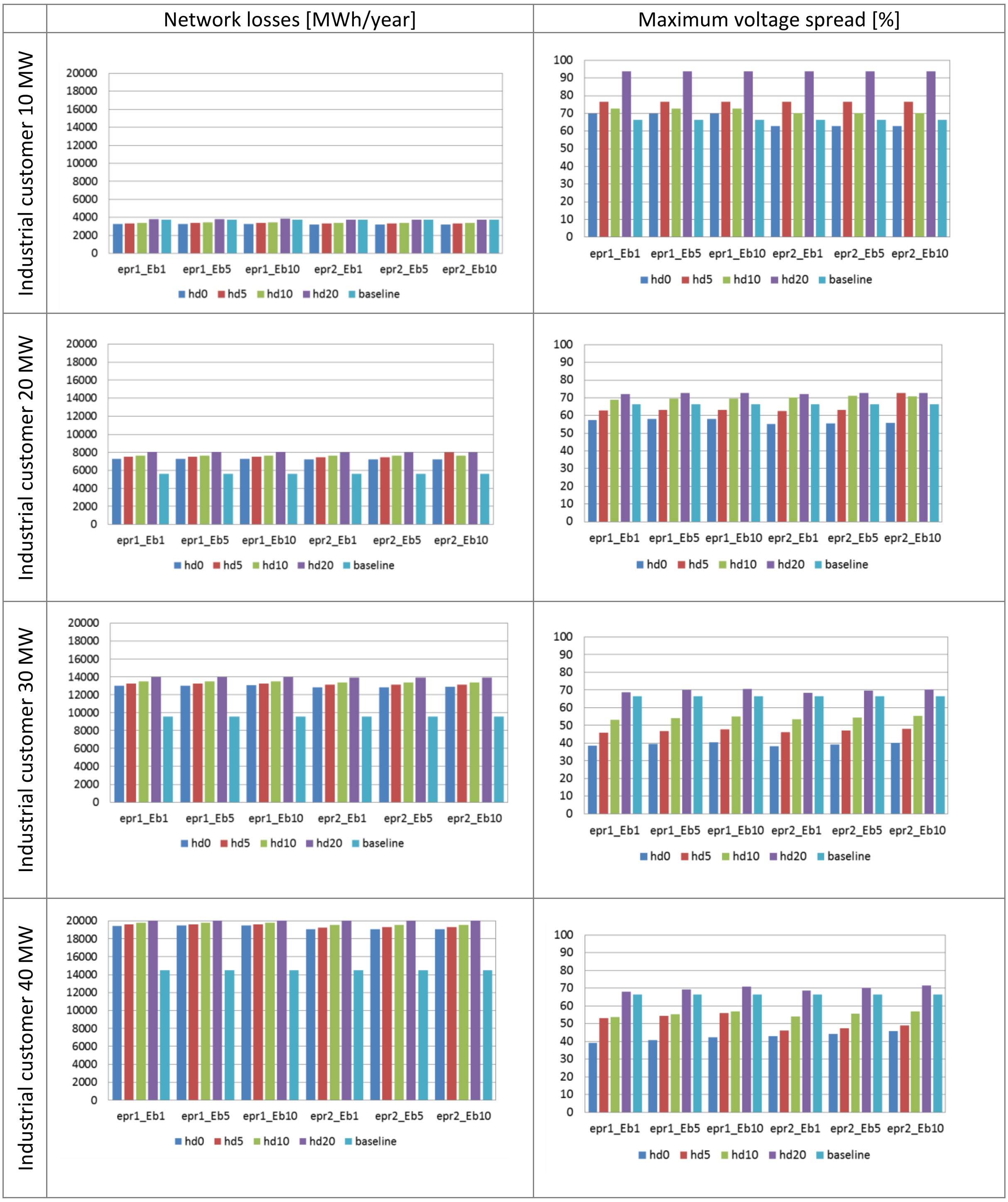


Figure 6: SKR2: network losses and maximum voltage spread of different scenarios and variations

The different variations of the scenarios, Industrial load 20 MW, Industrial load 30 MW and Industrial load 40 MW, show an increase in network losses between 28% and 34%.

Figure 7 presents the maximum transformer loading of transformer 1 which is reduced by 51.76% and 11.3% for scenario eprice1, no heat demand increase, and battery size 1 for both Industry 10 MW and Industry 20MW variations. On the contrary for both variations Industry 30 MW and Industry 40 MW, all different scenarios and variations show a transformer 1 loading increase. Additionally Figure 7 shows the duration of the transformer 1 overloading over 80% for 99% of the simulation time.

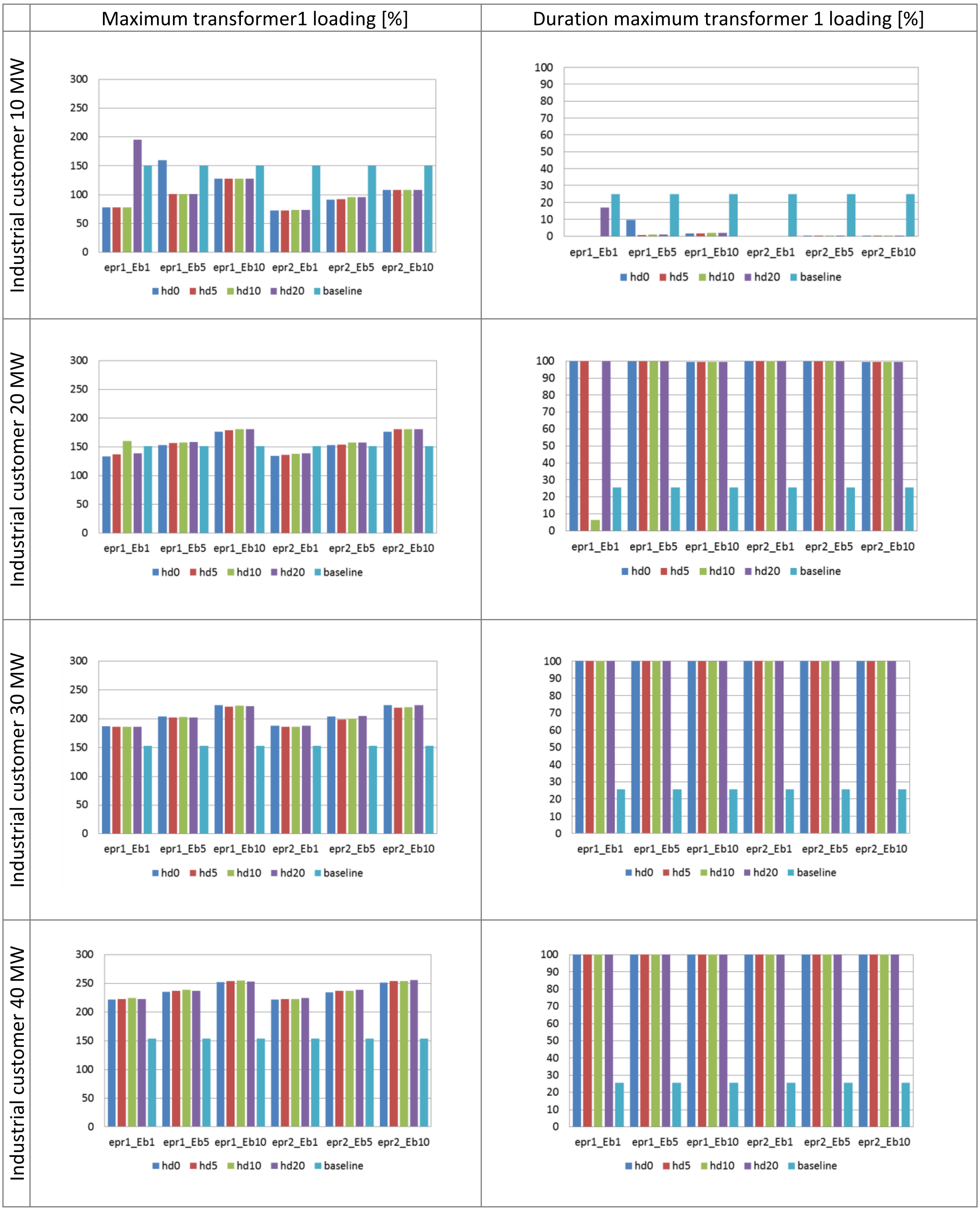


Figure 7: maximum first transformer loading and its duration of different scenarios and variations

Figure 8 shows that, there is transformer loading reduction of transformer 2 with respectively 33.3%, 10%, 31.3%, and 30% for the variations Industry 10 MW, Industry 20 MW, Industry 30 MW and Industry 40 MW for scenario eprice1, no heat demand increase, and electric battery size one. Additionally, Figure 8 shows the duration of the transformer 1 overloading over 80% which accounts for only 1% of the simulation time. Although in most scenarios and variations there is transformer loading reduction, still the values of the loading of both transformer are very high and are not within the acceptable operational limits.

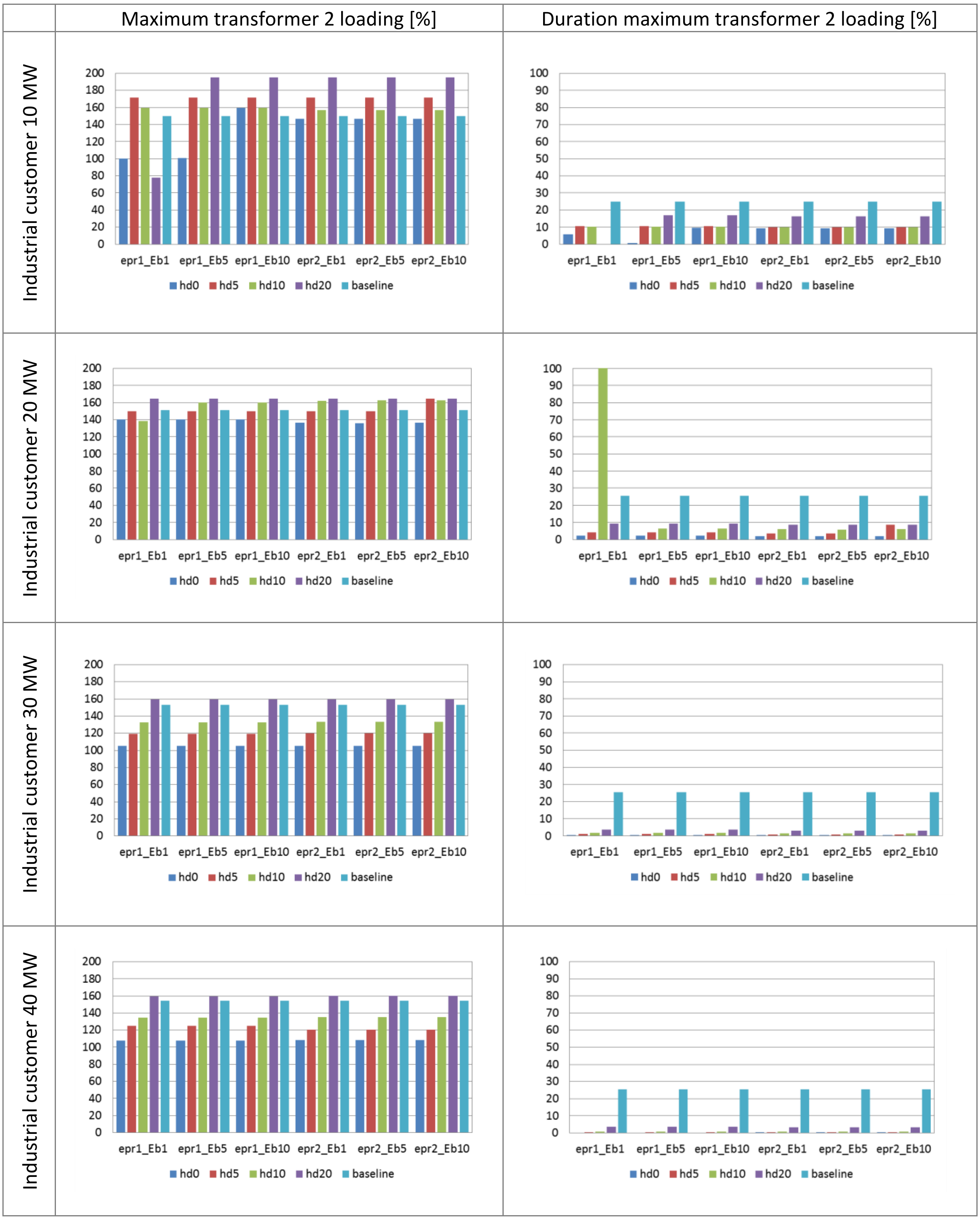


Figure 8: maximum second transformer loading and its duration of different scenarios and variations

Figure 9 presents the maximum line loadings and the duration of the overloading of lines over 80%. It shows very high lines overloading between 160% and 315% which cannot be accepted even when the duration of some of these violations is short. These violations accounts for around 40% of the simulation period.

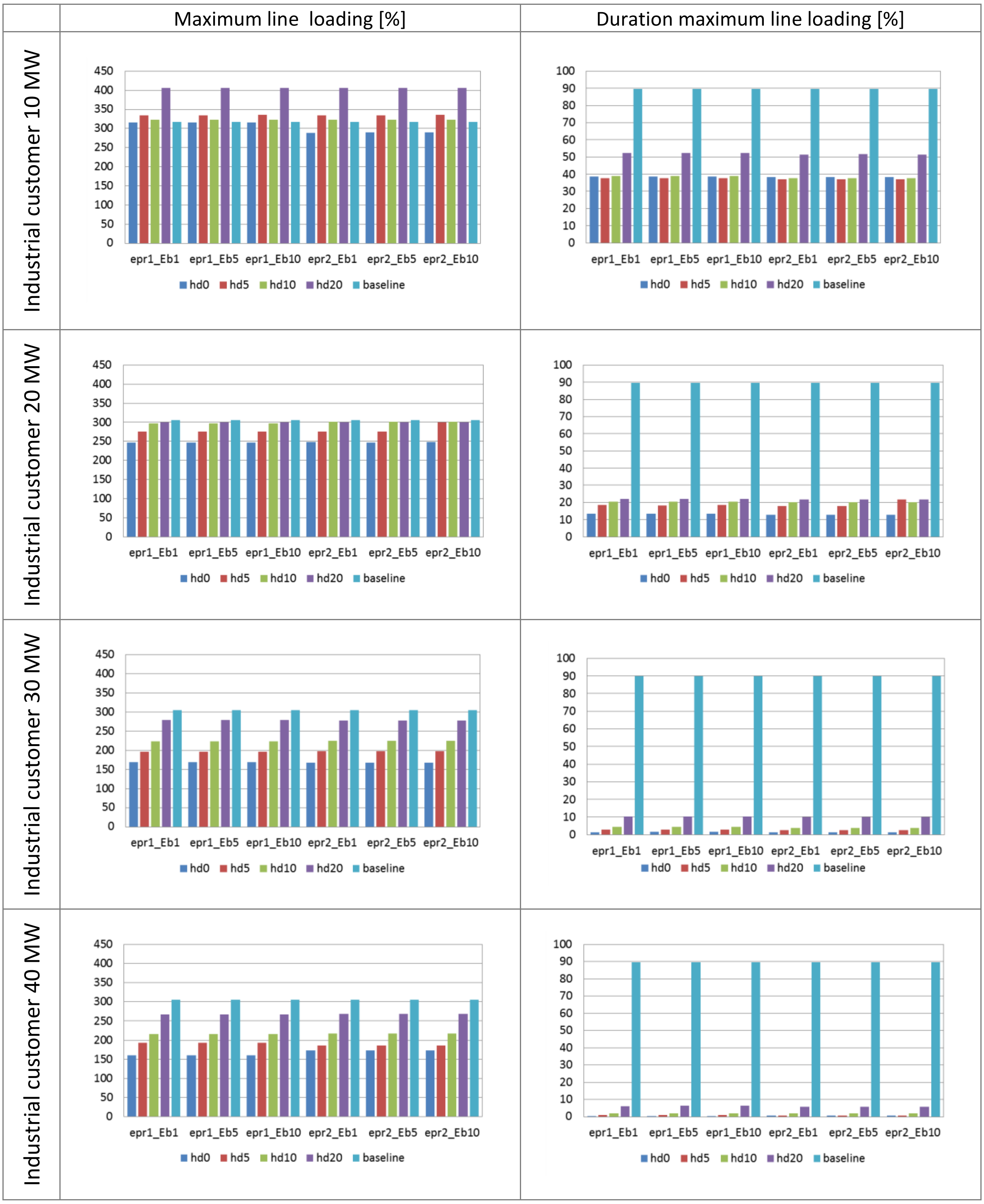


Figure 9: maximum line loadings and their durations of different scenarios and variations

As a conclusion from all results shown in this section there is an improvement of the different KPIs, especially for the scenario with low electricity tax conditions, no heat demand increase and electric storage size of 1 MW for different electricity industrial load consumptions. Nevertheless, both transformers and lines experience large violations of the network limits (loading exceeds 80% for long durations).

2.3 Ulm demo site

2.3.1 Introduction

For the Ulm demo site, two control strategies with one central electric boiler and heat storage have been evaluated: one is maximizing heat export, which targets to directly export the heat generated from PV surplus and the other is keeping the storage charged, which is targeted on keeping heat in the storage for local usage rather than exporting it.

As explained in deliverable D5.3.2 in the description section of the Ulm Future Scenario, the baseline assumes no storage tank installed and no usage of e-rods in Einsingen. The overall heat production comes from the 3.0 km long pipeline connected to the wider DH system of Ulm. Therefore all values were compared to the baseline values in order to evaluate the impact of different scenarios on the network KPIs and operation limits. The evaluation of the KPIs from the simulation results for the Ulm demo site has been divided into the electricity and thermal domains and is reported respectively in Sections 2.3.2 and 2.3.3.

For the two control strategies, a short summary of the parametric variations is reported in the following paragraph. For both control strategies, limitation of heat overproduction in Einsingen has been chosen and control goals have been analyzed.

- **PV penetration rate** – PV50% and PV75%: the penetration share describes the number of buildings on which PV plants are installed (e.g. 50% means that 50% of the buildings have a rooftop PV plant). Two possible penetration shares are suggested as the possible future by HSU and SWU.

- **Limitation of heat overproduction in Einsingen** – 0 kW - 100 kW – 200 kW - 300 kW - 400 kW – 500 kW - unlimited: on the basis of the limitations of thermal energy export to the heating network of Ulm, and therefore the amount of discharging is still limited by the sum of the local heat demand of Einsingen and the maximum heat export value of the particular scenario under consideration, these overheat production limitations are recommended to be investigated. No electric boiler usage is considered for the baseline.

- **Control strategies**– Baseline, Control A, and Control B: detailed description of the control strategies included in deliverable D5.3.2

The evaluation of the simulation runs for the Ulm demo site in the case of the Scenario 2 is reported in the Section 2.3.2 and 2.3.3 respectively for the electricity and thermal domain.

A detailed description of the control strategies as well as parametric variations is reported in the deliverable D5.3.2.

2.3.2 Electricity domain

The analysis of the simulation runs under different boundary conditions (e.g. PV penetration share, limitation of heat overproduction to Ulm as well as the two control strategies) is performed by assessing the KPIs defined in the deliverable D4.2. The results are visualized in a matrix approach by dividing them into 6 groups for which columns are the control strategies (A and B), and rows are the KPIs (total network losses, maximum voltage spread and duration transformer loading). The results are presented by comparing the baseline with the alternatives. The two PV penetrations levels are analysed separately and presented in Sections 2.3.2.1 and 2.3.2.2. The complete dataset of the results for the Ulm scenario is reported in Annex 4.

2.3.2.1 *PV 50% scenario*

Figure 10 shows a comparison of the different technical KPIs defined for electricity grid comparing the baseline with different heat transport limitation variations for control strategies A and B. In the same time these reflect the effect of these variations on the electricity network KPIs.

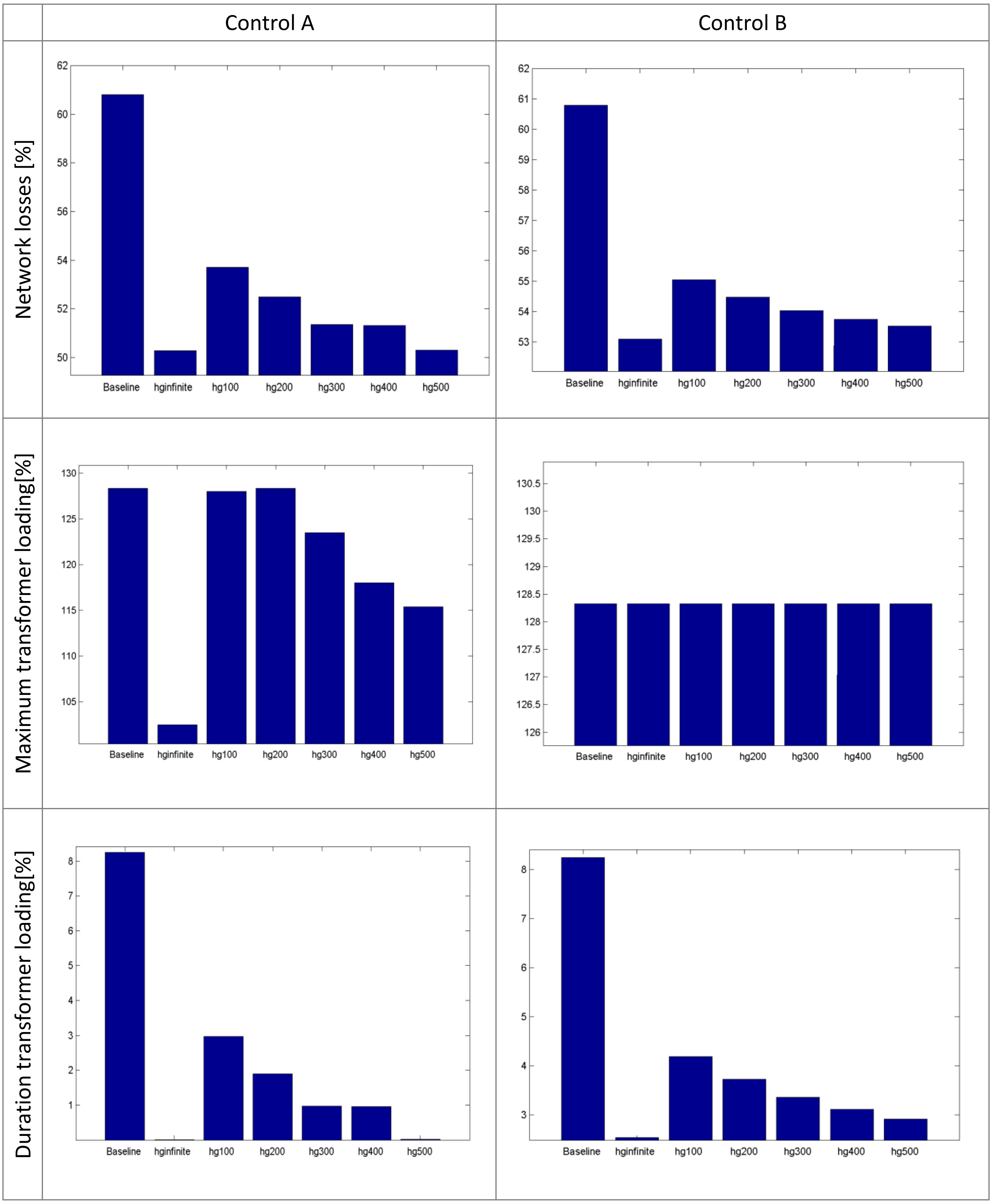


Figure 10: total network losses and maximum transformer loading

As shown in Figure 10, there is a reduction of the total network losses of about 17.3% in the case of control A with unlimited heat overproduction in Einsingen. Similar results for transformer loading can be seen in Figure 10, as control strategy A with unlimited limitation of heat overproduction shows the maximum reduction of the maximum transformer loading, compared to other scenarios, about 10.2%.

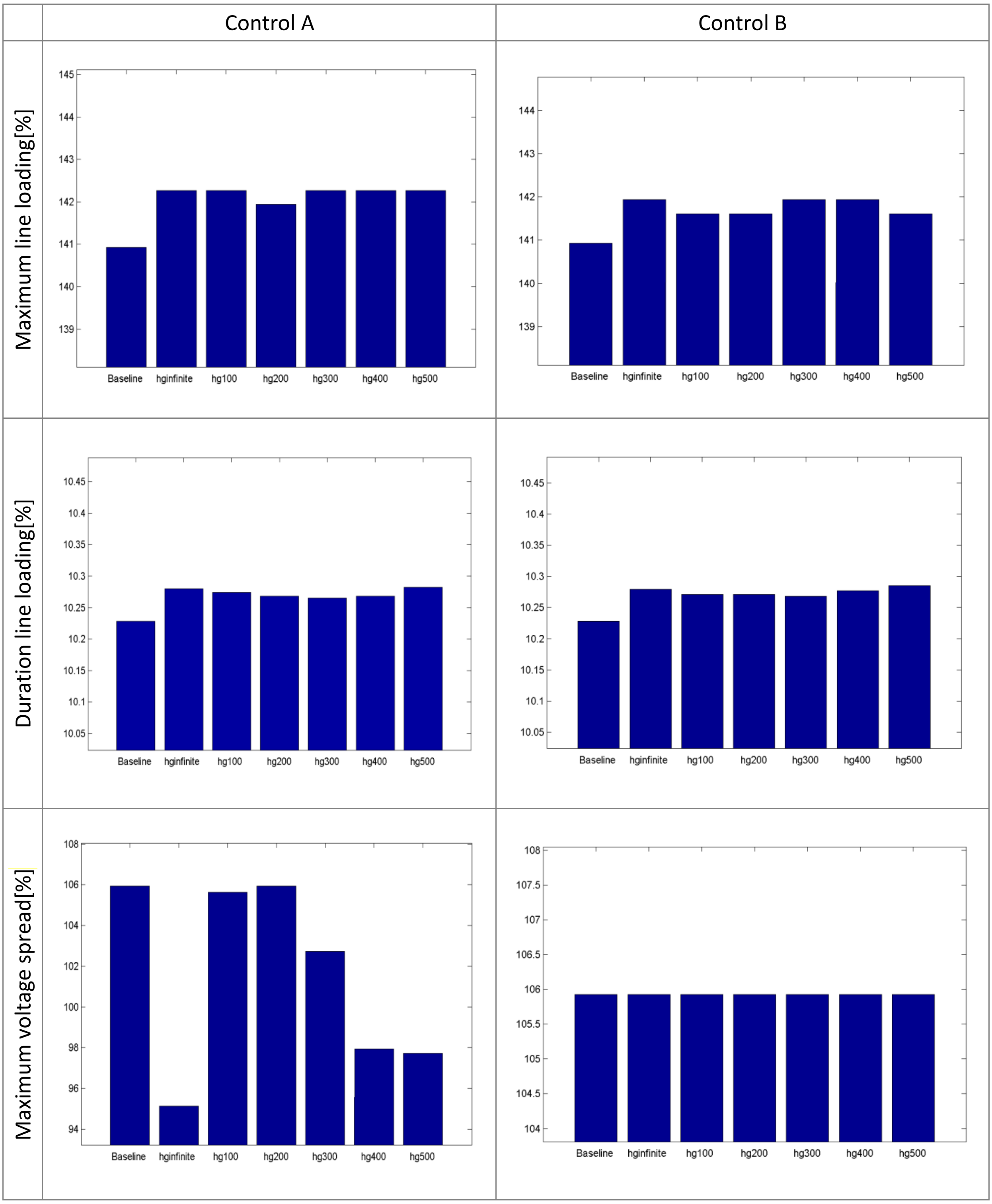


Figure 11: maximum line loading and maximum voltage spread

The same scenario shows a decrease of the maximum voltage spread of about 10.2% (Figure 11). With a total maximum voltage spread of 95%, this is within the limit. The results in Figure 11 shows that there is no improvement in the line loadings as it increases in a range from 0.5% – 1.0% compared to the baseline scenario. The duration of maximum line overloading over 80% is about 10% of the whole simulation time. Control A reflects better results than Control B from the technical operational point of view. Control A variations show improvement in total network losses, transformer loading, and voltage band usage. From the total results shown in Figure 10 and Figure 11, the control A strategy with unlimited heat overproduction in Einsingen, shows the best results and can be considered as the best solution from the introduced variations.

2.3.2.2 *PV 75% scenario*

Figure 12 shows a comparison of the different technical KPIs defined for the electricity grid comparing the baseline with different heat transport limitation variations for control strategies A and B. In the same time these reflect the effect of these variations on the electricity network KPIs.

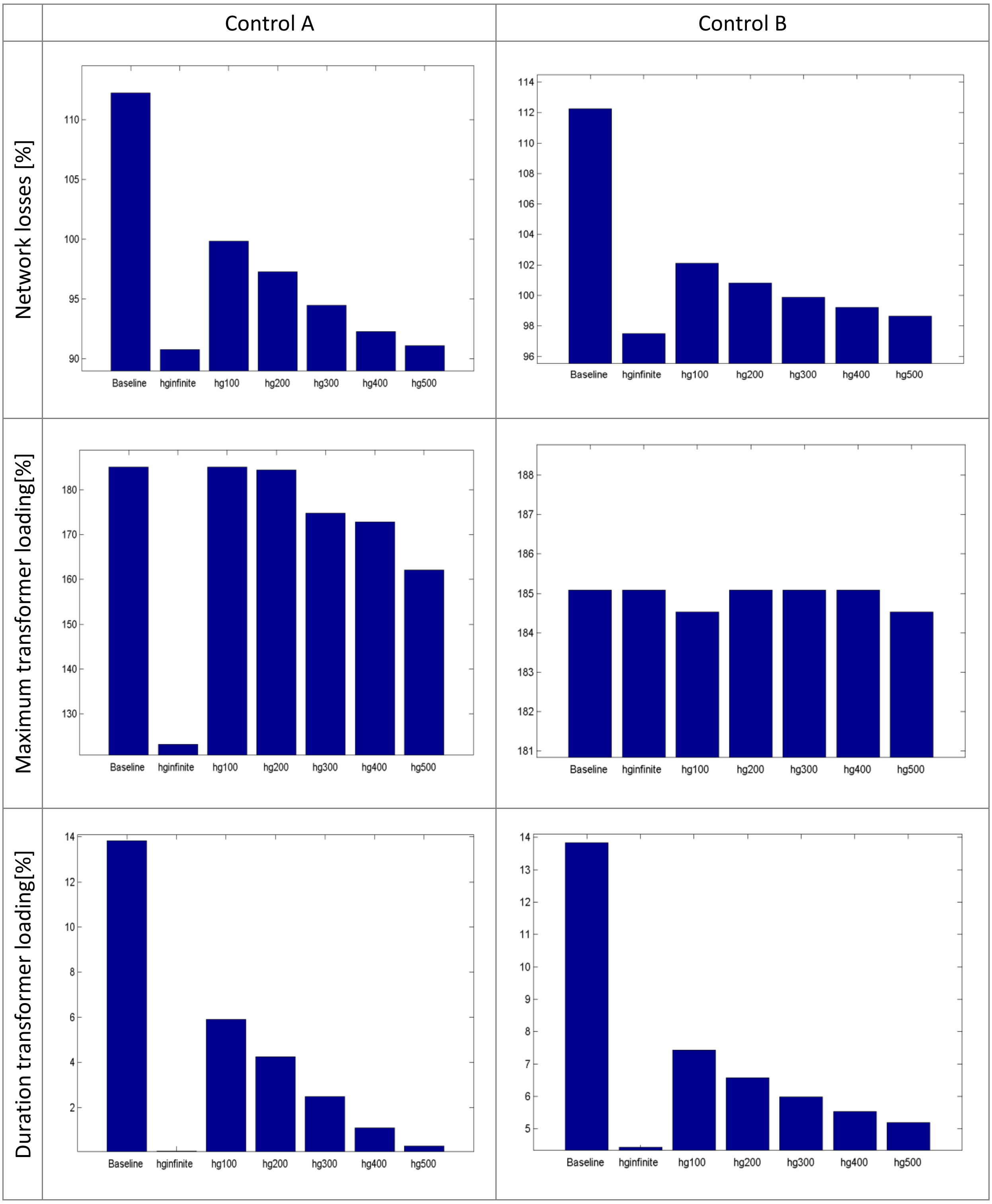


Figure 12: total network losses and maximum transformer loading

It shows similar results to the 50% PV penetration variation, as the total network losses decrease with about 19% in the case of control A with unlimited limitation of heat overproduction in Einsingen compared to the baseline scenario.

Similar results for transformer loading can be seen in Figure 12, as control strategy A with unlimited limitation of heat overproduction shows the maximum reduction of the maximum transformer loading, compared to other scenarios, of about 33.4%.

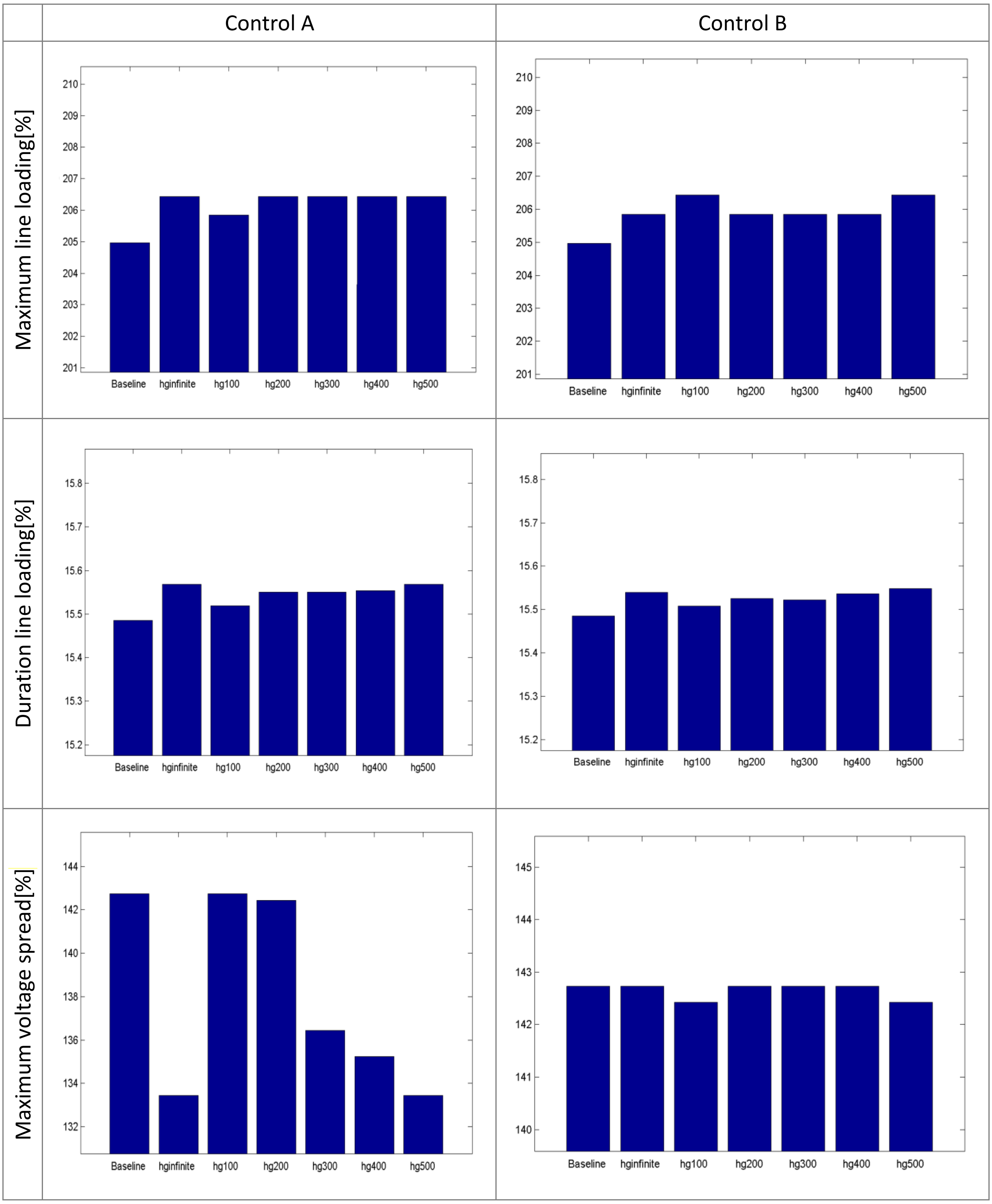


Figure 13: maximum line loading and maximum voltage spread

The same scenario shows a decrease of the maximum voltage spread of about 6.5% (Figure 13). With a total maximum voltage spread of 133.4%, this is not within the limit. As the results in Figure 13 shows that there is no improvement in the line loadings as it increases in a range from 0.4% – 0.7%

compared to the baseline scenario. The duration of maximum line overloading over 80% is about 16% of the whole simulation time.

Considering the evaluation of performance results in D5.3.2, it can be stated that analysing the technical indicators of the control strategies Control A performs better than Control B from the technical operational point of view. Control A variations show improvement in total network losses, transformer loading, and voltage band usage. From the total results shown in Figure 12 and Figure 13, the control A strategy with unlimited heat overproduction in Einsingen, shows the best results and can be considered as the best solution from the introduced variations.

2.3.3 Thermal domain

The analysis of the simulation runs under different boundary conditions (e.g. PV penetration share, limitation of heat overproduction to Ulm as well as different control strategies) is performed also considering the KPIs defined in the deliverable D4.2. The results, as showed for example in the Figure 17, are visualized in a matrix approach by dividing them into 3 groups for which the columns are the control strategies (A and B), and rows are the PV penetration shares (50% and 75%). Results are presented by comparing the baseline with the alternative. The complete dataset of the results for the Ulm scenario is reported in the Annex 3.

As explained in deliverable D5.3.2 in the description section of the Ulm Future Scenario, the baseline assumes no storage tank installed and no usage of e-rods in Einsingen. The overall heat production comes from the 3.0 km long pipeline connected to the wider DH system of Ulm. Therefore in the baseline both energy productions from e-rod and energy demand from the wider city of Ulm is respectively 0 MWh.

From Figure 14 to Figure 16 three single representative days are displayed in order to evaluate the effects of the control strategies on the heat production distribution (control A in the specific examples). In the case of control A, the target is to directly export the heat generated from PV surplus, by keeping discharging the storages as much as possible. Whenever there is PV generation surplus, the heating power of the e-boiler is set to exactly that surplus as long as the heat storage is not full, which, due to the aggressive heat export policy, is expected to happen only rarely. As shown in Figure 14, as soon as the storage temperature, due to charging from the e-rod, reaches the required supply temperature of the network the storage is discharged. Considering a small surplus in January from PV, the discharging of the storage is limited to daytime periods between 12:00 and 15:00.

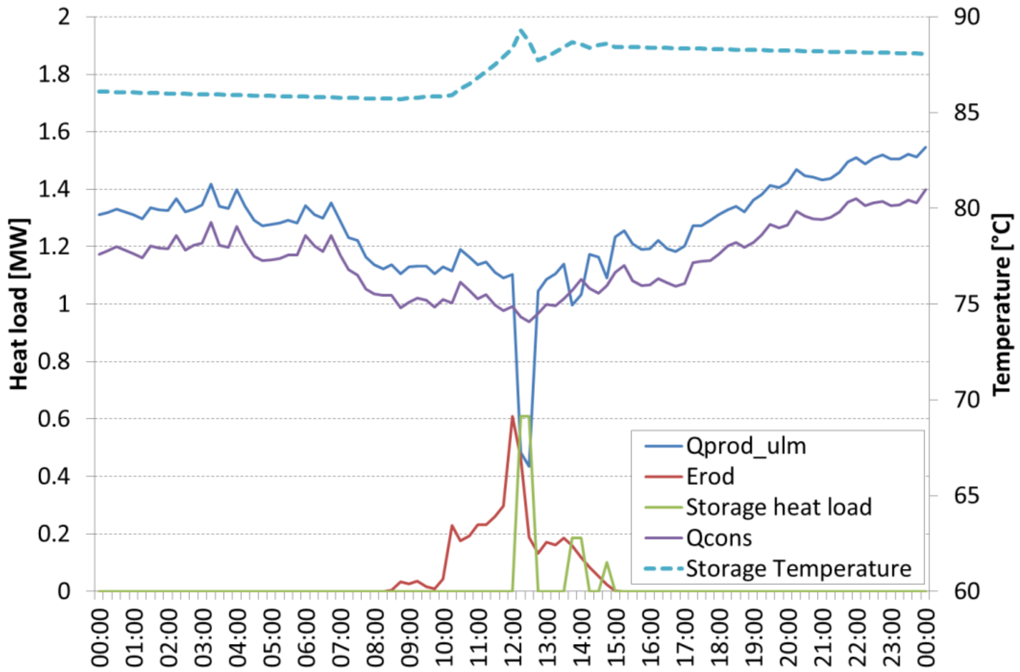


Figure 14: Ulm2, Heat load distribution (representative day in January with control A)

Considering the lower requirements in transitional period (April) and summer (July), Figure 15 and Figure 16 show an increasing discharging time period, which in the case of July is between 08:00 and 19:00, corresponding to the PV generation time period.

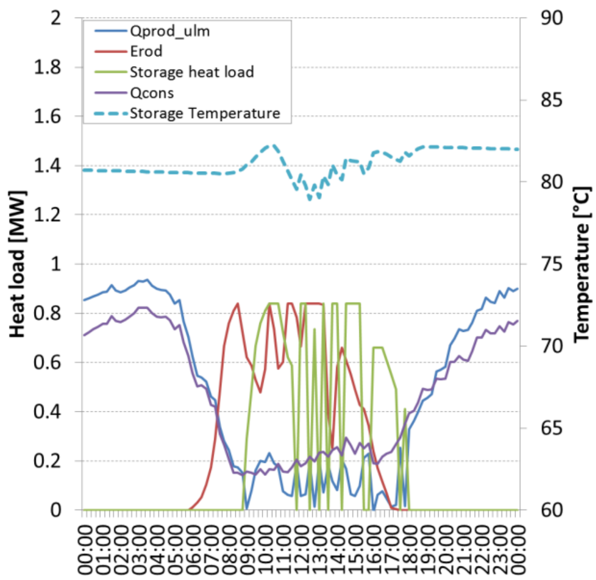


Figure 15: Ulm2, Heat load distribution (representative day in April with control A)

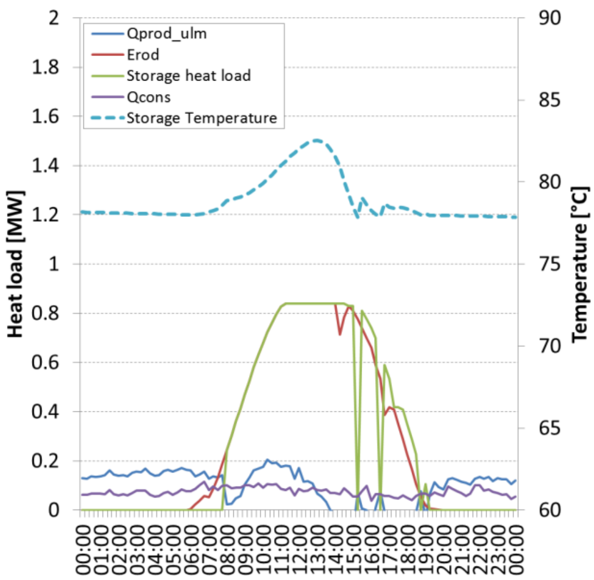


Figure 16: Ulm2, Heat load distribution (representative day in July with control A)

Figure 17 shows in blue bars: 1) the heat demand from Einsingen, 2) the exported heat (consumption) to Ulm and 3) the heat losses from the pipelines (including the connection to Ulm); and in red bars: 1) heat production coming from Ulm and 2) heat production from the e-rod.

Considering PV penetration 75% in the case of heat export limitation of 300 kW it shows that 1397 MWh is produced from the e-rod, covering totally the heat distribution losses and heat exported to the wider district heating grid of Ulm. In the case of PV penetration of 50% the effect of the heat export limitations show that in the case of unlimited export a maximum of 1692 MWh per year can be produced covering totally heat distribution losses but only partly the heat demand from Ulm.

In case of Control B the control strategy avoids exporting the heat to the city of Ulm (except when the storage is about to get full) and uses the surplus PV as heat production for the Einsingen demand. In this case having as target the Einsingen demand as priority, the limitation of Ulm are less influencing than in the control A. E-rod energy production for the different variations of heat export limitations is between 896 MWh and 1197 MWh. Small differences are assessed between PV50% and PV75%, considering the heat demand from Einsingen the limiting factor for e-rod energy production.

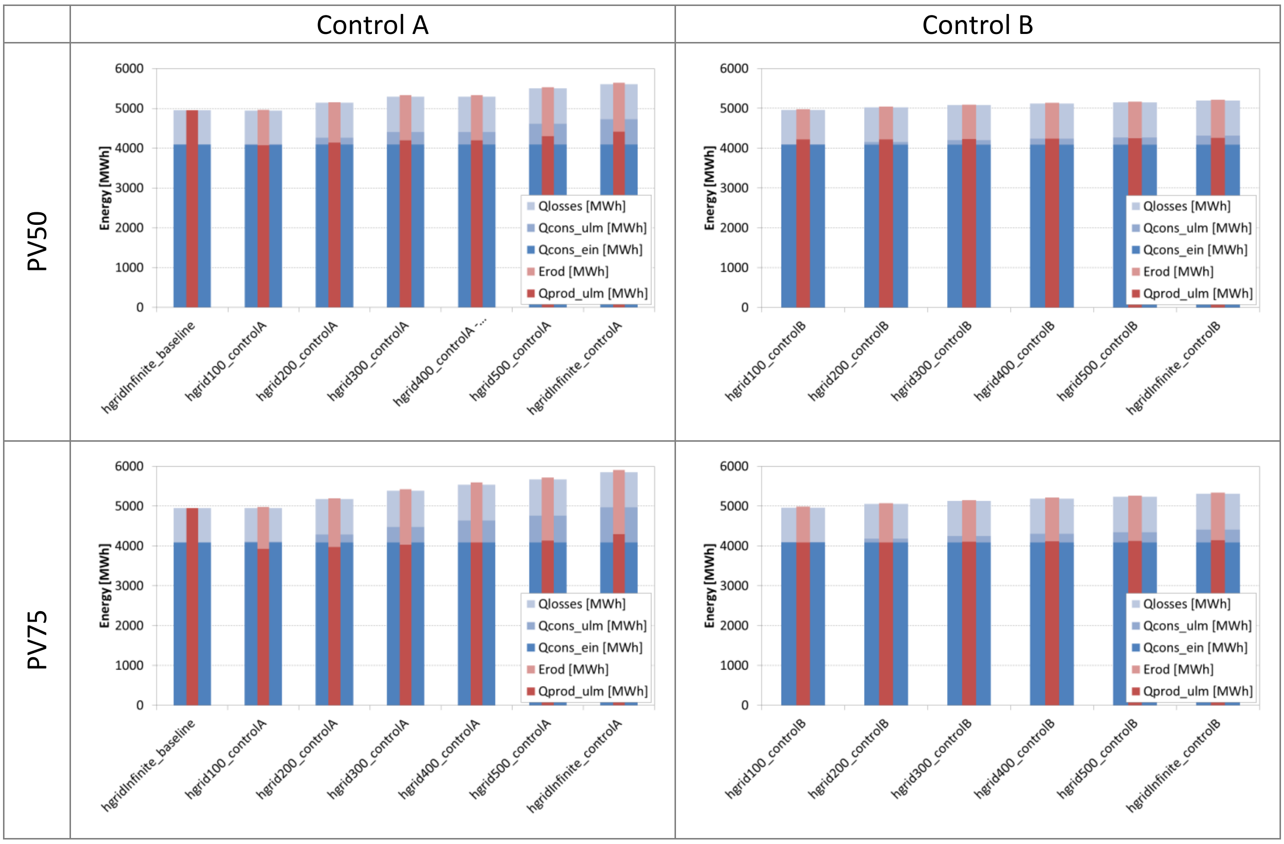


Figure 17: Ulm2, energy demand and production for different heat export limitations

Figure 18 shows the top layer temperatures from the highest to the lowest value for different heat export limitations split into different PV penetration and control strategies. Following the control logic of control B, the storage top temperature is not affected by the heat export limitations across all variations (see also Figure 19 for average values). The resulting decreasing storage top layer temperature follows the set point of the network supply temperature (linear function of outdoor temperature with 90°C at -10°c and 75°C at +15°C). In case of control A, the larger the amount of heat that can be exported to the city of Ulm, the lower the heat stored in the storage tank, assuming that the control logic simultaneously releases the heat from the storage tank when available (see also Figure 19 for average values).

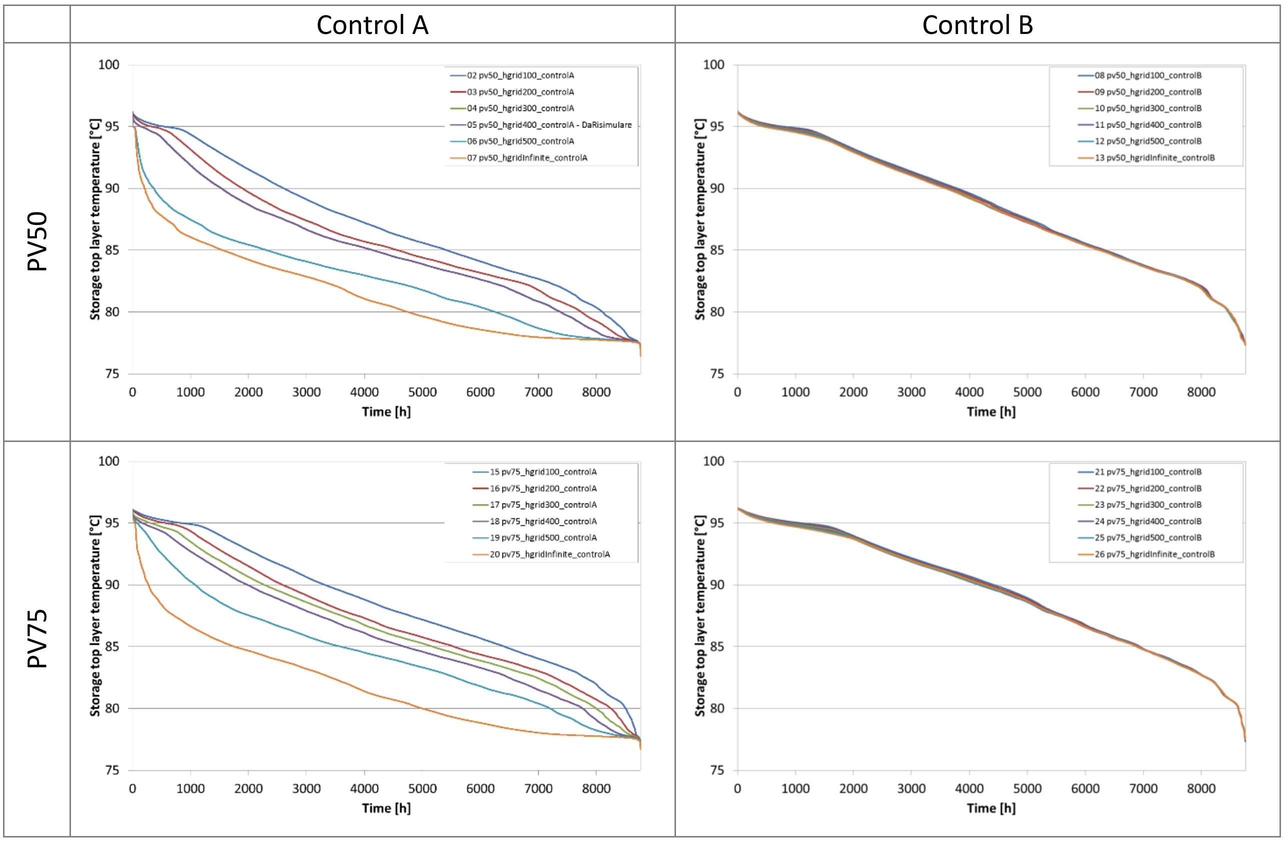


Figure 18: Ulm2, temperature levels of the top layer ordered from the highest to the lowest value for different heat export limitations

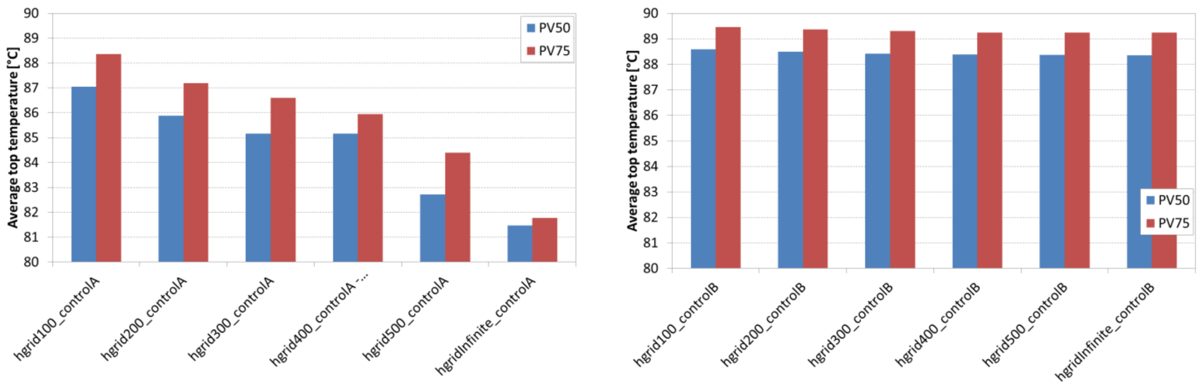


Figure 19: Ulm2, average temperature levels of the top layer ordered from the highest to the lowest value for different heat export limitations

2.3.4 Ulm2: Power to gas scenario

2.3.4.1 *Motivation*

Within the framework of the OrPHEuS project, this scenario did not require any control strategy development. A separate approach, from a feasibility study point of view, has been performed by HSU and it is reported in the following sections. The details of the methodology (modelling approach) used for the power-to-gas scenario are reported in Annex 5.

Power to gas represents an alternative solution, which has been requested by the network operator SWU to be analyzed, and recently is attracting more interest from the research and development point of view. Power to gas (PtG) systems could be a solution to minimize electric surplus problems. They are an opportunity for peak shaving measures and for seasonal storage. Power-to-gas systems are not state-of-the-art but actual R&D topics with some single demonstration projects around the world (with deliverable D3.2 showing an overview of the current PtG projects in Germany).

In principle, when more energy (e.g. from solar panels) is produced than consumed, the power can be used to split water it into hydrogen and oxygen by using electrolysis or hydrolysis. Further existing possibilities are:

- Up to 5% of hydrogen can be directly stored in the gas grid [8].
- The hydrogen can be stored in tanks and used in other applications
- With the methanation process, the hydrogen can be transformed into methane. This can be realized with the Sabatier process or in a bio-reactor by using specific bacteria [9]

The advantage of methanation is the available gas grid, which represents a big storage. It is possible to use the produced gas for heat supply or it can be converted back to electricity if needed. The actual problem concerning this process is the low efficiency. In combination with waste heat recovery processes efficiencies up to 85% are possible [8].

2.3.4.2 *Scenario description*

It has to be highlighted that PtG systems also do not avoid completely voltage band violations or overloaded lines due to the fact that those systems are connected to a single connection point of the electric grid. From that point of view decentral electric power loads is the only option able to completely avoid grid reinforcement [3].

The hybrid scenario extends the domestic hot water (DHW) and space heating (SH) discussed in D4.3.1 by using a PtG as coupling point to the gas grid. The output data (transformer load) from the co-simulation of ULM1 SH and DHW scenario is used as input for the PtG scenario. The analysis involved the scenario under PV-potential 50 % and 75 %. In Einsingen is the PtG scenario set on top of scenario 1.2 were decentral PtH for SH and DHW is involved. For Hittistetten the whole PV-surplus is used for the hydrogen production. However in Hittistetten no co-simulation has been considered.

2.3.4.3 *Baseline Results*

To evaluate the baseline in case of the gas grid and the correlation of the energy flows in the hybrid system, the heat demand and the PV surplus in the test area Einsingen is balanced and cumulated as shown in Figure 20. For this analysis only power and energy flows from the total test area Einsingen are used and neither grid, nor storage nor control strategies were implemented.

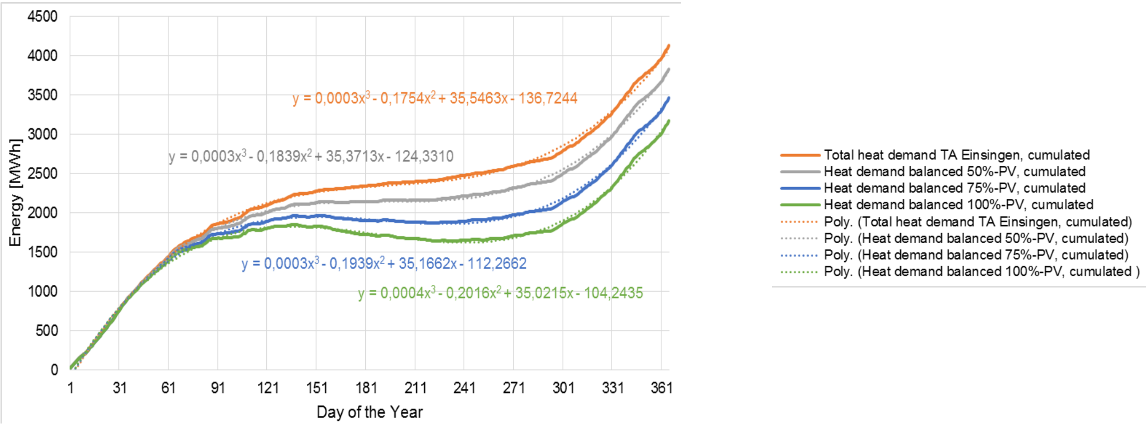


Figure 20 Cumulated daily energy demand of the electrical PV surplus and the total heat demand over on year test side Einsingen.

The PtG approach can only balance the PV surplus with the gas consumption. The gas demand is only part of the total heat demand and is therefore lower. The lower efficiency of the power to gas process (η(H_2) ≈ 0,75 and η(CH_4) ≈ 0,5) does not totally negates the effect on the seasonal PV surplus.

Figure 21 shows the total load flow of the gas in nominal cubic meters for the two test areas. It shows the strong difference of the gas consumption between summer and winter and the temperature dependency. Gas grid areas with more industrial and business companies have also in summer time a higher gas consumption for their production processes. These will result in a positive effect for PtG because more power can directly consumed and does not have to be stored or transported over long distances. The values in Figure 21 were simulated with the gas grid model described in Annex 5.

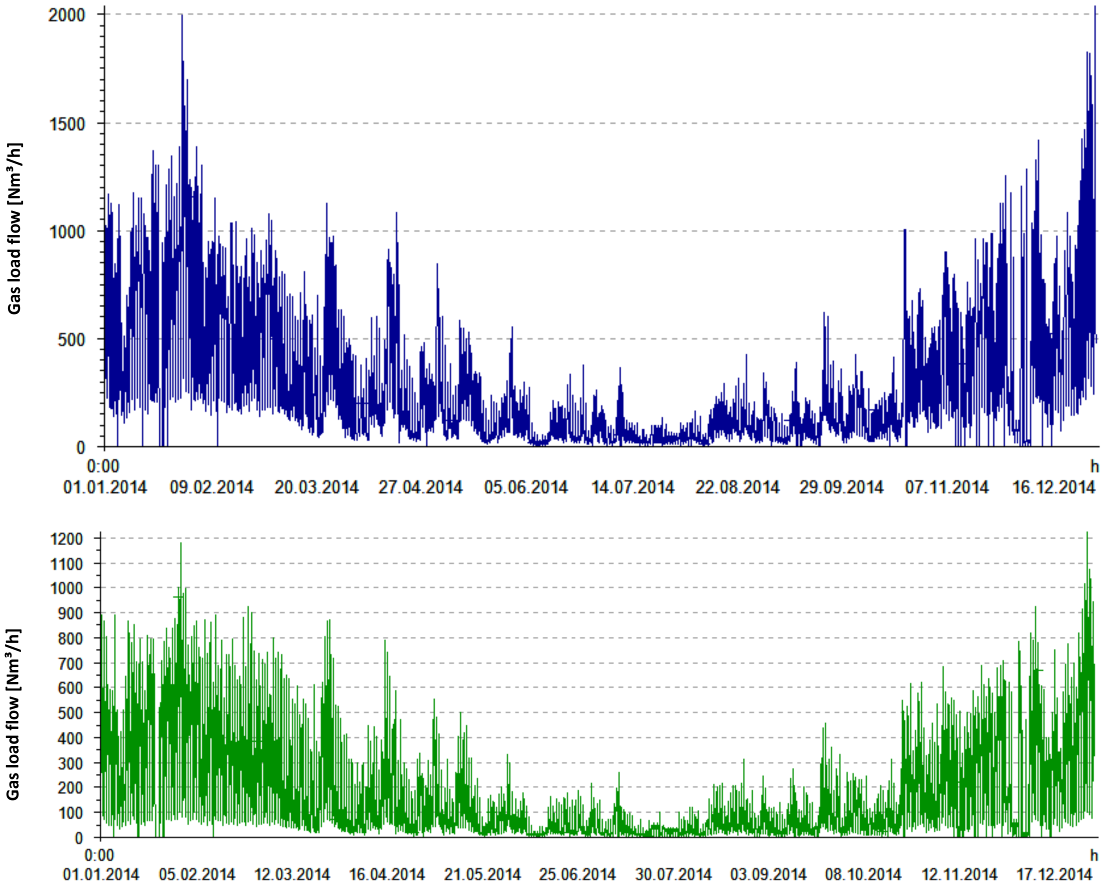


Figure 21 Total gas load flow at Einsingen (top) and Hittistetten (bottom) for the baseline

Table 1 gives an overview of the resulting PV surplus energy for three PV future scenarios in Einsingen. These scenarios are defined for the co-simulation in Einsingen. The additional hydrogen percentage is limited due to technical and legal (max. 5 %) specifications. This has a strong influence to the available feed-in capacity of the gas grid for hydrogen. The yearly seasonal PV surplus from summer into winter time could cover from 7 % to 23 % of the annual heat demand depending on the different PV potential scenarios. Without the seasonal PV surplus the usage could be from 6 % to 16 %. If a seasonal PV surplus is considered the usage rate increases by 7 % of the heat demand in the 100%-PV potential scenario.

Table 1: seasonal PV surplus for local PtG (H2) and (CH4) in Einsingen

	PtG (H2)	PtG (CH4)
100%-PV Surplus [MWh]	213.73	96.02
75%-PV Surplus [MWh]	126.87	43.87
50%-PV Surplus [MWh]	11.31	0

With the geometrical and topological information of the gas grid infrastructure the grid volume and the energy storage capacity can be calculated. The medium pressure (MP) grid is supplying a bigger area (Figure 24 in Annex 5) than the in OrPHEuS defined test area Einsingen. The downscaling of the storage capacity from the MP grid area to the test area is based on a calculation of a factor based on the inhabitance in the region and the test area. The MP gas grid in the test area Einsingen provides a storage capacity of 207.1 kWh for methane (100 % potential) and 3.11 kWh (5 % potential) for hydrogen, respectively. Suburban MP gas grids, as e.g. in the test area Einsingen, cannot deliver the seasonal storage capacity which is necessary if the seasonal PV surplus will increase to a high level of usage of roof potential for PV. Most urban areas include a high pressure (HP) distribution gas grid and can use this in combination with the PtG technology as a seasonal storage. A first estimation of the HP gas grid of the city of Ulm results in a storage capacity of 600 MWh. Combined with an average base load of 106.45 MW for summer time (June, July, August) results a high power shifting potential. The capacity in Ulm is strongly influenced by a pipe storage and is therefore not typical for most European cities. This pipe storage is fed from the transmission grid and has about the same volume as the total distribution HP gas grid of the city. However, it is operated on a higher pressure level and these results in a higher energy storage capacity. The HP distribution gas grid without the pipe storage in Ulm has an estimated storage capacity of 84 MWh (0.7 kWh per inhabitant of Ulm). [3]

2.3.4.4 *Power to gas scenario results*

The results from the grid models and approach of the controller and planning parameters of the electrolyser and methanation are described in Annex 5. These efforts deliver a more precise analysis than the calculation in the baseline analysis in Section 2.3.4.3. The daily average load flow at the transformer for the year 2014 in Hittistetten and Einsingen has been analysed. Figure 22 shows the analysis with PV50% and PV75% potential with and without electrolyzer for both Einsingen and Hittistetten. Negative values mean load flow without electrolyzer shows that on average for those hours of the day the total PV-production is higher than the demand over the year. For Einsingen (left), based on the results of Ulm SH and DHW with control strategy 2, a large amount of PV-surplus has already been used by the developed power-to-heat solution. For Hittistetten no power-to-heat has been developed therefore there are higher negative values in the case without electrolyzer. In both cases, the maximum power at the transformer will be strongly reduced, resulting in complete consumption of the PV Energy; see Figure 22. This reduces also the stress for all higher voltage grid levels and gains direct positive effect for the voltage, frequent and power regulation at the medium voltage grid to the city.

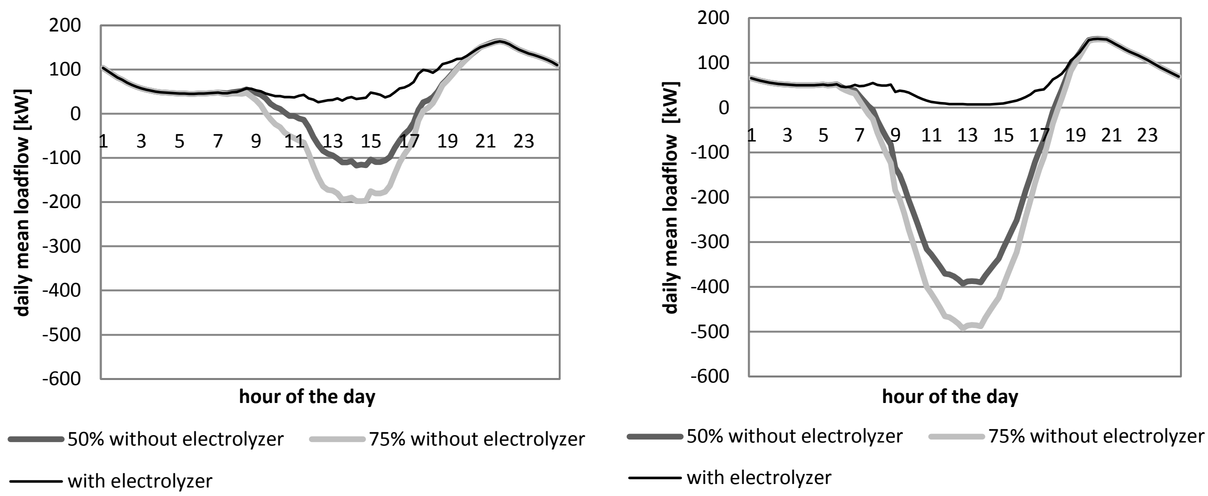


Figure 22: Daily averaged yearly loadflow with and without electrolyzer for Einsingen (left) and Hittistetten (right)

3 Hybrid grid technical evaluation of the control strategies

The following sections describe the evaluation from a combined thermal and electricity domain point of view for the Skellefteå and Ulm demo sites in Scenario 2 (future business model). "Best" configurations and effects of the boundary conditions for the control strategies performances are summarized and highlighted.

3.1 Skelleftea demo site

The Skellefteå future scenario analysed in this deliverable can be considered as "thermal-domain" driven, due to its nature. Indeed the aim of the scenario is the removal of peak oil boiler usage (zero CO_2 emissions targets) and waste heat usage from an additional industrial customer with high electricity demand. The high electricity demand has the implication on the electricity grid to stress it and therefore, both from an economic perspective and energy efficient perspective, hybrid grid solutions investigation assessed possible synergies. The coupling points between the two grids are represented by the heat pump and the electric boiler, the first enabling the conversion of low grade waste heat.

According to the evaluation of the results for the electric domain there is an improvement of the KPI's especially for the scenario with low electricity tax conditions, no heat demand increase and an electric storage of 1MW for the different industrial electricity load scenarios. Nevertheless transformer and line loading violations, outside the allowed/accepted limit, are occurring. This scenario therefore requires that, from a technical point of view, the maximum electric boiler size of 35 MW is considered or that decentralised small electric boilers are installed.

For the district heating network, the control strategy enables the efficient usage of low grade waste heat from the industrial customer, with heat pump operation of about 2900 hours per year in the case of an industrial customer of 10 MW and 2100h when the industrial customer electricity demand increases to 40 MW. Under future heating demand increase perspectives, the controller supports an additional increase of heat pump and electric boiler heat production respectively of 17% and 45% compared to the status quo heating demand of the grid. From the analysis of the technical indicators, the control strategy shows limited effects on the operation of the storage tank (reduced usage) and heat distribution losses (limited influence on the supply network temperature).

3.2 Ulm demo site

The Ulm future scenario analysed in this deliverable aims at increasing local consumption of electricity surplus generated by the PV plants, where a central electric boiler and heat storage are used as coupling points transferring energy from the electricity grid to the heating grid, in order to avoid transformer overloadings and electricity flow backs to the grid.

According to the evaluation of the results for the electric domain, Control A variations show improvement in total network losses, transformer loading and voltage band usage. From the total results shown in Figure 10, Figure 11, Figure 12 and Figure 13 the control A strategy with unlimited limitation of heat overproduction in Einsingen, outstands among the different variations, due to its contribution to minimize network losses, transformer loadings, as well as voltage band usage. There is a reduction of the total network losses of about 17.3% and 19% in the case of control A with unlimited limitation of heat overproduction in Einsingen, which reflects the reduction of the flow back to the medium voltage through the share of the PV systems. Similar results for transformer loading can be seen in Figure 10 and Figure 12, as control strategy A with unlimited limitation of heat overproduction shows the maximum reduction of the maximum transformer loading, compared to other scenarios, about 10.2% and 33.4%. The same scenario shows a decrease of the maximum voltage spread in about 10.2% and 6.5% (Figure 11 and Figure 14). The results in Figure 11 and Figure 14 show that there is no improvement in the line loadings as it increases in a range from 0.4% – 1.0% compared to the baseline scenario. The duration of maximum line overloading over 80% is about 10% - 15% of the whole simulation time. These results are reflected through the 50% PV and 75% PV variations results analysis.

On the thermal domain side the controller, under various heat export limitation conditions as well as target goals (control A and control B) maximizes up to 1692 MWh/year the heat production from PV surplus, covering totally the heat distribution losses but only partly the heat demand from Einsingen. Heat export limitations to the wider grid of Ulm have an effect on the storage design, showing a clearly decreased need for heat storage when heat produced with PV surplus can be directly exported to the wider grid of Ulm.

Annex 1: Skelleftea Thermal Side

The results from the simulation runs for the winter period (November to March) is reported in tabular form in the Annex 1

electricity price [€/MWh]	battery size [MW/MWh]	industry size [MW]	heat demand increase [%]	Strategy [-]	max eboiler output [MW]	heat demand [MWh]	heat losses [MWh]	biomass [MWh]	chp heat [MWh]	eboiler [MWh]	heatpump [MWh]
0_51	1	10	0	baseline	43.6	227133	12280	52803	141402	51647	0
0_51	1	10	0	control	45.3	227133	12265	22392	156748	25578	41103
0_51	5	10	0	control	45.3	227133	12265	22392	156748	25578	41103
0_51	10	10	0	control	45.3	227133	12265	22392	156748	25578	41103
0_51	1	20	0	baseline	43.6	227133	12280	52803	141402	51647	0
0_51	1	20	0	control	37.5	227133	12245	8346	152504	10815	74134
0_51	5	20	0	control	37.5	227133	12245	8346	152504	10815	74134
0_51	10	20	0	control	37.5	227133	12245	8346	152504	10815	74134
0_51	1	30	0	baseline	43.6	227133	12280	52803	141402	51647	0
0_51	1	30	0	control	25.4	227132	12199	4092	142163	2182	97309
0_51	5	30	0	control	25.4	227132	12199	4092	142163	2182	97309
0_51	10	30	0	control	25.4	227132	12199	4092	142163	2182	97309
0_51	1	40	0	baseline	43.6	227133	12280	52803	141402	51647	0
0_51	1	40	0	control	25.6	227132	12162	2539	130153	1145	111844
0_51	5	40	0	control	25.6	227132	12162	2539	130153	1145	111844
0_51	10	40	0	control	25.6	227132	12162	2539	130153	1145	111844
0_51	1	10	5	baseline	41.5	238488	12954	53553	140577	63157	0
0_51	1	10	5	control	49.3	238488	12901	30789	157210	25464	43763
0_51	5	10	5	control	49.3	238488	12901	30789	157210	25464	43763
0_51	10	10	5	control	49.3	238488	12901	30789	157210	25464	43763
0_51	1	20	5	baseline	41.5	238488	12954	53553	140577	63157	0
0_51	1	20	5	control	40.6	238488	12885	10786	153939	14692	77781
0_51	5	20	5	control	40.6	238488	12885	10786	153939	14692	77781
0_51	10	20	5	control	40.6	238488	12885	10786	153939	14692	77781
0_51	1	30	5	baseline	41.5	238488	12954	53553	140577	63157	0
0_51	1	30	5	control	29.9	238489	12851	5413	145898	3832	102021
0_51	5	30	5	control	29.9	238489	12851	5413	145898	3832	102021
0_51	10	30	5	control	29.9	238489	12851	5413	145898	3832	102021
0_51	1	40	5	baseline	41.5	238488	12954	53553	140577	63157	0
0_51	1	40	5	control	32.1	238488	12821	3797	136056	2213	115041
0_51	5	40	5	control	32.1	238488	12821	3797	136056	2213	115041
0_51	10	40	5	control	32.1	238488	12821	3797	136056	2213	115041
0_51	1	10	10	baseline	39.0	249845	13565	58998	142261	67395	0
0_51	1	10	10	control	48.0	249844	13500	38874	158019	25801	45895
0_51	5	10	10	control	48.0	249844	13500	38874	158019	25801	45895
0_51	10	10	10	control	48.0	249844	13500	38874	158019	25801	45895
0_51	1	20	10	baseline	39.0	249845	13565	58998	142261	67395	0
0_51	1	20	10	control	44.2	249844	13547	15396	155381	17099	80732

0_51	5	20	10	control	44.2	249844	13547	15396	155381	17099	80732
0_51	10	20	10	control	44.2	249844	13547	15396	155381	17099	80732
0_51	1	30	10	baseline	39.0	249845	13565	58998	142261	67395	0
0_51	1	30	10	control	34.3	249844	13500	6538	149135	6039	106852
0_51	5	30	10	control	34.3	249844	13500	6538	149135	6039	106852
0_51	10	30	10	control	34.3	249844	13500	6538	149135	6039	106852
0_51	1	40	10	baseline	39.0	249845	13565	58998	142261	67395	0
0_51	1	40	10	control	34.6	249844	13482	4423	141443	3601	119063
0_51	5	40	10	control	34.6	249844	13482	4423	141443	3601	119063
0_51	10	40	10	control	34.6	249844	13482	4423	141443	3601	119063
0_51	1	10	20	baseline	74.1	272556	14815	63283	154349	73736	0
0_51	1	10	20	control	58.4	272556	14787	46796	159315	37088	48193
0_51	5	10	20	control	58.4	272556	14787	46792	159311	37095	48193
0_51	10	10	20	control	58.4	272556	14787	46796	159315	37088	48193
0_51	1	20	20	baseline	74.1	272556	14815	63283	154349	73736	0
0_51	1	20	20	control	46.1	272556	14835	28446	155481	19040	88429
0_51	5	20	20	control	46.1	272556	14835	28446	155481	19040	88429
0_51	10	20	20	control	46.1	272556	14835	28446	155481	19040	88429
0_51	1	30	20	baseline	74.1	272556	14815	63283	154349	73736	0
0_51	1	30	20	control	43.5	272556	14804	12251	152316	10772	116025
0_51	5	30	20	control	43.5	272556	14804	12251	152316	10772	116025
0_51	10	30	20	control	43.5	272556	14804	12251	152316	10772	116025
0_51	1	40	20	baseline	74.1	272556	14815	63283	154349	73736	0
0_51	1	40	20	control	42.8	272556	14789	6809	148355	8902	127288
0_51	5	40	20	control	42.8	272556	14789	6809	148355	8902	127288
0_51	10	40	20	control	42.8	272556	14789	6809	148355	8902	127288
19_5	1	10	0	baseline	43.6	227133	12280	52803	141402	51647	0
19_5	1	10	0	control	41.8	227133	12265	22442	157533	24891	40954
19_5	5	10	0	control	41.8	227133	12265	22440	157534	24891	40955
19_5	10	10	0	control	41.8	227133	12265	22440	157532	24895	40954
19_5	1	20	0	baseline	43.6	227133	12280	52803	141402	51647	0
19_5	1	20	0	control	36.2	227133	12245	8338	153968	10148	73343
19_5	5	20	0	control	36.1	227133	12245	8340	154001	10142	73315
19_5	10	20	0	control	36.2	227133	12246	8338	154015	10163	73283
19_5	1	30	0	baseline	43.6	227133	12280	52803	141402	51647	0
19_5	1	30	0	control	25.1	227133	12198	4057	145831	1754	94094
19_5	5	30	0	control	25.1	227133	12198	4057	145831	1754	94094
19_5	10	30	0	control	25.1	227133	12198	4057	145831	1754	94094
19_5	1	40	0	baseline	43.6	227133	12280	52803	141402	51647	0
19_5	1	40	0	control	27.6	227132	12156	2120	136736	1120	105693
19_5	5	40	0	control	27.6	227132	12156	2120	136736	1120	105693
19_5	10	40	0	control	27.6	227132	12156	2120	136736	1120	105693
19_5	1	10	5	baseline	41.5	238488	12954	53553	140577	63157	0
19_5	1	10	5	control	49.3	238488	12902	31067	157789	24706	43662
19_5	5	10	5	control	49.3	238488	12902	31060	157788	24718	43659
19_5	10	10	5	control	49.3	238488	12902	31057	157800	24713	43654

19_5	1	20	5	baseline	41.5	238488	12954	53553	140577	63157	0
19_5	1	20	5	control	40.6	238488	12886	10772	155435	14031	76956
19_5	5	20	5	control	40.6	238488	12886	10769	155446	14018	76964
19_5	10	20	5	control	40.6	238488	12886	10769	155460	14020	76948
19_5	1	30	5	baseline	41.5	238488	12954	53553	140577	63157	0
19_5	1	30	5	control	30.1	238489	12851	5387	148975	3311	99483
19_5	5	30	5	control	30.1	238489	12851	5387	148975	3311	99483
19_5	10	30	5	control	30.1	238489	12851	5387	148975	3311	99483
19_5	1	40	5	baseline	41.5	238488	12954	53553	140577	63157	0
19_5	1	40	5	control	29.9	238488	12814	3739	141383	1783	110190
19_5	5	40	5	control	29.9	238488	12814	3739	141383	1783	110190
19_5	10	40	5	control	29.9	238488	12814	3739	141383	1783	110190
19_5	1	10	10	baseline	39.0	249845	13565	58998	142261	67395	0
19_5	1	10	10	control	45.5	249844	13503	39221	158557	24920	45894
19_5	5	10	10	control	45.5	249844	13503	39221	158557	24920	45894
19_5	10	10	10	control	45.5	249844	13503	39221	158557	24917	45897
19_5	1	20	10	baseline	39.0	249845	13565	58998	142261	67395	0
19_5	1	20	10	control	44.9	249844	13548	15389	156539	16495	80185
19_5	5	20	10	control	45.1	249844	13547	15391	156564	16463	80192
19_5	10	20	10	control	45.0	249844	13548	15388	156566	16461	80192
19_5	1	30	10	baseline	39.0	249845	13565	58998	142261	67395	0
19_5	1	30	10	control	34.5	249844	13502	6512	151756	5446	104849
19_5	5	30	10	control	34.5	249844	13502	6512	151756	5446	104849
19_5	10	30	10	control	34.5	249844	13502	6512	151756	5446	104849
19_5	1	40	10	baseline	39.0	249845	13565	58998	142261	67395	0
19_5	1	40	10	control	34.8	249844	13476	4381	145540	3200	115399
19_5	5	40	10	control	34.8	249844	13476	4381	145540	3200	115399
19_5	10	40	10	control	34.8	249844	13476	4381	145540	3200	115399
19_5	1	10	20	baseline	74.1	272556	14815	63283	154349	73736	0
19_5	1	10	20	control	58.4	272556	14788	47239	159864	36111	48172
19_5	5	10	20	control	58.4	272556	14788	47238	159856	36114	48180
19_5	10	10	20	control	58.4	272556	14788	47242	159851	36117	48180
19_5	1	20	20	baseline	74.1	272556	14815	63283	154349	73736	0
19_5	1	20	20	control	46.1	272556	14836	28663	156628	18227	87871
19_5	5	20	20	control	46.1	272556	14836	28662	156631	18233	87867
19_5	10	20	20	control	46.1	272556	14836	28663	156632	18248	87853
19_5	1	30	20	baseline	74.1	272556	14815	63283	154349	73736	0
19_5	1	30	20	control	43.4	272556	14806	12221	154541	10152	114445
19_5	5	30	20	control	43.4	272556	14805	12215	154544	10153	114451
19_5	10	30	20	control	43.4	272556	14805	12215	154544	10153	114451
19_5	1	40	20	baseline	74.1	272556	14815	63283	154349	73736	0
19_5	1	40	20	control	43.3	272556	14791	6776	151165	8338	125072
19_5	5	40	20	control	43.3	272556	14791	6776	151165	8338	125072
19_5	10	40	20	control	43.3	272556	14791	6776	151165	8338	125072

Annex 2: Skelleftea Electrical Side

The results from the simulation runs for the winter period (November to March) is reported in tabular form in the Annex 2

strategy				control	NL	MTL1	MTL2	DTL1	DTL2	MLL	DLL	MVS
Ind10	bat1	hd0	epr1	b	3757.13143	149.828	45.9965	24.875	0	317.264	89.75	66.585
Ind10	bat1	hd0	epr1	r	3250.61055	78.087	99.903	0	5.763889	315.106	38.611	69.67
Ind10	bat1	hd0	epr2	b	3120.07374	45.996	149.83	0	24.875	317.26	89.75	66.59
Ind10	bat1	hd0	epr2	r	3224.21125	72.271	146.95	0	9.284722	289.05	38.15	62.93
Ind10	bat1	hd5	epr1	b	3494.64035	149.34	46.0036	30.375	0	314.672	92.277778	64.094
Ind10	bat1	hd5	epr1	r	3350.50954	78.101	171.56	0	10.458333	334.81	37.625	76.47
Ind10	bat1	hd5	epr2	b	3494.64214	46.004	149.34	0	30.375	314.67	92.277778	64.1
Ind10	bat1	hd5	epr2	r	3323.40374	72.264	171.56	0	9.909722	334.81	36.868056	76.47
Ind10	bat1	hd10	epr1	b	3757.13768	46.001	138.46	0	44.555556	306.21	86.972222	60.18
Ind10	bat1	hd10	epr1	r	3412.14792	78.104	159.2	0	10.3125	322.97	38.840278	72.8
Ind10	bat1	hd10	epr2	b	3757.13768	46.001	138.46	0	44.555556	306.21	86.972222	60.18
Ind10	bat1	hd10	epr2	r	3385.41034	73.288	157.01	0	9.770833	322.97	37.777778	70.23
Ind10	bat1	hd20	epr1	b	4249.76897	46	235.63	0	34.555556	497.31	92.506944	122.93
Ind10	bat1	hd20	epr1	r	3798.85798	195.295	78.1451	17.034722	0	405.428	52.409722	93.849
Ind10	bat1	hd20	epr2	b	4249.76897	46	235.63	0	34.555556	497.31	92.506944	122.93
Ind10	bat1	hd20	epr2	r	3765.8534	73.287	195.3	0	16.340278	405.43	51.451389	93.84
Ind10	bat5	hd0	epr1	r	3260.5843	159.406	100.864	9.694444	0.722222	315.105	38.611111	69.67
Ind10	bat5	hd0	epr2	r	3226.23366	90.809	146.92	0.104167	9.208333	289.26	38.145833	62.91
Ind10	bat5	hd5	epr1	r	3360.3034	100.88	171.56	0.791667	10.458333	334.86	37.555556	76.46
Ind10	bat5	hd5	epr2	r	3325.85772	91.817	171.56	0.097222	9.972222	334.86	36.881944	76.46
Ind10	bat5	hd10	epr1	r	3421.7219	100.89	159.2	0.854167	10.305556	322.97	38.8125	72.8
Ind10	bat5	hd10	epr2	r	3387.26282	95.655	157.01	0.104167	9.777778	322.97	37.770833	70.23
Ind10	bat5	hd20	epr1	r	3808.86011	100.94	195.29	0.944444	17.041667	405.43	52.458333	93.85
Ind10	bat5	hd20	epr2	r	3768.17152	95.654	195.3	0.104167	16.361111	405.43	51.534722	93.84
Ind	bat	hd0	epr	r	3286.43	127.7	159.4	1.6736	9.6944	315.1	38.645	69.6

10	10		1		22	8	1	11	44	1	833	7
Ind10	bat10	hd0	epr2	r	3230.84093	108.23	146.84	0.354167	9.173611	289.92	38.173611	62.86
Ind10	bat10	hd5	epr1	r	3385.63599	127.8	171.51	1.75	10.458333	335.22	37.583333	76.43
Ind10	bat10	hd5	epr2	r	3330.02678	108.59	171.51	0.319444	9.9375	335.22	36.909722	76.43
Ind10	bat10	hd10	epr1	r	3446.95506	127.81	159.2	1.902778	10.277778	322.97	38.819444	72.8
Ind10	bat10	hd10	epr2	r	3391.28251	108.59	157.01	0.284722	9.770833	322.97	37.763889	70.23
Ind10	bat10	hd20	epr1	r	3833.74448	127.86	195.29	1.986111	17.048611	405.43	52.451389	93.85
Ind10	bat10	hd20	epr2	r	3771.55112	108.49	195.3	0.270833	16.298611	405.43	51.423611	93.84
Ind20	bat1	hd0	epr1	b	5629.09248	85.473	151.32	100	25.611111	305.21	80.166667	66.31
Ind20	bat1	hd0	epr1	r	7272.97738	133.81	140.33	99.979167	2.180556	247.1	13.465278	57.42
Ind20	bat1	hd0	epr2	b	5629.09248	85.473	151.32	100	25.611111	305.21	80.166667	66.31
Ind20	bat1	hd0	epr2	r	7224.95023	134.29	136.59	99.979167	1.791667	248.28	12.861111	55.08
Ind20	bat1	hd5	epr1	b	5983.10213	85.483	150.85	100	30.930556	302.61	88.416667	63.93
Ind20	bat1	hd5	epr1	r	7484.9024	136.92	149.69	99.979167	4.048611	275.03	18.388889	62.68
Ind20	bat1	hd5	epr2	b	5983.10213	85.483	150.85	100	30.930556	302.61	88.416667	63.93
Ind20	bat1	hd5	epr2	r	7433.09898	135.99	149.76	99.979167	3.611111	275.32	17.881944	62.65
Ind20	bat1	hd10	epr1	b	6230.94324	140.009	85.475	45.666667	100	294.19	83.736111	59.605
Ind20	bat1	hd10	epr1	r	7642.54644	160.021	138.381	6.5	99.986111	296.768	20.5625	68.865
Ind20	bat1	hd10	epr2	b	6230.9512	85.475	140.01	100	45.666667	294.19	83.736111	59.61
Ind20	bat1	hd10	epr2	r	7602.7218	138.38	162.15	99.986111	5.986111	300.98	20.138889	70.18
Ind20	bat1	hd20	epr1	b	6671.16683	85.472	236.93	100	37.604167	485.23	87.840278	122.71
Ind20	bat1	hd20	epr1	r	8024.52063	138.46	164.58	99.993056	9.402778	299.73	22.104167	72.06
Ind20	bat1	hd20	epr2	b	6671.16683	85.472	236.93	100	37.604167	485.23	87.840278	122.71
Ind20	bat1	hd20	epr2	r	7974.5331	138.42	164.6	99.993056	8.6875	299.78	21.666667	72.08
Ind20	bat5	hd0	epr1	r	7276.46474	153.55	140.33	99.798611	2.173611	247.1	13.493056	57.93
Ind20	bat5	hd0	epr2	r	7226.99917	153.55	136.08	99.736111	1.847222	247.03	12.770833	55.41
Ind20	bat5	hd5	epr1	r	7488.4342	156.5	149.69	99.840278	4.034722	275.03	18.347222	63.19
Ind20	bat5	hd5	epr2	r	7436.65312	154.02	149.76	99.798611	3.631944	275.31	17.798611	63.16
Ind20	bat5	hd10	epr1	r	7645.86401	157.99	160.02	99.854167	6.493056	296.77	20.555556	69.37

Ind20	bat5	hd10	epr2	r	7605.39229	157.99	162.81	99.784722	5.930556	302.06	20.131944	70.99
Ind20	bat5	hd20	epr1	r	8027.5813	158.06	164.57	99.833333	9.388889	299.77	22.131944	72.56
Ind20	bat5	hd20	epr2	r	7977.63062	158.03	164.59	99.847222	8.6875	299.82	21.673611	72.57
Ind20	bat10	hd0	epr1	r	7285.26228	176.72	140.33	99.520833	2.173611	247.1	13.541667	58.01
Ind20	bat10	hd0	epr2	r	7234.50285	176.72	136.59	99.451389	1.805556	248.28	12.847222	55.67
Ind20	bat10	hd5	epr1	r	7497.37807	178.84	149.69	99.527778	4.034722	275.03	18.368056	63.27
Ind20	bat10	hd5	epr2	r	7985.32672	180.92	164.59	99.638889	8.701389	299.87	21.743056	72.64
Ind20	bat10	hd10	epr1	r	7654.70802	180.86	160.02	99.590278	6.479167	296.77	20.576389	69.45
Ind20	bat10	hd10	epr2	r	7613.78875	180.86	162.35	99.541667	6	300.91	20.013889	70.9
Ind20	bat10	hd20	epr1	r	8036.07464	180.92	164.57	99.638889	9.388889	299.82	22.166667	72.62
Ind20	bat10	hd20	epr2	r	7985.32672	180.92	164.59	99.638889	8.701389	299.87	21.743056	72.64
Ind30	bat1	hd0	epr1	b	9565.47798	122.29	152.74	100	27.305556	293.77	63.465278	66.01
Ind30	bat1	hd0	epr1	r	13036.3485	187.17	105.32	100	0.472222	168.16	1.458333	38.48
Ind30	bat1	hd0	epr2	b	9565.47798	122.29	152.74	100	27.305556	293.77	63.465278	66.01
Ind30	bat1	hd0	epr2	r	12853.656	187.61	104.88	100	0.409722	167.54	1.326389	38.13
Ind30	bat1	hd5	epr1	b	9899.4616	122.3	152.28	100	31.555556	291.14	85.9375	63.73
Ind30	bat1	hd5	epr1	r	13257.1583	185.88	118.92	100	1.027778	195.55	2.902778	45.64
Ind30	bat1	hd5	epr2	b	9899.4616	122.3	152.28	100	31.555556	291.14	85.9375	63.73
Ind30	bat1	hd5	epr2	r	13107.3807	185.88	119.67	100	0.847222	197.21	2.520833	46
Ind30	bat1	hd10	epr1	b	10133.4463	122.29	141.47	100	47.277778	282.73	80.875	59.05
Ind30	bat1	hd10	epr1	r	13498.3779	186.05	132.43	100	1.854167	223.21	4.3125	52.98
Ind30	bat1	hd10	epr2	b	10133.4463	122.29	141.47	100	47.277778	282.73	80.875	59.05
Ind30	bat1	hd10	epr2	r	13375.9219	185.78	133.13	100	1.465278	224.77	3.784722	53.32
Ind30	bat1	hd20	epr1	b	10528.2529	122.28	238.1	100	41.4375	473.5	84.701389	122.39
Ind30	bat1	hd20	epr1	r	13990.8173	185.66	159.61	100	3.5625	279.14	10.416667	68.74
Ind30	bat1	hd20	epr2	b	10528.2529	122.28	238.1	100	41.4375	473.5	84.701389	122.39
Ind30	bat1	hd20	epr2	r	13888.5203	187.88	159.1	100	3.180556	278.04	9.965278	68.48
Ind30	bat5	hd0	epr1	r	13038.2153	203.78	105.32	100	0.472222	168.16	1.472222	39.53
Ind	bat	hd0	epr	r	12855.5	204.1	104.8	100	0.4097	167.5	1.3263	39.1

30	5		2		352	9	8		22	4	89	8
Ind30	bat5	hd5	epr1	r	13259.0603	201.66	118.92	100	1.027778	195.55	2.902778	46.69
Ind30	bat5	hd5	epr2	r	13109.2845	198.84	119.67	100	0.847222	197.21	2.520833	47.05
Ind30	bat5	hd10	epr1	r	13500.2063	202.77	132.43	100	1.854167	223.21	4.3125	54.03
Ind30	bat5	hd10	epr2	r	13377.7988	200.67	133.13	100	1.465278	224.77	3.798611	54.37
Ind30	bat5	hd20	epr1	r	13992.4977	201.85	159.61	100	3.555556	279.14	10.4375	69.79
Ind30	bat5	hd20	epr2	r	13890.5394	204.44	159.1	100	3.166667	278.04	10.020833	69.53
Ind30	bat10	hd0	epr1	r	13045.2048	223.08	105.32	99.951389	0.472222	168.16	1.479167	40.41
Ind30	bat10	hd0	epr2	r	12862.3568	223.45	104.88	99.944444	0.409722	167.54	1.326389	40.06
Ind30	bat10	hd5	epr1	r	13265.9494	220.77	118.92	99.951389	1.027778	195.55	2.916667	47.57
Ind30	bat10	hd5	epr2	r	13115.9963	218.58	119.67	99.965278	0.847222	197.21	2.520833	47.93
Ind30	bat10	hd10	epr1	r	13506.8025	222.2	132.43	99.958333	1.854167	223.21	4.326389	54.91
Ind30	bat10	hd10	epr2	r	13384.4371	220.22	133.13	99.965278	1.465278	224.77	3.833333	55.25
Ind30	bat10	hd20	epr1	r	13998.8737	221.32	159.61	99.979167	3.555556	279.14	10.4375	70.67
Ind30	bat10	hd20	epr2	r	13897.1089	223.67	159.1	99.986111	3.159722	278.04	10.083333	70.41
Ind40	bat1	hd0	epr1	b	14498.2246	155.89	154.06	100	29.270833	283.15	46.597222	65.68
Ind40	bat1	hd0	epr1	r	19452.3059	221.85	107.57	100	0.347222	160.67	0.402778	39.2
Ind40	bat1	hd0	epr2	b	14498.2246	155.89	154.06	100	29.270833	283.15	46.597222	65.68
Ind40	bat1	hd0	epr2	r	19057.7777	221.56	108.45	100	0.513889	172.52	0.659722	42.86
Ind40	bat1	hd5	epr1	b	14813.0548	155.9	153.6	100	31.965278	280.47	81.409722	63.49
Ind40	bat1	hd5	epr1	r	19586.755	222.65	124.97	100	0.576389	193.06	0.9375	53.02
Ind40	bat1	hd5	epr2	b	14813.0548	155.9	153.6	100	31.965278	280.47	81.409722	63.49
Ind40	bat1	hd5	epr2	r	19271.3252	222.64	120.32	100	0.416667	186.17	0.722222	46.07
Ind40	bat1	hd10	epr1	b	15034.254	155.88	142.82	100	49.006944	272.04	75.409722	58.53
Ind40	bat1	hd10	epr1	r	19772.4304	224.11	134.61	100	0.8125	215.49	1.958333	53.87
Ind40	bat1	hd10	epr2	b	15034.254	155.88	142.82	100	49.006944	272.04	75.409722	58.53
Ind40	bat1	hd10	epr2	r	19535.0863	222.65	135.12	100	0.708333	216.65	1.826389	54.11
Ind40	bat1	hd20	epr1	b	15391.0544	155.87	239.11	100	45.118056	462.39	80.361111	122
Ind40	bat1	hd20	epr1	r	20229.7756	222.55	159.35	100	3.604167	266.99	6.201389	67.99

Ind40	bat1	hd20	epr2	b	15391.0544	155.87	239.11	100	45.118056	462.39	80.361111	122
Ind40	bat1	hd20	epr2	r	20076.8004	224.56	160.04	100	3.215278	267.95	5.777778	68.72
Ind40	bat5	hd0	epr1	r	19453.2217	235.12	107.57	100	0.347222	160.67	0.402778	40.63
Ind40	bat5	hd0	epr2	r	19058.8661	234.39	108.45	100	0.513889	172.52	0.659722	44.31
Ind40	bat5	hd5	epr1	r	19587.5924	237	124.97	100	0.576389	193.06	0.9375	54.45
Ind40	bat5	hd5	epr2	r	19272.345	236.99	120.32	100	0.416667	186.17	0.722222	47.5
Ind40	bat5	hd10	epr1	r	19773.3423	238.26	134.61	100	0.8125	215.49	1.965278	55.3
Ind40	bat5	hd10	epr2	r	19536.0728	237	135.12	100	0.708333	216.65	1.826389	55.54
Ind40	bat5	hd20	epr1	r	20230.6422	236.61	159.35	100	3.604167	266.99	6.215278	69.44
Ind40	bat5	hd20	epr2	r	20077.6569	238.84	160.04	100	3.215278	267.95	5.791667	70.17
Ind40	bat10	hd0	epr1	r	19456.8066	251.95	107.57	100	0.347222	160.67	0.402778	42.13
Ind40	bat10	hd0	epr2	r	19062.8093	251.27	108.45	100	0.513889	172.52	0.659722	45.81
Ind40	bat10	hd5	epr1	r	19591.0458	253.64	124.97	100	0.576389	193.06	0.944444	55.95
Ind40	bat10	hd5	epr2	r	19276.1466	253.63	120.32	100	0.416667	186.17	0.722222	49
Ind40	bat10	hd10	epr1	r	19776.8605	254.67	134.61	100	0.8125	215.49	1.972222	56.8
Ind40	bat10	hd10	epr2	r	19539.728	253.64	135.12	100	0.708333	216.65	1.833333	57.04
Ind40	bat10	hd20	epr1	r	20233.9408	252.97	159.35	100	3.590278	266.99	6.229167	70.94
Ind40	bat10	hd20	epr2	r	20081.0344	255.4	160.04	100	3.201389	267.95	5.8125	71.67

Annex 3: Ulm Thermal Side

The results from the simulation runs of the first six months of the year are reported in tabular form in the Annex 3.

	Sim name	Qprod_ulm	Erod	Qcons_ein	Qcons_ulm	Qlosses
	UNIT	[MWh]	[MWh]	[MWh]	[MWh]	[MWh]
PV50	hgridInfinite_baseline	4955	0	4090	0	859
	hgrid100_controlA	4073	892	4081	25	841
	hgrid200_controlA	4135	1020	4090	170	879
	hgrid300_controlA	4193	1135	4090	315	893
	hgrid400_controlA - DaRisimulare	4193	1135	4090	315	893
	hgrid500_controlA	4304	1231	4090	521	887
	hgridInfinite_controlA	4410	1233	4090	636	878
	hgrid100_controlB	4222	758	4090	7	861
	hgrid200_controlB	4225	819	4090	68	867
	hgrid300_controlB	4235	862	4090	116	873
	hgrid400_controlB	4245	893	4090	151	878
	hgrid500_controlB	4252	919	4090	179	881
	hgridInfinite_controlB	4263	956	4090	221	885
PV75	hgridInfinite_baseline	4955	0	4090	0	859
	hgrid100_controlA	3925	1050	4087	25	844
	hgrid200_controlA	3971	1222	4091	200	884
	hgrid300_controlA	4027	1397	4091	391	904
	hgrid400_controlA	4085	1510	4090	546	907
	hgrid500_controlA	4139	1582	4090	675	901
	hgridInfinite_controlA	4293	1612	4090	881	883
	hgrid100_controlB	4089	896	4090	8	863
	hgrid200_controlB	4089	986	4090	93	872
	hgrid300_controlB	4103	1049	4090	161	880
	hgrid400_controlB	4117	1095	4090	213	886
	hgrid500_controlB	4128	1133	4090	255	890
	hgridInfinite_controlB	4145	1197	4091	324	896

Annex 4: Ulm Electrical Side

The results from the simulation runs of the first six months of the year are reported in tabular form in the Annex 4.

PV50%

strategy	hg	NL	MTL	DTL	MLL	DLL	MVS
[-]	[-]	[%]	[%]	[%]	[%]	[%]	[%]
Baseline	Hg infinite	60.8	128.33	8.25	140.93	10.23	105.93
Control A	Hg infinite	50.3	102.46	0.003	142.27	10.28	95.13
Control A	Hg 100	53.71	128	2.98	142.27	10.28	105.63
Control A	Hg 200	52.5	128.33	1.904	141.94	10.27	105.93
Control A	Hg 300	51.356	123.47	0.98	142.27	10.27	102.73
Control A	Hg 400	51.32	118.02	0.965	142.27	10.27	97.93
Control A	Hg 500	50.31	115.38	0.02	142.27	10.28	97.73
Baseline	Hg infinite	60.8	128.33	8.25	140.93	10.23	105.93
Control B	Hg 100	53.1	128.33	2.53	141.94	10.28	105.93
Control B	Hg 200	55.044	128.33	4.19	141.61	10.27	105.93
Control B	Hg 300	54.5	128.33	3.73	141.61	10.27	105.93
Control B	Hg 400	54.04	128.33	3.362	141.94	10.27	105.93
Control B	Hg 500	53.75	128.33	3.11	141.94	10.28	105.93
Control B	Hg infinite	53.52	128.33	2.914	141.61	10.285	105.93

PV 75%

strategy	hg	NL	MTL	DTL	MLL	DLL	MVS
[-]	[-]	[%]	[%]	[%]	[%]	[%]	[%]
Baseline	Hg infinite	112.25	185.08	13.83	204.97	15.5	142.73
Control A	Hg infinite	90.8	123.25	0.0542	206.43	15.6	133.43
Control A	Hg 100	99.8	185.08	5.91	205.85	15.5	142.73
Control A	Hg 200	97.3	184.45	4.238	206.43	15.55	142.43

Control A	Hg 300	94.5	174.79	2.48	206.43	15.55	136.43
Control A	Hg 400	92.3	172.8	1.09	206.43	15.55	135.23
Control A	Hg 500	91.11	162.1	0.3	206.43	15.6	133.43
Baseline	Hg infinite	112.25	185.08	13.83	204.97	15.5	142.73
Control B	Hg 100	97.5	185.08	4.435	205.85	15.54	142.73
Control B	Hg 200	102.12	184.53	7.44	206.43	15.51	142.43
Control B	Hg 300	100.8	185.08	6.58	205.85	15.53	142.73
Control B	Hg 400	99.88	185.08	5.985	205.85	15.522	142.73
Control B	Hg 500	99.22	185.08	5.531	205.85	15.54	142.73
Control B	Hg infinite	98.64	184.53	5.188	206.43	15.55	142.43

Annex 5: Ulm Power to Gas scenario

Electrical grid model

Inside the project for both test sides, Einsingen and Hittistetten, a simulation model in power factory was built by HSU. Therefore, the real network structure was used and implemented in the model. To create a time course in 15 minute steps for a whole year standard load profiles (SLP) of the distribution grid operator (DSO) were used [2]. SLP's are the state of the art procedure of all DSO's for the estimation of the customers demand. SLP's are categorized in several groups like household, industry or agriculture. With the information from Stadtwerke Ulm/Neu-Ulm Netze GmbH the customers in the test sites were categorized into these groups. In addition every value of the SLP has to be multiplied by yearly energy demand of the customers.

$$P_{customer} = SLP \ * E_{customer}$$

With

$P_{customer}$: electrical power of the customer in kW

SLP: Standard Load Profile in kW/kWh

$E_{customer}$: yearly Energy demand of the customer in kWh

For the calculation of the PV-feed in a matlab library, PVlib [5], was used. Therfore various input parameters are necessary which are listed in Table 2. For the different irradiations data from CAMS-irradiation-service [6] was used.

Table 2: input parameter for simulation model of the testsides

	Element	Parameter	unit
Grid structure	Cables Transformer	Cable Length Cable size [mm²] Nominal power Transformer type	m mm² kW
Demand	Households Industry Agriculture	Standard load profiles Yearly energy demand	kW/kWh kWh
PV-feed in	Photovoltaik systems Irradiation Temperature	Nominal power Orientation Inclination Global horizontal irradiation Beam normal irradiation Diffuse horizontal irradiation Temperature	kWp ° ° W/m² W/m² W/m² °C

Gas grid model

The Figure 23 shows the way of the data preparation for the gas grid simulation model. . The data base sources are an extraction from LIDS and SAP of the Stadtwerke Ulm/Neu-Ulm Netze GmbH. HSU prepared the topology and the demand of the customers for the simulation in STANET by using QGIS (geo information system tool) and KNIME (an open source data mining tool). With the transferred data into STANET is it possible to create almost automated a simulation model of the grid.

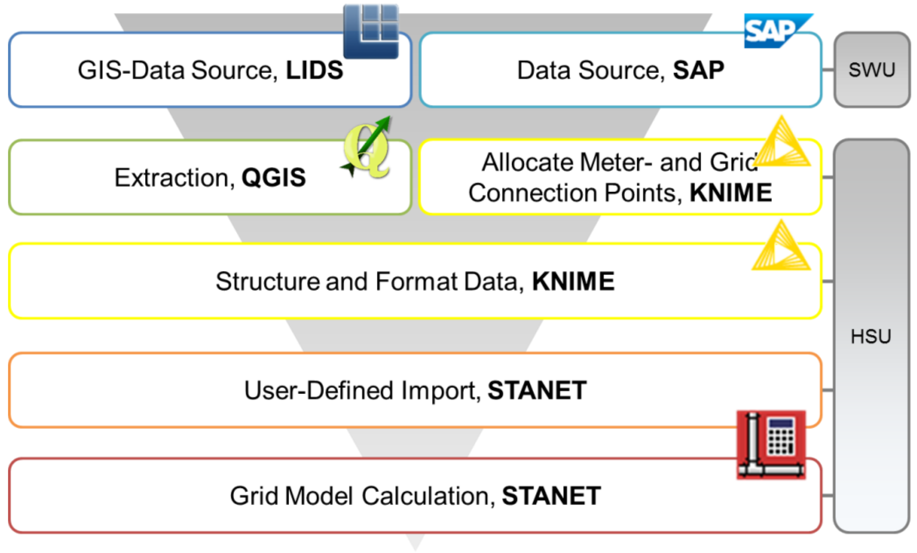


Figure 23: data preparation for the automatically creation of the gas grid simulation model

Figure 24 visualise the two grid models and show the structure. The models cover a bigger area than the test sides. This is caused of the connection points to the higher pressure grid level. Like the Transformer station in the electrical grid.

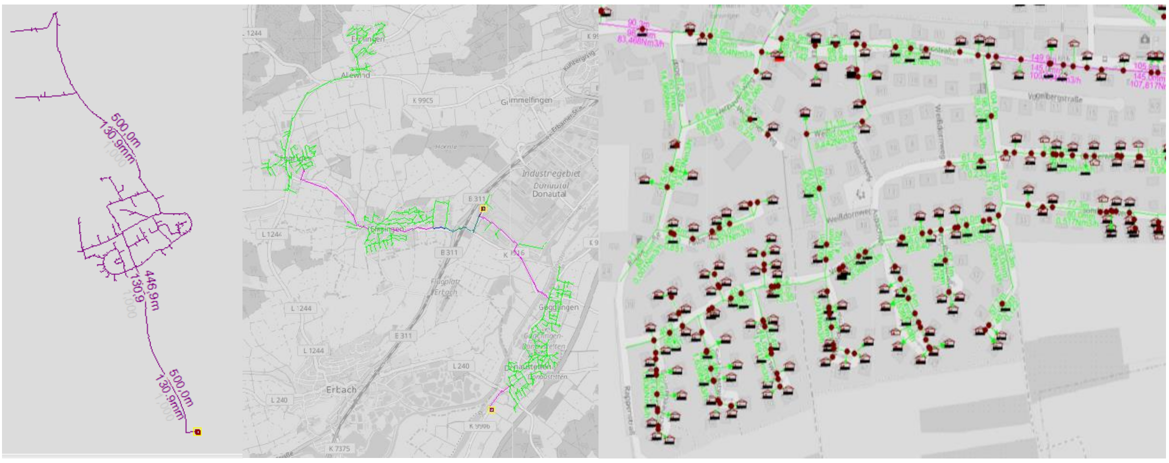


Figure 24: Overview of the two gas grid models from sides Hittisteten (left), Einsingen (middle) and the zoomed test side in Einsingen (right)

Table *1* gives a feeling for the range of the two gas grid models. Einsingen is for every Parameter nearly doubled as Hittistetten. However, with the developed data process is it not that big difference to model such grid models for simulation and analysis. That is also an important tool for planning and operating the gas grid by the DSO.

Table 1 Key values of the two gas grid models at the area at Einsingen and Hittistetten

Parameter	Einsingen	Hittistetten
Number of Nodes	1,106	522
Number of Pipes	1,133	559
Number of Pressure controller	2	1
Number of annual demand from meter	1,130	97
Pipe Volume [m³]	379	59
Pipe length [km]	46,1	10,4

Electrolyzer

For the conversion from electrical power to hydrogen, the technical parameter of the Silyzer 100 was used in the simulation. The silyzer is developed by Siemens and purchasable over the company [7]. The parameters of the Silyzer 100 are listed in Table 3. The produced hydrogen was calculated by following formula:

$$H_2 = 2.113 * \exp(-0.001648 * P_{el})$$

H_2: produced hydrogen in kg

P_{el}: electrical surplus in kW

Table 3: Parameters of the Silyzer 100

Parameter	Value	unit
Nominal power	100	kW
efficiency	50 – 60	%
Nominal power gas	20.022	Nm³/h
Hydrogen production	18	Kg/MW
Output pressure	50	Bar
Maximum power (overload)	300	%
Warm start	<10	Sec
Life time	>60000	h

A Matlab script did the calculation of the produced hydrogen. For the script only the loadflow at the transformer and the number of used electrolyze stacks are needed. If there, more than one stack is necessary they are connected in parallel and the consumption, that all stacks consume the same power, was made. For the number of stacks the maximum PV-feed in of the year was precise and two approaches were done. The first is that the electrolyzer should work within the nominal power and the second was the utilization of the maximum overload of 300 %. The second variation shows worse efficiency and less investment costs. For the conversion of H_2 in kg into H_2 the calorific value 33.3 in kWh/kg [4], a) as used.

Methanation

Based on the out coming hydrogen (H2) from the electrolysis will be the methanation output be calculated. The methanation is much less flexible than the electrolysis. For a first assumption, an easy to handle definition was fixed. The assumed nominal power of the methanation is the average value of the maximum H2 production (Energy) over day and the methane production within 12 h(P_CH4_nominal=E_H2_max_day/12h). That represent the approach that the hydrogen production by electrical PV power and electrolysis over the day will be produced during the night to methane. Table 4 gives an over view of the resulting nominal methanation power and the size of the hydrogen buffer storage for the different control strategies.*Table 4* gives an overview of the resulting nominal methanation power and the size of the hydrogen buffer storage for the different control strategies.

$$\dot{Q}_{CH4} = \frac{\hat{Q}_{H2,1d}}{12h}$$

$\hat{Q}_{H2,1d}$: Maximum daily hydrogen production

$\dot{Q}_{CH4}$: Calculaded input nominal power of the methanation

The volume of a hydrogen tank can be calculated by the following equation:

$$V_1 = \frac{V_{standard} \cdot p_{standard}}{p_1}$$

p: Pressure

V: Volume

p_1 is the aimed pressure of the buffer hydrogen storage (e.g. 750 bar). p_standard is the standard pressure value for the standard conditions of the gas.

The controller of the methanation starts working if the hydrogen buffer storage has enough hydrogen for one hour production and stop the methane production if the charge drops under this level. The efficiency of the methanation process was fixed to 60 %.

With this approach is the volume of a hydrogen buffer storage in Einsingen from 26,031 Nm³ up to 43,159 Nm³ and in Hittistetten from 102,040 Nm³ up to 160,884 Nm³. For a reduction of the simulation effort and time is a reduction of the variation based on a technical and economic point of view done. All volumes at 750 bars in *Table 4* are in a technical dimension that is realistic to handle. The investment costs will be more economic for a bigger hydrogen buffer storage instead a methanation with a higher nominal power. The hydrogen production is decreasing with a lower number of stackes. This is caused by the lesser efficiency. More losses means more heat production in the process. Because of the Power to Heat approach from hybrid scenario 1 in the same area is it not possible to use the heat direct there. Only the additional usage of the DHN can make It possible to transport the heat power in other areas of the city where it could be used. However, the DHN is not in the story line of hybrid scenario 1.

Table 4: results of the power to gas analysis

Test area	Scenario	Nominal methanation power [kW] left, [Nm³/h] right		Hydrogen buffer storage capacity [Nm³]	Hydrogen buffer storage (tank) [m³] at 750 bar
Einsingen	**Control 3, 3 Stacks, 50%-PV**	530.27	3.981	26,031	35
Einsingen	**Control 4, 3 Stacks, 50%-PV**	532.13	3.995	26,040	34.7
Einsingen	**Control 3, 5 Stacks, 75%-PV**	916.68	6.882	42,845	57.1
Einsingen	**Control 4, 5 Stacks, 75%-PV**	917.48	6.888	43,159	57.5
Einsingen	**Control 3, 13 Stacks, 75%-PV**	1937.39	14,545	35,313	47.08
Einsingen	**Control 4, 13 Stacks, 75%-PV**	1934.06	14,52	35,574	47.43
Hittistetten	**11 Stacks, 50%-PV**	1662.34	12.48	130,064	173.41
Hittistetten	**4 Stacks, 50%-PV**	829.84	6.23	102,040	136.05
Hittistetten	**13 Stacks, 75%-PV**	1984.68	14.9	160,884	214.51
Hittistetten	**4 Stacks, 75%-PV**	865.80	6.5	110,825	147,76

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