Schweizerische Eidgenossenschaft
Confédération suisse
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Eidgenössisches Departement für
Umwelt, Verkehr, Energie und Kommunikation UVEK

Bundesamt für Energie BFE

Jahresbericht 2010

Vision of Future Energy Networks (VoFEN)

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BFE-Vertrags- und Projektnummer: 153579 / 100669

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Zusammenfassung

Das Projekt "Vision of Future Energy Networks (VoFEN)" beschäftigt sich mit dem Entwurf, der Modellierung und der Analyse zukünftiger Infrastrukturen zur Energieübertragung und -verteilung. Ursprünglich 2002 mit vier verschiedenen Themenschwerpunkten bzw. Arbeitspaketen initiiert, umfasst das Projekt im Jahr 2010 sechs Arbeitspakte. Bearbeitet werden Fragen hinsichtlich Risikomanagement und Investitionsstrategien für nachhaltige Energiesysteme, dezentraler Regelung in Verteilnetzen, optimalem Netzdesign als auch der Netzintegration von Plug-In Hybriden Fahrzeugen. Ziel ist es, ein umfassendes Verständnis möglicher zukünftiger Energienetze zu erarbeiten, wobei der Fokus nicht nur auf der Elektrizität liegt. Das Projekt verfolgt einen sogenannten Multi-Energieträgeransatz, d.h. die kombinierte Betrachtung von diversen leitungsgebundenen Energieträgern wie z.B. Elektrizität, Gas, Fernwärme, Kälte etc. Zentral für das Projekt sind dabei auch die zwei Fallstudien zur praktischen Verifizierung der theoretischen Ansätze in Anwendung auf die Energienetze in Baden-Dättwil und Bern. Das Projekt VoFEN stellt eine wichtige Basis für thematisch verwandte Forschung am Power Systems Laboratory dar, wie z.B. das von der Europäischen Union finanzierte Projekt "Infrastructure Roadmap for Energy Networks in Europe (IRENE-40)". 2010 wurde ein Arbeitspaket (Dissertationen) abgeschlossen.

Abstract

The energy supply chain from production over transmission and distribution to final consumption generally involves several energy carriers. The project “Vision of Future Energy Networks”' (VoFEN) at ETH Zurich aims at systematically analyzing multi-carrier energy systems in order to design optimal structures for future sustainable energy systems. Models for the representation of power flow, conversion and storage of multiple energy carriers have been developed within the project. Among them the Energy Hub model is the key concept, which has been used in several other contexts, comprising risk management and investment analysis for multi-energy carrier systems, agent-based control schemes for decentralized generation, a framework to assess the influence of Plug-In Hybrid Electric Vehicles on power systems as well as two exemplary case studies involving Swiss municipalities (Bern and Baden-Dättwil).

VoFEN research has been presented at major conferences in 2010 (see references in the work package describtions). The results within the individual work packages as well as an outlook for the year 2010 are presented in the sections below. The work package on “Evaluation of Investments in Multi-Carrier Energy Systems under Uncertainty” has been concluded with a successful PhD defense.

1. Introduction

Problem Description

Bulk electricity generation and transmission technologies often exhibit large economies of scale. Driven by these scale effects, power systems historically evolved into large, interconnected structures, where electricity is mostly produced in “centralized”' power plants with ratings ranging from several hundreds to thousands of Megawatts. On the contrary, climate change, fossil resource depletion, policy incentives as well as higher public awareness in term of sustainability have promoted the deployment of small decentralized and renewable generation technologies, typically including photovoltaics, microturbines, combined heat and power (CHP), waste and wood incineration plants etc. Nonetheless, the size of distributed generation facilities is not the only aspect influencing the currently prevailing power system structure. A number of these technologies also provide the possibility for so-called co- or tri-generation. Using e.g. CHPs or microturbines it is possible to produce electricity and heat out of natural or bio gas, biomass etc. Together with the deployment of distributed storage technologies or the prospective integration of Plug-In Hybrid Electric Vehicles (PHEVs) complex interactions between the different energy carries and systems arise. The traditional “setup” of the power system with the typical power flow from higher to lower voltage levels may be altered. Infeeds from lower voltage levels are becoming increasingly common. Additionally, new building standards promote energy efficiency benefiting from advanced information and communication technologies to “exploit”' the intensified couplings between both: production, transmission and consumption as well as the different energy carriers. Such an operational and topological flexibility calls for a generic framework to describe the effects on economic, ecological and technical indicators related to energy systems.

Since 2002 the VoFEN project aims at developing such a generic modeling and analysis framework, where the approach is in more detail outlined in the next section.

Proposed Course of Research

Since the start of the project in 2002, VoFEN was focused on a so-called Greenfield approach, targeting the question on how future transmission and distribution systems for energy should look like for the improvement of technical, economic and ecological performance. The concept of choice is to build a fictitious optimum system from scratch neglecting the current system structure and then to identify the differences between the present situation and the desirable system. Main drivers of the research work were the increasing share of decentralized and renewable generation sources as well as an integrated look on energy systems, i.e. the incorporation of a multi-energy perspective, studying the dependency of major grid-bound and non-grid-bound energy carriers, such as electricity, heat, gas, biomass etc. This integrated view on energy systems provides the opportunity to study the dependencies and synergies among different energy carriers in order to, i.e. minimize primary energy use by optimizing overall energy efficiency. It also allows developing innovative operational and control strategies for multi-carrier energy networks, as found for instance in urban areas where water, gas and electricity networks are closely linked. In that, the VoFEN project aims to identify future structures for transmission and distributions networks and to show strategies how to move from the current system setup to a hopefully more efficient and sustainable system incorporating the various needs of network participants, such as households, industrial customers, large-scale and small-scale generation and transmission and distribution system operators themselves.

In previous years the so-called “energy hub” was developed and identified as major modeling and analysis tool. An energy hub is an integrated system of units that allows the conversion, conditioning and storage of multiple energy carriers. It represents an interface between different energy infrastructures and/or loads. Energy hubs consume power at their input ports connected to e.g. electricity and natural gas infrastructures, and provide certain required energy services such as electricity, heating, cooling, compressed air, etc. at the output ports. Within the hub, energy is converted and conditioned using e.g. combined heat and power technology, transformers, power-electronic devices, compressors, heat exchangers, and other equipment. Existing facilities that can be considered as energy hubs are for example industrial plants (steel works, paper mills), big buildings (airports, hospitals, shopping malls), rural and urban districts, and island energy systems (trains, ships, aircrafts).

The energy hub is the major modeling concept of the VoFEN project, i.e. the underlying theory serves as basis for the currently running working packages described in the respective sections.

2. Objective of the Research Project

Using the energy hub approach, and thus, relying on a multi-energy carrier perspective the following objectives of the VoFEN project could be identified:

- Contributions to identifying future network topologies facilitating the grid integration of small, renewable generation facilities.
- The development of innovative control strategies for decentralized generation units (e.g. in distribution grids) as well as analyzing the prospective economic benefits of certain generation portfolios by means of risk and portfolio management tools.
- Verification of the theoretical concepts by means of case studies in close cooperation with Swiss municipalities (Baden-Dättwil and Bern)

3. Results

The following section summarizes the six work packages of VoFEN in 2010

I) RISK ASSESSMENT AND INVESTMENT STRATEGIES FOR MULTI-CARRIER ENERGY SYSTEMS (Florian Kienzle)

In 2010 the work within this work package was focussed on the extension and refinement of the basic energy hub Monte Carlo valuation model developed in 2009.

In a first step an approach to incorporate information about locational energy prices into the energy hub valuation model was proposed. This approach consists in using the nodal energy prices resulting from an optimal power flow (OPF) analysis of multi-carrier energy systems as input to the Monte Carlo valuation model. In this way energy hubs can be valued depending on their specific location in a network. Combining an OPF analysis with the valuation model allows for analyzing how investments in multi-energy generation assets at a certain location in the network are affected by changes in the network topology, by line capacity enhancements or by changes of generation and/or demand throughout the network. In [1] a detailed description of the model is provided and the approach is illustrated with an application example analyzing the system shown in Figure 1.

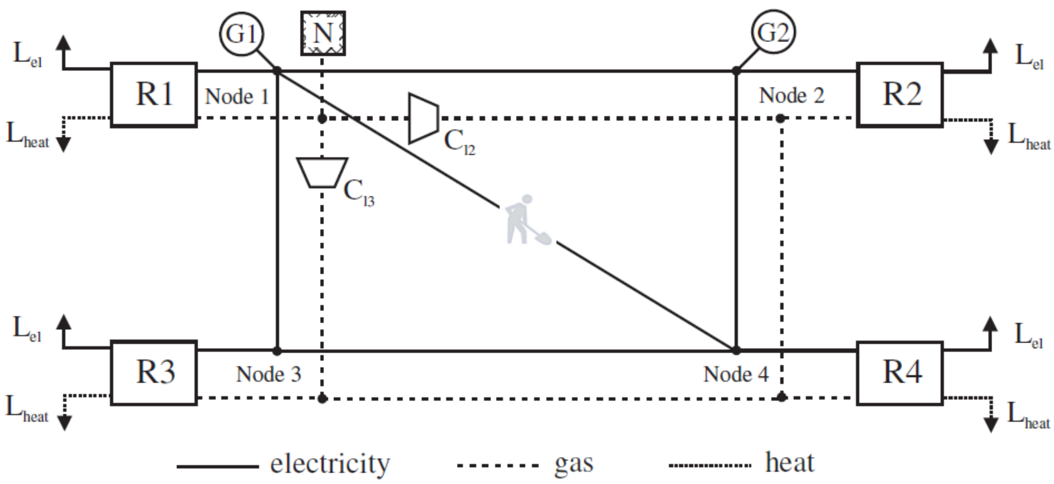

Figure 1: System with four hubs (R1 to R4) interconnected by a natural gas and electricity system. The impact of constructing an electricity line between node 1 and node 4 is assessed.

Furthermore, the basic energy hub valuation model was extended in such a way that energy hubs containing storage devices can be valued. With the rising share of fluctuating renewable energy sources in electricity networks, the importance of storage increases. The developed model extension takes into account the increased flexibility of an energy hub due to storage devices and allows for calculating the economic value of this flexibility. The complete model as well as an illustrative application example, where a CHP unit is combined with heat and electricity storage devices, is also described in [1].

Another extension of the valuation method for energy hubs with conversion and storage devices was elaborated in collaboration with Peter Ahčin. He had developed an energy hub model additionally considering the possibility of performing demand side management with the load(s) connected to the hub output. This extended energy hub model was combined with the Monte Carlo valuation approach. The resulting method can be used to value investments in multi-energy conversion, storage and demand side management systems. By comparing different hub configurations with storage and/or demand side management, the value of the corresponding investments in liberalized markets with volatile prices can be assessed. The proposed model is documented in [3].

A substantial part of the work in 2010 was devoted to writing the dissertation which describes all outcomes of this work package [4]. The thesis as a whole provides methods and models for the evaluation of investments in multi-carrier energy systems under uncertainty. It consists of two main parts. Part I describes the scenario-based portfolio model and its application to generation portfolios providing multiple energy carriers. The model considers long-term cost uncertainties from a societal point of view. Part II describes the energy hub Monte Carlo valuation method. The models presented in part II focus on taking into account short-term price uncertainties and an energy hub's flexibility to react to them. The valuation is done from the perspective of an individual profit-maximizing entity.

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II) DISTRIBUTED CONTROL FOR COMBINED ELECTRICITY AND NATURAL GAS SYSTEMS (Michèle Arnold)

Due to DG technologies, such as photovoltaic, wind, micro-CHP, biomass, etc., energy production changes from centralized units to diverse distributed units, located at lower voltage levels. In addition, installations of renewable energy resources are promoted by receiving a feed-in tariff. These trends provide new opportunities for consumers, deciding when to consume or produce energy. For investigating these aspects, the energy hub modeling framework [5] is used, which describes energy systems comprising multiple energy carriers. Figure 2 shows an exemplary system setup, where to hubs, containing micro-CHP, furnace, heat storage and PV, are connected to an electricity and natural gas supply grid. The hubs represent residential areas, i.e. an aggregation of households.

The households decide when to:

- produce electricity locally via micro-CHP,
- feed electricity back to the grid (gained via micro-CHP or from PV installations),
- import electricity form grid [8].

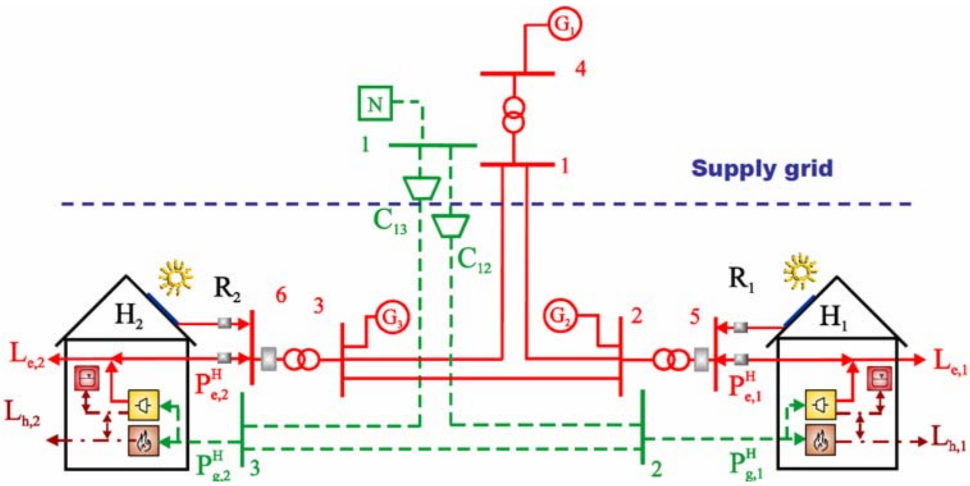

Figure 2: Households (micro-CHP, furnace, heat storage, PV) connected to supply grid.

For determining the optimal operation strategy, a look-ahead scheme (MPC: Model Predictive Control) is allowing for the incorporation of future energy prices, load profiles and predicted available solar power into operation planning. Forecasts of prices signals, load profiles and renewable infeeds are never perfect but contain forecast errors. By operating the system in a receding horizon fashion, the consequences of forecast uncertainties can be kept at acceptable levels. At every time step updated system measurements and forecasts are used to predict the future behavior of the system. Instead of compensating forecast uncertainties with fast acting backup generators or balancing energy, as it is often done in current practice, the imbalances can be compensated with storage devices, placed close to locations where uncertainties arise. Monte-Carlo simulations show that a major part of the disturbances can be compensated by storage devices without increasing the system operation costs significantly. In cases where storages are not sufficient, generator settings are changed from the day-ahead schedule, representing additional balancing costs. However, by optimally operating the storage devices, a major part of the balancing energy can be replaced by the storage devices. Figure 3 shows the spreading of operational costs of the two hub system depicted above. Electricity and heat load profiles are modeled with 5% randomly distributed disturbances (normal distribution). The operation costs show a normal distribution of 1.1% deviation. Thus, major part of the disturbances can be compensated by the storage devices.

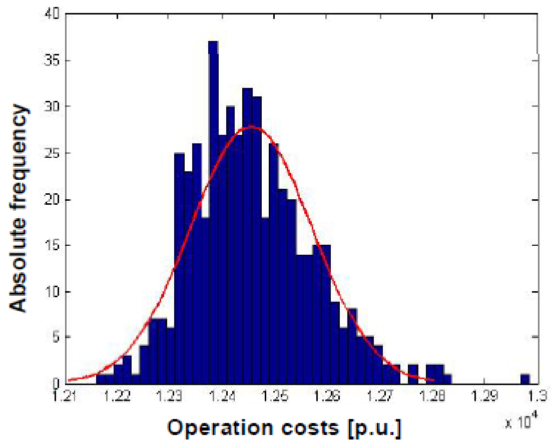

Figure 3: Spreading of operation costs when modeling electricity and heat load profiles with 5% dis-turbance

The controller can either be implemented in a centralized or distributed way. A centralized, supervisory controller measures all variables in the network and determines actions for all actuators [4]. Due to practical and computational issues implementing such a centralized controller may not be feasible. Therefore, a distributed MPC scheme, in which the control is spread over the individual hubs is implemented. Each controller solves its own local MPC problem using the local model of its hub. However, this local MPC problem depends on the MPC problems of the other controllers, since the electricity and gas networks interconnect the hubs. Therefore, the MPC optimization problems of the controllers have to be solved in a cooperative way [6],[7]. For catching non-convergence cases, a

Newton-Raphson method in combination with preconjugate gradient method (GMRES) is used for solving the individual subproblems [6].

Evaluation 2010 and Outlook 2011

In 2010 the following research has been covered:

- Investigating renewable infeed from residential areas and analyzing hub operational costs.
- Incorporating forecast uncertainties within the load profiles and analyzing performance of predictive control scheme.
- Implementating Newton-Raphson method for solving subproblems in distributed control scheme, for enhancing coordination between areas.

In 2011, final simulations regarding the topics discussed above will be carried out. Finally, the models, insights and results obtained in the course of this WP will be written in a dissertation. The final presentation of the dissertation is expected to take place in Spring 2011.

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III) INTEGRATED ANALYSIS OF POWER AND TRANSPORTATION SYSTEMS (Matthias Galus)

This project investigates the potential impacts and benefits of PHEV integration into power systems [9] in corporation with the institute for transport planning and systems (IVT, ETH) and the laboratory for aerothermochemistry and combustion systems laboratory (LAV, ETH).

First, a simplified PHEV model based on the energy hub approach [10] was derived incorporating energy management schemes for PHEVs [11]. Using this model, energy levels at arrival and average consumption data for vast amounts of PHEVs can be simulated. The model is integrated into an agent based transportation simulation tool called MATSim. This model is capable of simulating large numbers of PHEVs including their temporal and spatial recharging behaviour. The recharging vehicles are aggregated dependent on their spatial distribution through the concept of PHEV managers [12,13].

These smart entities, which are located at nodes of the electrical grid, control the recharging behaviour, initially determined by MATSim. The manager ensure grid security while effectively distributing available power capacity at a respective node to the connected PHEVs based on an optimization scheme. The incorporates power system constraints imposed by the converters such as maximal input or output powers, e.g. converter ratings. Furthermore, the scheme can take possible line overloading into account [14]. The managers create nodal price signals to which the PHEVs react. These signals directly represent the system state (e.g. converter congestion, PHEV demand, etc.). Clearly, when the desired battery level cannot be achieved because power system constraints are violated, the PHEV agent might well change its transport behaviour. Hence, PHEV managers and MATSim have been integrated in order to account for behavioural changes of agent [15,16].

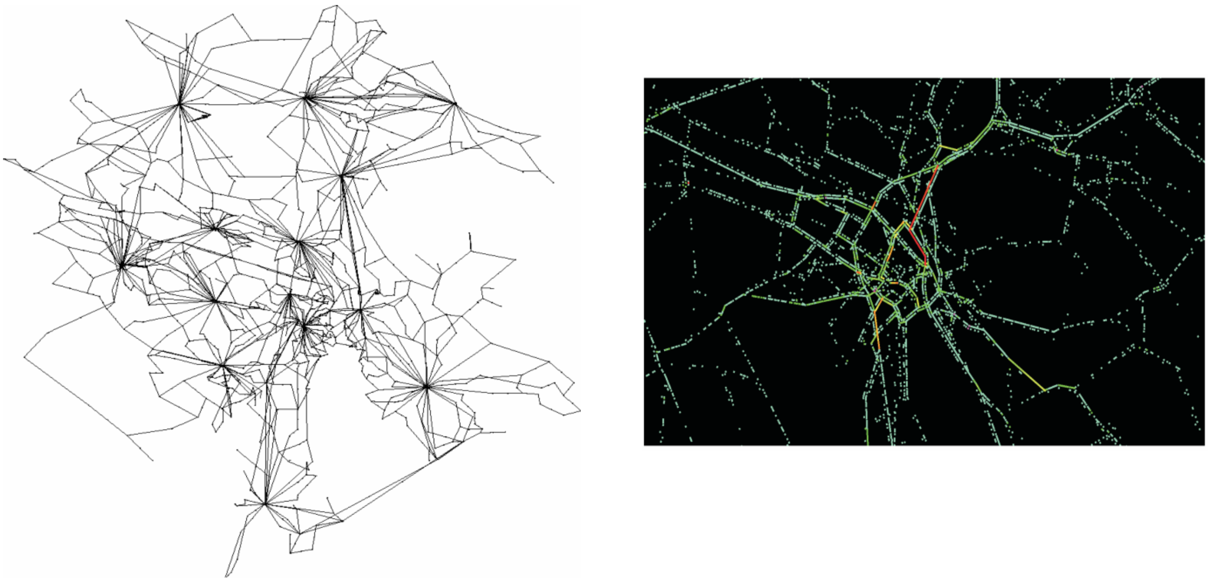

Figure 4: *(Left)* Power system of the city of Zurich
(Right) MATSim simulation output for the transportation behavior of the agents. Green dots indicate agents moving through the street network. Reds dots indicate agent stuck in a traffic jam.

The integrated approach has been tested on the power system of Zurich comprising ca. 1600 nodes and ca. 1800 lines. A fleet of 250’000 PHEVs has been simulated and managed by PHEV managers in the power system [17]. The managers incorporate a framework that allows to control them for vehicle-to-grid purposes for which they are clustered and controlled as a large aggregated storage, physically distributed over the whole power system [17].

Future work will include voltage- and line system state constraints in the PHEV-Manager scheme. Application of the scheme to dynamic pricing will be performed. Further, considerations will be given to balancing stochastic, renewable generation with PHEVs using potential vehicle to grid services. The individual transportation demands will as well be integrated in these services. Finally, case studies will be performed for the area of Zurich investigating system limitations due to increasing power demand by electrified mobility.

Evaluation of 2010

Goals:

- Incorporating system constraints such as voltage limits and line loading limits into the PHEV management scheme
- Incorporating a scheme into the PHEV Manager toll which allows PHEVs to be used for renewable energy generation balancing purposes and V2G in general.
- Case studies for the greater Zurich area using the integrated toll comprising PHEV Managers and MATSim

Evaluation:

All goals have been achieved and documented is [12, 15], [16, 17] and [14], respectively

Outlook 2011

The available tools will be integrated in order to simulate the city of Zurich for a wide scale PHEV utilization scenario. This scenario will incorporate the provision of V2G service to balance renewable energy sources. Furthermore, PHEV charging impacts will be investigated in the 400V network. Dynamic pricing will be incorporated in order to let the PHEVs charge during low price intervals and discharge during hours where electricity is expensive.

The final presentation of the dissertation is expected to take place at the end of the first half of 2011.

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IV) HUB TECHNOLOGY (Franziska Adamek)

Renewable energy use has been increasing significantly during last years, and forecasts say that this trend will continue and even increase in the future. Utilities build large- and medium-scale photovoltaic (PV) and wind farms or biogas plants to raise their ecological image and to reduce their dependency on fossil fuels. But private households are participating in the renewable boom, too, e.g. with roof-mounted PV plants, small combined heat and power plants (CHP) or heat pumps in residential buildings [18]. Owners are interested in making the most out of their renewable energy, either by selling it to the grid operator to gain profit, or by using it themselves to minimize their dependence on fossil fuels or energy suppliers.

Private households can either invest in energy storage or change their energy consumption habits (demand response) to exploit locally generated renewable energy and to benefit from low-tariff times [19]. For demand response, the question arises how flexible the consumers have to be to noticeably save costs or increase their independence, i.e. how much they have to be willing to change their consumption profiles. As energy storage can be expensive, it is of interest whether its installation causes further benefits, both if used exclusively or in combination with demand response. Besides only having in mind the own consumption profile, the household can also collaborate with its vicinity to maximize their collective welfare. But the question is if this is advantageous for the inhabitants, or if the efforts exceed the benefits. Generally spoken, for end users it is important to know which energy consumption behavior is necessary and expedient to save money or fossil fuels, while still keeping a certain level of comfort. On the contrary, utilities have to evaluate which price conditions encourage customers to apply demand response or to invest in storage devices.

To analyze the application of Demand Response and energy storage in private households, a single-family house is examined. The parameters of the house are chosen according to Swiss statistics and expedient building characteristics, and are implemented in a thermodynamic house model (Figure 5). For the electric and thermal energy supply, a grid connection, a gas furnace and a gas fueled combined heat and power plant (CHP) are available. Together with the storage device options (electric, warm water, electric-thermal (boiler)) and the locally installed photovoltaic (PV) plant, these technologies are represented in the energy hub model [20]. For different price conditions and varying amounts of locally available PV energy, different combinations of energy storage devices and demand response flexibility are simulated for the exemplary single-family house, analyzed and compared. First results could already be obtained. Simulations show that the application of an energy storage device is generally only expedient for larger amounts of locally available photovoltaic electricity (Figure 6). Also, already small storage capacities are sufficient to increase photovoltaic use and decrease overall energy costs. In most of the examined cases, demand response and energy storage use compete for the surplus PV electricity and the load shiftable from high to low tariff times. But e.g. for a high amount of renewable electricity, the combination of demand response and an electric-thermal storage device can be very beneficial for overall costs. In most cases, results for summer and winter differ significantly (Figure 6), as in winter thermal load dominates, and in summer electric load.

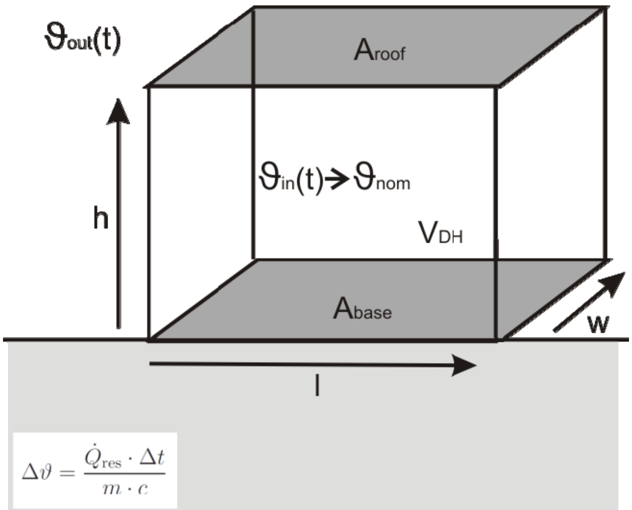

Figure 5: Schematic representation of the single-family house and the thermodynamic equation for the room temperature change

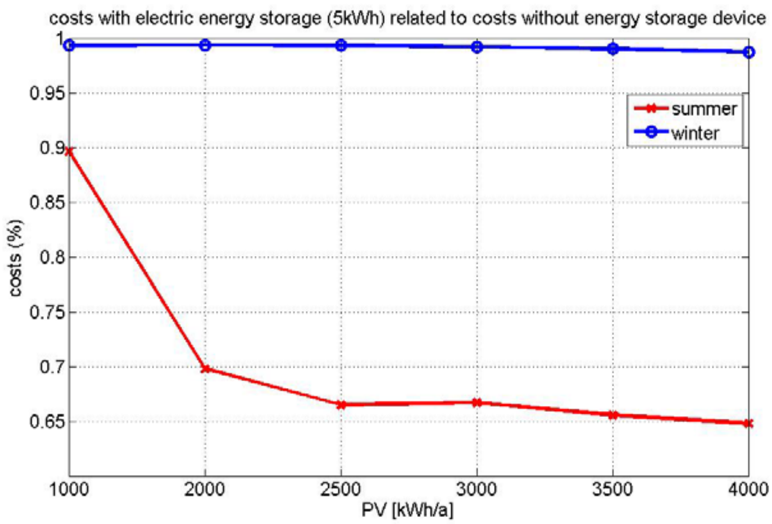

Figure 6: Comparison of overall energy expenditures for different amounts of locally available photovoltaic (PV) energy with energy storage, related to the costs without energy storage

The results of the simulations and hence the conclusions for the house inhabitants can vary significantly depending on the chosen frame conditions (prices, technology parameters, etc.). Consequently, future work will include a detailed analysis and comparison of different price structures and parameter setting to find trends and similarities/differences. Also, the investigation of the questions stated above will continue.

Instead of only looking at their own house, the inhabitants could also collaborate with their neighbors in using energy storage and demand response. A next step will be to analyze the potential for further cost savings when a vicinity of several houses teams up and acts as a unit. Therefore, the multiple-level model will be applied [21]. This model allows the simulation of an energy supply infrastructure on different levels combining several independent actors (each modeled as an energy hub). This model was developed and examined last year (2009). The synthesis of the results for one single-family house and those for several houses will round off the work done in the last two years.

Rating 2010

Aims

1. Implementation of the thermodynamic house model
2. Development of an exemplary single-family house and data acquisition
3. Adaptation of the simulation files
4. Run simulations
5. Analysis and examination of the simulations
6. Analysis of a vicinity of houses with the multiple-level model

Rating

The first three targets (aims 1-3) have been fully achieved. Also, a number of simulations have already been carried out (aim 4), but simulations are still going on with continuing evaluation. The results have been evaluated continuously during the second half of 2010 and analysis is still running (aim 5). The simulation files for the application of the multiple-level model will be adapted during December 2010 and January 2011, with the according simulation run and evaluation following end of January and in February (aim 6).

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V) CASE STUDY ENERGY HUB BADEN (Matthias Schulze)

The case study has started in September 2007 and concluded in August 2010. Dättwil, a district in the city of Baden (Switzerland), was chosen as the study object. The district contains about 3,500 inhabitants with industrial, commercial and residential area. A decomposition of the area into dependant energy hubs and the network topology used in the calculations, where nodes and corresponding hubs represent the essence of the present grid, can be seen in Figure 7 The hubs are interconnected with a grid for natural gas, district heating and of course electricity. The heating plant of a large hospital there is the supplier for the district heating network. There are four boilers fired with either natural gas or fuel oil to produce heat and steam. This facility will be substituted within the next few years by a biomass power plant. The new plant uses wood gas from the gasification of woodchips and could produce electricity and heat via a CHP, heat via a boiler and synthetic natural gas and heat via a purification process. For each individual hub measurements for the electricity consumption were taken. The measurements took place at the transformers, about three of them supply one hub's area. From weekly data and the annual curve of the near substation synthetic load curves for seven hubs are available, showing the typical behavior of e.g. industrial sites. Heat load is either feed from the district heating network, from natural gas or from fuel oil. The data of the network is already available. For the measurements of chemical feed heating probes are going to be used counting the flow rate. Because measurements can only show today's consumption scenarios are needed to provide an outlook into the Dättwil of 2060. Additionally future energy produced by distributed generation, from solar-thermal, photovoltaic or wind energy, was estimated. Both, the present data and the scenarios for future changes will allow an overall simulation of the energy infrastructure in Dättwil.

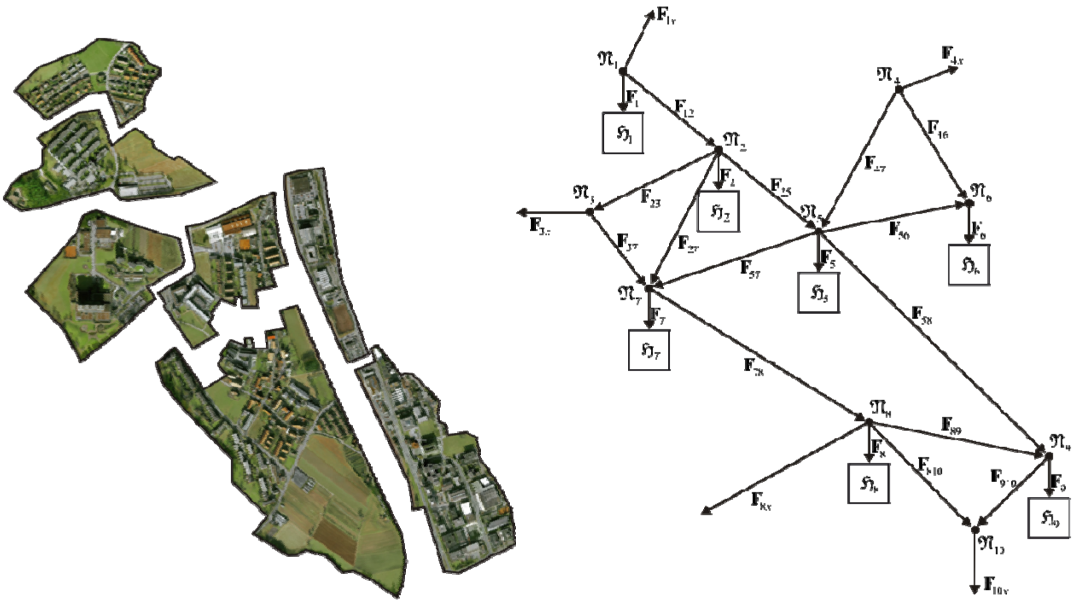

Figure 7: Decomposition of the investigation area into Hubs and configuration of Hubs and Nodes

Evaluation 2010

Planned activities

- Long term strategically optimization
- Sensitivity study of energy costs using parallel computing
- Evaluation of new load situations: cars & bikes
- Alternative energy carrier study, substitution of fuel oil and natural gas
- Measurement of heat and gas load curves
- Begin writing dissertation in spring / summer

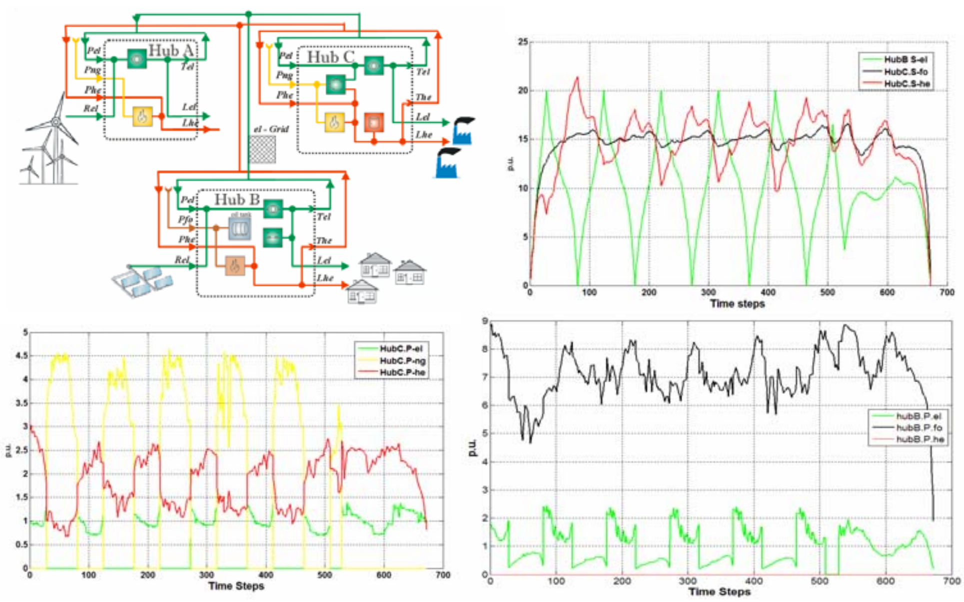

Figure 8: Example network configuration with three hubs (A, B & C). The power P taken from the grid and the energy exchange with the storages (oil tank, hot water tank, battery) are visualized for the optimization of one week. Due to the constraints and price settings all storages show different kinds of usage.

Achieved progress

In the last phase of this work package the previously gathered data has been used to produce an entire model of Dättwil. The study of more accumulative or synergetic effects was the goal. The technological settings, as they appear within the model's coupling matrix C, were selected in cooperation with the project partners from the Regionalwerke AG Baden (the local utility) and the Energiekommission der Stadt Baden (the advisory board for energy in Baden). In order to open the prices as weight factors, multiple optimization were run, with alternating prices for the energy carrier. This procedure yields in higher computational effort, so some work has been carried out to speed-up the hard- and software. Finally, a Matlab-independent program has been created, which is able to run without limits to processor cores on local workstations, servers or even clusters. The optimization is now, depending on the hardware, more than 103 times faster. For the project partners, it's now possible to bring in their knowledge about future markets and price developments.

Two different procedures are applied in order to simulate Dättwil's infrastructure: quarter-hourly values for analyzing time-based phenomena, e.g. the influence of photovoltaic's and intraday storage; annual energy consumption for sensitivity studies on costs and feasibility studies for alternative energy carriers. In Figure 8 an example network for the integration of multiple storages in a network of three hubs is shown. Here is the quarter-hourly dataset useful to evaluate the relevance of storage size and position, and of course to study the advantages depending on the kind of storage used.

The influence of mobility in Dättwil was another emphasized point. Since this topic is implemented with far less details as in the work package "Integrated Analysis of Power and Transportation Systems", the addressed questions are more energy-related than questions of grid stability or control. Therefore, qualitative assumptions were taken from [22], where charging load profiles for uncontrolled public and home charging exist. Applied on the Dättwil-model only the number of inhabitants, the car usage per-capita and the amount of public parking slot has to be determined. Assuming a 100% penetration with electric vehicles, as the worst or far future case, answers about additional load within the hub's areas and the medium voltage grid (22 kV) can be given. It has been show that home charging is possible without limits due to the already high capacity of the PCC from houses to the MV-grid. The opposite behavior results for public charging, where actions must be taken. Otherwise, at begin of a shift the electric load would more than double. It is advised again that stability questions are not addressed with this kind of investigation.

Four alternative energy sources and (partial) carrier were study within the case study. As an energy carrier, hydrogen, synthetic natural gas and ethanol were proved, whereas as sources we considered mainly biomass, and for the case of hydrogen, solar radiation. For the feasibility the energy conversion efficiency (from the source to the carrier) as well as the necessary land for the production are taken into account during the calculations. Consequences on the scarce good land displayed doubts in terms of sustainability issues. However, the physical and chemical integration has been demonstrated, and due to changing general conditions it might become reality in future.

On the theoretical side the energy hub model, in the version used for Dättwil, was extended to network related aspects. A nodal matrix for the energy exchange in between nodes and the surrounding environment (or higher grid level) has been developed. Grid-based prices were considered as well, enabling the integration of fees for grid usage and cross-border capacities into the model.

All in all the envisaged results were achieved, especially from the understanding of Dättwil's energy infrastructure, energy conversion and future trends point of view. The integration of storage into the model is still difficult in terms of the optimization.

Reference

[22] K. Parks and T. Markel, "Costs and Emissions Associated with Plug-In Hybrid Electric Vehicle Charging in the Xcel Energy Colorado Service Territory", NREL Technical Report, May 2007.

VI) CASE STUDY BERN (Peter Ahcin)

Main objectives of the project:

- Identify configurations of the energy distribution system that generate acceptable levels of greenhouse gas emissions.
- Develop a roadmap to a desired energy distribution system configuration.

Progress

During the first two years the first objective was partly achieved. Models of different power plants, storage units, consumers and demand side management were developed, that put together allow for a very flexible model of the city's energy distribution system. Focus had been put on a comprehensive modeling of demand side management that includes space and water heating, refrigeration, washing and drying as well as electric vehicles. Some focus had also been dedicated to improving the models of energy conversions devices and heating distribution. These models can be used to estimate the running system costs, greenhouse gas emissions and system efficiency for different system configurations.

Configurations that generate acceptable levels of greenhouse gas emissions, however, will not be explicitly identified. Instead of looking for system configurations that fulfill the emissions criteria a long-term investment planning problem has been formulated and will be shortly solved with dynamic programming. This formulation requires that there be an end objective defined, which can be in terms of system emissions, costs, total fuel consumption, total imported fuel consumption or other criteria relative with respect to today. How exactly this goal in achieved in the long term depends on the energy and technology price developments. The formulation of the problem has the advantage of not depending on any fixed price parameters. Its result is an investment policy that tells when and how the infrastructure should be built depending on the running and expected prices at the moment. It is also easily extendable to include such features as the possibility of waiting for a foreseeable technological solution that is not yet available or possible changes in price and consumption trends.

Outlook 2011

The planning problem has been developed but the algorithm will require some improvement. Currently the investment options in the problem formulation include generating units such as gas turbines, biomass boilers and co-firing systems, distributed and centralized heating systems and building renovation. This will be extended in early 2011 to include other conversion technologies, storage and demand side management as an investment option.

4. Discussion and Conclusion

Currently, the VoFEN project is in its late second phase, which started in 2006 and will end in summer 2011. Six work packages were running in 2010 dedicated to research ranging from control strategies and Plug-In Hybrid Vehicle (PHEV) integration to exemplary case studies. As last year project workshops were held to maintain the dialogue between practitioners and the individual researchers. In overall, the project progressed well during 2010. The targeted objectives have been met. The work package "Evaluation of Investments in Multi-Carrier Energy Systems under Uncertainty" has been concluded with a successful PhD defense.

Major results are expected for 2011, as three work packages (risk assessment and investment strategies, distributed control and the case study Baden-Dättwil) will be concluded with a PhD thesis. The individual research objectives have been specified in the work package descriptions. To present specific work package results and document research progress, further workshops are planned for 2011.