Innsbruck´s prototype for a cross-linked energy system

Reinhard Fohringer[1], Sophia Neuner[2]

[1]Electricity grid management, Innsbrucker Kommunalbetriebe AG, reinhard.fohringer@ikb.at, Innsbruck, Austria
[2]Product development and innovation, Innsbrucker Kommunalbetriebe AG, sophia.neuner@ikb.at, Innsbruck, Austria

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Abstract

The amount of electricity from decentralized renewable energy sources fed into the distribution grid in the city of Innsbruck has constantly grown over recent years. Both local and national energy strategies promote a heavy expansion of renewable energies, especially photovoltaics and wind, in the next ten years. One unwanted side effect is that demand and supply become less controllable by grid operators due to the increase in generation from fluctuating sources. Flexible adaptation of consumption to the current generation and the use of storage are necessary measures to successfully integrate renewables into the energy system. To ensure cost efficiency, optimization based on the existing infrastructure should always be the first means of choice before a network expansion is carried out. Energy Management Systems, like the one used at the IKB-Smart-City-Lab, make it possible to automatically control and allocate cross-sectoral energy flows and cover short- and medium-term fluctuations. This reduces the need of grid expansion. In order to deal with seasonal fluctuations, additional technologies like hydrogen electrolysis systems can be integrated into the IKB-Smart-City-Lab.

1 Introduction

The need of reducing greenhouse gas emissions to keep the global temperature rise below two degrees Celsius compared to pre-industrial values in combination with decreasing costs of renewable electricity generation technologies leads to a significant change in power supply. Especially generation costs of photovoltaics and wind energy have drastically decreased in the last decade and thus made them the fastest growing electricity sources worldwide [1].

By the year 2030, electricity generation should even out to 100% by renewable sources over the course of one year according to the Austrian climate and energy strategy.
This means an increase of 1100% in photovoltaic- and 220% increase in wind electricity generation compared to the year 2016 [2]. On the regional level, the state of Tyrol aims to be free of fossil fuels over all sectors by 2050 [3].

There are two major differences of electricity generation out of photovoltaics and wind compared to conventional generation units: First, the generation is far more weather dependent and therefor fluctuates more. Second, because of the lower energy density of renewable energies, production takes place in a far higher number of generation units with smaller power. These smaller generation units feed into lower network levels and can change the transport direction of electricity. Rooftop photovoltaic systems particularly often feed into the lowest network level. Resulting bidirectional power flows change the role of the distribution system and impact grid operation [1].

But not just the electricity supply structures are changing. Increasing installations of electric vehicles, heat pumps and air conditioning lead to both an electrification of the transport and heat sectors and emerging new patterns of demand [1].

Sector coupling enables decentralized renewable energy to be used in other sectors and thus to reduce the impact on the distribution network. Storage units in the heating and transport sectors (e.g. batteries in electric vehicles) make it possible to absorb fluctuations in renewable electricity generation. Heating systems are comparatively sluggish and prices for heat storage units are low. Coupling with heating systems offers great opportunities to take in the fluctuation of electrical generation of photovoltaic and wind power if needed [4].

This paper presents the results of the IKB-Smart-City-Lab project where a future energy system was replicated in a smart district within the premises of the utility in Innsbruck (IKB AG). It demonstrates how sector coupling can help to integrate distributed energy resources (DER) into the energy system and how energy flows can be managed.

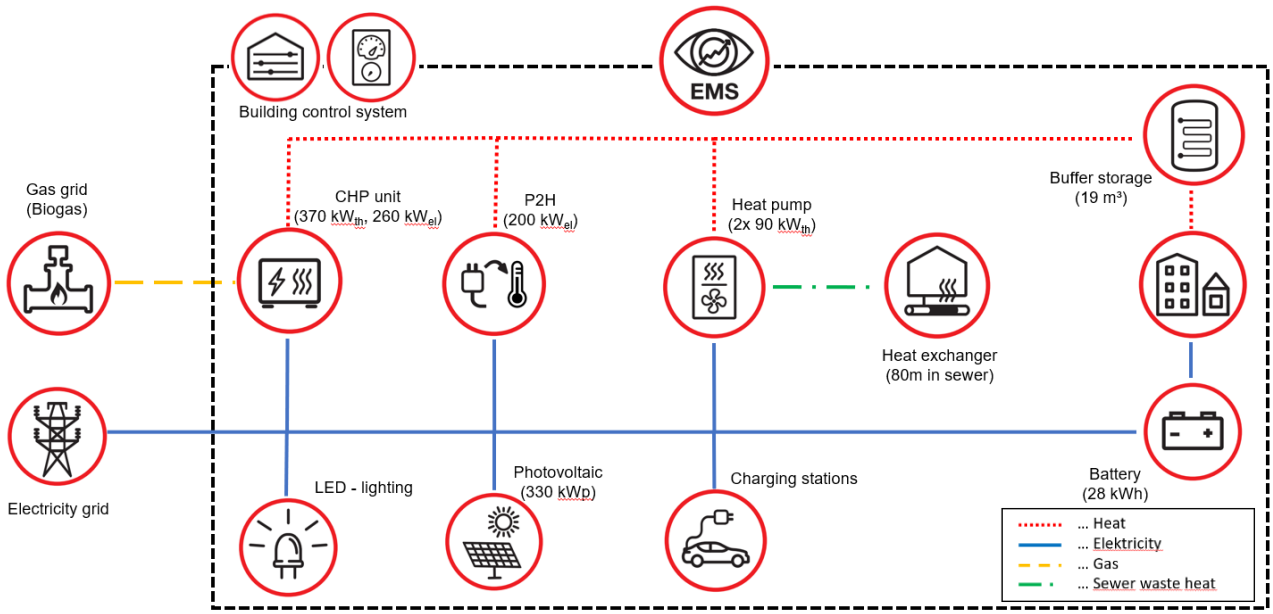

Fig. 1: overview of implemented measures in the IKB-Smart-City-Lab

Methodology

2.1 Smart District

Within the IKB-Smart-City-Lab project a smart district was developed within the premises of the utility of Innsbruck. One of the goals was to fully cover the energy demand with renewables. Therefor the pre-existing gas boiler was substituted with a power to heat system, a Combined Heat and Power unit (CHP), two heat pumps and a buffer storage. In addition to that, photovoltaic systems with a power of 330 kWp, battery storage and charging stations for electric vehicles were built. Lighting was mostly substituted by LED lighting. Figure 1 gives an overview of the implemented measures and the interfaces between the different sectors.

One relatively new technology makes it possible to use warm sewage water as a heat source for heat pumps. In one of the sewage channels in Innsbruck, approximately 1.2 meters wide, 80 heat exchanger modules were installed. This 80m long heat exchanger with an area of 57m² delivers an output of 150 kW before it enters the heat pump. The heat exchanger system consists of several interconnected stainless steel modules with an integrated water circuit. Temperature differences between the water circuit and the warm sewage water allow the heat to be transferred without the wastewater and the water in the heat exchanger system touching or mixing. An additional compression through electrical energy in the heat pumps enables a thermal output power of 200kW. Heat exchangers were installed on one of the main sewage water collectors of Innsbruck, which raised concerns about how it affects sewage temperatures and therefor treatment processes in the wastewater treatment plant. Results show that treatment processes have not been influenced by the minor temperature changes of the sewage water induced by the heat exchanger.

The CHP unit is connected to the local gas grid and the gas is purchased at a biogas tariff. It allows production of electricity and heat at the same time which makes it run with an average efficiency of about 93%.

2.2 Energy Management System (EMS)

The main goal of the project was the development of an Energy Management System that can operate a cross-sectoral energy system. This system was developed together with the companies “World-Direct eBusiness solutions” and “BEST – Bioenergy and Sustainable Technologies”.

In order to manage energy flows in the Smart District the EMS must decide:

- when to switch on/off producers,
- at which power levels producers should run,
- when to charge/discharge buffer storages and batteries
- and when to buy/sell how much energy from grids.

An optimal operation strategy depends on an unknown future demand, fluctuating yield from renewable sources and unknown future energy prices.

Predictions for energy prices, temperature and global radiation is bought from external data sources and serve as

input for the optimization algorithm. Using weather forecasting and previous consumption data, a self-learning algorithm calculates the future demand of the smart district and the future production of the photovoltaic systems. Based on this future demand and energy prices, a Multi-Linear Regression for continuous or discrete Markov Chain is used for switching processes. Information on when to switch on/off producers and at which power levels they should run are sent to the process control system (Underlying Programmable Logic Controller (PLC)) where the signals are further distributed to the low-level controllers of the single technical unit. Output of this optimization process is a production schedule with maximized revenues and minimal CO_2 emissions. The structure and process of the optimization are shown in figure 2.

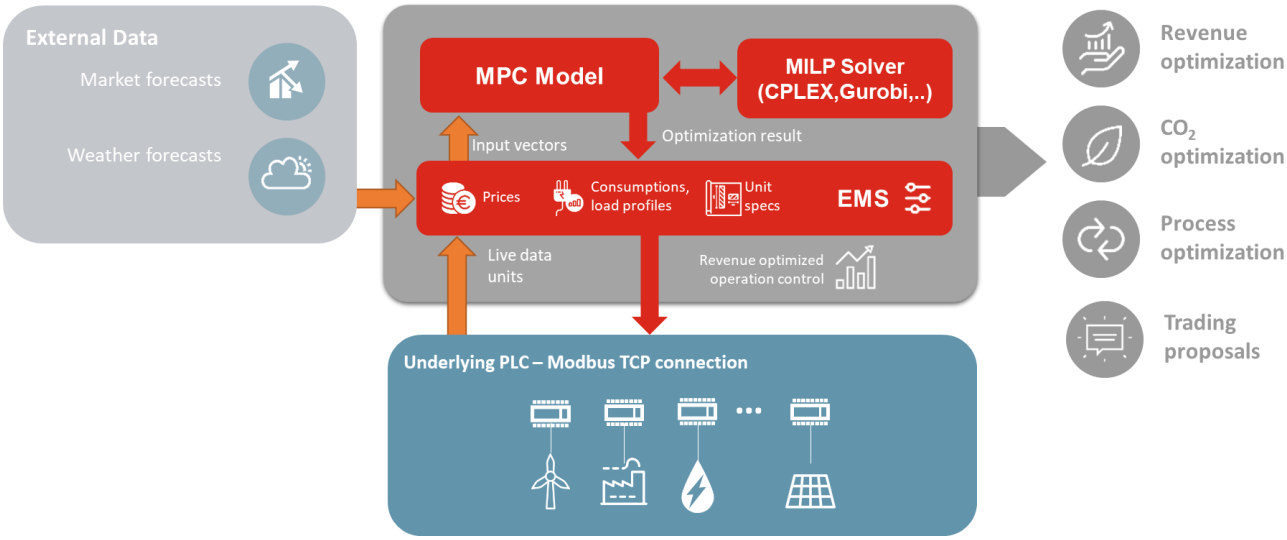

Fig. 2: Hybrid grid optimization – operation control

Results

Data analysis

A hybrid grid is a complex system incorporating several different elements. Many controllers, sensors and metering points for heat, electricity, water, gas, temperatures, pressures, flow rates etc. had to be installed as it is controlled by an energy management system. Data collection over a period of several months was necessary to achieve optimized results.

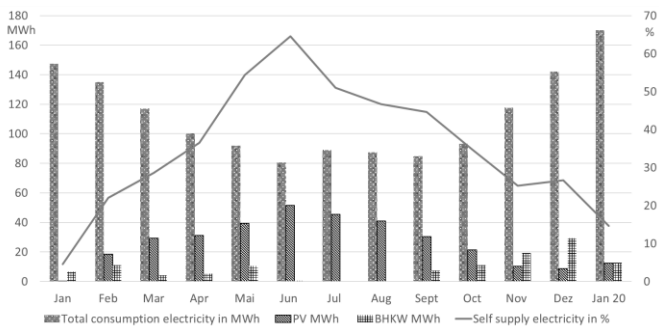

Fig. 3: Balance of energy generation and consumption for 12 months

The electricity generation of the IKB-Smart-City-Lab (Smart District) is depicted in Figure 3.

The optimum orientation of the installed PV-modules allows noticeable yields. Only in the winter months, where shading by the nearby mountains and fewer hours of daylight reduce the hours of direct solar irradiation, less electricity is produced. However, from the months February to October, self-consumption rates up to more than 60% have been observed. The mean annual self-consumption rate is at about 37%.

In an ideal scenario energy consumption and production would be distributed more evenly across seasons. However, as this is not the reality consumption of electricity in the smart district is much higher in the winter months. An opposite picture can be seen in the summer months when PV-productions peaks but is still hardly sufficient to supply the whole location. Larger battery capacities would be needed to shift PV-production to the evening hours during this season. When the CHP is not operated during the summer because there is no demand for heat, the solar power generation is sufficient to cover 60% of the electricity demand (e.g. June). The seasonal fluctuations can be mitigated when systems are combined in a calculated manner.

Even though the district where the hybrid grid is located has a high energy demand, the data has shown that during certain days 100% self-supply was possible due optimized operational schedules of the single producers. One advantage of the smart district is that the different buildings energy demands can be cumulated and organised as one big consumer.
The annual balance of both thermal and electrical energy is displayed in figure 4. Generation and consumption are contrasted respectively. 100% of thermal energy demand comes from self-sufficient renewable heat generation and integrated solutions. PV plants are mainly operated for electricity generation, while the CHP primarily generates heat and only secondary electricity. However, as the dashed line indicates, the self-generated electricity is (divided over the period of a year) sufficient to cover not only the electricity demand of the heat pumps and the power-to-heat plant but also a remarkable share of the consumption of the buildings within the smart city area. It must be mentioned that there is a seasonal imbalance of generation and consumption.

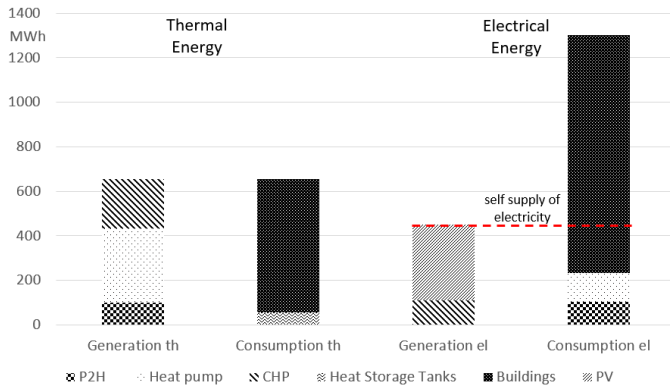

Fig.4: Generation and Self-consumption in the Hybrid grid over 12 months

These results show how energy efficiency can be fostered by combining PV power with consumers like heat pumps or power-to-heat, using surplus electricity to generate heat. One of the most relevant parameters, therefor, is the size of the heat storage.

The energy management system is interconnected with the process control system (PCS). The PCS interacts with each local controller of the individual generation units. During the launch of the hybrid grid and the EMS, several errors were reported daily until the system was better optimized. Exchange and interconnection of the multiple power and heat generation units within the PCS and the energy management system is highly complex.

Results show that determining a meaningful single value for the state of charge of thermal storages is difficult, even with the forecasted temperatures. Fluctuating temperatures lead to changing parameters, and even minor temperature changes have demonstrated impacts. Temperature forecasts are crucial, as incorrect predictions lead to false heat demand forecasts. This results in improper allocation of storage reserves.
Large workshops on the premises of the Smart-City-Lab require fan heaters running on hot water intake temperatures up to 80°C to properly heat their massive footprints. In contrast, the rest of the Smart-City-Lab site would only need water at lower temperature levels to meet its own heating demands as there are only compact office buildings connected. Without the need to heat the workshops, lower water flow temperatures would be possible. This would greatly increase efficiency.

4 Conclusion

In this project, a hybrid grid with sector coupling was installed and analysed. The focus was on shifting the needs for heat production and heat consumption. Nevertheless, the scope of the hybrid grid was to combine decentralised energy generation systems in an efficient way, utilising beneficial cross-sectoral effects. Having an adequate amount of sustainably produced electricity to supply the heat generation plants is a successful achievement within this project.

The main goal of the project was the development and implementation of an energy management system to fully automate and optimize cross-sectoral energy flows. Based on generation- and consumption forecasts, an algorithm creates optimized schedules for the individual units and storage facilities. This saves 310 tons of carbon dioxide emissions annually compared to the previously installed natural gas fired heating system.

Complexity and costs do not allow for easy replication mainly because the software architecture must be adjusted for each location and system. Surprisingly, one of the biggest challenges of the project was not technical development and implementation of the algorithm, rather the project was plagued by high maintenance requirements of the single technical units.

In 2020, a smaller project was initiated by IKB at two housing development locations. At these new sites, a similar product is tested in order provide a comparison to the results of the Smart-City-Lab. One aspect examined will be on how much intelligence is crucial to have a hybrid grid running smoothly. If results show potential for higher self-supply and system reliability at economically feasible costs, the project should be further expanded. With such expansion in mind standardization to easily include different producers and consumer will be the key for successful implementation

The Smart-City-Lab demonstrates how fluctuating renewable electricity generation, mainly out of PV-plants, can be flexibly transferred in the heating sector by using large buffer storages. This leads to higher self-consumption rates and reduces the negative effects on the

distribution grid. However, this mainly applies to the winter months. Seasonal storage technologies like the production of green hydrogen are necessary for the flexible, cross-sectoral use of renewable electricity production in the summer months.

Necessary interconnectivity of units, vulnerability that comes with a higher degree of digitalization, as well as the dependency on energy management software systems are key aspects for the operational success of an intelligent energy system.

Sector coupling and hybrid grids are necessary measures for integrating large amounts of renewable electricity generation in the existing energy system. They are crucial for the decarbonization of energy systems and for achieving climate goals set by the European Union and the individual countries. As mentioned by Arabzadeh et al. [5], cities play a particularly major role in achieving a decarbonized energy system as it was done in Innsbruck with the IKB-Smart-City-Lab. The results of the project motivate further actions in implementing intelligent energy management software solutions in sector coupling.

5 Acknowledgements

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