HOW TO OPTIMISE THE OVER PRODUCTION OF PV ELECTRICITY INTO THE GRID WITH THE IMPLEMENTATION OF ICT DEVICES THE ORPHEUS PROJECT

SUBJECT 6: PV APPLICATIONS
SUBSECTION 6.1: PV AND SMART BUILDINGS

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ABSTRACT

The OrPHEuS project elaborates hybrid energy network control strategies for smart cities implementing novel cooperative approach for the optimal interactions between multiple energy grids. The OrPHEuS project aims at optimising the synergies between multiple energy grids by enabling simultaneous optimization for individual response requirements, energy efficiencies and energy savings as well as coupled operational, economic and social impacts.

The project will investigate the implementation of the control strategies on specific use cases scenario in two demonstration sites located in the City of Skellefteå in Sweden and in the City of Ulm in Germany. The operational focus of the project is the cross-domain coupling of energy infrastructures in order to increase energy efficiency through energy transformation and grid coupling. In particular, the project researches scenarios for transition between energy resources and flexible infrastructures e.g. along Power-to-Heat processes. It investigates the balancing of fluctuating renewable energy generation against the flexibility in supply, demand and storage capacities within the power grid and via process coupling across energy networks. The project will look on technical as well as socio-economical aspects considered as multi-dimensional strategy framework.

With respect to the hybrid energy characteristics, both demonstration sites are quite distinct. At the demonstration site in Sweden, the reduction of vertical production (driven unsustainable with fossil fuel) is in the centre of the targeted control strategies. Looking on the specifics of the Ulm testing site, the major issue is the balancing of the high penetration of solar generation under today's operation with a pre-dominant operational challenge for PV control. The key focus is to define control strategies to increase the intake of the energy supply from PV on the roof generation into the grid while maximizing the benefits for the low voltage power grid.

The 29th European Photovoltaic Solar Energy Conference and Exhibition (EU PVSEC) in Amsterdam represented a unique opportunity to present information on the methodology adopted by the OrPHEuS Consortium to optimise the synergies between multiple energy grids. On the occasion of the EU PVSEC the OrPHEuS Consortium focused the project presentation on how to optimise the PV electricity production with the implementation of Information and Communication (ICT) devices at the Ulm demonstration site, the Test area in Einsingen, which presents an over production of the PV electricity of 230 MWh annually. The average annual electrical consumption is around 1000 MWh.

1. Introduction

The OrPHEuS project elaborates a 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 can be 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 (Fig.1).

The control strategies based on a *Cooperative Coexistence* design aim for reduction of operational costs and ensuring robust business models and market design with high renewable resources penetration and customer satisfaction across the hybrid energy networks. The Cooperative Control Strategies will be designed to achieve improved energy utilization levels and power balancing control throughout all energy network operations. The aim of the "cooperative" nature of the control design targets on one hand a technical optimization within and across the involved grids linked on the coupling points, and on the other hand to provide a win-win market situation to exploit technical benefits with the economical and societal benefits for all involved stakeholders.

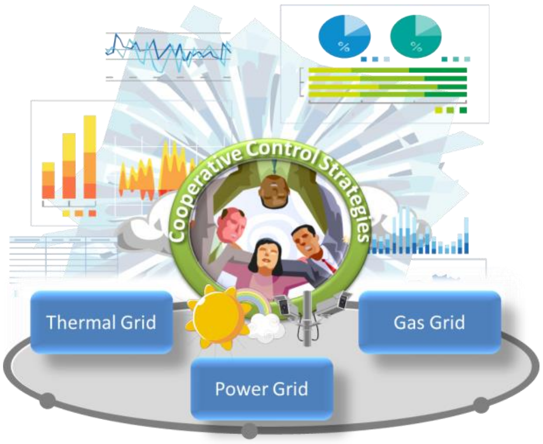


Fig 1. OrPHEuS Project Business and Technological Concept view

Within the OrPHEuS project the following Cooperative Coexistence concept will be based on:

- an interactive inter-play of smart metering in multiple energy grids on nodes for production,
- consumption and physical grid system coupling, context sensing and weather forecast, its comprehension with information from existing systems as well as for extended system information through co-simulation of the considered hybrid energy networks,
- modelling of the correlations between the energy systems and context systems (like weather/climate, human interaction through industrial processes) and its resolution through system prediction and cooperative control strategies across all energy systems.

Fig. 2 visualizes the OrPHEuS Cooperative Coexistence scientific concept. The project creates the advancements over today's existing situation by an evolution of the quality of the interactions of the energy systems by Advancement 1 with increasing the quality of the cooperativeness followed up with Advancement 2 with expanding the business models for a further quality level in cooperative integration realizing the OrPHEuS project target.

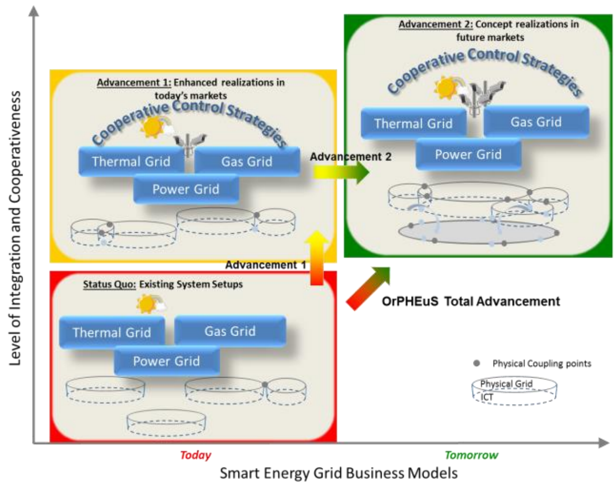


Fig 2. OrPHEuS Project Results mapped on parameters for Cooperative Control Strategies and business extensions

In detail, the novel aspect of the OrPHEuS project beyond the state of the art is founded on the following two advancements, providing a strong contribution in optimizing hybrid energy grids in smart cities:

Advancement 1: Enhanced realization of today's markets: Starting from existing physical coupling points of multi domain distribution energy grids and within today's business models (i.e. today's economic interactions of all market participants involved) both enhanced physical coupling options and enhanced control strategies are exploited. In particular, this includes among others: (i) definition of the technical needs across the energy distribution grids implied and corresponding functionalities of the grid coupling devices, (ii) investigation of the level of support of "smart" infrastructure (metering, sensors, ICT infrastructure) for operation control, (iii) adaptation of the monitoring systems of the existing energy grids with new advances available in the ICT Machine-to-Machine field (iv) incorporation of information like climate data to the different energy grids needs for different time resolutions to support enhanced hybrid energy grid control.

Advancement 2: Concept realizations in future markets: While the current business world implies certain restrictions to the interplay of various stakeholders, the OrPHEuS project will reach beyond the boundaries of existing business models by exploring opportunities for Cooperative Coexistence and System integration. In particular, among others this implies advancements in terms of (i) decision support system design for an energy control platform integrating multi-utility optimization based on different business models, (ii) definition of algorithms for control decisions capable of load balancing by optimising multiple utilities demand and supply preferences respecting independent operational needs and interactive operational control and energy storage opportunities, and (iii) definition of control algorithms and related services for providing incentives to integrate single and aggregated "prosumers" into the comprehensive cross-domain optimization protecting at the same time their privacy and confidentiality preferences.

2. Implementation and Results

2.1. Demonstration site Ulm

Looking on the specifics of the Ulm testing site, the major issue is the balancing of the high penetration of solar Photovoltaic (PV) generation under today's operation with a pre-dominant operational challenge for PV control. The key focus is to define control strategies to increase the intake of the energy supply from PV on the roof generation into the local community while maximizing the benefits for the low voltage power grid.

The content of this paper focuses on the methodology elaborated by the OrPHEuS Consortium how to optimise the strategies for grid intake of PV electricity surplus production through exploitation of Information and Communication (ICT), focussing on the Ulm demonstration site, specifically the Test area in Einsingen.

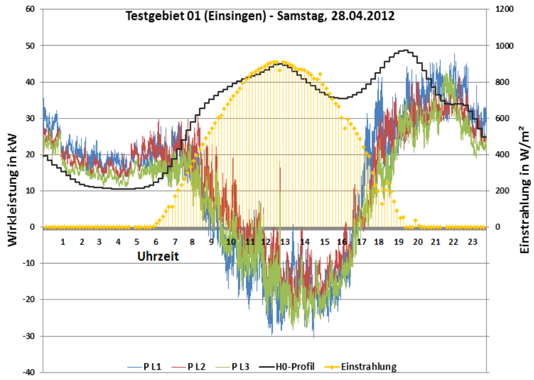
The Test area in Einsingen covers the area of one low voltage grid transformer in the village of Einsingen located in the City of Ulm, Germany. The test site contains a single secondary substation transformer with a nominal power of 630 kVA (10 kV/0.4 kV). 134 houses are attached via eight feeder lines to this transformer. The houses are single family houses or multi-family houses as well as a couple of older agriculture estates with living house, estate building and cot. The average annual electrical consumption of the households is around 1000 MWh. The PV generated over production, without self-consumption, is over 230 MWh annually while the demand energy over the transformer is around 700 MWh. This energy is fed back to the medium voltage grid. At the moment 21 PV systems with a summarized nominal power of 233 kWp are installed. The single system powers range from 2.2 kWp to 47.84 kWp. This equals to a penetration rate of 37 % of the transformer nominal power.An analysis of solar roof potential has been conducted.. These analysis results are information about irradiance including shadowing effects, declination and inclination of each roof with a yearly irradiation more than 750 kWh/m². An experimental data acquisition device is installed at the transformer station since April 2011. This device records the phase voltages and line currents on each of the 8 low voltage feeders. The time resolution is one second. Over one year of load flow data of this local grid are available. Detailed information about the Test Area Einsingen is available in the following figure 3.

Ulm-Einsingen		2013	2050
Households		134	150
PV systems		21	150
PV power	[kWp]	233	2.000
Load	[MWh]	1.047	1.100
PV energy	[MWh]	230	2.200
PV share (year)		25 %	200 %

Fig 3. Airborne image of the Test area in Einsingen in Ulm, Germany, with the position of the PV systems and the transformer (source: HS Ulm)

2.2 Monitoring

In Ulm at the test site monitoring was also performed during weekend days with a high irradiance. Figure 4 shows the measurement results of the three phases during a Saturday with high irradiance. The load profile would perfectly match the electricity production from the PV system, however, the measurement show the reverse power flow of the three phases at the low voltage transformer because of the high PV penetration into the low voltage grid.



- Black line indicates the average load curve of the 134 households
- Yellow background quarter hourly solar radiation at the test site
- The load measured at the low voltage transformer drops during daytime due to feed in of solar power (1 second resolution)
- Between 9 AM and 5 PM load flow is reverse at the transformer

Fig 4. Power flow at the LV transformer (source: G.Heilscher, H.Ruf, HS Ulm)

In Germany, curtailments occurred for RES due to security reasons 6 days in 2010 and 142 days in 2013. However, the electricity generated by RES should have the "feed-in priority"! PV curtailment cannot be a solution nowadays and neither in the future, when the global PV penetration is expected to reach 16% in 2050 (Figure 5).

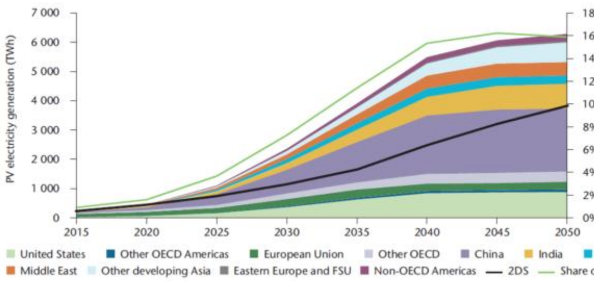


Fig 5. Increasing PV Generation until 2050 (source: IEA Report)

To avoid the curtailment of the power plants in the OrPHEuS project various solutions to use the electricity in other domains were developed. In order to deal with the PV curtailment at the demo-site in Ulm the 'Green Community' control strategy has been defined. For this purpose also the different coupling points were defined.

2.3 Coupling Points

Therefore, we have defined coupling points which are physical elements that connect two different energy domains and identify a hybrid energy grid (see Fig. 6).

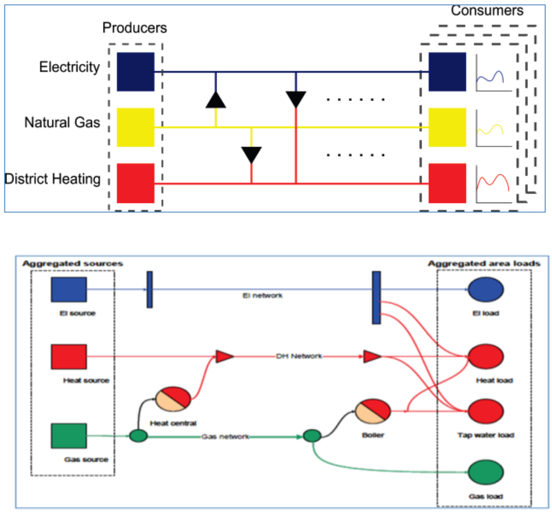
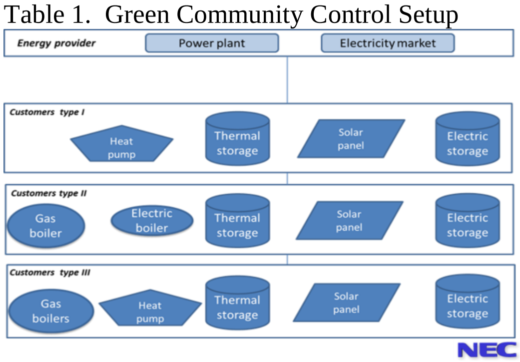


Fig 6. Different energy domains and the way of interaction between them (source: TUW-EEG)

2.4 Control Strategies

The control strategies for different system setups have been developed in the project however, as we focus on the demosite in Ulm only control strategy of 'Green Community is relevant. As mentioned before, in Ulm the focus is on the 'Green Community' control strategy where the customers are prosumers. They are owners of PV systems, heating devices and both electrical and thermal storage units (table 1).

Table 1. Green Community Control Setup



In the 'Green community' Control strategy the central control (server) performs the optimization and distributes storage requests to the nodes (prosumers) via communication infrastructure (Fig. 7).

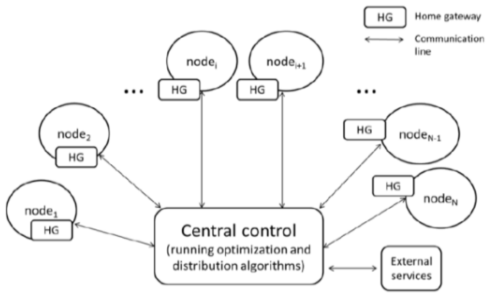


Fig 7. Central control running the optimization (source: NEC)

Figure 8 illustrates the data needed for an optimization over the planning horizon. The idea of this approach is to exploit demand/supply variation across customers and their storage resources in order to improve local load balancing performance. For the control algorithm, we will need aggregated forecasts of supply and demand, while rough forecasts for each participating household would help improve performance of the control algorithm (Fig 8).

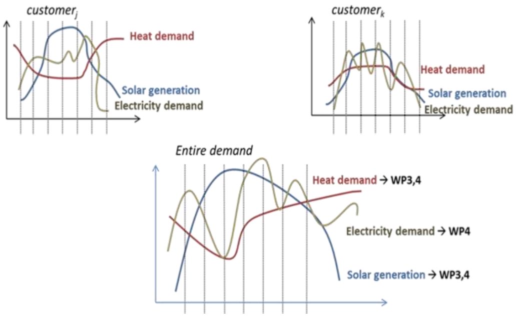


Fig. 8. Predicted data needed (source: NEC)

For the control strategies various data inputs are needed to optimize the control and further develop the strategies. Fig. 9 illustrates examples of the input data needed.

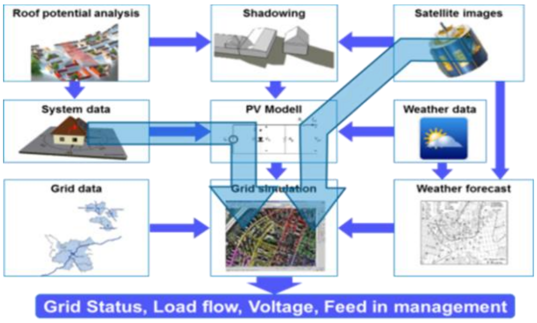


Fig 9. Input data required (source: DLR, HS Ulm)

3. Conclusions

In the setup "Green communities", we target the prosumers, meaning the distributed resources provided by end-customers with their own energy supply installed as a renewable energy system. At our demo sites in Ulm, these customers have roof-top mounted solar panels. Though the customers have their own energy supply, an energy supplier exists within the setup as a back-up energy source in the case that additional energy is needed.

Focusing on the "green community" control strategy, this is done by:

- Simultaneous control of multiple energy systems through ICT
- High resolution predictions of demand of multiple energy carriers and production of uncontrollable energy sources
- Interconnection of previously unlinked systems such as heat demand with electricity overproduction in order to use locally renewable energy and balance the local energy load with renewable energy generation avoiding curtailment of RES or PV.

To conclude, the OrPHEuS provided practical solutions to better balance surplus of PV electricity generation avoiding PV curtailment while maximising the benefits of local low voltage grid.

4. Acknowledgement

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5. Disclaimer

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