Keynote

From Smart Grid to Universal Grid – Generation, Storage and Communication in Hybrid Networks

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Abstract – Energy systems are hybrid networks, linking different forms of energy sources and loads. With growing amounts of renewable generation in the energy system, the hierarchical and centralized structure of the energy system gets increasingly transformed to a decentralized and distributed structure. The concept of Smart Grid is driven by these structural changes and provides solutions for the challenges resulting from the integration of distributed renewable energy sources into the system. The Universal Grid takes the concept of Smart Grid one step further as it exploits the fact that the hybrid networks of the future will be more closely interlinked. Communication is key to making these networks and concepts work, as it bridges the gap between different parts of the hybrid system.

1. Introduction

For the search term „Smart Grid“, tens of millions of web pages are returned. For „Universal Grid“, the number is less than thirty thousand. These numbers indicate the necessity for more detailed definition and explanation: With Smart Grid, each of us tends to have their own definition with focus on a different aspect, and many might not have heard of Universal Grid before.

Our energy systems are hybrid networks, consisting of parallel infrastructures for different forms of energy, e.g. electrical energy, gas and heat. At certain points in the system, these infrastructures are coupled, for example at a gas fired co-generation power plant producing both electrical energy and district heating. Certainly, the power plant is located in an area where sufficient gas supply is available, electrical energy can be fed to the transmission system, and district heating can be efficiently used. However, in the traditional hierarchical energy system these "coupling points" are of significant size, but limited in numbers. As more and more renewable generation gets integrated into the energy system (renewable generation tends to be decentralized and comparably small in amounts, but larger in number of individual units), the traditional hierarchical structure is transformed into a distributed and decentralized setup – and this is one of the main drivers for the Smart Grid. Basically, the Smart Grid developed from the application of automation and control features being used in the transmission network for decades to the distribution network. It is not that most of these applications weren't known of before; it just was not necessary or too costly to use them at the lower voltage levels, where sizes are smaller by three orders of magnitude but numbers are higher in the inverse ratio. However, this changes as the hierarchical structure with only few centralized power plants gradually gets replaced by a distributed structure with scores of decentralized power generation units. The Smart Grid provides the solution for challenges for the electrical energy system that are caused by this transformation. The Universal Grid extends this strategy and takes it even one step further by taking advantage of the fact that the coupling points for different energy sources are subject to the same transformation.

Renewable energy sources tend to be more volatile and rather refined methods for prognosis of their generation pattern are available and yield acceptable results (Figure 1), but they cannot be controlled in the same way as thermal power units.

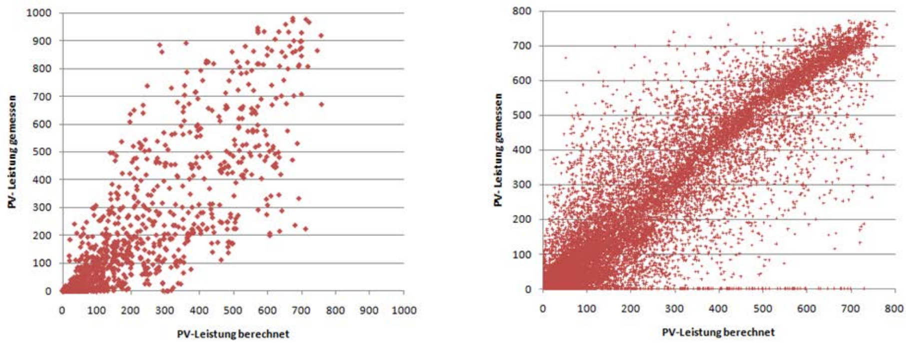

Figure 1. Comparison of actual PV generation ("PV-Leistung gemessen") and PV prognosis ("PV-Leistung berechnet") taken from [1]

Thus, storage will become increasingly important to balance out discrepancies between generation and load. Recent studies show that for a 100% renewable power generation scenario, existing storage capacity using conventional energy storage technology (i.e. pumped hydro) is way too small [1]. This means that new storage technologies, using conversion of energy carriers and creating additional coupling points between the different energy networks, are strongly required. In essence, Smart Grid is the solution to the distributed and decentralized renewable generation related to power, while Universal Grid provides answers in terms of energy. Communication is required for both concepts to enable and achieve optimum results.

2. Power and energy

An often seen trope is: “A modern wind turbine with 2 MW rated power generates the electrical energy required for 1.250 households or 4.000 inhabitants. Thus, one single wind turbine can power a small village”. This statement is not exactly true, but that happens if power and energy are mixed up. Power is the derivate of energy, i.e. energy per time. Energy is the integral of power, i.e. power multiplied by time. Consequently it is feasible that a modern wind turbine generates the same electrical energy over a certain time period, which is consumed by a certain number of households over that exactly same time period. But hardly ever will the power generation of the wind turbine exactly match the power consumption of these households. Most of the time, it will not even be close. However, our energy system works in such a way that power generation and load must be balanced all the time. Any larger deviation that is not balanced out within a few seconds results in a crash of the system, a.k.a. blackout. Thus, one single wind turbine alone cannot power a small village. Even if some part of the consumption may be managed (“demand side management”) in order to improve the balance, an additional part of the system has to take care of the rest. For a load flow calculation, this part is called “slack”. For the village demand and the wind turbine and probably some photovoltaic (PV) generation, the slack would be a rather big and fast generation and storage device of any sort. Figure 2 shows the requirement for such a storage device in a (fictional) setup of Austria being 100% powered by wind turbines and PV.

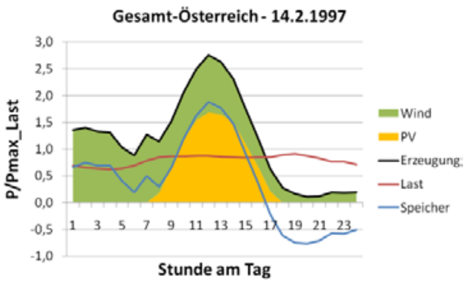

Figure 2. p.u. daily load curves (“Last”) and wind generation, photovoltaic and required storage (“Speicher”) in a (fictional) Austria 100% powered with renewable energy sources. [2]

Generally the rest of the energy system, including the thermal power plants, acts as slack. What happens is that, with an increasing number of volatile renewable energy sources, being a slack becomes increasingly difficult for the rest of the energy system [3]. When relying on the remaining thermal power plants becomes less of an option, any ideas for big and fast generation and storage devices become increasingly interesting and important. Storage of electrical energy itself is hardly possible. The electrical energy stored within the electrical energy system, e.g. in energized power lines or magnetized transformers, is negligible. The only significant quantity of energy stored within the system itself is given by the spinning masses of rotating electrical machines, i.e. generators and motors connected to the grid. All other energy storage relies on energy conversion, e.g. pumped hydro or “power to gas”. The Universal Grid, as defined in the previous chapter, features scores of these energy conversion points and thus the possibility for both short term and long term storage.

Again, communication is crucial to link these conversion points together to become the big and fast generation and storage device required for our future energy system.

3. Communication in the Universal Grid

Above, the drivers and requirements for the Universal Grid have been presented. Figure 3 shows an overview of what the Universal Grid looks like schematically: A hybrid network consisting of electricity, hydrogen, natural gas and heat networks, each with their independent generation, loads and storage, but closely coupled on a local level, i.e. in the part of the network usually described as "distribution network".

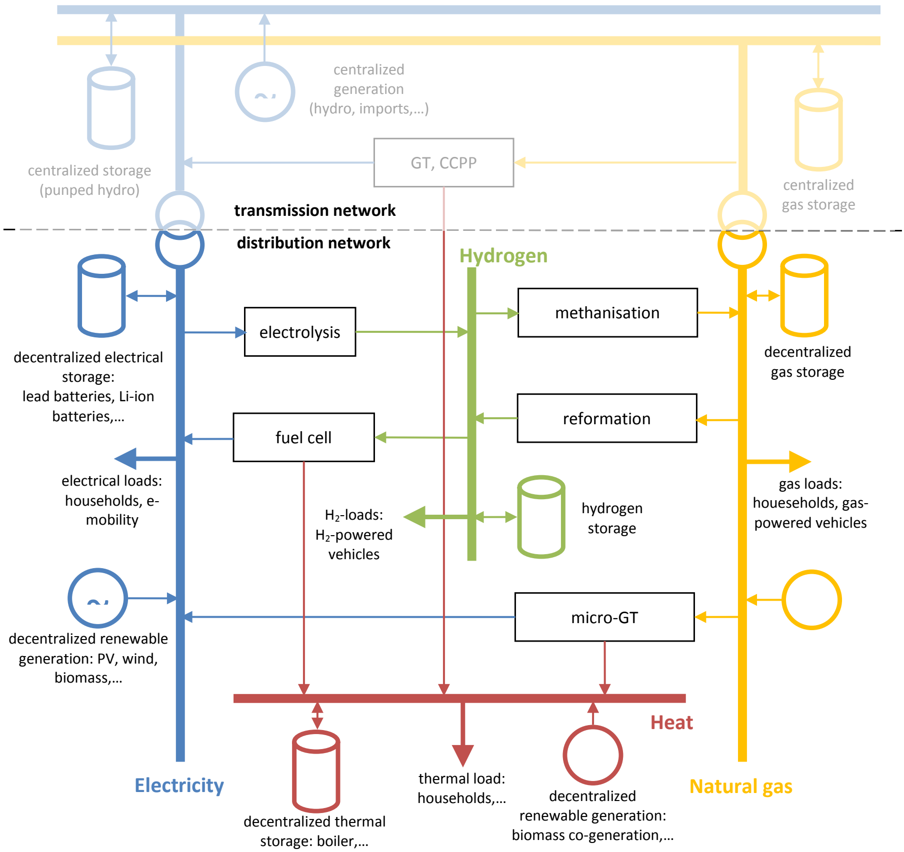

Figure 3. The Universal Grid as envisaged in the project "SYMBIOSE" jointly carried out by Vienna University of Technology, ENRAG and VKW AG.

It should be noted that this coupling is bi-directional. Hydrogen can be generated using electrolysis but also used to generate electricity in a fuel cell. “Power to gas” is a concept to synthesize methane using excess energy in the electricity network, which can then be stored for long time periods, and subsequently used to generate electrical energy in gas turbines again. The conversion technologies, their efficiency and related economic aspects are currently subject to immense research.

An electricity network comprises two intrinsic communication channels: Frequency and voltage. Frequency is a global parameter, identical at all points of the system, synchronously coupled, and depending on the balance of load and generation within the entire electrical system. Voltage, on the other hand, is a local parameter, dependent on the conditions at a specific part of the system. However, both parameters are available at any point of the electrical energy system and thus offer a robust signal for any automation and control concept. This is why electrical engineers, especially protection specialists, are rather hesitant to base their backup concepts on any additional communication channel, which does not offer the same robustness and thus generally is only use for optimization.

However, it is obvious that the Universal Grid, locally linking together the different parts of the hybrid energy system, does not feature such intrinsic communication channels. While each of the parts of the hybrid networks may offer a robust means for safe and secure automation and control, the Universal Grid itself will only work with communication channels bridging the gaps between different parts of this network.

4. Outlook

Smart Grids are becoming reality. Today, the energy system is struggling with integrating more and more renewable energy sources. With more distributed generation coming into the networks, distributed storage and demand side management are getting increasingly important. Especially electric vehicles offer a huge potential for distributed storage and demand side management. In the near future, the Universal Grid, a hybrid network of electricity, hydrogen, gas and heat that is multi-directionally interlinked on a local level and merged via communication, will offer the storage and demand side management capabilities required for a sustainable energy system powered by renewable energy sources.

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