Energy storage and grid for electricity, gas, fuel and heat –
A system-wide approach

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Kurzfassung

Energiespeicher und Netze für Strom, Gas, Treibstoff und Wärme –
Ein systemübergreifender Ansatz


Zur Bewältigung der Herausforderungen ist ein systemübergreifender Ansatz gefragt. Verschiedene Stromerzeugungstechniken und Speichersysteme müssen effizient, flexibel, wirtschaftlich, hoch verfügbar und umweltfreundlich zusammenarbeiten. Es werden Beispiele beschrieben, in denen verschiedene elektrische Netze, Fernwärmenetze und Netz für Stoffe wie CO₂, H₂ etc. zusammenarbeiten können. Die Methanolproduktion in Verbindung mit einem Kohlekraftwerk ist ein Beispiel für einen integrierten Ansatz, der folgende Vorteile bietet:

- Nutzung indirekter Speichereffekte für Strom
- Möglichkeit zur Nutzung von Strom aus Erneuerbaren aber auch
- von konventionellen Kraftwerken mit den Vorteilen der Kraft-Wärme-Kopplung
- Möglichkeit zur Reduzierung der Mindestlast die ins Netz geht und damit schnelle Reaktionsfähigkeit bei fehlendem Kraftwerkspotenzial
- verringerte CO₂ Emission durch Mehrfachnutzung des anfallenden CO₂
- Integration des Transportsektors und der energie-intensive Industrie sowie Hilfestellung bei der Erreichung ihrer CO₂-Reduktionsziele.

Der vorliegende Beitrag gibt einen Überblick über die verfügbaren Techniken und zeigt die strategischen Möglichkeiten eines solchen Vorgehens.

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Background

The share of renewable energy sources (RES) has been significantly increased in the worldwide energy mix. Ambitious projects for RES electricity generation are planned by energy policy; even though they cannot generate electricity 8,760 h/a. There are minutes, hours and days, where wind is not sufficiently blowing and sun is not shining enough. Although there are hours when full electricity demand can be covered by RES, there are still hours and days when other sources of energy have to support in order to cover the demand. This can be accomplished by flexible conventional power stations as well as by energy storage systems. Such energy storage systems have to be technically and especially economically developed in order to be able to compensate for the energy arbitrage in different time scales and to avoid energy curtailment. Germany is in the front run of RES penetration increasing significantly the installed RES capacity during the last years. Figure 1 presents the overall electricity production from RES in Germany, which clearly highlights the inherent problem of RES as regards their availability, even if their installed capacity is significantly increasing.

The future energy system in the EU28 still requires large amounts of conventional power plants to assure grid stability and electricity supply. According to Mitsubishi Hitachi Power Systems Europe GmbH (MHPSE), an installed capacity of conventional power plants of 300 to 400 GW is needed in the EU28. The operation of this conventional fleet harmonised with fluctuating RES must be based on the main criterion of the lowest minimum load capabilities of power plants while keeping the efficiency drop moderate. Without question, combined heat and power will play a role in the future.

In addition, energy storage systems have to be developed in a technically and economically efficient way. The back-bones of the future energy systems are grid extension, storage systems and flexible conventional power plants. Additional power plant capacity and storage capacity can be lower in case of extensive European-wide grid extensions.

Aside all resistance against any technology (“BANANA” which means “Build Absolutely Nothing Anywhere Near Anyone”), electricity is loved and although primary energy consumption will be reduced, electricity consumption is very likely to increase as more and more applications such
as electro mobility and other technologies require electricity, resulting in higher shares in final energy consumption. It can be observed clearly that there is a gap between vision and reality.

Options to bridge the gap between vision and reality

Therefore, a new commercial framework for conventional power plants is suggested. Combining conventional power generation – stand-alone and in industrial environment – with cross sectorial energy storage like power-to-gas, power-to-methanol or power-to-heat, could be the future. It can be shown that this new approach leads to a maximum of auxiliary services of conventional generation delivered to the grid.

The overall greenhouse gas emissions of conventional generation are minimised. In this approach, also a minimised electrical grid extension is needed resulting in reduction of electric losses over long distances but also in the avoidance of high-capital intensive technical solutions and at least increased acceptance. Therefore, the capability of the other grids like gas pipelines, transport fuel systems and district heating networks are involved. Long-distance energy transport in any kind will also be minimised. Cross-sectorial storage is able to bring the electricity source (generation) virtually closer to the sink (consumption).

Grid balancing service is maximised with minimised efforts. At least, this kind of coupling makes the complete grid capacity available much larger compared to isolated solutions thus requiring further consideration of “systems”.

Systemic approach

Stabilisation of the electrical frequency always has to be borne in mind. It is not a problem in case of a direct link between generation and consumption. But it needs attention, if generation and consumption are not balanced. Frequency has to be stabilised by other partners than renewables generating stochastically. Storage systems, conventional plants and the grids described can stabilise the electrical grid with their buffering capabilities. In the future a more systemic approach will be needed. Different kinds of generating and storage technologies have to work efficiently and economically together, being highly available and environmental-friendly at the same time.

Isolated generation can only survive in case of direct relationship between generation and consumption. In case of electricity being generated without a sufficient sink, storage options have to be used. This can be a direct storage solution such as pump storage or batteries. Another option could be an indirect storage solution, such as the transformation of electricity into a substitute natural gas (SNG) to store it in the natural gas grid or in hydrogen grids of the chemical industry. Furthermore, overproduced power could be used to produce fuels and products in stock for time, when RES do not supply enough power.

Flexible conventional power plants balance electricity demand. Therefore, electricity can be consumed in this systematic approach as needed. What does flexibility stand for in this context?

- generation of power on demand,
- high ramp up and down rates,
- optimised low minimum load to avoid frequent start-ups and shutdowns as well as simultaneous production of combined heat and power on demand.

For example, frequent start-ups, which are quite inefficient and thus not environmentally friendly, can be reduced by power-to-fuel technology. Electricity-driven water electrolysis can absorb excess electricity and produce hydrogen. Combined with captured CO2, it can be converted to gaseous or liquid fuels.

Combined heat and power is desired also in times of the so-called “Energiewende”, the energy turnaround, but this is sometimes troublesome considering missing electricity sink. The district heating network itself can act as thermal storage, if there is a time gap between electricity generation and consumption. Another opportunity to link electrical grid and thermal storage is power-to-heat in district heating networks, meaning that electric energy is converted to thermal energy during off-peak hours.

Power-to-power storage technologies could be an additional option. Accordingly, they have to be further developed to combine optimum capacity and time responses, to be integrated into the generation systems and different grids.

Considering these effects it is trivial that it is no longer sufficient to consider the individual elements of the electricity generating system but the entire system with generators of all kinds of grids and consumers. Or to say it in other words: The systemic approach is a necessity.

Even more examples can be found, how different electrical grids, district heating networks and grids of different chemical products can cooperate. At least electricity generation and process industry will be directly linked. This combined partners and systems could be strong partners of the “Energiewende”.

Methanol as an option

Why is methanol discussed? Power-to-liquid is competing with power-to-gas and against hydrogen, which are other options in the overall power-to-fuel concept, where electric energy is converted to chemical energy. In comparison to the investment for methane and methanol production to that of pure hydrogen production in power plants, additional equipment is needed for capturing CO2 and also catalytically converting it to fuel. The production of pure hydrogen, which is as well part of the synthesis of methane and methanol, is less capex and opex intensive, but there are specific considerations raised for the market of the final product. There are many technical risks to safely turn to a hydrogen economy, while there is a lack of infrastructure leading to more capex intensive technologies for using hydrogen as a product. Although, there are a lot of R&D efforts towards hydrogen technologies, it is unlikely that a hydrogen economy would compete in the near future with the large existing gas and fuel infrastructure, the wide range of end users and the market already developed.

What are now the benefits although the capex of the power-to-liquid process might in some cases be higher than power-to-gas, while using the same consumables and having similar efficiency? Taken as an example, the use of produced methanol in the transportation sector, no new logistics and transportation system is required and no new engines or concepts or fuelling stations are needed. The current infrastructure can be used with only some gasket changes.

The unstable political situation and the related natural gas supply favour the use of gas storages only for natural gas and not for electricity. To have additional storage capacity, methanol only requires some tanks and is not reflecting on limited natural gas storage capacities like methane and hydrogen. In addition, the use of the natural gas grid and storage for higher percentages of hydrogen is not recommended due to the leakage risk of the relatively small H2 molecules.

Conventional methanol is produced by using synthetic gas from natural gas or coal. Typically big production facilities with an output of more than 1 million t/a are erected close to natural gas fields. Big vessels later transport methanol to consumers. The power-to-methanol idea allows decentralised production in smaller batches closer to consumers so that long ways of transportation can be avoided.

For every tonne of methanol, 1.4 t of CO2 have to be separated from flue gases of power plants. This has to be compared to 0.6 to 1 t/methanol generated when producing methanol from natural gas with latest technology. If coal gasification is employed for conventional methanol production, CO2 emissions are even higher: 3 t/methanol.

The main components of a power-to-methanol plant (PTM) are electrolysis for hydrogen generation, CO2 separation after combustion (post-combustion capture = PCC) and catalytic methanol synthesis of CO2 and H2. The size of such kind of plant can be accordingly adapted to the size of the power plant at which it is integrated. The
size of the related electrolysis will be chosen depending on the typical operational capacity of the power station or based on surplus from renewables being available at the site. A typical capacity of the methanol plant could be 20 % of a 700 MW class power station which equals to capacity of some 150 MW of the methanol plant.

Profit is basically generated resulting from the price difference between market price for electricity and methanol price. The power plant can be operated continuously synchronised with the electrical grid and offer all the necessary system services which are demanded. This allows additional revenues. The avoided CO2 emissions in this special case have a magnitude of 4.3 % to 18 % depending on load of the power plant. Integrated heat reuse, use of efficient scrubbing fluids and advanced CO2 capture technologies allow less than 20 kW electricity losses per MW heating value of the produced methanol (Figure 2).

Use of methanol of a PTM process offers a lot of advantages:

- Indirect storage effect for electricity either as a shadow operation of power plants or as effective energy storage of RES power avoiding energy curtailment.
- Conventional power plants are still able to provide combined heat and power to the networks but in a flexible and efficient operational mode.
- Reduction of minimum load delivered to the grid of coal-fired plants is achieved via energy storage allowing a quicker response in case of missing RES electricity as well as reduction of start-up costs.
- Integrating the transport sector as well as process and energy intensive industries and their necessary CO2 reduction targets with the power sector.
- CO2 capture, utilisation and conversion to valuable chemicals, significantly reducing the carbon footprint in product end users and reducing specific CO2 emissions in power plants.
- Initiating a new market for power plants both from sales of electricity and valuable chemicals as well as from provision of auxiliary services and reserve power.

The full capability of the load following abilities of the power-to-methanol-technology will be investigated within the HORIZON 2020 project MefCO2 shown in Figure 3. In the MefCO2-pilot plant, MHPSE as system integrator is cooperating with Hydrogenics as technology supplier.
of electrolysis, with the Duisburg-Essen University providing the CO₂ capture plant and with Carbon Recycling International as the methanol technology supplier. The pilot plant is hosted by STEAG GmbH.

Power-to-methanol could be part of the answer to the challenges of the “Energiewende”. Using surplus electricity, captured CO₂ and offering more load flexibility, power-to-methanol plants can be the solution in a wide range of services from primary to secondary control, load following and large energy storage. “Must-run-power plants”, e.g. producing combined heat and power, could be kept in operation in a more efficient and environmental friendly way.

Is there enough demand for methanol?

Another general question is: “Is there enough demand for an additional methanol production (Figure 4)?” This is a good and important question, because over-supplies of any goods will involve dramatic price drops. But there is no need for such worries on the methanol market. Figure 5 shows the expected demand for the next three years and outlines that the new plants cannot fulfill this demand today.

The reasons for this positive market development are numerous new fields of application for methanol in current technical development in the chemical and fuel industry. Investments in methanol production facilities are secured and there is a double benefit, if there is also the benefit for the “Energiewende” and climate change.

Conclusion

The paper gives an overview showing the technical features as well as the strategic opportunities of a systemic approach in general and about the power-to-methanol technology especially.

Electricity use is highly appreciated and its demand will probably rather grow than decrease in the future. An open discussion on the technologies is required in order to optimally combine the benefits of renewables, conventional generation and storage technologies. Flexible coal-fired power stations using combined heat and power and storage features will be an important part of the “Energiewende”. More complete systems instead of individual technologies will be of importance in the future.

Methanol is not the solution, but a part of the solution in future energy supply. A market approach combining all the strategies could make the necessary “Energiewende” economic.
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