POWER SYSTEMS OF THE FUTURE

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Abstract

Power systems across the globe are in the process of fundamental shift towards climate neutrality. The scale and urgency of this transformation is enormous (OECD, 2019) and will affect most industries due to the central role of energy and electricity. In this presentation we give an overview of main ongoing developments and future trends that also imply a closer coordination between power industry and various industrial processes.

Keywords

Power Systems, Energy efficiency, Sector Coupling, Renewables, Industrial Processes.

Introduction

There are several major parallel pathways, which the industry needs to develop and follow in order to reduce carbon emissions and increase the sustainability of the global energy system:

- Significantly increase renewable generation capacity, ultimately replacing fossil fuels.
- Electrify final energy consumption in industrial processes, transport and building sectors.
- Improve energy efficiency of building stock and industrial processes.
- Complement direct electrification with liquid and gaseous fuels synthesized by using clean electricity.
- Ensure sufficient capacity deployment of all other enabling technologies such as flexible transmission and distribution grids, energy storage and digital solutions to handle the imbalance between consumption and production of energy.

Renewable energy generation is growing rapidly, driven by falling costs and supporting national and international policies (IPCC, 2022). This results in that more power is supplied by intermittent, weather-dependent sources such as wind and solar PV, which is clean but may result in various operational challenges and potentially threaten the security of power supply (Figure 1).

The transition is also driving a rapid growth of distributed power generation, energy storage (Heuberger et al., 2017) and flexible loads enabled by sector coupling, demand-side management (Merkert et al, 2015) and electrification of road transport and space heating.

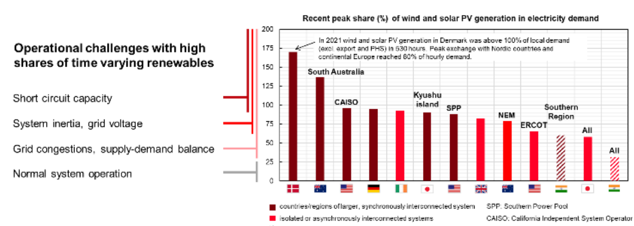

Figure 1 Instantaneous peak share of wind and solar PV generation as percentage of electricity demand.

A growing share of inverter-based volatile renewable sources raises a set of operational challenges starting with network congestions and supply-demand balance due to an intermittency of weather-dependent energy sources at moderate shares, followed by low inertia and short circuit capacity in inverter-dominated systems.

Regardless of the transition scenarios, the future power systems will have a higher level of complexity and faster dynamics, where complexity depends on the number, size, geographic distribution of new active system elements, as well as on the changing operational environment, for example due to a shorter market settlement or an effect of severe weather events. Growing system complexity and dynamics outpace operators' ability to absorb and interpret large volumes of information and make decisions within required timeframe resulting in higher operational risks (Figure 2).

New concepts must be developed to structure and manage the power system of systems landscape, where interdependencies also with the consumers (industrial, municipal, private) are significant. How to model and efficiently optimize and coordinate these systems is a research and implementation challenge for the next few decades.

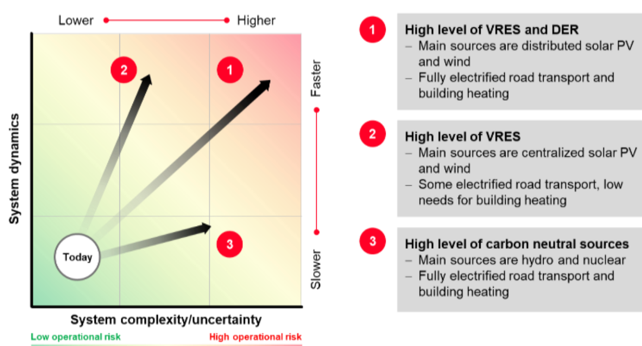

Figure 2. Growing power system operation risks as a function of increasing complexity and faster system dynamics.

As effect of ongoing climate change, the frequency and severity of extreme weather events is increasing since the past few years, increasingly affecting the power system infrastructure both from a physical point of view and from increased stress from the demand side. Future power systems must be strengthened and controlled in an intelligent way to ride through such events with a minimum impact on safety of consumers and continuity of critical businesses.

Luckily, there are a toolbox of technologies that can help to operate the future power systems in the new environment:

a. Inverter based resources equipped with grid forming control can effectively support a system operation with 100% renewable generation by providing inertia, short circuit power and dynamic voltage regulation.

b. Interconnecting remote, high-quality wind and solar resources to large demand centers as well as linking together regions with different, complementary weather patterns to optimize the use of resources. Single, point to point links will evolve into multi-terminal interconnectors which will finally form meshed and flexible HVDC grids.

c. New processes are needed for efficient energy conversion as well as transforming today's fossil fuel-based processes to carbon neutral alternatives. There are clear synergies between the simultaneously increasing electricity demand and processes that either produce or consume hydrogen or ammonia in balancing the volatile renewable electricity production, which can also result in a need to balance between different zones (Figure 3) due to the fact that e.g., renewable energy is often produced far from the consumers. Apart from already explored demand-side management scenarios (mostly triggered by grid operators) other types of energy-driven partnerships are needed across the power and process sectors to ensure a sustainable and resilient energy infrastructure.

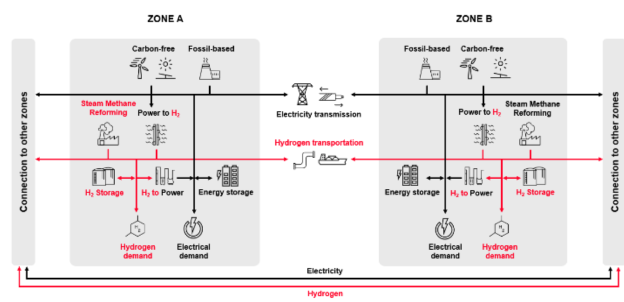

Figure 3. Sector coupling of energy and various processes with connectivity across various zones

d. At the grid edge, we expect a significant growth of distributed energy resources such as rooftop solar PV, distributed batteries, heat pumps and battery electric vehicles creating a true multi-energy vector system with an enormous potential to optimize energy balance, reserves and overall system cost. Consumers will evolve into prosumers who will play an important role in balancing the future supply-demand. Distributed Energy Resource Management Systems will aggregate and optimize their operation locally and globally in coordination with Transmission System Operators.

e. Digital solutions are crucial in bringing all information together, create collaborative optimization solutions including long-term planning, operations and maintenance to ensure and secure uninterrupted energy availability also through efficient control and protection solutions. Much of the power grid is already today highly automated and due to the fast-increasing number of generation units and the need to dynamically couple various processes the role of AI/ML can be expected to grow significantly in the next decades.

Conclusions

In order to meet create the energy systems of tomorrow, there are many important research steps and challenges that must be managed.

- Maximize synergies between energy-intensive processes for helping to reduce the need for primary energy (sustainability).
- Use optimization tools together with AI/ML to design (Lara et al, 2020; Li et al, 2021) the future grid components acknowledging the role of sector-coupling (ETIP SNET, 2021) and alternative energy storage forms.
- Create new and large-scale energy storage options both for short-term and seasonal balancing.
- Build and integrate schemes between process systems engineering and energy systems of systems.

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