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Report

The Technologies Adding Flexibility to the Future Low-carbon Power System

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#Carbon Neutral #Sustainability #Energy

Highlight

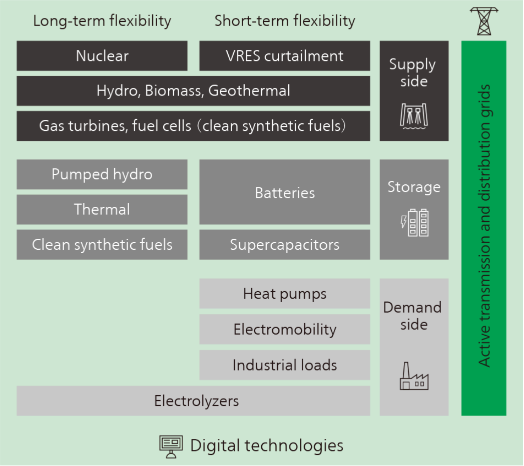
This is the second article in our two-part series discovering the notion of power system flexibility and why it is crucial in a low-carbon world. Just as in our first piece, Albert Moser, Professor at the Institute of High Voltage Equipment and Grids, Digitalization and Energy Economics at RWTH Aachen University, Jochen Kreusel, Global Head of Market Innovation at Hitachi Energy, and Alexandre Oudalov, Manager of Power Systems of the Future at Hitachi Energy, share their thoughts, this time on which technologies are at the core of providing power system flexibility. They will also paint a picture of what a future flexible electricity system will look like.

The Four Key Dimensions of Flexibility

In our first article, we established that flexibility allows a power system to cope with variability and uncertainty at all times, two factors that are increasingly a fact of life as our electricity system grows more reliant on weather-dependent renewable sources. Managing residual load is becoming more important and complex than ever, and it is the flexibility tools that lie at the heart of staying on top of the fast-paced variability associated with the future clean electricity system.

Delving more deeply into the technologies which encompass the necessary flexibility tools, we have identified four dimensions that we will unpack in this article: supply-side flexibility, demand-side flexibility, energy storage, and dynamically controllable grids. Advanced digital technologies are essential for unlocking the full potential and complementarity of these four dimensions for an optimal and coordinated response (see Figure 1).

Figure 1 | Advanced Landscape of Future Power Systems: Integrating Dominant Short- and Long-term Flexibility Solutions



Supply-side Flexibility

On the generation front, renewable energy assets such as solar PV plants and wind farms that produce electricity in unprecedentedly variable flows are putting an end to the highly controllable and dispatchable power generation system of the past. Where electricity supply was previously decided by power plant managers, it will be increasingly influenced by meteorological conditions, regardless of whether the output is needed or not.

By far the biggest task is managing the volatility in renewable power generation but also the increasing fluctuation of demand brought on by electrification. The near-constant state of distortion between supply and demand is also a major frequency stability challenge for network operators, worsened by times of congestion.

It is only with digital tools that grid operators can manage fluctuating power output, for example by curtailing solar plants and wind farms at times of excess production. This has to be done at the right time and location, which only thoroughly analyzed data can determine.

Looking ahead, the flexibility of supply-side will be enhanced by the advent of innovative zero carbon emission generation alternatives based on sustainable fuels like green hydrogen and ammonia. These will act as back-up generation to renewable electricity production and will often replace fossil-based stand-by generators. These types of new generation sources will help supply clean electricity and will complement the short-term capabilities of batteries, for example during extreme weather events like sandstorms and monsoons, as mentioned in the previous article.

Demand-side Flexibility

Power system flexibility solutions do not only reach the generation side but are also being applied to power networks. To distribution grids, congestion management is instrumental to seamlessly integrating exponentially growing distributed renewable energy capacity – much of which is solar PV placed on household rooftops – as well as absorbing potentially simultaneously appearing new types of load, such as EV charging and heat pumps into the market.

Flexibility is inherent in electric vehicles and heat pumps, thanks to their ability to store energy in batteries and insulated water tanks for subsequent use. Electric vehicles are not only capable of flexible charging but can also discharge their batteries to supply power back to the grid during emergencies. Key to harnessing this potential are bidirectional chargers, either onboard or integrated into the grid, and digital connectivity for efficient data exchange and optimal control.

Demand-side flexibility, especially at residential level, will increasingly be managed by aggregators. These middlemen group the electricity generation and consumption of large numbers of small prosumers into flexibility services that they can commercialize by offering demand-side response measures into the balancing and reserve markets as well as into the day-ahead and intraday electricity markets.

Nowadays, aggregators already offer demand-side response services into reserve capacity markets to act as standby levers in unexpected situations. In some of the largest European markets, minimum capacity size of assets admitted into reserve market bidding has already been reduced from the traditional 5 MW standard to 1 MW in order to accommodate smaller, flexible capacity. We expect to see much more of these services in our future power system.

Energy Storage

Energy storage plays a vital role in providing flexibility ranging from short (seconds-hours) to long-term (days-weeks) intervals. But it will also help manage the load and electricity supply from prosumers. Energy storage's ability to shift demand as well as production is absolutely key to a well-working, flexible future power system. In some markets, storage needs are supplied by local solutions such as networks of EV batteries or hot water tanks.

In the traditional electricity market, energy storage capacity was largely provided by pumped hydro power plants. These gigantic reservoirs use electricity to power water pumps that shift large amounts of water from a lower mountain reservoir to higher at times of oversupply, only to release them again to drive electric turbines and generate electricity at times when more power is needed.

The National Energy Administration of China is actively prioritizing the development of pumped storage projects. This initiative is crucial for enhancing the flexibility of the power grid, especially to better integrate the increasing contributions from wind and solar power sources. As per the strategic plan laid out in 2021, China aims to achieve a significant milestone in its pumped storage capacity. The target is to reach an installed capacity of 62 GW by 2025, followed by an ambitious goal of 120 GW by 2030. These efforts are a testament to China's commitment to advancing its renewable energy infrastructure and optimizing its power system.

Hydroelectric generation will continue to play an important role in offering system flexibility. Norway's natural water feed hydro reservoirs, for example, are already acting as a flexibility tool to balance out intermittent wind power production in neighboring countries that are connected via submarine cables. The NordLink interconnector(1), for example, linking the German and Norwegian power markets by enabling the integration and cross-country exchange of renewable solar, wind and hydro power underlines the importance of interconnections in sharing flexibility resources across geographic areas, which we'll explore in the next section.

The more imminent focus for the provision of electricity storage solutions lies on battery energy storage systems (BESS). Lithium-ion is the main electric battery storage technology that is being deployed. Compared to electric vehicle batteries, stationary, utility scale BESS offer greater flexibility in terms of acceptable battery technologies and energy densities. This flexibility allows for more adaptable supply chains and the potential for second-life applications of EV batteries.

However, storage technologies are currently not addressing the lack of seasonal flexibility, which would also help deal with the challenges thrown up by severe weather phenomena, as discussed in the first article. Economically, current battery applications are constrained to a few hours of discharge capacity.

But how will the low-carbon electricity system address longer periods of low wind speeds and solar irradiation, often coupled with high demand during cold winter spells? This is one of the questions keeping many experts awake at night because, as of yet, there is no obvious answer.

Addressing long-term energy deficits requires technologies capable of storing substantial amount of energy at considerably low cost. The above-mentioned technologies such as green hydrogen and ammonia are some of the solutions being touted, but their limited efficiency and substantial initial investment costs are the primary barriers to widespread adoption.

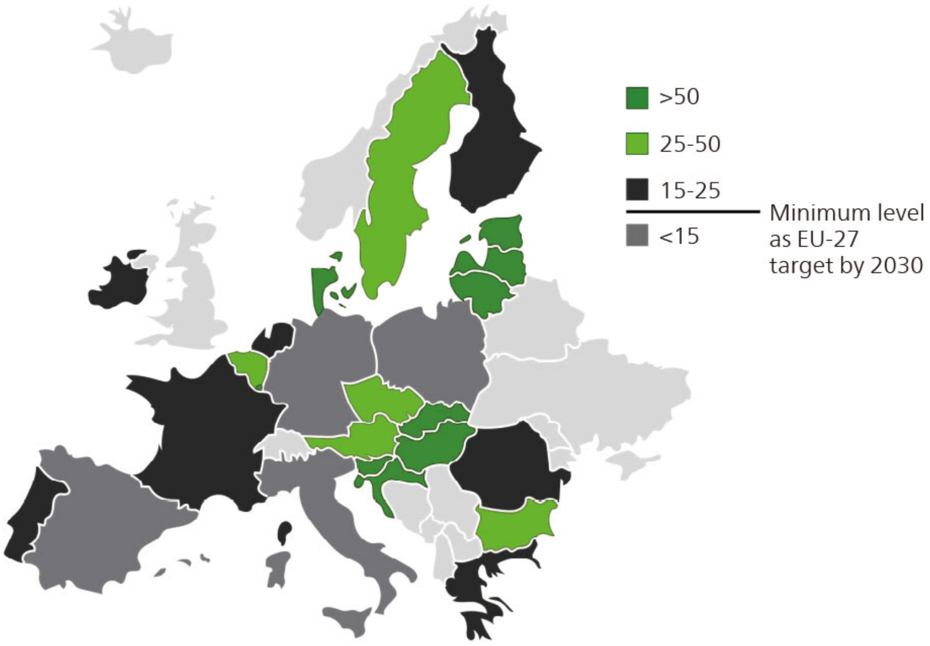
The Need for a More Controllable and Interconnected Grid

We concur that grids which are both more interconnected and controllable play a crucial role. Integrating storage capacity with a robustly interconnected grid forms a key pillar in the architecture of the low-carbon, flexible electricity system of the future because it enables the shifting of supply and demand over the widest possible area. The greater the variety of climatic, geographic, and temporal locations linked, the more flexible the power system becomes. For instance, if a region reliant on solar PV experiences less sunlight than expected, it can compensate by importing energy from a remote coastal area with active offshore wind farms.

Interconnected power systems excel in sharing flexibility resources, surpassing the capabilities of more isolated markets. In fact, a well-interconnected network diminishes the need for flexibility measures by more effectively distributing the variability of renewable energy over a wider area. Enhancing the interconnection of electricity markets emerges as the most cost-effective strategy to increase power system flexibility. Various research papers consistently indicate that isolated electricity systems incur higher costs, resulting from underutilized renewable generation capacity and, in some cases, the need to curtail this capacity, and because the isolated systems often require extra energy storage facilities.

In the European Union (EU), internal electricity market rules mandate that by 2030, all member states must have a cross-border interconnection capacity in place that is equivalent to at least 15% of a nation's power generation capacity. Furthermore, by the end of 2025, EU grid operators are required to allocate at least 70% of their cross-border capacities for daily power trading. However, current trends show that European TSOs are falling short of this target, risking higher prices for European energy consumers, EU energy regulator Acer recently warned(2).

Figure 2 | Cross-border Transmission Capacity in EU-27 Countries as a Percentage of their Installed Generation Capacity



Countries shaded in dark grey are currently falling short of the EU's 2030 interconnection target.

Interconnectors play a pivotal role beyond merely enhancing electricity transmission; they also facilitate the integration of demand sinks that will enable more efficient offtakers for surplus renewable energy production, as well as addressing clear needs for additional power. This will be particularly beneficial in densely populated areas; for instance, the recent HVDC interconnection(3) between Canada and the US will enable the delivery of renewable energy between Québec and the New York City metro area.

Cross-market interconnections are not only important to serve the spot market, but they are also an increasingly useful tool in the reserve market. The ability to procure reserve capacity from neighboring countries means stronger energy security across the interconnected markets, positioning interconnectors as a key flexibility tool for the reserve power market.

Within the EU, there are a number of important interconnector projects underway which will substantially improve these countries' flexibility – and ultimately that of the entire internal power market. A notable example is the interconnection between England and France(4), which aims to strengthen power networks in both countries and the integration of renewable energy.

Similarly, a new submarine HVDC interconnector(5) between Spain and France will ease the transmission of Spanish renewable electricity to central and northern Europe.

These projects highlight a crucial aspect: increasing the flexibility of the entire power systems necessitates enhanced flexibility within the grids themselves.

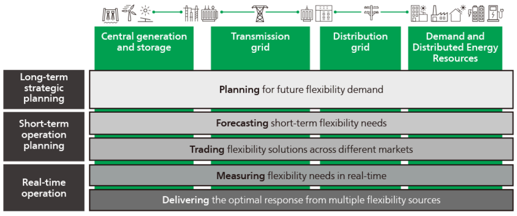
Traditionally, AC power lines distribute electricity following the path of least impedance. However, the future power systems will require power transmission into new directions. For instance, Germany has historically been a net electricity exporter to southern Europe. But with the expected surge in solar and wind generation capacity around the Mediterranean, there will be a significant shift in electricity flow from south to north.

In the evolving energy landscape, dynamic and flexible power flow control through technologies based on advanced power electronics will become increasingly essential. HVDC technology(6) plays a crucial role in modernizing power grids, efficiently controlling and routing the flow of electrons where needed, thereby optimizing electricity transmission, and minimizing the curtailment of renewable energy.

Digitalization is Fundamental in Advancing Power System Flexibility

Overarching all of these changes is digitalization(7), which is one of the key enablers of a flexible low-carbon power system. Without high-speed computers, signal detection, data collection and usage by smart algorithms, and a capable and secure communication system, we will not be able to move forward with the energy transition. Digitalization provides us with better accuracy, insights and control over the energy market and leads the industry to greater autonomy.

Figure 3 | Key Roles of Digital Technologies in Advancing Power System Flexibility.



Digitalization is also the glue that fuses all flexibility technologies that the future low-carbon electricity system needs. It helps orchestrate each piece of the puzzle, such as battery storage, interconnectors, or demand-side response tools, which all add their own value within the coordinated power system. We need the help of digital tools at various stages within the transition to a low-carbon electricity system: to plan the most efficient power system, to forecast its needs in terms of supply and demand, and to monitor operations in real time so as to best react to unforeseen circumstances. It is vital for TSOs to invest in the cutting-edge digital tools that maximize the efficiency of all available flexibility solutions.

The Flexible Power Future

As laid out above, there is a wealth of technologies already available to increase flexibility measures in a low-carbon power system. Every market has different legacy-based characteristics that influence the choice of technology, but we firmly believe that a mix of solutions is the best provision for a stable power system. There is no one-size-fits-all solution when it comes to flexibility.

Taking all of the discussed elements into account, what will a flexible, digital power system look like?

In reality, power system flexibility needs and solutions will look different across the globe and will be determined by regional geography and power system specifications.

In Europe, efforts are intensifying to enhance power system flexibility to meet climate targets, while bolstering energy security, and optimizing the efficiency of power system assets. This trend is anticipated to gain momentum globally in the coming years.

For nations that have a relatively isolated electricity market, such as South Korea or Japan energy storage in combination with strong regional grids will be the main elements of flexibility.

Other areas which stand out are those that plan to be 100% reliant on renewable energy production in the coming years. Saudi Arabia’s carbon-neutral city NEOM, for example, will source its entire electricity supply from solar PV and wind generation. The main challenge to NEOM’s electricity system will not be a diurnal variability of solar PV generation, but the effect of seldom sandstorms on solar panels that can last several days. These extended periods of reduced solar power production necessitate sustained flexibility solutions which can be achieved through long duration pumped hydro and thermal energy storage, and by interconnecting with a broader national grid(8).

In highly interconnected regions, power system flexibility will encompass all four elements outlined in this article: demand-side flexibility, supply-side flexibility, energy storage, and controllable grids. Coordinating and optimizing these diverse and geographically dispersed resources is a complex challenge that necessitates advanced digital solutions. As flexibility becomes increasingly crucial in future sustainable energy systems, it will emerge as a significant, market-based service, offering substantial rewards to all providers of flexibility.

Most importantly, grid infrastructure needs to be adapted as a top priority to meet the challenges that a digital, flexible power system will require.

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