Hitachi Review

April 2024 Special Articles

Power System Flexibility

A Key Enabler for the Energy Transition

#Carbon Neutral #Energy

Highlight

In this Perspectives, 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, explore the essential topic of power system flexibility.

The Low-carbon Power System of the Future Needs Flexibility at its Core

In this Perspectives, 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, explore the essential topic of power system flexibility.

It is the buzzword of the moment in conversations discussing the shape of our future power system. But what is meant by the term ‘flexibility?’ Why is it crucial in the transition to a low-carbon economy, and what challenges does it bring? This article explores the definition of power system flexibility and unpacks how flexibility tools are shaping a carbon-neutral power system.

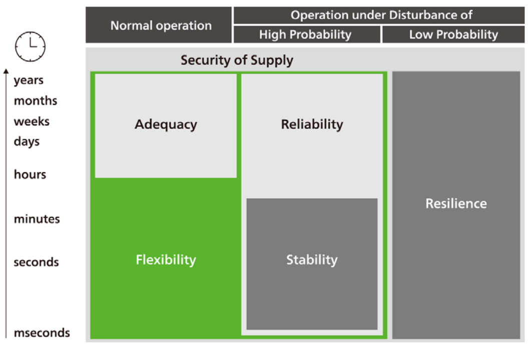
Definition of flexibility

We have done some extensive research into the exact definition of power system flexibility, and it is quite remarkable how many different interpretations there are. This underscores our aim to delve deeper into this interesting topic. We conceptualize flexibility as the ability of power systems to cope with variability and uncertainty at all times.

A flexible power system is key to managing operations during normal conditions and times of high probability disturbances, always ensuring sufficient security of supply. Flexibility solutions are able to respond at any length of duration, stretching from milliseconds to years, and encompass power system stability, reliability and adequacy (see Figure 1).

The future power system will need to adapt quickly to any operational change, may it be the unplanned outage of a large power station or a high ramp-up or down in weather-dependent renewable energy output. Whether the event occurs suddenly for just a few minutes or will last for weeks over the high-demand period, the aim always needs to be a resolution at the lowest cost and with minimum impact on consumers.

Figure 1—Flexibility and Other Operational Requirements of Modern Power Systems



Measuring Flexibility

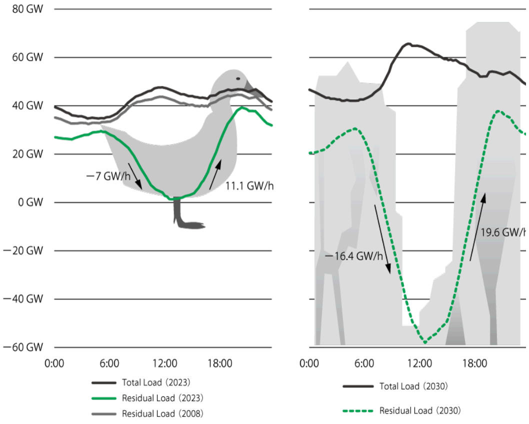
With flexibility becoming so important, how can we measure it to identify potential shortfalls and anticipate future flexibility needs? We believe that the simplest measure to quantify how flexible a power system is lies in determining how effectively it can re-establish a supply-demand balance following any change. How quickly can the system’s flexible capacity ramp up or down at times of renewable supply shortage or overproduction? It is also important to assess whether the system can quickly and economically address short as well as long-duration occasions of imbalance in supply and demand and that it could, in an extreme situation, meet the highest demand peak.

Residual Load Ramping Challenge

When defining flexibility, it is also important to understand the rising prevalence of residual load. Whereas in the past, electricity demand was largely predictable throughout the day, the fast-growing connections of fluctuating renewable energy capacity, especially solar PV, has created a deepening distortion between when electricity demand is highest and when generation peaks. Residual, or net, load is defined as the total demand on the power grid minus the electricity production from variable renewable energy sources. Managing residual load is becoming increasingly important because it is characterized by incredibly fast ramping, or rate of change on the grid. This is where flexibility resources are essential to minimizing curtailments of clean electricity.

This change in the residual load profile has been especially pronounced in the German power market, which has seen installed solar PV capacity rise from around 6.1 GW in 2008 to more than 67.5 GW in 2022, a ten-fold increase over the period. By 2030, the German government is targeting installed solar PV capacity of 215 GW, indicating that the renewable energy source will continue deepening its impact on the German market. As a result, the residual load profile in Germany has evolved from the typical 'duck' shape to a 'canyon' shape, highlighting the market's current steep ramping needs (see Figure 2).

Figure 2—From Duck to Canyon Curve



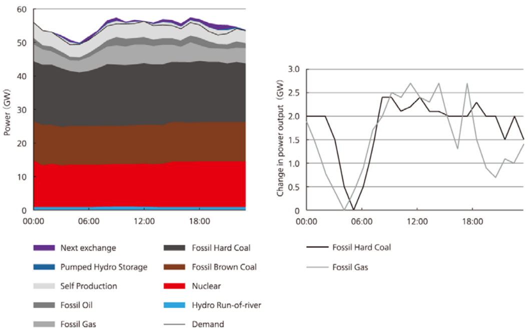
The figure shows an evolution of residual load profile in Germany 2008-2023 and a 2030 projection (from Hitachi Energy analysis). Reference day May 1st, 2023.(1), (2)

Flexibility in History

Although current discussions may lead one to think so, flexibility within the electricity system is not new at all. In the past - and to a certain extent, we still benefit from it in our power system - flexibility was provided by large power plants that could add or remove electricity supply simply by burning more or less fuel, mainly natural gas or coal (see Figure 3).

Even in a very large power system like the continental European one these amounted to only several hundred flexibility providers whose services were relatively straightforward to call upon amid predictable and stable electricity demand patterns. This meant that electricity was purchased precisely according to anticipated demand needs; negative prices due to oversupply, which we are increasingly witnessing nowadays, were unheard of. In this system, flexibility was more a byproduct of a centralized, highly dispatchable power production machine.

Figure 3—Generation and Network Load Curves and a Flexible Performance of Fossil-based Generation



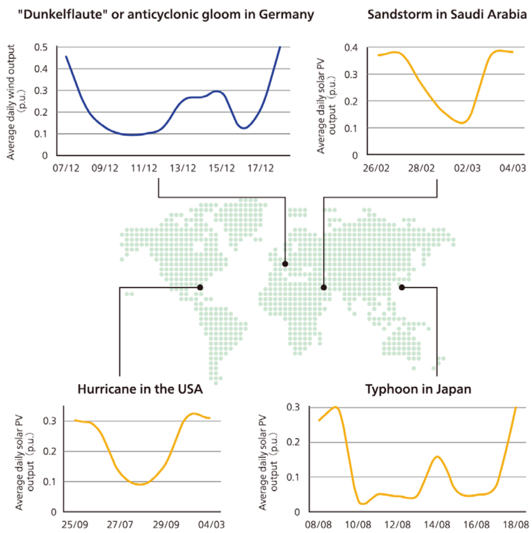
The figure shows generation and network load curves (left) and a flexible performance of fossil-based generation (right) on Wednesday, January 16, 1985 in Germany (formerly known as West Germany until 1990).

The Impact of Weather

Flexibility is now becoming front and center of the proactive power system needed in a carbon-neutral economy. Next to residual load impact, the increasing reliance on renewable energy output has also forced a direct dependence on weather conditions. Unexpectedly calm weather days can have huge impact on grid balancing needs, as well as a spell of sunnier-than-expected weather.

Regional weather patterns pose unique challenges to electricity markets in various parts of the world. For instance, in the Middle East, sandstorms can severely disrupt solar photovoltaic (PV) production for extended periods of several days. Similarly, Europe experiences the 'Dunkelflaute,' a phenomenon characterized by reduced light and wind levels that slow down renewable energy production, often occurring during the high-demand winter months. Additionally, in some Asian countries, monsoons with their dense cloud coverage can result in prolonged interruptions in solar PV output (see Figure 4).

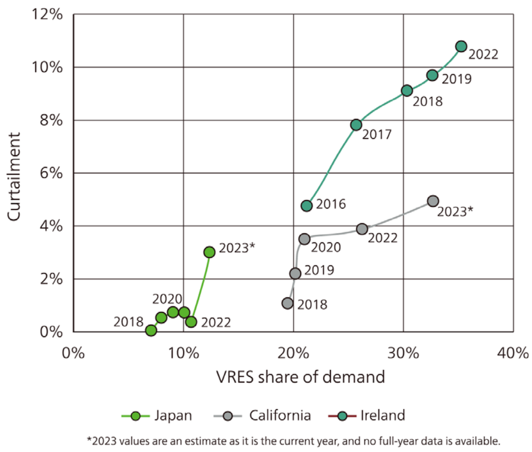
Figure 4—The Effect of Severe Weather Events on the Regional Variable Renewable Energy Production(3), (4), (5)



Simultaneously, weather conditions in other regions might cause an oversupply of renewable energy, exceeding the actual demand. This surplus can potentially lead to a significant curtailment of green electricity, a phenomenon which sits uneasily with global efforts to reach net-zero emissions goals. Curtailment is highest in power systems where flexibility measures are limited or non-existent and as renewable energy capacity is rising across the globe, flexibility tools will become increasingly important in preventing valuable green electrons from getting cut off.

In countries such as Japan and Ireland and in the US state of California we have noticed strong correlation between the rising share of variable renewable energy sources (VRES) and curtailment (see Figure 5).

Figure 5—Correlation between Curtailment of Variable Renewable Energy Sources (VRES) and their Share of Demand in Selected Regions(1), (3), (4), (6), (7)

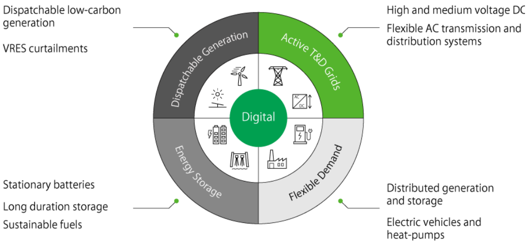


The Four Dimensions of Flexibility

We have identified four dimensions that we think are most crucial to dealing with the growing variability and uncertainty that a future carbon-neutral energy system brings: supply-side flexibility, demand-side flexibility, energy storage and active transmission and distribution grids. Digital technologies play a pivotal role in enhancing flexibility of power systems, acting as a catalyst for ensuring an optimal contribution of all four areas. It facilitates this across various time scales and locations, leveraging connected resources for maximum efficiency and adaptability.

It is important to underscore the escalating necessity for dealing with variability and uncertainty in future power systems. This need is propelled by the ongoing energy transition toward decarbonizing power generation by integrating more weather-dependent renewable energy sources. Addressing the expanding variability in supply and demand requires harnessing both existing and emerging tools for flexibility.

Figure 6—Four dimensions of flexibility with digital technology at the core.



In our second article, we will look more closely at the key technology segments and how they each contribute to a more flexible power system.

The second article is available here.

REFERENCES

1) ENTSO-E Transparency Platform
2) Fraunhofer Institute
3) Renewable Energy Institute Japan (REI)
4) Energy Information Administration (EIA)
5) renewables.ninja
6) California Independent System Operator (CAISO)
7) EirGrid

Hitachi Review

Hitachi Review is a technical medium that reports on Hitachi's use of innovation to address the challenges facing society.

The *Hitachi Review* website contains technical papers written by Hitachi engineers and researchers, special articles such as discussions or interviews, and back numbers.

Hitachi Hyoron (Japanese) website	*Hitachi Review* (English) website
https://www.hitachihyoron.com/jp/	https://www.hitachihyoron.com/rev/

Hitachi Review Newsletter

Hitachi Review newsletter delivers the latest information about Hitachi Review when new articles are released.