International Energy Agency
Secure Sustainable Together

CLEAN ENERGY MINISTERIAL
Accelerating the Global Clean Energy Transition

21st Century POWER PARTNERSHIP
Accelerating the transformation of power systems

Executive Summary

Status of Power System Transformation 2018

Advanced Power Plant Flexibility

INTERNATIONAL ENERGY AGENCY

The IEA examines the full spectrum of energy issues including oil, gas and coal supply and demand, renewable energy technologies, electricity markets, energy efficiency, access to energy, demand side management and much more. Through its work, the IEA advocates policies that will enhance the reliability, affordability and sustainability of energy in its 30 member countries, 7 association countries and beyond.

The four main areas of IEA focus are:

- **Energy Security**: Promoting diversity, efficiency, flexibility and reliability for all fuels and energy sources;
- **Economic Development**: Supporting free markets to foster economic growth and eliminate energy poverty;
- **Environmental Awareness**: Analysing policy options to offset the impact of energy production and use on the environment, especially for tackling climate change and air pollution; and
- **Engagement Worldwide**: Working closely with association and partner countries, especially major emerging economies, to find solutions to shared energy and environmental concerns.

IEA member countries:

Australia
Austria
Belgium
Canada
Czech Republic
Denmark
Estonia
Finland
France
Germany
Greece
Hungary
Ireland
Italy
Japan
Korea
Luxembourg
Mexico
Netherlands
New Zealand
Norway
Poland
Portugal
Slovak Republic
Spain
Sweden
Switzerland
Turkey
United Kingdom
United States

The European Commission also participates in the work of the IEA.

International Energy Agency
Secure
Sustainable
Together

International Energy Agency
Website: *www.iea.org*

Executive summary

Power systems are undergoing a rapid transformation

Across the world, change is accelerating in power systems. Three main factors are driving this transformation. First, the advent of abundant, low-cost variable wind and solar energy resources. Second, the deployment of decentralised energy resources, including rooftop solar and smart loads such as electric vehicles and smart appliances. And third, the spread of digitalization, which is reaching across entire power systems to uncover new opportunities to reduce costs and improve resiliency, from generation all the way to customers.

These changes are driving a structural shift in the way power systems are best planned and operated. They also have systemic implications for ensuring energy security, especially security of electricity supply. Hence, they require a co-ordinated and proactive response by policy makers and relevant stakeholders in the power sector, encapsulated by the term power system transformation (PST). The task of PST is to create appropriate policy, market and regulatory environments to manage the impacts of change, and in doing so achieve the upgrading of power system operational and planning practices. PST helps accelerate investment, innovation and the use of smart, efficient, resilient and environmentally sound technologies. PST is crucial for ensuring electricity security in modern power systems (21CPP, 2015a/b; IEA, 2017).

Power system flexibility has become a global priority

Enhancing power system flexibility is often an important objective of PST. This report defines power system flexibility as all relevant characteristics of a power system that facilitates the reliable and cost-effective management of variability and uncertainty in both supply and demand. Driven in many contexts by the integration of variable renewable energy (VRE) in daily operations and a growing intensity and frequency of high-impact events, power system flexibility is an increasingly important topic for policy makers and system planners to consider. A lack of system flexibility can reduce the resilience of power systems, or lead to the loss of substantial amounts of clean electricity through curtailment of VRE.

Keeping the lights on requires the continuous balancing of supply and demand across all timescales, from moments to years – it is thus useful to consider flexibility across these timescales. To help understand different flexibility needs, as well as the different mechanisms for meeting them, this report groups flexibility requirements on the basis of timescales, ranging from short-term (subseconds to hours) to medium-term (hours to days) and long-term (days to years) (Table ES.1).

Importantly, power systems are already designed with the flexibility to manage variability and uncertainty. Historically this has been needed in particular to meet variable electricity demand or the sudden loss of a large generator or transmission line. Requirements for flexibility may grow and change over time, particularly as VRE shares increase. Power system flexibility is also important in modern power systems for managing outages and extreme weather events, promoting resiliency, and other important purposes. A number of different investments and operational and policy changes can be made to increase flexibility in modern systems, and the realisation of additional flexibility can result in cleaner, more secure, more resilient and more affordable power systems.

Table ES.1 • The timescales of issues addressed by power system flexibility

	Short-term flexibility			Medium-term flexibility	Long-term flexibility	
Timescale	Subseconds to seconds	Seconds to minutes	Minutes to hours	Hours to days	Days to months	Months to years
Issue	Address system stability, i.e. withstanding large disturbances such as losing a large power plant.	Address fluctuations in the balance of demand and supply, such as random fluctuations in power demand.	Manage ramps in the balance of supply and demand, e.g. increasing electricity demand following sunrise or rising net load at sunset.	Decide how many thermal plants should remain connected to and running on the system.	Manage scheduled maintenance of power plants and larger periods of surplus or deficit of energy, e.g. hydropower availability during wet/dry season.	Balance seasonal and inter-annual availability of variable generation (often influenced by weather) and electricity demand.

Key point • System flexibility addresses a set of issues that span a wide range of timescales, from subseconds to years.

Power plants play a critical role in enhancing system flexibility

Based on a wealth of real-life case studies and data, this report provides a comprehensive overview of how power plants can contribute to making power systems more flexible, while enhancing electricity security. It summarises the findings of the Advanced Power Plant Flexibility (APPF) campaign of the Clean Energy Ministerial (CEM). The work of the campaign seeks to build strong momentum and commitment from governments and industry to implement solutions that make power generation more flexible.[1] The solutions presented in this study have been collected in close collaboration with industry stakeholders, including manufacturers, expert consultancies, system operators and plant operators.

The report showcases technical options and examples of successful flexibility retrofits to existing power plants. It provides guidance on how the contribution of power plants to overall system flexibility can be analysed. It also provides examples of the policy, market and regulatory instruments available to unlock power plant flexibility. It shows that conventional power plants – including coal- and natural gas-fired units – can assist in the rapid uptake of clean energy technologies and accelerate PST. Depending on the specific system context, a number of low-cost measures are readily available to make existing power plants better suited to complement the fluctuating output of wind and solar, and ensure security of supply at all times in a reliable and cost-effective manner.

The role of power plants in power systems is changing

Historically, baseload, intermediate and peaking plants helped meet specific segments of electricity demand at least cost by providing the appropriate mixture of energy and capacity. These plants were designed, from a technical standpoint, with these specific operating conditions in mind. From an economic standpoint, the plants were financed under the expectation of a certain number of operating hours. Today, as a new generation of technologies with distinct cost structures and technical characteristics enter power markets at

[1] See http://cleanenergyministerial.org/campaign-clean-energy-ministerial/advanced-power-plant-flexibility for more information.

scale, many existing power plants are being asked to operate with greater flexibility, and in some cases for a reduced number of operating hours.

For example, in response to significant VRE curtailment in certain regions of China, the China National Energy Administration requested that the Electric Power Planning & Engineering Institute (EPPEI) conduct research on the pathways for enhancing power system flexibility in the period 2016-20 (NDRC, 2016). The study found that nearly 220 gigawatts (GW) of thermal power plants could be retrofitted by replacing old equipment or improving operations in order to increase flexibility and significantly reduce VRE curtailment rates. The goal of retrofitting some or all of this 220 GW of capacity was codified into China's 13th Five-Year Plan for the power sector. Similarly, a recent study for India demonstrates that a large, coal-dominated power system can accommodate over 20% wind and solar generation (GTG, 2017). Reducing the minimum generation levels of coal plants significantly reduces VRE curtailment. Together with other operational changes, the Indian power system can operate more flexibly, enabling greater VRE integration at lower operating costs.

A diverse range of strategies can make existing plants more flexible

This report discusses a diversity of strategies to make existing power plants more flexible, ranging from modifications to how existing plants are operated to adding new generators to the grid that provide additional, system-appropriate flexibility capabilities. These strategies include:

- **Changes to operational practices for existing plants.** Significant new capital investments are not necessarily required to operate power plants more flexibly. Changes to certain plant operational practices – often enabled by improved data collection and real-time monitoring – can be used to unlock latent flexibility at existing plants. For example, better monitoring and control equipment can allow plants to start faster and ramp output more dynamically without compromising reliability.
- **Flexibility retrofit investments for existing plants.** Depending on the plant technology, a range of retrofit options may be available to improve various flexibility parameters of power plants (e.g. ramp rates, start-up times, minimum economic or technical generation levels). This report details specific retrofit opportunities across various power generation technologies, including coal, combined-cycle gas turbine (CCGT) co-generation, carbon capture and storage (CCS), nuclear, bioenergy and hydropower
- **New flexible generation opportunities.** Many state-of-the-art flexible power plant technologies can be deployed in power systems; several of these technologies are described in this report. Good long-term planning practices can ensure new flexible power plant investments are risk-hardened against a range of uncertain futures.

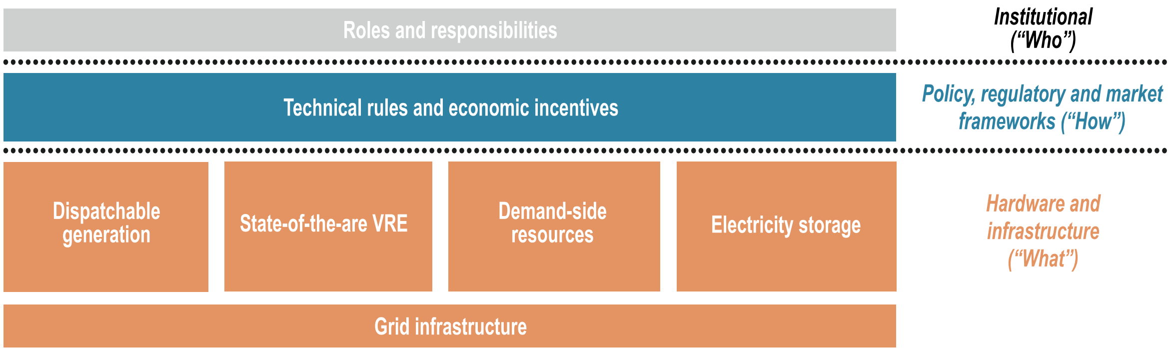
Countries such as Denmark, Germany and Italy, and also most recently countries such as China and India, have deployed a number of strategies to improve flexibility, particularly for their coal-fired and, where prevalent, CCGT power plants. For example, the thermal power plant fleet in Germany has upgraded its operational performance substantially in response to higher flexibility requirements. Power plants that were initially designed to run around the clock and were built over 40 years ago have been upgraded to start and stop twice a day, while also providing a range of additional services to the system.

Options for country-wide roll-out

The flexibility of a power system is determined by the hardware and infrastructure available (the "what"), the policy, regulatory and market frameworks (the "how"), and the institutional roles and responsibilities of entities providing flexibility (the "who"). All three aspects must work in concert to support system flexibility (Figure ES.1).

Consequently, not only technical factors will determine system flexibility. For example, the Thai power system includes features that make it relatively flexible from a technical standpoint, such as strong transmission grids and fairly high shares of hydropower and CCGT generation. However, from an economic standpoint many of the generators are inflexible, operating under take-or-pay power purchase agreements and fuel supply agreements. A recent analysis found that the relaxation of take-or-pay contracts could reasonably cut operational costs if natural gas procurement arrangements and power purchase contracts were made more flexible in the long term (IEA, forthcoming).

Figure ES.1 • Relevant dimensions for unlocking system flexibility



Key point • Technical, economic and institutional policy layers mutually influence each other and have to be addressed in a consistent way to enhance power system flexibility.

At a system level, creating a suitable flexibility strategy to roll out various flexibility measures requires consideration of current and future system needs, taking into account the existing generation fleet, market conditions, status of the transmission network, and potential for innovative flexibility solutions.

Enhancing system-wide flexibility

Enhancing system-wide flexibility can mitigate the need for additional flexibility provision from power plants. For example, improving communication and co-ordination among neighbouring balancing areas can eliminate the need for new power plant flexibility measures. For the transmission network, innovative approaches to control and monitoring – such as dynamic line rating and targeted investments in high-voltage transmission lines and equipment – can reduce the need for additional plant flexibility requirements that would otherwise arise due to grid congestion.

Unlocking existing power plant flexibility

Making use of existing generation assets can be cost-effective, but may require regulatory modifications and the introduction of certain economic incentives. Regulatory approaches include measures such as allowing for VRE participation in reserve provision, reviewing must-run requirements on existing power plants, enabling faster scheduling and dispatch intervals, and certain types of performance-based regulatory approaches. As for economic incentives, providing policy support for reviewing inflexible contract terms and creating new revenue streams for flexibility services can encourage plant owners to operate more flexibly.

Incentivising additional power plant flexibility investments

Both regulated and market-based power systems can ensure appropriate investment in additional power plant flexibility measures by identifying the value of specific flexibility services and ensuring fair compensation for them. This can be accomplished in market-based power systems by improving energy pricing schemes, especially close to the moment of delivery (intra-day markets) and during times of scarcity. Implementing well-designed market mechanisms that accurately reward generators for the system value of their flexibility can also incentivise increased flexibility. These remuneration mechanisms may be structured around specific services, such as ramping or start-up time, and could provide a complementary source of income for power plants that are necessary to the system but unable to maintain business-as-usual profitability due to reduced utilisation. In regulated contexts, power plant flexibility investments can be secured by allowing for cost recovery of flexibility retrofits, as well as by offering financial incentives for developers to utilise highly flexible technical components.

Policy approaches for long-term flexibility planning

Policy actions to accommodate future flexibility needs will be beneficial even in systems without an urgent flexibility deficit. Measures to prepare the system include requiring technical flexibility assessments in periodic adequacy assessments, facilitating the creation of a power system flexibility inventory, requesting the consideration of operational flexibility in long-term planning exercises, and requesting the use of start-of-the-art decision support tools used in long-term planning exercises.

Policy guidelines for advanced power plant flexibility

The strategy adopted and the prioritisation criteria formulated will depend largely on the local power system's conditions; however, a set of general policy guidelines can be identified to ensure sufficient system flexibility and safeguard electricity security. Policy makers should:

1. ASSESS – Commission assessments of system-wide flexibility requirements, opportunities and barriers, including the role of power plant flexibility, and periodically refresh these assessments to inform both near- and long-term decision-making and planning processes.
2. ENGAGE – Engage with stakeholder communities to strengthen technical, policy and institutional capabilities to enhance power system and power plant flexibility, and engage with international communities to share best practices.
3. ENHANCE – Enhance the use of available power system flexibility by adapting a range of market, regulatory and operational best practices at the system level.
4. UNLOCK – Update regulations, policies and practices that govern power system operation to unlock latent flexibility. These options include more flexible power purchase agreements with independent power producers and fuel supply contracts for thermal generators.
5. INCENTIVISE – Facilitate the opportunity to seek fair and appropriate remuneration for all assets that can provide flexibility to the power system, through changes to policy, regulatory and market frameworks.
6. ROADMAP – Enhance planning procedures to incorporate future expectations of system flexibility requirements; ensure consideration of all possible flexibility options to mitigate the long-term costs and operational impacts of PST.

Future work

In the context of the CEM, the work of the IEA and 21CPP on enhancing electricity security through power system flexibility will continue. Notably, the CEM campaign will be relaunched at CEM9 with a broader scope as the *Power System Flexibility Campaign*, covering concepts and experiences around power plants, grids, demand-side resources and storage over the next 12 months. This relaunched campaign will complement the efforts of the 21CPP Initiative of the CEM, which will continue to advance state-of-the-art solutions and provide a platform for in-depth capacity building, working closely with all related CEM campaigns and complementary initiatives.

In its analysis and advice to governments, the IEA continues to prioritise PST and its role in bolstering energy security.

References

21CPP (21st Century Power Partnership) (2015a), Status Report on Power System Transformation: A 21st Century Power Partnership Report, NREL, Golden, CO, www.nrel.gov/docs/fy15osti/63366.pdf.

21CPP (2015b), *Power Systems of the Future: A 21st Century Power Partnership Thought Leadership Report*, NREL, Golden, CO, www.nrel.gov/docs/fy15osti/62611.pdf

GTG (Greening the Grid) (2017), *Pathways to Integrate 175 GW of Renewable Energy into India's Electric Grid*, US Agency for International Development and India's Ministry of Power, www.nrel.gov/analysis/india-renewable-integration-study.html.

IEA (International Energy Agency) (forthcoming), *Thailand Grid Renewable Integration Assessment Report*, OECD/IEA, Paris.

IEA (2017), *Status of Power System Transformation 2017 – System Integration and Local Grids*, OECD/IEA, Paris

NDRC (National Development and Reform Commission) (2016), *China 13th Renewable Energy Development Five-Year Plan (2016-2020)*, NDRC, Beijing.

IEA/OECD possible corrigenda on: www.oecd.org/about/publishing/corrigenda.htm

IEA Publications
International Energy Agency
Website: www.iea.org
Contact information: www.iea.org/about/contact
Typeset in France by IEA - May 2018
Cover design: IEA; Photo credits: © GraphicObsession

International Energy Agency
Secure Sustainable Together

CLEAN ENERGY MINISTERIAL
Accelerating the Global Clean Energy Transition

21st Century POWER PARTNERSHIP
Accelerating the transformation of power systems