FORATOM
THE VOICE OF THE EUROPEAN NUCLEAR INDUSTRY

FLEXIBLE OPERATION OF NUCLEAR POWER PLANTS

Renewable energy sources, such as wind and solar, are one of the tools available which can help Europe decarbonise its electricity system. The challenge which they face today is their intermittent nature, given that they depend on the sun shinning and the wind blowing. Hence why they need to be combined with other sources of low-carbon energy – such as nuclear, the only large-scale form of electricity production which is not weather dependent.

NUCLEAR

- Provides both baseload and flexible electricity
- Ensures network stability
- Decarbonises the electricity system

EU POLICY MUST

- Recognise the specificities of long-term investments in low-carbon energy sources
- Deliver on a long-term and predictable carbon price
- Reward flexible electricity production as a partner for intermittent renewables

07-05-2018

Flexible operation of nuclear power plants

Executive summary:

- Nuclear energy is an essential component of the EU power system and the main partner of renewables in the decarbonisation of the European power system: nuclear power plants provide around 27% of electricity generated in the EU and almost 50% of its low-carbon electricity.
- With the increasing share of variable renewable energy sources in the European power mix comes the challenge of ensuring security of electricity supply at an affordable cost for consumers while reducing CO_2 emissions.
- Despite a broad perception that nuclear power plants are inflexible baseload sources, fact is that nuclear power can also provide large scale solutions to answer the request for flexibility and network stability in some Member States. Technically, existing nuclear power plants (NPPs) and new designs can perform both frequency control and load-following operations but practices are heterogeneous in the EU. In some Member States or regions, there is currently no need or incentives for flexible operations of NPPs. In other Member States, flexible operations of NPPs is a standing and proven practice.
- Flexible operations of NPPs depend on:
    - the applicable regulatory framework which may vary from one Member States to another and which includes conditions set by the grid system operator and the nuclear safety regulator (at design and operational stage).
    - the commercial decision of the operator considering the market environment. Nuclear power plants have high upfront capital costs and relatively low fuel and operational costs when compared with fossil fuelled generating units. Operating nuclear power plants at full capacity is therefore generally considered as the best option.
- Nuclear power is needed in the EU in the long-run as an important contributor to a decarbonized EU power system. For that reason, the EU needs a well-functioning electricity market recognizing the specificities of long-term investments in low-carbon energy sources and a functioning EU Emissions Trading Scheme (EU-ETS) delivering a long-term and predictable carbon price.
- As the request for flexible operations of NPPs increases, the electricity market design will need to incorporate appropriate mechanisms to reward flexible operation in a system containing an increasing proportion of intermittent renewables.

1. Introduction

In most places, the best economic and technical option is to operate nuclear plants in baseload mode – generating at full rated capacity for as long as maintenance and refuelling allows. This has led some to believe that nuclear plants are inflexible and therefore incompatible with high shares of variable renewable energy sources (vRES), when analysis shows for a fact that the two can be highly complementary if the right framework is adapted.

Motivated by concerns about relying on fossil fuel imports and climate change, the European Union decided to develop policies which promote the development of renewable energy sources. With a current target set for 2020 at 20%, policymakers are currently discussing the 2030 targets that range between 27%-35%. It should be clarified that a 27% RES target in energy consumption means circa 45% of installed RES in the power mix.

However, the rapid expansion of intermittent renewable energy forms, namely wind and solar, is driving an increasing need for technologies capable of providing flexible power when it is needed. As the share of vRES sources in electricity production has increased, so too have concerns about the future reliability and resilience of EU transmission and distribution networks.

Today, the energy debate in Brussels is calling for more European flexible networks to enable the 'energy transition towards a decarbonised electricity system' and the European Commission is actively supporting both. However, both the concepts of flexibility and energy transition need careful definition. Flexibility should not itself be the goal, but rather an enabler that helps to achieve a deep decarbonisation of electricity supplies at an acceptable cost, without compromising system reliability and security.

It is important to realise that no one option listed in the Box 1 below is expected to do the job of managing the impacts of an increasing share of vRES all by itself. This is not even the case for system balancing today. Rather, there needs to be a shift in thinking about which options working together can provide sufficient flexibility while still allowing other energy goals to be met, in particular decarbonisation of the power system. It is also important to realise that back-up options imposed by vRES come with an additional system cost and may face technical challenges in their implementation. This system cost will need to be passed onto consumers who should recognise it fundamentally as the price of accommodating an increasing share of vRES. The individual challenges will require focused efforts to overcome and will need to be constantly re-evaluated as the situation evolves.

Range of options which can help provide flexibility services to electrical networks, including the potential limitations:

- Gas, coal and biomass plants. These all play a role in system balancing today. However, they also cause issues with CO_2 emissions and air quality that need to be mitigated. There is an increasing body of evidence on the urgency of climate change which suggests that natural gas has a limited role to play as a bridging technology if targets are to be met.
- Energy storage. Current technologies (notably batteries and pumped hydro) are ideal for voltage and frequency control, and can provide supply for limited time periods. However, fundamental breakthroughs in technical performance and cost would be needed for significant energy storage over longer timescales to become economic. Hydro power and pumped hydro face geographical limitations and can have severe environmental impacts, while there may be potential raw material and recyclability constraints for batteries.
- Demand Side Management (DSM). This relies on having a portion of instantaneous demand on the system that is elastic, i.e. readily and economically transferable to another time in response to a price signal. The deployment of digital 'smart grid' technology is expected to assist with this. While DSM offers some opportunities to better manage systems, there may only be limited potential for genuine demand elasticity and it is unrealistic to expect customers to forgo one the key benefits of electricity, i.e. its availability on demand when required.
- vRES curtailment. This requires adequate control systems to be put in place on vRES generators. It also requires a willingness to forfeit some zero fuel cost vRES generation for reasons of system security, with compensatory payments to participating vRES generators.
- Nuclear load follow (flexible operations). This requires that reactors are physically adapted to operate in flexible generation mode, depending on their design, fuel and reactor control. To date, some 2/3 of NPPs in France have been operated routinely in flexible mode. As with vRES curtailment, there would need to be compensation to account for lost generation revenue. There are also concerns in some instances over the effects of thermal cycling and the potential for increased wear and tear on critical components.

2. Technical aspects

2.1 What is flexibility

Power system flexibility is an inherent feature in the design and operation of power systems. Power systems are designed to ensure a spatial and temporal balancing of generation and consumption at all times. Power system flexibility represents the extent to which a power system can adapt electricity generation and consumption as needed to maintain system stability in a cost-effective manner. Flexibility is the ability of a power system to maintain continuous service in the face of rapid and large swings in supply or demand.[1]

Flexible operating modes of the electricity generating power plants

- Frequency regulation (primary regulation): is the direct picture of the balance between production and consumption. Frequency increases if the production is in excess and decreases if the reverse is true. The primary frequency regulation, which aims at restoring the most feasible operating system conditions in the short-term (between 0 and 15 seconds) after a disturbance, is completely automatic and is decentralised.
- Secondary regulation/Load following. The adaptation to the demand is automatically performed. After a load change and the consequent primary regulation, the system frequency is not generally coincident with the nominal one. For this reason a secondary frequency regulation is needed in order to get the system frequency back to the nominal reference value. The secondary regulation is a control action developed at central level in the power system.
- Tertiary regulation/Load following. The adaptation to the demand is performed by the operator. The tertiary frequency regulation represents a further longer-term subdivision of the effects of a load change among the concerned generators with the scope of cost minimisation. This regulation is operated at a constant frequency level.

[2]

[1] Flexibility options in electricity systems – ECOFYS – March 2014
[2] Load-following operating mode at Nuclear Power Plants (NPPs) and incidence on Operation and Maintenance (O&M) costs. Compatibility with wind power variability – JRC 2010

2.2 Can nuclear reactors be flexible?

In several European countries (France, Germany, Slovakia, Czech Republic and so on), nuclear power plants have actual and noticeable load following and flexibility manoeuvring capabilities. The original motivation for the introduction of these nuclear power plant capabilities has generally been the relatively large share of nuclear energy in the national or regional electricity mix and, therefore, the need for these nuclear power plants to contribute to the stability of the electrical system by adapting to changes in demand. Nonetheless, this has demonstrated on a grand scale the ability of nuclear energy to balance the intermittency of variable renewables. Actually, nuclear energy appears as being the only large scale, non-weather dependent low carbon technology that is capable of doing so. The other low carbon technology, but with smaller installed capacities, is biomass, although there are increasing doubts about just how low carbon biomass is when transportation is taken into account.

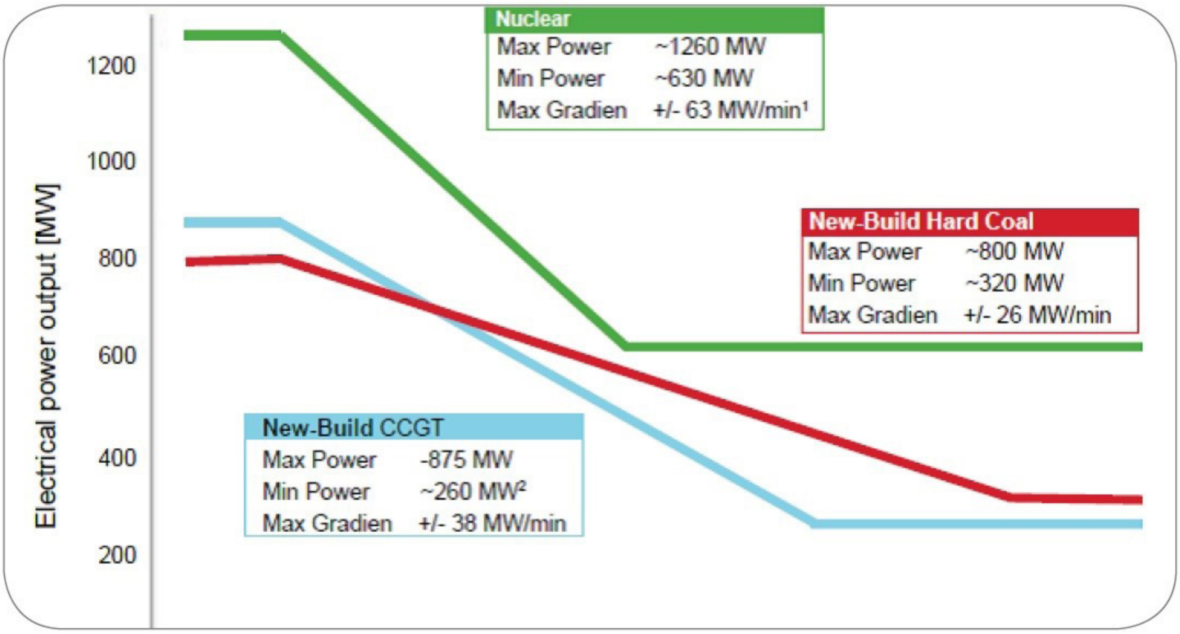

Figure 1. Comparison of load follow ability of NPP, hard coal power plants and CCGT [3]

The majority of nuclear power plants in the world are operated in a base load mode: their output remains more or less constant (generally at the maximum rated power) during their whole production cycle. This is motivated by operational ease and maximization of economic efficiency. However, existing experience shows that a large variety of reactor technologies can actually cope with load following provided the necessary technical provisions are made and authorised by the nuclear safety regulator: Pressurized Water Reactors (including VVER), Boiling Water Reactors and so on. The analysis developed during the design and licensing of these NPPs with load following capacity, and the now accumulated experience feedback, demonstrate that this operating mode complies with the highest safety standards.

[3] Nuclear Energy Factsheets Load following capabilities of Nuclear Power Plants – SNETP 2017

When combining the different capabilities, power variations of up to 10,000 MW could be absorbed by German NPPs in 2010. In France, with an average of 2 reactors out of 3 available for load variations, the overall power adjustment capacity of the nuclear fleet equates to 21,000 MW (i. e. equivalent to the output of 21 reactors) in less than 30 minutes. In addition, it is also possible to disconnect units temporarily from the grid, and then restart them later. If kept in 'hot stand-by' mode, full load can then be resumed within a couple of hours.

The European Utilities Requirements (EUR), a set of documents developed by European utilities1 with a view to harmonizing design specifications for the safe and reliable operation of future nuclear power plants, include provisions for frequency control (both primary and secondary) and load following capabilities. The already existing most performant NPPs in this domain are fully in line with EUR.

3. Enabling conditions

3.1 Regulatory aspects

The flexible operation of the nuclear power reactors has to comply with the specific regulatory aspects of both the TSOs and the nuclear regulator.

3.1.1 TSOs

Typically, the grid system operator governs the access to and usage of the grid system according to a grid code. Such codes set the technical and commercial requirements with which the grid users must comply. The grid code may require generating units to have a specified capability for frequency control or load following. The owner/operator of a NPP needs to enter into discussions with the grid system operator at an early stage, to ensure a common understanding of the requirements, how they are to be interpreted, and how compliance with the requirements will be assessed.

3.1.2 Nuclear regulator

While specific regulations governing the safe operation of NPPs vary among Member States, the general regulatory philosophy is consistent: NPPs must be designed, built and operated within the bounds set by the operating licence and the safety criteria. Regardless of small variations in the national regulatory framework, the nuclear regulatory body's roles and responsibilities are consistent: establish and maintain regulatory requirements governing safe operation, oversee the owner/operating organization's compliance with those requirements, and approve changes to the NPP's design and licensing bases. Nuclear safety prevails over any other aspect and, therefore, the nuclear regulatory body has a critical and primary role in the flexible operation decision and it is essential to obtain their involvement in this decision making process as early as possible.

3.2 Economic aspects

From an economic perspective, operating nuclear power plants at baseload is generally considered as the most economically advantageous mode. New nuclear units have high upfront capital costs but the sum of the costs for operation and maintenance and fuel are lower when compared with fossil fuelled generating units. Therefore, in competitive markets, revenues from electricity generation are usually maximized at full load operation. When the levelized cost of electricity (LCOE) produced by nuclear is calculated for a more accurate comparison with the other technologies, a capacity factor of 85%[5] is taken into account. The situation is different for nuclear units that are part of a long-term operation (LTO) program where the capital costs for lifetime extension are significant lower that for new ones leading to very competitive electricity prices and providing more economic margins for more flexible operation.

Consequently, enabling NPPs to physically ramp up and down for load following — to varying degrees at different times — will certainly affect the economics of NPP operation. The NPP owner/operator will consider providing flexible operation as a value to the grid system and the nation's energy policy at large and will expect to be compensated for the associated costs. The electricity market design needs to incorporate the appropriate mechanisms to reward flexible operation in a system containing an increasing proportion of intermittent renewables, otherwise guaranteeing security of energy supply and the stability of the grid will increasingly be jeopardised.

The decision to perform load following depends very much on how flexibility is valued by the national electricity market and on legal/regulatory constraints.

[5] Projected Costs of Generating Electricity 2015 Edition – IEA/OECD-NEA

4. Conclusions

Nuclear power plants are the only large non-weather-dependent low-carbon electricity source that are capable of operating in both baseload and flexible modes.

Despite a broad perception that nuclear power plants are inflexible and can only operate as baseload sources, experience has shown that, when authorised to do so, nuclear can be very flexible, being able from a technical point of view to perform both frequency control and load following operations in a similar manner to other sources (i.e. gas, coal or hydro) and to provide stability to the grid system.

From the flexibility point of view, nuclear is the best partner for vRES as it is the only source that can provide flexibility without producing CO_2, like fossil fuels, or being dependent on the availability of water, like hydro.

The EU needs a well-functioning electricity and carbon market, including long-term predictability of the carbon price. That would lead to a level playing field for all low-carbon energy sources in a market where subsidies were not needed. In such a market, a proper reward for flexibility would encourage nuclear power plant operators to operate in a flexible way.

« If Europe is committed to reducing its CO_2 emissions whilst at the same time ensuring security of supply, then it needs to take low-carbon nuclear energy seriously as a flexible partner for renewables. »

Yves Desbazeille
Director General, FORATOM

About us

The European Atomic Forum (FORATOM) is the Brussels-based trade association for the nuclear energy industry in Europe. The membership of FORATOM is made up of 15 national nuclear associations and through these associations, FORATOM represents nearly 800 European companies working in the industry and supporting around 800,000 jobs.

A flexible nuclear solution to the intermittent renewable challenge

Flexible nuclear power plants are the best partners for variable renewable energy sources and can help Europe achieve its two main goals:

- Ensure security of energy supplies
- Reduce its CO_2 emissions.

Today, the general misconception is that nuclear can only provide a baseload solution. But this is not necessarily the case, as nuclear power can also be flexible. It can provide a large-scale solution to the need for network stability and flexibility. By combining intermittent renewables with flexible nuclear, Europe will decarbonise its electricity system, whilst at the same time ensuring security of supply – at an affordable cost!

When it comes to nuclear flexibility, two elements need to be taken into consideration: the regulatory framework (which can vary from one Member State to another), and the market environment.

FORATOM therefore believes that EU energy policy needs to ensure:

- a well-functioning electricity market recognizing the specificities of long-term investments in low-carbon energy sources
- a functioning EU ETS which delivers a long-term and predictable carbon price
- the implementation of appropriate mechanisms to reward flexible operation in a system containing an increasing proportion of intermittent renewables

For more information, please contact :

- Jessica Johnson (Communications Director) jessica.johnson@foratom.org
- Andrei Goicea (Executive Manager) andrei.goicea@foratom.org

FORATOM
THE VOICE OF THE EUROPEAN NUCLEAR INDUSTRY

Avenue des Arts 56
1000 Brussels
tel +32 2 502 45 95
foratom@foratom.org
www.foratom.org

07-05-2018