International Youth Nuclear Congress: Nuclear flexibility from myth to reality, a point of view from the younger generation.

Prepared by the International Youth Nuclear Congress, a global network of young volunteers advocating for the use of nuclear technologies in support of furthering the United Nations SDG goals.

The International Youth Nuclear Congress (IYNC) is a global network of young volunteers advocating for the use of nuclear technologies in support of furthering the United Nations SDG goals. With representatives in over 50 countries, IYNC aims primarily at promoting knowledge transfer between generations and across international boundaries in the field of nuclear science and technology.

1.1 Introduction

The deployment of renewable energies is accelerating worldwide, and it is often claimed that this is incompatible with nuclear power (Ueckerdt and Kempener 2015). "Nuclear plants are inflexible base load energy sources" (Ueckerdt and Kempener 2015) is a prevailing myth. Yet, the reality is largely different. For the past decades, several countries, including France and Germany, have operated nuclear power plants as flexible power generators (Feutry 2017). And future nuclear power plants will have enhanced flexibility potential to support grid stability and the integration of renewable energies.

In this chapter IYNC reviews examples from France and Germany to debunk the 'nuclear inflexibility myth' and share perspectives from the 'younger generation'.

1.2 From a Base Load Power Legacy

Historically there are both technical and economic reasons for nuclear power plants to operate as base load generators. Most nuclear plants operating today were designed and constructed during the second part of the 20th century, during a time when energy needs were constantly increasing and the variability in the power grid was limited.

The supply of power had to always equate to the demand in the power grid to ensure its stability – that physical constraint still applies today. Base load power, mostly hydro (running water), coal and nuclear, supplied the minimum power needed at all times. The variability, mostly coming from the changes in electricity demand, was supplied by gas or hydro (storage) plants, known as "peaking plants".

Nuclear power plants have hence been designed to mostly operate with a constant level of power. This approach was supported by the economics of nuclear power. With high investment costs and low operational costs, it was preferable for nuclear plants to generate as many kWh as possible to grow revenues. The remuneration of those plants were often indexed on the energy generated at a fixed price, regardless of when a kWh was generated. Almost no economic value was given to

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dispatchable power, i.e. the ability to supply energy when needed, also often called flexibility. This paradigm has shifted.

The start of the 21st century coincides with an acceleration of renewable energies deployment and a changing landscape for grid stability: with more renewable energies, variability is added on the supply side, which challenge existing power grids. At the same time, the remuneration mechanisms for power generators have evolved in several OECD countries with the liberalization of energy markets and the introduction of power exchanges. Generation assets are dispatched using a merit-order ranking system, based primarily on plant marginal costs and volumes available.

In the current context, nuclear plants remain at the lower end of the merit order. Their marginal costs are lower than coal or gas plants. Usually only wind, solar and hydro power have priority dispatch over nuclear generation, either due to lower marginal costs or the local regulatory framework. As a consequence, baseload is the preferred mode to operate nuclear power plants in many countries. This does not mean nuclear plants cannot operate in a flexible manner. In fact, most nuclear power plants have the technical capability to operate flexibly, leveraging the heritage of the very flexible nuclear submarine reactors.

Only a few countries have converted those technical capabilities into services to the grid thus far. The lack of economic incentives and the legacy of operating and licensing rules are the main reasons for explaining the limited appetite of nuclear operators for flexible operations. With the growing share of intermittent renewables, nuclear plants will likely see increased opportunities to ramp-up flexible operations, as the experience of some countries is already showing.

1.3 Successful Flexible Operations

In France and Germany, nuclear plants have been operated as flexible assets for many years. Both countries had different motivations and took distinct routes, but both have successfully demonstrated that nuclear power plants are flexible generators. The most visible aspect of their flexibility is the ability to operate in load-follow modes, i.e. to adapt the level of power output when required. Another aspect, less known, is the capability to provide services essential to grid stability, such as frequency control.

As described in EDF as part of the Flexible Nuclear Campaign, the large share of nuclear energy in the electricity mix (70.6% in 2019 (RTE 2019)) in France led the operator, EDF, to adapt its fleet of 56 pressurized water reactors (PWRs) to ramp-down and ramp-up power levels. This is particularly needed on weekends or at night when the demand shrinks. French plants can lower their output between 100% and 20% of nominal power in 30 minutes and after 2 hours go back to full power, twice a day (Feutry 2017).

The experience accumulated by EDF, with 30+ years of load-follow operations, shows limited impact of flexible operations on plant performance and without any impact to safety. EDF estimates that increased wear and tear induced by load-follow operations (IAEA 2018) reduces plant availability by 0.5 %. Similar to gas plants, it is meaningful to operate nuclear units at constant power from a cost perspective, as has been discussed in other chapters. At the same time, there is a significant upside for load-follow operations since it enables EDF to generate power when most needed. In addition, besides 'slow' power changes or load-follow operations, nuclear plants have been adapted to offer extended capabilities on frequency control.

The German energy landscape is somewhat different. As part of its "energy transition", Germany is phasing-out nuclear power with the intent to shut-down all its nuclear power plants by 2022 ("Germany 2020 - Energy Policy Review" 2020). Currently six nuclear plants are still in operation. Those six units have an opportunity to substantially contribute to grid stability using flexible operations. Such situation, in which nuclear power plants can play a significant role in providing grid services, has been observed since 2011, mostly dueto the acceleration of renewable energies deployment. In 2019, one-third of German power came from wind and solar alone ("Public Net Electricity Generation in Germany 2019: Share from Renewables Exceeds Fossil Fuels - Fraunhofer ISE" n.d.). As a consequence, several nuclear plants have increased their flexible operations in recent years.

Most nuclear plants in Germany are PWRs[1] designed to accommodate flexible operations. In the 1960s Germany planned that nuclear energy would become its largest source of power [5]. Anticipating a large share of nuclear generation KWU/Siemens, the German nuclear plant designer, adapted its designs to provide load-follow operations capabilities. According to their technical specifications, German nuclear units are able to reduce their power at 5%/min between 100% and 50% nominal power and at 2%/min up to 20/30% of nominal power (IAEA 2018). Considering a standard Konvoi PWR German plant with 1200 MW nominal electrical output, this translates to a power change of up to 600 MWe in 10 minutes at 60 MW/min. As such, nuclear plants are among the most flexible units in the German power system.

For many years, the potential for flexible operations of nuclear plants was barely used. Nuclear units operated mostly as baseload generators due to economic considerations. However, load-follow operations grew substantially since 2011, in particular for the plants operated by E.ON/PreussenElektra. PreussenElektra, the nuclear division of the German utility company E.ON, operates half of the nuclear power plants still in operation and contributes to grid stability with three types of flexibility: ancillary services, portfolio optimization and load shadowing.

Ancillary services are divided into "primary", "secondary" and "minute" control reserves for PreussenElektra. Primary reserve corresponds to fast power changes within a limited power range, whereas "secondary" and "minute" reserves require slower but more extensive load-follow operations. The German transmission system operators (TSOs) define and procure the control reserves, partly in cooperation with neighbouring countries. Various tendering processes are organised to select the most relevant bidding units. For operators, participating to those markets either by offering capacities or adjusting power, translates into additional revenues.

Portfolio optimization refers to the adaptation of power levels to market conditions. High shares of wind and solar regularly pressure market clearing prices to low or negative levels. This encourages nuclear operators to voluntarily reduce their power output, and buy back the power

[1] One boiling water reactor (BWR) is still in operation in Germany. BWRs are by conception even more flexible than PWRs with regards to load-follow operations.

hedged using long-term contracts, from the short-term markets. This mechanism also enables additional revenues.

Load shadowing, or power redispatch/curtailment, is performed on TSOs demand in case grid stability is at risk, often due to bottlenecks in power transmission lines. Those situations have substantially increased over recent years in Germany. Redispatch requirements must be legally enforced by operators and they receive compensation for the lost energy revenues. From an operational perspective load-shadowing is similar to "secondary" control reserve load-follow for nuclear plants.

Ancillary services, portfolio optimization and load shadowing are leading to various reductions in power output. Load-factors are hence decreasing but revenues and profitability are increasing. This might sound counter-intuitive but is simply the result of compensation mechanisms, beyond energy price only. This is market dependent and applies at least to the examples previously described. Overall, experiences gathered in France and Germany demonstrate the ability of nuclear energy to operate as flexible power generators, supporting grid stability and the integration of variable renewable energy sources, while offering additional revenue streams to plant operators.

1.4 Perspectives from the younger generation

The energy business is going through a fast and deep transformation and it is the right time to broaden the discussion on nuclear flexibility. Nuclear power provides 10% of the world's electricity and is the world's second largest source of low-carbon power after hydro (IEA 2019). Renewables and nuclear are both needed to help decarbonize our economies and should coexist in the current and future global clean energy mix ("Summary for Policymakers of IPCC Special Report on Global Warming of 1.5°C Approved by Governments — IPCC" n.d.). To meet the growing needs of the energy market, there is a need for flexibility in nuclear energy, both for existing plants and innovative technologies. In truth, nuclear offers more than one type of flexibility and those flexibilities must be recognized, further developed and appropriately compensated.

In order to economically operate nuclear power plants, a cultural and regulatory shift is needed in most regions around the world to enhance load-follow operations and grid services compensation. A "base load is better" dogma still seems to apply, whereby several operators are reluctant to support load-following operations. The experiences of France and Germany, among others, indicates that flexible operations are an opportunity. Most nuclear plants could also perform more load-follow activities. Operational wisdom, processes and even global actors, such as World Association of Nuclear Operators (WANO), who often highlights the challenges to perform load-follow operations, need to adapt to unlock nuclear flexibilities.

Some operators are moving towards more load-follow operations, with successful examples recently stemming out of the USA. Their motivations are unfortunately often defensive choices against adverse market conditions. As system costs are becoming the focus of power markets versus energy cost alone, market mechanisms have to be re-evaluated. Beyond frequency control, generators should be duly compensated for their roles in providing reactive power, inertia, supporting black start sequences and being reliable and dispatchable assets.

New nuclear designs offer further possibilities. Some technologies have advanced technical load-follow capabilities, including small modular reactors (SMRs). Often SMRs concepts are building on the multi-dimensional aspect of flexibility: long term vs. short-term, load-follow vs. non-load-follow with co-generation, hydrogen production, desalination or thermal storage options. Those different approaches to nuclear flexibility will together amend the persistent widespread misconception that nuclear plants can only function as baseload sources of power.

In this journey to debunk the "inflexible base load" myth, communication and advocacy groups have a paramount role to play for which the younger generation and IYNC are committed to take an active role. Since 2009, IYNC organised or sponsored events at UN COP conferences to foster a dialogue around the capability of renewables and nuclear to work together towards carbon emissions reduction. Among other examples, since 2014 a specific technical track on "renewable and nuclear coexistence" is focused on innovative nuclear flexibility solutions during IYNC bi-annual conference. Looking ahead, IYNC will continue to support knowledge transfer between generations and across international boundaries on this topic, leveraging its bi-annual conferences, innovation contest I4N, mentorship program, and broader climate change activities.

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