The Load Change Ability of Nuclear Power Plants – Experience and Outlook

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Myths and Facts

Technical design

Operational practice
Nuclear Power Plants: Obstacle for the development of renewables?
Myths...

"Nuclear power plants are the most inflexible facilities within the traditional power plant fleet. Because NPPs are hardly adjustable and frequent starts and shut-downs should be avoided for safety reasons, if possible."

Some further quotations…

"Extended lifetimes of extremely inflexible, literary non-adjustable nuclear power plants would interfere with the necessary development of a flexible and decentralized energy supply" ¹

"Power Plants that are supposed to balance the fluctuation of energy production based on wind and sunlight need to be flexible above all. Nuclear power plants are exactly the opposite – inflexible and limited adjustable. They are designed to operate preferably at 100% load, constantly producing the same amount of energy, no matter if it is needed or not." ²

"A lifetime extension for nuclear power and additional coal-fired power plants jeopardize the development of renewable energies. Because inert base load power plants blocking the grid cannot provide a sufficient flexibility to complement the offer from renewables in line with demand." ³

² Atomkraft – kein Weg für die Zukunft, Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU), June 2009, p. 2 (translated)
³ Nicht alles passt in Deutschlands Zukunft (poster), Bundesverband Erneuerbare Energie e.V. (BEE), June 2009 (translated)
…and facts:
Example of a fast change in power output at the Emsland NPP

Proof of load-following ability during the commissioning of the Emsland nuclear power plant

Maximum power ramp rate: 140 MW/min
What is the origin of the flexibility of German nuclear power plants?

- A high flexibility was implemented into the design of German nuclear power plants since the 1970ies.

- Flexibility is not a result of an ex post upgrade.

- At that time, the German government was aiming at an extended use of nuclear power and thus, an increase of the nuclear share in power production was to be expected.

- Changes in demand would have needed to be balanced by nuclear power plants according to the common practice in France today.

"Social-democratic chancellor Willy Brandt, who took office in 1969, had been a committed friend of nuclear power before. [...] The energy program published under Brandt in 1973 recommended the commission up to 50000 Megawatts of nuclear power until 1985. That would have corresponded to 40 to 50 reactors." (Frankfurter Rundschau, translated)
Extension of the "4. Deutsches Atomprogramm" ...

> Social-liberal federal government (1972-1974)

> Autumn 1973: First oil crisis in connection with Yom Kippur war

> Extension of the "4. Deutsches Atomprogramm" (4th German nuclear power program):

  "labored development of nuclear power until 1985"

  - goals: 18,000 MW$_e$ of nuclear power until 1980
  - 40,000 MW$_e$ of nuclear power until 1985 ("preferably 50,000 MW$_e$")

Gross power production in 1985 (actual data)

- hydro 4,1%
- nuclear 31,2%
- fossil 64,7%

What if…?

- hydro 4,1%
- fossil 27,0%
- nuclear 68,9%
Examples from practical experience (1): Unterweser and the turn of tides...
Examples from practical experience (2): Biblis was operated in load-follow mode for many years...

- Routine adjustment of power production inline with demand from 1986 to 1994
  - optimizing the power plant fleet
  - preventing coal-fired power plants from damage
- Comparable operation also in other German power plants

After the deregulation of the markets, emphasis lay mainly on economical aspects. This caused operators to maximize the load factor of nuclear power plants…
… but then, wind conquered the land
The development of renewable energy increases the need for load-following capacity and flexible units

The residual power demand from 02 to 09 Feb 2009

The residual load (blue) equals the demand minus renewables. The residual load needs to be generated by the traditional power plant fleet.

Steep increase in demand coincides with a rapid decrease in wind power production: The traditional power plant fleet has to provide additional 30 GW within a short period of time.

> Fluctuations in the offer from renewable energy will cause an increasing need for flexibility of the power plant fleet in the short and medium term

> In addition: necessity to store energy from renewable sources and to provide capacity reserves in the long term.
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Pressurized water reactor NPPs
Proven abilities...

Anforderungen der DVG¹ für Kernkraftwerke

<table>
<thead>
<tr>
<th></th>
<th>KWU-1300 MW-DWR-KKW zeigten bereits</th>
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<tbody>
<tr>
<td>Rampen: ± 5%/min um 50% der Vollast</td>
<td>± 2%/min um etwa 80% der Vollast</td>
</tr>
<tr>
<td></td>
<td>± 10%/min um 20% der Vollast</td>
</tr>
<tr>
<td>Sprünge: ± 5% (mit 1%/s = 60%/min)</td>
<td>± 5%/min um etwa 55% der Vollast</td>
</tr>
<tr>
<td>in etwa 5 min Abstand</td>
<td>± 10%/min um etwa 23% der Vollast</td>
</tr>
<tr>
<td>alles im Bereich von 40 bis 100% der Vollast</td>
<td>±60%/min um 8/10/15% der Vollast („Sprung“)</td>
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</tbody>
</table>

Source:
Dipl.-Ing. W. Aleite "Lastfolgefähigkeit von Kernkraftwerken mit Druckwasserreaktoren", KWU AG, Erlangen
VGB-Kongreß „Kraftwerke 1985"
Comparison of ramp capacities...

Within the power plant fleet, nuclear power plants rank among the most flexible facilities.

1 For a power ramp that lies below 20% of the maximum unit power, a ramp rate of up to 126 MW/min can be attained.

2 One turbine gets turned off.
Reactor control
Example: Pessurized water reactor

**Design: load changes "fully automated" from the control room**

Fast, "gentle" load changes with a constant average primary coolant temperature

- Low fatigue of material in the reactor coolant system
- Fast control: control rods
- Supplemental control: boric acid

**Safety:**
Double surveillance of reactor physical parameters (e.g. neutron flux, power density) by limitation systems and reactor protection
Restrictions to load change ability:
Reactor and neutron physical boundaries, safety issues...

Good Practice: **No load changes** …

… during **fuel "conditioning"** (begin of cycle)

… at a **low boron concentration** in PWR (end of cycle)

… along with **fuel element damages** (whole cycle)

… shortly before and during **recurrent tests of the core instrumentation**
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High flexibility could be shown in practice
26 Dec 2009: Nuclear power plants meeting the demands of the electrical grid

> Temporary increase in wind power coincided with a low demand.
> Total reduction of nuclear power (RWE/E.ON): ~ 4,700 MW
Output power reduction at the NPPs operated by RWE
01 Jan 2011

> Ramp rates of ~ 25 MW/min
Different kinds of balancing energy
Minimum requirements (Germany) ...

> **Primary control:**
  Adjustment of the power output within 30 seconds by 2%\(^1\) of the nominal unit power as response to a 200 mHz signal (frequency stabilization). The adjusted output level has to be maintained for 15 min.
  > At nuclear power plants usually with approx. ± 12 MW/sec within a range of 40-75 MW

> **Secondary control:**
  Adjustment of the power output within 5 minutes within the qualified range. Remote control required.
  > Example: 1200 MW unit, qualified range 120 MW, ramp rate: 24 MW/min

> **Minutes reserve:**
  Adjustment of the power output within 15 minutes within the qualified range.
  > Example: qualified range 225 MW, ramp rate: 15 MW/min

> Nuclear power plants fulfill the technical requirement to provide all kinds of balancing energy.

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\(^1\) Depending on the optimum dispatch, less than 2% of \(P_{\text{max}}\) can be delivered as response to frequency deviation of +/-200 mHz; nevertheless 2% of \(P_{\text{max}}\) have to be attained during the prequalification.
Summary

Nuclear Power Plants ...

... are able to adjust their power output over a wide range within a short period of time.

... do not need to be upgraded to meet future demands. High flexibility is already implemented into their original design.

... could demonstrate their load-following abilities in practice.

... show only few temporary restrictions concerning load-following due to reactor physics.

... can be optimized concerning fuel element design and core loading in case of an increasing demand of load-following. Thus, the output of nuclear power plants could be adjusted even faster and more often.

... can be operated safely both in base load and in load-following mode.

... are ideal partners of the renewable energies.

"peaceful" coexistence at Unterweser and Brokdorf
Backup
Einsatz der Kernkraftwerke für negative Minutenreserve
Greenpeace-Studie "Grenzen und Sicherheitsrisiken des Lastfolgebetriebs von Kernkraftwerken"¹

> Die Vorwürfe:

- "Die Zulässigkeit des Dauerbetriebs von Kernkraftwerken im Lastfolgebetrieb […] bedarf […] der atomrechtlichen Genehmigung. […] Solange diese Genehmigungen nicht vorliegen, ist die Atomaufsicht verpflichtet, den Lastfolgebetrieb durch aufsichtliche Maßnahmen zu beschränken." (S.3)

- "Durch den Lastfolgebetrieb werden die Risiken des Betriebs von Kernkraftwerken erhöht." (S.29)

- "Bereits nach den veralteten Herstellerspezifikationen sind die sicherheitsrelevanten Komponenten der Kernkraftwerke nur für etwa 40 Jahre ausgelegt." (S.30)

¹ Autor: Wolfgang Renneberg
Lastwechselfähigkeit und Sicherheit: Die Fakten ...

> Die Kernkraftwerke wurden bereits in der Vergangenheit routinemäßig im Lastfolgebetrieb eingesetzt. Dies gilt insbesondere für Biblis in der Zeit, als der Autor der Studie Leiter der Atomaufsicht im hessischen Umweltministerium war.

> Der Anlagenhersteller hat die Auswirkungen des Lastfolgebetriebs unter heutigen Bedingungen untersucht und bestätigt, dass der Lastfolgebetrieb keine Auswirkungen auf das Sicherheitsniveau der Kernkraftwerke hat.

> Der Einsatz der Kernkraftwerke im Lastfolgebetrieb war viele Jahre lang nicht erforderlich. Daher ist selbst bei den älteren Anlagen bisher nur ein kleiner Bruchteil der spezifizierten Leistungsänderungen aufgebraucht.
Brennstoffkonditionierung beim Anfahren des Reaktors nach Stillstand, bei mehrtägigem Teillastbetrieb

Beim Anheben der Reaktorleistung:

> Der Brennstoff erhitzt sich.

> Die Temperatur steigt im Inneren der Brennstäbe schneller als im äußeren Bereich. Pellets legen sich an das Hüllrohr an.

> Die Hülle braucht Zeit, um sich mit dem Brennstoff auszudehnen. (Riss-Prävention)

Pellet-Clad-Interaction (PCI), Rissbildung im Hüllrohr