Increasing Incitation for Non-Baselode Operation of Nuclear Power Plants - IAEA’s Observations

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Primary consideration: Reliable electricity

- Electrical grid system is to ensure the provision of secure and reliable electricity, i.e. with an adequate power quality and with tolerable interruptions to all consumers (and with reasonably minimal effect on the society and environment).

- The electrical power grid systems are designed, operated and controlled to collect, transmit and deliver large amounts of power between power plants (including nuclear generators) and demand points, by connecting all sources of electrical power to consumers, in a secure and effective manner.

- All electrical grid systems require the output of generating units to be adjusted (flexible generation) so that the total generation changes to match variations in the demand during the day, week, month, season.

- Controlling the total generation is equivalent to controlling the system frequency. A stable system frequency is a common good for all users of the electricity system — although it is presently not a traded commodity.
Affordable Electricity

• In any system that has a mix of generating technologies, the commercially sensible method that minimizes overall operational costs is to operate the generating units in a merit order, so that the output from generating units with the lowest marginal cost is maximized, and generating units with higher marginal costs are operated flexibly.

Note that the $$/MWh values are for illustration purposes only.
Value of Electricity, Value of Generation

• However, in real markets, the ‘least cost’ stacking of the generation sources is only one part of the equation between generation cost and demand price, as demand response may lower the marginal cost. This requires the management and optimization of generation technologies.

• Optimization of a generation plan of an electrical system aims to minimize, for a defined period of time, the cost of the generation.

• On the other hand, in almost all cases, the merit order is built on factors, such as:
  • Dispatch priority: Either for technical reasons (e.g. in the case of ‘run of the river’ hydropower) or for regulatory reasons (e.g. in the case of wind or solar power);
  • Must operate in baseload unit: The units that are limited to only baseload operation due to technical reasons;
  • Incapacitated unit: The operational limitation/availability of equipment in a particular generation plant;
  • Provision of frequency containment reserve and/or frequency restoration reserve to control frequency deviations.
For example: NPPs vs. Coal/Oil Plants

- Nuclear energy generating units have high fixed costs and low marginal costs (low fuel costs) when compared with generating units powered by some fossil fuels, such as coal and oil, which have relatively lower fixed costs but typically higher marginal costs.

- Hence, in any system that has a mix of nuclear and fossil fuel energy generating units, the overall lowest cost method of operation is generally for the nuclear units to run at full load (i.e. baseload) as much as possible, and for the fossil fuel energy generating units to provide frequency control and to perform load following **.

** This is true even if the nuclear energy generating units have the design and operational capability to operate flexibly.
Typical rule for nuclear generation flexibility needs

Generally, if the total output capacity of the nuclear generating units in an electrical grid system is:

(a) a small fraction of the total generating capacity; and,
(b) significantly less than the minimum residual demand;

then the grid system operator should be able to balance electricity generation with demand and to control the system frequency without requiring nuclear generating units to operate flexibly.
Common mind set: More beneficial economic reasons and less complexity of operation have made the “baseload” mode of operation preferable.

Starting in the late 2011, numerous Newcomer and Established Member States (MSs) contacted IAEA for a guidance on Flexible Operations of NPPs:

- An increasing need for NPPs to operate in “flexible” modes(*)

(*) i.e. load following, frequency control, or abrupt changes to output upon requests from grid operators
IAEA’s Planned Series of Activities

- Publication 1 of 3: The Guideline (NPES)
- Publication 2 of 3: Economic Modelling of Flexible Operations (PESS/NPES)
- Publication 3 of 3: Flexible Operation in New and Advanced Reactor Technologies including SMRs (NPTDS/INPRO/PESS)
Non-baseload Operation in Nuclear Power Plants: Load Following and Frequency Control Modes of Flexible Operation

IAEA Nuclear Energy Series
No. NP-T-3.23
Definition of Flexible Operations

AFC – automatic frequency control; AGC – automatic generation control
FCR – frequency containment reserve; FRR – frequency restoration reserve
Aspects and Players of Flexible Operations

- Technical aspects
- Operational/Procedural aspects
- Fleet aspect
- Economic aspects
- Policy aspects
- Regulatory aspects
Flexible nuclear and challenging grid

- Changes in electricity market structure and rules
  - Equal grid service
  - Deregulation
- Constraints on non-nuclear units
  - Shutting down old
  - Shutting down dirty coal
- Local grid constraints
  (e.g. best wind field is nearby NPP)
- Large share of nuclear generation
  - National
  - A region in a country
- Growth in RES or non-dispatchable generation
  (e.g. renewable energy share targets)
- Large nuclear unit on a small grid
  e.g. Newcomers
Conclusions (1/2)

• Primary consideration is ensuring secure and reliable grid that serves all consumers affordable electricity with an adequate power quality and with tolerable interruptions and minimal effect on the society and environment.

• The flexibility needs of the grid system for reliability drives the need and the capabilities of NPPs for flexible operations. (Therefore, the owner/operators of the NPP and the grid system have to understand and agree on value and impact on each other).

• As the nuclear safety is overriding priority, it is necessary for grid and nuclear regulators to communicate with each other to inform and obtain guidance.
In several countries, flexible operations have been a daily operational reality for many years with full compliance and conformance with safety, quality and reliability requirements while managing the efficiency and financial impacts.

Despite the common mind-set that generation units with high fixed capital costs and low fuel costs should be operated in baseload mode, the growing necessity for grids using flexible nuclear generation has other cost-benefits that need to be accounted for.
IAEA and Flexible Operation (circa 2018)

Benefits

Incentives

NUCLEAR GENERATION

New Builds

Costs

Closures and Retirements
Industry*** Recommendation to IAEA-NE on the Revenue Side

- Renewables are, and continue to be tomorrow, in the electricity generation landscape.

- NPP flexibility in terms of the provision of grid reliability, stability and resilience should be valued and quantified.

- Tariff and pay for grid services need to reflect such benefits.

*** Through the IAEA Technical Working Group on Nuclear Power Plant Operation (TWG-NPPOPS), which consists of the high level executives of NPPs in the operating Member States to ensure that (not only the technical and programmatic issues but also) policies, visions and strategies are directly communicated and advised to the IAEA Secretariat.
Economic Interfaces of Flexible Operations
Impact, value, incentives, regulations at all levels
Main results

- Integration of renewable energy sources is not the only reason driving flexible nuclear;
- Flexibility of NPPs may not be needed in some regions;
- Flexibility needs may not be resolved in some regions

(SEE EXTRA SLIDES BY DR VICTORIA ALEXEEVA)
Where is flexibility needed?

High requirements for flexible NPP in regions with high shares of nuclear and RES (Region 3) and low interconnections (Regions 4 and 5).

- Region 1: **no** need for additional FL
- Region 2: need for FL for a better grid stability, not for IRES integration
- Region 3: need for FL due to high IRES + high nuclear
- Region 4: need for FL due to high IRES + poor interconnections
- Region 5: need for FL due to high IRES + poor interconnections

### RES Curtailment (MWh)

<table>
<thead>
<tr>
<th>Region</th>
<th>IRES (%)</th>
<th>IntD (%)</th>
<th>LF (MWh)</th>
<th>BL (MWh)</th>
<th>Variation LF-BL (MWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>12</td>
<td>32</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>39</td>
<td>17</td>
<td>0</td>
<td>2 225</td>
<td>-2 225</td>
</tr>
<tr>
<td>1</td>
<td>17</td>
<td>39</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>19</td>
<td>7</td>
<td>225</td>
<td>759</td>
<td>-504</td>
</tr>
<tr>
<td>5</td>
<td>34</td>
<td>4</td>
<td>589</td>
<td>874</td>
<td>-286</td>
</tr>
</tbody>
</table>

Additional FL of NPPs is not sufficient
IAEA’s Planned Series of Activities

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Publication 2: Economic Modelling of Load Following

Specific questions being addressed:

What is the benefit/cost for a NPP operator to operate in load-following mode?
- Plant level costs? Fleet level value?

What is the value ($$) of load-following (or other flexibility) to the grid?
- Quantified for control reserves, other ancillary services? Paid by grid operator?

What market approach would be best to reward NPP operators for flexibility?
- Energy, capacity, mix? ‘Commodity’ market, e.g. market for inertia, active/reactive power, frequency?

What regulatory approach would be best to level the playing field for NPP operators for flexible output if the market does not pay enough?
Final Thoughts

• If there is no need otherwise, the NPPs should operate in baseload mode.

• Unless the nuclear energy sources adapt to the new energy structure and/or portfolios by being flexible, it will be hard for expansion of nuclear power

• Even more significant when the grid capacity and energy distribution is limited, such as in case of several embarking countries
Final Thoughts (cont.)

• Nuclear energy is “a part” of many Member States’ energy policies and portfolio.

• Thus, it has to adopt and adjust to those policies and long term strategies while remaining a viable and economic component of those.

• Owing to dynamic energy market and governments’ energy policies and strategies there have been an increasing need for NPPs to operate in “flexible” modes.
Thank you!
EXTRA SLIDES
Short IAEA economic study in Publication 1
Two sets of assumptions

Assumptions on energy scenarios up to 2050 (at the regional level – EU28):

- Installed capacities per technology (in line with RES rate, CO2 constraints and EE targets).
- Fuel costs and CO2 prices.
- Interconnection degree.
- Instruments such as feed-in tariffs, etc.

Assumptions on flexibility up to 2050 (at the technology level – T12):

- Ramping rates.
- Max. transient budget.
- Maximum load factors.
- Minimum operational loads.
## Regional assumptions in 2050

<table>
<thead>
<tr>
<th>Region</th>
<th>IRES (%)</th>
<th>NUC (MW)</th>
<th>NUC (%)</th>
<th>Load (GWh)</th>
<th>Min Load (MWh)</th>
<th>Max Load (MWh)</th>
<th>Intercon degree (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEEU</td>
<td>12</td>
<td>31006</td>
<td>55</td>
<td>496178</td>
<td>34768</td>
<td>82560</td>
<td>32</td>
</tr>
<tr>
<td>CWEU</td>
<td>39</td>
<td>55940</td>
<td>35</td>
<td>748760</td>
<td>48466</td>
<td>150456</td>
<td>17</td>
</tr>
<tr>
<td>NCWU</td>
<td>17</td>
<td>18054</td>
<td>61</td>
<td>250841</td>
<td>16072</td>
<td>44843</td>
<td>39</td>
</tr>
<tr>
<td>WEEU</td>
<td>19</td>
<td>9600</td>
<td>52</td>
<td>410534</td>
<td>25624</td>
<td>73967</td>
<td>7</td>
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<tr>
<td>SWEU</td>
<td>34</td>
<td>7393</td>
<td>16</td>
<td>373027</td>
<td>26174</td>
<td>63363</td>
<td>4</td>
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</table>
Key technology-related assumptions

**Ramping rates**
define the speed at which a power plant is capable of modulating its output within one hour time frame: ±14% for coal-fired plants; and ±50% for CHP, biomass and combined cycle gas turbines (Traber and Kemfert (2011). All other technologies: fully flexible.

<table>
<thead>
<tr>
<th>Load cycle (%)</th>
<th>Number of cycles</th>
</tr>
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<tbody>
<tr>
<td>100-90-100</td>
<td>100 000</td>
</tr>
<tr>
<td>100-80-100</td>
<td>100 000</td>
</tr>
<tr>
<td>100-60-100</td>
<td>15 000</td>
</tr>
<tr>
<td>100-40-100</td>
<td>12 000</td>
</tr>
</tbody>
</table>

**Max. transient budget**
puts an upper limit on number of cycles with the amplitude of 10%, 20%, 40% and 60% of rated power within a given licencing period.

Source: Ludwig et al., 2010, EnBW (2013)
NPP operators’ perspective – load factors

IAEA study (2016) on flexibility requirements up to 2050 in the EU

<table>
<thead>
<tr>
<th>Region</th>
<th>LF (%)</th>
<th>BL (%)</th>
<th>Variation LF-BL (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>87</td>
<td>95</td>
<td>-716</td>
</tr>
<tr>
<td>2</td>
<td>84</td>
<td>79</td>
<td>425</td>
</tr>
<tr>
<td>3</td>
<td>94</td>
<td>98</td>
<td>-350</td>
</tr>
<tr>
<td>4</td>
<td>90</td>
<td>98</td>
<td>-701</td>
</tr>
<tr>
<td>5</td>
<td>90</td>
<td>98</td>
<td>-701</td>
</tr>
</tbody>
</table>

Observation: a more heterogeneous picture in comparison to the OECD/NEA (2012).
NPP operators’ perspective – revenue impacts (short run)

No additional reimbursement schemes for the provision of the flexibility services!

<table>
<thead>
<tr>
<th>Region</th>
<th>LF (€/MW)</th>
<th>BL (€/MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEEU</td>
<td>1 057 834</td>
<td>1 135 817</td>
</tr>
<tr>
<td>CWEU</td>
<td>846 935</td>
<td>744 749</td>
</tr>
<tr>
<td>NCWU</td>
<td>1 343 614</td>
<td>1 198 543</td>
</tr>
<tr>
<td>WEEU</td>
<td>1 218 772</td>
<td>1 245 839</td>
</tr>
<tr>
<td>SWEU</td>
<td>1 219 244</td>
<td>1 299 280</td>
</tr>
</tbody>
</table>

Average NPP operator revenues (1650 MW), €

<table>
<thead>
<tr>
<th>Region</th>
<th>LF (M€)</th>
<th>BL (€)</th>
<th>% change</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEEU</td>
<td>1 745</td>
<td>1 874</td>
<td>-6.9%</td>
</tr>
<tr>
<td>CWEU</td>
<td>1 397</td>
<td>1 229</td>
<td>13.7%</td>
</tr>
<tr>
<td>NCWU</td>
<td>2 217</td>
<td>1 978</td>
<td>12.1%</td>
</tr>
<tr>
<td>WEEU</td>
<td>2 011</td>
<td>2 056</td>
<td>-2.2%</td>
</tr>
<tr>
<td>SWEU</td>
<td>2 012</td>
<td>2 144</td>
<td>-6.2%</td>
</tr>
</tbody>
</table>

By how much would a NPP like to be reimbursed for the provision of the flexibility services?
### Energy system operators’ perspective

What happens to total energy system costs when nuclear operates in LF mode?

<table>
<thead>
<tr>
<th>Region</th>
<th>Var. LF-BL (M€)</th>
<th>% change</th>
<th>Total Cost</th>
<th>CO2 emissions (Mt)</th>
<th>RES Curtailment (MWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>LF (Mt)</td>
<td>BL (Mt)</td>
<td>Variation LF-BL (Mt)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>LF (MWh)</td>
<td>BL (MWh)</td>
<td>Variation LF-BL (MWh)</td>
</tr>
<tr>
<td>CEEU</td>
<td>159.0</td>
<td>3.7%</td>
<td>18</td>
<td>16.5</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>CWEU</td>
<td>-3.0</td>
<td>-0.0%</td>
<td>16.6</td>
<td>24.6</td>
<td>-8.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0</td>
<td>2 225</td>
<td>-2 225</td>
</tr>
<tr>
<td>NCWU</td>
<td>62.0</td>
<td>2.1%</td>
<td>7.8</td>
<td>6.8</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>WEEU</td>
<td>119.0</td>
<td>1.4%</td>
<td>59.9</td>
<td>58.5</td>
<td>1.5</td>
</tr>
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<td>225</td>
<td>759</td>
<td>-504</td>
</tr>
<tr>
<td>SWEU</td>
<td>159.0</td>
<td>1.8%</td>
<td>54.1</td>
<td>53.1</td>
<td>1.0</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>589</td>
<td>874</td>
<td>-286</td>
</tr>
</tbody>
</table>

- Decreasing total short-run costs
- FL is needed for a better grid stability
- No need for additional FL