Load following with nuclear – is that a reality?

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Conclusions

• Feasible to use nuclear power as regulating power
• Examples of good experience from Sweden and other countries
• Focus on day, - or week-scale, but possible as primary control (sec-scale)
• Further study of problematic working points
• Plant-specific issues to be verified
  – Turbine optimisation
  – Pump status
  – Fuel load pattern
  – Power ramping performed according to specifications
Load following with nuclear –
Studies carried out 2011-2012

First study already 2011 about possibilities to load-follow with nuclear (in Swedish): Elforsk 12:08

Follow-up study with focus on costs related to load-following, Elforsk 12:71 www.elforsk.se/Rapporter/?rid=12_71

Summary:
– Load-following (LF) operation means only minor additional costs. In the case the operation is planned, no additional cost is foreseen.
– Increased fuel cost in case of unplanned LF: up to 4% increase of total production cost in a BWR (4-7% in a PWR).
– Increased need for maintenance in control rod mechanism and lower availability seen in France during primary (frequency) control.
– It is recommended to use several reactors in series to avoid larger power decreases, below 60% nominal reactor power
– Some work ranges for pumps and other components need to be identified.
Introduction

• Future requirements could demand a more flexible generation at our Nuclear Power Plants (NPPs):
  • The variation in production and consumer load will be much larger and faster than before.
  • New electric grid code with tougher demand on regulating power.

• A flexible power control of NPPs could, with increased intermittent energy production, be a valuable asset.
Background

Why load-following?

• More intermittent power in the grid
• New grid requirements
• Differentiated market (four market regions in Sweden)
• New transmission links to other markets
• Trading opportunities
Background

- **Primary control** (frequency compensation to establish 50Hz).
- **Secondary control** (return to daily average of 50Hz in grid).
- **Load-following**: Adjusting power to demand.
Experience in France

French PWRs are flexible in operation (all modes of power control)

One transmission system operator (in France) and one operator (EDF) simplifies demand-response.

Load-following is carried out in the power range 37%-93% during the first 85% of the fuel cycle.

Primary/Secondary power control performed from 93% power:
  2% margin for frequency compensation,
  5% margin to secondary control.

Power variation (load-following) about 2-5%/min (25-65 MW/min)

Primary control: 1%/s (26 MW variation)
Overview of study

Example of PWR fuel cycle with primary and secondary power control

85% of fuel cycle

Example of PWR reactor power during a 18 months cycle
Fuel costs: Modelling 6 fuel cycles

Additional fuel costs. Different scenarios with ”unplanned” load-following were considered during one cycle followed by 5 "normal" cycles:

1. Reference fuel cycle 100% power,
2. 1st fuel cycle 100% power but 20% shorter cycle length
   a) BWR
   b) PWR
3. 1st cycle operated at 60% power during first half of the cycle (BWR only)

Case 1: Reference case (72.94 EFPH/FA)
Case 2a: 5% cost increase
Case 2b: 17% cost increase
Case 3: 25% cost increase

Costs due to unplanned (forced) load-following:
- The additional production cost for BWRs could be 1-5%.
- For PWRs, the additional production cost could be 4-7 %.

( Fuel costs account for about 20% of total production cost)
Limited experience of load-following operation in Sweden

Swedish NPPs are co-owned: power decrease is compensated per MW to the other owners due to possible wear and tear.

BWRs are mainly power regulated by main re-circulation pumps (to 60-70% power).
Load-following pattern, BWR

- The **optimal working point** cannot always be reached, resulting in lower turbine efficiency.

- The optimal (and less demanding) power range is 60-100% power.

- The power increase is hampered by new thermal equilibrium of fuel, xenon-poisoning, et c.

- Usage of several reactors in a fleet (to avoid larger power decreases).
Risks

• Damaged fuel
  – Limits in operation and flexibility when having damaged fuel

• ”Under-loading” fuel
  – Would affect fuel cycle length and/or coast-down period.

  *With strong seasonal variations in the Nordic countries, outage is preferable in the summer, hence 11 month fuel cycles*

• Component wear
  – The power ramps need to be performed according to specifications to avoid wear.

  *As long as no design transient specifications (DTS) are ”used”, no risk of additional wear is seen*

• Increased risk of operational disturbances
  – Every change to steady-state operation could case disturbance

  *No indications of such situation has been given.*
Price areas in Sweden

- A large new intermittent power production, i.e., wind power that influence the power system and the market. Intermittent power production demands more regulating power.

- Therefore, can NPPs also provide flexible power production to the market such as primary and secondary control?
Variation and wind power in Sweden

- The production from wind power 2010 was 3.5 TWh.
- The production from wind power 2014 was 11.6 TWh.
- In 2015, Sweden has 5.4 GW of installed wind power.
- Wind power production varies with 0 - 4 GW (see below).
- The consumption in Sweden varies during a normal day with 5 GW.
Remaining issues

- How precise can power production variations be in present nuclear power plants?
- Examination of the NPP’s possibility to deliver reactive power to the grid (voltage stability) and if this is affected by any mode of operation.
- Is this only hypothetical for old/present reactors? Is it feasible for new plants? Specific needs for BWRs and PWRs to be further studied regarding present NPPs.
- What are the manpower and competence needs for flexible power production? Possible constraints in operation during flexible power generation? (maintenance, safety,…)

Load-following with Nuclear, Hans Henriksson

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Thank you for your attention!

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Please read the report: Elforsk report 12:71

Conclusions:
– Load-following would mean only minor additional operational costs. If planned properly, these costs may even be avoided.
– Fuel cost increase in unplanned situations (up to 4% increase of production price in a BWR). Slightly higher relative fuel cost in PWRs.
– No wear of components detected due to load-following
– Additional maintenance in control rod drive mechanism decreased availability (<1.8%) in France (due to primary control operation).
– It is recommended to use several reactors in series to avoid larger power decreases, below 60% nominal reactor power.