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Nuclear is a Dispatchable Electricity Source

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Nuclear power is not only a proven, reliable source of carbon-free energy. It is also a dispatchable emission-free resource (DEFR) that can contribute to the reliability of New York's evolving grid. Scientists from the National Renewable Energy Laboratory recognize that fossil fuel (mostly methane gas) combustion presently provides the grid stabilization services to complement intermittent generation.[2] The National Bureau of Economic Research evaluated solar and wind deployment across 26 OECD countries between 1990 and 2013 and found that all other things equal, the more renewable sources were installed, the more fast-reacting fossil fuel plants were needed to compensate for supply variability.[3] A one percentage point increase in the share of fast-reacting fossil generation capacity in a country is associated, on average, with a 0.88 percentage point increase in the long-run share of renewable energy. However, as climate and air pollution policies aim to drive out fossil fuel combustion, advanced nuclear technology is a leading candidate for the replacement of that capacity.[4]

Load Following Nuclear Plants?

Nuclear plants are technically capable of more flexible operation, changing their power output over time (i.e. ramping or load following) and contributing to power system reliability needs, including frequency regulation and operating reserves.[5]

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[2] Denholm et al., 2021, June. The challenges of achieving a 100% renewable electricity system in the United States. Joule Volume 5, Issue 6, Pages 1331-1352 https://www.sciencedirect.com/science/article/pii/S2542435121001513

[3] NBER. 2016, October. A Role for Fossil Fuels in Renewable Energy Diffusion https://www.nber.org/digest/oct16/role-fossil-fuels-renewable-energy-diffusion

[4] The Royal Society. 2020, October. Nuclear Cogeneration: civil nuclear in a low-carbon future https://royalsociety.org/topics-policy/projects/low-carbon-energy-programme/nuclear-cogeneration/

[5] Jenkins et al. 2018. The Benefits of Nuclear Flexibility in Power System Operations with Renewable Energy https://pdf.sciencedirectassets.com/271429/1-s2.0-S0306261918X00117/1-s2.0-S0306261918303180/am.pdf

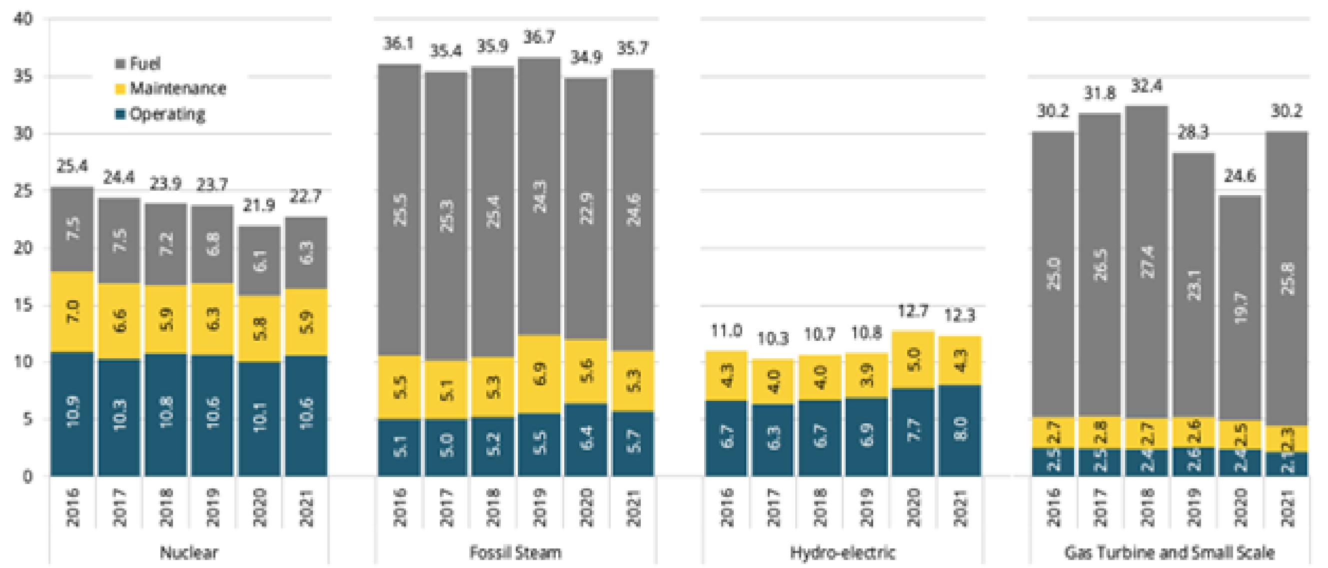
Any steam-cycle power plant can throttle very quickly by sending its steam past the turbine. Canadian CANDU reactors are set up to load-follow by using secondary steam-bypass, keeping the (thermal) reactor core at full output and ready to support full electrical output again at a moment's notice.

Boiling and pressurized reactors, dominating outside of Canada, throttle the heat generation in the nuclear reactor in order to provide load-following. They can do so without major changes in core temperatures and pressures in the higher range of power output, largely avoiding stress on the equipment. However, if output is being throttled below 50% or so, some stress can occur. Power can be ramped up at the same pace as down unless the reactor is approaching the end of the fuel cycle, in which case ramping up can be slowed down.

No Need for Load Following by the First Nuclear Reactors

The economics of running a nuclear power plant are well-known: high capital costs and high operating costs due to 24/7 staffing, factors unaffected by whether electricity is being generated or not. Fuel costs, the only variable cost component, are minimal. In an electricity market dominated by fossil fuel power generation, the market price for power rarely, if ever, dips below zero.

Average Power Plant Operating Expenses for Major U.S. Investor-Owned Electric Utilities
dollars per megawatt-hour



Source: U.S. Energy Information Administration Electric Power Annual 2021 (published November 2022)
Gas Turbine and Small Scale category consists of gas turbine, internal combustion, photovoltaic, and wind plants.

Consequently, there has been no economic incentive to throttle nuclear power plant output in order to load follow, let alone invest good money in more robust equipment that can handle routine ramping. As a result, U.S. Generation II nuclear power plants were designed for little if any load-following.

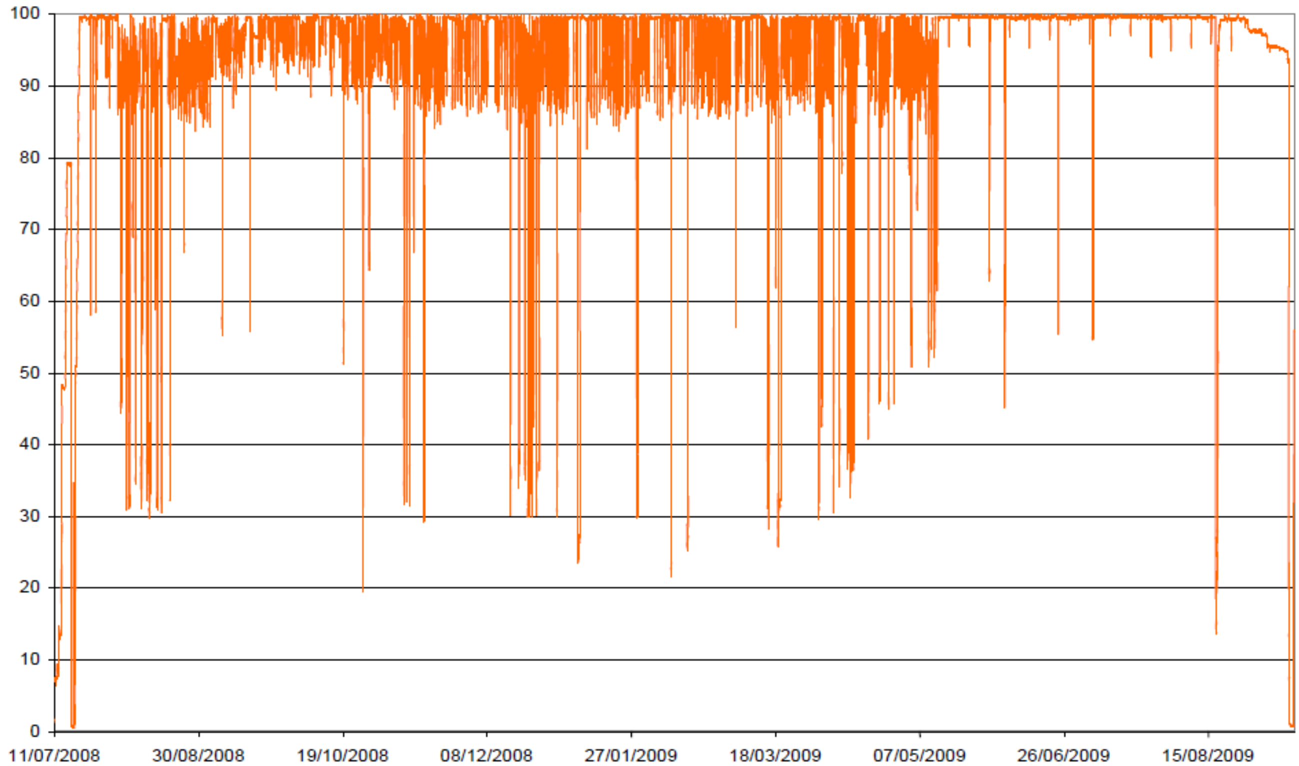
However, this has translated into the widespread misconception that nuclear reactors are unable to load-follow.

The only load-following that typically occurs in U.S. nuclear plants corresponds to the scheduling of refueling and maintenance periods in spring and fall, matching periods of low electricity demand and low energy prices.

Technology for Different Economics: France and Germany

France

The French Messmer Plan, announced March 6, 1974, set the nation's energy policy on an "all electric, all nuclear" course. Without the ability to balance daily and seasonal load changes by ramping fossil-powered plants, France had to plan for load-following by its nuclear reactors. The first reactors, built on U.S. designs, were not designed to do so. However, subsequent French reactors were set to adjust their output to grid demand and absorb the bulk of load following. That being said, even the older generation of reactors was participating in load-following by scheduling refueling- and maintenance-outages to match times of low demand.

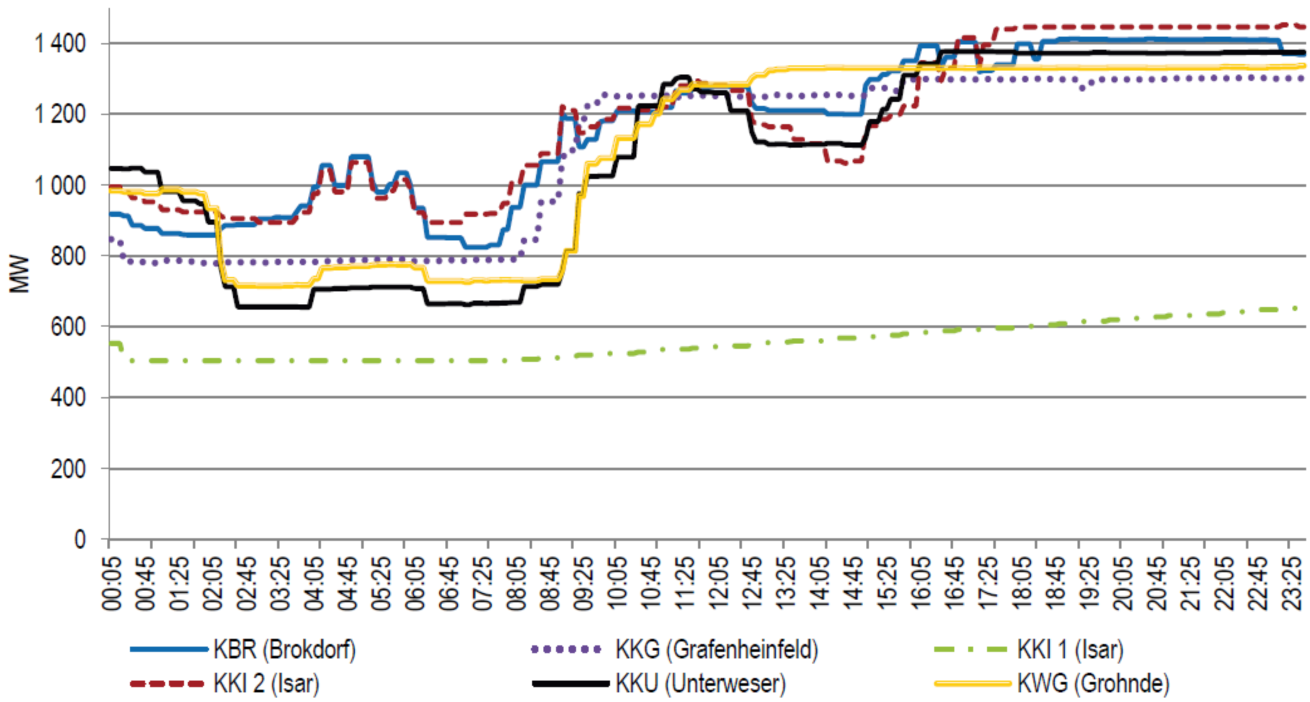


Example of a typical power history during a cycle in a EDF reactor (in % of rated power)[6]

Germany

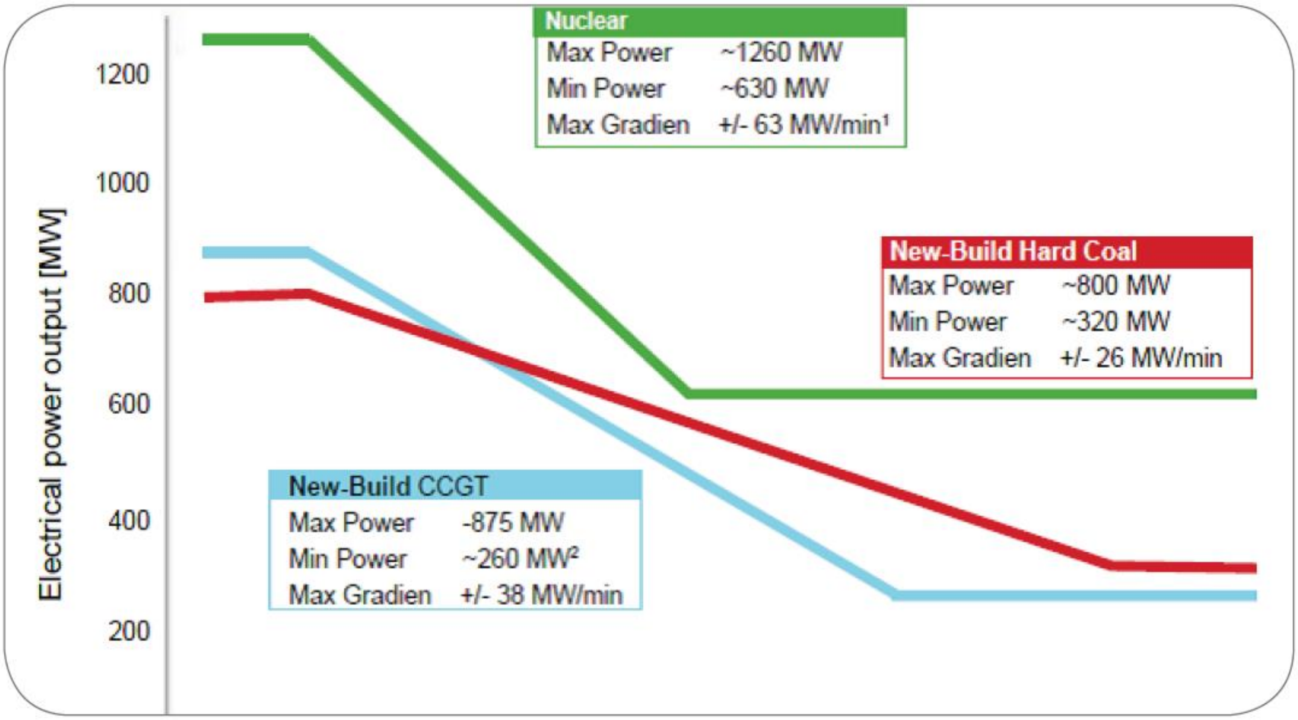
Germany was also determined to stop burning fossil fuels for electricity generation at one time, and it demanded from industry to provide a reactor with very strong load-following capability. The "Generation II" line of nuclear reactors coming online in Germany during the 1980s featured ramping rates of up to 5% of capacity per minute in the range between 50% and full capacity. Germany failed to add as many reactors to its grid as had been planned, so the share of nuclear energy on the grid topped out at 30%. Nevertheless, the superior ramping capacity of those modern nuclear plants resulted in grid operators calling on nuclear plants to provide much of the adjustments in generation needed to match changing loads. Fossil plants, despite their significant fuel costs, were much slower to ramp up and down, in particular the plants fueled by lignite coal.

[6] OECD NEA. 2011, June. Technical and Economic Aspects of Load Following with Nuclear Power Plants. Nuclear Development. https://www.oecd-nea.org/upload/docs/application/pdf/2021-12/technical_and_economic_aspects_of_load_following_with_nuclear_power_plants.pdf



Example of electricity generation with some German nuclear power plants[7]

[7] OECD NEA. 2021, June. Technical and Economic Aspects of Load Following with Nuclear Power Plants. Nuclear Development https://www.oecd-nea.org/upload/docs/application/pdf/2021-12/technical_and_economic_aspects_of_load_following_with_nuclear_power_plants.pdf



Comparison of load follow ability of NPP, Hard Coal PP and CCGT[8]

Modern Fast Ramping Nuclear Reactors

The nuclear sector today offers many options, large and small, for meeting the needs of a modern dynamic grid. Upgrades to existing nuclear plants include the Advanced Load Following Control (ALFC) system for pressurized water reactors. ALFC enables load cycling, part-load operation, and primary or secondary frequency control according to the requirements of the grid.9 However, a number of advanced nuclear reactors also exist or are being developed with enhanced ramping capacity as a feature. The following are a few examples.

Westinghouse AP1000

The "Advanced Passive" AP1000 reactor is classified as a generator III+ reactor, mainly due to its ability to remove decay heat for 72-hours after a shutdown without any operator intervention. It's ramping capabilities are improved over Generation II reactors:

- Provide 10% step changes between 25% and 100% of rated power without steam bypass

[8] Nuclear Energy Factsheets. Load following capabilities of Nuclear Power Plants. Sustainable Nuclear Energy Platform. https://snetp.eu/wp-content/uploads/2020/05/SNETP-Factsheet-7-Load-following-capabilities-of-nuclear-power-plants.pdf

[9] Framatome. 2019. Advanced Load Following Protocol for Non-Baseload Operation of Pressurized Water Reactors . https://www.framatome.com/solutions-portfolio/docs/default-source/default-document-library/product-sheets/a0655-p-ge-g-en-0655-201901-advanced-load-following-control.pdf

- Withstand a sudden grid disconnection without reactor shutdown and with continually serving "house loads" for the operation of the plant
- Ramp 5% per minute between 25 and 100 percent subject to the freshness of the core
- Guarantee a "design basis load follow cycle" over 90% of the fuel cycle with 2-hour ramps down and up again between 50 and 100 percent of capacity[10]

This dispatchable technology has the highest technical readiness level of real-world system operations experience (in the U.S. and in China), and is ready to deploy in New York and beyond today.

International competitors to the AP1000 are mainly the Korean APR1400 and the French EPR in addition to Russian and Chinese reactors. The APR1400 is designed for daily ramping between 50 and 100 percent of full capacity at a rate of 5% per minute.[11] The EPR can ramp up and down at 5% between 60% and 100% of capacity and 2.5% between 25% Pr and 60%, over the first 80% of the load cycle, for a total of 22 minutes between 25% and 100%.[12]

Natrium

Terrapower's Natrium reactor is a sodium-cooled "fast" reactor with thermal storage. Natrium's reactor heats up a large nitrite salt tank that effectively stores energy. This thermal energy in turn is used to run a steam turbine/generator. While the reactor is sized to provide enough heat for a continuous 345 MW electrical output, the steam generators, turbine, and generator can deliver boosts of power up to 500 MW by drawing extra heat stored in the hot salt.

The minimum output of the Natrium power plant is 100 MW, which can be ramped up at 40 MW per minute to 500 MW. This maximum output can be held for 5-½ hours, after which the heat storage will be depleted and power output drops to 345 MW.[13]

The first Natrium reactor will be deployed at a retiring coal power plant in Kemmerer, Wyoming by 2030. The U.S. utility PacifiCorp recently added two further units to be deployed in Utah to its plan.[14] Pacificorp's plan includes 1200 MW (electric) of unspecified "non-emitting peaking resources," and its climate commitments may further increase the scope for new nuclear plants.

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[10] Westinghouse AP1000 Design Control Document Rev. 19 https://www.nrc.gov/docs/ML1117/ML11171A330.pdf

[11] Status report 83 - Advanced Power Reactor 1400 MWe (APR1400). https://aris.iaea.org/PDF/APR1400.pdf

[12] Technical and Economic Aspects of Load Following with Nuclear Power Plants https://www.oecd-nea.org/upload/docs/application/pdf/2021-12/technical_and_economic_aspects_of_load_following_with_nuclear_power_plants.pdf

[13] https://www.powermag.com/ge-hitachi-terrapower-team-on-nuclear-storage-hybrid-smr/

[14] World Nuclear New. 2023, April. Two more Natrium units for coal-to-nuclear switching https://world-nuclear-news.org/Articles/Two-more-Natrium-units-for-coal-to-nuclear-switchi

BWRX-300

The BWRX-300 is a 300 MWe boiling water reactor offered by GE Hitachi. It can maneuver from 100% and 50% power, with a ramp rate of +0.5%/minute, and return to full power with the same ramp rate, daily. The plant can reduce electric power at a faster rate by dumping steam to the condenser instead of using the main turbine/generator control valves.

GE Hitachi is working on BWRX-300 projects with Ontario Power Generation and the Tennessee Valley Authority, and additional projects in Saskatchewan, Poland, and elsewhere are in negotiation.

Xe-100

X-Energy's Xe-100 is an 80 MWe helium-cooled pebble bed reactor. It can ramp up or ramp down between 40% and full power in 12 minutes (5% per minute) and dynamically adjust heat generation in the core to match the required steam amount and pressure.[15]

Conclusion

Nuclear power plants have evolved from providing baseload power and grid stability, to today becoming a viable option for dispatchable peaking and load following. This makes them capable of not only matching the load changes between daily peaks and nightly lows but also complementing supply swings from intermittent, weather-dependent wind and solar resources.[16] Ramping to 75% of capacity in 15 minutes with the AP1000 and to even 80% of capacity in ten minutes with Natrium, nuclear power is more than just dependable baseload energy. It can also bring the flexibility needed on a highly dynamic grid while retaining its advantages of very low fuel costs and virtually unlimited runtime.

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[15] https://www.nice-future.org/docs/nicefuturelibraries/default-document-library/x-energy.pdf

[16] For air quality, climate, and system costs, it makes no difference whether drops in load are being answered by throttling a nuclear power plant or curtailing a wind or solar facility.