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Load following Capability of New Nuclear Power Plants

Presentation to the Nuclear Institute, Glasgow

21 September 2010

By John Morris, EDF Energy

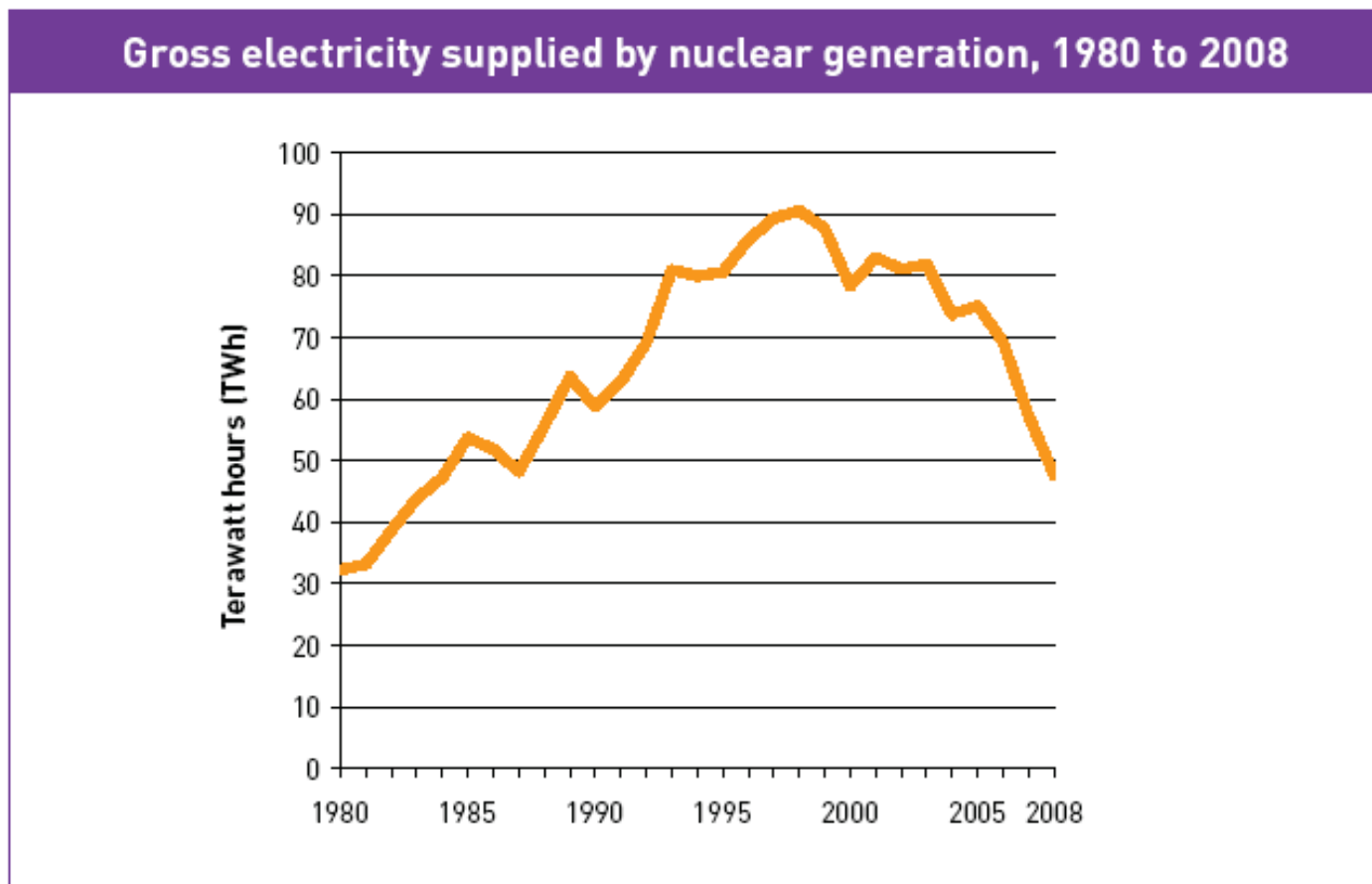


Summary

- Nuclear New Build Programmes
- Flexible Operation and the GB Grid Code
- Existing Nuclear Plant is Inflexible?
- French Experience
- New Nuclear Plant Capability
- Economics
- Future Scenarios



UK Nuclear Production Declining



Source: UK Energy in Brief 2009, DECC



Plant life extensions

Assumed Nuclear Closure Dates 'Slow Growth' or 'Dash for Energy' Scenarios

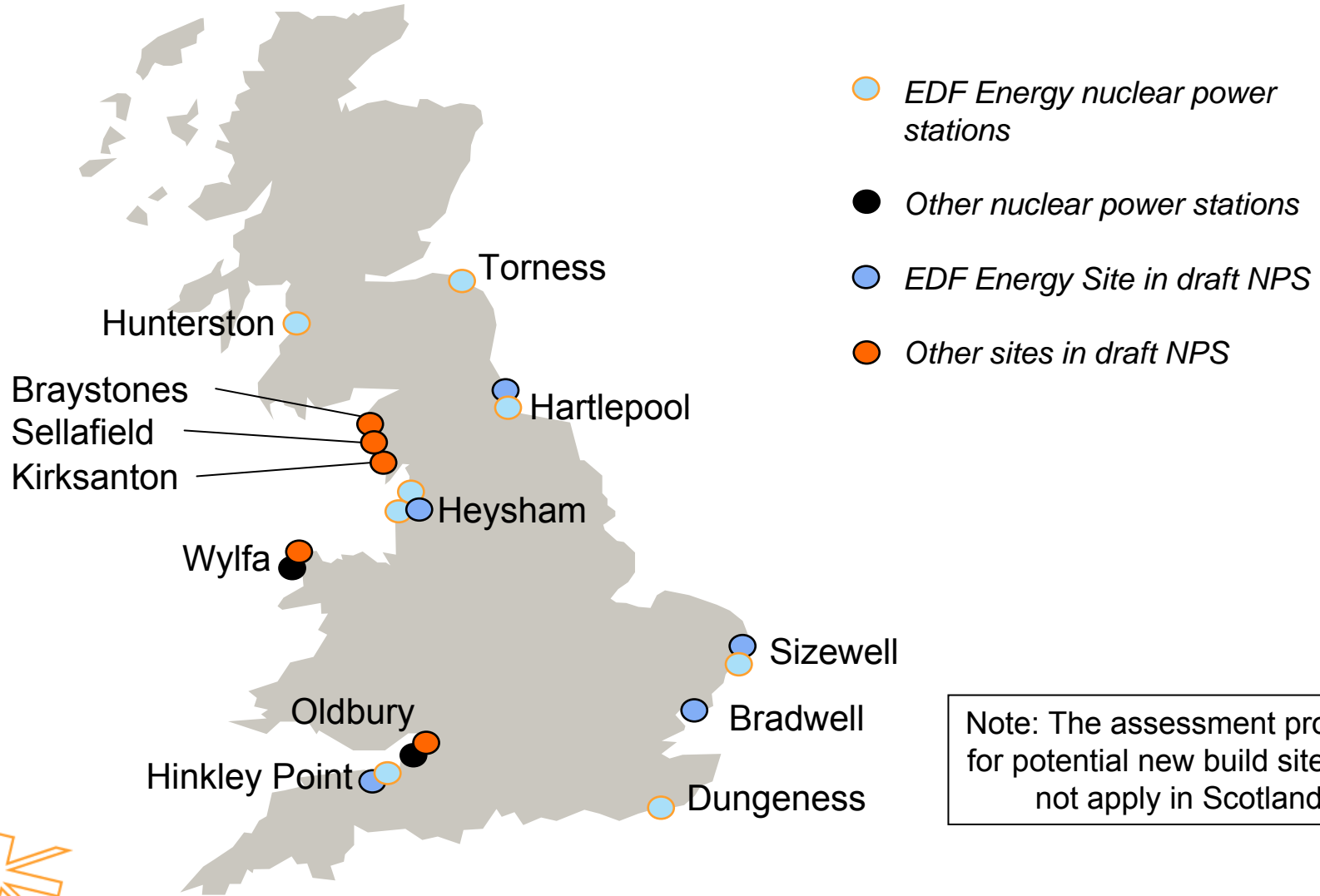
<u>Station</u>	<u>Year</u>
Oldbury	2009
Wylfa	2012
Hinkley B/Hunterston B	2016
Dungeness B	2018
Heysham 1/Hartlepool	2019
Heysham 2/Torness	2023
Sizewell B	2035

Source:Ofgem Project Discovery Ref:122/09

- EDF Energy are currently reviewing the possibility of life extensions of the existing AGR plant.
- Operation of PWR plant looks possible for 60 years and beyond



GB nuclear power station sites



Site	Substation	TEC (MW)	Date	Type
Hinkley Point C	Hinkley 400kV GIS	1670	01/09/2017	Nuclear EPR
Wylfa B	Wylfa 400kV Substation	1670	31/10/2017	Nuclear EPR
Hinkley Point C	Hinkley 400kV GIS	1670	01/09/2018	Nuclear EPR
Dungeness C	Lydd 400kV GIS	1650	31/10/2018	Nuclear EPR
Sizewell C (Stage 1)	Sizewell North 400kV GIS	1670	01/03/2020	Nuclear EPR
Oldbury-on-Severn Power Station	Oldbury-on-Severn	1600	01/04/2020	Nuclear EPR
Wylfa C	Wylfa	1200	31/10/2020	Nuclear APR
Bradwell B	Bradwell 400kV	1670	01/09/2021	Nuclear EPR
Sizewell C (Stage 2)	Sizewell North 400kV GIS	1670	01/09/2021	Nuclear EPR
Wylfa C	Wylfa	1200	31/10/2021	Nuclear APR
Wylfa C	Wylfa	1200	31/10/2022	Nuclear APR
Heysham 3	Heysham B	1650	31/10/2022	Nuclear EPR
Oldbury C	Oldbury-on-Severn	1600	31/10/2023	Nuclear EPR
Sellafield	Sellafield	1600	31/10/2023	Nuclear EPR
Sellafield	Sellafield	1600	31/10/2025	Nuclear EPR
Totals		23320		

Source: NG TEC Register 13/09/2010



Government's Draft Nuclear National Policy Statement (NPS)

- Published for consultation on 9 November 2009:
 - Provides a framework for planning decisions
 - Lists 10 sites considered strategically suitable for new nuclear power stations by 2025 (including Hinkley and Sizewell)
 - All ten sites are needed
 - Expects that a significant proportion of the 25 GW of new conventional generating capacity needed by 2025 will come from nuclear power
 - Government is satisfied that effective arrangements will exist to manage and dispose of waste arisings
 - New government plans to finalise and formally approve in 2010

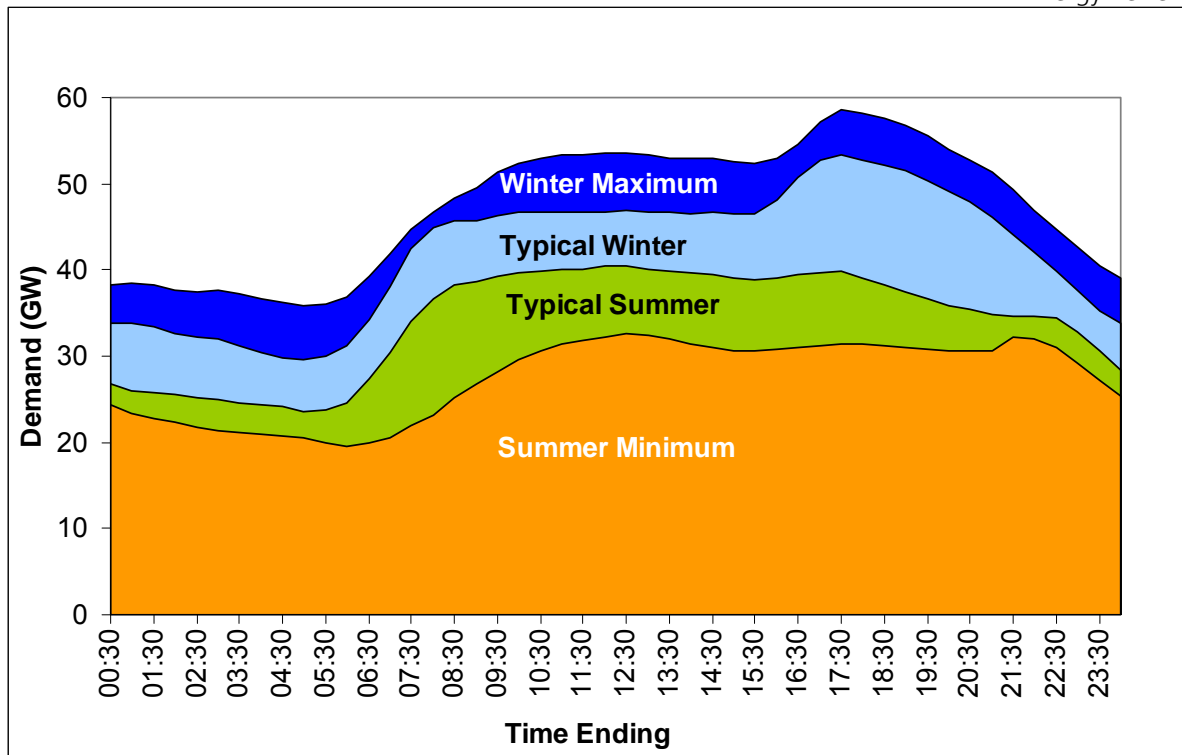


Flexible Operation - Load Following

Perception:

...[Nuclear Power] has the disadvantage that it cannot easily follow peaks and troughs in energy demand.

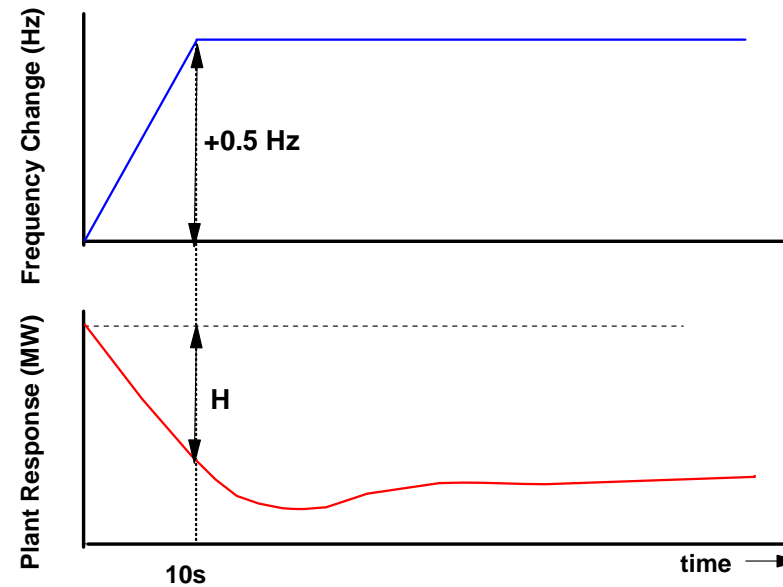
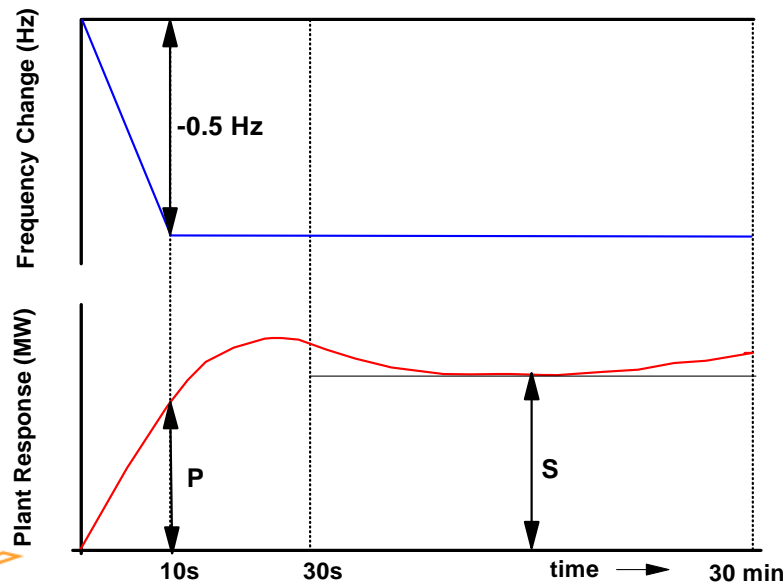
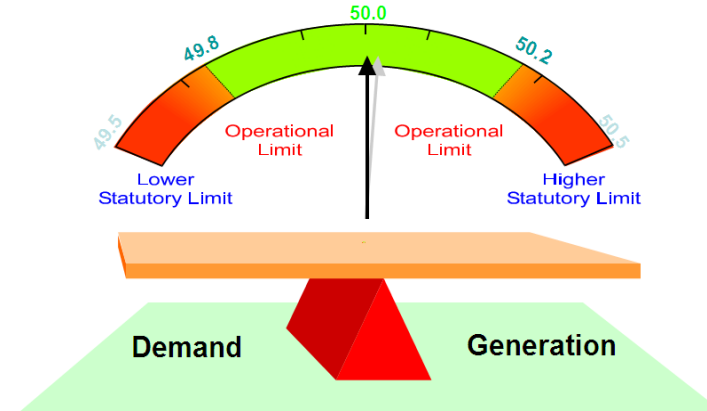
2006 DTI Energy Review



Source: NG Seven Year Statement

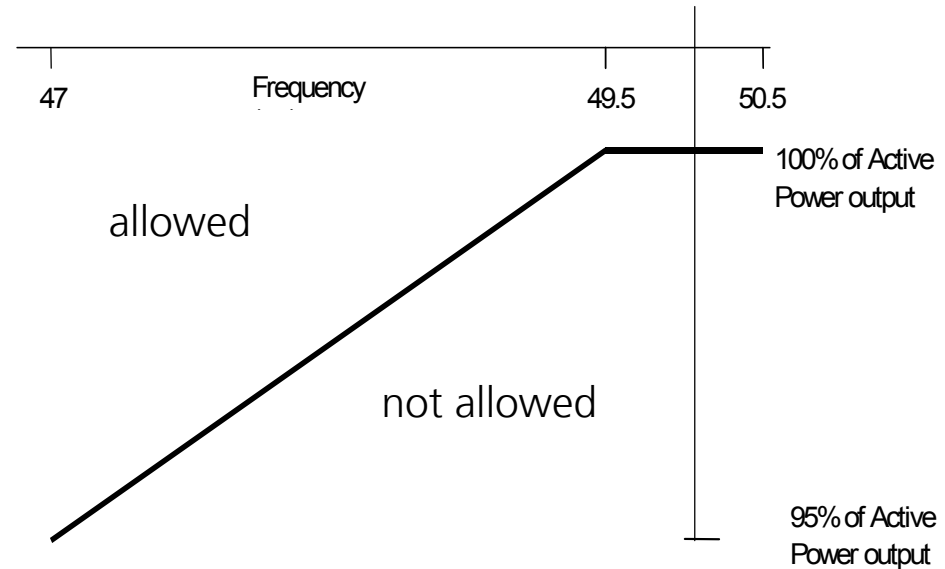
Flexible Operation – Frequency Response

Frequency sensitive mode of operation (primary, secondary or high in any combination) is a mandatory requirement of the Grid Code in order to get a Final Operational Notification to be able to connect to the transmission system.



Limited Frequency Sensitive Mode

- Grid Code CC.6.3.3
- ...maintain constant Active Power output for System Frequency within range 50.5 to 49.5Hz; and
- ...for System Frequency change within the range 49.5Hz to 47Hz, ... Active Power output does not decrease by more than 5%

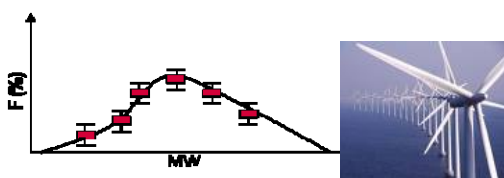


- Existing gas cooled reactor plant permitted to operate in Limited Frequency Sensitive mode at all times.
- Current obligation to maintain frequency is with the System Operator.

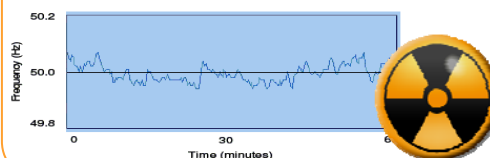


Operating the system in 2020 - Generation

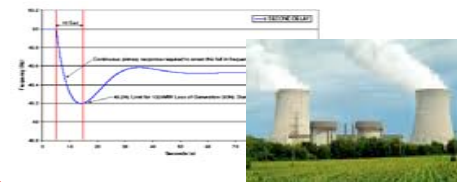
Variable generation



Inflexible generation



Large generation



How to meet these challenges in the most economic and sustainable way whilst maintaining security of supply?



Source: Recent slide from NG Industry Presentation on Smart Networks

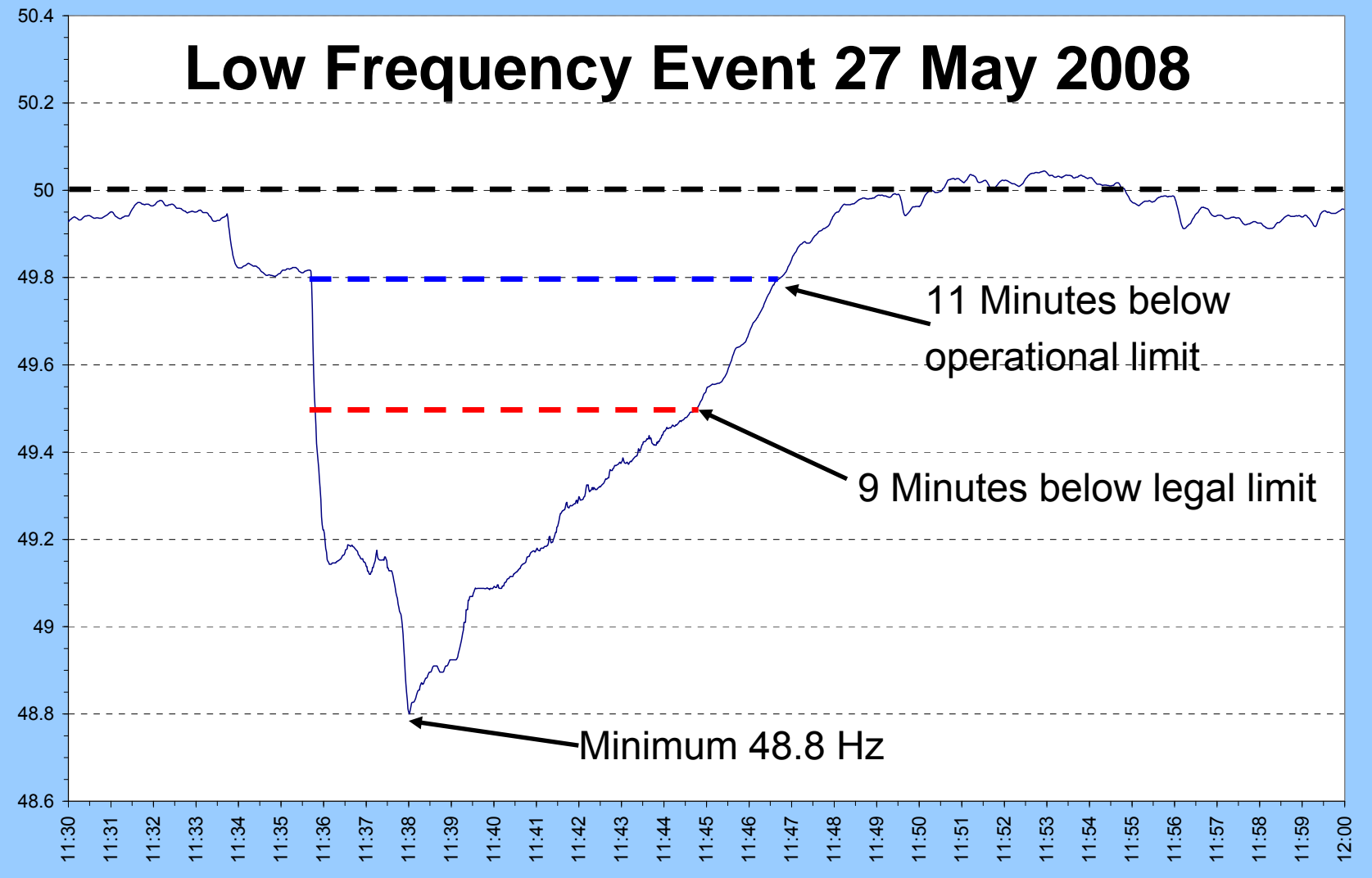
Existing Nuclear Plant Flexibility

- Gas reactors were designed as baseload plants
- Four AGR's can on-load refuel and have some implied flexibility
- Sizewell PWR has operated for a period with one turbogenerator in service (nominally half power)
- Generation curtailment services can be negotiated with NG for thermal transmission constraints

However any significant change to the existing nuclear operating regime may require a re-assessment of the safety case, particularly for fuel integrity.



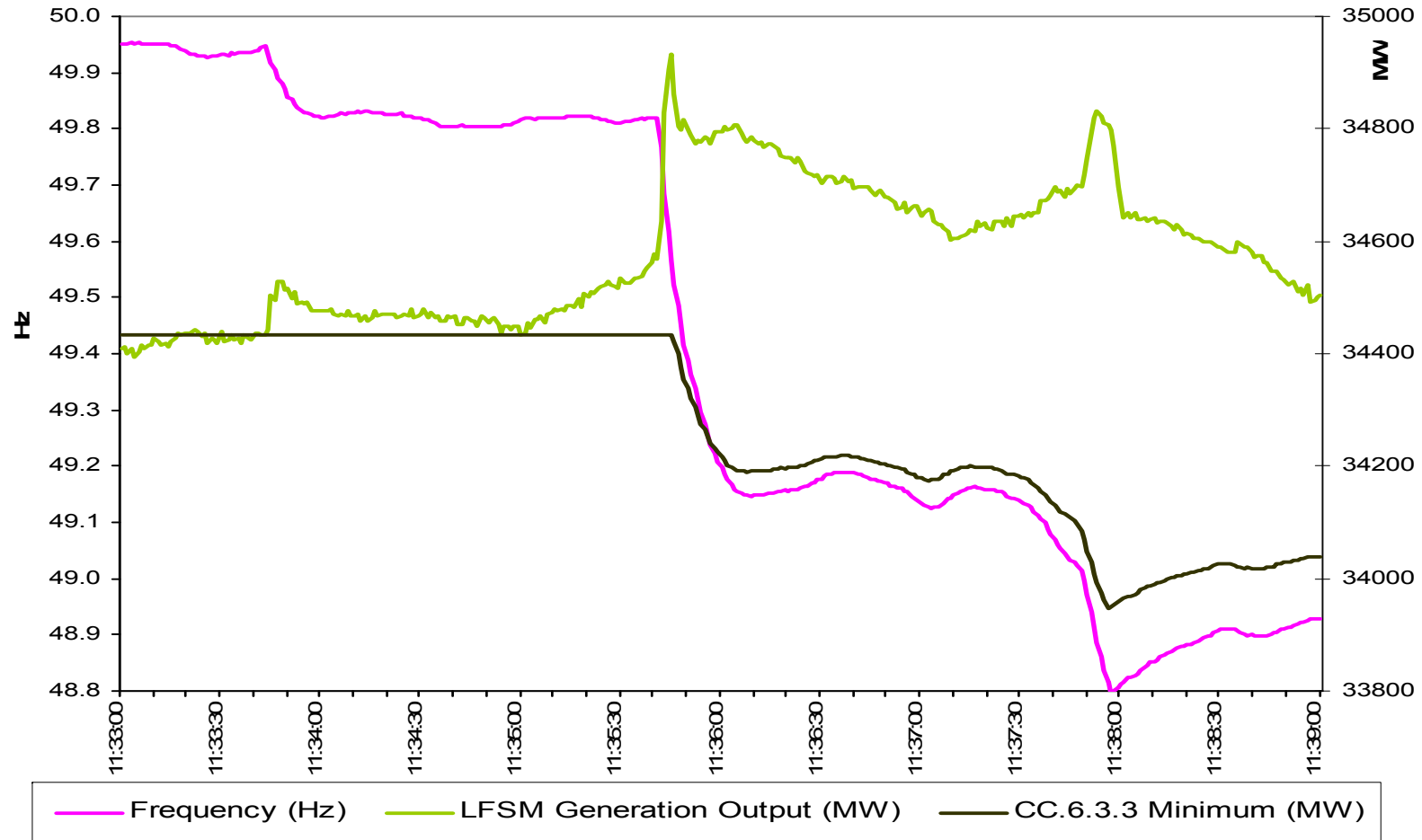
Low Frequency Event 27 May 2008



Source: National Grid data

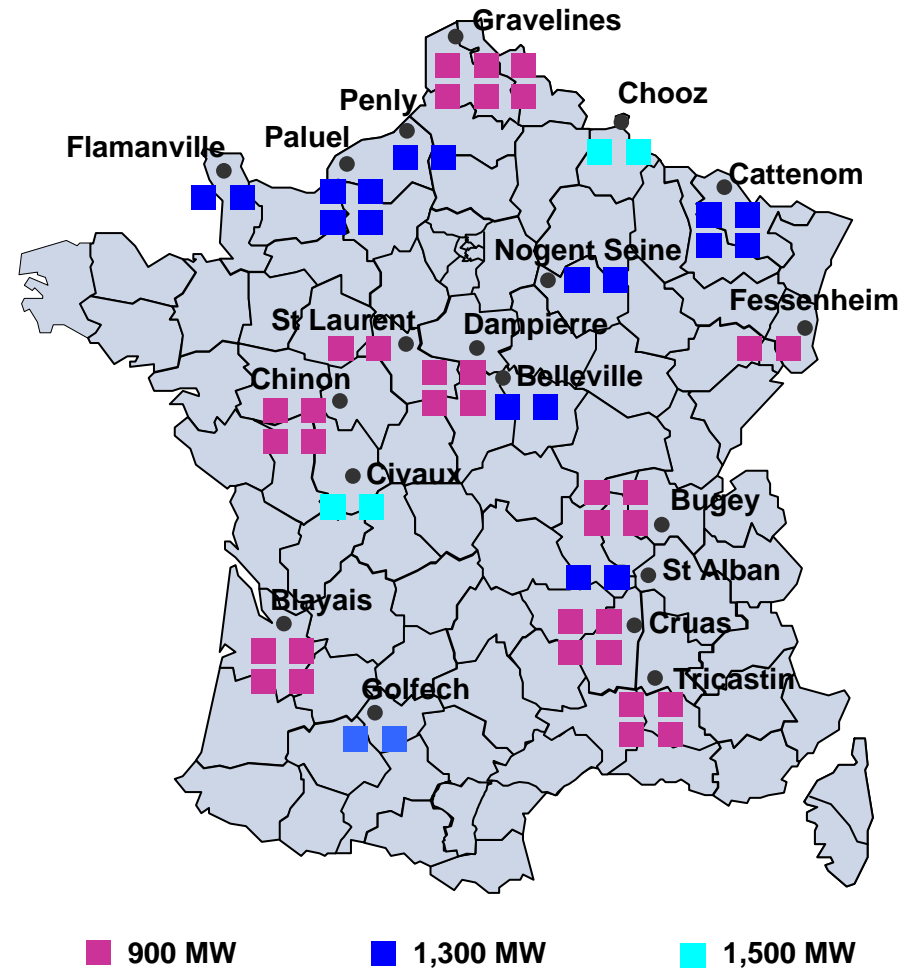


Aggregate Output of LFSM Generation



EDF Nuclear Generation Sites in France

- 58 reactors in operation
- Distributed over 19 sites
- Single technology: PWR (“Pressurised Water Reactor”)
- 3 Electrical power levels :
 - 900 MW: 34 units, 31 GW
 - 1,300 MW: 20 units, 26 GW
 - 1,500 MW (N4): 4 units, 6 GW
- EDF owns the nuclear power plants and the sites



Nuclear Flexibility in France – Frequency Response

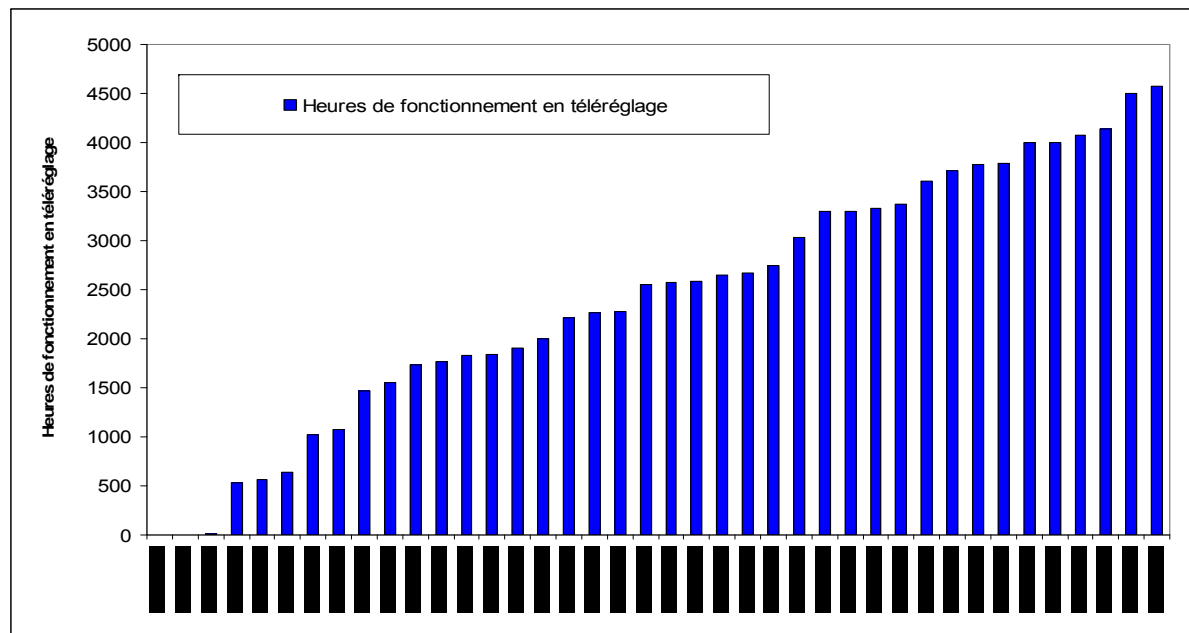
- Differences between demand and generation give rise to frequency variations.
- Primary regulation acts within a 30 seconds on plants generation level to limit variations of the frequency.
- Secondary regulation acts after primary adjustment to recover the reference frequency within the following minutes and balance transfer flows across boundaries.
- Those ancillary grid services (primary and secondary regulation) are provided by companies according to contractual terms with RTE (French Grid System Operator).
- EDF provides 1300 MW (average value) of ancillary services equally divided between primary and secondary regulation.
- As a rule-of-thumb, gas and coal fired plants are the first choice to provide ancillary services (for a given power output, it is better to reduce the power of plants with higher variable cost) ... but fossil-fired plants can contribute only when started at a minimum power level, which is not the case when they are outranked in the merit-order. Nuclear must then contribute.
- In 2008, 50% of system services provided by EDF to RTE were provided by the nuclear fleet (Hydro : 32% Thermal : 18%).



French Grid Services : Frequency Response

Possible contribution depends on the class and the specification of each plant ...

Type of regulation	Amplitude	900 MW	1300 MW	1500 MW
Primary regulation	2% P _n	18 MW	27 MW	30 MW
Secondary regulation	5% P _n	50 MW	70 MW	not avail.



Nuclear Flexibility in France – Load Following

Mid-merit : a net need of flexible generation amounting circa 80 TWh.

Mainly sourced in equal parts by:

- Imports = European fossil
- Hydro and pump storage
- French fossil

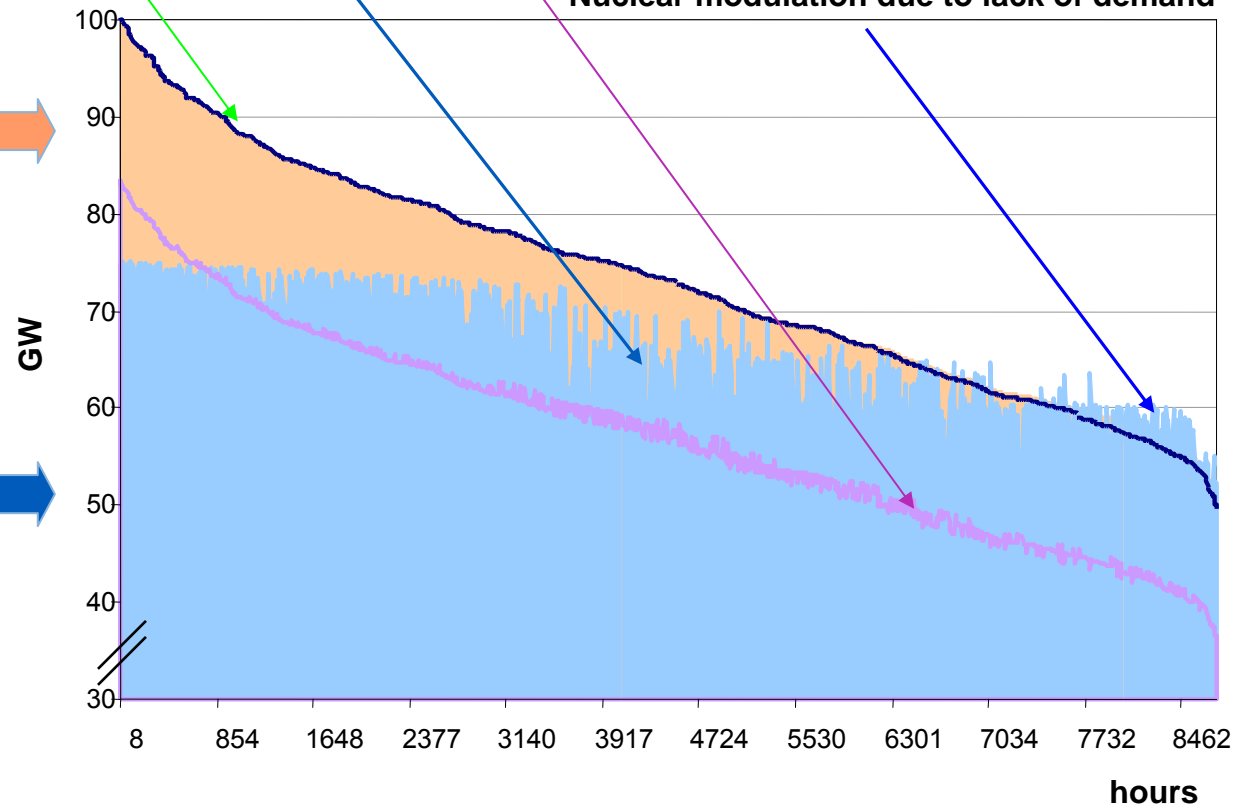
Nuclear and must-run capacities are sufficient to match the baseload demand .

Moreover, due to scheduling of nuclear outages , those capacities (nuclear+must-run) cover circa 90% of the whole demand, including exports when feasible.

Domestic consumption (including pump storage) + maximum interconnection use
Nuclear (after scheduled outages) + must-run generation (run-of-river, wind...)

Domestic consumption (including pump storage)

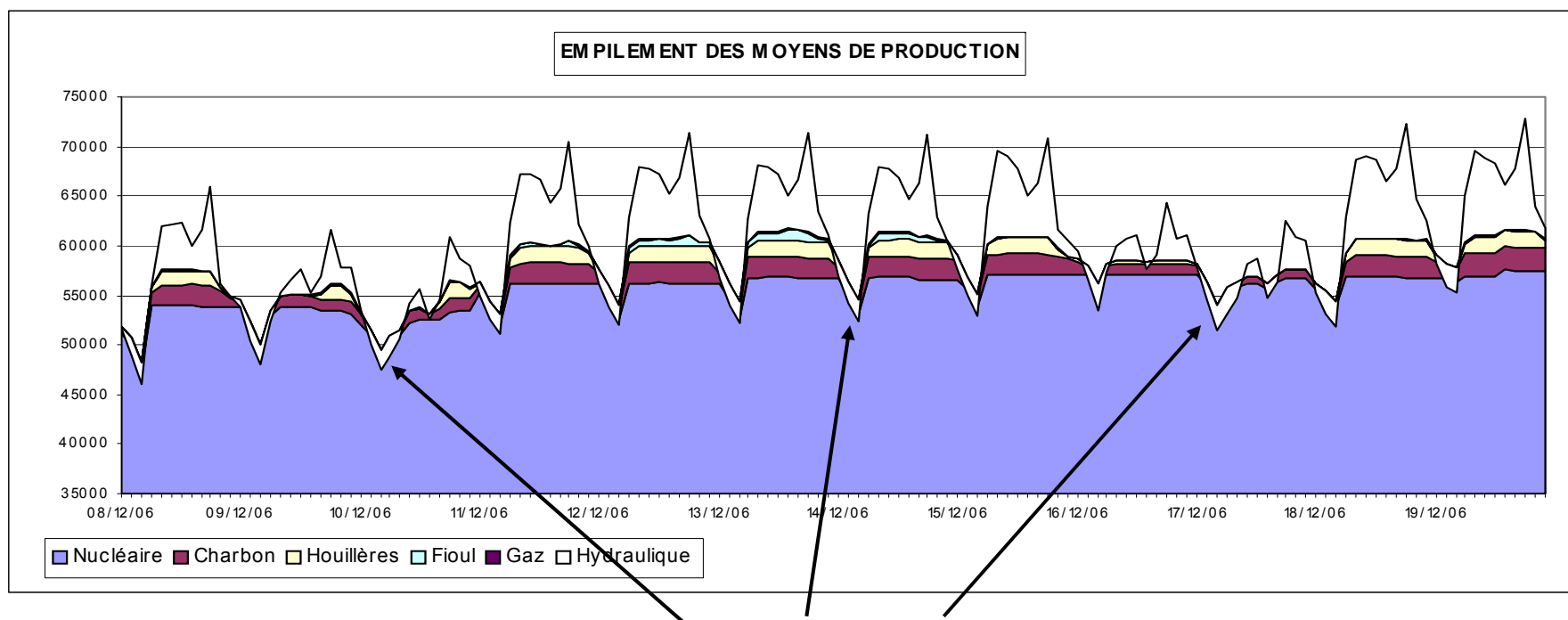
Nuclear modulation due to lack of demand



French electric system (+ interconnections) : illustrative curves and figures



Meeting demand in France



The total offer (available nuclear + must-run power) sometimes exceeds demand (domestic + interconnections), hence NPP are used to help match demand.

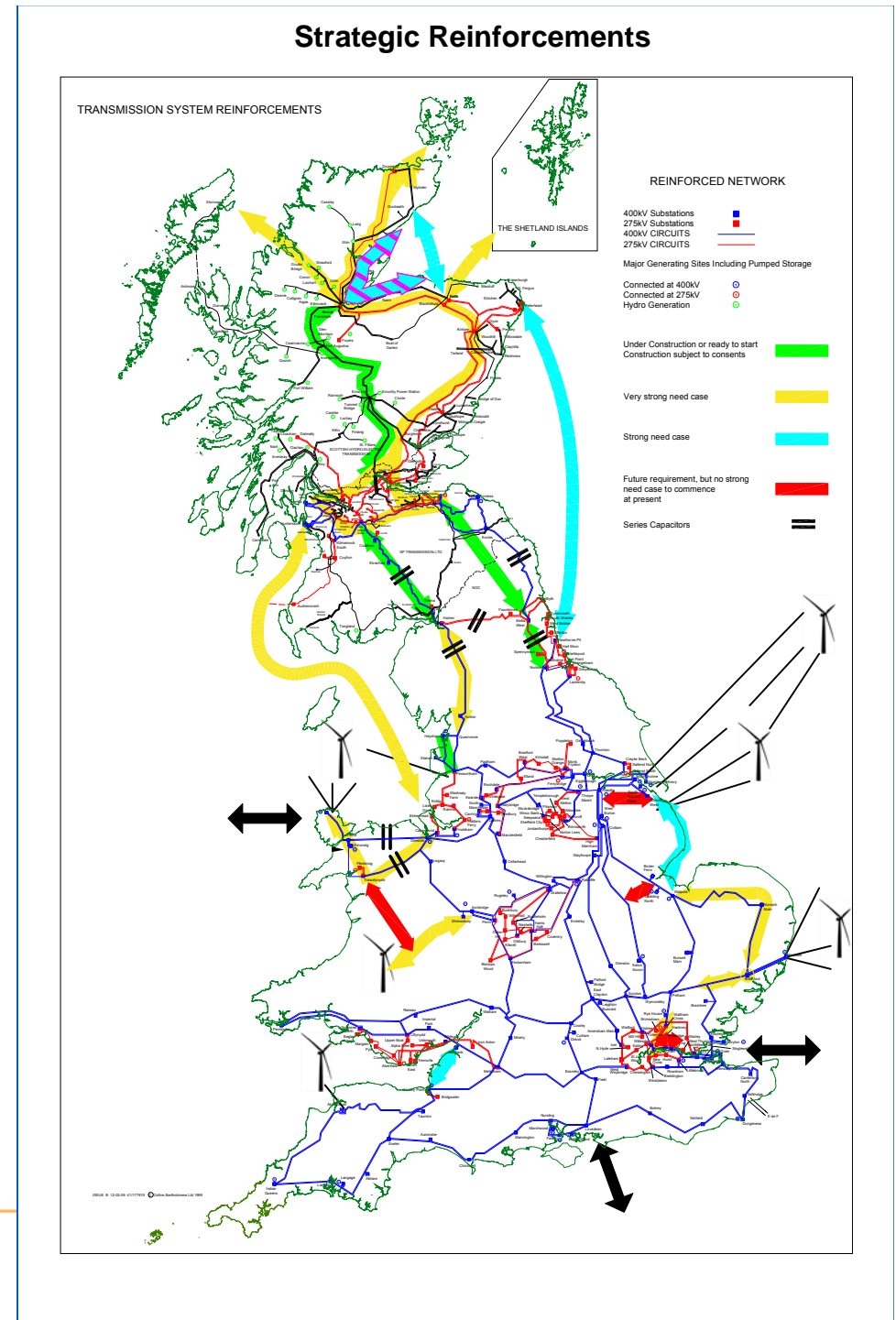
- **Output reduction** : mainly during night and week-end
- **Short-term stoppages** : mainly during week-end and public holidays (24 hours minimum, 36 hours is possible according to burn-up of the fuel)



An NGET Future Scenario

'Gone Green 2020'

- Plant closures
 - 12GW Coal & oil LCPD
 - 7.5GW nuclear
 - Some gas & additional coal
- Significant new renewable
 - **29 GW wind (2/3 offshore)**
 - Some tidal, wave, biomass & solar PV
 - Renewable share of generation grows from 5% to 36%
- Significant new non renewable build
 - 3GW of new nuclear
 - 3GW of new supercritical coal (some with CCS)
 - 11GW of new gas
- Electricity demand remains flat (approx 60 GW)
 - Reductions from energy efficiency measures
 - Increases from heat pumps & cars



NNB Flexibility

AP1000

The plant is designed to accept a step load increase or decrease of 10% between 25-100% power.

The plant is designed to accept ramp load changes of 5% per minute while operating in the range 25-100% power subject to core power distribution limits.

The plant is designed to permit a 'design basis' daily load follow cycle for at least 90% of the fuel cycle length. This design basis allows operation down to 50% power for between 2-10 hours with 2 hour linear ramps.

During load follow the plant is designed to routinely make load changes of $\leq 10\%$ at $\pm 2\%$ per minute for the purposes of responding to grid frequency changes.

Source: Chapter 1 of the AP1000 European Design Control Document



NNB Flexibility

EPR

The unit is designed to move between nominal power (P_n) and the technical minimum power. Load follow can be activated between 25-100% P_n with two possible profiles:

- Light load follow between 60-100% P_n at a maximum rate of 5% per minute.
- Deep load follow between 25-60% P_n at a maximum rate of 2.5% per minute.

Between technical minimum power and P_n the unit can supply:

- A reserve of +/- 2.5% P_n for primary frequency response at a maximum rate of 1% P_n per second
- A reserve of +/- 4.5% P_n for secondary frequency response at a maximum rate of 1% P_n per minute between technical minimum and 60% P_n
- A reserve of +/- 10% P_n for secondary frequency response at a maximum rate of 2% P_n per minute between 60% P_n and 100% P_n

Source: EPR Pre-Construction Safety Report Chapter 1



GB Grid System v. European Synchronised Network

GB Grid Frequency Variation

- Across the year, the average standard deviation was 0.06Hz, implying that the “ 3σ ” extremes of the statistical distribution are 49.82Hz and 50.18Hz.

European Grid Frequency Variation

- Standard frequency variation in France is less than 0.03Hz on a typical day

Potential implications for NNB plant in GB

- More plant response in frequency sensitive mode leading to more control rod movements



PWR Load Variations Impact on Reactor

Thermo-mechanical stresses on components

- Power variations induce temperature and pressure fluctuations

Mechanical Wear

- Frequency control leads to frequent rod movements

Fuel Cladding Behaviour

- May need specific qualification programme

Liquid Waste Arisings

- For load following boration concentrations may change



Economic Considerations

NNB is capital intensive with low marginal cost

- Most appropriate for baseload operation

Load following and response will reduce load factor

- Increases surveillance and maintenance burden

Subsequent changes to operating regime

- May need to re-visit safety case
- Modify plant e.g. 'grey' rods

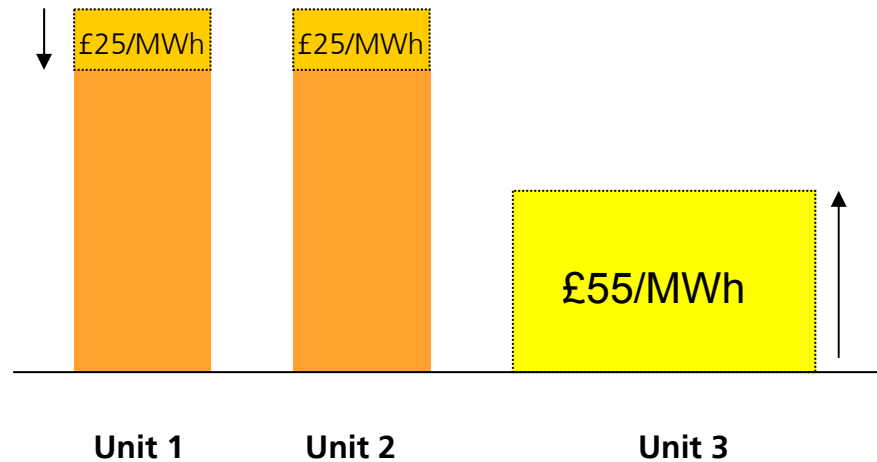
How can such costs be factored into the pricing of services?

- How often will such services be required?



Economics of Response Dispatch

For example, if no free headroom...



NG instructs synchronisation of addition unit to provide headroom to create required 100MW of response:

Synchronise Unit 100MWh at £55/MWh

Balancing Bids at £25/MWh

Bid/Offer Spread = £30/MWh

Cost of BOA's: £30/MWh x 100MWh=£3000

Cost of Response Creation:

$£3000 / 100MW_{\text{response}} = £30/MW_{\text{response}}$



Bid & Offer Acceptance



Default bid price of nuclear units:

-£9999/MWh

.....and other plants wishing to be inflexible

(price paid to generator (BMU) for each MW of headroom deload)



Costs of Automatic Response

Response holding payments to each generating unit:

	Typical Av	Sizewell B
Primary	£3/MW/h	£25/MW/h
Secondary	£2/MW/h	£43/MW/h
High	£7/MW/h	£43/MW/h

Total mandatory frequency response holding costs
2009/10 were £59m

Source: NG Procurement Guidelines Report



Challenges for the electricity supply chain – Smart Grid drivers

Demand Responsiveness

- Efficient use and TOU of energy
- Integrating flexible demand

Decarbonising electricity

- Integrating inflexible generation
- Integrating Intermittency
- Integrating embedded generation

Electrifying heat and transport

- Increased demand:
 - Electric vehicles
 - Heat pumps

Efficient and reliable network invest & operation

- Timely capacity – planning & consent / supply chain
- Providing flexibility and avoiding stranding assets
- Secure and Affordable

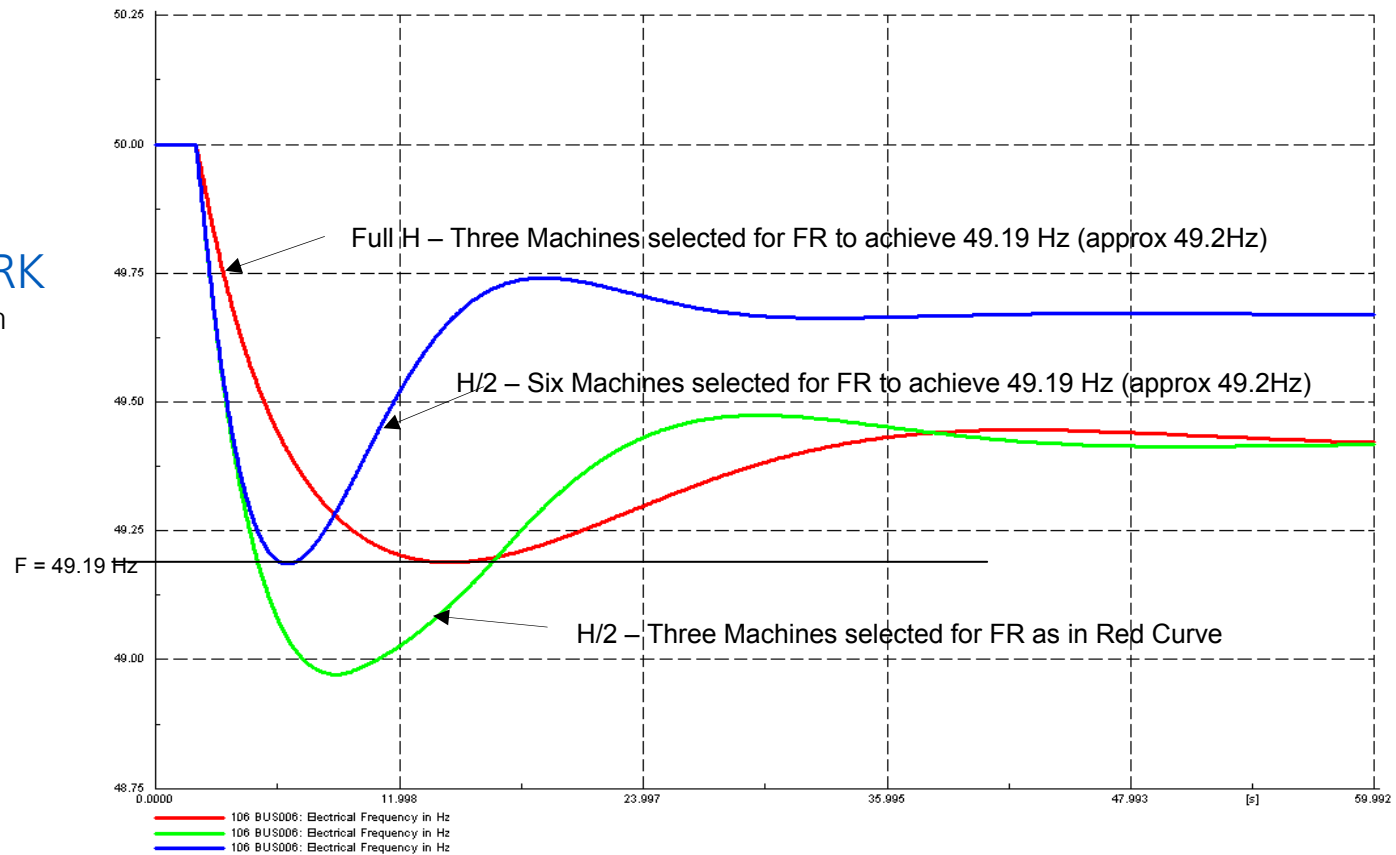


Source: Recent slide from NG Industry Presentation on Smart Networks

1320MW Loss – Effect of Inertia and FR

TEST NETWORK

- Simplified GB system
- 25GW demand
- 11 generators
- 1320 MW Loss
- No Load Response



Assessment of NG Study Work

- Inertia has a significant effect on System Frequency
 - Increased rate of change of frequency (Hz/s)
 - With Frequency response included, the minimum recorded system frequency is increased
- If System Inertia is allowed to drop substantially additional fast acting Reserve / Response will need to be scheduled at additional cost to ensure standards of security are maintained.
- It is also likely that if left unchecked, faster acting dynamic response would be required (ie greater than 10% Primary, 10% Secondary and 10% High).
- Analysis undertaken to date demonstrates the need for Generators and HVDC Converter Owners to contribute towards System Inertia unless additional reserve is scheduled at considerable cost.



Concluding Remarks

The operating mode of a nuclear power plant is determined by many factors including design, regulatory, contractual and economic factors.

New build reactor designs for the GB market should be technically capable of providing flexible operation to support Grid system operation.

Nuclear new build may be operated away from baseload providing there is adequate commercial incentive.



thank you