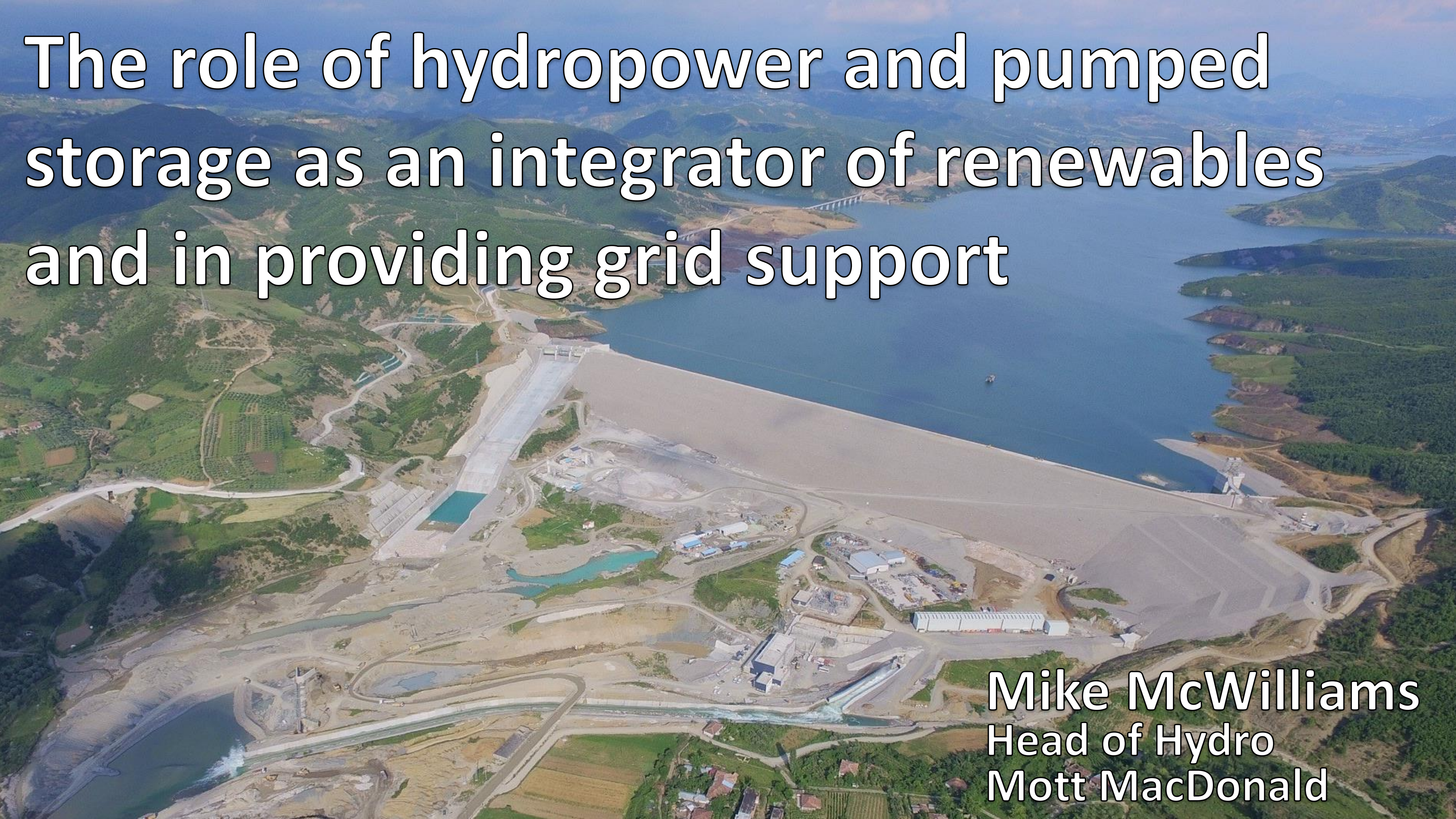
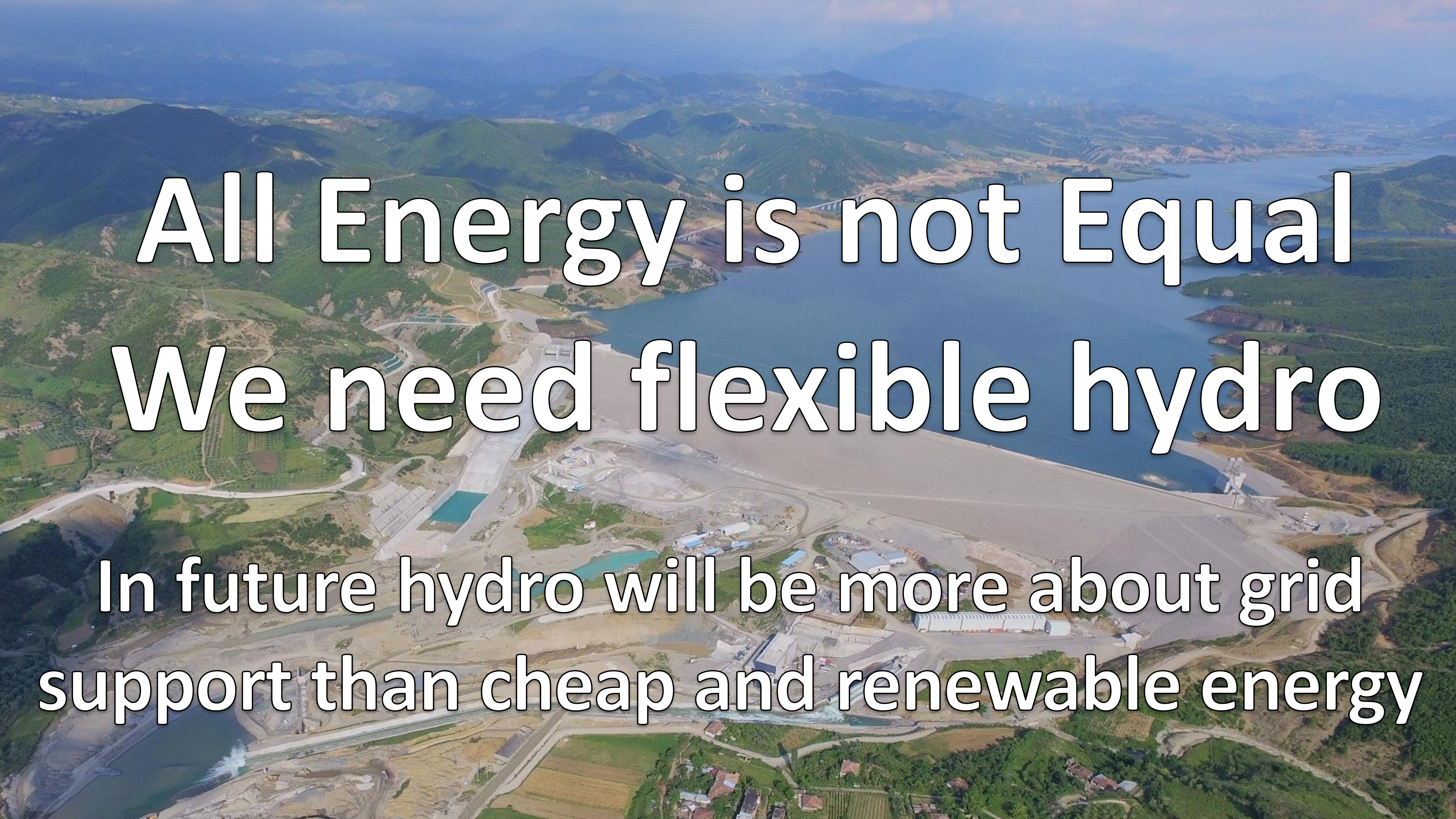
The role of hydropower and pumped storage as an integrator of renewables and in providing grid support



Mike McWilliams
Head of Hydro
Mott MacDonald


All Energy is not Equal
We need flexible hydro
In future hydro will be more about grid
support than cheap and renewable energy

"We are in the midst of an energy revolution. The economic landscape, developments in technology and consumer behaviour are changing at an unprecedented rate, creating more opportunities than ever for the energy industry."

Richard Smith
Head of Network Capability (Electricity)
In the introduction to National Grid's
System Operability Framework Report, 2016

"The power system operation stability requires the system to minimise fluctuations between demand and supply.

This encompasses, for example, short term reserves (generation, storage, demand response) to cover potential incidents, which decrease power supply to the system, or to respond to short-term variations in demand and generation.

Hydropower therefore provides an ideal solution for the challenges of a transitioning power system."

Opening paragraph of the Hydropower section (7.2)
of the **Indian National Electricity Plan 2016**

Contents

- Why are power systems changing?
- How are power systems changing?
- Can hydro and pumped storage help?
- How can we pay for this flexibility?

Why are Power Systems Changing?
1. Demand

- Improved efficiency and reducing link between Energy Demand and GDP mean flat or falling demand in developed countries.

- Increased access to electricity and increasing affluence mean rising demand in transitional and developing countries.

- More use of electricity for transport and space heating (Paris commitments) increases demand.

Why are Power Systems Changing?
2. Generation

- Decarbonisation will soon see the end of coal fired generation.
- “Intermittents” and “predictables” are replacing traditional technology.
- Traditional base-load generation (eg CCGT) will have lower load factor, affecting the economics.

Cost of renewables

- In some places the unsubsidised cost of PV and wind is the cheapest form of energy production.
- Recent PV and wind bids have been as low as $30 per MWh (i.e. 3¢ / kWh), or even less in UAE.
- While this is cheap energy, it does not do much for the power system as it is non-despatchable, non-firm and often uncontrollable.

All energy is not equal

Generation characteristics

Technology	Constant	Predictable	Despatchable	Low Carbon
Steam (coal / oil)	Yes	Yes	(Yes)	No
Open Cycle Gas Turbine	Yes	Yes	Yes	No
Combined Cycle Gas Turbine	Yes	Yes	(Yes)	No
Reciprocating (diesel / HFO)	Yes	Yes	Yes	No
Nuclear	Yes	Yes	No	Yes
Hydroelectric with storage	(Yes)	(Yes)	Yes	Yes
Hydroelectric: run-of-river	No	No	(Yes)	Yes
Solar Photovoltaic	No	No	No	Yes
Solar Thermal	Yes	No	No	Yes
Wind	No	No	No	Yes
Tidal Stream	No	Yes	No	Yes
Tidal Range	No	Yes	(Yes)	Yes
Biomass / MSW	Yes	Yes	(Yes)	Yes
Geothermal	Yes	Yes	No	Yes

Generation characteristics

Technology	Constant	Predictable	Despatchable	Low Carbon
Steam (coal / oil)	Yes	Yes	(Yes)	No
Open Cycle Gas Turbine	Yes	Yes	Yes	No
Combined Cycle Gas Turbine	Yes	Yes	(Yes)	No
Reciprocating (diesel / HFO)	Yes	Yes	Yes	No
Nuclear	Yes	Yes	No	Yes
Hydroelectric with storage	(Yes)	(Yes)	Yes	Yes
Hydroelectric: run-of-river	No	No	(Yes)	Yes
Solar Photovoltaic	No	No	No	Yes
Solar Thermal	Yes	No	No	Yes
Wind	No	No	No	Yes
Tidal Stream	No	Yes	No	Yes
Tidal Range	No	Yes	(Yes)	Yes
Biomass / MSW	Yes	Yes	(Yes)	Yes
Geothermal	Yes	Yes	No	Yes

Traditional generation mix

Technology	Constant	Predictable	Despatchable	Low Carbon
Steam (coal / oil)	Yes	Yes	(Yes)	No
Open Cycle Gas Turbine	Yes	Yes	Yes	No
Combined Cycle Gas Turbine	Yes	Yes	(Yes)	No
Reciprocating (diesel / HFO)	Yes	Yes	Yes	No
Nuclear	Yes	Yes	No	Yes
Hydroelectric with storage	(Yes)	(Yes)	Yes	Yes
Hydroelectric: run-of-river	No	No	(Yes)	Yes

Good mix of constant supply, predictable output and fully or moderately despatchable generation make the power system easy to operate – but typically high carbon.

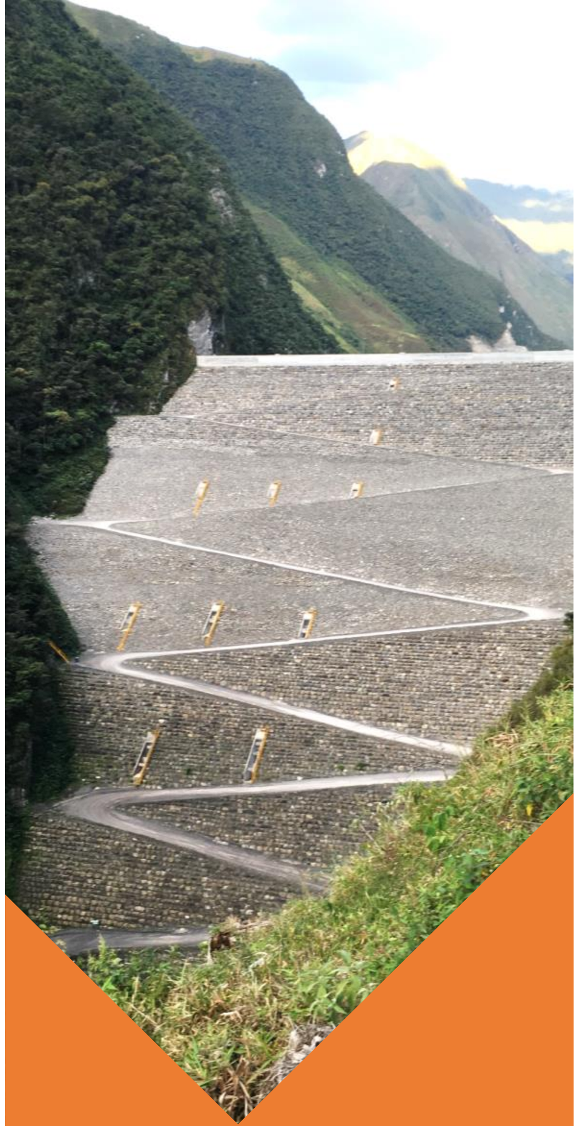
Future generation mix

Technology	Constant	Predictable	Despatchable	Low Carbon
Nuclear	Yes	Yes	No	Yes
Hydroelectric with storage	(Yes)	(Yes)	Yes	Yes
Hydroelectric: run-of-river	No	No	(Yes)	Yes
Solar Photovoltaic	No	No	No	Yes
Solar Thermal	Yes	No	No	Yes
Wind	No	No	No	Yes
Tidal Stream	No	Yes	No	Yes
Tidal Range	No	Yes	(Yes)	Yes
Biomass / MSW	Yes	Yes	(Yes)	Yes
Geothermal	Yes	Yes	No	Yes

Removing the high carbon generation reduces constancy, predictability and most of all despatchability. The system becomes very difficult to operate.

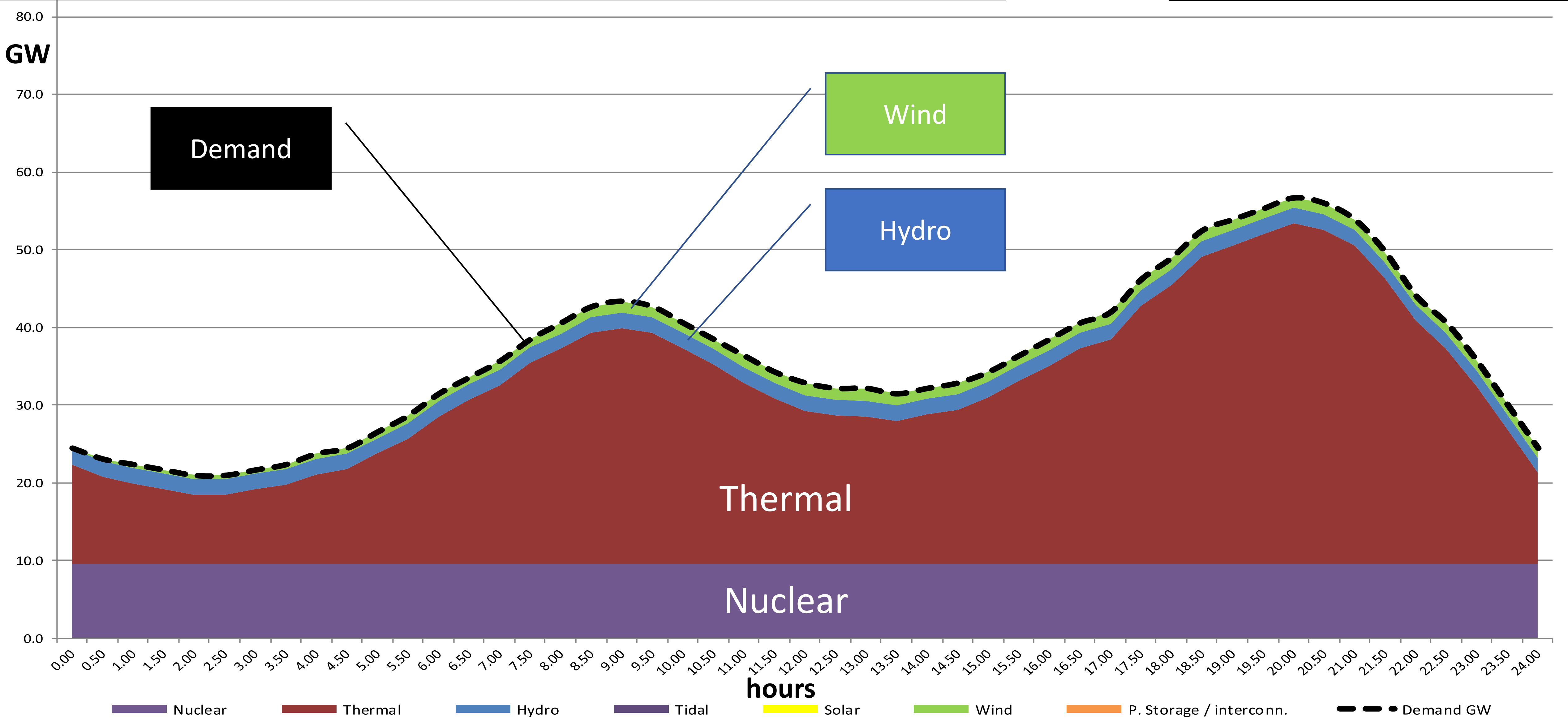
How are Power Systems Changing?

- Intermittency and variability of generation means continually changing energy mix – difficult to manage, especially with uncontrolled generation.
- Need for more stop-starts, faster ramping, storage, stand-by generation, frequency regulation, interconnectors.
- System inertia – historically provided by large rotating plant – is becoming a major issue.



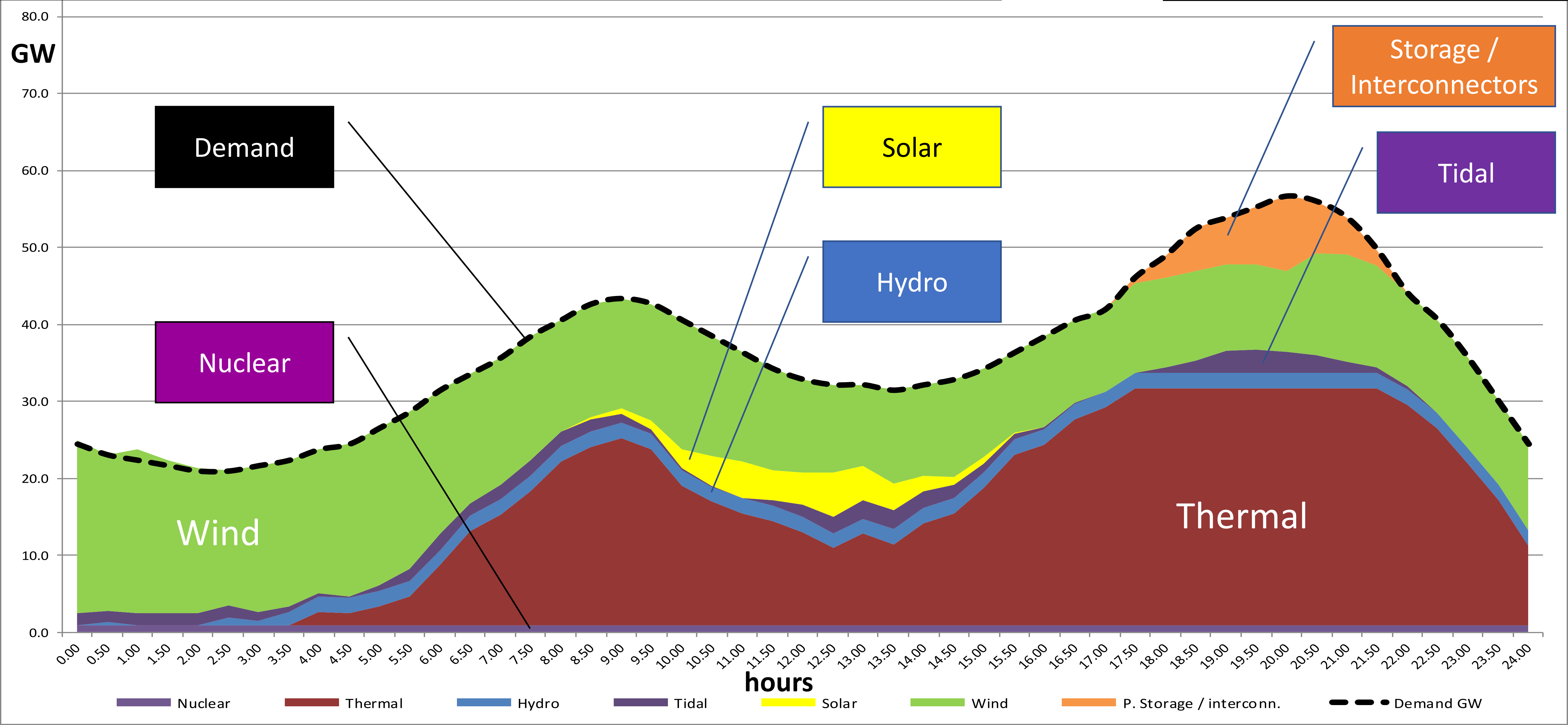
Generation Despatch before significant renewables

UK 2010 Winter Day



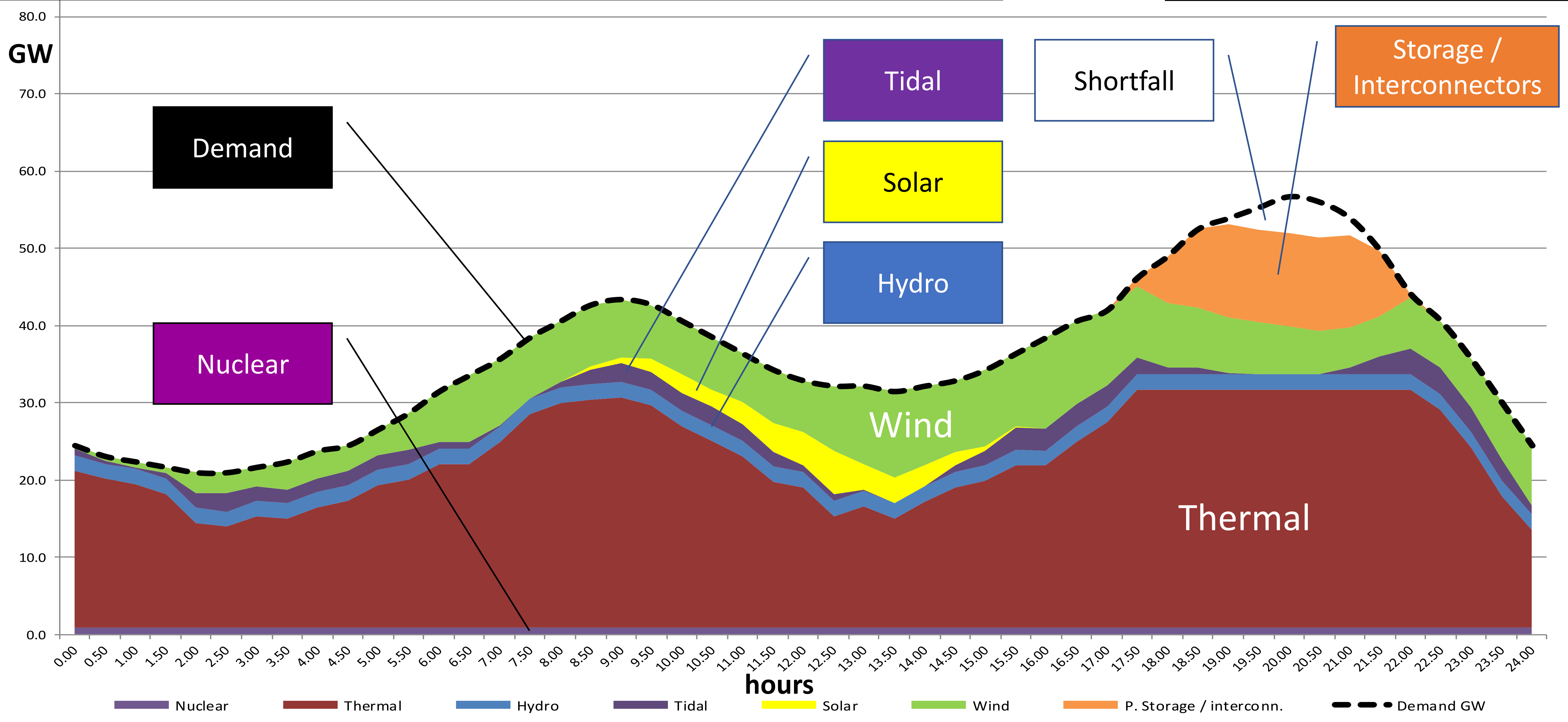
Generation Despatch with more Renewables – High Wind Day

UK 2025 Winter Day



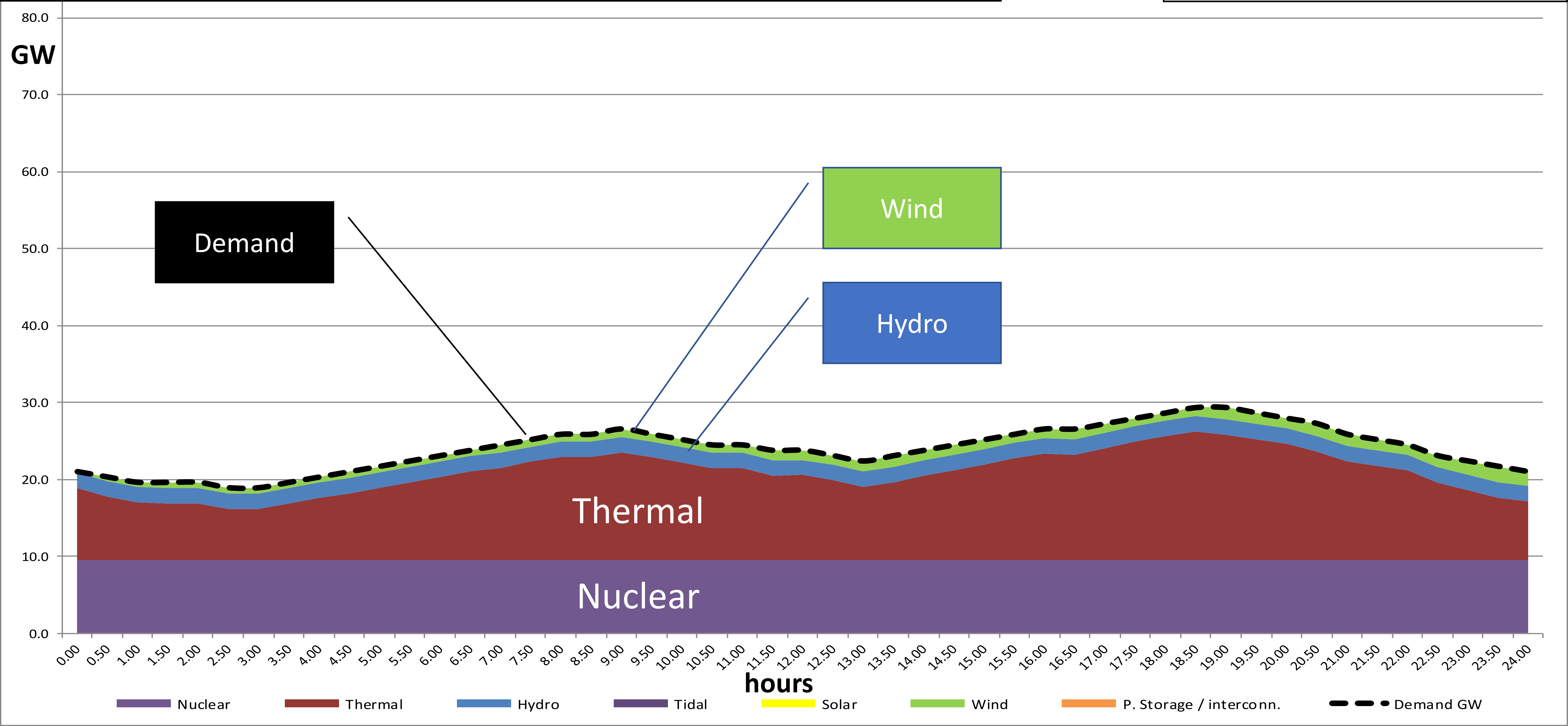
Generation Despatch with more Renewables – Low Wind Day

UK 2025 Winter Day



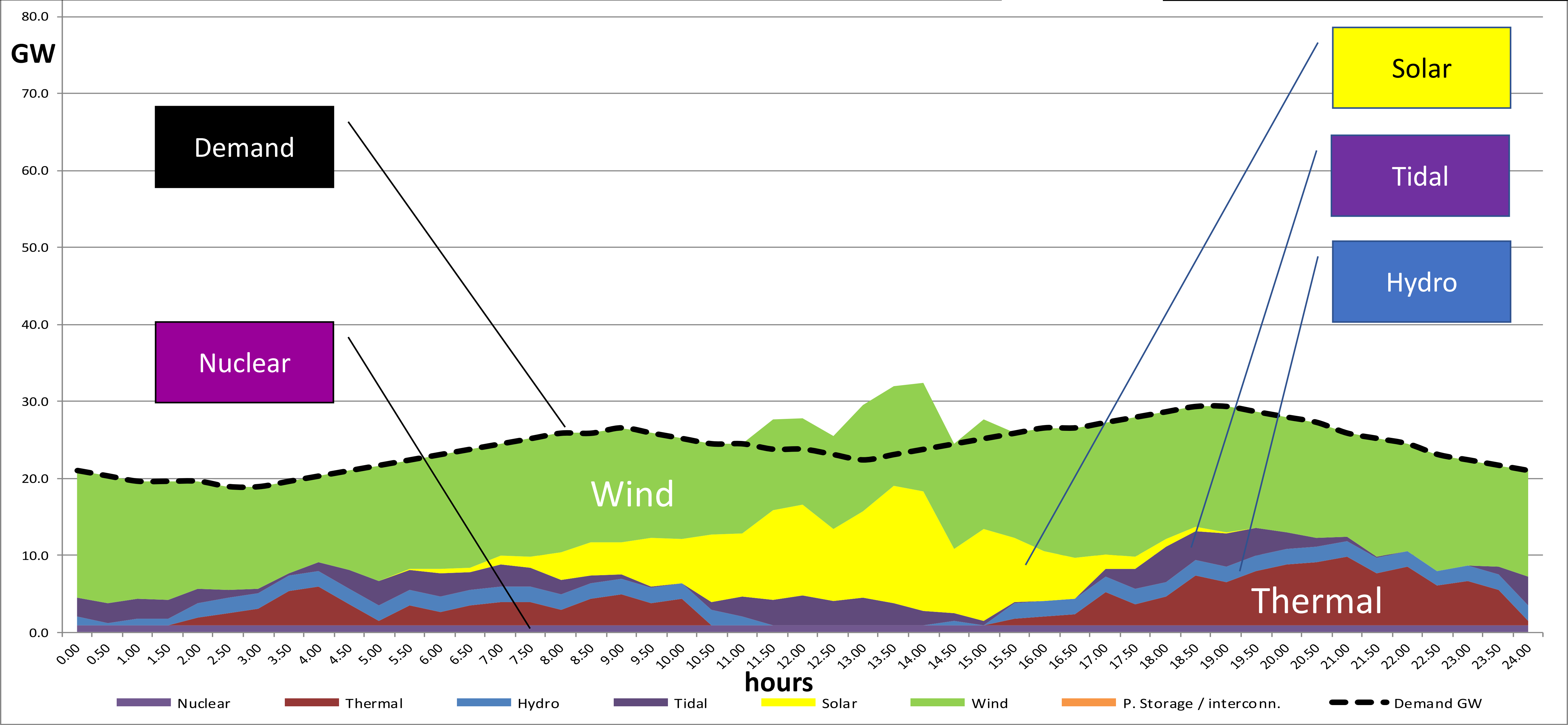
Generation Despatch before significant renewables

UK 2010 Summer Day



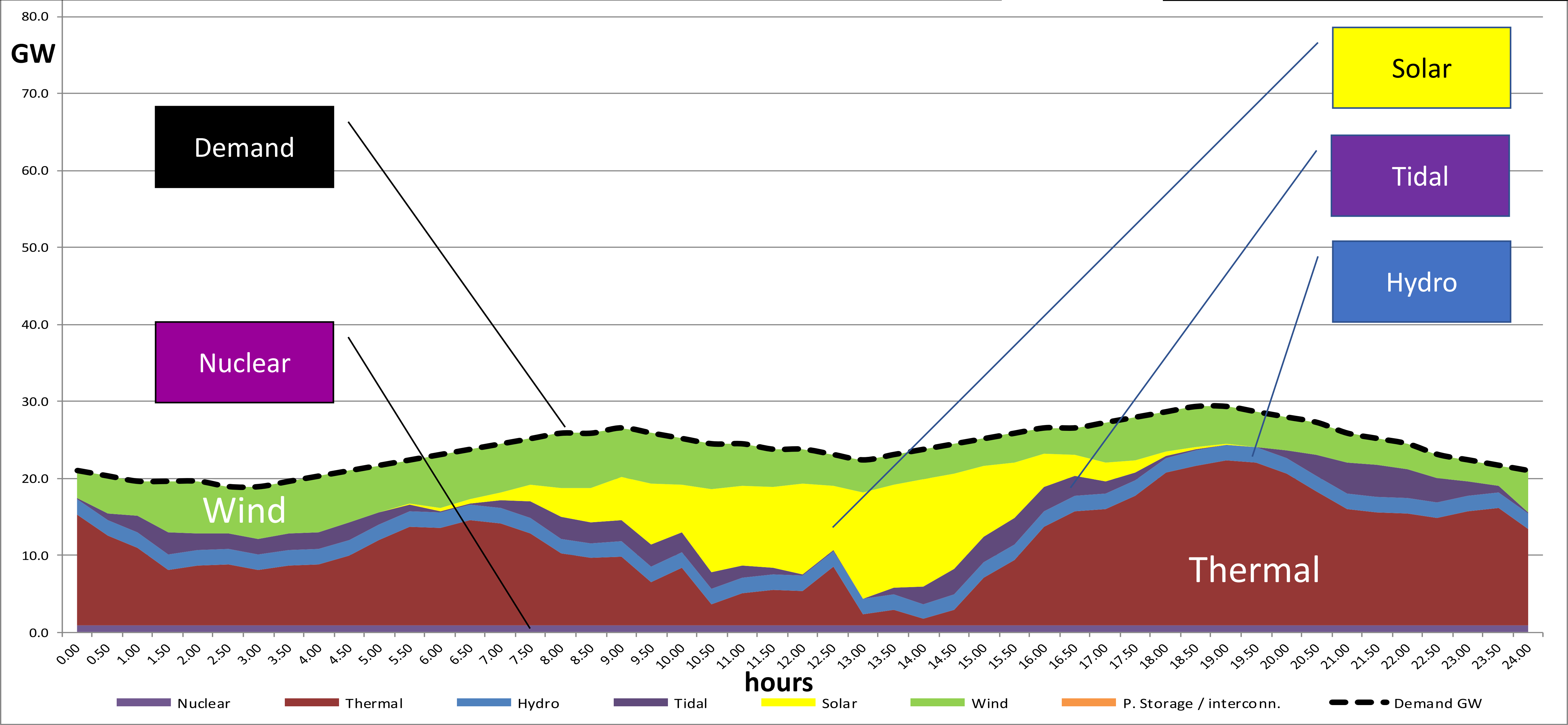
Generation Despatch with more Renewables – High Wind Day

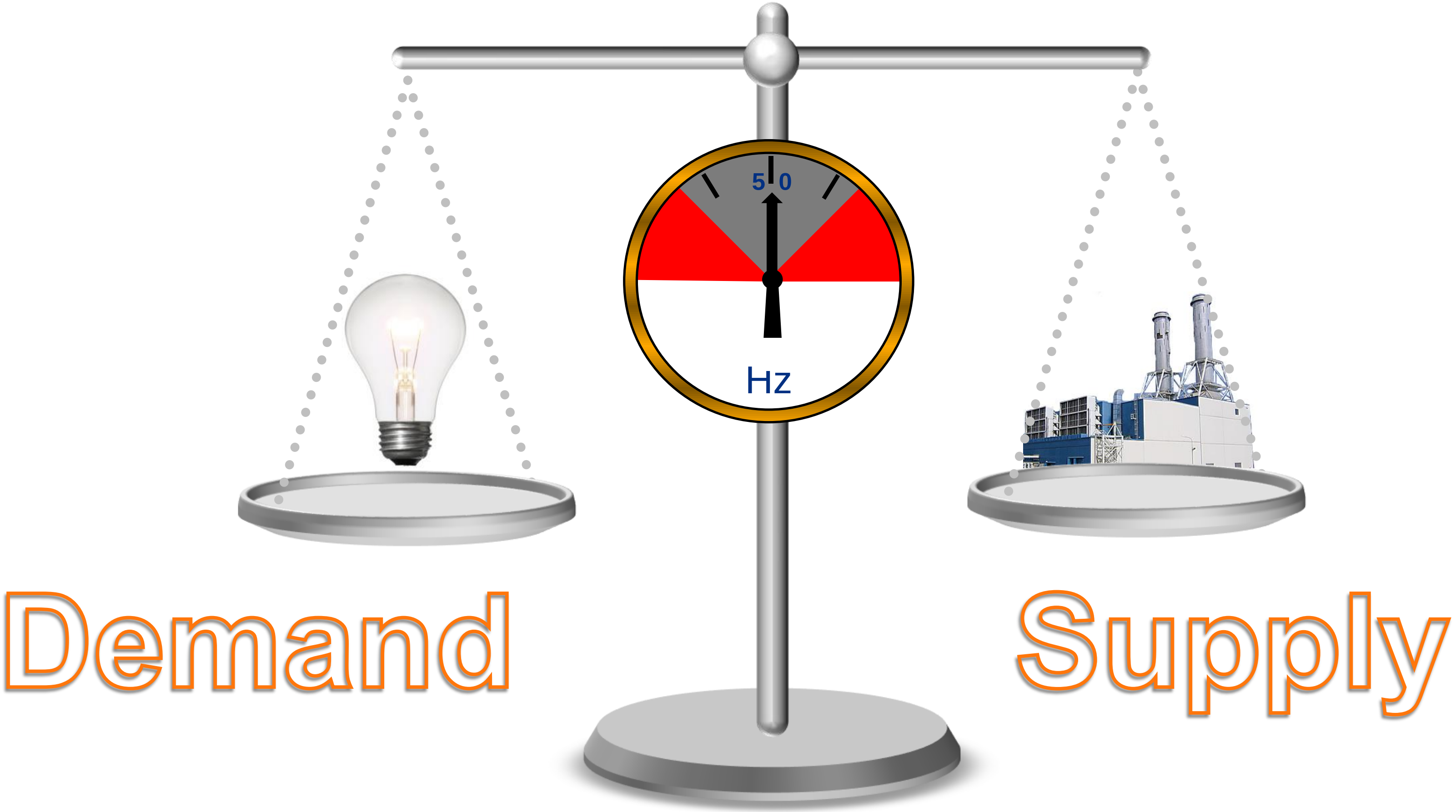
UK 2025 Summer Day



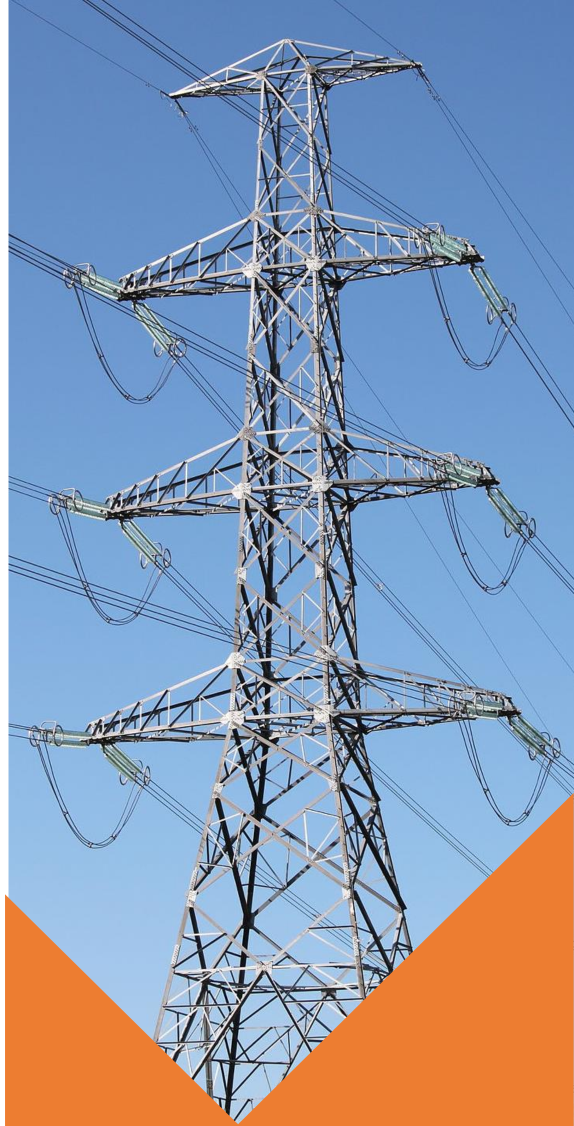
Generation Despatch with more Renewables – Low Wind Day

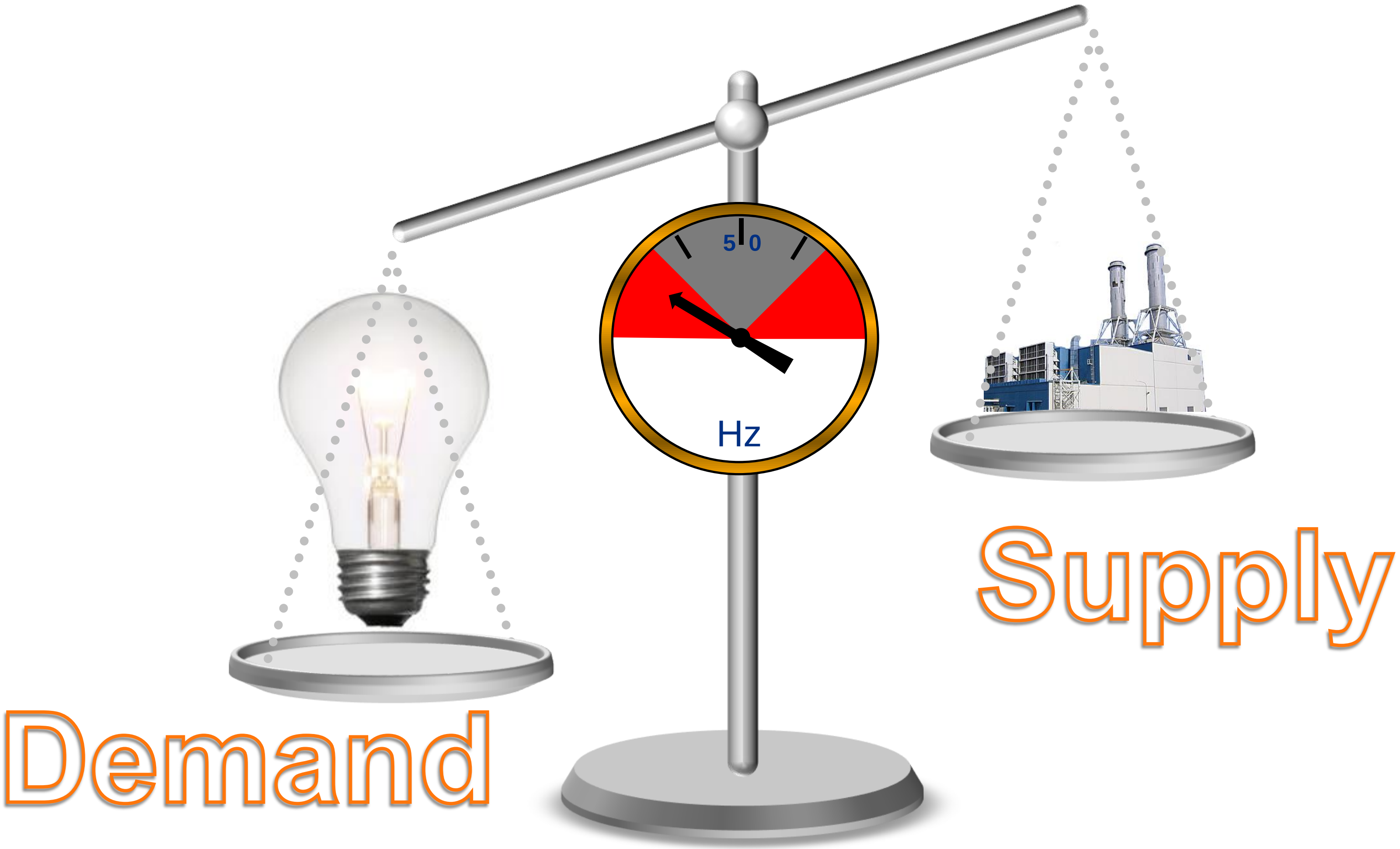
UK 2025 Summer Day

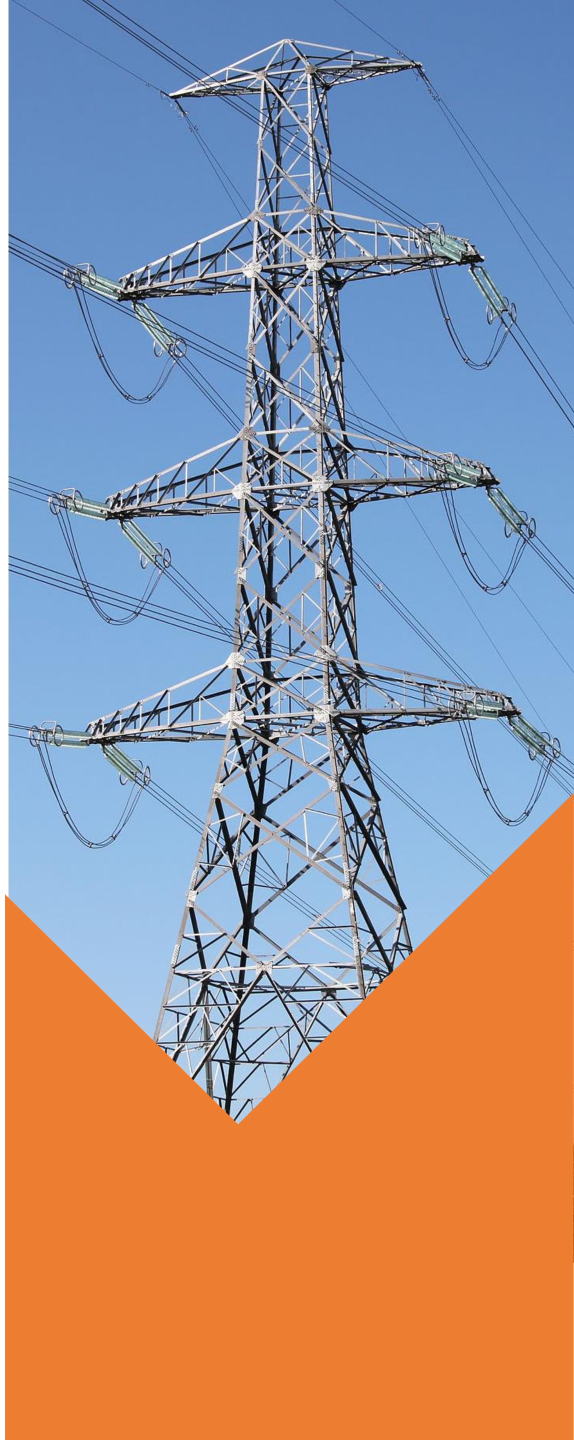




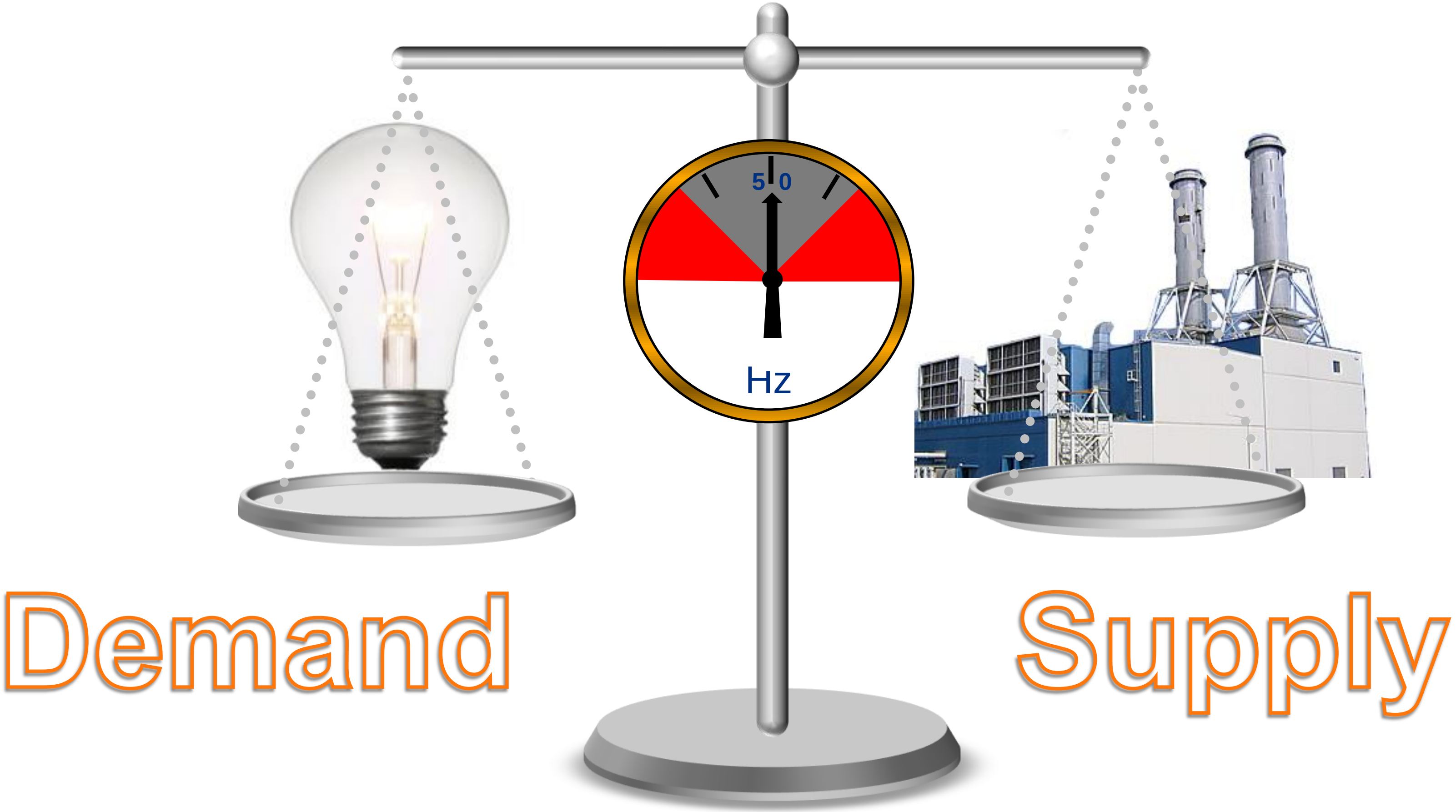
Power demand and supply must be in balance



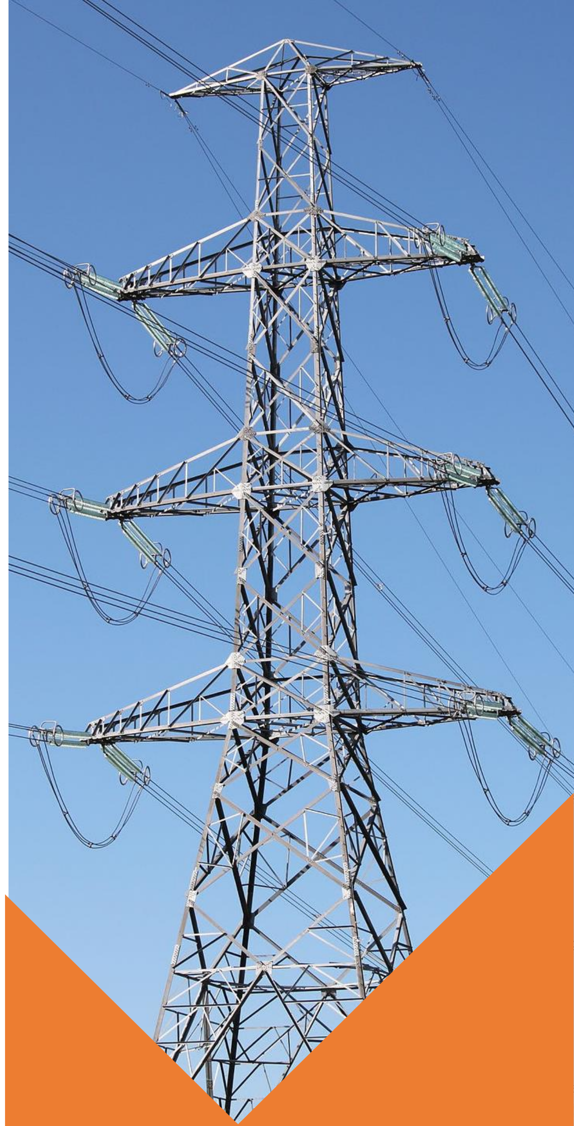




If power demand exceeds supply,
frequency falls below 50 Hz



When supply is increased to match demand, frequency recovers to 50 Hz



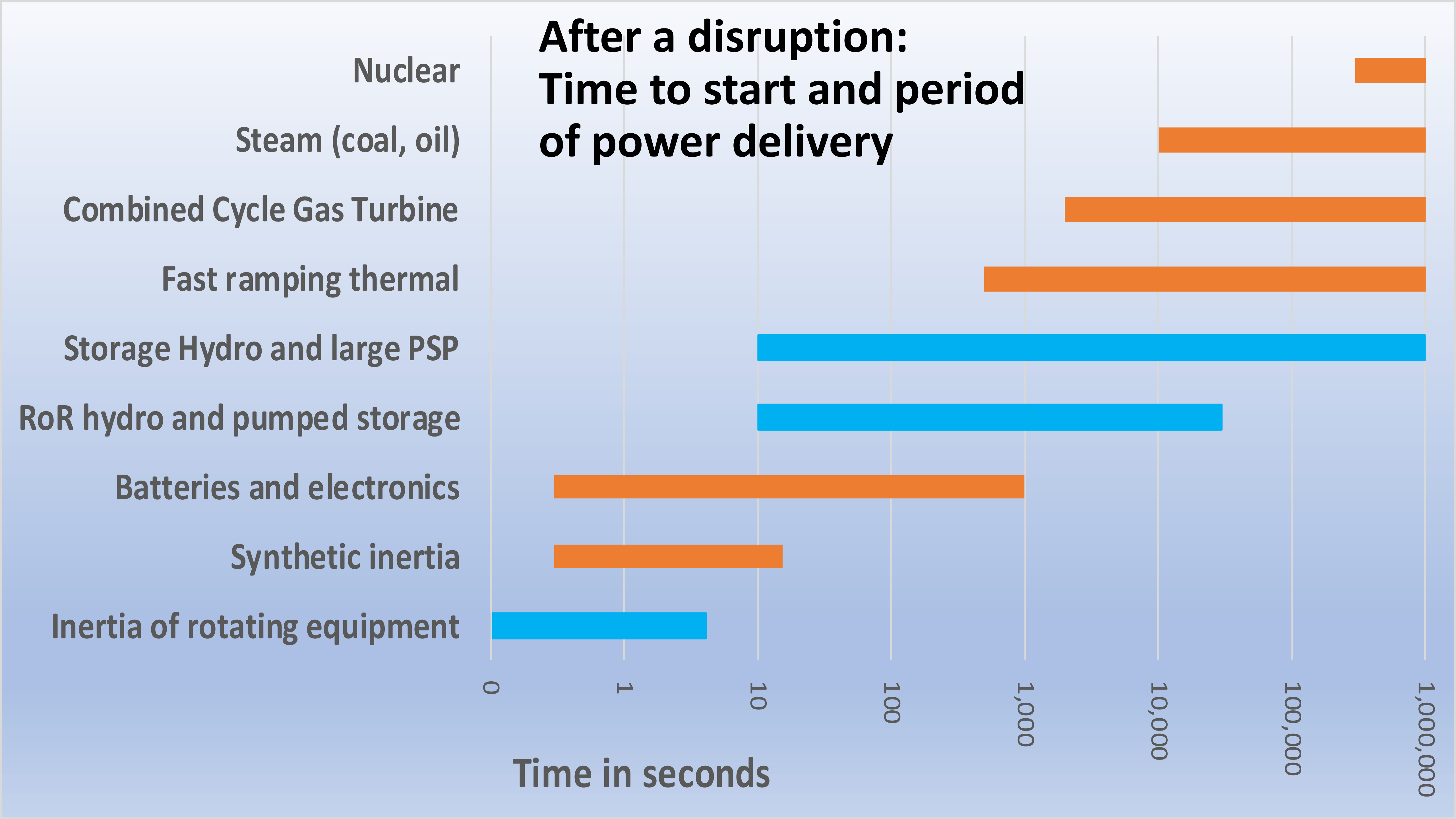
System inertia is becoming a problem

System Inertia: kinetic energy in rotating masses directly coupled to the grid – instantly balances surplus or deficit.

Fast Active Power Injection (Synthetic Inertia): power injected quickly but following a measurement delay, typically from power electronics and batteries

Synthetic Inertia: is not fast enough (typically 200 ms to measure, 100 ms to respond) to prevent frequency drop and protection tripping.

Operators may need to keep large synchronous plant on the grid purely to provide system inertia.


After a disruption:
Time to start and period of power delivery
Nuclear
Steam (coal, oil)
Combined Cycle Gas Turbine
Fast ramping thermal
Storage Hydro and large PSP
RoR hydro and pumped storage
Batteries and electronics
Synthetic inertia
Inertia of rotating equipment
0
1
10
100
1,000
10,000
100,000
1,000,000
Time in seconds

How can Hydro help?

- Storage
- Fast ramping
- Inertia
- Other services

"PUMPED STORAGE PLANTS – BEST FRIEND OF ELECTRICITY GRID"
(Title of section 7.3 of India NEP3)

Pumped storage can store intermittent and variable energy from solar, wind and other RE technologies, and is:

- technically proven – since 1930
- cost effective
- highly efficient (~80% cycle efficiency)
- large scale (1000s of MW, 10s of GWh)
- operationally flexible
- has exceptional longevity

Conventional storage hydro can be operated as virtual pumped storage, generating when other renewables are not available, and stopping when not needed.

Ireland's DS3 Summary of System Services

Service Name	Abbrev.	Unit of Payment	Short Description
Synchronous Inertial Response	SIR	MWs2h	(Stored kinetic energy)*(SIR Factor – 15)
Fast Frequency Response	FFR	MWh	MW delivered between 2 and 10 seconds
Primary Operating Reserve	POR	MWh	MW delivered between 5 and 15 seconds
Secondary Operating Reserve	SOR	MWh	MW delivered between 15 to 90 seconds
Tertiary Operating Reserve 1	TOR1	MWh	MW delivered between 90 seconds to 5 minutes
Tertiary Operating Reserve 2	TOR2	MWh	MW delivered between 5 minutes to 20 minutes
Replacement Reserve – Synchronised	RRS	MWh	MW delivered between 20 minutes to 1 hour
Replacement Reserve – Desynchronised	RRD	MWh	MW delivered between 20 minutes to 1 hour
Ramping Margin 1	RM1	MWh	The increased MW output that can be delivered with a good degree of certainty for the given time horizon.
Ramping Margin 3	RM3	MWh	
Ramping Margin 8	RM8	MWh	
Fast Post Fault Active Power Recovery	FPFAPR	MWh	Active power (MW) >90% within 250 ms of voltage >90%
Steady State Reactive Power	SSRP	Mvarh	(Mvar capability)*(% of capacity that Mvar capability is achievable)
Dynamic Reactive Response	DRR	MWh	MVAr capability during large (>30%) voltage dips

Ireland's DS3 – portfolio ability to provide services

source: DS3 System Services: Portfolio Analysis, Eirgrid & SONI, 2014

Hydro can be designed to provide these services

Service:	Capacity	SIR	FFR	POR	SOR	TOR1	TOR2	RR (S)	RR (D)	RM1	RM3	RM8	SSRP	DRR	FPFAPR
Technology	**MW**	**MWs^{-2}**	**MW**	**MW**	**MW**	**MW**	**MW**	**MW**	**MW**	**MW**	**MW**	**MW**	**Mvar**	**MW**	**MW**
Combined Cycle Gas Turbine	4,287	65,901	169	338	463	586	655	2,044	-	-	-	996	2,344	4,287	4,287
Combined Heat and Power	171	-	4	8	8	18	60	169	9	9	171	171	76	171	171
Demand Side Management	60	-	-	-	-	-	-	64	114	215	64	64	-	-	-
Hydropower (conventional)	216	3,466	3	5	24	51	99	193	148	176	178	178	177	216	216
Interconnector (with UK)	750	-	750	750	750	750	750	750	750	750	750	750	350	-	500
Open Cycle Gas Turbine	1,097	37,186	93	186	242	265	348	1,096	634	1,080	1,080	1,080	864	1,097	1,097
Pumped Storage (Turlough Hill)	292	55,620	40	80	272	272	292	292	292	292	292	292	309	292	292
Thermal (coal, peat, oil & gas)	3,055	149,262	98	195	248	269	291	952	-	-	18	126	1,963	3,055	3,055
Wind	617	-	-	-	-	-	-	-	-	-	-	-	191	-	-
Total	**10,545**	**311,435**	**1,157**	**1,562**	**2,007**	**2,211**	**2,495**	**5,560**	**1,947**	**2,522**	**2,553**	**3,657**	**6,274**	**9,118**	**9,618**

Ireland's DS3 – percentage of each service by technology

Service:	Capacity	SIR	FFR	POR	SOR	TOR1	TOR2	RR (S)	RR (D)	RM1	RM3	RM8	SSRP	DRR	FPFAPR
Technology	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
Combined Cycle Gas Turbine	41%	21%	15%	22%	23%	27%	26%	37%	0%	0%	0%	27%	37%	47%	45%
Combined Heat and Power	2%	0%	0%	1%	0%	1%	2%	3%	0%	0%	7%	5%	1%	2%	2%
Demand Side Management	1%	0%	0%	0%	0%	0%	0%	1%	6%	9%	3%	2%	0%	0%	0%
Hydropower (conventional)	2%	1%	0%	0%	1%	2%	4%	3%	8%	7%	7%	5%	3%	2%	2%
Interconnector (with UK)	7%	0%	65%	48%	37%	34%	30%	13%	39%	30%	29%	21%	6%	0%	5%
Open Cycle Gas Turbine	10%	12%	8%	12%	12%	12%	14%	20%	33%	43%	42%	30%	14%	12%	11%
Pumped Storage (Turlough Hill)	3%	18%	3%	5%	14%	12%	12%	5%	15%	12%	11%	8%	5%	3%	3%
Thermal (coal, peat, oil & gas)	29%	48%	8%	12%	12%	12%	12%	17%	0%	0%	1%	3%	31%	34%	32%
Wind	6%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	3%	0%	0%
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Does technology contribute above or below average?

	Better than 120%		Between 80% and 120%		Less than 80%

Technology / Service:	Capacity %	SIR %	FFR %	POR %	SOR %	TOR1 %	TOR2 %	RR (S) %	RR (D) %	RM1 %	RM3 %	RM8 %	SSRP %	DRR %	FPFAPR %
Combined Cycle Gas Turbine	41%	21%	15%	22%	23%	27%	26%	37%	0%	0%	0%	27%	37%	47%	45%
Combined Heat and Power	2%	0%	0%	1%	0%	1%	2%	3%	0%	0%	7%	5%	1%	2%	2%
Demand Side Management	1%	0%	0%	0%	0%	0%	0%	1%	6%	9%	3%	2%	0%	0%	0%
Hydropower (conventional)	2%	1%	0%	0%	1%	2%	4%	3%	8%	7%	7%	5%	3%	2%	2%
Interconnector (with UK)	7%	0%	65%	48%	37%	34%	30%	13%	39%	30%	29%	21%	6%	0%	5%
Open Cycle Gas Turbine	10%	12%	8%	12%	12%	12%	14%	20%	33%	43%	42%	30%	14%	12%	11%
Pumped Storage (Turlough Hill)	3%	18%	3%	5%	14%	12%	12%	5%	15%	12%	11%	8%	5%	3%	3%
Thermal (coal, peat, oil & gas)	29%	48%	8%	12%	12%	12%	12%	17%	0%	0%	1%	3%	31%	34%	32%
Wind	6%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	3%	0%	0%
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

When thermal disappears

And Ireland is planning for 75% non-synchronous penetration!!

Better than 120% | Between 80% and 120% | Less than 80%

Service:	Capacity	SIR	FFR	POR	SOR	TOR1	TOR2	RR (S)	RR (D)	RM1	RM3	RM8	SSRP	DRR	FPFAPR
Technology	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
Combined Cycle Gas Turbine	57%	41%	16%	25%	26%	30%	30%	44%	0%	0%	0%	28%	54%	71%	65%
Combined Heat and Power	2%	0%	0%	1%	0%	1%	3%	4%	0%	0%	7%	5%	2%	3%	3%
Demand Side Management	1%	0%	0%	0%	0%	0%	0%	1%	6%	9%	3%	2%	0%	0%	0%
Hydropower (conventional)	3%	2%	0%	0%	1%	3%	4%	4%	8%	7%	7%	5%	4%	4%	3%
Interconnector (with UK)	10%	0%	71%	55%	43%	39%	34%	16%	39%	30%	30%	21%	8%	0%	8%
Open Cycle Gas Turbine	15%	23%	9%	14%	14%	14%	16%	24%	33%	43%	43%	31%	20%	18%	17%
Pumped Storage (Turlough Hill)	4%	34%	4%	6%	15%	14%	13%	6%	15%	12%	12%	8%	7%	5%	4%
Wind	8%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	4%	0%	0%
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Hydro can help support the grid

- Hydro can provide the full range of system support services
- BUT the scheme must be designed for this purpose (storage, rapid response etc)
- It must not be constrained from operating flexibly (many existing schemes have tight constraints on how and when they operate)
- In particular storage is needed – recent trends are for run-of-river schemes

Does this require new technology?

No: many existing schemes are designed for flexible operation.

Pergau HEP, Malaysia (1996)

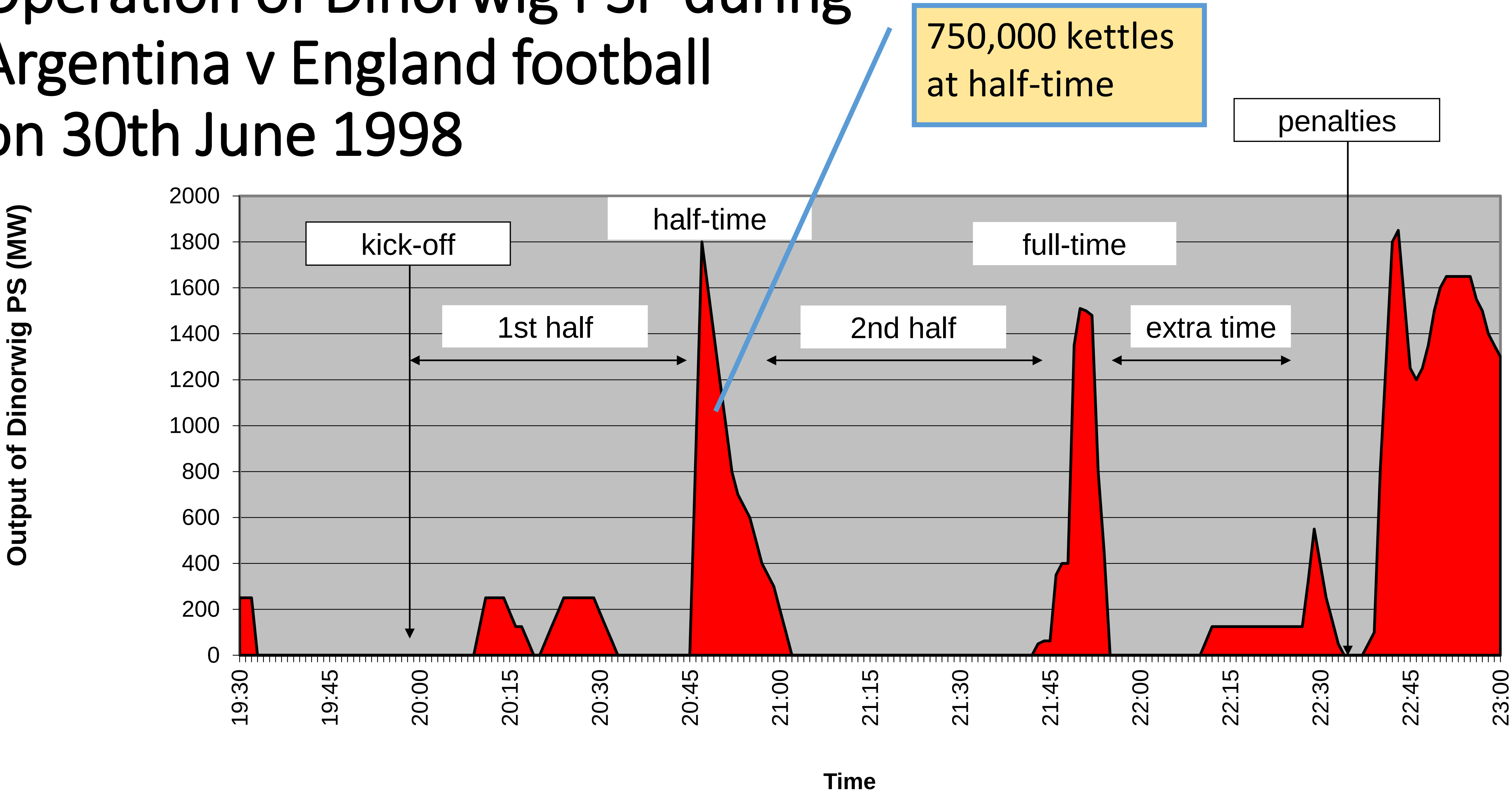
- Peaking operation (~10% load factor)
- rapid response (0 – 600 MW in <20 sec)
- weekly storage (empties during week, refills weekends)
- 500 kV line direct to heart of load centre (Klang Valley)

Dinorwig Pumped Storage Scheme (1984)

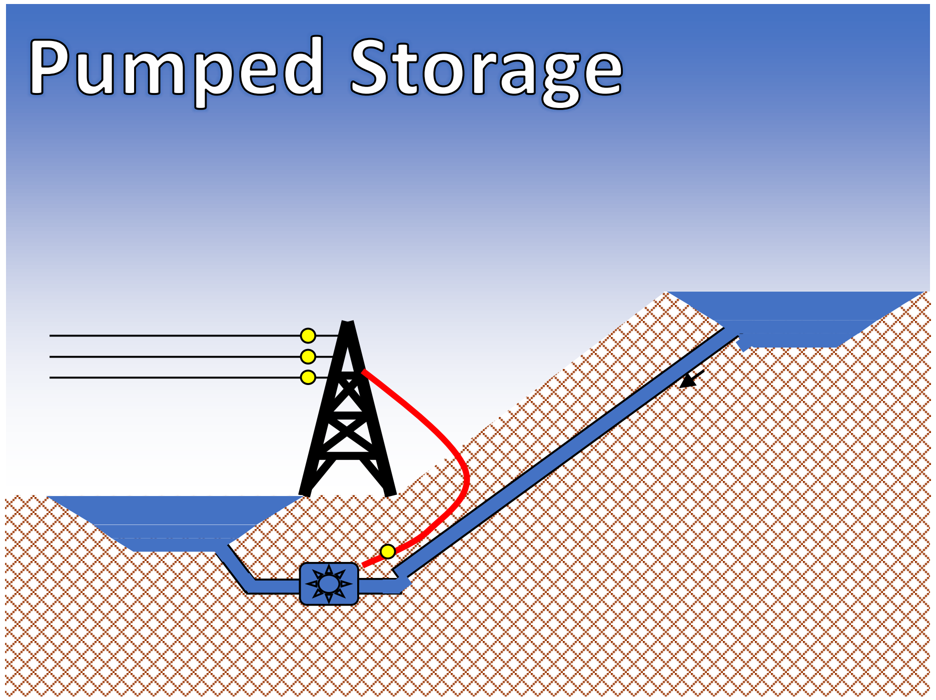
- Synchronised, spinning in air: 0 to 1320 MW in 12 seconds
- 1728 MW peak output
- 5 hours of storage (9000 MWh)

cf Musk is building the world's largest battery storage in South Australia – 129 MWh

Operation of Dinorwig PSP during Argentina v England football on 30th June 1998



OR



In my view – BOTH:

a scheme comprising 1000 MW, 8000 MWh of pumped storage (high head, ternary units) plus 1000 MW, 10 minutes (i.e. 170 MWh) of batteries would be invaluable to any high non-synchronous penetration grid.

How to fund “flexible hydro”?

- Traditionally in deregulated markets payment is made for energy
- Current approach is to auction system services (eg DS3, UK etc)
- However bidders will “game” the market, and operator is unlikely to get what he wants.

A new concept – FEL / FELT

Under Finance, Engineer, Lease and Transfer (**FELT**):

- operator specifies his requirements
- Developer finances, designs and constructs the scheme
- leases scheme to system operator, who operates it for maximum system benefit
- Optional transfer at end of lease term

In summary

- Power systems are becoming harder to operate due to decarbonisation and RE penetration
- Flexible storage hydro and pumped storage can greatly assist operation
- Hydro must be designed for system support and allowed to operate flexibly
- New funding mechanisms (eg FEL / FELT) needed to ensure system operator gets what he needs