EMERGING AREAS | ENERGY SECTOR

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ASIA CLEAN ENERGY FORUM
Thematic Track Session 2.2
Diversification and Decentralization of Energy Sources

Grid Control Technologies to Manage Growing Share of Renewable Energy Sources in Power Grids

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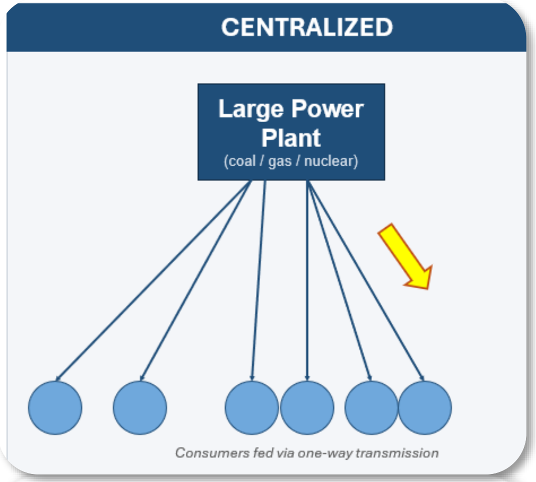
Decentralized and Diversified Energy Sources

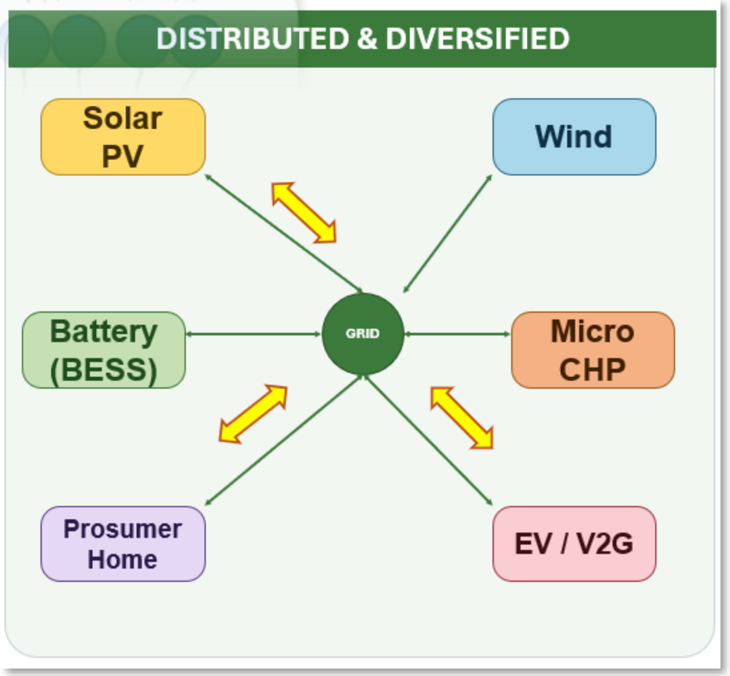
Previously
- Large centralized power plants.
- Power flow from generation to grids to demand.

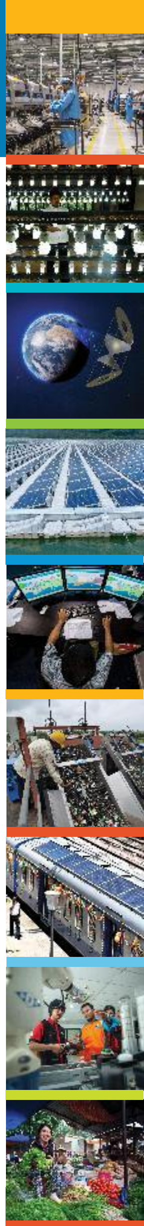
Nowadays
- More distributed renewable energy sources.
- Diversified grid elements - EV charging stations, VPP, etc.
- Bidirectional and dynamic power flow within grids.

Challenge
- Harder than ever for grid operators to monitor and control power supply quality.

Countermeasures
- Proactive grid control by **high-level technologies (HLTs)** - energy storage, RE forecasting, smart wide-area real monitoring, grid-forming IBRs.







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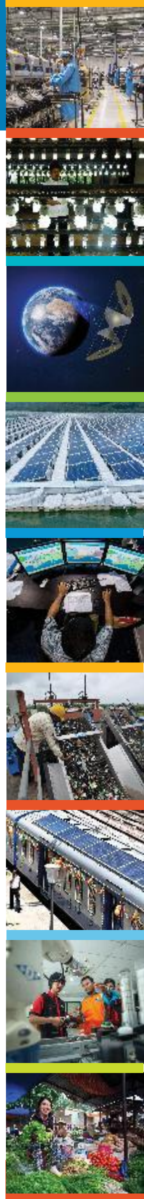
Grid Challenges as VRE Increases

1	2	3	4	5
Fluctuating Power Output by Weather	**Fewer synchronous units online**	**Voltage support depends on inverter controls**	**Inertia and fault current become locational**	**New Transmission Line Needs to be developed**
Issue: Decreased power supply reliability.	During high-VRE or low-load hours, displacement of synchronous generation reduces both inertia and fault-current contribution.	Post-fault voltage recovery and reactive support shift from synchronous machines to dynamic reactive devices and IBR controls.	System-wide averages mislead — the relevant metric is at each connection point and weak corridor.	Issue: Right of Way (ROW).

1	2	3	4	5
Frequency & Inertia	**System Strength & Protection**	**Voltage & Reactive**	**Transfer & Congestion**	**Flexibility & Reserves**
OPERATOR SEES	OPERATOR SEES	OPERATOR SEES	OPERATOR SEES	OPERATOR SEES
Fast frequency decline · low nadir · reserve uncertainty	*Low fault levels · relay sensitivity · selectivity issues*	*Slow recovery · weak buses · reactive devices at limits*	*Curtailment · corridor constraints · N-1 violations*	*Ramp stress · manual activation · over-procurement*



Why HLTs Matter?

As power systems integrate higher shares of solar, wind, and other inverter-based resources, the challenge is no longer only to connect more capacity.

The real challenge is to keep the grid secure, controllable, and resilient under changing operating conditions.

High-Level Technologies (HLTs) matter because they help TSOs:

- manage low-inertia and weak-grid conditions
- improve voltage and reactive power control
- increase observability and faster system awareness
- unlock transfer capacity and operational flexibility
- translate renewable capacity into securely usable capacity

HLTs provide the tools needed to keep the grid secure, visible, and controllable

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Selective List of HLTs

- **Grid-Forming BESS**
  - Best when speed and waveform support are both needed
- **Grid-Following BESS**
  - The fastest flexible platform — but only if SoC and control rules are governed
- **Synchronous condensers**
  - Physics-based strength, fault current and inertia
- **PSS/AVR/Excitation System Upgrades**
  - Making the existing synchronous fleet more useful under high-IBR operation
- **Hydropower Governor & AGC Modernization**
  - A high-leverage quick enabler in hydro-rich systems
- **Advanced Wind Plant Controls**
  - Turning wind plants from energy-only assets into qualified support resources
- **Pumped Storage Hydropower (PSD/PSPP)**
  - Large-scale flexibility and sustained system support
- **PV+BESS/Hybrid IBR Applications**
  - Making solar-rich nodes more controllable and grid-supportive
- **HVDC/Interconnector Grid-Support Controls**
  - Fast controllable power exchange when agreements and reserves exist
- **WAMPAC/PMU-Bases Remedial Action Schemes**
  - It does not provide inertia — it makes fast corrective action possible

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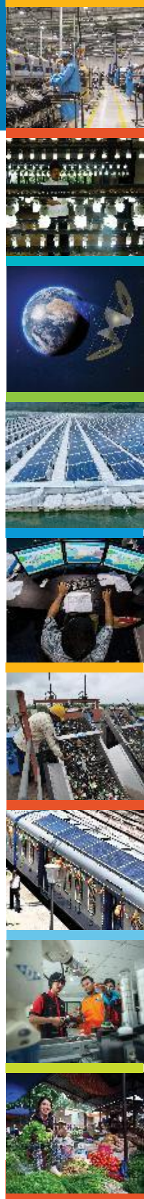

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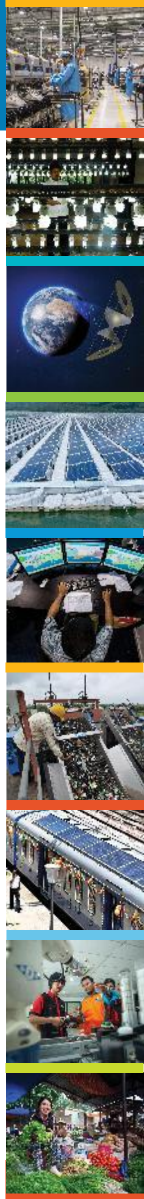
Five-Categories of HLTs

Category 1	**Frequency Stability, Inertia & System Strength** *Grid-forming IBRs · TSO-controllable BESS · Synchronous condensers · Hydro governor/AGC modernisation · Advanced wind controls · Pumped storage · Hybrid PV+BESS*
Category 2	**Voltage Control, Reactive Support & Transfer Enhancement** *STATCOM · SVC · FACTS · Series compensation · HTLS · Dynamic Line Rating · Online voltage security tools*
Category 3	**Interconnection, Controllability & Regional Coordination** *HVDC · Tie-line controllers · AGC/AVC upgrades · Cross-border reserve platforms · Inter-TSO data exchange hubs*
Category 4	**System Awareness, Protection Adaptation & Resilience Automation** *WAMS/WAMPAC · Wide-area control · Adaptive protection · SPS/RAS · Digital twins · EMS/SCADA · Black-start enablement*
Category 5	**Forecasting & Flexibility Enablers** *Renewable forecasting platforms · Multi-driver forecast integration · Aggregated flexibility interfaces · Reserve qualification systems*



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Four Case Studies — Why These Four

Each case captures a different aspect of high-VRE operability and a different implementation lever

IE

Ireland / all-island

Operational-framework-led

High-renewable operation enabled by system services, qualification rules and live monitoring.

GB

Great Britain / NESO

Locational stability procurement

Stability unbundled from energy production; procured by the location where the deficit exists.

AU

Australia / South Australia

Declared shortfalls + staged release

Weak-grid security governance; SynCons and grid-forming BESS released constraints once evidence was in.

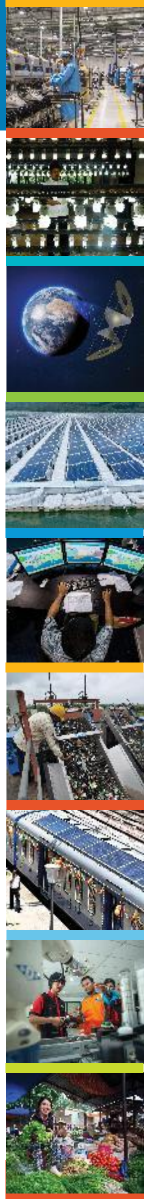
EU

Europe / IGCC

Regional coordination via imbalance netting

Cross-border imbalance netting reduces unnecessary aFRR counter-activation across TSOs.

HLTs should be shortlisted as portfolios designed to address identified constraint patterns, rather than as isolated technologies considered independently of system needs.



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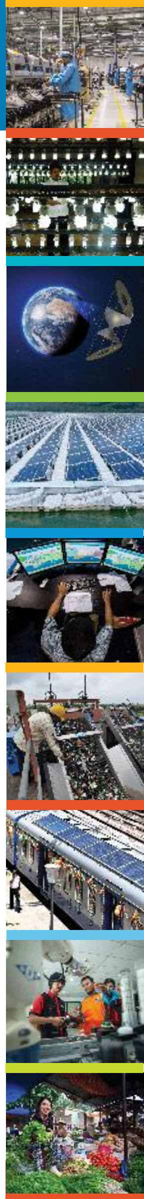
Four Cases at a Glance

SYSTEM	BINDING ISSUE	HLT / OPERATIONAL RESPONSE	TRANSFERABLE LESSON/ OPERATIONAL OUTCOME
Ireland all-island	**High wind & SNSP · inertia / RoCoF · reserve security**	**Operator-led system-services framework: DS3 services · SNSP limit · inertia / RoCoF monitoring · BESS FFR · synchronous compensation**	***The first HLT is the operating framework — services, monitoring, qualification, staged limit release/*** **SNSP ceiling 50 → 75 % · wind peak 4,629 MW**
Great Britain	Locational inertia · short-circuit · dynamic voltage gaps after coal retirement	Stability Pathfinder · stability services · SynCons · flywheels · converted rotors · GFM batteries	*Procure stability outcomes at the location where the deficit exists — not generic equipment/* Phase 1 delivered · Phases 2+3 add 6.7 + 17.1 GVA·s
South Australia	Weak grid · low system strength · high RoCoF · minimum synchronous generation	Declared shortfalls · 4 SynCons · Hornsdale virtual machine / GFM · EMT / model validation	*SynCon and GFM BESS are complementary · constraints relax only once evidence confirms it/* IBR cap 1.3 → 2.5 GW · Reg FCAS price –91 %
Europe IGCC	Opposite aFRR activations across borders create unnecessary balancing cost	Imbalance netting · automated cross-border aFRR optimisation	*Regional coordination can start with no-regret netting before full reserve-sharing maturity/* ~11.2 TWh aFRR avoided (2022) · €790m savings in 2022 · 24 countries, 27 TSOs operational



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Case of Ireland

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ISSUES | *Binding security problem*

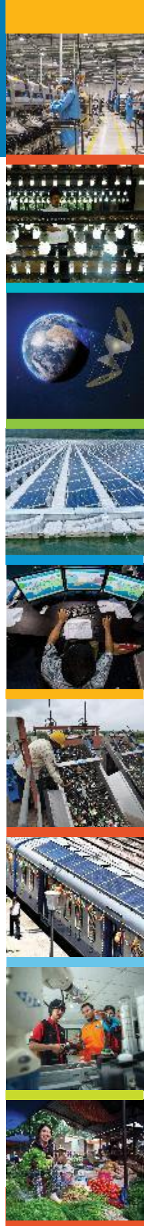
CASE 1 · IRELAND

What became binding

- Low inertia
- High RoCoF risk
- Frequency nadir risk
- Fast reserve delivery
- Protection under higher RoCoF

Operational question

- How much non-synchronous generation can be online at once?
- Can the system survive a major contingency?
- When must renewable output be constrained?



Not a generation adequacy issue

The issue was not “not enough generation”. It was whether very high instantaneous wind and other non-synchronous generation could be operated securely.

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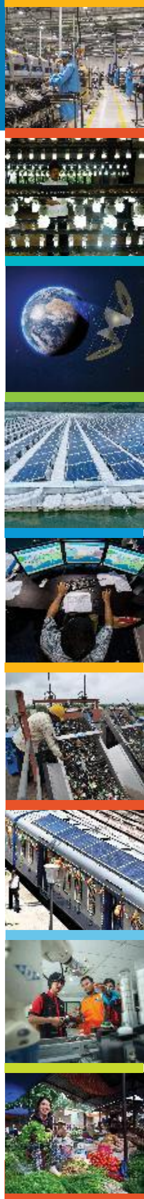
APPROACH | *Framework-Led High-SNSP Operation*

CASE 1 · IRELAND



CONTEXT

- Small synchronous system, large wind fleet (now > 40 % electricity)
- Inertia, RoCoF and reserve security became day-to-day operational issues
- Protection dialogue under low-fault-level conditions became formalised
- SNSP limit (System Non-Synchronous Penetration) introduced as the operational ceiling
- DS3 (Delivering a Secure, Sustainable electricity system) programme — multi-year framework

IMPLEMENTATION STACK

- **DS3 system services** — fast frequency response, ramping, reactive, dynamic reserve
- **SNSP operating limit** — staged release as evidence accumulates
- **Inertia / RoCoF online monitoring** with alarm thresholds
- **BESS fast frequency response** procured under DS3
- **Synchronous compensation** deployed for low-carbon inertia
- **Grid-code updates** aligned with service performance envelopes

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APPROACH | *Implementation Stack*

Services, limits and monitoring — deployed as a coordinated stack

CASE 1 · IRELAND

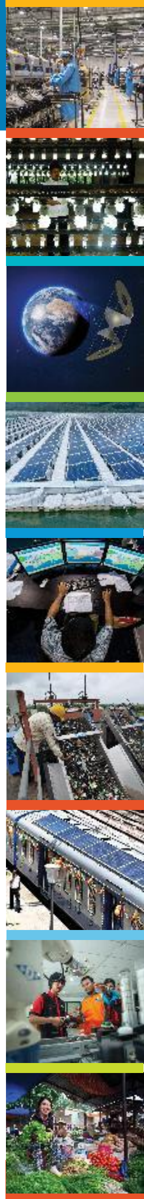
DS3 System Services
Frequency response, reserve, ramping and reactive performance converted into paid, measurable services — FFR, SIR, DRR and post-fault active power recovery. 14 distinct services are now procured regularly.

SNSP Operating Limit
Real-time boundary controlling instantaneous non-synchronous generation. SNSP ceiling moved from 50% (pre-2017) to 75% (2022) through monitored evidence; 95% targeted by 2030.

Inertia & RoCoF Monitoring
Near-real-time inertia estimation and RoCoF risk tracking in the EMS/SCADA. Constraint release became evidence-based — limits moved only when control-room telemetry and event replay confirmed secure performance.

BESS Fast Frequency Response
Grid-scale BESS fleet (~1 GW connected) delivers sub-second response. All-island peak BESS discharge reached ~300 MW. Governed by SoC management, trigger settings, telemetry and recovery rules.

SynCon + Flywheel (Moneypoint)
World-scale synchronous condenser commissioned Q4 2022. Contributes 4,000 MW·s of inertia — equivalent to two retiring 305 MW coal units — plus fault current and dynamic reactive support, with zero fuel burn.



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APPROACH | *HLT Envelopes*

CASE 1 · IRELAND

Each service is procured against a defined, measurable performance envelope — not a generic capability claim

POR / SOR / TOR1	FFR	RoCoF	DRR / SIR
0.15–5 s	**≤ 2 s**	**≤ 1 Hz/s**	**20 / 25 s**
Primary, Secondary, Tertiary 1 operating reserve windows	Fast frequency response — sustained 8 s minimum	Withstand spec for IBR and synchronous units (post-2018)	Dynamic / synchronous inertial response sustained delivery

DS3 product family — what is procured and from whom

SIR	Synchronous inertial response · rotating-mass H × MVA	*Synchronous units*
FFR	Fast frequency response · ≤ 2 s · sustained ≥ 8 s	*BESS · IBRs · DSU*
POR	Primary operating reserve · delivered 5–15 s window	*Conv · BESS · DSU · wind*
FPFAPR	Fast post-fault active power recovery · return to setpoint	*IBRs (wind / PV / BESS)*
DRR	Dynamic reactive response · voltage support during faults	*Conv · STATCOM · IBR*

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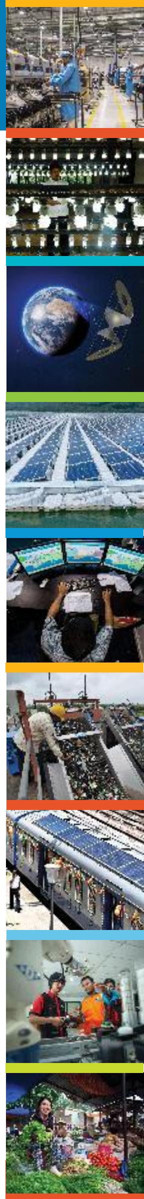

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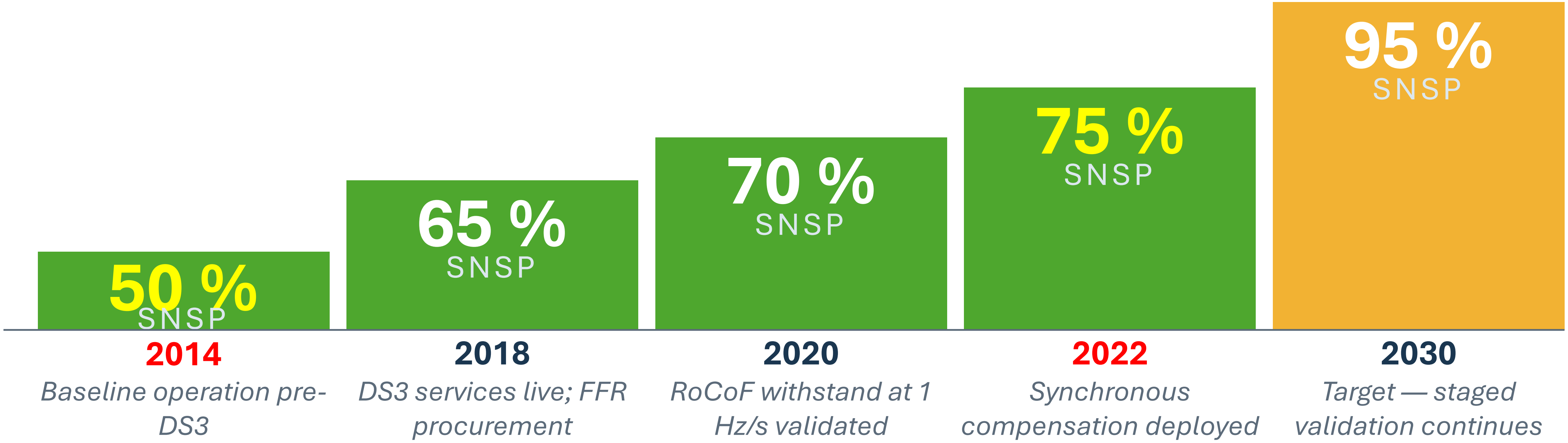
OUTCOME | *SNSP Staircase & Evidence*

CASE 1 · IRELAND

The operational ceiling has been raised in stages — each step required quantified evidence before approval

EVIDENCE PRINCIPLE *each SNSP increase required dynamic studies, real-time monitoring of inertia and RoCoF, and observed performance under credible disturbances.*



SNSP staircase — non-synchronous penetration ceiling raised in evidence-bound steps

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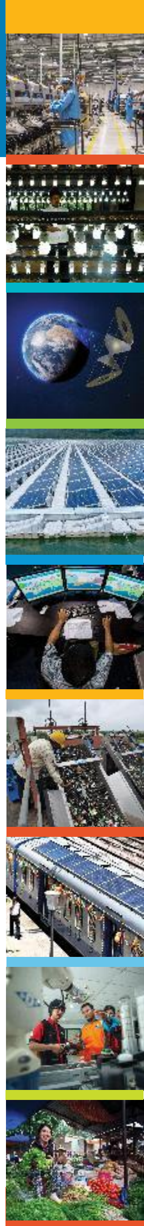

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OUTCOME | *Measured outcomes and operational effect*

Renewable headroom rose because the operator could rely on quantified services, real-time monitoring and new low-carbon inertia.

75 %
world-leading operational SNSP ceiling

4,000 MW·s
Moneypoint syncon inertia (single machine)

14
distinct DS3 system services

4,629 MW
instantaneous wind peak (6 Dec 2023)

Practical Benefits

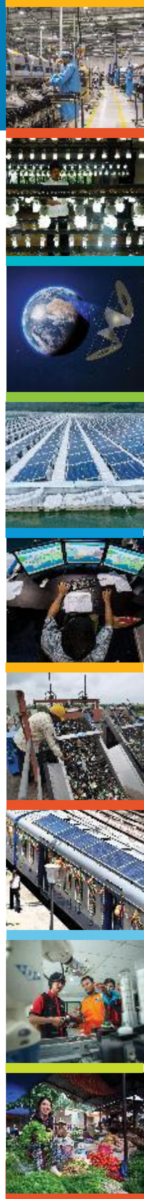
- Reduced curtailment caused by stability limits
- Secure operation during low-inertia hours
- BESS and fast resources become system-service providers
- Syncons replace retiring thermal inertia without fuel burn
- Renewable limits raised gradually through evidence

Transferable Lessons

The first HLT is not hardware — it is the operating framework.

1. Define stability services and qualification rules
2. Monitor inertia and RoCoF in the EMS
3. Pay for capabilities, not technologies
4. Start the protection dialogue early

High-renewable limits are relaxed only after control-room evidence exists.



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LESSONS · Transferable Lesson

CASE 1 · IRELAND

How the framework moves the system to higher renewable headroom — repeatedly

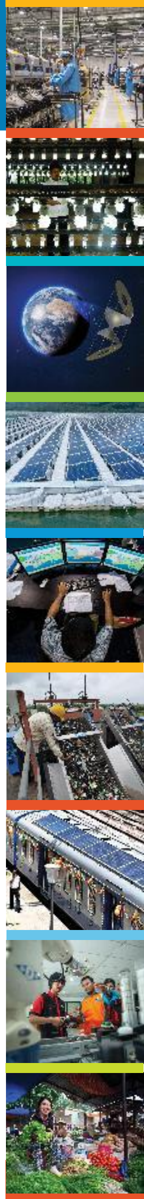
TRANSFERABLE LESSON

Define stability services and qualification rules before assuming high renewable operation can be secure.

The Irish operating cycle

1 Define service	2 Qualification	3 Procure	4 Monitor	5 Release limit
FFR, dynamic reserve, ramping, reactive — measurable	Tested rules per resource type (BESS, wind, conv.)	Service tenders / arrangements, not technology labels	Real-time inertia / RoCoF / delivered MW	SNSP raised in stages once evidence confirms it

NOTE *The SNSP limit is not a target — it is an evidence-bound operating envelope.*



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Thank you!

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