Modern Grid Practices: Unlocking High VRE Integration

Presented by:

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- Evolution of the System Operator
- Role of Independent System and Market Operator
- Generation Mix
- Renewable-Based Electrification. Why???
- Renewable Energy Landscape
- Pakistan’s Changing Power Demand Landscape
- Challenges due to increased VRE Integration
- Grid Practices for Renewable Electrification
- Way Forward
- Conclusion
- Q & A

Evolution of the System Operator

Load Despatch Center – LDC in the 1970s at Kot Lakhpat, Lahore

1st Up Gradation (1980s – 1991) NPCC Islamabad

2nd Up Gradation (2010 – Feb 2025)

3rd Up Gradation (2021 – In Process)

Independent System and Market Operator (ISMO) (30-04-2025)

Why Independent System & Market Operator?

Impartiality – Neutrality and Fairness

Conflict-Free Operation

Why Independent???

Transparency

Credibility

Role of Independent System and Market Operator

ISMO

1. Integrated System Planning

1. Long Term Generation Planning
2. Transmission Planning
3. Long Term Demand Forecast

2. System Operation

1. Generation Despatch
2. Network Operation
3. Operational Planning
4. Commercial Settlement

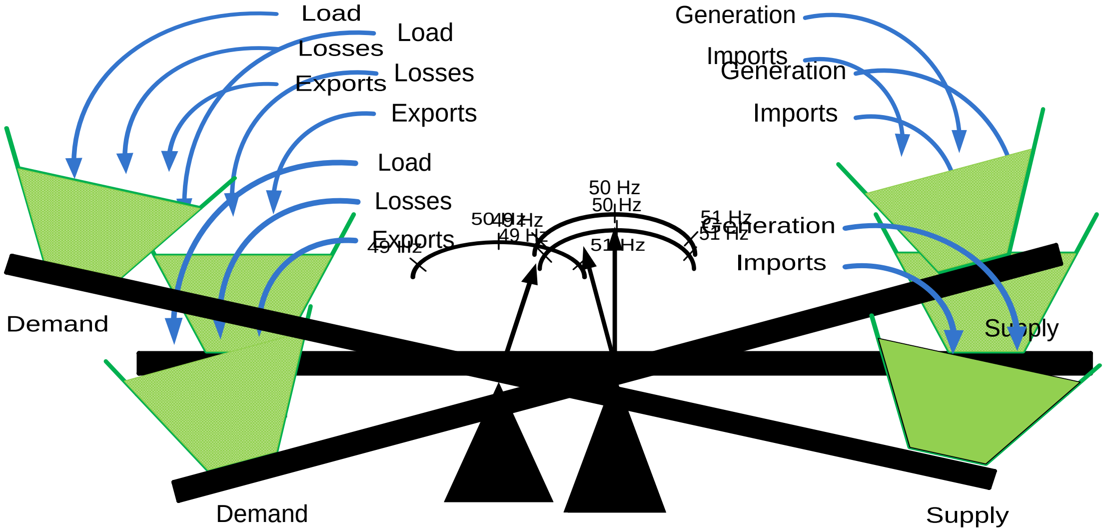
3. Market Operation

1. Registering Participants and Contracts
2. Running IT Platforms for Trading
3. Settlement and Payments in CTBCM
4. Design for Future Evolution of Competitive Market

4. Monitoring & Compliance

1. Grid Code and Market Code Compliance
2. Market Surveillance
3. Generator's Testing

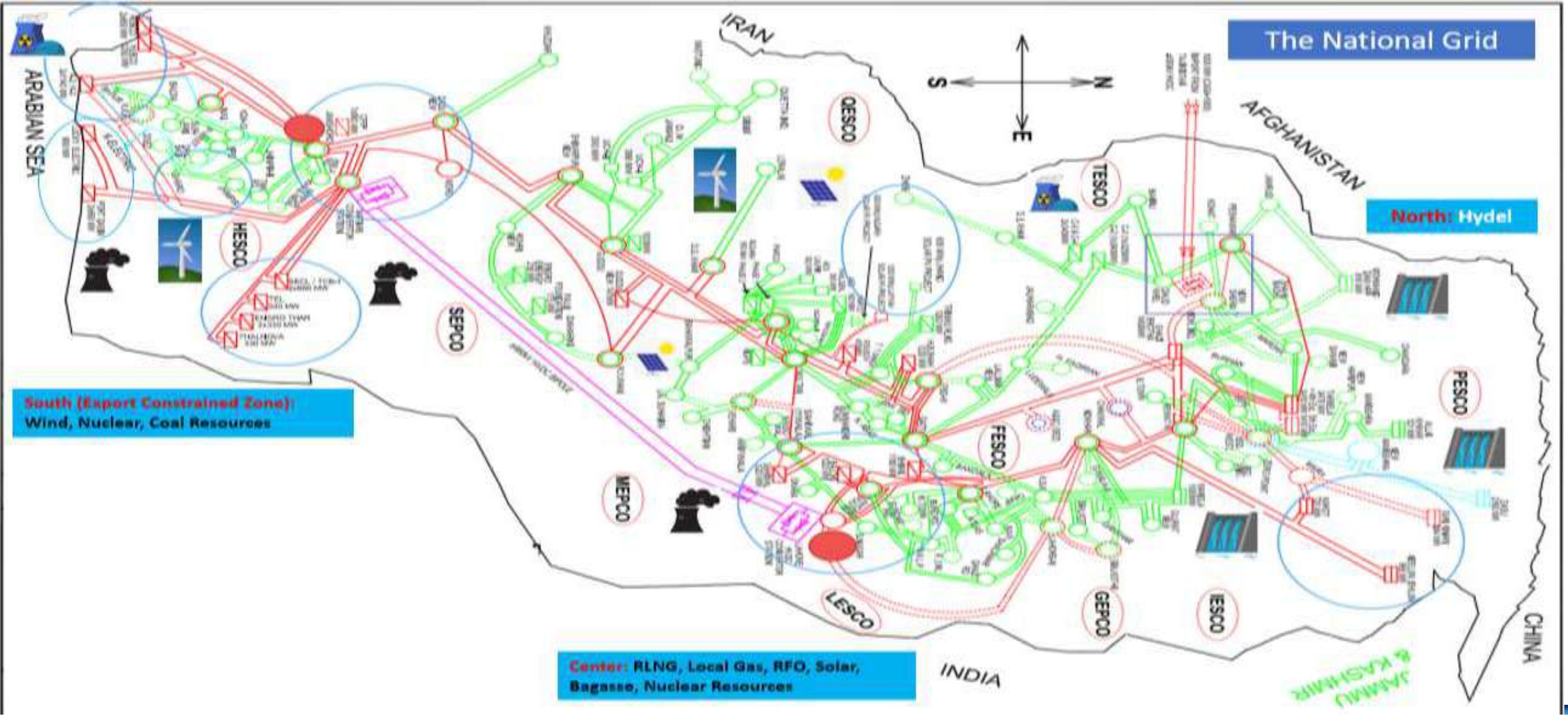
System Operator/Generation Dispatch



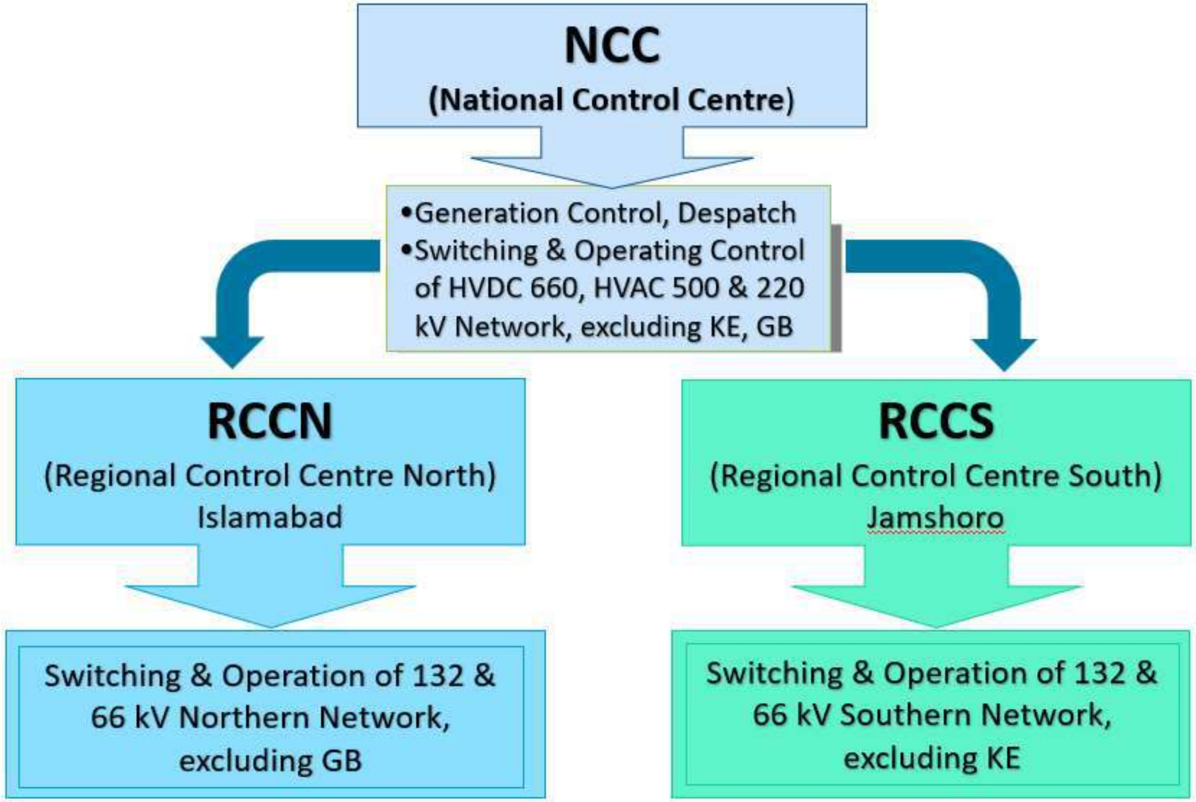
1. Generation Dispatch (Short term Load Forecast, Unit Commitment & Economic Dispatch)

2. Power System Operation & Control (Safe, Secure & Reliable System Operation)

System Operation/Network Operation



System Operation/Network Operation



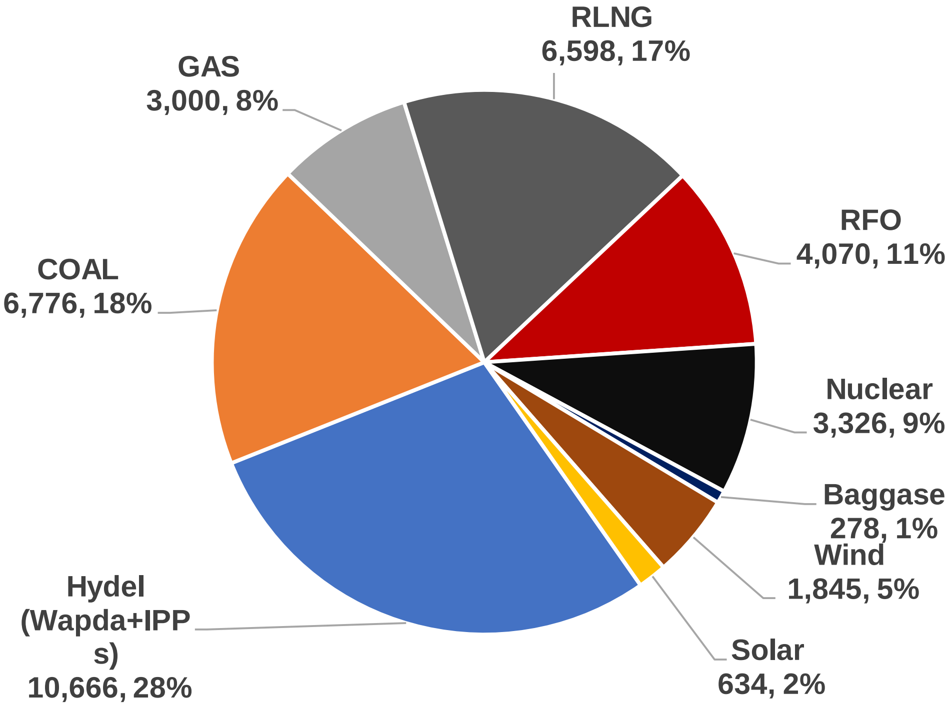
System Operation/Operational Planning

- Year Ahead (Month-wise) Demand Forecast.
- Allocation of Maintenance/Non-Maintenance & Demonstration Period.
- Year Ahead Energy Targets to IPPs.
- Quarter Ahead Energy Targets to IPPs.
- Month Ahead Energy Targets to IPPs.
- Week Ahead MW Targets to IPPs.
- Day Ahead MW Targets to IPPs.
- Schedule Outage approval for next year.

System Operation/Operational Planning

Installed and Dependable Generation Capacity (MW)

Type	Installed Capacity	Dependable Capacity	
	MW	MW	(%)
Hydel (Wapda+IPPs)	10,681	10,666	29%
COAL	7,260	6,776	18%
GAS	3,536	3,000	8%
RLNG	6,943	6,598	17%
RFO	5,706	4,070	11%
Nuclear	3,545	3,326	9%
Baggase	364	278	1%
Wind	1,845	1,845	5%
Solar	650	634	2%
Total	40,530	37,193	100%



Note: (i) Capacity of 1640 MW of GENCOs power plants (Jamshoro, Muzaffargarh, Guddu) out of 2600 MW are generally not dispatched being inefficient and costly, decreasing the dependable capacity to 35,530 MW.

(ii) As a prudent practice 10% of total dependable capacity remain under scheduled/forced outage which further reduces the effective generation capacity to 31,997 MW, during peak summer season.

Network Summary

HVDC (±660 kV PMLT)	
No. of Converter Stations	2
No. of Poles & No. of Transmission Lines	2
Transmission Capacity (MW)	4,000
Length of 660 kV Transmission lines (km)	886×2
NTDC Grids	
500 kV	
No. of 500kV Grid stations	21
No. of 500/220 kV Transformers	46
No. of 500 kV Transmission Lines	65
Length of 500 kV Transmission lines (km)	8,484.05
220 kV	
No. of 220kV Grid stations	50
No. of 220/132 kV Transformers	170
No. of 220 kV Transmission Lines	168
Length of 220 kV Transmission lines (km)	11,816.42
Power Plants	
No. of IPPs (All Types)	111
No. of Hydel Power Houses	30
No. of Thermal Power Houses (GENCOs)	6

Renewable-Based Electrification. Why???

01 Climate Change Mitigation

02 Energy Security & Independence

03 Economic Benefits

04 Access & Electrification

05 Grid Modernization & Efficiency

05 Demand Growth & Future-Proofing

Renewable Energy Landscape

Policy Ambitions

Government targets 60% Clean Energy (VREs, DERs, REs) in the Generation Mix by 2030. Requires major interventions in grid infrastructure and operational practices.

Operational Challenges

Balancing demand and supply
Integrating Variable Renewable Energy (VRE)
Ensuring grid reliability.

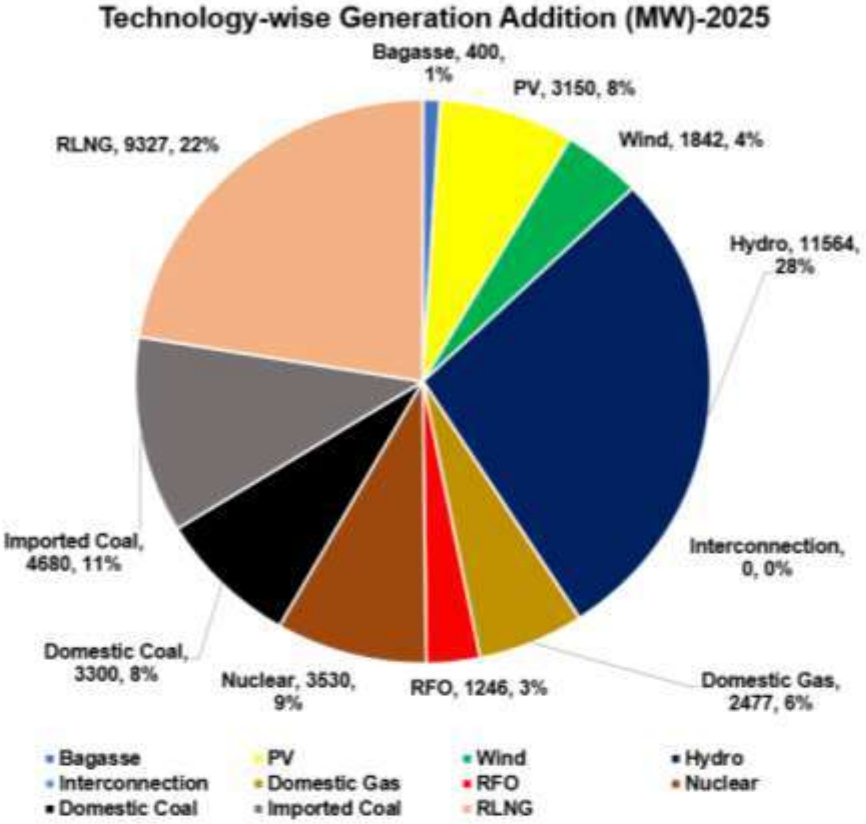
Fuel-wise Generation Addition (MW)				
Technology	2025		2030	
	MW	%	MW	%
VREs	5392	13%	12656	23%
Hydro	11564	28%	17889	33%
Thermal	24560	59%	23353	43%
Total	**41516**		**53898**	

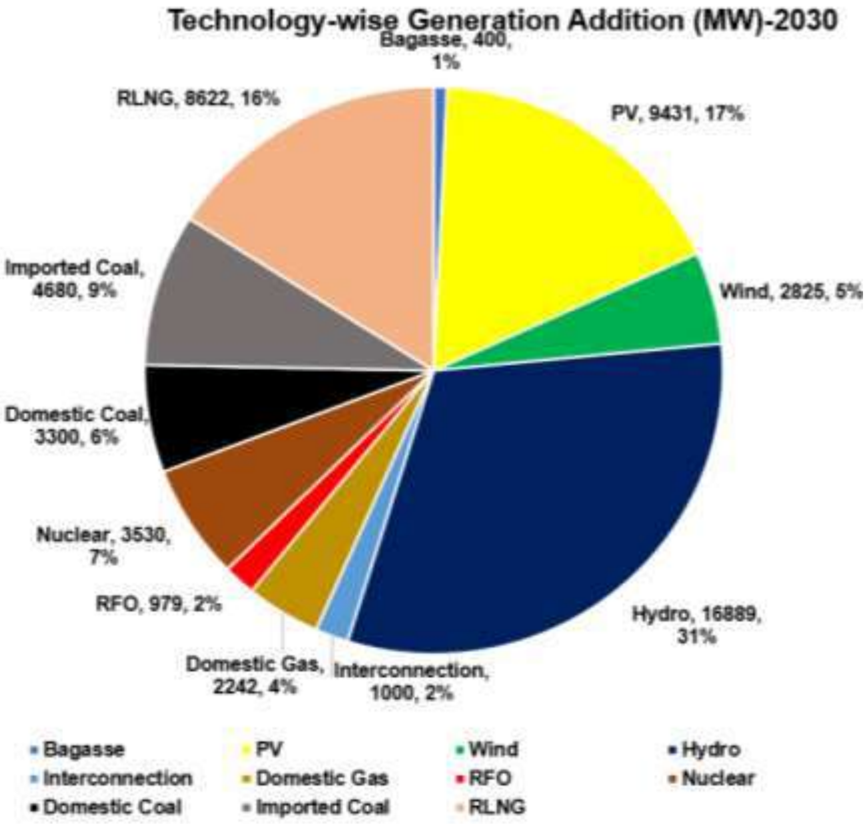
Note:

VREs include Wind, Solar PV and Bagasse

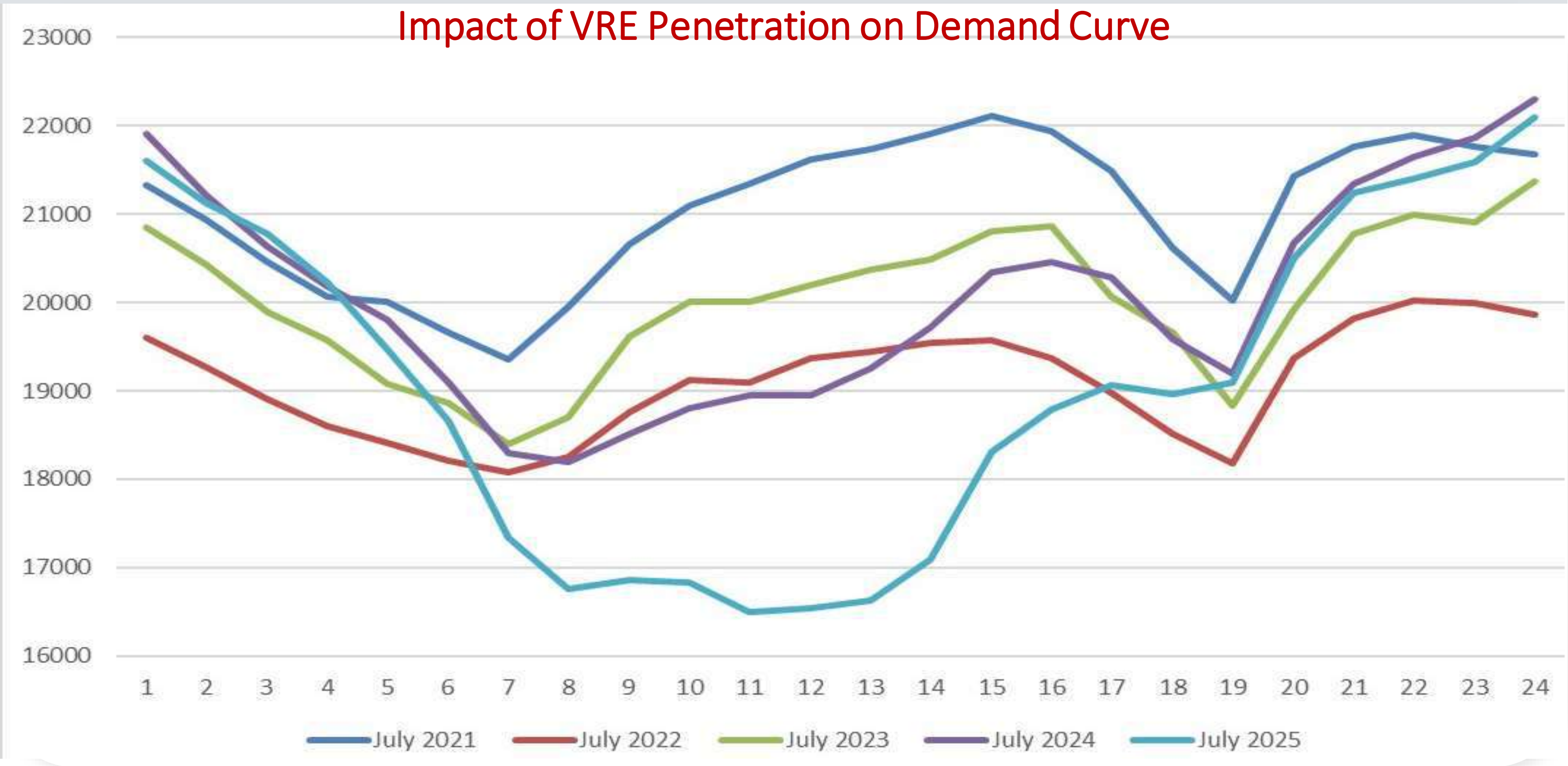
Hydro includes 1000 MW CASA also

Renewable Energy Landscape





Pakistan’s Changing Power Demand Landscape



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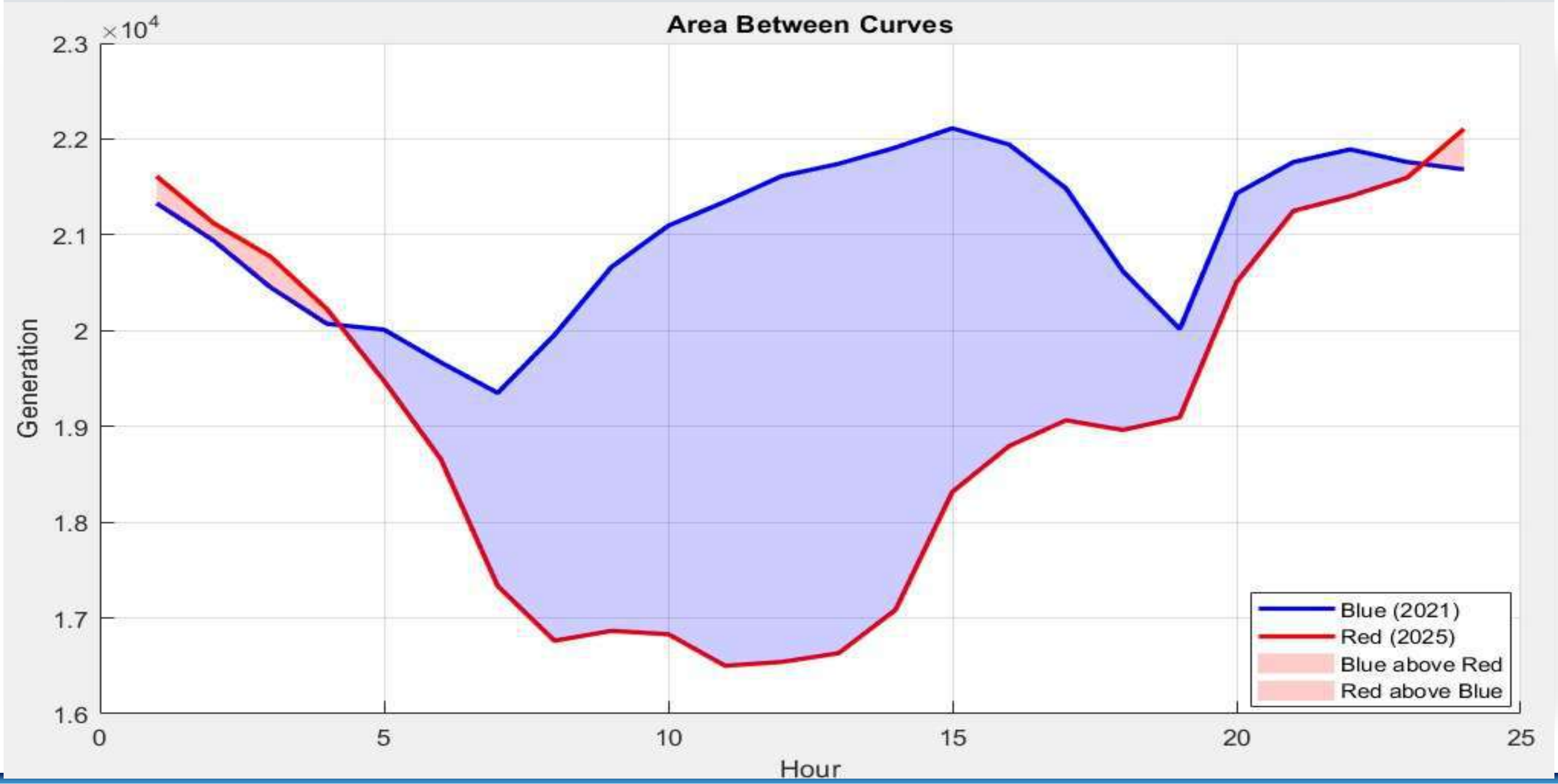


Challenges due to increased VRE Integration

Frequency Regulation
→ Intermittency & forecast errors

Large Unit Contingencies
→ K2/K3

Consumers → **prosumers**
→ Net Metered+ Rooftop/Off-grid solar + Batteries

VRE generation curtailment risk

Duck Curve
→ High daytime solar output and Steep evening ramps

Sharp load variation

Curtailment and Stability Risks

Grid resilience & black start capability

Grid Practices for Renewable Electrification

- Application of Modern forecasting Tools
- Storage technologies: BESS
- Smart Grid (SCADA, WAMPAC, Energy Management Systems, AMR etc.)
- Dynamic reactive power compensation. STATCOMs and SVCs
- Ancillary Services market mechanisms
- Flexibilization of the conventional generators
- Enabling policy and regulatory frameworks
- Strengthening and Modernization of the Transmission & Distribution Grid
- Distributed Energy Resources Management, Monitoring, and Integration

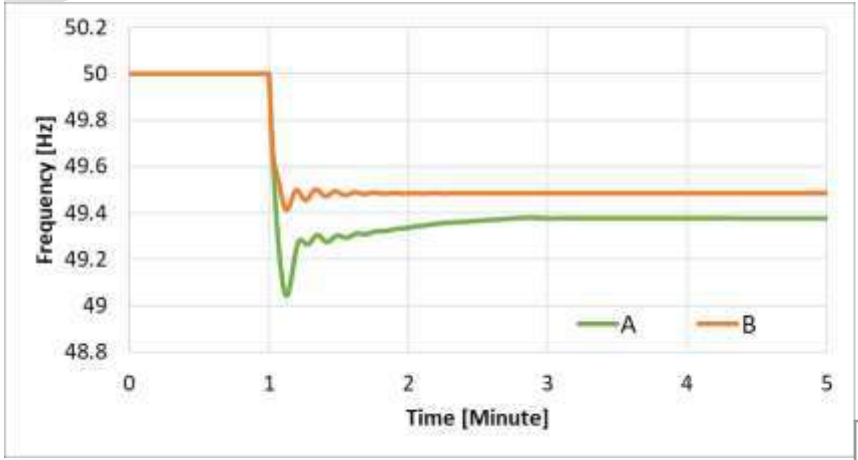
Application of Modern forecasting Tools

Modern forecasting tools could help with enhanced VRE integration converting forecasting uncertainty into manageable variability, allowing higher renewable penetration without risking reliability.

- **Accurate scheduling** → Better day-ahead and intraday forecasts reduce imbalance between demand and renewable supply.
- **Reserve optimization** → Improves estimation of required spinning/non-spinning reserves, lowering costs.
- **Reduced curtailment** → Operators can plan transmission and dispatch more efficiently, using more renewable output.
- **Grid stability** → Short-term (minutes to hours) forecasts help manage ramping of solar/wind and maintain frequency/voltage.
- **Market participation** → Enables VRE generators to commit energy reliably in electricity markets.
- **Advanced analytics** → AI/ML models and satellite/weather data improve prediction of sudden changes (cloud cover, wind ramps).

Storage technologies: BESS

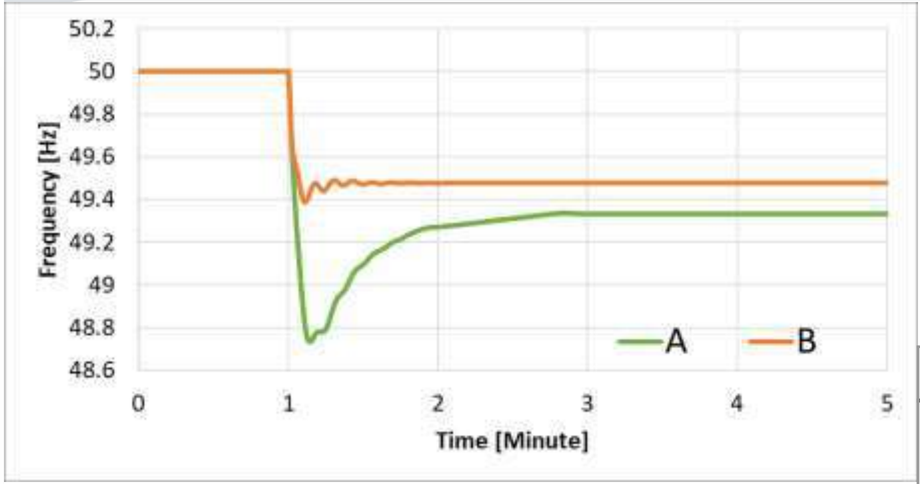
Fast Frequency Reserves (FFR) requirement (Winter-Off Peak)



BESS Requirement for FRR:
Inverter: 500 MW, Storage: 150 MWh

	Scenario – A	Scenario – B
ROCOF [Hz/sec] – in 1 second	-0.244	-0.240
ROCOF [Hz/sec] – till frequency Nadir	-0.126	-0.077
Frequency nadir [Hz]	49.04	49.41
Steady state frequency [Hz]	49.38	49.48

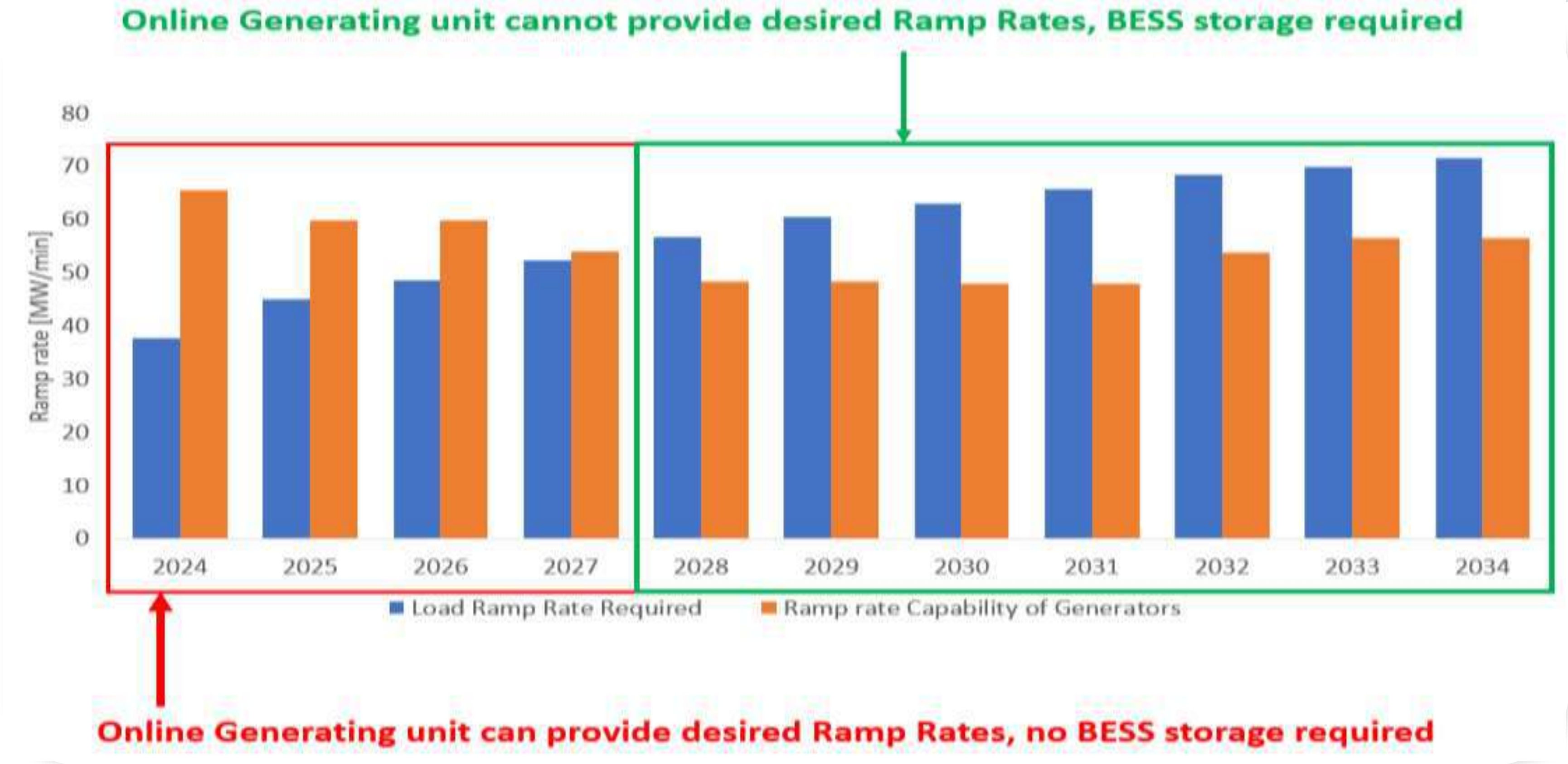
Fast Frequency Reserves (FFR) requirement (Extra VRE Case)



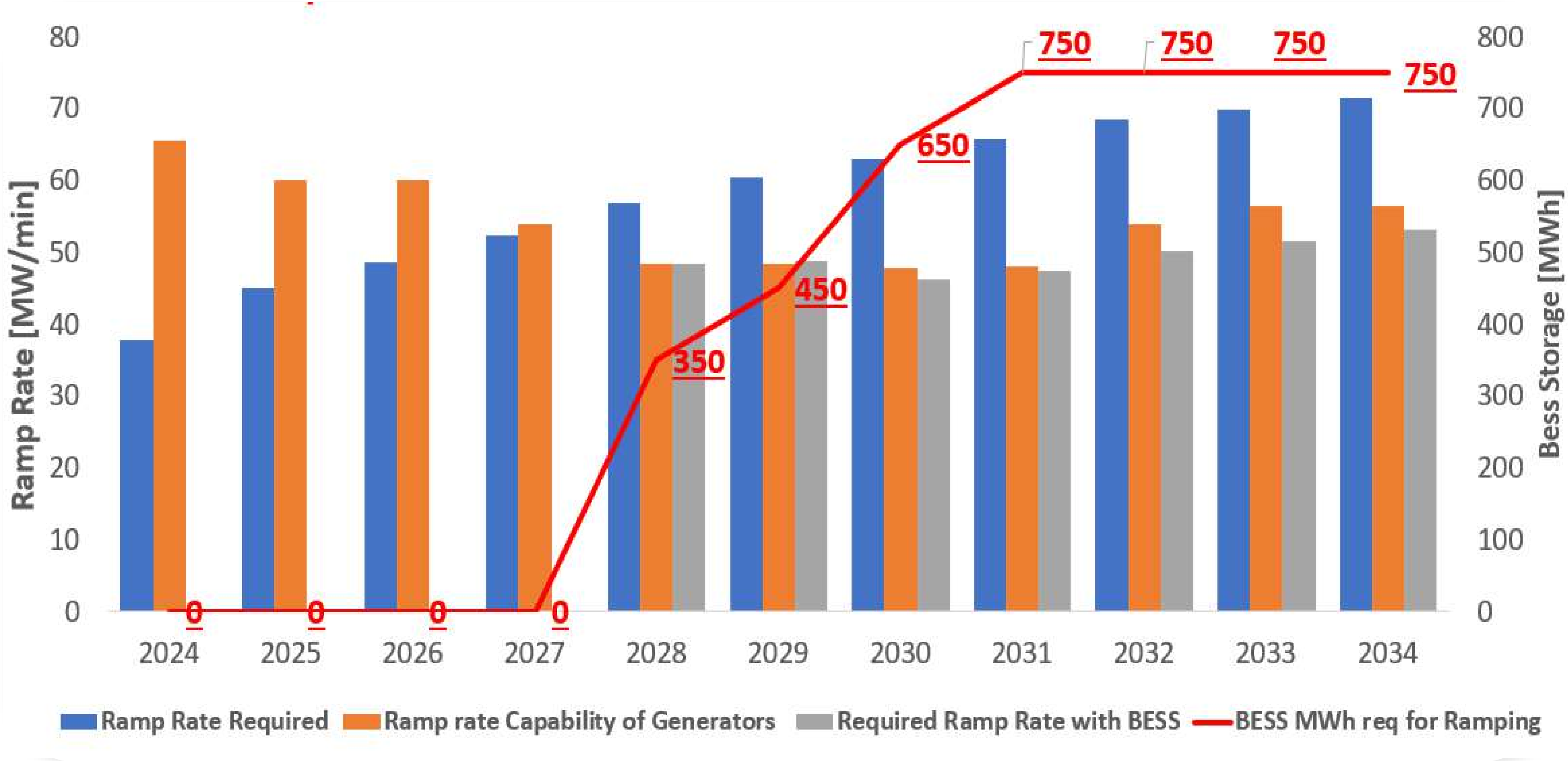
BESS Requirement for FRR:
Inverter: 500 MW, Storage: 150 MWh

	Scenario – A	Scenario – B
ROCOF [Hz/sec] – in 1 second	-0.284	-0.272
ROCOF [Hz/sec] – till frequency Nadir	-0.147	-0.091
Frequency nadir [Hz]	48.73	49.4
Steady state frequency [Hz]	49.33	49.48

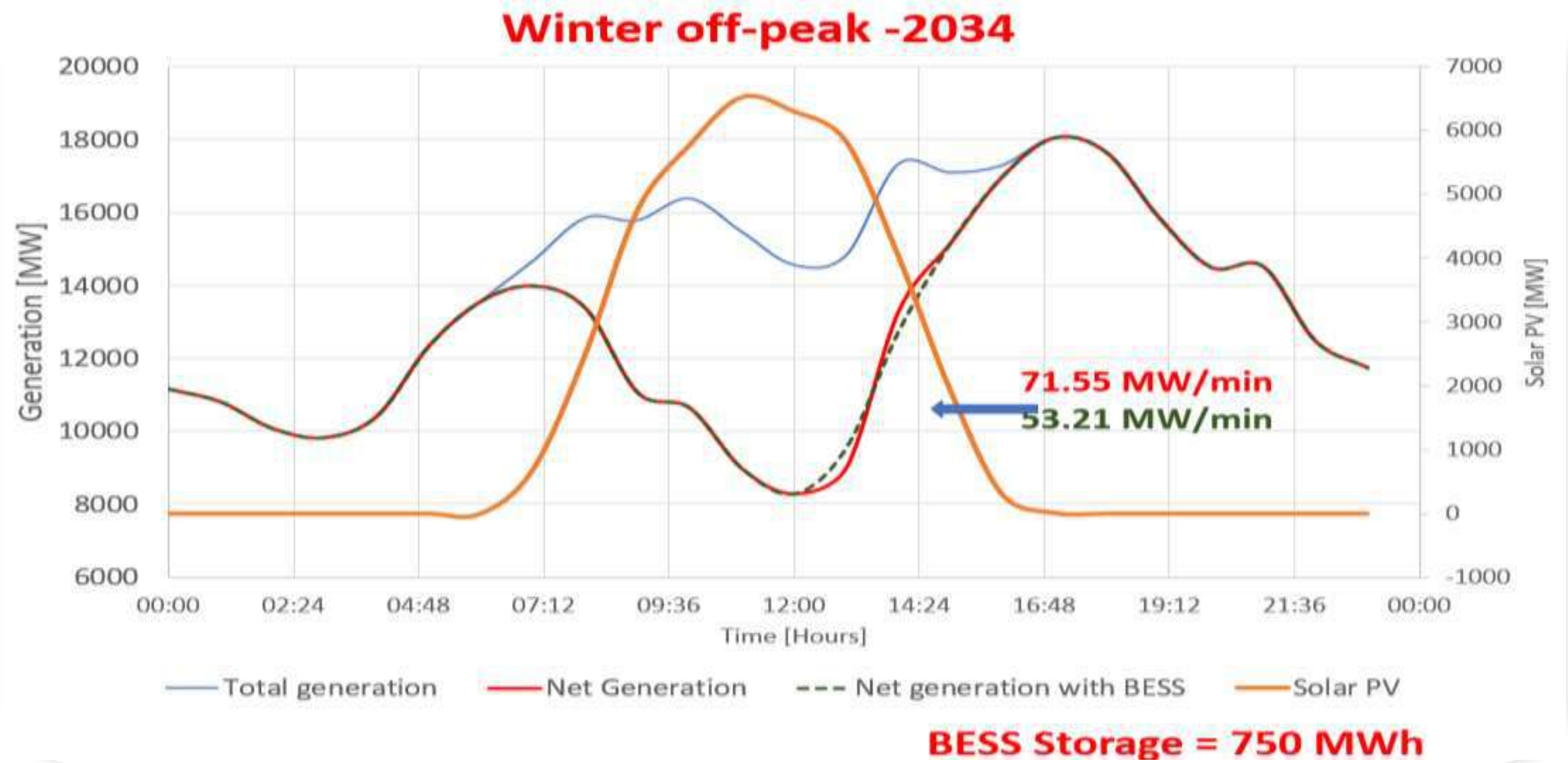
Ramp Rate Requirement



Ramp Rate Requirement



Ramp Rate Requirement



Smart Grid

- **SCADA** → Real-time monitoring & control at plant/grid level.
- **WAMS** → System-wide dynamic visibility to accommodate fluctuating renewables.
- **WAMPAC** → Automated, intelligent response that allows higher penetration of renewables without compromising reliability.

In short, these technologies shift grid operation from passive monitoring to proactive, adaptive management, which is essential for integrating high levels of VRE.

Application of FACTS Devices (STATCOM & SVC)

- Provide **fast dynamic voltage support** to handle solar/wind fluctuations.
- Supply or absorb **reactive power** for grid stability.
- Enable **low-voltage ride-through (LVRT)** of renewable plants.
- Improve **power transfer capacity** of transmission lines carrying VRE.
- Enhance **transient and small-signal stability** under disturbances.
- Improve power quality by **mitigating harmonics and oscillations.**

Ancillary Services market mechanisms

Ancillary Services (AS) market mechanisms are crucial for enhanced VRE (Variable Renewable Energy) integration in terms of:

- Frequency Stability → AS markets incentivize resources (BESS, hydro, fast-ramping plants) to provide frequency response.
- Voltage Support → Market-based procurement of reactive power ensures stable voltages with high solar/wind penetration.
- Reserves & Balancing → Markets for spinning/non-spinning reserves allow efficient allocation of backup capacity for forecast errors.

Ancillary Services market mechanisms

Flexibility Compensation → Rewards fast-responding assets (BESS, demand response, flexible gas plants), making the grid more adaptable.

Reduced Curtailment → By valuing ramping and balancing services, operators can absorb more VRE instead of curtailing it.

Fair Cost Allocation → Ensures the costs of managing variability are shared through market signals rather than socialized.

Flexibilization of the conventional generators

Absorbs variability → Fast ramping up/down balances sudden solar/wind changes.

Supports daily cycles → Quick start/stop handles evening demand peaks after solar drops.

Enables higher VRE share → Lower minimum load lets renewables generate more without curtailment.

Provides reserves & ancillary services → Frequency control, spinning reserve, voltage support.

Reduces reliability risks → Flexible thermal/hydro plants act as backup during low VRE output

Distributed Energy Resources Management, Monitoring, and Integration

1. Management

- DERMS (Distributed Energy Resource Management Systems) coordinate DERs as “virtual power plants.”

2. Monitoring

- Real-time visibility of thousands of distributed solar, wind, EVs, and storage systems.

3. Integration

- Grid integration platforms connect DERs with distribution and transmission system operators.

Distributed Energy Resources Management, Monitoring, and Integration means treating small, scattered solar, storage, and demand-side assets as coordinated, grid-supporting resources. This makes the grid more flexible, reduces curtailment, and enables higher VRE penetration without compromising reliability

Way Forward

- Accelerate investment in modern grid infrastructure and digitalization.
- Scale up Battery Energy Storage Systems (BESS) and flexible reserves.
- Strengthen regulatory frameworks and market mechanisms.
- Promote distributed energy resources (DERs), VPPs, and microgrids.

Conclusion

- Renewable-based electrification is key to sustainable energy transition.
- Modern grid practices ensure flexibility, reliability, and resilience.
- Coordinating policies, markets, and technologies is essential.
- The future grid will be smarter, cleaner, and more decentralized

Question

Answer

Thank You